MOVING BEYOND THE MILLENNIUM DEVELOPMENT GOAL FOR WATER: TESTING THE SAFETY AND SUSTAINABILITY OF DRINKING WATER SOLUTIONS IN HONDURAS & EL SALVADOR

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By

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International Rural Water Association & Agua Desarrollo Comunitario--Honduras
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Publications

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Abstract

Diarrheal disease is responsible for 2.2 million deaths, of which 1.5 million are of children under five; and inadequate access to drinking water is a major cause of these deaths. Providing households with piped drinking water is often considered the gold standard approach for reducing diarrheal disease, and is an aim of the Millennium Development Goal (MDG) for water. Unfortunately, even piped drinking water systems often provide unreliable water of poor quality, and in insufficient quantity to protect households from disease. This is especially true for rural community-run drinking water systems in developing countries. Identifying technological and programmatic innovations that protect households better from water-borne disease at low cost would thus be of great value.

This dissertation measures the water quality, health and sustainability impacts of three interventions that might reduce the global burden of water-borne disease and documents the shortcomings of the MDG for water. In Paper I, using a case-control design, qualitative and quantitative methods, and matched pair analysis, it first examines the performance of the Circuit Rider (CR) model in 60 communities in El Salvador. The CR model provides technical, financial, and operational assistance to community-run rural water systems. The results establish that CR communities enjoyed significantly better microbiological water quality, enhanced financial management and transparency, and greater investment in water treatment and system maintenance. Paper II examines the impacts and cost of distributing household-level water filters and safe storage units (HWFS) relative to community-level treatment systems (CTS) for use with low quality piped drinking water, using a quasi-randomized trial involving 334 households (135 HWF, 62 CTS, and 137control) over one-year in Honduras. HWFS and CTS households had significantly improved microbiological water quality, and 61% of HWFSs and 46% of CTSs were still in use after one year. In Paper III, data collected over two years for the HWFS and control households reveal that 47% of the filters were still in use and continued to provide households with water of significantly higher quality. In sum, the CR model, HWFS and CTS are all associated with significantly improved water quality, are low-cost drinking water interventions (cost per person per year is $.20 CR model, $3.63 for the HWF and $1.37 for the CTS), and could be utilized to reduce the global disease burden.

This work is dedicated to

Silvia Fiallos & the children of Honduras and El Salvador

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To complete the field research in Paper I, I am grateful to the International Rural Water Association and Asociación Salvadoreña de Sistemas de Agua in El Salvador for opening their doors. I am indebted to Brianna Bond for her untiring assistance with data collection in El Salvador in the heat of the dry season. To complete the field research in Paper II and III in Honduras, I am indebted to the International Rural Water Association, Agua Desarollo Communitario (ADEC), and Shoulder to Shoulder. They introduced me to a range of community water systems and provided the treatment technologies to the households studied. I am especially grateful to Silvia Fiallos for sharing her extensive experience working in WASH throughout Honduras, and her assistance in organizing a phenomenal research team. This research team in Honduras included: Silvia Fiallos, Melissa Alvarado, Diana Calix, Margarita Amaya, Jesus Fiallos, Josue Cartagena, Oneida Garcia, Brianna Bond, and Laura Wille.

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TABLE OF CONTENTS

1.1 INTRODUCTION

Unsafe drinking water is a major cause of an estimated 4 billion cases of, and 2.2 million deaths from, diarrheal disease per year (Pruss-Ustun et al., 2008; Wardlaw et al., 2010; Bryce et al., 2005). The disease burden falls heaviest on children under five. Gastrointestinal and diarrheal diseases reduce absorption rates of food and micronutrients, decrease childhood growth rates, drain energy levels, contribute to lower attendance levels at school, decrease the number of hours one is physically able and willing to work, and increase rates of morbidity and mortality, especially among children (Checkley et al., 2008; Billig, et al, 1999). The health benefits from a sufficient supply of safe drinking water are unequivocal.

The international response to this global burden is the Millennium Development Goal (MDG) #7, Environmental Sustainability, target 7c—to reduce by half the proportion of people without sustainable access to safe drinking water (WHO and UNICEF, 2006). Progress toward the MDG for water is tracked by counting households in each country with access to an improved water source. 'Improved' water sources include household connections and public taps, standpipes, tubewells and boreholes, protected dug wells and springs, and/or rainwater collection, provided the source is no more than one kilometer from the user's dwelling[1] (WHO and UNICEF, 2006). To reduce poverty and related health problems, however, access to "improved" water sources may not be enough.

[1] 'Unimproved' water sources include: unprotected dug wells, unprotected springs, tanker trucks, surface water, and bottled water.

Ideally, the gold standard for drinking water sources, piped drinking water, begins with a protected water source that has a sufficient year-long supply of water for all users, meets a health standard of biological and chemical treatment (coagulation, sedimentation, filtration and disinfection) prior to distribution, and then travels along an uninterrupted network of pipes to supply households with safe drinking water throughout the day and year round. Unfortunately, piped water, in both the developed and developing world, does not always reach this standard (Sobsey, 2006; Moe and Rheingans, 2006). Many 'improved' drinking water systems, especially in the rural Global South[2], provide water that is *not* reliable, readily available, or microbiologically safe (Rizak and Hrudy, 2008). Water delivered, even by piped systems in the developing world, is consistently compromised, whether because of the quality of water at the source, insufficient supply, high costs, scarce resources, aging infrastructure, intermittent service, inadequate technical knowledge, poor operational management, or defunct community-based water committees (Lee and Schwab, 2005; Rizak and Hrudey, 2008; Whittington et al., 2009, Davis et al., 2008). As piped drinking water networks grow old, and, in the absence of adequate monitoring and technical repairs, pipes break and leak (Lee and Schwab 2005). Also, bacteriological treatment is not always continuous or consistent, increasing the burden of disease (Lee and Schwab 2005). In Honduras and El Salvador, the countries of study, despite high access to improved water sources, diarrheal disease is the third leading cause of child mortality, and contributes to high rates of stunting in children under-five years of age (WHO 2010; Checkley et al., 2008). Increasingly, research has demonstrated that MDG drinking water infrastructure targets are not enough; efforts must

[2] The problems that affect piped systems in the Global South are not unique to the Global South. The Global North has many documented cases of disease outbreaks from contamination of drinking water in piped networks (Rizak and Hrudey, 2008; Craun et al., 2002).

be made to ensure that the infrastructure delivers a safe and sufficient supply of water if improvements are going to be seen in the areas of health and wellbeing (Clasen, 2010; Bartram, 2008).

This dissertation reflects on the shortcomings of the global health policy, the Millennium Development Goal for water, and tests the efficacy of specific technologic and programmatic solutions that may substantially improve human and environmental health outcomes. This research fills current gaps in the literature, and through collaborative partnerships with two NGOs in El Salvador and three NGOs in Honduras tests the efficacy of a technical assistance model and two drinking water technologies—a household filter and safe storage unit and a community-scale water treatment system. The specific research questions are stated on page 16.

The dissertation is structured as three papers. Each paper is a chapter of my research, and after an extensive literature review, incorporates the field research conducted over three years in Honduras and El Salvador. This introduction is structured as follows: a brief overview of the global burden of water-borne disease and the international response is given, the MDG for water is briefly described, and the health benefits of drinking water quality and piped drinking water specifically are documented. Some of the obstacles faced by community-run piped water supply networks are reviewed, a brief overview of possible solutions to the problems faced by piped networks is given, the research question are outlined, and then the three interventions studied in the field described. The gaps in the literature filled by the research in Papers I, II and III are touched on throughout, and finally a short overview of the drinking water services in each of the countries where the research took place—Honduras and El Salvador—is given.

Paper I tests the efficacy of a technical assistance model and its impact on water quality and system sustainability in 60 community-run rural water systems in El Salvador. Principal study activities in Paper I in 60 villages (28 Circuit Rider and 30 control communities) included: a structured interview with the water system operator; a separate structured interview with the president or treasurer of the VWC or community water board; microbiological water quality tests (*E.coli* and total coliform) at the first and last households on each drinking water distribution line in every community; and a residual chlorine tests at the first and last house on the piped system. *Paper II* measures the impacts of household-level water filtration and safe storage (HWFS) relative to a community –level water treatment system (CTS) on household water quality, health, and compares the sustainability of the interventions over a one year time frame in Honduras based on a quasi-randomized trial. It utilizes household surveys conducted with the female head of household and microbiological water quality tests in 334 households pre and post-intervention. *Paper III* measures the impact of the household health and sustainability of a household ceramic water filter over a two-year time frame in 272 households in Honduras based on a clustered randomized trial. At baseline and after year one and year two, household surveys, microbiological water quality tests were taken. Anthropometric measures (height and weight) of children under five were also utilized pre and one-year post intervention. Each paper was written for a specific journal, and each includes its own abstract introduction, methods, conclusion and discussion section.

In the conclusion of the dissertation, there is an overview of the research results, recommendations for water-sector practitioners interested in household water treatment technology studied, an example of how these recommendations were adapted and utilized in Honduras. The costs of the three interventions are then compared, the challenges and opportunities of bringing the water interventions to scale discussed, water-related global policy, post-2015, recommendations for improving the delivery of safe household water is provided, and future research needs are summarized.

1.2. BACKGROUND

1.2.1 Diarrheal Disease, the Global Burden

Diarrheal disease kills more children than AIDS, malaria and measles combined, and is the leading cause of death for children under five after pneumonia. Every week, 29,000 children in low-income countries die from diarrheal diseases – approximately 4,100 deaths every single day. Out of the 1.5 million children killed by diarrheal disease in 2004, 80% were under two years old (WHO, 2009). According to the World Health Organization, approximately 88 percent of the 1.5 million diarrheal deaths worldwide are attributable to unsafe water, inadequate sanitation and poor hygiene. Calculations that compare the returns on investments of water and sanitation interventions, estimate that for every dollar invested, the return is between $5 and $28 (Hutton, Haller, Bartram, 2007).

1.2.2 The Millennium Development Goal for Water

The international response to the global burden of disease is the Millennium Development Goals (MDG) #7, Environmental Sustainability, target 7c, to reduce by half the proportion of people without sustainable access to safe drinking water[3] (WHO and UNICEF, 2006). Safe drinking water is tracked by estimating the proportion of those with an 'improved' source. Improved' water sources include household connections and public taps, standpipes, tubewells and boreholes, protected dug wells and springs, and/or rainwater collection provided the source is no more than one kilometer from the user's dwelling[4] (WHO and UNICEF, 2006). Piped water to a household tap has long been considered the gold standard because of the constant water supply, treatment prior to distribution, and proximity to the household. Unfortunately, piped water, in both the developed and developing world, does not always reach this standard (Sobsey, 2006; Moe and Rheingans, 2006).

1.2.3 Water Quality and Supply

Unsafe drinking water is a major cause of global disease burden described in section 1.2.1.. The pathogens (bacteria, viruses, helminthes and protozoa) that cause gastrointestinal disease and skin infections in water[5] can be stopped if water sources are adequate and protected, water treatment is comprehensive, the distribution network is watertight, and a constant and regular supply of water is delivered to the user at the point of consumption. Drinking water can become contaminated if any of the water-borne pathogens listed in Appendix 1.A.1 get into the water supply and are not killed with disinfection. It is too difficult to detect and enumerate each of the pathogens, however, and so normal *Escherichia coli (E.coli)* are routinely detected and enumerated to

[3] In 2000, 1.1 billion did not have access to an improved source of drinking water. Today 884 million do not have access to an improved source of drinking water (WHO, 2010).
[4] Unimproved' water sources include: unprotected dug wells, unprotected springs, tanker trucks, surface water, and bottled water.
[5] This research focuses on drinking water, yet, recognizes that hygiene and adequate sanitation services are critical to diarrheal disease reduction (Fewtrell et al, 2004).

determine if water is safe for human consumption and used as an indicator of the presence of water-borne pathogens.

1.2.4. Source Water & Distribution

Common water sources include groundwater, surface water, springs and rainwater. If the source can feasibly be protected, this protection can decrease the risk of contamination. Surface water sources (springs, lakes, rivers, ponds) are usually easier than groundwater sources to access, but because they are exposed to humans and animals, they are often more contaminated. Springs are less exposed than surface lakes or rivers, but still should to be protected to reduce the risk of microbiological contamination. A randomized trial in Kenya points to the reduction in *Escherichia coli (E.coli)* by 66% by protecting springs from contamination (Kremer et al., 2011). Groundwater is usually at less risk of microbiological contamination, but to move groundwater to the surface requires energy (human or motor) and this can be expensive. Rainwater is of better microbiological quality than surface water initially; however, it is subject to contamination after collection. In a study in Cambodia, rainwater was more microbiologically contaminated than some lake water sources, and the authors suggested that the long storage time in uncovered containers as a possible explanation (Murphy, McBean and Farahbakhsh, 2010). While groundwater is often safer, if fluoride or arsenic is found in concentrations that can cause harm to humans, it will need to be addressed prior to consumption or another source of water found (Skinner, 2003)[6]. Boreholes, tubewells and protected dug wells are all different ways of accessing groundwater. Pumps powered by human, wind,

[6] Neither the MDG nor this research are considering contamination from industrial or agricultural chemicals or agricultural.

water, or motor can facilitate the movement of the water from the ground to the surface. Water can be pumped from the ground to individuals with storage containers or to pipes and then transported to households. If surface water is the source and if communities have sufficient resources, distribution tanks often hold water until it is distributed by pipes to households.

1.2.5. Water Treatment Methods

A water treatment plant that combines coagulation, flocculation, sedimentation, filtration, and disinfection prior to distribution may be the best option for ridding water of the many diarrheal disease causing pathogens and for protecting water until consumption. Water from a surface source can be quite turbid, especially during the rainy season, and to disinfect the water, the particles need to be removed. Chemical coagulants, like aluminum sulfate, are often used to force the solid particles together into flocs which can then settle out of the water through sedimentation (Cairncross and Feachem, 1993). Filtration pushes water through sand and or clay. These methods improve the microbiological quality of the water significantly, but for the water to be free of pathogens it must be disinfected, and this is often achieved with chlorination (Cairncross and Feachem, 1993).

Water treatment at this level; however, is often not possible in rural areas of developing countries (Cairncross and Feachmem, 1993). The expense of constructing a water treatment plant and the unreliability of the operation and maintenance of these plants in most rural settings are significant constraints, especially in resource poor settings. In the best case scenario, a drinking water treatment plant treats the drinking water before it is delivered to households through watertight pipes, regularly without disruption[7]. In many lesser developed countries, resources limit the possible water treatment processes. In rural areas of developing countries, water treatment may include only one of the methods—coagulation, flocculation, sedimentation, filtration or disinfection—but all of these methods are needed to ensure a reliable supply of safe water. The treatment necessary often depends on the quality of the source water.

A less expensive form of disinfection at the community-level, in piped systems that do not have comprehensive treatment plants prior to distribution, is disinfection with chlorine in liquid, granular or tablet form. High levels of turbidity, often found in surface sources in the rainy season, however, can create obstacles in treatment with chlorine as suspended particles reduce the microbiological efficacy of chlorine and other chemical disinfectants (WHO, 2006). If water is very turbid (<5NTU), some form of filtration is necessary prior to disinfection with chlorine (Cairncross and Feachem, 1993; WHO, 1996).

Lower cost household level -treatment options exist and include ceramic filtration, fabric filtration, biosand filtration, SODIS or solar UN radiation, free chlorine disinfection (bleach), coagulation and disinfection, simple sedimentation, and thermal (boiling) (Brown et al; 2010b). (See Appendix 1.A.2 for a table of these methods, their pathogen removal ability, water quality requirements, disinfectant residual necessary, availability of needed materials for construction, length of time need to treat, skill level needed, and

[7] Other treatment mechanisms include mixed oxidant gasses systems, ozone, and reverse osmosis, but these are not usually options in lesser developed countries, especially in rural areas, because of their cost and the technical skill required to operate such treatment methods (Gadgil, 1998).

the cost of the method.). A meta-analysis of 21 studies determined that as microbiological water quality improves at the household level, there is a median reduction in endemic diarrheal disease of 42 percent compared to control groups (Clasen et al., 2004). See Appendix 1.A.2. for an overview of the household treatment methods, their effectiveness, turbidity requirements for treatment, disinfectant residual, needed materials, acceptability, length of treatment time, skill level needed, and the cost per person of each method. In an analysis of the pathogens (bacteria, viruses and protozoa) that can be removed with different household treatment methods, ceramic water filters, chlorine bleach, boiling, and coagulation and disinfection had the greatest reduction in pathogens. In a cost-benefit analysis of water and sanitation interventions, the cost-benefit ratio was highest for household water treatment when compared to other water and sanitation interventions, at approximately $20 for every Disability Adjusted Life Years saved (Hutton, Haller, Bartram, 2007).

1.2.6. Piped Water Networks

Piped drinking water is often cited as the gold standard in drinking water technologies because of its impact on disease reduction and its association with falling mortality rates in major cities around the developed world. Retrospective research on the history of expansions in piped drinking water networks points to the subsequent fall in infant mortality rates in major cities in developed countries (Cutler and Miller, 2005; Watson, 1996; Burstrom et al., 2005). Watson documented the falling mortality rates on Native American reservations across the United States as drinking water improvements were made—drinking water treatment plants were built, piped systems were extended to serve more households, and wells were dug (Watson, 2006). In the Watson study water quality and water quantity cannot be disaggregated. In the United States, between 1905 and 1925, falling infant mortality was found to be associated with the use of filtration and chlorine treatment in piped drinking water systems, with total social benefits in Baltimore, Chicago, Cincinnati, Cleveland, Detroit and Jersey City equal to $700 million per city (Cutler and Miller, 2005). In many of these cities studied in the USA, prior to filtration and treatment with chlorine, households had piped service that delivered untreated river water to their households.

1.2.7. The Problems in Piped Water System

Ideally, piped drinking water delivered to a household tap begins with a protected, year-round water source that meets community health and hygiene needs, undergoes biological and chemical treatment (coagulation, sedimentation, filtration, and disinfection) and is distributed through an uninterrupted network of watertight pipes to households throughout the day. It is an intervention that improves household health and economic livelihoods as the burden of diarrheal disease from both water-washed and water-borne disease is reduced (Cutler and Miller 2005; Watson, 2006). In much of the Global South[8], however, piped water does not reach this standard (WHO, 2004; Sobsey, 2006). Unfortunately, the quality of water delivered, by piped systems in the developing world, is consistently compromised, whether because of poor water quality at the source, an absence of drinking water treatment, insufficient supply, intermittent service, leakages, high costs, aging infrastructure, inadequate technical knowledge, poor operational management or defunct water committees (Bartram, 2008; Rizak and Hrudey, 2008; Lee

[8] This problems that affect piped systems in the Global South are not unique to the Global South. The Global North has many documented cases of disease outbreaks from contamination of drinking water in piped networks (Rizak et al., 2008; Hrudey, et al., 2004; Craun et al., 2002).

and Schwab, 2005; Yassin, Amr, and Al-Najar, 2006; Whittington et al., 2009). Households are forced to use alternative unimproved sources because of insufficient supply or poor quality in their piped network (Pattanayak et al., 2005). This in turn has adverse health and economic impacts on the household (Pattanayak et al., 2005; Kyessi, 2005).

Small water systems in rural and urban areas of developing countries are especially at risk (Rizak and Hrudey, 2008). In tropical areas, the rainy season brings with it disease, and the dry season brings water shortages. Intense rains can cause contamination of surface water sources. Shortages can lead to unsafe storage, and intermittent service can lead to negative pressure in the pipes and contamination of the entire network (Tauxe et al., 1994). Also, bacteriological treatment is not always constant or consistent, increasing the burden of disease (Lee et al., 2005; Craun et al., 2002). Increasingly, research has demonstrated that infrastructure targets are not enough; efforts must be made to ensure that the infrastructure delivers a safe and sufficient supply of water if improvements are going to be seen in the areas of health and wellbeing (Clasen, 2010; Bartram, 2008).

1.3. SOLUTIONS

Governments, development organizations, and NGOs have begun to experiment with technological and programmatic solutions that may substantially improve human and environmental health outcomes and address the goals of safe and sustainable drinking water. The present research compares the efficacy of two low-cost, locally manufactured, drinking water technologies in Honduras over one year: a household filter and safe storage unit and a community-based treatment system. It then measures water quality impacts on the household filter and safe storage unit over two years. The technologies have never been studied together for their relative sustainability and impact on water quality and household health. The household filter and safe storage unit has never been studied in the context of combination with contaminated piped water systems nor studied for its impact on the height and weight of children under five. The community-level treatment technology in the present research has never been studied. The author is also unaware of any research on the on-going post-construction support, the Circuit Rider model specifically.

1.3.1. Post-Construction Support

Research suggests that post-construction support (PCS)—investment in community capacity for operation and maintenance—may in fact significantly improve the sustainability of water systems (Sohail et al., 2005; Schouten, 2003; Lockwood, 2003). PCS can provide communities with technical expertise and access to spare parts so that water systems do not break down (Whittington et al., 2009) and it can improve financial performance and overall household satisfaction (Prokopy et al., 2008). Communities that receive management-oriented PCS visits from external agencies, and those whose system operators attended training workshops, have better performing systems than communities that received no such support (Whittington et al., 2009; Davis et al., 2008). PCS can include capacity building in technical operations, financial management, water source protection, community training in the importance of water quality treatment. Engineering-oriented (technical operations) PCS visits to communities had no measurable impact on system functioning or user satisfaction according to research in Bolivia (Davis et al., 2008). Currently, the best configuration of PCS is not sufficiently detailed, and no study to date has measured the impact of PCS on microbiological water quality. Paper I tests the efficacy and impact of the Circuit Rider model of PCS on system performance (functioning systems, water quality, and water supply) and sustainability (technical capacity and management, financial and operational management, and environmental protection) in community run rural water supplies in El Salvador.

1.3.2. Household vs. Community Treatment

It has been suggested that if piped water is not safe or not perceived as safe, it could be treated at the point of use (Sobsey, 2006). Evidence also points to the decline in microbiological quality of drinking water after collection in many settings (Wright et al., 2004), and household drinking water treatment and safe storage can drastically improve the microbial quality of drinking water at the point of consumption (WHO, 2007). Others have suggested that communal water infrastructure may be effective in fighting diarrheal disease in some cases, but research has yet to document the evidence necessary to prioritize communal infrastructure (Zwane et al., 2007). There is little to no experiment on treatment at the community level, and no known research compares the relative effectiveness and the sustainability of the community treatment to household treatment in the field. Evidence is required to determine that it reduces diarrheal disease and that it can be effectively maintained by local users (Zwane et al., 2007). An adequate supply of clean water for handwashing and other personal hygiene measures can decrease rates of pneumonia and skin infections (Luby et al., 2005). At this point, however, evidence does not demonstrate that improved access without changing the quality reduces diarrhea incidence (Ahuja et al., 2010). Paper II reports the findings of a field study in Honduras that tests the water quality and health impacts, and sustainability over time, of household vs. community level treatment.

1.4 IMPACTS

1.4.1. Health Impacts

When drinking water interventions are tested in the field, their impact on diarrheal disease is often measured (Esrey et al 1991; Watson, 2006; Ferrie et al., 2006; Burstrom et al. 2005; Clasen et al., 2007), water quality is only sometimes measured (Brown , 2010), and anthropometric impacts for children under-five are rarely studied. Two studies provide evidence of the synergistic association between access to water and sanitation and stunting (Merchant, et al., 2003; Checkley et al., 2004). A multi-country analysis of diarrheal disease and its impact on stunting, reveals that a higher cumulative burden of diarrhea increases the risk of stunting (Checkley et al., 2008). There is also evidence that suggests that diarrhea gastrointestinal illness can impair cognitive function and school performance (Niehaus et al, 2002). Further research demonstrates the association between stunting and cognitive development, and the subsequent relationship between cognitive functioning in childhood on economic status in adulthood (Currie, 2009; Case and Paxson, 2008). It is well documented that children who are taller for their age, even before schooling begins, perform better on cognitive tests (Case and Paxson, 2008). The association between cognitive functioning in childhood and earnings in adulthood (Currie, 2009), and the association between height in childhood and earnings in adulthood have also been documented (Case and Paxson, 2008). A better understanding of the effects of water and sanitation on linear growth is warranted, and on the interaction effects of drinking water, diarrhea and malnutrition (Checkley, 2004).

1.4.2. Sustainability

The sustainability of water infrastructure can be simply defined as infrastructure that is functioning and utilized over a significant period of time (Carter, Tyrrel, and Howsam, 1999). Very few studies on water services follow the use of the interventions in the field over a time frame that is greater than six months. When this research began, no research had followed the household ceramic water filters and safe storage (HWFS) units in the field over time for more than 6 months.

1.5. RESEARCH QUESTIONS

1. What is the efficacy of build-and-walk-away drinking water supply relative to build-with-on-going-technical support water supply in rural and peri-urban areas of El Salvador? Specifically, what is the effect of the Circuit Rider model of post-construction support on *system performance* (water quality) and *system sustainability* (technical capacity and management, financial and operational management, and environmental protection) in community-run piped drinking water systems in El Salvador?

2. In rural and peri-urban areas of Honduras, which of two types of drinking water treatment technologies, in the presence of contaminated piped drinking water, is most effective when measured for their impact on household water quality, health, and sustainability: household or community-level water treatment?

3. What is the health impact and sustainability of household filtration and safe storage over a two-year time frame in Honduras?

1.6. THE INTERVENTIONS STUDIED

1.6.1. Post-Construction Support: the Circuit Rider Model:

The CR model provides on-going technical assistance to Village Water Committees and their water system operators, and is aimed at expanding their capacity to overcome technical, financial and operational obstacles to successful operation and maintenance.

The CR model was created by the United States National Rural Water Association (NRWA) in the early 1970's to help small rural water utilities meet the regulatory standards of the US Safe Drinking Water Act of 1974. NRWA now has several hundred Circuit Riders working in every state across the United States. Most are licensed water or wastewater operators in their respective state, and all have years of technical and managerial experience. Currently, the CR model also operates in Honduras, El Salvador, and Guatemala with locally trained technicians, and funding and technical support from the International Rural Water Association (IRWA), the international arm of NRWA. IRWA partners with host-country organizations, such as the Asociación Salvadoreña de Sistemas de Agua (ASSA) in El Salvador, Asociación Hondureña de Juntas Administradoras de Sistemas de Agua (AHJASA) and Agua Desarollo Comunitario (ADEC) in Honduras, and Agua Para la Salud in Guatemala. These CR programs have been funded by external NGOs, IRWA and in some cases (AHJASA) by monthly compensation by member communities for the ongoing post-construction support. Many in the sector have declared post-construction support to rural water supply an unmet need in the sector, but no one has studied the efficacy of a specific model of post-construction support (Prokopy et al., 2008; Davis et al, 2008, Whittingon et al., 2008). The impact of the Circuit Rider model on water quality and piped water system sustainability are measured in Paper I.

1.6.2. Household Filter and Safe Storage The Potter for Peace (PFP) household ceramic water filter and safe storage unit (HWFS) is a low-cost, locally made household water filter. It is designed to provide a household solution to the developing world's water quality problem. Designed by Fernando Mazariegos, a Guatemalan chemist, the technology employs a ceramic mixture of clay and sawdust or rice husks that leave tiny pores that allow water through but block most water-borne disease-causing pathogens. Currently the household filters and safe storage units are manufactured and distributed in 20 countries across Latin America, Asia and Africa. In laboratory experiments and field trials, HWFSs significantly improved microbiological water quality and reduced diarrheal disease in households in Cambodia with 'unimproved[9]' water sources (Oyanedel-Crave et al., 2008; Brown et al., 2010). In review of the household water treatment literature, ceramic filters were deemed the most effective interventions for improving household water quality and reducing waterborne infectious disease (Sobsey et al., 2008). The ceramic filter combines the advantages of household filtration, and safe storage until the point of use, and they are cost effective. No research has followed households with the filters over a two year time when combined with 'improved' water sources. Paper III provides the evidence of a two-year study in Honduras on the household water quality, health, and sustainability impacts of the HWFS when combined with an 'improved' water source.

1.6.3 Community-scale Treatment System (CTS)

The community–scale water treatment system is designed to offer village water committees the technology to treat and disinfect their drinking water.

[9] 'Improved' is citied throughout this dissertation and refers to the 'improved' Millennium Development Goal standard. Improved' water sources includes household connections and public taps, standpipes, tubewells and boreholes, protected dug wells and springs, and/or rainwater collection, provided the source is no more than one kilometer from the user's dwelling[9] (WHO and UNICEF, 2006).

Community-scale water treatment systems (CTS) combine sedimentation and coagulation with chlorine disinfection. CTSs have been installed in communities in Honduras, Guatemala, Haiti, and Ghana. The technology moves contaminated water through a sedimentation-coagulation tank where aluminum sulfate must be stirred into the water for 20 minutes by the operator to rid the water of turbidity. The spout is then opened to allow the water to pass into the second tank where chlorination treatment occurs. Residual chlorine can then be tested with a small easy-to-use testing kit. The CTS removes bacteria, viruses and protozoa at a level that exceeds most all of the low-cost treatment processes because it combines coagulation and sedimentation with chemical disinfection (Refer to Appendix II). In this study, the CTS is a centrally located stand alone system with a single communal tap and is no more than a ten minute walk for the furthest household. In this research the CTS is combined with contaminated piped water so that the water can be treated before it is consumed by households. Paper II measures the relative efficacy of the CTS and HWFS in Honduras over one year.

1.7. COUNTRIES OF STUDY

1.7.1. El Salvador

In El Salvador, as of 2008, 87% of households have access to improved water, 65% have piped water to the household. In rural areas, 76% have access to improved water sources and 42% have water piped to a household tap. The National Water and Sanitation Authority, Administración Nacional de Aceuductos y Alcantarillados (ANDA), is responsible for water and sanitation services in El Salvador. ANDA is not able to carry out its mandate in rural areas (Linares et al, 1999), and this was confirmed in interviews in preliminary data collection. Much of the funding for rural water system construction has been provided by NGOs. These rural water systems are managed by a locally elected village water committee (VWC) or Junta de Agua, and operated by a community member who is paid by the communities' water fees. Little attention has been given to the technical, financial, operational, and maintenance needs of these systems after construction so as to ensure their sustainability (Linnares et al, 1999). Some NGOs provide initial support on how to set up a VWC, but few train community members in how to collect water tariffs, how to budget for future maintenance costs, where to obtain operational and maintenance assistance, or how to protect water sources, and return to check water quality. Even those NGOs that do offer this initial training, few return to check on operation and maintenance, water quality or financial management. Some villages turn to their municipal government for help, but report that funds for water systems are often scarce or tied to political voting patterns, and are not easily accessed. The results of the research on the PCS-Circuit Rider Model in El Salvador can be found in Paper I. To complete this research, GK collaborated with two NGOs in El Salvador the International Rural Water Association (IRWA) and Asociación Salvadoreña de Sistemas de Agua (ASSA).

1.7.2. Honduras

In Honduras, water and sanitation coverage rates are high compared to other Latin American countries. As of 2008, 86% of Honduran households have access to an improved water source, 83% have access to water piped to the household, and in rural areas, 77% have access to an improved water source and 72% have water piped to a household connection (WHO, 2010). Ninety-six percent of piped water is accessed from surface sources, including springs, small creeks and rivers (USAID, 2006) and 98% of the population has intermittent water service (PAHO, 2000). Approximately 43 % of the networked coverage is provided by small drinking water systems and managed by elected Village Water Committees (VWCs)[10] (USAID, 2006). Many of the VWCs have difficulty charging water fees or insuring that these fees are paid on time, with huge effects on the resources available for maintenance and operation costs (COSDU 2004). Only 13% regularly treat their drinking water (PAHO, 2000; COSDU 2004). In a recent study of piped rural water networks in Honduras, it was estimated that 85% have fecal contamination (Argeta, 2005; COSDU, 2004). Diarrheal disease is the largest cause of morbidity and mortality for children under five after respiratory infection (WHO, 2009). The results of the HWF and CTS research in Honduras are in Paper II and Paper III. To complete this research, GK collaborated with three NGOs in Honduras, the International Rural Water Association (IRWA), Agua Desarrolló Comunitario (ADEC) and Shoulder to Shoulder.

[10] Another 29% are managed by municipalities, 15% by the national governments Water and Sanitation directive, SANNA, and the other 13% are run by private companies or private-public partnerships.

1.A. APPENDICES

1.A.1 Table I. WASH Related Diseases

Category	Infection	Pathogenic Agent
1) Fecal- oral (water borne/water washed)		
	Diarrhoeas and dysenteries	
	Amoebic Dysentery	P
	Balantidiasis	P
	Campylobacter enteritis	B
	Cholera	B
	Cryptosporidiosis	P
	E-coli	B
	Giardiasis	P
	Rotavirus-diarrhoea	V
	Salmonellosis	B
	Chingellosis	B
	Yersiniosis	B
	Enteric fevers	
	Typhoid	B
	Paratyphoid	B
	Poliomyelitis	V
	Hepatitis A	V
	Leptospirosis	S
2) Water-washed		
(a) skin and eye infections	Infectious skin disease	M
	Infectious eye diseases	M
(b)other	Louse-borne typhus	R
	Louse-borne relapsing fever	S
3) Water-based		
(a) penetrating skin	Schistosomiasis	H
(b) ingested	Guinea worm	H
	Clonorchiasis	H
	Diphyllobothriasis	H
	Fasciolopsiasis	H
	Paragonimiasis	H
	Others	H
4) Water-related insect vector		
(a)biting near water	Sleeping sickness	P
(b) breeding in water	Filariasis	H
	Malaria	P
	River blindness	H
	Mosquito-borne viruses	
	Yellow fever	V
	Dengue	V
	Others	V

B=Bacterium H=Helminth M=Miscellaneous P=Protozoon R=Rickettsia S=Spirochaete V=Virus **Source: Cairncross and Feachem, 1996, pg.10**

1.A.2. Table II – Household Water Treatment

Treatment Process	Pathogen Group	Baseline Removal (LRVa) b	Max Removal (LRV)c	Quality Requirements for treated water	Disinfectant Residual*	Availability of Needed Materials	Acceptability	Length of Treatment Time	Skill level needed	Full Cost ‡ ($/person/year)
Ceramic Filtration	Bacteria Viruses Protozoa	2 0.5 4	6 4 6	High Turbidity can clog ceramic pores over time	No	Ceramic Filter	High Probability	A few hours	No Skill	$2.50
Fabric Filtration (e.g., Sari cloth filters)	Bacteria Viruses Protozoa	1 0 0	2 0 1	None	No	Sari	High Probability in certain locations	Minutes	No Skill	$0.70
Biosand Filtration	Bacteria Viruses Protozoa	1 0.5 2	3+ 3 4+	NA	No	Local materials	High Probability	A few hours	No Skill	$13.00
SODIS (solar UV radiation + thermal effects)	Bacteria Viruses Protozoa	3 2 1	5.5+ 4+ 2+	Low Turbidity (<30 NTU)	No	Plastic PET bottle	High Probability	Full sun (hours); partial sun (days); No sun (not effective)	No Skill	$0.63
Free Chlorine Disinfection (bleach)	Bacteria Viruses Protozoa	3 3 3	6+ 6+ 6+	Low Turbidity (<30 NTU)	Yes	Chlorine for purchase	High to Moderate	Tens of minutes	No Skill	$0.66
Coagulation/ Disinfection	Bacteria Viruses Protozoa	7 4.5 3	9 6 5	None	Yes	Coagulant, Disinfectant	High to Moderate	Tens of minutes	Moderate Training Needed	$4.95
Simple Sedimentation	Bacteria Viruses Protozoa	0 0 0	0.5 0.5 1	None	No	Container	High Probability	Hour(s)	No Skill	$0
Thermal (e.g., boiling)	Bacteria Viruses Protozoa	6 6 6	9+ 9+ 9+	None	No	Source of Fuel	High to Moderate	Minutes to tens of minutes	No Skill	Cost of fuel

a. Log_{10} reduction value, a commonly used measure of microbial reduction, computed as log_{10} (pre-treatment concentration) – log_{10} (post-treatment concentration). **b.** Baseline reductions are those typically expected in actual field practice when done by relatively unskilled persons who apply the treatment to raw waters of average and varying quality in developing countries and where there are minimum facilities or supporting instruments to optimize treatment conditions and practices. **c.** Maximum reductions are possible when treatment is optimized by skilled operators who are supported with instrumentation and other tools to maintain the highest level of performance in waters of predictable and unchanging quality. ***** A safe storage container can decrease the likelihood of contamination after treatment/filtration. ‡Prices vary by country.

Table adapted from Brown et al., 2010c; UNICEF, 2008; WHO, 2008)

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PAPER I

Water Quality and Sustainability Gains in Piped Rural Drinking Water Supply Networks: Assessing the Impacts of Post-Construction Support in El Salvador

Abstract

The sustained provision of sufficient, safe, and reliable drinking water challenges piped community-run rural water systems. Post-construction support (PCS) may address these obstacles. Using a case-control design, qualitative and quantitative methods, and matched pair analysis, I measured the impact of the Circuit Rider (CR) model of PCS in El Salvador. The CR model provides technical, financial, and operational assistance to rural community-run piped water networks. CR communities had significantly better microbiological water quality, enhanced financial management and transparency, and greater investment in water treatment and system maintenance. CR PCS is associated with improved system performance and sustainability and is a low-cost (<$1 per household per year) drinking water intervention.

Prepared for the Journal of Water and Health

2.1 INTRODUCTION

Every year 2.5 million people die from diarrheal disease, and it is the second leading cause of death for children under five (Wardlaw et al., 2010). In an effort to improve human health, reduce poverty, and improve the lives of millions of people worldwide, trillions of dollars have been invested in improving drinking water supply systems in the Global South since the mid-1900's, and billions each year since the adoption of the Millennium Development Goal for Water in 2000 (Grover, 1998; OECD, 2009). Unfortunately, many drinking water systems, especially in the rural Global South, provide water that is *not* reliable, readily available, or microbiologically safe. These water systems may initially supply communities with sufficient, safe drinking water, supplied at regular intervals; but many fail to sustain quality service over the long-run (Blackburn et al., 2004; Craun and Calderon1999). Aging infrastructure, intermittent service, corroding pipes, inadequate disinfection and treatment, insufficient operation and maintenance, and poor financial management present obstacles for many community-run rural water supply systems (Rizak and Hrudey, 2008; Lee and Schwab, 2005). With the hope of improving the quality of water delivered by such systems, a variety of development actors (NGOs and Governments) have begun experimenting with post-construction support (PCS) programs. PCS provides technical assistance in operation and maintenance, resources for spare parts, and management training for the Village Water Committee (VWC)[11].

[11] VWCs are community elected water boards that govern decisions around water supply systems, "Junta de Agua" in Spanish.

Effective PCS that strengthens community management of rural water systems is expected to improve access to safe drinking water at low costs; however, no studies to evaluate their impact on water quality and system sustainability have been reported, and no study has calculated the costs of operating such a program. This paper examines the impact of the CR model of PCS in rural El Salvador. The CR model offers regular access to a trained technician for operation and maintenance problems, monthly visits by this technician for water quality and disinfection testing, and budgeting and accounting trainings for the Village Water Committee (VWC). A case-control design and matched pair analysis was utilized in this field-based study to assess the effects of the Circuit Rider model on water *system performance* (water quality and water supply) and water *system sustainability* (technical capacity and management, financial and operational management, and environmental protection) in 60 randomly selected intervention (Circuit Rider) and control (no Circuit Rider) communities in rural and peri-urban El Salvador. It then documents the costs of the water supply intervention. Principal study activities included: structured interviews with Village Water Committee (VWC) members and village water system operators, microbiological water quality tests, and drinking water disinfection tests in each community.

2.2. BACKGROUND

Infrastructure Maintenance in Small Systems: The rural sector has a very poor record of maintaining infrastructure investments (Ahuja, Kremer and Zwane, 2010). Many community run rural water systems in the Global South are characterized by poor water quality, insufficient supply, intermittent service, leakages, high costs, and aging infrastructure (Rizak and Hrudey, 2008; Moe and Rheingans, 2006, Lee and Schwab, 2005). In South Asia, more than a third of water infrastructure is non-functional (World Bank, 2003). Community-run piped drinking water networks, in the absence of adequate monitoring and technical repairs, quickly develop leaks that go unrepaired (Blackburn et al., 2004; WHO, 2004; Craun and Calderon, 1999). This is due to inadequate technical and operational knowledge, poor accounting and budgeting, and insufficient funds for spare parts as they are needed (Rizak and Hrudey, 2008; Lockwood, 2003). In tropical areas, the rainy season brings high levels of poor quality water and the dry season brings water shortages and intermittent service (Cairncross and Feachem, 1993). Shortages can lead to unsafe storage and often forces households to use unimproved sources (Pattanayak et al., 2005). The combination of leaky pipes and intermittent service leads to both water losses and to the intrusion of contaminated water into the piped system when negative pressure suctions occur (Rizak and Hrudey, 2008, Lee and Schwab, 2005, Semenza et al, 1998, Tauxe et al., 1994). Chlorine or other disinfectants used inconsistently or in inadequate quantities increases the burden of disease (Lee and Schwab, 2005, Cotruvo, Gunther and Hearne1999). High flows of poor quality water, common in the rainy season, can contaminate otherwise clean surface water supplies, are difficult to treat, and require regular monitoring (Musa et al., 1999). Poor maintenance is not limited to piped networks: in a large Kenyan study, 50% of borehole wells dug in 1980 had fallen into disrepair by 2000 (Ahuja, Kremer and Zwane, 2010).

A shift from top-down management to decentralized community management was once believed to be sufficient to sustain rural water supply service quality over time (Whittington, Davis and McClelland 1998; Sara and Katz, 1997). Decentralization gives communities control over technical, operational, and financial decisions. Community participation in decision making is associated with greater user satisfaction, improved access and time savings (Prokopy, 2005), but does not have a positive impact on the sustainability of the water system (Kleemeier, 2000). Women's participation and management in policy decisions can lead to more water infrastructure investment (Chattopadhyay and Duflo, 2004), but does not improve infrastructure maintenance (Kremer, 2008; Ahuja, Kremer, and Zwane, 2010; Prokopy, 2004). We now recognize that decentralized management and community participation alone is insufficient to sustain drinking water supply over the long-term. Factors recognized to influence sustainability include: the physical size of water systems (piped network) and user fees (Kleemeirer, 2000), and capital costs and distance and location of taps (Briscoe et al., 1990).

Addressing the Problem: Post-Construction Support: Most recently, post-construction support (PCS)—investment in community capacity for operation and maintenance—has received attention for its impact on project sustainability (Sohail et al., 2005; Schouten, 2003; Lockwood, 2003). PCS can provide communities with technical expertise and access to spare parts so that water systems do not break down (Whittington et al., 2009) and it can improve financial performance and overall household satisfaction (Prokopy et al., 2008). Communities that receive management-oriented PCS visits from external agencies, and those whose system operators attended training workshops, have better performing systems than communities that received no such support (Whittington et al., 2009; Davis et al., 2008). Engineering-oriented PCS visits to communities, however, had no measurable impact on system functioning or user satisfaction (Davis et al., 2008). Currently, the best configuration of PCS is not sufficiently detailed, and no study to date has researched the impact of PCS on microbiological water quality. This study assesses the efficacy and impact of the Circuit Rider model of PCS on system performance (functioning systems, water quality, and water supply) and sustainability (technical capacity and management, financial and operational management, and environmental protection) in community run rural water supplies in El Salvador.

The Circuit Rider Model of Post-Construction Support*:* The CR model provides on-going technical assistance to VWCs and their water system operators, and is aimed at expanding their capacity to overcome technical, financial and operational obstacles to successful operation and maintenance. The CR model was created by the United States National Rural Water Association (NRWA) in the early 1970's to help small rural water utilities meet the regulatory standards of the US Safe Drinking Water Act of 1974. NRWA now has several hundred Circuit Riders working in every state across the United States. Most are licensed water or wastewater operators in their respective state, and all have years of technical and managerial experience. Currently, the CR model also operates in Honduras, El Salvador, and Guatemala with locally trained technicians, and funding and technical support from the International Rural Water Association (IRWA), the international arm of NRWA. IRWA partners with host-country organizations, such as the Asociación Salvadoreña de Sistemas de Agua (ASSA) in El Salvador, AHJASA (Asociación Hondureña de Juntas Administradoras de Sistemas de Agua) and ADEC, (Agua Desarollo Comunitario) in Honduras, and Agua Para la Salud in Guatemala. These CR programs have been funded by external NGOs, IRWA and in some cases (AHJASA) by monthly compensation by member communities for the ongoing post-construction support.

Drinking Water in El Salvador*:* The National Water and Sanitation Authority, Administración Nacional de Aceuductos y Alcantarillados (ANDA), is responsible for water and sanitation services in El Salvador. ANDA is not yet able to carry out its mandate in rural areas (Linares and Rosenweig, 1999). Much of the funding for rural water system construction has been provided by NGOs. These rural water systems are managed by a locally elected village water committee (VWC) or Junta de Agua, and operated by a community member who is paid by the community. Little attention has been given to the technical, financial, operational, and maintenance needs of these systems after construction so as to ensure their sustainability (Linares and Rosenweig, 1999). Some NGOs provide initial support on how to set up a VWC, but few train community members in how to collect water tariffs, how to budget for future maintenance costs, where to obtain operational and maintenance assistance, or how to protect water sources. Some villages turn to their municipal government for help, but report that funds for water systems are often scarce or tied to political voting patterns, and are not easily accessed.

The Circuit Rider Model in El Salvador*:* ASSA provides CR PCS in El Salvador with Salvadorian engineers and technicians, and has been in operation since 2001. It offers CR PCS in four main areas: technical, financial, and administrative management, and environmental sustainability. CR PCS is provided in the form of trainings, on-call technical support, monthly visits, and capacity building workshops (see Figure I). CR technicians periodically visit participating communities to address technical problems, and test for chlorine disinfection and microbiological water quality. Chlorine is used to disinfect water, and small residual amounts of chlorine provide protection against bacterial regrowth or contamination after the initial disinfection. Sufficient presence of residual chlorine is routinely tested for in drinking water to determine if this protection exists. The presence of *Escherichia coli* and other coliform bacteria is tested for as a direct measure of contamination. An ASSA technician or engineer trained in drinking water treatment, water system maintenance, water committee organization and accounting makes monthly visits to 25 participating communities.

Prior to initiation of the monthly visits, the ASSA technician examines the water system and facilitates a needs assessment of the system and its management body. This appraisal includes questions about system conditions (from the source through its treatment and distribution), and VWC or operating committee activities. These include: the presence of a VWC, VWC membership and responsibilities, operator technical assistance, regularity of VWC meetings, household water fees, presence of water meters[12], nature of administration of financial accounting and bookkeeping, existence of an inventory of supplies, presence of a VWC bank account for monthly water fee deposits by users, and presence of a plan for maintenance and operation. The technician then tests the water for disinfection (residual chlorine) and microbiological quality (*E.coli* and total coliform bacteria). The needs assessment and disinfection evaluation allow the technician to organize individualized community-specific trainings and assistance. Technicians relay drinking water standards and inform operators and their water boards about disinfection technologies. ASSA technicians supply support for the Bio-Dynamic® technology by

[12] In metered communities, the household incurs additional fees if it uses more water than the community-agreed to baseline?

Norweco [Norweco, Norwalk, Ohio, USA]. This easily used device feeds chlorine from tablets, used for disinfection, into the piped water distribution tank and is easier to use and maintain than granular chlorine. The technicians continue to conduct regular drinking water tests for residual chlorine and microbiological safety (presence/absence for *E.coli*).

To receive Circuit Rider assistance from ASSA, the VWC or ASSA or both may initiate a discussion. ASSA employs 6 people: 3 Circuit Riders; a secretary/laboratory technician; and a marketing representative and director, both of whom also perform Circuit Rider activities. All personnel can explain what assistance can be provided. Given the recent civil war and political fracture in El Salvador, the first introductory CR meeting is the most sensitive. ASSA is an apolitical organization, while the VWC in rural areas is often a political group that does not easily accept outsiders, and thus the process of building a relationship can be slow. Once the VWC agrees that the assistance could be helpful, the subsequent meeting begins with a needs assessment. This is followed by the individualized monthly visits. ASSA has the resources to assist 175 community managed rural water supply systems with CR PCS, and it concentrates its efforts in San Vicente and five surrounding Departments, including Usulután, La Paz, Cabañas, San Miguel, and Cuscatlán.

Descriptions of the Circuit Rider model and anecdotal references to its success exist (Trevett and Nuñez, 1998; Stottlemyer, 1998; Holden, 1998); however, no rigorous assessment of its impact on water quality and long-term system sustainability has been published.

2.3. METHODOLOGY

Ethics: Free and informed consent of the participants were obtained and the study protocol was approved by the Protection of Human Participants, the Institutional Review Board, The Fletcher School, Tufts University, Massachusetts, USA, on June 13, 2007.

Research Design: I use an ex-post facto case-control design and matched pair analysis to assess the effects of the Circuit Rider model on randomly selected intervention (Circuit Rider) and control (no Circuit Rider) communities. I randomly selected 28 treatment communities. To construct a set of control communities, I matched the selected treatment communities to non-participating, non-Circuit Rider communities that were similar in population served, water system design, water source type, proximity to a paved road, and presence of a community run and operated water system. Sixty villages (28 intervention CR villages and 32 control no CR villages) were selected using primary and secondary data. Primary data included lists of drinking water systems given to the researchers by non-government organizations, treatment and control operators, village water committees, municipal offices located close to treatment and control communities and a roster of Circuit Rider communities that had received PCS approximately every month for the past 4 years, provided by ASSA. Secondary data included census information and department maps. Intervention communities were randomly selected from the ASSA roster. Control communities were selected in a two step procedure, using primary and then secondary census and geographic data for matching to the treatment communities. Of the 32 control communities, 22 communities had received no PCS, and ten had received an average of 3 days of PCS from a non-ASSA, non CR model organization[13].

Principal study activities included: a structured interview with the water system operator; a separate structured interview with the president or treasurer of the VWC or community water board; microbiological water quality tests (*E.coli* and total coliform) at the first and last households on the drinking water distribution line; and a residual chlorine test at the first and last house on the piped system. (Refer Appendix 5.A.3 and 5.A.4 for the English version of each structured interview.) Key informant interviews with Salvadorian professionals in the water sector served to enhance the validity and reliability of the results.

Site Description: Sample villages were in the Departments of La Paz, San Vicente Usulután at elevations between 200 and 2600 meters. Most sample villages were located in tropical savannah lowlands, at the bottom of the Rio Lempa watershed[14], the largest river basin in Central America, with a drainage area covering over 18 000 square kilometers (USACE, 1998). There is a distinct rainy season from May through September and a distinct dry season from October through April[15]. Surface waters of the lower basin

[13] This PCS in control communities included was far less consistent, occurred for a three day time period, on average, and was supplied by a water infrastructure supply company, a church, the Honduran government or an NGO, and consisted of a short training on chlorination, system maintenance, or organization of VWCs

[14] The Rio Lempa is shared by Guatemala, Honduras and El Salvador. The Departments of La Paz, San Vicente and Usulutan are at the bottom of the watershed.

[15] In San Vicente in June, the height of the rainy season, precipitation averages 353 mm; in February, the height of the dry season, precipitation averages 7 mm per month. (NASA Langley Research Center Atmospheric Science Data Center; New et al. 2002). Temperatures in the study vary between 21 C in the

region of the Rio Lempa are contaminated with high levels of fecal coliforms (FUSADES, 2008). This leads most villages to use groundwater sources for their drinking water if possible.

Data Collection: Field work and data collection in El Salvador took place in February, 2009[16]. Each village was visited by GK and a research assistant for approximately 4 hours. During this time, the operator and the Treasurer or President of the drinking water committee were interviewed separately with parallel structured interviews. In each village, water samples were taken at a proximate household closest to the distribution or treatment tank and at distal household furthest from the tan. Both samples were tested for chlorine residual on site, and for microbiological quality in an offsite laboratory. GPS coordinates were taken at each sample site.

***Performance and Sustainability: Water Testing and Structured Interviews*:** To test water quality, I combined the 3M™ Petrifilm™ and the Colilert® tests with residual chlorine measurements to enable a risk assessment of high, moderate and low risk water quality, according to World Health Organization standards (WHO, 1996). Residual chlorine levels were determined on-site using HACH 5ml free chlorine tests and DPD reagent. 3M™ Petrifilm™ and Colilert® microbiological tests were used offsite to test for *Escherichia* coli (*E.coli)* and total coliform. 3M™ Petrifilm™ is a simple *E.coli* enumeration method, for assessment of high and very high risk water quality (100 *E.coli*

rainy season to 25 C in the dry season (NASA Langley Research Center Atmospheric Science Data Center; New et al. 2002).

[16] February is the dry season in El Salvador. This time period was selected to determine if water availability and intermittent service were problems for the studied communities.

per 100ml sample). Colilert® is coupled with the 3M™ Petrifilm™ to measure the presence or absence of moderate to high risk water (> 10 *E.coli* per 100 ml). Water samples were drawn from the first (proximal) and last (distal) household on the piped distribution line. They were tested for residual chlorine and the results were recorded on site. Sterile 100 ml transparent Whirl-Pak® bags (Nasco, Modesto, CA) were used to collect a 100 ml water sample, which was coded and placed on ice until the microbiology tests were performed. Samples were plated (3M™ Petrifilm™) and bottled (Colilert®) using sterile plastic spreaders and pipettes and then incubated for 24 hours at 35 ^{o}C in a portable Hach incubation chamber[17]. *E-coli* and total coliform were enumerated via the Petrifilm test, and the presence or absence of *E.coli* and total coliforms was assessed via the Colilert test. This methodology has been validated and is well suited to rural sites where access to lab technology is limited (Trottier, 2010; Albert, Luoto and Levine, 2010).

In each village, the president or treasurer of the VWC and the drinking water system operator were interviewed with previously piloted structured-interviews. The structured interviews were designed after preliminary research. Interview piloting and testing included over 50 interviews with drinking water operators in Honduras, El Salvador, and the United States, visits to drinking water supply systems and interviews with CR technicians in all three countries, and interviews with health professionals and water quality testing facilities in all three countries. From these discussions, the variables

[17] The Portable HACH incubator (#25699) was donated to Dr. Jeffrey Griffiths by the HACH company (Loveland, CO, USA).

relevant to assessing performance (the delivery of safe drinking water) and long-term sustainability had been identified.

System performance variables include: microbiological quality, drinking water disinfection and water supply. System sustainability categories include: financial management, technical management, administrative management, and environmental protection. The financial management variables include: average monthly water fee, VWC debt, equity, percent of households not connected within the reach of the system, average monthly expenditure for water, percent of households that pay a monthly user fee, transparency (monthly user fee place of deposit such as bank, VWC members house, or at monthly meeting), and water system operating costs, and debt. Technical management variables include: operator's knowledge about disinfection, actual disinfection (chlorine residual) results, presence of leaky pipes, and sufficient spare parts (according to operators and VWCs). Administrative management variables include: presence of a water committee, women's participation in village water committee, average monthly wage of operators, and average work week for operators. Environmental protection variables include: water source protection, reforestation projects to protect watershed[18], and meters in each household to provide incentives for water conservation.

Analysis: Since much of the outcome data were not normally distributed, I analyzed most of the water quality results and the interviews with non-parametric statistical tests in SPSS. I used t-tests to assess normally distributed data, Mann-Whitney U test when the

[18] Forests are an important, long-term, low-cost tool that can limit pollution, prevent erosion, decrease run-off, and thus protect water supply and improve water quality.

data distribution was not normal, Chi-square tests for frequency data, and Fisher Exact tests when the frequency data was small (< 5). Tables II-VI (Appendix 2.A.1- Appendix 2.A.6) give an overview of the data collected and the results.

The data were also re-analyzed without one control community which is privately run with operational funding from the federal government, unlike all other intervention and control villages which have community run and managed water systems. By chance, this community had been chosen during the matching process. While this system is an outlier in terms of higher number of households served, higher system construction cost, ownership and operating budget, our results were essentially identical with or without its inclusion. I report the results of analyses with this community included in the control group.

2.4. RESULTS

Systems with and without CR PCS did not differ by the number of households served, age, and construction cost; however, CR systems had significantly less microbiological water contamination detected and significantly higher rates of disinfection. Their operators displayed improved knowledge about water treatment, and these communities displayed less negative aesthetic perceptions of chlorine. CR systems also had significantly better financial status (as measured by water payment service rates), transparency (as indicated by auditable banking records) and spending on repairs and water treatment (as calculated by VWC water system operating budgets). In contrast, the provision of CR technical assistance was not associated with the presence of sufficient residual chlorine throughout the piped network which met WHO standards (between 0.2

and 2 ppm), greater water supply or the initiation of reforestation projects to protect the water source. In sum, in matched systems, CR PCS was associated with significantly better water quality and significantly better financial and operational performance. The selected CR and control communities were comparable which leads us to believe that these results may be more widely generalizable (see below).

Comparability of Treatment and Control Communities: To assess the comparability of control and intervention (Circuit Rider) communities and their water systems, variables that are associated with project sustainability, according to previous studies, were compared. These variables included: number of households served, the presence of private household vs. public taps, water source data, pump use, age of the water system, water system construction cost, in-kind community contribution and NGO contributions for construction costs, presence of sanitation facilities in each household, and distance from nearest paved road. This information was obtained from the structured interviews. No significant differences were detected in these and similar variables. On average, systems were 12.5 years old and the distance to paved roads was 1 km or less. In summary, Circuit Rider and control communities did not differ by any variables that have previously been identified with project sustainability (Refer to results in Table II in Appendix 2.A.2).

System Performance*:* System performance, in this analysis, is determined by the presence of functioning systems, microbiological water quality and residual chlorine test results, and drinking water supply characteristics. *E.coli* and total coliform "presence/absence" and enumeration tests were used to determine if the water was microbiologically safe to drink. Residual chlorine tests were used to determine if water has been adequately treated. These two water tests were utilized to gauge drinking water safety. Interview questions for water system operators and VWCs were used to gauge water supply and system functionality.

Improved microbiological water quality in Circuit Rider communities: Unexpectedly, all but one of the 60 study water systems were functioning. CR communities had significantly lower rates of microbiologically contaminated water and higher rates of drinking water disinfection. 20% of control community water samples assessed with the most sensitive test, Colilert®, were positive for *E.coli* compared to only 3% of CR community samples; similarly, 62% of control community total coliform tests were positive versus 32% of CR communities. Using the Petrifilm test, 36% of control community water samples were positive for *E. coli* and/or total coliforms, versus 12% of CR samples. 59% of all control communities samples were positive by one or both of the microbiological tests, versus only 23% of CR water samples. I also found that operators in CR communities have significantly greater knowledge of the importance of drinking water disinfection and are more likely to be trained in disinfection. These results strongly suggest that participation in the CR program is linked to significantly improved water quality (See Table III in Appendix 2.A.3 for results).

Residual chlorine was significantly more prevalent in CR community samples than in control samples. In CR communities, 46% tested positive for some residual chlorine compared to 19% of control communities (See Table III in Appendix 2.A.3 for these results).

Water supply characteristics were similar in both control and Circuit Rider communities

The water supply data was similar for control and CR communities. Only 25% of control communities have water 24 hours a day, compared to 21% of CR communities. During both the rainy and dry seasons, on average, households in control and CR communities received seven to eight hours of water per day. Water was typically delivered to households for a few hours in the morning and a few hours in the evening, distributed at intervals and by sector, throughout the community. Most households have water at some period during the day (66% of control, and 68% of CR communities). Water availability ranged from daily to only weekly. One community reported that they had water only twice a month, each day for 8 hours[19]. Financial constraints, such as the energy cost of water pumping, were frequently mentioned as reasons for reduced water supply See Table III in Appendix 2.A.3 for these results).

System Sustainability: Sustainability for drinking water systems, in this analysis, is defined as safe drinking water delivered over time by VWCs and their operators. Our preliminary work suggested that technical capacity and management, financial and administrative management, as well as a basic understanding of source water source protection were critical sustainability parameters. Interview questions for water system operators and VWCs were used to gauge system sustainability.

[19] This particular community faulted the politicians, the town mayor who had not received support from this particular community in the last election, and was in control of water supply scheduling.

Enhanced technical capacity in Circuit Rider communities*:* When compared to control communities, CR communities had a significantly higher rate of operators who report they are disinfecting their drinking water, are more likely to be trained in disinfection, significantly less likely to have negative community perceptions of chlorine use, and are significantly more likely to use the Norweco active release chlorine tablet feeders to treat their drinking water (See Table IV in Appendix 2.A.4). The enhanced technical capacity in CR communities may in part explain the better microbiological water quality they enjoy compared to control communities.

All CR communities reported that in the last three months they had been visited by an ASSA Circuit Rider who tested chlorine and/or educated community members about chlorination; 89% reported that they had maintenance assistance or operator training; 61% reported training in accounting, budgeting and/or billing: 40% reported administration training for VWC members, and 18% reported training in water source or watershed protection.

Operators in all communities knew about drinking water disinfection and understand its importance, but when measured, in most systems the chlorine residuals did not achieve the WHO standard of at least 0.2 ppm (Table IV). In interviews, operators report that chlorine disinfection is important because: chlorine kills microbes that cause diarrhea, chlorine kills bacteria so that the water is free of contamination, chlorine kills bacteria that cause gastrointestinal sicknesses, chlorine purifies the water, makes it safe for children to drink, and chlorine makes the water potable so that people do not die. According to operators, community members believe chlorine makes the water taste bad, makes the water taste heavy, causes cancer, is the reason for liver problems, and is the root of kidney problems. According to VWCs and operators, community members often pressure the operator to use less chlorine than is necessary, or not to chlorinate at all. CR community operators, however, were more likely to say that they treat their drinking water and were more likely to have detectable residual chlorine in their water systems than control communities.

Fewer CR communities reported insufficient funds to make all repairs, but this did not achieve statistical significance. More CR villages reported leaky pipes in their systems, perhaps indicating enhanced awareness of system needs, given their significantly higher spending on system repairs than in control communities (See Tables IV and V in Appendix 2.A.4 and 2.A.5).

Improved financial management in Circuit Rider communities: CR communities, on average, had a significantly greater number of households who pay their water bill, higher spending on drinking water treatment and repairs of the water system, were more likely to have VWC members who know the cost of their drinking water system, and were more likely to have greater transparency. By transparency I mean that monthly water fees are deposited in a bank account instead of into the hands of a single community member. All but one community charged a water fee for service. A similar monthly fee for service, and a fee for late payment, was charged in both control and CR communities. The average monthly wage for operators and the average costs of energy did not differ between CR and control communities. (See Table V in Appendix 2.A.5).

CR communities and control communities all report that they have a household water fee, similar populations served, and similarly priced water fees; however, fee non-payment was more common in control communities than in CR communities, 31% versus 17%, respectively . Investment in water systems operation and maintenance (O&M)—repairs, operator wages, water treatment, and electricity costs for pump usage—are significantly greater in CR communities when compared to control communities. O&M investments averaged $509 per month in control communities, compared to $1310 in CR communities. Much of this difference relates to investments for repairs and water treatment. On average, treatment investments are $17 per month in control communities and $42.70 in CR communities; repair investments averaged $30 per month in control communities compared to $389.24 in Circuit Rider communities (See Table V in Appendix 2.A.5).

In both control and CR communities, the majority of VWCs reported that household water fees did not meet operating costs, and that energy costs (related to pumping water out of wells, and for distribution) make up the highest portion of the operating budget. VWC debt is higher in CR communities when compared to the controls, and is a result of greater overall investment in operations (See Table V in Appendix 2.A.5)

Administrative Management does not differ significantly between communities

CR communities were more likely to have a VWC and have women represented on the VWC than those control communities, and were also more likely to pay operators a higher wage; but these results were not statistically significant in my sample. Importantly, drinking water operators work an average of 48 hours a week and receive $134.43 a month (Table VI). This is less than the El Salvador minimum monthly wage of $143.84, and far less than Columbia University's lowest minimum living wage estimate for El Salvador of $421.00 per month (National Labor Committee, 2009). (See Table VI in Appendix 2.A.6).

Environmental Protection: CR Communities are more likely to use water meters

CR communities were significantly more likely to install water meters than control communities. Metered communities typically charge a baseline fee for a basic household water allotment determined by the community, and then charge an additional household fee for water consumed above the agreed upon baseline. Forestation within the watershed and around the water source did not differ significantly between CR and control communities: only one CR community had begun reforestation projects in their watershed. The number of communities that protect their water source with a forest and or fence was similar in control and CR communities. Fencing was more commonly used to protect water supplies than forestation. (See Table VI in Appendix 2.A.6).

2.5. DISCUSSION

The research found that post-construction support, the presence of the circuit rider model specifically, leads to lower rates of microbiologically contaminated water, higher rates of drinking water disinfection, improved operator knowledge about treatment, less negative community perception of chlorine, higher rates of community payment for water service, greater financial transparency, and greater rates of household water meters ($p < .05$, statistically significant*). Circuit rider communities were also more likely to have village water committees (VWCs) and more likely to have women participating on these VWCs than control communities; however, no statistical significance was found ($p > .05$). Circuit rider communities are more likely to be financially transparent: households were more likely to deposit their monthly water fee, the funds that pay for operation, maintenance and technical fixes in rural water supply systems, in a bank than in the household of a single community member ($p < .05$,*). Meters, installed in households to reduce water waste, are also more likely in circuit rider communities ($p < .05$,*), especially important in water scarce communities.

The cost of operating ASSA is less than $1 USD per household per year. The operating costs of the Circuit Rider program in El Salvador are ~$50,000/year, and benefit approximately 51,000 households per year. ASSA serves 170 villages with technical assistance, capacity building workshops, regular water and disinfection testing, and on-call assistance with maintenance and operation questions. On average, each village is home to 300 households. Relative to other water related interventions, this is a very low cost intervention that is associated with significant improvements in microbiological drinking water quality, financial and technical outcomes.

This study has several limitations. This data was collected in one specific region, had a relatively small sample size, and lacks baseline information collected before communities adopted the CR PCS intervention. Greater confidence could be placed in our results had CR PCS been investigated in a prospective fashion, via a randomized trial or a prospective staggered implementation. Thus, these associations must be carefully and cautiously interpreted. This study does however strongly suggest a link between CR PCS and improved water quality and improved system sustainability.

Further research is needed on reported versus actual water treatment and its impact on water quality. In interviews 96% of CR drinking water system operators reported that they disinfect their water with chlorine; yet, only 21% of the CR communities had detectable chlorine residuals which met WHO standards. There are four potential explanations for this, according to qualitative research: operators may overestimate their own treatment; inadequate chlorine may have been released by inexpensive generic chlorine tablets used instead of the ones recommended for the tablet feeder by circuit riders[20]; operators may be administering less chlorine because of pressure from community members who do not like the taste; or water may be standing in the distribution system for a long period of time, allowing the chlorine to dissipate before it reaches households. Some operators reported they treat with lower levels of chlorine than is mandated to avoid complaints by community members. More research is needed to determine the cause of the low rates of residual chlorine detected relative to reported treatment, given the importance of residual disinfectants when recontamination is possible.

In the PCS context, additional investigation may help to determine how specific aspects of improved financial management affect the availability of resources for operation and maintenance costs in community-run water systems. CR community households were

[20] Post-field research interviews with Norweco revealed that the Norweco BioDynamic ® tablet feeders are best used with NSF approved Norweco Pinnacle 70® trichlorite or Biosanititizer® tablets. In El Salvador, however, Circuit Rider s did not have these tablets. According to interviews, they had a used a less expensive Chinese manufactured tablet. According t to observation, they have a much shorter shelf-life than the Pinnacle 70® trichlorite or Biosanititizer® tablets. The Circuit Riders have since stopped using the Chinese manufactured tablets and are now using Norweco tablets. Further research is needed on the varying tablet technologies and their relative effectiveness.

significantly more likely to pay their water fee than control, and are more likely to deposit that fee in a bank account, while investing more in water treatment and repairs. If fees are deposited in bank accounts, corrupt financial practices can be prevented. If community members believe that user fees are spent to improve and repair their water system, they may be more likely to pay their water fees. I found that infrastructure debt is common in both control and CR communities; yet, only 53% and 54% of control and CR communities, respectively, charged a late fee if household water payments are not made on time. If user fees are unpaid or paid late, the capacity to repair or improve the water system is likely to be degraded. This in turn can decrease the long-term sustainability of water system supply and the quality of the water provided over time. The influence of post-construction support on the relationships between late and unpaid fees, and the impact of financial resource availability on maintenance and operations in community-run water systems have not been well studied.

The importance of source water environmental protection, and its role in sustainability, does not appear to be reflected in the beliefs and actions of the communities I studied. Only one community had engaged in reforestation activities to protect their water supply into the future. As populations and their water needs grow, this aspect of sustainability will become imperative.

The findings are relevant to international water policy. The MDG for Water has given the water sector an important baseline with which to determine the infrastructure status of a particular household's drinking water source; however, in my view much greater attention needs to be given to water quality, water supply and the reliability of the service. The Millennium Development Goal for water has focused national WASH priorities on infrastructure criteria. These criteria are likely to be inadequate for measuring true progress towards the goal of safe, adequate, and dependable water supplies. Water quality is not currently tracked as part of the MDG target for water, nor is system reliability or water quantity. A piped household system that delivers highly contaminated water only once a week would be considered "improved" according to the water MDG definitions; yet, such water would be unsafe, the quantity insufficient and the service unreliable. Furthermore, these households would be forced to find water at other water sources that may be "unimproved." These factors demand further attention in international water policy circles. If water quality, quantity, and service reliability were tracked along with the status (improved or unimproved), it is likely that the value of PCS would be appreciated by governments, NGOs, and international organizations, especially given its low cost per household served.

2.6. CONCLUSION

The Circuit Rider model of PCS, in El Salvador, is associated with improved community drinking water quality outcomes and improved financial management, technical capacity, and environmental protection outcomes. CR communities have significantly less microbiological water contamination than control communities and they invest significantly more of their operating budget on treatment and on repairs than control communities. This suggests that CR communities have systems that are better maintained and operated. The CR model leads to less water contamination; less drinking water contamination is related to less pathogen transmission; it is thus likely to lead to healthier communities; and, it is a surprisingly low cost intervention.

2.A. APPENDICES

2.A.1. Table I Circuit Rider Model

Circuit Rider, PCS	**Technical Assistance**
Technical Management	• CR technicians provides operator trainings and workshops on water system operation and maintenance (eg. chlorine disinfection and pump maintenance) • CR technicians provides monthly visits to test village drinking water for microbiological water quality (presence/absence of *E.coli*) and disinfection (residual chlorine), • CR technician's on-call assistance aids communities with technical problems that arise overtime.
Financial Management	• CR technicians provide VWC (village water committees) training in budgeting, accounting, and billing
Administrative Management	• CR technicians provide VWCs trainings in their responsibilities and inform them of national water quality regulations.
Environmental Performance	• CR technicians stress the importance of household water meters, protection of the water source with a fence and forest, and most recently in watershed protection through reforestation projects

2.A.2. Table II Comparability of Control and Circuit Rider Communities.

Parameter	Control %	Control N	Circuit Rider %	Circuit Rider N	Statistical Significance
Average number of households served by water systems		362		286	p = 0.411 *
Average Age of Water System (years)		13		12	p = 0.970 *
Private household tap	91%	(29/32)	89%	(25/28)	p = 1.000 †
Public community tap	6%	(2/32)	11%	(3/28)	p = 0.657 †
Functioning taps	97%	(31/32)	100%	(28/28)	p = 1.000 †
Source water: ground water	56%	(18/32)	57%	(16/28)	p = 0.945 χ
Source water: surface water	6%	(2/32)	11%	(3/28)	p = 0.657 †
Source water: spring	38%	(12/32)	32%	(9/28)	p = 0.667 χ
Pump used to access or distribute water	78%	(25/32)	82%	(23/28)	p = 0.700 χ
NGO constructed system	66%	(21/32)	75%	(21/28)	p = 0.433 χ
In-kind contribution to water system construction by village	97%	(31/32)	93%	(26/28)	p = 0.188 †
Monthly user fee charged in communities	97%	(31/32)	100%	(28/28)	p = 1.000 †
Households not connected but within the area of community water system	15%		21.5%		p = 1.000 ‡
Access to Sanitation (given as % of village)	91%		83%		p = 0.765 *
Cost of water system (known in 11/32 control and 17/28 CR communities ($)		$718,545.45		$602,758.71	p = 0.495 *
Range of households served		22-644, +5809		31-800	p = 0.411 *
Monthly user fee per household		$ 3.70		$4.25	p = 0.441 ‡
Distance from nearest paved road		0.68 km		1km	p = 0.765 *

* Mann Whitney U test
† Fisher exact test
‡ Student's t-test
χ Chi-squared
Statistical significance at p < 0.05

2.A.3. Table III – Water Quality& Water Supply

Parameter	Control %	Control N	Circuit Rider %	Circuit Rider N	Statistical Significance
A. Water Quality					
E.coli presence (Colilert®)	20%	(13/66)	3%	(2/60)	**$p = 0.0051$†**
Total coliform presence (Colilert®)	62%	(41/66)	32%	(19/60)	**$p = 0.0007$ χ**
Any presence total coliform or *E.coli* (3M™ Petrifilm™)	36%	(24/66)	10%	(7/60)	**$p = 0.0010$ χ**
Any positive test (Colilert® or 3M™ Petrifilm™)	59%	(78/132)	23%	(28/120)	**$p < 0.0001$χ**
Residual chlorine present	19%	(12/64)	46%	(26/56)	**$p = 0.0010$χ**
Residual chlorine sufficient in proximal household (at least 0.2ppm, WHO standard)	16%	(5/32)	32%	(9/28)	$p = 0.1340$ †
Residual chlorine sufficient in distal household (WHO standard)	13%	(4/32)	18%	(5/28)	$p = 0.7210$ †
Residual chlorine sufficient in proximal and distal households (WHO)	13%	(4/32)	18%	(5/28)	$p = 0.7210$ †
B. Water Supply					
24 hours of water supplied daily	25%	(8/32)	21%	(6/28)	$p = 0.7460$ χ
Water supplied everyday for some period to households	66%	(21/32)	68%	(19/28)	$p = 0.8560$ χ
Average hours of water supply daily	9.6 hrs		8.8 hrs		$p = 0.0700$ ‡
Range of water supply	3hrs once a week - 24hrs/day		12 hrs every 15days -24 hrs/day		

† Fisher exact test
‡ Student's t-test
χ Chi-squared
Statistical significance at $p < 0.05$

2.A.4. Table IV. Technical Capacity & Management

Parameter	Control		Circuit Rider		Statistical Significance
A. Technical Capacity and Management	**%**	**N**	**%**	**N**	
Operators believe drinking water treatment to be important	100%	(32/32)	100%	(28/28)	p = 1.0000 χ
Operators report that they are treating their communities drinking water	63%	(20/32)	96%	(27/28)	**p = 0.0014†**
Operator received training in drinking water treatment	50%	(16/32)	96%	(27/28)	**p < 0.0001†**
Residual chlorine present in water tests	19%	(12/64)	46%	(26/56)	**p = 0.0012** χ
Operators report that they have leaky Pipes in their systems	31%	(10/32)	57%	(16/28)	**p = 0.0452** χ
Operators report that they have insufficient funds to purchase parts to make repairs	69%	(22/32)	50%	(14/28)	p = 0.1424 χ
Community members have a negative perception of chlorine	56%	(18/32)	25%	(7/28)	**p = 0.0151** χ
Use Norweco Biodynamic® active release chlorine tablet technology	9%	(3/32)	82%	(23/28)	**p < 0.0001†**

† Fisher exact test
χ Chi-squared
Statistical significance at p < 0.05

2.A.5. Table V. Financial Management

Parameter	Control		Circuit Rider		Statistical Significance
B. Financial Management	**%**	**N**	**%**	**N**	
Monthly household water fee charged	97%	(31/32)	100%	(28/28)	p = 1.000 †
Household receive water from system but do not pay monthly water fee	31%		17%		**p = 0.037** *
Household water fees do not cover operating costs	68%	(22/32)	50%	(14/28)	p = 0.142 χ
Transparency: monthly water fees are deposited in a bank	16%	(5/32)	39%	(11/28)	**p = 0.0475**†
Monthly operating cost for water system		$ 509.27		$ 1,310.20	**p = 0.007** *
Monthly water treatment costs		$17.06		$42.70	**p = 0.003** *
Monthly repair costs		$30.00		$398.24	**p = 0.003** *
Cost of energy per month		$466.77		$676.62	p = 0.723 *
Average water committee debt		$2393.00		$2712.84	**p = 0.011** *
VWC reports cost of energy is Highest or second highest operating cost	66%	(21/32)	86%	(24/28)	p = 0.791 †
VWC charges a fee for late monthly household water fee payment	53%	(17/32)	54%	(15/28)	p = 0.973 χ
VWC knows the cost of their water system	34%	(11/32)	61%	(17/28)	**p = 0.043** χ

* Mann Whitney U test
† Fisher exact test
χ Chi-squared
Statistical significance at $p < 0.05$

2.A.6. Table VI. Administrative Management & Environmental Protection

Parameter	Control		Circuit Rider		Statistical Significance
C. Administrative Management	**%**	**N**	**%**	**N**	
VWC present in village	75%	(24/32)	89%	(25/28)	p = 0.4913 †
Women participate in the VWC	74%	(23/31)	87%	(20/23)	p = 0.3187 †
Monthly wage for operator		$126.20		$149.22	p = 0.2140 ‡
Hours operator works per week		48		49	p = 0.7800 ‡
D. Environmental Protection					
Undertake reforestation projects in water supply watershed	0%	(0/32)	4%	(1/28)	p = 0.4745 †
Protect water source with forest	28%	(9/32)	29%	(8/28)	p = 0.9697 χ
Protect water source with fence	69%	(22/32)	64%	(18/28)	p = 0.7166 χ
Meters Installed in households	9%	(3/32)	32%	(9/28)	**p = 0.0498** †

_† Fisher exact test
‡ Student's t-test
χ Chi-squared
Statistical significance at p < 0.05

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PAPER II

Household vs. Community-level Drinking Water Treatment: Evidence from Honduras

Abstract

Inadequate operation, maintenance, and financial resources, frequently lead community-run piped drinking water systems in developing countries to deliver unsafe drinking water. Households served by such systems may thus benefit from household or community-level treatment systems which improve microbiological water quality. A quasi-randomized experimental design was used to test the efficacy and sustainability of two treatment technologies—the household ceramic water filter (HWFS) and the community-level treatment system (CTS)—in eleven communities and 334 households (135 HWFS, 62 CTS, and 137control) in Honduras. At baseline, household water service in the eleven communities was characterized as untreated piped water to a household or yard tap, microbiologically unsafe, at high and very high water quality risk levels, intermittent, and turbid in the rainy season. After one year with the technologies, HWFS and CTS households still using the technologies had significantly improved microbiological water quality ($p<.05$), 61% of HWFSs and 46% of CTSs were still in use, and the technologies are relatively low-cost ($3.63 per person per year for the HWFS and $1.37 for the CTS). To further increase the use of the technologies over time, additional education about water quality, a market for spare parts (HWFS) and technical assistance over the longer term in maintenance and operation (CTS) may be necessary.

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3.1 INTRODUCTION

Unsafe drinking water is a leading cause of 2.2 million deaths from diarrheal disease per year (Wardlaw et al., 2010). Diarrhea is caused by bacterial, viral and parasitic organisms that are spread by contaminated water, often from fecal contamination. The international response to this global disease burden is guided by the Millennium Development Goal (MDG) for water—to halve, by 2015, the proportion of people without sustainable access to safe drinking water. This target is designed to reduce diarrheal disease and, thus, improve human and environmental health, and reduce poverty. The MDG water target is tracked by counting the proportion of households in each country with access to “an improved water source.” Improved water sources include household connections and public taps connected to a centralized water distribution system, standpipes, tubewells and boreholes, protected dug wells and springs, and/or rainwater collection, and can be no more than one kilometer from the user’s dwelling [21] (WHO et al., 2006). Unfortunately, the goal of providing safe drinking water cannot be met using just these infrastructure criteria (Bartram, 2008). Because ‘improved’ water is frequently not microbiologically safe, it may still transmit the pathogens which cause diarrheal disease (Rizakand Hrudey, 2008; Lee and Schwab, 2005; Moe and Rheingans, 2006). With this understanding, Governments, NGOs and households have been experimenting with household and community level water treatment to address this problem. This paper documents some of the obstacles for the provision of a sufficient supply of safe drinking water in rural community-run piped drinking systems in Honduras, and then tests the

[21]‘Improved’ water sources are household connections and public taps connected to a centralized water distribution system, standpipes, tubewells and boreholes, protected dug wells and springs, and/or rainwater collection, and it is no more than one kilometer from the user’s dwelling ‘Unimproved’ water sources include: unprotected dug wells, unprotected springs, tanker trucks, surface water, and bottled water

efficacy of household vs. community level treatment in settings where piped drinking water is contaminated. Specifically, it tests the household health and sustainability impacts of a household-level water filter and safe storage (HWFS) compared with a community-level treatment system (CTS).

3.2. BACKGROUND

Piped drinking water to a household tap is often considered the gold standard for water delivery and its impact on diarrheal disease reduction. Ideally, piped drinking water begins with a protected water source that can supply sufficient quantities of water year round, meets a standard of biological and chemical treatment (coagulation, sedimentation, filtration and disinfection) prior to distribution, and then travels along an uninterrupted network of pipes to supply households with safe drinking water throughout the day. Piped water, in both the developed and developing world, however, does not always reach this gold standard (Bartram, 2008, Moe and Rheingans, 2006).

Research documents the challenges of the provision of a safe and sufficient supply of drinking water delivered through a network of watertight pipes regularly over time. In the Global South[22], many piped networks are characterized by poor source water quality, an absence of drinking water treatment, insufficient supply, intermittent service, leakages, high costs, and aging infrastructure (Bartram, 2008; Rizak and Hrudey, 2008; Lee and Schwab, 2005; Yassin, Amr and Al-Najar, 2006). Small water systems in rural and urban areas of developing countries that access water from surface sources are especially at risk

[22] Even in developed countries, aging infrastructure has increased the vulnerability of piped networks, and led to the intrusion of contamination which has contributed to waterborne disease outbreaks (Moe et al., 2006).

(Howard, Bartram, and Luyima, 1999). In tropical areas, the rainy season brings with it high levels of turbidity, and the dry season brings water shortages. Intense rains can cause contamination of surface water sources, and treatment becomes more difficult[23]. Shortages can lead to unsafe storage and intermittent service. Intermittent services can lead to suctions in the pipes and contamination of the entire network (Tauxe et al., 1994). This can lead to a lack of trust of the piped water and the use of alternative unimproved sources (Pattanayak et al., 2005). When households have intermittent service, they are often forced to store water for periods of time, increasing the risk of contamination between collection and point of use (Wright, Gundry and Conway, 2004; Trevett and Nuñez, 2006). We are increasingly aware of the MDG drinking water infrastructure target's shortcomings, and that a new paradigm may be necessary (Clasen, 2010; Bartram, 2008; Sobsey, 2006).

In Honduras, water and sanitation coverage rates are high compared to other developing countries. Ninety-six percent of piped water is accessed from surface sources, including springs, small creeks and rivers (USAID, 2006), and 98% of the population has intermittent water service (PAHO, 2000). Approximately 43 % of the networked coverage is provided by small drinking water systems and managed by elected Village Water Committees (VWCs) [24] (USAID, 2006). Many of the VWCs have difficulty charging water fees or insuring that these fees are paid on time, with huge effects on the resources available for maintenance and operation costs (COSDU, 2004). Only 13%

[23] Chlorine is commonly used to treat drinking water because it is widely available at a low-cost, and maintains a residual; however, it is well known that the disinfection efficiency of chlorine is negatively correlated with turbidity (LeChevallier et al., 1981).

regularly treat their drinking water (PAHO, 2000; COSDU, 2004). In a recent study of piped rural water networks in Honduras, it was estimated that 85% have fecal contamination (Argeta, 2005; COSDU, 2004). Diarrheal disease is the largest cause of morbidity and mortality for children under five after respiratory infection (WHO, 2009).

Recently, it has been suggested that if piped water is not safe or not perceived as safe, it should be treated at the point of use (Sobsey, 2006). Others have suggested that communal water treatment may be effective in preventing pathogen transmission, but a complete case has not been made for choosing to treat at the community level (Zwane and Kremer, 2007). No known study compares household to community-level treatment. In this study we compare the efficacy and sustainability of household treatment and community level treatment in communities that have piped water that is characterized as microbiologically unsafe, intermittent, turbid in the rainy season, and perceived as unsafe by its users. This research adds to the current debate about the best place for water treatment—the household or the community. The treatment technologies are described below.

***Household Water Filters and Safe Storage*:** Household ceramic water filters and safe storage (HWFS), made by Potters for Peace, combine the advantages of household filtration and safe storage, so that safe water can be consumed at the point-of-use. HWFS are locally manufactured in over 20

countries across the Global South and retail for US$10-25. The filters are lined with colloidal silver, an effective antibacterial agent (Brown, Sobsey and Loomis 2008; Oyanexdel-Craver and Smith, 2008). In a survey of HWT methods, ceramic filters were deemed the most effective interventions for improving household water quality and reducing waterborne infectious disease (Sobsey et al., 2008). The ceramic filter combines the advantages of household filtration, safe storage, and cost effectiveness. The filter and the safe storage unit keep water safe until the point of use and costs only $20 per household.

In laboratory experiments and field trials, HWFSs improve microbiological water quality, reduce diarrheal disease, and are a low cost drinking water intervention. Under laboratory conditions, the efficacy of the HWFSs has been well documented (Oyanedel-Crave and Smith, 2008; Brown and Sobsey, 2010). A randomized trial in Cambodia documented a 49% reduction in reported diarrheal disease rates and an improvement in water quality over a four-and-a-half-month period for Potter for Peace HWFS users (Brown, Sobsey and Loomis, 2008). A randomized trial in Zimbabwe and South Africa documented an 80% reduction in diarrheal disease rates, recorded from pictorial diaries for children 26-34 months of age with HWFSs when compared to control groups over a 6 month period (Du Preez et al., 2008)[25]. A study of the health benefits to immune compromised HWFS users in South Africa documented a reduction in reported days of diarrheal illness of HIV patients over a 10 month period (Abebe et al., 2010).The health and water quality benefits documented in field experiments and under laboratory conditions have led the World Health Organization and UNICEF to promote HWT throughout the world (WHO, 2007; UNICEF, 2008).

[25] The type of ceramic filter is not reported.

Community- level Treatment System: Community-level treatment systems (CTS) which combine coagulation-flocculation-sedimentation and chlorination have been installed in Honduras, Guatemala, Haiti, and Ghana[26]. The CTS is a centrally located stand alone system with a single communal tap. CTS households have to walk to the CTS, collect their water and then return back to the household. It is less than a ten minute walk for the farthest household to the CTS. In this study, the CTS treats piped water that is delivered to each house and provides households with all other water needs. The CTS is available to households to improve their drinking water. Each community is required to elect an individual who lives centrally, and is trained to maintain and operate the CTS free of charge. Each elected operator receives training and then operates and maintains the CTS for the community free of charge. The community is responsible for purchasing the aluminum sulfate and the chlorine.

The Community Treatment System (CTS) in Honduras utilizes contaminated piped water, often piped from surface water sources, and runs this water through a coagulation-sedimentation tank where aluminum sulfate is stirred into the water for 20 minutes by the operator to rid the water of turbidity. Water then passes into the second tank where chlorination takes place. Residual chlorine can then be tested with a simple kit by the operator. The CTS removes bacteria, viruses and protozoa at a level that exceeds any of

[26] In Ghana, these CTSs are constructed by Community Water Solutions, an NGO. In Ghana, these CTSs are coupled with a safe storage unit for each household. The operator is also paid for his/her work. Each bucket of water costs a small fee and each household pays for each bucket of safe drinking water drawn from the CTS.

the other low-cost treatment processes because it combines coagulation-sedimentation with chlorination (Brown and Sobsey, 2010b). The advantage of this system relative to household filters is that it removes turbidity (i.e. the suspended matter that can reduce the microbiological efficacy of chlorine and other chemical disinfectants) and then uses chlorine for disinfection.

In this study, the challenges faced by community-run piped drinking water networks in Honduras are documented. The efficacy and sustainability of two drinking water technologies, a community treatment system vs. a household treatment system pre and one-year post-intervention were evaluated.

3.3 METHODS & MATERIALS

Setting: The study was conducted in and around the municipalities of Marcala and Concepción, in the Departments of La Paz and Intibucá, two of the poorest in Honduras. Eleven villages in total were included, nine villages in La Paz and two villages in Intibucá. Marcala, the municipality closest to the nine La Paz villages is 90km from the regional capital. Concepción, the municipality closest to the two Intibucá villages is 122 km from the regional capital. Baseline data was collected in 2008 and follow-up data was collected in 2009, during the rainy season. Rainfall in the area follows a bimodal distribution with distinct wet and dry seasons. These patterns contribute to poor water quality in the rainy season and restrict water availability in the dry season.

Experimental Design**:** In a quasi-randomized experimental design, household surveys and household microbiological water quality tests were used to compare the efficacy of the two technologies in 11 communities and 334 households (135 HWFS, 62 CTS, and 137 control). Female heads of household were interviewed, and household drinking water sampled for microbiological contamination at baseline and one year after the technologies were distributed or constructed. Change in diarrheal disease in all persons in all households in the communities was also recorded based on responses from the female head of household. Secondary data collected from the Honduran NGO, ADEC, on any monitoring done on CTSs or HWFSs were also referenced. Secondary data were used to verify the validity and reliability of the results. The HWFS were sold to households for the subsidized cost of $5 (the rest of the total $20 cost was absorbed by participating NGOs). The CTSs were constructed free of charge by the NGOs for the CTS communities, however, the CTS communities had to pay for the chlorine and aluminum sulfate used for treatment over the course of the year. This yearly cost of this treatment was approximately $1 per household over the course of one year.

Preliminary Data Collection**:** We collected preliminary data in 35 rural communities with community-run piped drinking water in the rural areas of the Departments of La Paz and Intibucá. This included the results of microbiological drinking water quality and residual chlorine tests in each community and conversations with a Village Water Committee representative, an elected water board member, in each community to determine the number of households served, the drinking water sourced, water availability in hours per day in both the rainy and dry seasons, the age of the water system, the presence or absence of water treatment prior to distribution, and the distance to the nearest paved road and nearest market town.

Structured household interviews and key informant interviews were designed by GK after preliminary research (See Appendix 5.A.5 a copy of this interview in English[27]). Preliminary research included over 50 interviews with drinking water operators in Honduras, El Salvador, Guatemala and the United States, visits to drinking water supply systems in all four countries, interviews with health professionals in Honduras, and visits to water quality testing facilities in the United States. Other household surveys and information related to Water, Sanitation, and Hygiene (WASH) survey collection informed the creation of the household survey (Billig, Bendahmane and Swindale, 1999; WHO and UNICEF, 2006; UNICEF, 2005).

Community Selection**:** Of the 35 rural community-run drinking water supply systems studied in the preliminary research, none were treating or filtering their drinking water, no system had chlorine residual in their drinking when tested in May, 2008, and 23 of the communities had high to very high levels of drinking water microbiological contamination. Of the 23 communities with high to very high levels of microbiological contamination, 4 communities were randomly selected. These communities were then matched as closely as possible based on population served, water system design, water source type, paved road proximity, system age, water quality risk level, sanitation presence, and other socioeconomic indicators to 4 other communities. (See Appendix 3.A.1. Table 1 for an overview of community characteristics). Three other communities were then selected that closely matched the HWFS and control communities. Once matched, the communities were chosen to be HWFS, CTS or control in a blind-from-the-hat selection process. Households were then randomly selected from each community so

[27] The author can be contacted for copies in Spanish.

that approximately 50% of the households in each village were interviewed. In total, 334 households were interviewed (135 HWFS, 62 CTS and 137 control).

Data Collection**:** The study consisted of two baseline visits in June and November, 2008, and two follow-up visits in June and November of 2009[28]. Pre-intervention data in each household included household interviews with 334 female heads of household with the previously piloted household survey, bacteriological water quality tests, and a household geo-reference with GPS. Directly after baseline data collection, the research team, with the assistance of two NGOs (Shoulder to Shoulder in Intibucá and Agua Desarollo Communitario in La Paz), facilitated the distribution of the subsidized HWFSs in four communities, and the subsidized construction of the CTSs in three communities in 2008.

Post-intervention data collection trips were timed so that each community was re-visited one year after the HWFSs were distributed there. Post-intervention data collected in 2009 was drawn from the same households interviewed in 2008, and included the household interview administered at baseline, a HWFS and CTS specific survey, bacteriological water quality tests in each household, and anthropometric measures of the same children measured at baseline. (See Appendix 5.A.6 for the HWFS specific survey and 5.A.7 for the CTS specific survey). All interviews were administered after obtaining informed consent from the female head of household. All data were collected by GK and a team of six Hondurans, hired and trained by GK.

[28] Data post-intervention was collected in the middle of the military coup that occurred in Honduras in 2009.

Three NGOs were involved: Shoulder to Shoulder, a public health NGO with its base in Intibuca, Honduras, ADEC (Agua Desarrollo Comunitario)[29], a Honduran based water systems engineering NGO, and the International Rural Water Association (IRWA), a drinking water systems engineering organization that offers funding, technical support, and training to host-country NGOs like ADEC. They assisted the research group in community introductions, the purchase and delivery or construction of the technologies, and provided a one-day community training on village water quality and the maintenance and operation of the technologies. They subsidized the cost of the HWFS and the CTS.

Water Quality Testing and Analysis**:** To test water quality, I combined the 3M™ Petrifilm™ and the Colilert® tests to enable a risk assessment of very high, high, moderate, and low risk water quality, according to World Health Organization standards (WHO, 1996). 3M™ Petrifilm™ and Colilert® microbiological tests were used offsite to test for *Escherichia* coli (*E.coli)* and total coliform. 3M™ Petrifilm™ is a simple *E.coli*[30] enumeration method for assessment of high and very high risk water quality (100 *E.coli* per 100ml sample). Colilert® is coupled with the 3M™ Petrifilm™ to measure the presence or absence of low (<1-10 *E.coli* per 100ml) to very high risk water (>1000 per *E.coli* per 100 ml), according to World Health Organization guidelines (See Figure I). The water samples were drawn from the drinking water source of each household. If the tap was the drinking water source, it was drawn directly from the tap. If the female head of household said they treated their drinking water in the household by boiling or chlorine

[29] ADEC focuses their work in the departments of Copan and La Paz. They construct drinking water treatment systems with communities, offer post-construction support, and provide capacity building trainings, water quality testing, and community based water, sanitation and hygiene (WASH) education.
[30] *E.coli* is an indicator of fecal choliform and its presence is regularly accessed to determine if water is safe to drink.

disinfection, the water was drawn from the storage container that held the treated drinking water. The tap was not flamed or disinfected. The sample reflects normal collection procedures and contamination from everyday use. If tap water was the drinking water source and there was not water in the tap at the time of the house visit and interview, water was drawn from the storage container of the household. Sterile 100 ml transparent Whirl-Pak® bags (Nasco, Modesto, CA) were used to collect a 100 ml water sample, which was coded to match the interview and placed on ice until the microbiology tests could be performed mid-day for morning samples and in the evening for afternoon samples. Samples drawn from storage containers were drawn with an individually packaged sterilized pipette. Samples were plated (3M™ Petrifilm™) and bottled (Colilert®) using individually packaged and sterilized pipettes (Fisher Scientific Inc.) and plastic spreaders (3M™ Petrifilm™) and then incubated for 24 hours at 35 ^{o}C in a portable HACH® incubation chamber[31]. *E-coli* and total coliform were enumerated via the Petrifilm test, and the presence or absence of *E.coli* and total coliforms was assessed via the Colilert test. This methodology was developed by Dr. Robert Metcalf, Professor of Microbiology at California State University at Sacramento, has been validated (Trottier, 2010), and recommended by the United Nations as a practical method for rapid assessment of bacterial water quality, particularly well suited to rural sites in developing countries (UN Habitat, 2010).

[31] The Portable HACH incubator (#25699) was donated to Dr. Jeffrey Griffiths by the HACH company (Loveland, CO, USA).

Figure I - WHO Guidelines[32]	
Risk Level	**E.coli in Sample (CFU or MPN/100ml)**
Conformity (Nil)	<1
Low	1-10
Intermediate	11-100
High	101-1000
Very High	>1000

***Household Interview Data Collection and Analysis*:** Previously piloted structured interviews were held with the female heads of household, the person generally responsible for household water collection, and management, and its use for cooking, cleaning and washing. The questions in the household survey instrument elicited data on household demographics, primary drinking water source in the rainy and dry season, water availability, perceptions of water quality, water handling practices, sanitation type, hygiene behavior, and presence of specific gastrointestinal diseases for the children and adults in the household. The household survey was administered at baseline and one year after the filters were distributed. (See Appendix 5.A.5 for the household survey). An additional survey specific to each technology included questions about usage, reasons for non-usage, maintenance and operation, and perceptions of water quality. See Appendix 5.A.6 and 5.A.7 for the technology specific interviews). These data were utilized to demonstrate that the groups were well balanced; thus a simple comparison of mean outcomes post-intervention could provide an unbiased estimate of HWFS and CTS impacts. The technology surveys were administered one year after the filters were distributed.

[32] Adapted from WHO Risk Levels for E.coli (WHO, 1997). Replaced “thermotolerant bacteria” with *E.coli*.

Secondary Data**:** The Honduran NGO, Agua Desarollo Communitaro, provided the results of an evaluation of 38 CTSs monitored in the Department of La Paz, Honduras from May-June, 2008 by their water systems technicians. This evaluation documented the turbidity, residual chlorine and related observations for the 38 systems.

*Data Entry & Analysis***:** Household surveys and technology surveys were recorded on hard copy paper forms and entered into digital forms using Excel (Microsoft Corp., Redmond, WA). Digital tables were then exported into SPSS version 19 (SPSS) and analyzed. Chi-square tests were used to analyze frequency data, ANOVA was used to analyze normally distributed data across the three groups, and Fisher Exact tests were used when the frequency data were small (< 5). (See Appendix 3.A.1 through 3.A.11 for the results.)

Ethics**:** Informed consent was obtained from the female head of household at the beginning of the study. The participants were not subjected to risks of any kind as a result of the project. This study was approved by the Institutional Review Board of the Fletcher School of Law and Diplomacy at Tufts University on June 13, 2007. All intervention households received their filters in 2008 after baseline data were collected. All control groups received filters in November and December, 2009, and one control village was provided a chlorine tablet feeder for their distribution tank by a proximate NGO, after the study was complete. All results were shared with community leaders after the study was completed, and lessons learned were reported to the Honduran based NGOs, ADEC and Shoulder to Shoulder, working in the communities so that they could follow-up and apply the lessons learned from the study in their work with the communities.

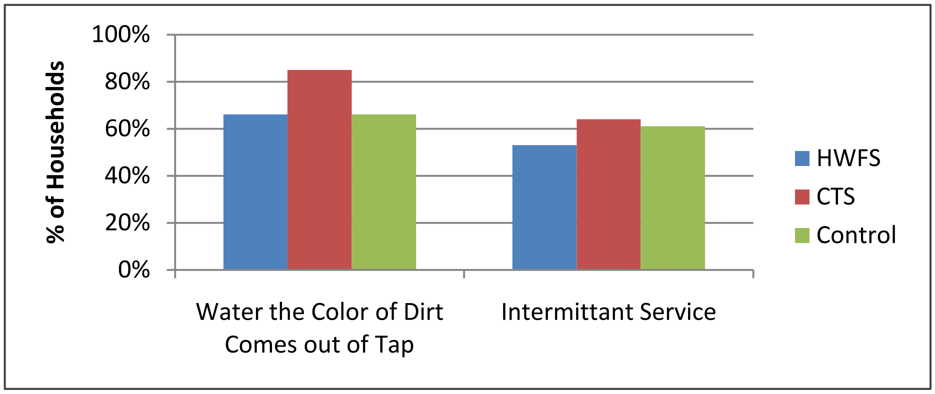
3.4. RESULTS

Baseline Data

Household Respondent Characteristics: A total of 334 households and 1853 persons from 11 communities and 13 water systems (two communities had two piped water networks) located in rural and peri-urban areas near Marcala, La Paz and Concepción, Intibucá were recruited into the study (754 persons in the HWFS group, 364 in the CTS group, and 735 in the Control group). The mean household size was 5.5 persons. The female head of household's mean education was 4.2 years. Baseline data did not differ in most demographic areas except control households had a higher prevalence of electricity, and ownership of televisions and refrigerators. CTS household were more rurally located and significantly more likely to own land than control or HWFS households. The demographics, household and respondent characteristics for the aggregate intervention and control groups are shown in Appendix 3.A.1.

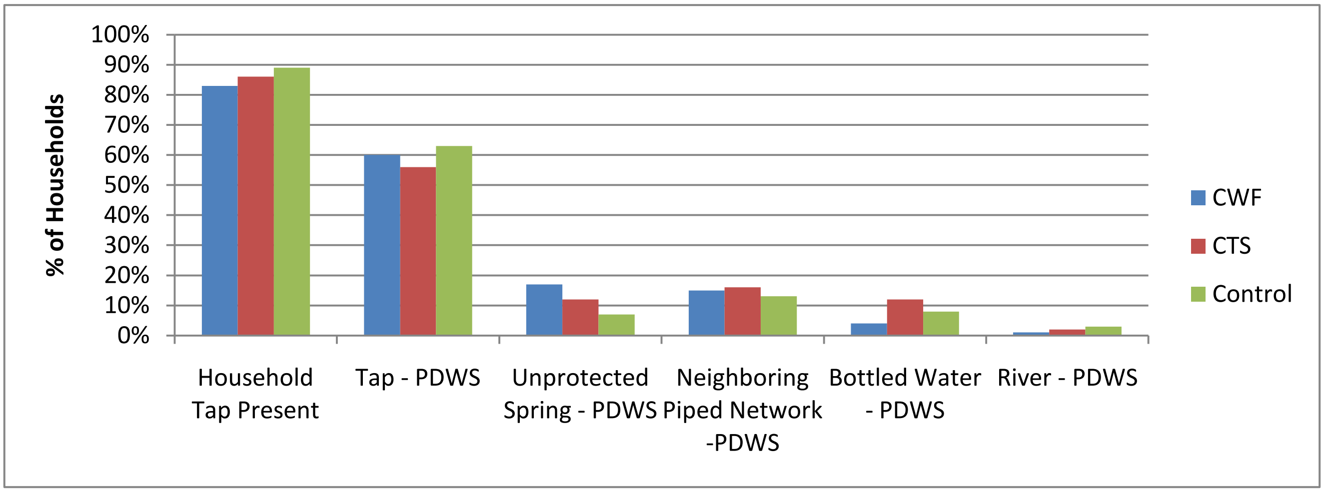
Drinking Water Source and Cost: Of the 334 households interviewed, in both control and intervention groups, no significant difference was reported in number of household taps, quality or quantity of water received or primary source utilized in the rainy and dry season at baseline. Of households interviewed, 86% have a tap in their house or yard; yet only 60% of households use that tap as their primary water source in the rainy season, and 64% in the dry season. Sixty-nine percent of households say that water the color of dirt comes to their tap (66% HWFS, 85% CTS, and 66% control). According to interviews, this happens weekly in the rainy season, especially when there are heavy rains. Fifty-eight percent (58%) of households have an intermittent water service and 38% said that they had insufficient water available to them in the dry season. In communities where water was available at reduced supply in the dry season, water was delivered every 2-3 days or every 5-8 days in some communities. See Appendix 3.A.3 for an overview of perceptions of water reliability, availability and quality.

Figure II: Water Quality and Water Availability



Of all households interviewed, 85% of households had a tap inside their house or yard; yet, only 60% used that household tap as their primary drinking water source in the rainy season and 64% of households used that tap in the dry season. Primary drinking water sources in the rainy season included a household or yard tap (60%), a neighbor's municipal tap (15%), an unprotected spring (12%), bottled water (8%), river water (2%), and a hose from a public spring (2%). Water sources accessed for drinking water in the dry season included a household or yard tap (64%), a neighbor's municipal tap (13%), an unprotected spring (7%), bottled water (8%) and other (2%). No significant difference was found between treatment and control groups primary drinking water source in the dry or rainy season. These drinking water data for the aggregate intervention and control groups are shown in Appendix 3.A.2. Average household water fee payment is $0.53 per month ($0.32 in HWFS households, $0.53 in CTS households and $0.71 in control households.

Figure III: Taps in Household vs. Primary Drinking Water Source (PDWS) - Rainy Season



Perceptions of Water Quality**:** Perceptions of water quality did not differ significantly at baseline between groups. According to VWC members, no water is treated prior to distribution in any of the study communities; however, many of the households are unaware of this fact at baseline. Twenty-two percent of both intervention groups and 42% of the control group falsely believe their water is treated before distribution or do not know if it is treated or not. Fifty-five percent of households, however, do not believe their water is safe. Improvements that households would like to see in their water service include infrastructure (29%), water quality (28%), quantity (22%), and purification (44%) (and did not differ significantly between groups). Most of those interviewed perceived water quality to be the color of the water and purification to be water treatment with chlorine.

Water Handling Practices*:* Water handling practices did not differ significantly at baseline between groups. Ninety-four percent of respondents store their drinking water in a storage vessel, 84% cover the storage container, and 53% access their water from storage with a cup or ceramic bowl, while 37% pour it from the container. Sixteen percent say they chlorinate their drinking water, but only 4% respond with the correct number of drops required per liter. Thirty-six percent of households report that they treat their drinking water with chlorine or by boiling it; however 65% of these households had a high number of *E.coli* in their drinking water samples such that their water was at high to very high risk level. See Appendix 3.A.4 for an overview of the results.

Sanitation, Hygiene and Health: Sanitation, hygiene and health information did not differ significantly between HWFS, CTS and Control groups. Eighty-seven percent of households have access to improved sanitation (a pit latrine, a pour flush latrine to a septic tank, or a toilet with a connection to a septic system). Soap was found to be present near the bathroom in 46% of households. Respondents report that they wash their hands before preparing food (39%), after defecating (46%), before eating (54%), after changing a child's diaper (3%), when asked when they wash their hands in an open-ended question with no prompted answers. When asked what is your most trusted source of health information, the responses were: health worker or health center (38%), Radio (25%), TV (17%), local NGO (6%), family (6%), other (7%). See Appendix 3.A.5 for an overview of the results.

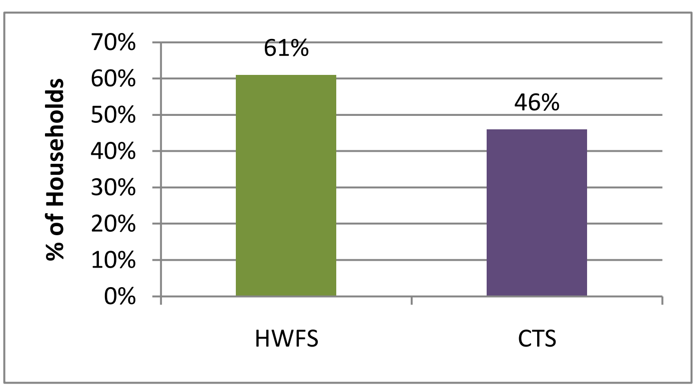
AFTER ONE YEAR WITH THE TECHNOLOGIES

One year after HWFS were purchased at the subsidized rate of $5, and the CTSs constructed, households were re-visited to determine the percent of households that knew about the projects, the use of the treatment technologies, reasons for disuse, the water quality of drinking water at the household level, and gastrointestinal illness one year later. See Appendix 3.A.4 and 3.A.5 for an overview of the results.

Knew about Project, Purchased*:* Of those in HWFS and CTS communities, 98%of HWFS households and 95% of CTS households knew about the HWFS and CTS water treatment projects in their communities. Of those interviewed in HWFS communities, 87% of households had purchased filters. The other 13% gave reasons for not purchasing filters, which included cost (3%), insufficient funds on date of filter delivery (4%), not present on day filters were delivered (3%), not enough filters for everyone (2%), other (1%).

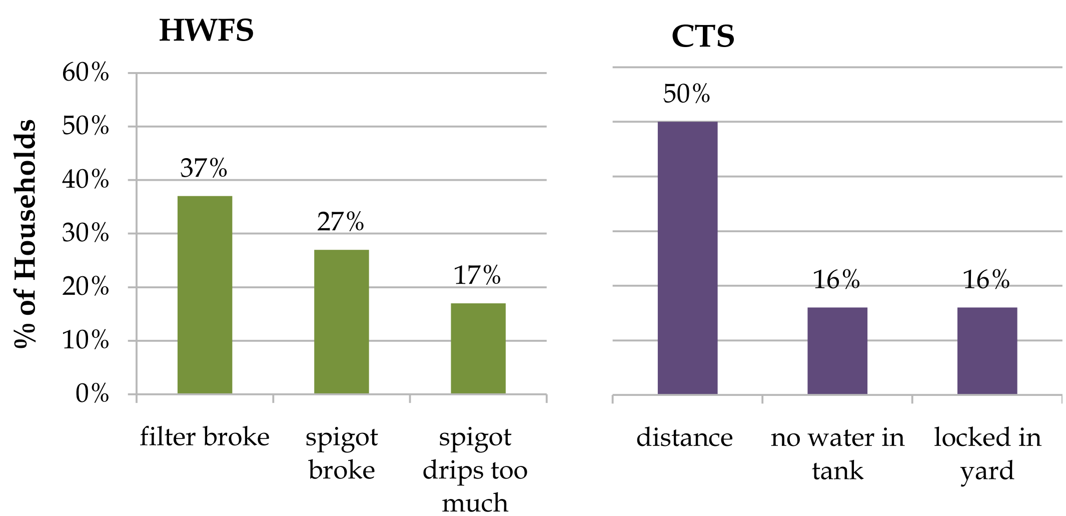
Usage: Many CTS and HWFS households were still using their drinking water treatment technologies after one year; however, disuse of the CTS was significantly greater than of the HWFSs. Sixty-one percent (61%) of HWFSs purchased were still in use, and 46% of CTSs were still in use (p=.08). HWFS households were 32% more likely to be using the water treatment technology than CTS households.

Figure IV: Use of HWFS and CTS after One Year



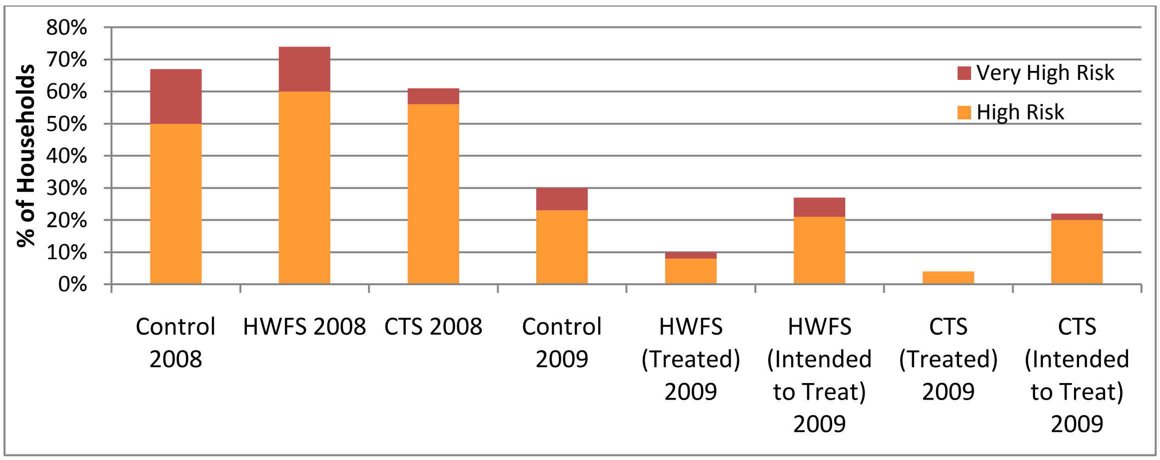
Common reasons for disuse of HWFSs were breakage of the filter and the spigot. Common reasons for disuse of the CTS included: distance from household and the CTS does not always have water in it (see Figure V). The top three reasons for disuse of the HWFSs include the filter broke (37%), the spigot broke (27%), the spigot drips too much (17%), and the filter does not filter enough water. Reasons for disuse of the CTS included the distance from the house to the CTS is too great (50%), there is not water in the CTS all of the time (16%), and the CTS is locked in the school (16%). See Appendix 3.A.8 for an overview of all of the reasons for disuse for the CTS and The HWFS.

Figure V: Reason for Disuse



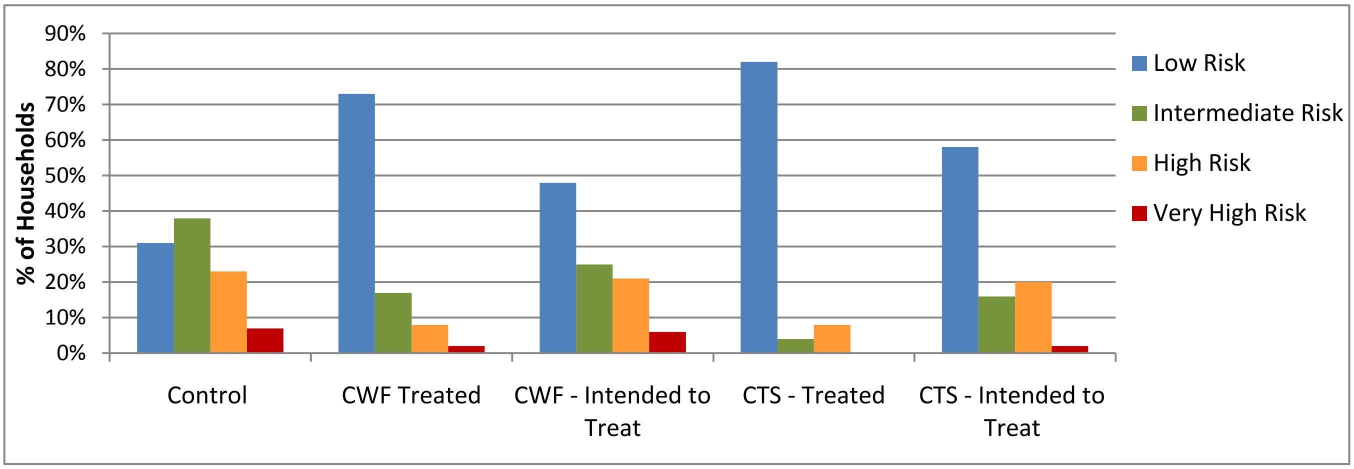
Water Quality Improvements**:** At baseline, control, CTS and HWFS households had similar levels of microbiological contamination: 68% of HWFS, 74% of control, and 61% of CTS household samples were contaminated with *E.coli* ($p > .05$), at high and very high water quality risk levels. Microbiological water quality dropped in 2009, one year from when the technologies were distributed to *E.coli* contamination at high and very high risks of 30% for control, 21% for CTS and 25% for HWFS (intended to treat) ($p > .05$). In those treated households, households still using the technologies the water quality improved significantly, and *E.coli* contamination at high to very high risk levels (3m) reduced to 10% for HWFS and 8% for CTS households ($p<.005^*$). (See Figures VI and VII).

Figure VI
Water Quality at Baseline (2008) and 1 year after technologies were distributed



After one year, HWFSs and CTSs households were significantly less likely than control households to have water at medium risk level and more likely to have drinking water at low risk. HWFS and CTS households still using their treatment technologies were significantly less likely to have water quality at high risk ($p< 0.05^*$) and medium risk levels ($p<0.0005^*$), and significantly more likely to have water quality at low-risk levels ($p<0.0000005^*$). Households still using the technology were 41% (HWFS) and 56% (CTS) less likely to test positive for *E.coli* (Colilert) than control households ($p<0.000005^*$) one year later. (See Figure VII). See Appendix 3.A10 and 3.A.11 for an overview of water quality results.

__Figure VII: Water Quality 1 Year After Technologies Were Distributed__



Treated households water improved significantly from baseline and when compared to control households at one year. Nonetheless, some treated households still had intermediate, high and very high risk level. The contamination of the HWFSs may be associated with improper cleaning of the ceramic filter. In HWFS households, of those with microbiological contamination in their filtered water, 70% clean the bottom of their filter with unfiltered water. The contamination of the CTS water may occur between collection at the CTS and usage in transport from the CTS to the household, in storage at the household. CTS households have to walk to the CTS, collect their water and then return back to the household. Further research is needed to understand how water from HWFSs becomes contaminated in a field setting.

***Secondary Data**:* The study by ADEC that monitored 38 CTS systems in the Department of La Paz revealed that many were not operating according to health regulations for drinking water quality. In May-June of 2008, during the height of the rainy season in Honduras, ADEC, the water system engineering NGO, visited 38 CTSs throughout the

Department of La Paz to monitor the turbidity and the chlorine residual, and provided a short list of observations. Their data reveal that three of the CTSs were not operating and had no water in them. Of the 35 operating CTSs monitored, 85% were serving water that exceeded the WHO level of 1NTU turbidity for drinking water. Thirty-seven percent of CTSs were serving drinking water that was above the turbidity level required for chlorination (5 NTU). Seventy-five percent of CTSs did not have sufficient chlorine residual, and 9% were over chlorinating. In the three systems we tested in primary data collection, residual chlorine was present in the CTS on post-intervention visits, after one year.

Gastrointestinal Disease: While the HWFS and CTS were both effective in improving water quality, our results do not provide evidence that it was protective against diarrhea. At baseline, HWFS, CTS, and control households reported diarrheal disease cases at similar and unrealistic low levels. Only 2% of the sampled population reported to have diarrhea. After the HWFSs were distributed and the CTSs built, one year later, the intended to treat group of HWFS, CTS and control did not differ significantly in reports of vomiting, nausea, or diarrhea cases (diarrhea, diarrhea and cramps or runny diarrhea). The treated groups also did not differ significantly from the control group or from baseline levels. (See Appendix 3.A.12 for the results.)

3.5. DISCUSSION

This study, as implemented in Honduras, provides further evidence that 'improved' water is not always safe, and documents the associated water quality benefits of two low-cost technologies, household and community level treatment technologies, the HWFS and

CTS specifically. HWFS, CTS and control households all had similar water quality levels at baseline, and after one year, HWFS and CTS households had significantly improved water quality relative to control households. Those still using the technology after one year were 41% (HWFS) and 56% (CTS) less likely to test positive for *E.coli* than control households. After one year, 61% of households were still using their HWFS and 46% were still using the CTS. The main reason cited for ceasing to use the technology ware breakage for the HWFS and distance from the household for the CTS. According to secondary data and household surveys CTSs and HWFS are also subject to operator errors and oversights which can decrease their effectiveness. HWFS and CTS technologies significantly improved water quality and are low-cost interventions ($20 per household for the HWFS and $7.58 per household for the CTS) that could reduce the burden of waterborne disease.

A HWFS requires a single initial unsubsidized investment of approximately$20 per household compared to $7.58 per household for the CTS. The average cost of a CTS is $240, and it has a capacity of 1000 liters. On average, in Honduras, each CTS serves 32 households at an investment cost of $7.58 per household. On average, each household has 5.5 persons with a per person cost of $3.63 for the HWFS and $1.37 for the CTS. To maintain the systems over a two year time frame, would require a new spigot and a new filter at a cost of $7 for the household over two years. To maintain the CTS, chlorine and aluminum sulfate need to be purchased, but are quite inexpensive and estimated at approximately $2 per household over two years.

While the CTS is less expensive to construct and to operate, there was much higher rates of disuse for the CTS than the HWFS. The distance from the CTS to the furthest household was not more than 8-10 minutes, however, distance was the main reason cited for disuse of the CTS. The HWFS has the advantage of location at the household which makes its use convenient for users. It is also coupled with a safe storage unit which protects the filtered water until the point of consumption. In communities where households are very spread out, the CTS may not be the best form of water treatment. Furthermore, the maintenance and operation of the CTS requires a commitment by a single operator. According to secondary data, CTSs are not always maintained properly. According to household surveys, CTSs were also sometimes empty. A very recent discussion in May, 2011 with a NGO who monitors CTSs, said that 20 of the 35 CTSs are still in use, and those placed in schools are better maintained and operated, in regular use and sufficient chlorine applied to treat water.

In Ghana, an NGO, Community Water Solutions, experimented with fee-based water provision at the CTS to creates an incentive for the operator to maintain and operate the CTS and provides funds for maintenance and operation. Users come to the CTS and give the operator a small fee. The operator is then responsible for applying the coagulant and the chlorine, and making sure that water is in the CTS at all times. Anecdotal evidence points to the success of this model; however, no experimental research has been done on this fee-based water provision model with the CTS.

The continued use of the HWFS requires households to have the motivation to purchase replacement parts when breakage occurs, such as spigots, and the for the replacement parts to be available. While the parts of the CTS can be replaced in any market town in Honduras, and the spigots for the HWFS can also be located in most market towns in Honduras, the ceramic filters for the HWFS are manufactured in the capital, and are not easily located or purchased in local markets. Availability of replacement parts for these technologies is critical to the sustainability of the technological interventions.

If the replacement parts are available, the scalability of the interventions will depend on the motivation by households to find and purchase the spare parts when they break. This motivation may come from household's awareness of the impact of consuming microbiologically contaminated drinking water and improved information about water quality at their own taps. For example, at baseline 55% of households thought their water was safe, and 31% falsely assumed their drinking water was treated or did not know if it was treated or not. It may be necessary to couple technology interventions with follow-up water quality and related health information if use is to be maintained over time. In Kenya, for example, utilization of household treatment improved by 8-13% with water quality information, and by 9-11% with social marketing methods from a baseline of 72% (Luoto, J., 2010).

To improve water quality over the long-term in a technical-engineering solution may not be sufficient on its own. Water quality or health information at the household level (HWFS) and sufficient training, technical assistance at the community level (CTS), and availability of spare parts, may help to improve use over time.

There was a much lower than expected incidence of diarrheal disease in the population studied at baseline and in follow-up. Given the water quality results at baseline and the significant improvement in water quality with the technologies, the low diarrheal disease levels at baseline and one year later was surprising. In this study, toward the end of each interview, each female head of household was asked first about the range of gastrointestinal disease for each child in the household and then each adult. Based on conversations with Honduran researchers, the low rates of diarrheal disease reporting may be based on the social stigma attached to the disease in Honduras. Anecdotal evidence suggests Hondurans in rural areas associate diarrhea to personal or household "dirtiness" and visits to health clinics for persons with diarrhea result in scolding of the mother for poor hygiene and unsanitary household conditions. Honduran researchers acknowledged on a number of occasions that female-heads of household did not like to discuss diarrhea illness in their household and may in fact be falsifying their response. On a few occasions, during the interviews, children corrected their mothers and said they did in fact have diarrhea. Research suggests that diarrheal recall for episodes of diarrhea is unreliable beyond 48 hours, especially for members other than oneself (Boerma, 1991). In this study, the female head of household was asked to discuss gastrointestinal disease for everyone in the household over the past 2 weeks, and so the data is likely unreliable. Given the social stigma surrounding diarrheal disease in Honduras suggested by this research, future research could consider more objective measure. Ideas include pictorial sticker journals for each household member that document different stool consistencies or weekly stool samples.

Water samples were taken at similar points in the year at baseline and one year later, after filter distribution; yet, the drinking water quality improved significantly in both control and intervention households after one-year. Interviews with households about water quality, diarrheal disease, and perceptions of water quality in each village in this study may have provided the incentive for the households and community as a whole to improve their piped drinking water networks. If this is the case, it would suggest that simple visits to a community to ask questions about a specific community health issue may bring some awareness to the community as a whole and may motivate community members to make important improvements in their water system. Also, water quality measurements were taken on one day before and after the intervention, to get a more complete record of water quality would require more regular sampling throughout the year, and could be an opportunity for future research. Nonetheless, a significant improvement in microbiological water quality was detected in households still using the HWFS when compared to control households after one year.

3.6. CONCLUSION

At baseline, HWFS, CTS, and control households' water access and quality did not differ and was characterized as untreated piped water to a household or yard tap, microbiologically unsafe, intermittent, and turbid in the rainy season. CTS, HWFS and control households had similar rates of microbiological water contamination at baseline. One year after HWFSs had been distributed and CTSs had been constructed, HWFS and CTS households had relatively higher quality water than control households. HWFS and CTS households still using the water treatment technologies had significantly improved water quality compared to control households, 41% (HWFS) and 56 % (CTS) fewer households with *E.coli* contamination than in control households. After one year, use of the technologies reduced by 39% for HWFS and 54% for CTS households. HWFS and CTS are both low-cost interventions with the potential for significant improvements in water quality. The proximity of the HWFS has advantages for users, and there are fewer opportunities for operator error relative to the CTS. The disadvantage of the HWFS is the availability of spare parts proximate to the households and the lack of chemical treatment. The advantage of the CTS is the regularly available replacement parts that are easily accessible in any local market and the lower cost. To enhance the sustainability of the technologies, future research could look into the impact of the technologies coupled with markets for replacement parts (HWFS), technical assistance for operators (CTS), or information on the health risks of drinking microbiologically contaminated water (CTS and HWFS).

3.A APPENDICES

3.A.1 Demographic Data

TABLE I

Demographics	**HWFS**	**CTS**	**Control**	**P**	**Significant ***
Households	135	62	137		
Total	754	364	735		
Children < 5	94	48	86		
Men	358	171	313		
Women	388	158	418		
Household Characteristics					
Mean number of rooms	3.5	3.37	3.8	0.162 A	NS
Mean number of occupants	5.45	5.85	5.32	0.399 A	NS
Mean years of schooling for female head of household	3.7	4.3	4.5	0.164 A	NS
# of Households	135	62	137		
Electricity present in household	47%	42%	74%	0.0000 A	*
Earthen Floor	33%	41%	25%	0.038 A	*
Fuel Source					
wood	76%	82%	73%	0.452 A	NS
electricity	4%	3%	6%	0.705 A	NS
gas	3%	6%	4%	0.519 A	NS
wood & gas or electric	14%	8%	15%	0.349 A	NS
No chimney for wood stove	60%	70%	60%	0.130 A	NS
Amenities					
refrigerator	23%	25%	49%	0.000 A	*
television	46%	43%	67%	0.001 A	*
radio	88%	85%	84%	0.669 A	NS
bed	90%	86%	95%	0.062 A	NS
motorcycle	5%	6%	7%	0.770 A	NS
car	7%	8%	11%	0.429 A	NS
cell phone	75%	67%	77%	0.466 A	NS
livestock	71%	63%	63%	0.357 A	NS
Do not own land	10%	25%	11%	0.007 A	*
Distance from nearest:					
Health Center				0.000 A	*
Paved Road				0.000 A	*
Market town				0.018 A	*

χ Chi-squared ‡ Student's t-test † Fisher exact test A Anova " same as above

All percent values are out of # of households

3.A.2 Primary Drinking Water Sources

Table II					
	HWFS	**CTS**	**Control**	**P**	**Significant ***
# of Households	135	62	137		
Tap present in house or yard	83%	86%	89%	0.209 A	NS
Primary Drinking Water Source Rainy Season				0.226 A	NS
Household tap or yard tap	60%	56%	63%	"	NS
Unprotected spring	17%	12%	7%	"	NS
Neighboring water system	15%	16%	13%	"	NS
Bottled water	4%	12%	8%	"	NS
River	1%	2%	3%	"	NS
Rain water	0%	0%	1%	"	NS
Other	3%	2%	5%	"	NS
Drinking Water Source Dry Season				0.325 A	NS
Household tap or yard tap	65%	59%	67%	"	NS
Unprotected spring	6%	11%	7%	"	NS
Bottled water	7%	10%	7%	"	NS
Neighboring water system	12%	17%	12%	"	NS
River	4%	2%	4%	"	NS
Other	2%	0%	2%	"	NS

A Anova   * Significant   “ same as above   % values are out of # of households

3.A.3. Water Oualitv. Availabilitv & Reliabilitv

TABLE III					
	HWFS	**CTS**	**Control**	**P**	**Significant ***
# of Households	135	62	137		
Water Quality					
Water the color of dirt comes out of tap in rainy season	66%	85%	66%	0.092 A	NS
Water Availability					
Insufficient water (dry season)	45%	27%	43%	0.060 A	NS
Water Reliability					
Intermittent Service	53%	64%	61%	0.214 A	NS
Perceptions of Piped Water					*
Not safe to drink	57%	53%	55%	0.875 A	NS
Water is not treated	77%	77%	58%	0.001 A	*
Water is treated/Do not know if it is treated or not	22%	22%	42%	“	

A Anova   * Significant   “ same as above   % values are out of # of households

3.A.4. Water Handling Practices

Table IV					
	HWFS	**CTS**	**Control**	**P**	**Significant ***
# of Households	135	62	137		
Drinking Water Storage					
Store in storage vessel	96%	98%	90%	0.030 A	*
Cover storage vessel	93%	77%	78%	0.001 A	*
Draw Drinking Water from Storage					
by pouring	42%	38%	31%	0.133 A	NS
with cup or ceramic bowl	53%	48%	55%	0.707 A	NS
Treat Drinking Water (Response)					
boiling	21%	12%	22%	0.314 A	NS
chlorination	18%	14%	15%	0.824 A	NS
adequate number of chlorine	3%	5%	3%	0.805 A	NS
total boil or chlorinate	39%	27%	36%	0.307 A	NS
Boil or chlorinate but have high to very high risk water quality (*E. coil*)	67% (35/52)	58% (10/17)	64% (32/50)	0.809 A	NS
A Anova * Significant % is out of # of households unless otherwise mentioned					

3.A.5. Sanitation, Hygiene & Health

Table V					
	HWFS	**CTS**	**Control**	**P**	**Significant ***
# of Households	135	62	137		
Sanitation					
Improved Sanitaiton	86%	79%	91%	0.085 A	NS
Hygiene					
Soap present near bathroom	43% (30/69)	41% (16/39)	50% (49/99)	0.805 A	NS
Wash hands (not prompted)					
before cooking	29%	48%	43%	0.016 A	*
after using the bathroom	47%	48%	43%	0.697 A	NS
before eating	57%	37%	58%	0.012 A	*
after changing a childs diapers	4%	0%	3%	0.321 A	NS
Trust Health Information Most from				0.091 A	NS
health worker or health center	41%	38%	34%	"	NS
radio	23%	30%	26%	"	NS
TV	13%	18%	20%	"	NS
local NGO	6%	8%	5%	"	NS
family member	7%	6%	6%	"	NS
other	10%	0%	8%	"	NS
A Anova * Significant % is out of # of households unless otherwise mentioned					

3.A.6. Water Fee & Improvements Needed

Table VI					
	HWFS	**CTS**	**Control**	**P**	**Significant ***
# of Households	135	62	137		
Payment for Piped Water Service					
Mean fee for water service/month	$0.32	$0.53	$0.71	0.000 K	*
Improvements would like to see in water system					
Infrastructure	30%	29%	27%	0.828 A	NS
Quality (Turbidity)	25%	29%	31%	0.523 A	NS
Quantity	24%	14%	23%	0.300 A	NS
Purification (Treatment)	44%	43%	45%	0.484 A	NS

A Anova K Kruskal-Wallis * Significant % is out of # of households

3. A.7. Purchased Filters & Knowledge About Project

HWFS vs CTS		
Purchased Filters	**HWFS**	**CTS**
Purchased Filters	85% (104/122)	
Did Not Purchase Filters	15% (18/122)	
Knew About Project		
Knew about the project	98% (120/122)	95% (52/55)
Did not Know about the project	2% (2/122)	5% (3/55)

3.A.8. Usage of Technologies after 1 Year

Usage after 1 year	HWFS	CTS
Using	61% (63/104)	46% (24/52)
Not Using	39% (41/104)	56% (31/55)

3.A.9. Reasons for Disuse of HWFS & CTS

Reason for Disuse			
HWFS		**CTS**	
Filter broke	37% (15/41)	Distance to CTS from household	46% (12/26)
Spigot broke	27% (11/41)	Locked in school	19% (5/26)
Spigot drips too much water	17% (7/41)	No water in CTS	16% (4/26)
Does not filter enough water	7% (3/41)	Piped project is safe	8% (2/26)
Not in house to use it	5% (2/41)	Don't trust CTS	8% (2/26)
Bucket broke	2% (1/41)	Buy water	4% (1/26)
It was stolen	2% (1/41)		
Gave it away	2% (1/41)		

3.A.10. Water Quality

Table					
	HWFS	**CTS**	**Control**	**P**	**Significant ***
# of Households	135	62	137		
Water Quality Baseline					
Presence *E.coli* (3m)	68% (91/132)	61% (38/62)	74% (99/133)	0.415 A	NS
Presence TC (3m)	96% (127/132)	90% (56/62)	97% (130/133)	0.197 A	NS
E.coli (3m)	626 CI:302-950	276 CI:146-401	870 CI:529-1210		
TC (3m)	5320 CI:4272-6369	2761 CI:1743-3779	5139 CI:3855-6425		
Water Quality After 1 Year					
Treated					
Presence of *E.coli* (3m)	10% (6/62)	8% (2/24)	30% (38/126)	0.0014 A	*
Presence of TC (3m)	39% (24/62)	29% (7/24)	83% (104/126)	0.000000 A	*
Presence of *E.coli* (Colilert)	27% (17/62)	12% (3/24)	68% (86/125)	0.00000000A	*
Presence of TC (Colilert)	61% (38/62)	62% (15/24)	90% (113/125)	0.000004 A	*
Intended to Treat					
Presence of *E.coli* (3m)	25% (30/121)	21% (12/55)	30% (38/126)	0.574 A	
Presence of TC (3m)	64% (77/121)	63% (35/55)	83% (104/126)	0.002 A	*
Presence of *E.coli* (Colilert)	52% (63/121)	38% (21/55)	69% (86/125)	0.001 A	*
Presence of TC (Colilert)	80% (97/121)	78% (43/55)	90% (113/125)	0.024 A	*
A Anova K Kruskal-Wallis * Significant					

3.A.11. Risk Level Water Quality

	HWFS	CTS	Control	P	Significant*
# of Households	135	62	137		
Risk Level of Water Quality					
Baseline					
Risk Level				0.111 K	NS
High Risk Water Quality	50% (66/132)	56% (35/62)	60% (80/133)	0.246 A	NS
Very High Risk Water Quality	17% (23/132)	5% (3/62)	14% (19/133)	0.058 A	NS
1 yr Later					
Treated					
Risk level				0.000 K	*
Low Risk Water Quality	73% (45/62)	82% (20/24)	31% (39/125)	0.000000 A	*
Medium Risk Water Quality	17% (11/62)	4% (1/24)	38% (48/125)	0.00025 A	*
High Risk Water Quality	8% (5/62)	8% (2/24)	23% (29/125)	0.0168 A	*
Very High Risk Water Quality	2% (1/62)	0% (0/24)	7% (9/125)	0.1303 A	NS
Intended to Treat					
Low Risk Water Quality	48% (58/121)	58% (32/55)	31% (39/125)	0.001 A	*
Medium Risk Water Quality	25% (30/121)	16% (9/55)	38% (48/125)	0.005 A	*
High Risk Water Quality	21% (26/121)	20% (11/55)	23% (29/125)	0.938	NS
Very High Risk Water Quality	6% (7/121)	2% (1/55)	7% (9/125)	0.352	NS
A Anova K Kruskal-Wallis * Significant					

3.A.12. Gastrointestinal Disease

	HWFS	CTS	Control	P	Significant *
# of Persons	**754**	**364**	**736**		
Gastrointestinal Illness Baseline					
Vomiting	0.60%	0.20%	0.80%	0.573 A	NS
Nausea	1%	0.20%	0.50%	0.107 A	NS
Diarrhea and Cramps	3%	1%	1%	0.059 A	NS
Diarrhea	0.30%	0.20%	0.80%	0.406 A	NS
Runny Diarrhea	0%	0.20%	0.10%	0.405 A	NS
All Diarrhea	3%	2%	2%	0.413 A	NS
# of person	**345**	**141**	**666**		
Gastrointestinal Illness 1 yr later					
Treated					
Vomiting	0.20%	1%	0.30%	0.065 A	NS
Nausea	1%	2%	0.10%	0.017 A	*
Diarrhea and Cramps	2%	0.70%	1%	0.475 A	NS
Diarrhea	5%	2%	1%	0.153 A	NS
Runny Diarrhea	0%	0%	0%	1 A	NS
All Diarrhea	5%	3%	3%	0.217 A	NS
Δ from baseline	2%	1%	1%		NS
#of persons	**697**	**329**	**666**		
Intended to Treat					
Vomiting	0.40%	2%	0.30%	0.003 A	*
Nausea	1%	0.30%	0.10%	0.117 A	NS
Diarrhea and Cramps	1%	3%	1%	0.222 A	NS
Diarrhea	3%	3%	1%	0.096 A	NS
Runny Diarrhea	0.20%	0%	0%	0.239 A	NS
All Diarrhea	4%	3%	3%	0.548 A	NS

A Anova   K Kruskal-Wallis   * Significant

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PAPER III

Water Quality, Sustainability and Scalability of Ceramic Water Filters in Households with Inadequate 'Improved' Water: Evidence from Honduras

Abstract

The delivery of a constant supply of safe drinking water to households regularly challenges many community-run piped water systems. Households served by such systems may benefit from the use of household ceramic water filters and safe storage units (HWFSs), which are clinically proven to remove key microbes that cause waterborne disease and safely store water until the point of use. This paper examines the sustainability and impact on household-level water quality and child health of HWFSs. The data are derived from a clustered randomized trial in rural and peri-urban Honduras, in which four pairs of similar communities were chosen, and one community in each pair was randomly selected for intervention. Households in these communities were offered the HWFS at a subsidized rate of $5. Employing data on 272 households (135 intervention and 137 control households), we find that the percentage of treatment households using the filters was 61 percent after one year and 47 percent after two years, and that water quality is significantly higher in households still using the HWFS than in control households The main reasons households gave for ceasing to use the filters were breakage and malfunctioning of spigots or breakage of the ceramic filter. The HWFS is a sufficiently low-cost drinking water intervention ($10 per household per year) and could improve water quality and health in communities where water supply is characterized as 'improved' but is nonetheless inadequate, whether because the system delivers untreated water, delivers turbid water, or provides only intermittent service. This research suggests that the use of the HWFS could be enhanced further with a market for spare parts, and technical assistance on filter maintenance. The paper identifies a viable value chain through which purchase and sustained use of the filters could be promoted at larger scale.

Prepared for: Environmental Science & Technology

4.1. INTRODUCTION

Every year, 2.2 million die from diarrheal disease, 1.5 million of these deaths are children under five years of age, and one of the main causes of this disease burden is unsafe drinking water (Wardlaw et al., 2010; Kosek, Bern and Guerrant, 2003). Unsafe drinking water leads to an increase in gastrointestinal and diarrheal diseases which, in turn, affects human health and development by reducing absorption rates of food and nutrition, decreasing childhood growth rates, draining energy levels, decreasing attendance at school, reducing the number of hours one is physically able and willing to work, and increasing morbidity and mortality rates, especially among children (Checkley et al., 2008; Billig, Bendahmane and Swindale, 1999). While piped drinking water to a house or yard tap is often considered the gold standard, many piped networks are characterized by poor source water quality, an absence of drinking water treatment, insufficient supply, intermittent service, leakages, high costs, and aging infrastructure (Bartram, 2008; Rizak and Hrudey, 2008; Lee and Schwab, 2005; Yassin, Abu Amr, and Al Najar, 2006). In some cases, households are forced to use alternative unimproved sources because of insufficient supply or poor quality in their piped network (Pattanayak et al., 2005). A point of use treatment method that has recently received a great deal of attention for its improvement of microbiologically water quality and its reduction in diarrheal disease is the *Potters for Peace* household filter and safe storage (HWFS) units. With the hope of improving water quality and human health of those households with ‘improved’ water systems that deliver contaminated water, transport an unreliable supply of water, or deliver turbid water in the rainy season, a variety of development actors (NGOs and Governments) have begun experimenting with the distribution or sale of HWFSs at a subsidized rate.

Research on the HWFSs have documented their efficacy in laboratory settings (Oyanedel-Craver and Smith, 2008; Brown and Sobsey, 2010). A randomized trial in Cambodia documented a mean reduction in diarrhea of 49% and a significant improvement in water quality over 18 weeks in households with unimproved water sources that were given a HWFS (Brown, Sobsey and Loomis, 2008). No research to date has tracked their effectiveness one and two years after distribution at subsidized cost in a field setting, measured the impact of their use on the height and weight of children under five, or followed households over two years to document usage over time. In addition, no research has studied HWFS when coupled with an improved water source, contaminated piped water specifically.

Diiarrheal disease is often studied to measure the effectiveness of drinking water interventions (Fewtrell et al., 2005, Esrey et al., 1991). Recently, however, reporting on diarrheal disease results has drawn some criticism because it is not objective and is subject to responder bias (Schmidt and Cairncross, 2009). This research, therefore, takes an extra step to measure the height and weight of children under five, a more objective measure of child health (Schmidt and Cairncross, 2009). Research has documented the association between environmental factors (water, sanitation and hygiene) and children's height and weight (Checkley et al., 2008; Merchant, 2004; Wamani et al., 2006), but no known randomized field trials have investigated the role of HWFS on the height and weight of children under five.

Recently, the sustainability and scalability of point of use water treatment, specifically the HWFS, has come under significant debate in the literature (Sobsey et al., 2008;

Langtagne et al., 2009; Hunter, 2009; Schmidt and Cairncross, 2009). Sustainability has been defined d as technology that is functioning and utilized over a significant period of time (Carter and Howsam, 1999). Drinking water technology is only viable if it will have a beneficial impact on communities, and if the impact will be long-lasting or sustainable (Carrter and Howsam, 1999). Continued use is critical to the sustained impact of the HWFS, and is critical if the intervention is to be scaled. One study did return to households four years after HWFSs were distributed and asked households to retrospectively ascertain when they stopped using the filters (Brown, Proum and Sobsey, 2009); however, the estimated dates over four years are subject to recall bias.

In this study, intervention households were offered the HWFS at a subsidized rate of $5 (the total cost of the filter in Honduras is $20). There is evidence that suggests that if people are willing to pay for the costs of a water service, it is a clear indication that the service is valued (and therefore will most likely be used and maintained) and that it will be possible to generate the funds required to sustain the project over the longer term (Whittington et al., 1990). Research in Bolivia, a Latin American country with similar per capita GDP to Honduras, provided evidence that 77% of households studied would be willing to pay approximately $7.00 for a ceramic water filter, similar to the HWFS studied in this research (Clasen et al., 2004).

This research aims to assess the impact of the HWFS on diarrheal disease and the height and weight of children under five in rural and peri-urban Honduras over a one-year time frame, and measure the use and water quality of the HWFS at one and two-years after HWFS distribution with pre and post-interventions assessment. In an attempt to evaluate the HWFS, I collaborated with the three NGOs, Shoulder to Shoulder, Agua Desarollo Comunitario (ADEC) and International Rural Water Association (IRWA) in Honduras. Intervention households were offered the option to purchase a HWFS after baseline data were collected at a subsidized rate of $5. Households were returned to one and two years after HWFS distribution. Key informant interviews with operators of drinking water systems and village water committee members after the two-year study documented some of the obstacles to the provision of safe drinking water in community-run piped drinking water networks.

In Honduras, the country of study, 96% of piped water is accessed from surface sources, including springs, small creeks and rivers (USAID, 2006), and 98% of the population has intermittent water service (PAHO, 2000). Approximately 43% of the networked coverage is provided by small drinking water systems and managed by elected Village Water Committees (VWCs)[33] (USAID, 2006). Many of the VWCs have difficulty charging water fees or insuring that these fees are paid on time, with huge effects on the resources available for maintenance and operation costs (COSDU 2004). Only 13% regularly treat their drinking water (PAHO, 2000; COSDU 2004). In a recent study of piped rural water networks in Honduras, it was estimated that 85% have fecal contamination (Argeta, 2005; COSDU, 2004).

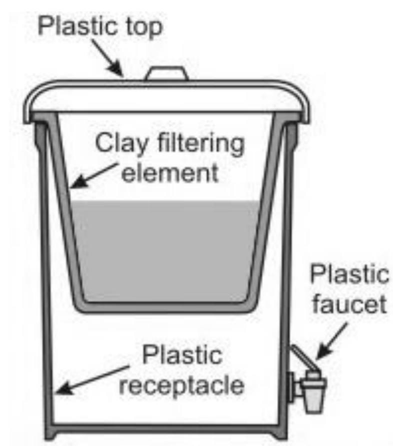
[33] Another 29% are managed by municipalities, 15% by the national governments Water and Sanitation directive, SANNA, and the other 13% are run by private companies or private-public partnerships.

4.2. METHODS & MATERIALS

Study Site: I conducted the research in and around the municipalities of Marcala and Concepcion, in the Departments of La Paz and Intibucá, Honduras, two of the poorest Departments in Honduras. The study included eight villages in total in the Departments of La Paz and Intibucá. Marcala, the municipality closest to the villages in La Paz, is 90km from the regional capital. Concepcion, the municipality closest to the villages in Intibucá, is 122 km from the regional capital. Rainfall in the area follows a bimodal distribution with distinct wet and dry seasons. These patterns strongly affect water quality in the rainy season and water availability in the dry season.

Intervention**:** Intervention group households received a HWFS for the cost of 5$. The HWFS consisted of a ceramic filter laden in a safe storage unit (a 5 gallon plastic bucket with a spigot and a plastic top). Water is poured onto the top of the filter, and approximately 1.5 liters of water can be filtered through the ceramic filter per hour and safely stored below the ceramic filter in the safe storage unit until the user is ready to access the water from the spigot. See Figure 1 for a picture of the HWFS[34].

Figure 1



Experimental design: To study the impact of the HWFS on household microbiological water quality, diarrheal disease, height and weight of children under-five, and measure the long-term usage of the HWFS in eight communities (4 intervention and 4 control) pre and post-intervention, a clustered randomized experiment was conducted. Four pairs of

[34] The drawing of the HWFS is care of Potters for Peace: http://www.pottersforpeace.org/

similar communities were chosen, and one community in each pair was randomly selected for intervention, followed by the random selection of 272 households (135 intervention and 137 control) from the matched communities in rural and peri-urban Honduras (See Appendix 3.A.12 for a table of the matched communities and their relative water and sanitation characteristics.) Intervention households were offered the option to purchase a HWFS at a subsidized rate of $5 (the total cost of the filter in Honduras is $20). Principal study activities included: household interviews with the female head of household, microbiological water quality tests, and drinking water disinfection tests in each household. (A diagram of the study timeline and activities is in Appendix 4.A.14).

Key informant interviews with operators of drinking water systems and village water committee members after the two-year study document some of the obstacles to the provision of safe drinking water in community-run piped drinking water networks. Three NGOs were involved: Shoulder to Shoulder, a public health NGO with its base in Intibucá, Honduras, ADEC (Agua Desarrollo Comunitario), a Honduran based water systems engineering NGO, and the International Rural Water Association (IRWA), a drinking water systems engineering organization that offers funding, technical support, and training to host-country NGOs like ADEC. They assisted the research group in community introductions, the purchase and delivery of filters at a subsidized rate, and provided a one-day community training on village water quality and the maintenance and operation of the filter.

Preliminary Data Collection**:** We collected preliminary data in 32 communities. Data included microbiological drinking water quality tests and chlorine residual tests in rural communities with piped drinking water in the rural areas of the Departments of La Paz and Intibucá, and a conversation with a VWC representative in each community. The goal of the VWC conversation was to determine the number of households served, the drinking water sourced, water availability in hours per day in both the rainy and dry seasons, the age of the water system, and the distance to the nearest paved road and nearest market town.

Structured household interviews and key informant interviews were designed after preliminary research. This included over 50 interviews with drinking water operators in Honduras, El Salvador, Guatemala and the United States, visits to drinking water supply systems in all four countries, interviews with health professionals in Honduras, and visits to water quality testing facilities in the United States. Other household surveys and information related to Water, Sanitation, and Hygiene (WASH) survey collection informed the creation of the household survey (Billig, Bendahmane and Swindale, 1999; WHO and UNICEF, 2006; UNICEF, 2005).

Community Selection**:** Of the 32 rural community-run drinking water supply systems studied in the preliminary data collection, none chemically treated or filtered their drinking water, no system had chlorine residual in its drinking water when the water was tested in the month of May, 2008, and 20 of the 32 communities had high to very high levels of microbiological contamination in their drinking water. Of the 20 communities with high to very high levels of microbiological water quality, four communities were randomly selected and then matched with four communities of the remaining 16 communities with high and very high levels of microbiological water contamination. Communities were matched based on population served, water system design, water source type, paved road proximity, system age, water quality risk level, sanitation presence, and other socioeconomic indicators. (See Table 1 for an overview of community characteristics). Once matched, the community was determined to be a control or intervention community in a blind-from-the-hat selection process. Households were then randomly selected from each community so that approximately 50% of the households in each village were interviewed. In total, 272 households were interviewed (135 treatment and 137 control). The study consisted of two baseline visits in May and November, 2008 and three follow-up visits, two in May and November of 2009 and one in December, 2010. In December, 2010 after the household interviews were conducted, a short key-informant interview was conducted with the operator or VWC representative to understand some of the challenges faced by these community-run systems in Honduras.

Data Collection: Baseline data were collected in 2008 and post-intervention data were collected in 2009 and 2010. Pre-intervention data were collected in June and November 2008. Pre-intervention data in each household included household interviews with 272 female heads of households with the previously piloted household survey, bacteriological water quality tests, anthropometric data for children under five, and a geo-reference of the household. The research team took anthropometric measures (height or length, weight, age), birth date, and date of interview for 134 children under five at baseline. After baseline data collection, the research team, with the assistance of two NGOs (Shoulder to Shoulder in Intibucá and Agua Desarollo Communitario in La Paz), facilitated the distribution of the filters in each community, sold at a subsidized rate to all households for $5[35].

Post-intervention data collection trips occurred in June and November, 2009[36] so that each community was visited one year after the HWFSs had been distributed in the community. Post-intervention data collected in 2009 included the household interview administered at baseline, a ceramic filter specific survey, bacteriological water quality tests in each household, and anthropometric measures of the same children measured at baseline. (These interviews can be found in Appendix 5.A.5 and 5.A.6). Anthropometric measures were taken of 134 children (62 control, 72 intervention) at baseline. One year after baseline, 26 of the children had aged beyond the under-five cut off and so were excluded from the calculations. Final calculations included 109 children (52 control, 57 intervention). A final post-intervention trip took place in early December, 2010. The data collected in December 2010 included the ceramic filter specific survey and the bacteriological water quality tests. All interviews were administered after obtaining informed consent from the female head of household. All data were collected by GK and a team of six Hondurans, hired and trained by GK.

Water Quality Testing and Analysis**:** To test water quality, the 3M™ Petrifilm™ and the Colilert® tests were combined to enable a risk assessment of very high, high, moderate and low risk water quality, according to World Health Organization standards (WHO,

[35] The NGOs absorbed the rest of the $20 cost of the filters. Replacement of the ceramic filter piece costs $5.
[36] Data post-intervention were collected in the middle of the military coup that occurred in Honduras in 2009. The "northern triangle" of Central America which includes Honduras, Guatemala and El Salvador, has been called the most violent region on earth because this region suffers the world's highest murder rates outside (Economist, 2011).

1997). 3M™ Petrifilm™ and Colilert® microbiological tests were used offsite to test for *Escherichia* coli (*E.coli)* and total coliform. 3M™ Petrifilm™ is a simple *E.coli*[37] enumeration method, for assessment of high and very high risk water quality (100 *E.coli* per 100ml sample). Colilert® is coupled with the 3M™ Petrifilm™ to measure the presence or absence of low (<1-10 *E.coli* per 100ml) to very high risk water (>1000 per *E.coli* per 100 ml), according to World Health Organization guidelines (See Figure I). At baseline, 3M™ Petrifilm™ was used to access water quality at high and very high risk levels in control and intervention communities. At one and two years after the distribution of the HWTS, 3M™ Petrifilm™ and Colilert® were used to access water at low, medium, high and very high risk levels in control and intervention communities. The water samples were drawn from the drinking water source of each household. If the tap was the drinking water source, it was drawn directly from the tap. If the female head of household said they treated their drinking water in the household by boiling or chlorine disinfection, the water was drawn from the storage container that held the treated drinking water. The tap was not flamed or disinfected. The sample reflects normal collection procedures and contamination from everyday use. If there was not water in the tap at the time of the house visit and interview, water was drawn from the storage container of the household. Sterile 100 ml transparent Whirl-Pak® bags (Nasco, Modesto, CA) were used to collect a 100 ml water sample, which was coded and placed on ice until the microbiology tests could be performed mid-day for morning samples and in the evening for afternoon samples. Samples drawn from storage containers were drawn with an individually packaged sterilized pipette. Samples were plated (3M™

[37] *E.coli* is an indicator of fecal choliform and its presence is regularly accessed to determine if water is safe to drink.

Petrifilm™) and bottled (Colilert®) using individually packaged and sterilized pipettes (Fisher Scientific Inc.) and plastic spreaders (3M™ Petrifilm™) and then incubated for 24 hours at 35 ^{o}C in a portable HACH® incubation chamber[38]. *E-coli* and total coliform were enumerated via the Petrifilm test, and the presence or absence of *E.coli* and total coliforms was assessed via the Colilert test. This methodology was developed by Dr. Robert Metcalf, Professor of Microbiology at California State University at Sacramento, has been validated (Trottier, 2010), and recommended by the United Nations as a practical method for rapid assessment of bacterial water quality, particularly well suited to rural sites in developing countries (UN Habitat, 2010).

Figure I - WHO Guidelines[39]

Risk Level	***E.coli* in Sample (CFU or MPN/100ml)**
Conformity	<1
Low	1-10
Intermediate	11-100
High	101-1000
Very High	>1000

***Household Interview Data Collection and Analysis*:** Previously piloted structured interviews were held with the female heads of household, the person generally responsible for household water collection and management, and its use for cooking, washing and household management. The questions in the household survey instrument elicited data on household water services in the rainy and dry season, perceptions of water quality, sanitation type, hygiene behavior, household demographics, household economic characteristics, and presence of specific gastrointestinal diseases for children

[38] The Portable HACH incubator (#25699) was donated to Dr. Jeffrey Griffiths by the HACH company (Loveland, CO, USA).
[39] Adapted from WHO Risk Levels for *E.coli* (WHO, 1997). Replaced "thermotolerant bacteria" with *E.coli*.

and adults in the household. The household survey was administered at baseline and one year after the filters were distributed. An additional survey on the HWFS included questions about usage, reasons for non-usage, household maintenance and operation of the filter, and perceptions of water quality from the tap and ceramic filtered water. The HWFS survey was administered one and two years after the filters were distributed.

Height and Weight of Children Under-Five: At the end of each interview, the interviewer asked the mother if she could measure all children under five in the household. There were no refusals by the mothers; however, some children could not be weighed because they would not get on the scale or be measured[40]. A SECA 364 digital Pediatric Scale, a baby and floor scale in one, with accuracy to the hundredth kilogram, was used to weigh each child under five. The Seca 214 Road Rod Portable Stadiometer was used to measure the height of each child under five who could stand. The Seca 210 Baby Length Measuring Mat was used to measure infants and children who could not stand on their own. Photographs were taken of all child birth certificates that were available in the household so that the birth date of each child could be validated. Children were measured according to an anthropometric measurement guide (Cogill, 2001), and based on trainings for GK from a physician at Tufts Medical School, a researcher at the Tufts School of Food and Nutrition, and in Honduras by University of Rochester medical doctors. These measurements were taken at year one and year two, and only the same children measured at baseline, were then measured at year one.

[40] We learned that children are typically weighed at health centers on the same visit that they receive vaccinations. Children, therefore, associate being weighed with receiving an injection, and so would sometimes refuse to get on the scale by crying. We were unable to weigh these children.

A sample size of 152 children under five was determined to be adequate according to Lenth's calculation of differences in means, (76 intervention and 76 control) with a power of .9 and a α of.05 to see a true difference in means of .53 (Lenth, 2008).

Key Informant Interviews: After the two year study, open-ended key informant interviews were facilitated with the operators of drinking water systems or an elected VWC member in each community to determine the obstacles of managing and operating their community-run drinking water system. Questions were asked about water treatment and, households' water fee payments, water supply and water quality challenges, associated with the maintenance and operation of drinking water treatment in their piped networks.

***Data Entry*:** Household surveys and the height and weight of children under five were recorded on hard copy forms and entered into digital forms using Excel (Microsoft Corp., Redmond, WA). Digital tables were then exported into SPSS version 19 (SPSS). In the analysis of the height and weight of children under five, the z-scores on height for age (HAZ), weight for age (WAZ), and weight for height (WHZ) were calculated at baseline and one year after filters were distributed to households using the WHO Anthro software. It was assumed that all children younger than one year were measured lying down and all children older than one year were measured standing up. The baseline and one-year post intervention data were then merged in SPSS 19 (SPSS), and the relative difference in z-score between baseline and year one were recorded.

***Ethics**:* Informed consent was obtained from the female head of household at the beginning of the project. The participants were not subjected to risks of any kind as a result of the project. This study was approved by the Institutional Review Board of the Fletcher School of Law and Diplomacy at Tufts University on June 13, 2007.

All control groups received their filters in November and December, 2009. All results were shared with community leaders after the study was completed, and lessons learned were reported to the Honduran based NGOs, ADEC and Shoulder to Shoulder, working in the communities so that they can follow-up and apply the lessons learned from the study in their work with the communities.

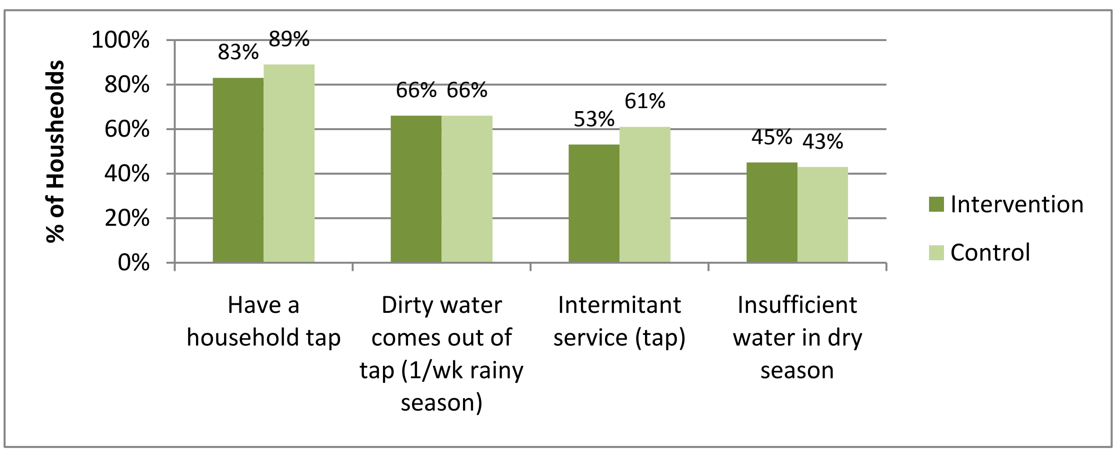
4.3. RESULTS

Baseline Data

Household Respondent Characteristics: A total of 272 households and 1489 persons from 8 communities located in rural and peri-urban areas near Marcala, La Paz and Concepción, Intibucá were recruited into the study (ceramic water filters: 135 intervention households with 754 persons and 137 control households with 735 persons). The mean household size was 5.4 persons and 44% of households had a child under the age of five. The female-head of household's mean education was 4.1 years. Baseline data did not show statistically significant differences between intervention and control households in most demographic household categories (household amenities, livestock and land ownership, distance from the nearest paved road, health center and market town). Control communities had greater access to electricity and therefore also owned more refrigerators and televisions. The demographics, household and respondent characteristics for the aggregate intervention and control groups are shown in Appendix 4.A.1.

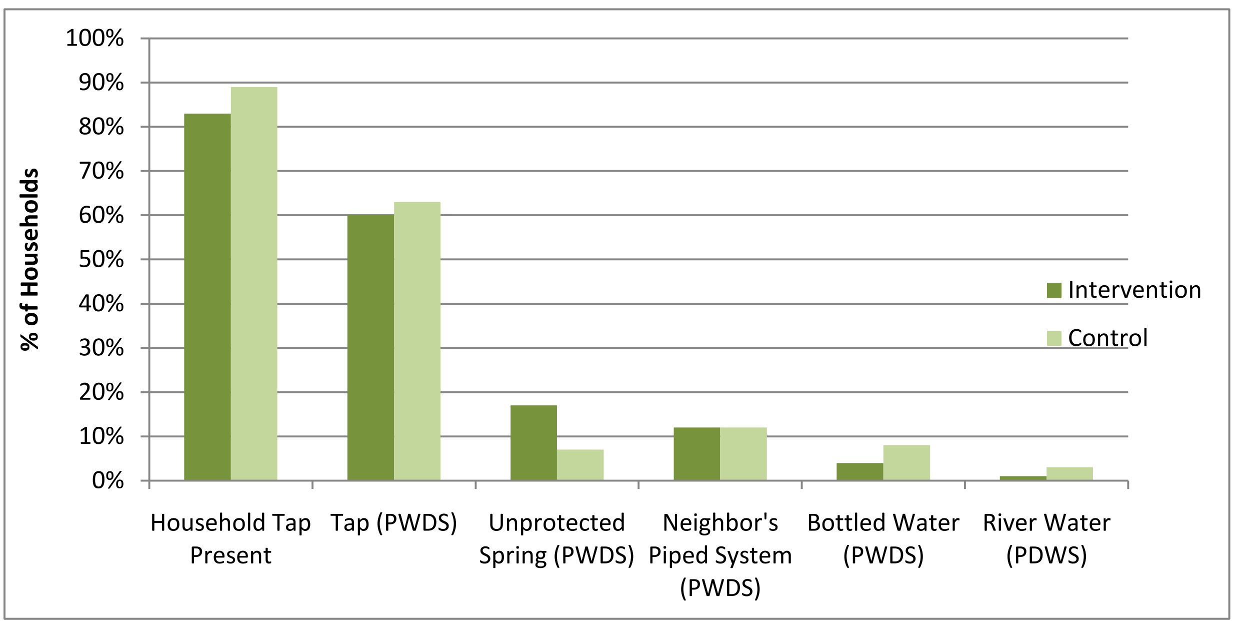
Drinking Water Quality, Reliability, Availability and Cost: Baseline data did not show statistically significant differences between intervention and control households in drinking water quality, supply or availability. Of households interviewed, 86% have a tap in their house or yard and 65.5% say that water the color of dirt comes to their tap. According to interviews, this happens weekly, during heavy rains, in the rainy season. Fifty-six percent (56%) of households have an intermittent water service, and 44% said that they had insufficient water available to them in the dry season. In communities where water was available at reduced supply in the dry season, water was delivered every 2-3 days or every 5-8 days. On average, each household pays $0.54 per month (10.27 lempiras) for their water service. See Appendix 4.A.3 for an overview of the results on perceptions of water quality, availability and cost of the households studied.

Figure II – Water Quality, Availability & Reliability



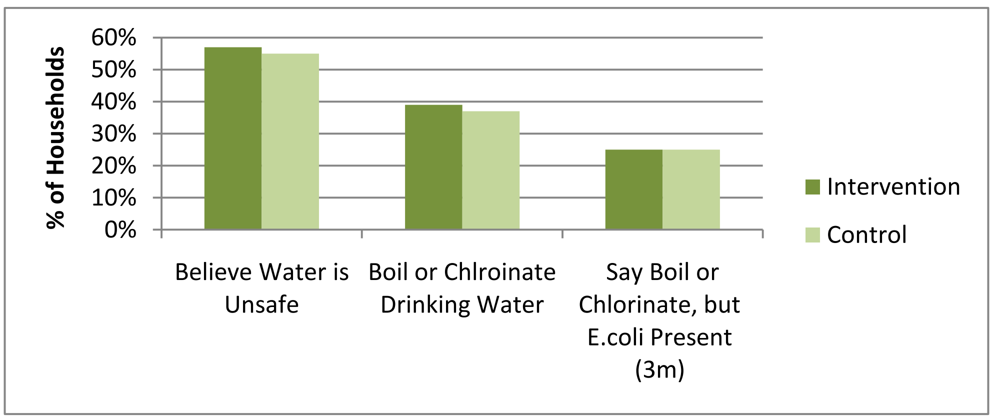
Eighty-six percent of households had a tap in their household. Only 61% used that household tap as their primary drinking water source in the rainy season and 66% of households use that tap in the dry season. The number of those who access their drinking water from an unprotected spring is significantly higher for the treatment group than the control group in the rainy season. Primary drinking water sources in the rainy season include a neighbor's municipal tap (14%), an unprotected spring (12%), bottled water (7%), river water (2%), and a hose from a public spring (2%). (See Figure III). No significant difference was found between treatment and control groups primary drinking water source in the dry season. Water sources accessed for drinking water in the dry season include: a neighbor's municipal tap (12%), an unprotected spring (6%), and bottled water (7%). (See Appendix 4.1.2 for the primary drinking water sources of households).

Figure III: Primary Drinking Water Source (PWDS) vs. Tap in Household



According to Village Water Committee members, no water is treated prior to distribution in any of the study communities; however perceptions of drinking water quality reveal that many of the households are unaware of this fact. Thirteen percent of the intervention group and 35% of the control group falsely believe their water is treated before distribution, and 9% in intervention and 7% in control do not know if it is treated or not. Fifty-six percent of households do not believe their water is safe. When asked what improvements they would like to see in their water system, the responses included (respondents answers were tallied into four categories): infrastructure (28%), water quality (28%), quantity (24%), and treatment (44%).

Figure IV: Perceptions of Water Safety & Household Water Treatment



Water Handling Practices**:** Water handling practices did not differ significantly at baseline between groups. Ninety-three percent of respondents store their drinking water in a storage vessel, 85% cover the storage container, and 54% access their water from storage with a cup or ceramic bowl, 36% pour it from the container. Approximately, 38% of households report that they treat their drinking water with chlorine or by boiling it; however 67% of drinking water samples from these households were at high to very high water quality risk levels. (See figure IV).

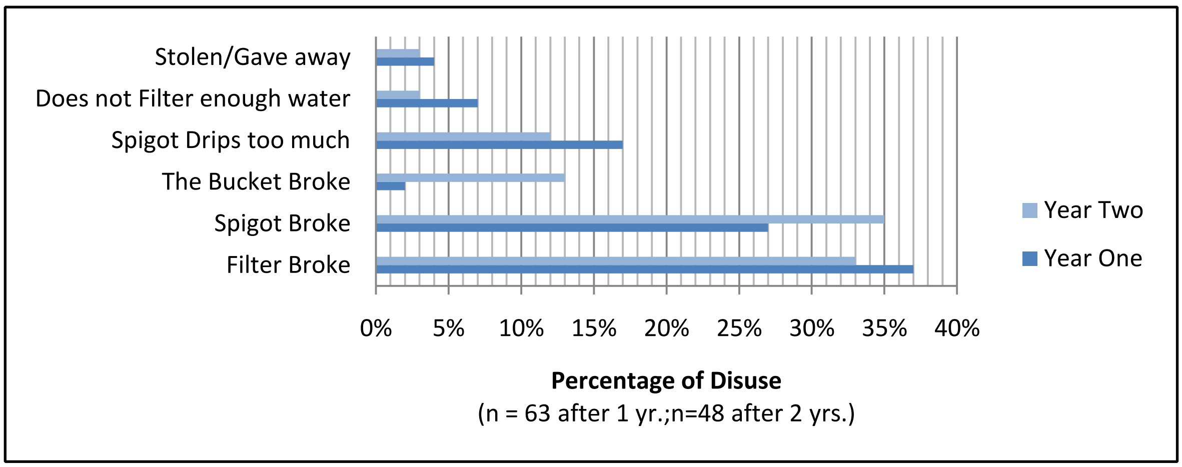
***Sanitation and Hygiene and Health*:** Sanitation, hygiene and health information most trusted did not differ significantly between control and intervention households. Eighty-nine percent of households have access to improved sanitation (a pit latrine, a pour flush latrine to a septic tank, or a toilet with a connection to a septic system). Soap was found to be present near the bathroom in 47% of households. Respondents wash their hands before preparing food (36%), after defecating (45%), before eating (58%), after changing a child's diaper (3%), according to unprompted responses. When asked what is your most trusted source of health information, the responses were: health worker or health center (38%), Radio (24%), TV (17%), local NGO (6%), family (6%), other (9%). See Appendix 4.A.5 for an overview of these results.

One & Two Years Post-Filter Distribution

Filters Purchased*:* One year after filters were purchased at the subsidized rate of $5, households were re-visited. Of those interviewed, eighty-five percent (85%) of households had purchased filters. The other 15% gave reasons for not purchasing filters, which included cost (3%), insufficient funds on date of filter delivery (4%), not present on day filters were delivered (3%), did not know about project (2%), and not enough filters for everyone (2%), and other (2%).

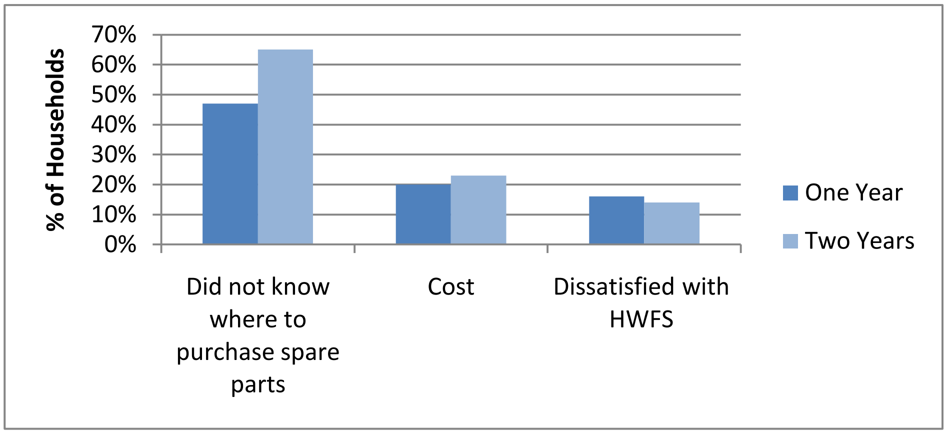
Filter Usage*:* After one year, 61% of filters purchased were still in use, and after two-years, 47% of filters purchased were still in use. Common reasons for disuse were breakage of the filter, the spigot. Reasons for disuse at year one included the filter broke (37%), the spigot broke (27%), the spigot drips too much (17%), the filter does not filter enough water (2%), the bucket broke (2%), it was stolen (2%), and gave it away (2%). Of those still using the filter, 19% had either replaced their spigot or had found a way to fix their broken spigot. After two-years, reasons households gave for non-usage included the filter broke (33%), the spigot broke (35%), the bucket broke (13%), the spigot drips too much (12%), the filter does not filter enough water (3%), and sold it or gave it away (3%). See Figure V.

<u>Figure V: Reasons for Filter Disuse</u>



The lack of a market for the spare parts was the main reason given for not purchasing replacement spigots, filters, or buckets. Reasons given for the non purchase of replacement parts for the HWFS after year one included did not know where to purchase replacement parts (47%), the cost (20%), HWFS was not useful (16%), plan to buy a replacement part in future (10%), and waiting to be given a replacement piece (6%). After year two, the reasons for not purchasing spare parts included didn't know where to buy the spare parts (65%), cost (23%), unhappy with filter because it filters water too slowly (7%), and did not like the filter (7%). These reasons have interesting implications for the intervention. See Figure VI.

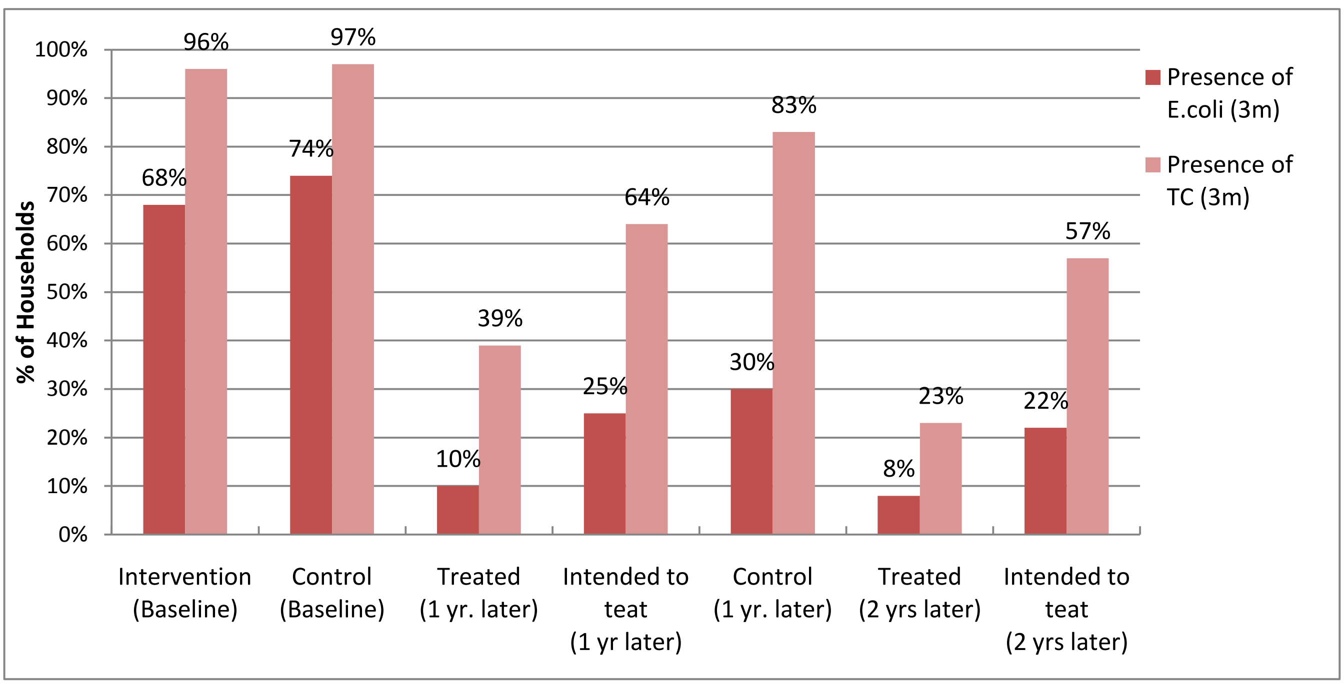
Figure VI: Reasons for Not Purchasing Spare Replacement Parts



At year one, 75% of households reported that children in the households only drink from the HWFS, 22% report children drink from the HWFS every day, but not always, and 2% reported that children in the household rarely drink from the HWFS. At year two, 78% of households reported that children in the household only drink water from the HWFS, 13% drink from the HWFS every day, but not always, and 6% rarely drank from the filter. A time-line of the number of households that purchased HWFS and ceased using the HWFS is in Appendix 4.A.14

Water Quality Improvements**:** At baseline, control and intervention households had similar levels of microbiological contamination: 67% of control household samples and 74% of HWFS were contaminated with *E.coli* at high to very high risk levels and 96% and 97% of household respectively had water that was contaminated with *total coliform*. After one year, water quality improved in HWFS households relative to control households. Intervention households were more likely to have low-risk water quality ($p<0.05$*) and less likely to have contamination with *E.coli* ($p<0.05$*). However, 39% of intervention households were no longer using the filter. Of those households still using the filters, these treated households were significantly less likely than control households to have water at high risk levels ($p < 0.05^*$), and medium risk level ($p < 0.005^*$) and more likely to have low-risk water quality levels ($p<0.00001^*$). The microbiological water quality in both control and intervention groups improved significantly from baseline levels; however, those households using HWFSs had significantly better microbiological water quality than control households after year one. Similarly, households still using the HWFS were significantly less likely to have water contaminated with *E.coli* one year after distribution ($p<0.00001^*$) than control households. This water quality was maintained in households still using the HWFS at year two. See Appendix 4.A.10, 4.A.11 and 4.A.12 for water quality results.

<u>Figure V – Water Quality Results over Two Years (3m)</u>



Some of the HWFS households did have water at the intermediate, high and very high risk levels after one year and after two years. (See Table I). This may be associated with the improper cleaning of the HWFSs. Twenty-seven percent (27%) of households with filtered water had water at intermediate, high or very high risk level. Of those still using the filter after one year, 60% say they wash the bottom of the filter with non-filtered water. Of those using their filters after one-year that have microbiological contamination in their filtered water, 70% clean the bottom of their filter with unfiltered water. This is one possible explanation for the contamination of the filtered water. Further research is needed to understand how water from HWFSs becomes contaminated in a field setting.

Table I – Water Quality Results After 1 and 2 Years

	Low Risk 1-10 *	**Intermediate Risk** 11-100 *	**High Risk** 101-1000 *	**Very High Risk** >1000 *
Control 1year later	31% (39/125)	38% (48/125)	23% (29/125)	7%(9/125)
HWFS (treated) 1year later	73% (45/62)	17% (11/62)	8% (5/62)	2% (1/62)
HWFS 1 year later	48% (58/121)	25% (30/121)	21% (26/121)	6% (7/121)
HWFS (treated) 2years later	85% (33/39)	8% (3/39)	3% (1/39)	5% (2/39)
HWFS 2 years later	61% (58/95)	20% (19/95)	17% (16/95)	2% (2/95)
*(E.coli/100ml)				

Gastrointestinal Disease: While the filter was very effective in improving water quality, my results do not provide evidence that it was protective against diarrhea. At baseline, total cases of reported diarrhea disease prevalence in intervention and control groups were not significantly different; and, after the filters had been in use for one year, the intervention group's prevalence of reported diarrheal disease did not change significantly from baseline nor was it significantly less than the control group (See Appendix 4.A.13). At baseline, 3% of the 754 intervention persons and 2% of 735 individuals in control households were reported to have diarrhea in the two weeks preceding the interview. After one year, 4% of intervention persons and 3% of control persons reported to have diarrhea in the two weeks preceding the interview. In the treated group, after one year, 5% were reported to have cases of diarrhea. In the discussion we suggest some possible reasons for the surprising low prevalence of diarrheal disease, especially when looked at next to the water quality results.

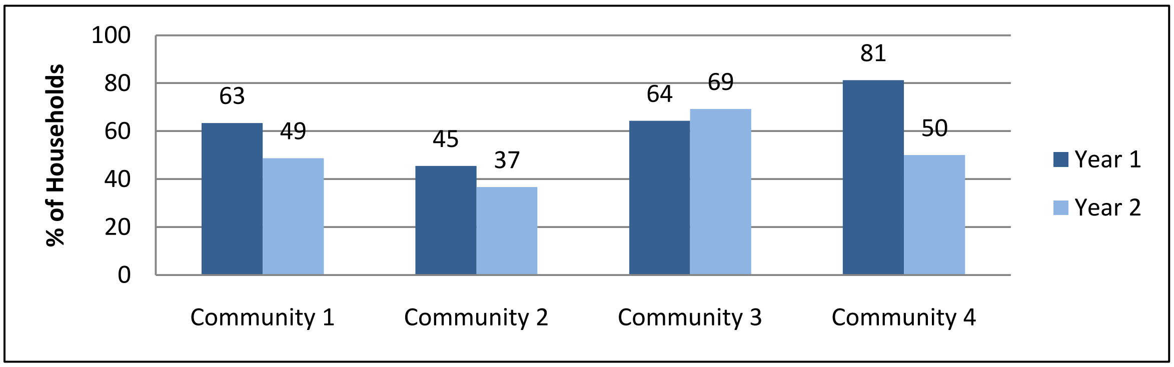
Height and Weight of Children Under-Five: A total of 52 control, 57 intervention and 28 treated children under five were measured for height for age (HAZ), weight for age (WAZ), and weight for height (WHZ), and z-scores were calculated. The power of the small sample size was much lower than intended primarily because of breakage of the filters in the intervention households. The sample size affects the ability to show significance. With a sample size of 28 children, in a test of proportions, the power is .08, and this gives very little confidence. When we calculate the mean Z-scores, there was no significant change for either control or intervention children under five or for children under five in households with functioning HWFSs from baseline to year one. At baseline, children under five were mildly underweight (WAZ) and moderately stunted (HAZ), but had normal weight for height (WHZ) z-scores. At baseline, 86% of children under five had a negative Z score for height for age (87% intervention and 85% control), 75% had a negative z score for underweight (78% intervention and 73% control), and 45% had a negative Z-score for weight for height (40% intervention and 50% control).

The mean z-scores did decrease slightly in all groups at one year later, in 2009. See Appendix 4.A.14 for the Z-scores for baseline in 2008 and in 2009. In the discussion there are a few explanations for the results.

Drinking Water Treatment in Honduras: Some may suggest that community-run piped water systems could be improved so they provide a reliable safe supply of drinking water instead of distributing household filters to households. While this may be true with adequate government funding and commitment, in key informant interviews with operators of drinking water systems and elected VWC members in Honduras after the household interviews were completed, some of the many obstacles were identified: high turbidity in the rainy season makes chlorine treatment less effective; chlorine is not always available in rural markets; the VWCs cannot afford to purchase chlorine when household water fees are not paid; some drinking water distribution tanks are far from the village and difficult to access by an operator; water service is intermittent making chlorine disinfection difficult; operators work on a voluntary basis; there is an aversion to the taste of chlorine and perceived negative health effects from its consumption. Also, the elected Village Water Committees have short electoral cycles and often have little prior knowledge about drinking water treatment, water system maintenance, or the budgeting and accounting necessary for water fees to be properly managed and allocated.

Technical Assistance: One of the intervention communities (community 3) had an increase in usage between year one and year two. All intervention communities, except community 3, experienced a reduction in filter use because of breakage. After some questioning, it was revealed that an NGO in the town closest to community three brought replacement spigots to the community for purchase between year one and year two. These spigots replaced broken spigots on the HWFSs. Twenty-three percent of households interviewed in year two in Community 3 had purchased another spigot to replace a broken or leaking spigot, and it is reflected in the increase in usage of the filters in community three compared to the other communities.

Figure VI – Use by Community of HWFS over Time

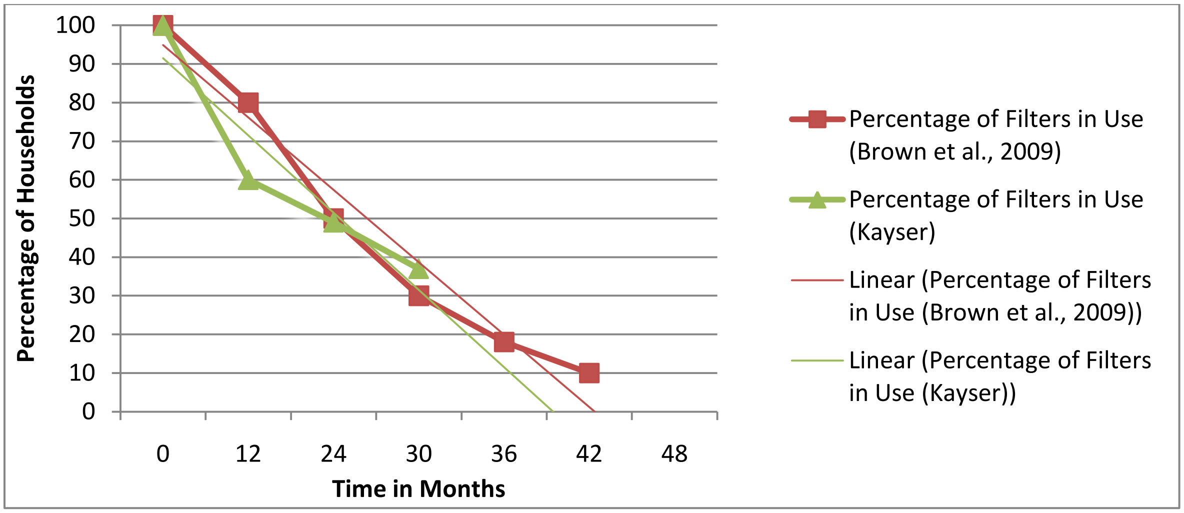


4.4. DISCUSSION

At baseline, the water service in control and intervention households were very similar. Eighty-six percent of households have a household tap; yet, only 61% use their household tap in the rainy season. It is likely that this is due to the water quality in their piped water systems. None of the piped water is treated prior to distribution and 71% of households had high to very high levels of microbiologically contaminated drinking water; 66% report that water the color of dirt comes out of the tap, regularly, in the rainy season; 56% have an intermittent water service, and 56% believe their water is unsafe. Even though 39% of households say they treat their water with chlorine or by boiling, two-thirds of those households had drinking water that had high to vey high levels of microbiological contamination. This suggests that over one third of female heads of household know that treatment is important, but do not actually treat their water or contaminate their drinking water in storage. The HWFS requires little extra effort by the female head of household, is coupled with safe storage, and significantly improved microbiological water quality after one year, and maintained that quality over two years in rural and peri-urban Honduras. Furthermore, it is a low cost drinking water intervention ($10 per household per year). Although, 39 and 52 percent of households stopped using their filters after year one and year two, respectively, this research suggests that these rates could be improved. The main reasons for ceasing to use the HWFS were breakage of the spigot or filter, and the main obstacle in locating replacement pieces was the lack of a market for spare parts. It is suggested that when spare parts are made available, households are willing to buy them and this enables them to continue to use the HWFS. This viable value chain could be promoted and would be likely to enhance the sustainability and the scalability of the technology over time.

The results of this study give us an opportunity to compare my results to other published data on the use of the HWFS over time to evaluate the consistency of information. A recent field study in Cambodia asked 506 households four years after they had received HWFSs to retrospectively ascertain when they stopped using their filters and the reason for non-usage. They found that filter use decreased by 2% per month, to 80% use after one year, 50% use after 2 years, and 10% use after 3 and a half years (Brown, Proum, and Sobsey, 2009). While the research in Cambodia looked at households with unimproved water sources and retrospectively, the rate of disuse in Honduras, where the HWFS was coupled with 'improved' water sources, is similar. See Figure VII.

Figure VII: Disuse of HWFS over Time – Results of Two Studies



The diarrheal disease result, especially when considered alongside the water quality data, emphasizes the subjectivity in diarrheal disease reporting, and should be read with caution. Based on conversations with Honduran researchers, there is a social stigma surrounding diarrheal disease in Honduras, and people associate diarrhea to personal or household "dirtiness." Anecdotal evidence suggests that visits to health clinics for persons with diarrhea result in scolding of the mother for poor hygiene and unsanitary household conditions. Honduran researchers acknowledged on a number of occasions that female heads of household did not like to discuss diarrhea illness in their household and may in fact be falsifying their response. Some children would even correct their mothers during the interview, and say they did in fact have diarrhea.

According to other research, self-reported gastrointestinal illness is subject to observer and responder bias (Schmidt and Cairncross, 2009). Also, diarrheal recall for episodes of diarrhea is unreliable beyond 48 hours, especially for members other than oneself (Boerma, 1991). In this study, recall for diarrhea was two weeks and reported by the female head of household, not each individual. While this study did not provide evidence of a decrease in diarrhea in household still using the filter after one-year, in other cultural contexts there may be less of a social stigma surrounding diarrheal disease. Also, diarrhea in one place may just be loose stool in another place where water-borne disease is more prevalent. Pictorial diaries that use stickers with different stool consistencies pictured on each sticker may be a solution to some of the many challenges of collecting diarrheal disease information, especially in places with high rates of illiteracy.

Water quality is a much more objective measure than reported diarrheal disease, is less invasive than stool samples, and is more easily compared across settings. It would be especially useful if a particular method was identified and used across many different studies to improve comparability of water quality data. The water quality method utilized here is easy to use, low-cost, and combines a sensitive and highly sensitive test to ascertain water quality risk level.

Height and weight of children under five is also an objective measure; however, the small sample of 28 under-five children that were still treated with the HWFS after one year gave such low power that I can do no more than suggest that future studies use this measure, plan for breakage, and increase the sample size significantly at baseline so that there is sufficient power to draw conclusions. We calculated a sample size of 76 children under five for treatment, but were only able to treat and measure 28 children under five after one year, mainly because many filters went into disuse and so the children in these households did not receive the benefits of the filtered water.

There was a slight trend toward an increase in stunting and underweight in both control and intervention groups, and while no conclusions can be drawn from the small sample size. One explanation for this is the military coup that occurred in Honduras in June, 2009 (Finnegan, 2009). This coup started half way through the treatment time period. The coup caused many of the children to miss almost a year of schooling, and schools are a place where many are fed one nutritious meal. Many countries also halted aid to Honduras during this time, which might have affected the nutrition of the children. Furthermore, height and weight is affected not only by environmental factors (water, sanitation, and hygiene), but also by food availability, care by the mother, and women's status (Smith and Haddad, 2000). Another added factor is the heighted violence over the past few years in Honduras. Honduras, part of the "northern triangle[41]" of Central America, has been called the most violent region on earth because it suffers the world's highest murder rates (Economist, 2011). Homicide rates, driven mainly by drug trafficking, have risen drastically in the past three years in Honduras, and costs Honduras approximately 9.6% of GDP (World Bank, 2011).

Water samples were taken at similar points in the year at baseline and one year later, after filter distribution; yet, the drinking water quality improved significantly in both control and intervention households after one-year. As suggested in *Paper II*, household interviews with households about water quality, diarrheal disease, and perceptions of water quality in each village in this study may have provided the incentive for the households and community as a whole to improve their piped drinking water systems. If this is the case, it would suggest that simple visits to a community to ask questions about

[41] includes Honduras, Guatemala and El Salvador

a specific community health issue may bring some awareness to the community as a whole and may motivate community members to make important improvements in their water system. Nonetheless, a significant improvement in microbiological water quality was detected in households still using the HWFS when compared to control households after one year.

Further research is needed to explore the effects of technical assistance, a market for spare parts, and promoters of the technology on the use of the HWFS over time. Promoters of the HWFS who educate households about water quality and the effects of the use of the HWFS may improve usage rates. Improved awareness specific to water quality and its impacts on diarrheal disease and the subsequent impacts on household health and economics may also improve usage over time. Awareness could target health information sources most trusted in the particular region. For example, in Honduras, respondents said they trust health information from their health centers and local doctors most and health information on the radio second. Over 85% of households own a radio in the rural areas studied and most households are less than 14 minutes from a health center or health post. Further research is needed on the impact of technical assistance on communities with HWFSs, post distribution, to determine if increased awareness about the importance of the water filtration technology and basic maintenance, can improve the usage, subsequent demand for replacement parts, and water quality. As cited in Paper II, in Kenya, for example, take up of the household chlorination treatment method improved by 50% by hiring a local promoter of the chlorination method (Ahuja, Kremer and Zwane, 2010). Another study field experiment in Kenya demonstrated that water quality information increased use of POU technologies by 8-13%, while social marketing methods increased use by 9-11% from a baseline of 71% (Luoto, J., 2010).

Technical assistance on the exclusive usage of the HWFS for drinking has the potential to increase the sole and regular use of HWFSs for drinking water among all household users, especially children. It could also improve the maintenance of the HWFS and decrease the contamination that seems to occur during the washing of the filter. An even more sustainable and scalable intervention to be researched might look at how the private sector could be involved in this process. Awareness and markets for the technology and its spare parts could be promoted by entrepreneurs.

4.5. CONCLUSION

In-home HWFSs were found in this study to be effective in the reduction of microbiological water contamination in households where piped networks deliver water that is characterized as intermittent, unsafe, turbid, and unsafely stored in containers in the household. After one year, intervention households were significantly less likely than control households to have microbiologically contaminated water (52% in intervention and 69% in control) and significantly more likely to have low-risk water quality ($p<.05$*). Those households still using the HWFS were also significantly less likely to have microbiological contaminated water, and less likely to have intermediate ($p<.005$*) and high risk water quality ($p>.05$), and more likely to have low risk water quality than control households after one year ($p<.00001$*). The improvements in water quality in HWFS households were sustained over two years without any additional local promotion of the technology training or market for spare filters. The use of the filters, however, dropped to 39% after one year and 53% after two years, and the main reasons given for this reduction in usage include: breakage of the filter or spigot. This research suggests there is a demand for replacement parts if they were available in a local market. This viable value chain could be promoted and would be likely to enhance the sustainability and the scalability of the technology over time.

4.A. APPENDICES
4.A.a Matched Communities

TABLE I - Matched Communities

	Intervention 1	Control 1	Intervention 2	Control 2	Intervention 3	Control 3	Intervention 4	Control 4
Community Name Abbrev.	**Guaq(I)**	**Jic ©**	**AE (I)**	**VC©**	**Charco (I)**	**Pesc©**	**Chorro**	**Colon ©**
sample size	45	63	41	34	25	20	24	20
population	81	105	62	68	38	40	41	50
Proportion of population sampled	56%	60%	66%	50%	66%	50%	59%	40%
Water source	unprotected spring piped to households	unprotected spring piped to households	Protected Spring and piped to households	river piped to households	Unprotected spring piped to households	River piped to households	unprotected spring piped to households	1 spring and 1 river source, piped to households
water per day	daily in rainy season, every 5-8 days in dry season	2-4 hours in dry season, daily in rainy season	24 hrs/day	24 hrs/day	12-20hrs/day	24 hrs/day	24 hrs/day	2-3 days in dry season, 24 hours in rainy season
Risk level, water quality	High Risk	Very High Risk	High Risk	High Risk	Very High Risk	Very High Risk	Very High Risk	Very High Risk
distance from urban market	1 hour walk, 1/2 hour bus	1 hour walk, 1/2 hour bus	10 min walk	10-20 min walk	40 min drive; 2 hour walk	1 hour walk; 1/2 hour walk and 45 minute bus ride	1 hr walking,	1 hour walking
Age of System	13 years	25 years	20 years	12 years	10 years	7 years	20 years	7 years
Water Treatment	No	No	No	No	No	No	No	No
Latrines	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

4.A.1 Table I - Demographics

TABLE I - Demographics				
Demographics	**HWFS**	**Control**	**P**	**Significant ***
# of Households	135	137		
Total Persons	754	735		
Children < 5	94	86		
Household Characteristics				
Mean # of rooms	3.5	3.8	0.148 ‡	NS
Mean # of occupants	5.45	5.32	0.721 ‡	NS
Mean years of schooling (female head of household)	3.7	4.5	0.060 ‡	NS
Total Number of Households	135	137		
Electricity present	47%	76%	0.000 †	*
Type of Floor			0.057 †	NS
Earthen Floor	33%	25%	"	NS
Fuel Source			0.992 A	NS
wood	76%	73%	"	NS
electricity	4%	6%	"	NS
gas	3%	4%	"	NS
wood + gas or electric	14%	15%	"	NS
No chimney with wood stove	60%	60%	0.825 χ	NS
Refrigerator	23%	49%	0.000 χ	*
Television	46%	67%	0.001 χ	*
Radio	88%	84%	0.376 χ	NS
Chairs	91%	93%	0.234 χ	NS
Bed	90%	95%	0.049 χ	NS
Bicycle	30%	39%	0.098 χ	NS
Motorcycle	5%	7%	0.452 χ	NS
Car	7%	11%	0.216 χ	NS
Cell phone	75%	77%	0.460 χ	NS
Cows or horses	11%	12%	0.584 χ	NS
Pigs	11%	19%	0.387 χ	NS
Chickens	71%	63%	0.387 χ	NS
Land Ownership			1.00 A	NS
0 manzanas	10%	11%	"	NS
1 manzana (=1.68 acres)	64%	64%	"	NS
2-5 manzanas	18%	18%	"	NS
> 5 manzanas	4%	4%	"	NS
Distance from				
Market			0.995 A	NS
Health Center			0.991 A	NS
Closest Paved Road			0.995 A	NS

χ Chi-squared ‡ Student's t-test A Anova " same as above
All percent values are out of # of households

4.A.2 Primary Drinking Water Source

Table II				
	HWFS	**Control**	**P**	**Significant ***
# of Households	135	137		
Tap present in house or yard	83%	89%	0.148 χ	NS
Primary Drinking Water Source				
Rainy Season				NS
Household tap or yard tap	60%	63%	0.730 χ	NS
Unprotected spring	17%	7%	0.005 χ	*
Neighboring water system	15%	13%	0.570 χ	NS
Bottled water	4%	8%	0.062 χ	NS
River	1%	3%	0.348 †	NS
Rain water	0%	1%	0.503 †	NS
Dry Season				NS
Household tap or yard tap	65%	67%	0.732 χ	NS
Unprotected spring	6%	7%	0.974 χ	NS
Bottled water	7%	7%	0.972 χ	NS
Neighboring water system	12%	12%	0.888 χ	NS
River	4%	4%	0.739 χ	NS
Other	2%	2%	1.000 χ	NS

χ Chi-squared * Significant † Fisher exact test % values are out of # of households

4.A.3. Water Quality, Availability & Reliability

TABLE III				
	HWFS	**Control**	**P**	**Significant ***
# of Households	135	137		
Water Quality				
Water the color of dirt comes out of tap in rainy season	66%	66%	0.996 χ	NS
Water Availability				
Insufficient water (dry season)	45%	43%	0.348 χ	NS
Water Reliability				
Intermittent Service	53%	61%	0.184 χ	NS
Perceptions of Piped Water				
Not safe to drink	57%	55%	0.684 χ	NS
Believe water is treated/do not know if it is treated or not	22%	42%	0.005 χ	*

χ Chi-squared * Significant % values are out of # of households

4.A.4. Water Handling Practices

Water Handling practices	HWFS	Control	P	Significant
# of Households	135	137		
Store water in storage vessel	96%	90%	0.094 χ	NS
Cover storage vessel	93%	78%	0.003 χ	*
Draw Water from storage by				
pouring	42%	31%	0.0478 χ	*
cup or ceramic bowl	53%	55%	0.722 χ	NS
Treat Water by (responses)				
boiling	21%	22%	0.816 χ	NS
chlorination	18%	15%	0.477 χ	NS
adequate chlorine (response)	3%	3%	0.752 χ	NS
Boil or chlorinate but have high to very high risk water (*E. coil*)	67% (35/52)	64% (34/50)	0.780 χ	NS
χ Chi-squared NS Not significant * Significant				

4.A.5. Sanitation, Hygiene & Health

Table V

	HWFS	Control	P	Significant *
# of Households	135	137		
Sanitation				
Improved Sanitation	86%	91%	0.303 χ	NS
Hygiene				
Soap present near bathroom	43% (30/69)	50% (49/99)	0.442 χ	NS
Wash hands (not prompted)				
before cooking	29%	43%	0.022 χ	*
after using the bathroom	47%	43%	0.471 χ	NS
before eating	57%	58%	0.082 χ	NS
after changing a child's diapers	4%	3%	0.718 χ	NS
Trust Health Information Most from				NS
health worker or health center	41%	34%	0.178 χ	NS
radio	23%	26%	0.619 χ	NS
TV	13%	20%	0.118 χ	NS
local NGO	6%	5%	0.768 χ	NS
family member	7%	6%	0.766 χ	NS
other	10%	8%	0.642 χ	NS

χ Chi- Squared * Significant NS Not significant
% is out of # of households unless otherwise mentioned

4.A.6. Cost of Water Service & Improvements Wanted in Water System

Table VI				
	HWFS	**Control**	**P**	**Significant ***
# of Households	135	137		
Payment for Piped Water Service				
Mean fee for water service/month	$0.32	$0.71	0.000 ‡	*
Improvements would like to see in water system				
Infrastructure	30%	27%	0.517 χ	NS
Quality (Turbidity)	25%	31%	0.354 χ	NS
Quantity	24%	23%	0.833 χ	NS
Purification (Treatment)	44%	45%	0.797 χ	NS
* Significant	‡ student t-test	χ Chi- squared	% is out of # of households	

4.A.7. Purchased HWFS & Reason for Not Purchasing

Purchased HWFS	**Percent**
Purchased Filters	85% (104/122)
Did Not Purchase Filters	15% (18/122)
Reason for Not Purchasing	
Cost	3% (3/122)
Insufficient money on day distributed	4% (5/122)
Not available on day of delivery	3% (4/122)
Did not want a filter	1% (1/122)
Bought one from another Ngo	1% (1/122)
Did not know about project	2% (2/122)
Not enough filters for everyone	2% (2/122)

4.A.8. Use after 1 and 2 Years

HWFS Usage	
After 1 Year	**61%** (63/104)
After 2 Years	**47%** (45/93)

4.A.9. Reason for Disuse of HWFS Yr 1 and Yr 2

Reason for Disuse			
HWFS After Year 1		**HWFS After Year 2**	
Filter broke	37% (15/41)	Filter broke	33% (20/60)
Spigot broke	27% (11/41)	Spigot broke	35% (21/60)
Spigot drips too much water	17% (7/41)	Spigot drips too much	12% (7/60)
Does not filter enough water	7% (3/41)	Bucket broke	13%% (8/60)
Not in house to use it	5% (2/41)	Does not filter enough water	3% (2/60)
Bucket broke	2% (1/41)	Sold it /Gave it away	3% (2/60)
It was stolen	2% (1/41)		
Gave it away	2% (1/41)		

4.A.10. Water Quality (*E.coli* and Total Coliform)

Table				
	HWFS	**Control**	**P**	**Significant ***
# of Households	135	137		
Water Quality Baseline				
Presence *E.coli* (3m)	68% (91/132)	74% (99/133)	0.403 χ	NS
Presence TC (3m)	96% (127/132)	97% (130/133)	0.466 χ	NS
E.coli (3m)	626 CI:302-950	870 CI:529-1210		
TC (3m)	5320 CI:4272-6369	5139 CI:3855-6425		
Water Quality After 1 Year Treated				
Presence of *E.coli* (3m)	10% (6/62)	30% (38/126)	0.0018 χ	*
Presence of TC (3m)	39% (24/62)	83% (104/126)	0.0000000 χ	*
Presence of *E.coli* (Colilert)	27% (17/62)	68% (86/125)	0.0000000 χ	*
Presence of TC (Colilert)	61% (38/62)	90% (113/125)	0.000002 χ	*
Intended to Treat				
Presence of *E.coli* (3m)	25% (30/121)	30% (38/126)	0.492 χ	NS
Presence of TC (3m)	64% (77/121)	83% (104/126)	0.001 χ	*
Presence of *E.coli* (Colilert)	52% (63/121)	69% (86/125)	0.009 χ	*
Presence of TC (Colilert)	80% (97/121)	90% (113/125)	0.016 χ	*
χ Chi-Squared * Significant				

4.A.11. Water Quality- Risk Level

	HWFS	Control	P	Significant *
# of Households	135	137		
Risk Level of Water Quality				
Baseline				
High Risk Water Quality	50% (66/132)	60% (80/133)	0.097 χ	NS
Very High Risk Water Quality	17% (23/132)	14% (19/133)	0.485 χ	NS
After 1 yr				
Treated				
Low Risk Water Quality	73% (45/62)	31% (39/125)	0.000000 χ	*
Medium Risk Water Quality	17% (11/62)	38% (48/125)	0.0042 χ	*
High Risk Water Quality	8% (5/62)	23% (29/125)	0.01 χ	*
Very High Risk Water Quality	2% (1/62)	7% (9/125)	0.1108 χ	NS
Intended to Treat				
Low Risk Water Quality	48% (58/121)	31% (39/125)	0.007 χ	*
Medium Risk Water Quality	25% (30/121)	38% (48/125)	0.022 χ	*
High Risk Water Quality	21% (26/121)	23% (29/125)	0.747 χ	NS
Very High Risk Water Quality	6% (7/121)	7% (9/125)	0.653 χ	NS

χ Chi-Squared * Significant

4.A.12. Water Quality after 2 Years HWFS

Water Quality After 2 Years (Collected in December, 2010)	
Treated (only those using HWFS)	
Presence of *E.coli* (3m)	8% (3/39)
Presence of TC (3m)	23% (9/39)
Presence of *E.coli* (Colilert)	15% (6/39)
Presence of TC (Colilert)	46% (18/39)
Low Risk Water Quality	85% (33/39)
Intermediate Risk Water Quality	8% (3/39)
High Risk Water Quality	3% (1/39)
Very High Risk Water Quality	5% (2/39)
Intended to Treat (all HWFS households)	
Presence of *E.coli* (3m)	22% (20/93)
Presence of TC (3m)	57% (53/93)
Presence of *E.coli* (Colilert)	38% (35/93)
Presence of TC (Colilert)	75% (70/93)
Low Risk Water Quality	62% (58/93)
Intermediate Risk Water Quality	20% (19/93)
High Risk Water Quality	17% (16/93)
Very High Risk Water Quality	2% (2/93)

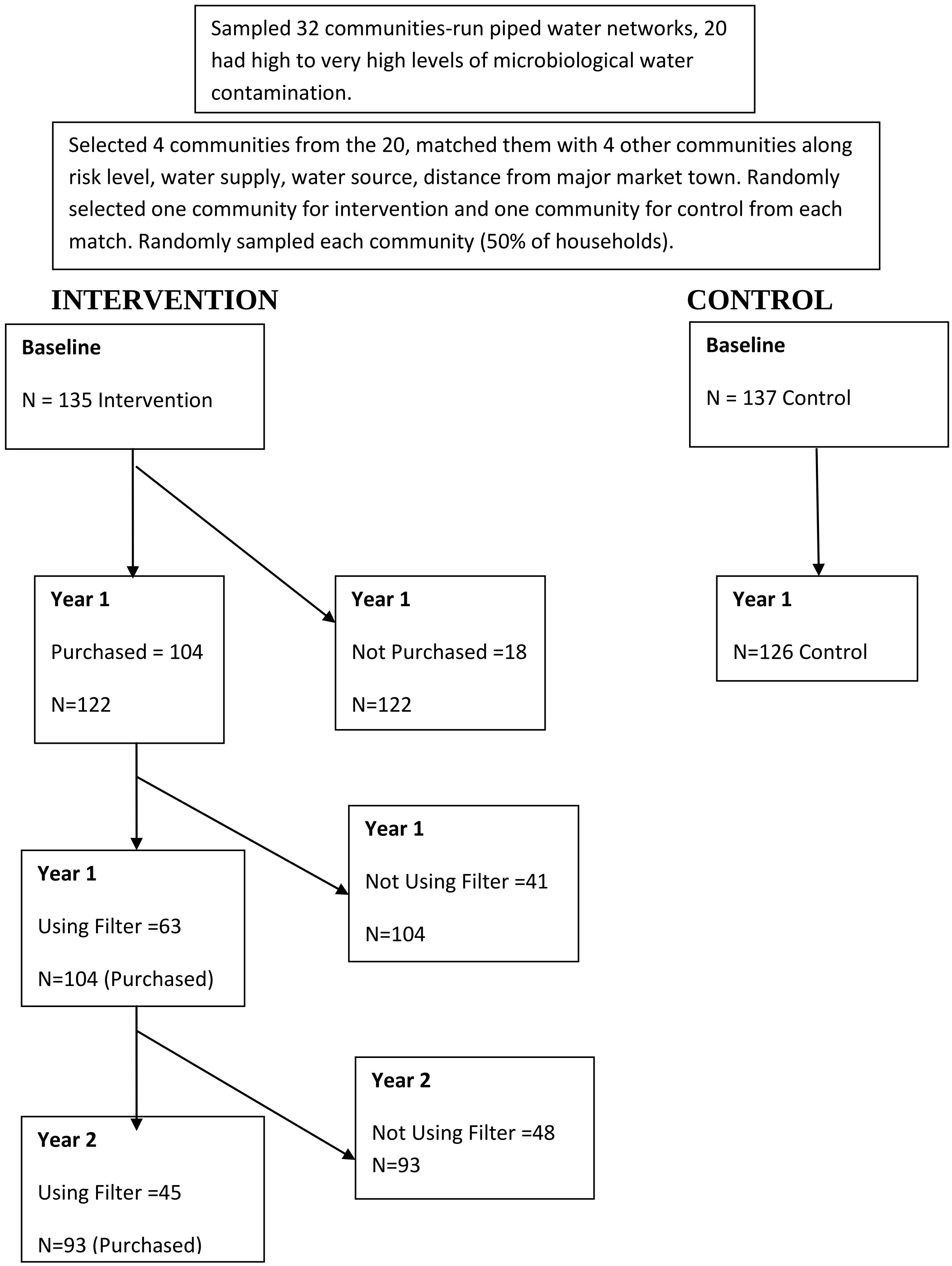
4.A.13. Gastrointestinal Disease

	HWFS	Control	P	Significant *
Baseline				
# of persons	**754**	**736**		
Vomiting	0.60%	0.80%	0.731 χ	NS
Nausea	1%	0.50%	0.117 χ	NS
Diarrhea and Cramps	3%	1%	0.026 χ	*
Diarrhea	0.30%	0.80%	0.298 χ	NS
Runny Diarrhea	0%	0.10%	0.311 χ	NS
All Diarrhea	3%	2%	0.289 χ	NS
1 yr later				
Treated				
# of persons	345	666		
Vomiting	0.20%	0.30%	0.977 χ	*
Nausea	1%	0.10%	0.030 χ	NS
Diarrhea and Cramps	2%	1%	0.649 χ	NS
Diarrhea	5%	1%	0.531 χ	NS
Runny Diarrhea	0%	0%	1.000 χ	NS
All Diarrhea	5%	3%	0.106 χ	NS
Δ from baseline	+2%	+1%		NS
Intended to Treat				
# of persons	697	666		
Vomiting	0.40%	0.30%	0.691 χ	NS
Nausea	1%	0.10%	0.039 χ	*
Diarrhea and Cramps	1%	1%	0.459 χ	NS
Diarrhea	3%	1%	0.062 χ	NS
Runny Diarrhea	0.20%	0%	0.166 χ	NS
All Diarrhea	4%	3%	0.322 χ	NS
Δ from baseline	+1%	+1%		
X Chi-squared * significant	all % based on # of persons			

4.A.14. Height and Weight of Children Under-Five

Table II Height & Weight of Children Under Five			
	HWFS	**Control**	P
Children Under Five	55	52	
Treated at Year 1	28		
Height for Age (HAZ)			
HAZ 1 (2008)	-1.737	-1.318	0.146 ‡
HAZ 2 (2009) Intended to Treat	-1.983	-1.526	0.132 ‡
HAZ 2 (2009) Treated	-2.34	-1.526	0.034 ‡
ΔHAZ2 Intended to Treat	**-0.307**	**-0.208**	**0.609 ‡**
ΔHAZ Treated	**-0.468**	**-0.208**	**0.311 ‡**
% - Z-score (2008)	87%	85%	0.304 χ
% - Z-score (2009)	93%	85%	0.183 χ
Weight for Age (WAZ)			
WAZ 1 (2008)	-0.9187	-0.646	0.174 ‡
WAZ 2 (2009) Intended to Treat	-1.133	-0.661	0.030 ‡
WAZ 2 (2009) Treated	-1.07	-0.661	0.110 ‡
ΔWAZ Intended to Treat	**-0.93**	**-0.015**	**0.269 ‡**
ΔWAZ Treated	**-0.1878**	**-0.015**	**0.484 ‡**
% - Z-score (2008)	78%	73%	0.540 χ
% - Z-score (2009)	87%	77%	0.183 χ
Weight for Height WHZ)			
WHZ 1 (2008)	0.178	0.162	0.938 ‡
WHZ 2 (2009) Intended to Treat	0.0869	0.2944	0.474 ‡
WHZ 2 (2009) Treated	0.471	0.2944	0.633 ‡
ΔWHZ Intended to Treat	**-0.091**	**0.1319**	**0.349 ‡**
ΔWHZ Treated			**0.815 ‡**
% - Z-score (2008)	40%	50%	**0.300 χ**
% - Z-score (2009)	54%	44%	**0.288 χ**
‡ student t test χ Chi-squared			

4.A.15 HWFS 2 Year Study Design & Timeline



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5.1. CONCLUSION

In 2015, the world will have met the Millennium Development Goal for water, to reduce by half the proportion of people without access to an 'improved' water sources. This is a laudable first step in the ultimate goal of guaranteeing universal access to safe and sustainable drinking water. Even when this goal is met, however, hundreds of thousands, quite possibly millions, of people will have access to 'improved' water sources that deliver insufficient quantities of water to households, deliver water that is microbiologically contaminated or provide only unreliable water supply. The research in Papers I, II and III provided evidence of the shortcomings of the 'improved' water standard, and evaluated specific measures that substantially improve water quality outcomes, even among households with access to piped water. The water treatment technologies identified and their impacts measured in the field significantly improve water quality and are low cost. This research furthermore establishes that even the construction or distribution of simple and appropriate technologies should be accompanied with some form of ongoing technical support if they are to produce sustained impacts over the longer term. It is not the technology alone that leads to the provision of a reliable, safe, sufficient, and sustainable drinking water service. It is the combination of an effective and appropriate technology, education about the importance of the technology and its health and economic benefits, ongoing technical support, and a market, proximately located, for spare parts. (These conclusions were shared with two of the NGOs that I worked with and are in Appendix 5.A.1. The NGO project created out of these recommendations is in Appendix 5.A.2.).

5.1.1. Overview of Research Questions & Results

This dissertation research proposed three research questions:

1. What is the effect of the Circuit Rider model of post-construction support on *system performance* (water quality) and *system sustainability* (technical capacity and management, financial and operational management, and environmental protection) in community-run piped drinking water systems in El Salvador?

2. In rural and peri-urban areas of Honduras, which of two types of drinking water treatment technologies, in the presence of contaminated piped drinking water, is most effective when measured for their impact on household water quality, health, and sustainability: household or community level treatment, or community-scale water treatment?

3. What is the health impact and sustainability of household filtration and safe storage over a two-year time frame in Honduras?

***Paper I*:** To study question 1, key informant interviews with operators of drinking water systems and Village Water Committee Members in sixty villages (28 intervention and 30 control communities) in El Salvador were used to measure *sustainability*; microbiological water quality tests and disinfection residual tests were used in households closest to and furthest from the water source in each village to measure *system performance*. The Circuit Rider model of PCS, in El Salvador, is associated with improved community drinking water quality outcomes and improved financial management, technical capacity, and environmental protection outcomes. Circuit Rider (CR) communities have significantly less microbiological water contamination than control communities and they invest significantly more of their operating budget on treatment and on repairs than control communities. The CR model leads to less water contamination; less drinking water contamination is related to less pathogen transmission; it is thus likely to lead to healthier communities; and, it is a surprisingly low cost intervention.

Paper II*:* A quasi-randomized experimental design was utilized to study question 2 in rural and peri-urban Honduras, and included 334 household interviews with female-heads of household and microbiological water quality tests in each household at baseline and one year after the distribution of the two technologies: the community-level treatment systems (CTS), and the household-level water filter and safe storage unit (HWFS). After one year with the technologies, HWFS and CTS households had significantly improved microbiological water quality, 61% of HWFSs and 46% of CTSs were still in use, and the technologies are relatively low-cost ($3.63 per person per year for the HWFS and $1.37 per person per year for the CTS). A decrease in reported diarrheal disease for either intervention group was not found; however, this may be because of a social stigma[42] surrounding diarrheal disease in Honduras. HWFS and CTS households had similar improvements in water quality; however, more households were using the HWFS than the CTS after one year.

Paper III**:** Household water filters and safe storage units (HWFSs) are clinically proven to improve water quality. No research has tested the sustainability of the HWFS in the field over two-years when coupled with 'improved' water sources at a subsidized cost. In Paper III, a clustered randomized trial was used to test the health impacts and sustainability of the HWF over two years in eight villages and 272 households (135 intervention and 137 control) in Honduras. Filters were subsidized by NGOs and purchased for $5 by households. After one-year, 61% were still in use, and after two years, 47% were still in use. Significant improvements on water quality in households using the filters one and two years after the intervention were found. No significant

[42] This is explained in the Discussion section in Paper II.

change in the height and weight of children under-five were found, but the power of the sample size was too small to draw any conclusions. Many intervention children lived in households where the HWFS went into disuse and so effectively were not treated. The main reasons for ceasing to use the HWFS were breakage of the spigot or filter, and the main obstacle in locating replacement pieces was the lack of a market for spare parts. The research suggested that when spare parts are made available, households are willing to buy them and this enables them to continue to use the HWFS. This viable value chain could be promoted and would be likely to enhance the sustainability and the scalability of the technology over time.

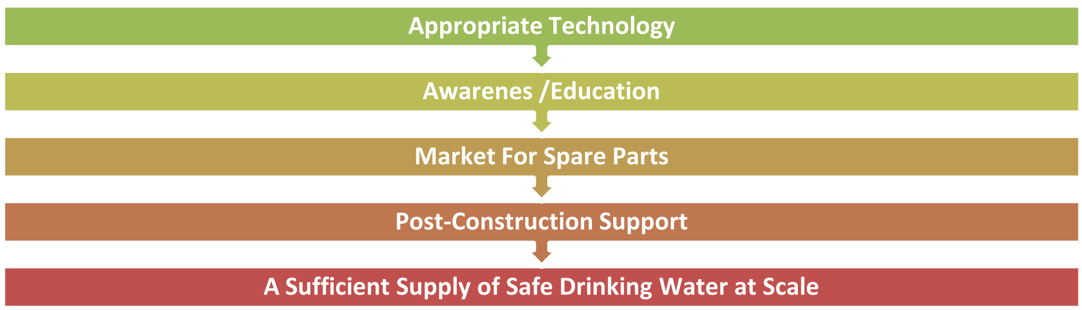
5.1.2. General Overview of Results

The field research on the three interventions coupled with discussions with engineers, drinking water technicians, and female-heads of household, suggests that appropriate technology is one of the necessary elements for a safe and sufficient supply of drinking water over time and at scale; however, the introduction of appropriate technology alone may fail to achieve sustained results. Papers 1, 2 and 3 suggest that availability of spare parts and some form of post-construction support may help communities maintain their piped networks and water treatment over the longer term. Informal field discussions and previous research suggest, furthermore, that awareness and education about the importance of the technology and its health and economic benefits are also important. See Figure I for a diagram of this conceptual framework.

Education about the importance of water quality builds awareness about the importance of water treatment, and this awareness increases the usage of the treatment method. In

Kenya, for example, research demonstrated that when households were given water quality information, use of household treatment technologies increased by 8-13%, while social marketing methods increased use by 9-11% (from a base of 72%) (Luoto, 2010).

Figure I: A Sufficient Supply of Safe Drinking Water at the Local-level: The Hardware and the Software



The ongoing use of the treatment technology depends on the maintenance of the piped network and the availability of spare parts. In many rural communities, if adequate economic resources are not available to purchase the spare parts when parts break, this will also be an obstacle in the long term sustainability of the piped water system or treatment technology.

Post-construction support can train operators in water treatment, help community-run water systems maintain water quality by providing on call technical assistance from a trained technician, and offer trainings in operation, maintenance, budgeting and accounting, and the importance of water source protection so a sufficient supply of safe drinking water is delivered to households.

5.1.3. Cost Comparison of Interventions

The technologies and the post-construction support model are low-cost and could be brought to scale in many different countries where 'improved' water service is characterized as microbiologically contaminated, intermittent, and unreliable and so have compromised piped water systems. When compared to chlorine, a low-cost and very effective water treatment that is widely used (see Appendix 1.A.2), the costs of the technologies and technical assistance model studied here are comparable. The interventions are also comparably effective in removing waterborne pathogens. The cost of chlorine is approximately $0.66 per person per year. The initial cost of the HWFS is approximately $3.33 per person and $1.37 per person for the CTS in Honduras (calculated by dividing the total cost per household by six persons). Cost of the Circuit Rider program in El Salvador was $0.20 per person per year. The ongoing costs, calculated every two years, included the costs of replacement filters and spigots for the HWFS and aluminum sulfate and chlorine for the CTS. The Circuit Rider ongoing costs include the cost of paying a technician and the operational costs of the Post-Construction Support organization (ASSA in El Salvador). See Table I for a cost comparison of the methods.

The estimates of each of the interventions are approximate. The setting, cost of labor, and any changes added to improve the intervention may change the initial and ongoing costs. For example, if the CTS were accompanied with a safe storage container or a paid operator, the price would increase, but the benefits might also increase. A safe storage container might improve the water quality at the household, and a paid operator might be more likely to maintain the CTS and regularly treat the drinking water, thus, improving the reliability of the CTS, and possibly the usage of the treatment system[43].

Table I: Cost-Benefit Comparison of Drinking Water Interventions

Intervention	Initial Fixed Cost (per person)	Ongoing cost every two years (per person)	Itemized Ongoing Costs (every two years)	Benefits compared to control households after 1 year	Use after one year
HWFS	$3.63	$1.18	Replacement filter and spigot	Improved water quality *	61%
CTS	$1.37	$1.00	Aluminum sulfate and chlorine for water treatment	Improved water quality *	47%
Circuit Rider Model	$0.00	$.40	Pay for technician and operational costs of the PCS organization	Improved water quality *	100% (no drop out noted)
Chlorine (Household)	$0.00	$1.32	Household level treatment with chlorine bleach	Improved water quality *	58% (after 2-7 months)
These calculations were made with an average of six individuals per household. Technologies and chlorine costs calculated from Honduras. PCS with CR model cost calculations from El Salvador. *Statistically significant (Studies have found a significantly improvement for all interventions. It is difficult to compare the magnitude of these differences, and this is discussed below.)					

The use rate comparisons reported in the table are imperfect, because they are taken from studies in different contexts, but they suggest that the treatment methods and technical assistance model examined in this these compare favorably to chlorine treatment. Research in Kenya on dilute chlorine treatment at the household level documented adoption rates of 10% before providing chlorine disinfectant free to the household, at which point use increased to 58%, measured at 2-7 months (Kremer et al., 2011). The usage rates of the HWFS and CTS in Honduras are comparable.

[43] In Appendix II, the cost of the coagulation, sedimentation, disinfection method is greater than the cost cited here. The CTSs operated in Honduras do not have a paid operator, and the communities are relatively small. These two factors reduce the price significantly.

In some contexts, methods involving chlorine disinfection may have disadvantages relative to the other methods. For example, while chlorine disinfection is more effective at reducing waterborne pathogens (protozoa, bacteria, viruses) than most other methods (see Appendix 1.A.2). It is difficult to use chlorine alone when water is especially turbid, a significant problem for many Honduran communities. High levels of turbidity, often found in surface sources in the rainy season, can create obstacles in chlorination as suspended particles reduce the microbiological efficacy of chlorine and other chemical disinfectants (UNICEF and WHO, 2008). The acceptance of chlorine can also influence its use. Anecdotal evidence in Honduras points to an aversion to its use because of the perceived negative health effects, the taste, and a general belief that if water is clear, it is safe.

The effectiveness of the CTS at reducing waterborne pathogens (protozoa, bacteria and viruses) is significantly better than point of use chlorine disinfection because it employs flocculation and sedimentation to rid the water of turbidity before disinfection with chlorine (see Appendix 1.A.2 for a comparison of the methods reduction of waterborne pathogens). However, this method had lower usage rates than the HWFS, and this may have to do with the cultural aversion to the taste of chlorine in Honduras. Coagulation and disinfection also require greater skill, and usually a trained operator, and this takes training and time by a single individual[44].

[44] Boiling water is often cited as the most inexpensive method and one of the most effective at removing waterborne pathogens, but in rural area it may require significant costs for the user, either in the form of time to cut and collect wood, possibly a scarce resource, or pay for fuel. (See Appendix 1.A.2 for a comparison of household treatment interventions.) In addition, in places where women spend most of their days preparing food and collecting wood for cooking, the benefits of the additional wood needed for boiling water may not outweigh the costs of its collection and the additional time spent boiling the water and storing it.

The HWFS significantly improves drinking water quality and has a high rate of sustained use compared to the other water quality treatment technologies, but breakage of the filter and spigot occur over time and reduce its long term sustainability in the field.

Further research is needed that compares treatment methods in the field and in different settings for not only their health impacts, but also their long term use. Few studies have looked at the determinants of long-term, sustained consistent use of point of use treatment methods (Lantagne et al., 2009). The adoption and sustained use of the four interventions over time, in a field setting, needs to be studied further, however, before any conclusions can be drawn.

Table I understates the cost of the CTS and the HWFS relative to the Circuit Rider model. The program and institutional costs are included in the ongoing costs of the Circuit Rider model but not the CTS, HWFS and point-of-use chlorine disinfection. In the case of the treatment technologies and chlorine disinfection, only the costs of the physical inputs are included. A more complete cost comparison of the approaches would also have to consider the costs and difficulty of creating institutional structures through which the interventions could be brought to scale in a large numbers of communities and sustained over time. Such structure is already built into the Circuit Rider model, but would have to be developed, and would imply additional costs and difficulties, for the CTS, HWFS and point-of-use chlorine disinfection.

5.1.4. Bringing the Interventions to Scale

One of the challenges for the HWFSs is their scalability (Clasen, Nadakatti and Menon, 2006). Further research is required to determine how water programs and specific technologies could be brought to scale. Increasing the distribution and use of a particular technology could be addressed by NGOs, governments, the private sector, or some combination of these development actors. Currently, the Circuit Rider model is funded by an NGO in El Salvador and is working with 170 communities; however, other successful Circuit Rider programs have been developed and brought to scale through government funding in the United States and through the government health department in Honduras. There is some encouraging work being done by Water for People that experiment with low-interest loans for water businesses that increase coverage. They are also monitoring functioning water systems with their program, Functioning Level Operations Watch (FLOW) to determine the sustainability of water infrastructure over time.

5.1.5. Recommendations for Service-Level Providers At the end of my field research, I was asked by two of the NGOS in Honduras that I collaborated with to write up a small report, summarizing my findings and offering my recommendations for practitioners interested in HWFS projects. This report, which can be found in **Appendix 5.A.1.,** recommends that HWFS projects be coupled with technical support, community education, and access to a market for spare parts.

In response to this report, the NGOs formed a partnership with local Peace Corps volunteers working in Honduras. The partnership provides technical assistance, education and capacity-building in communities. They work with Village Water Committees as sources for spare parts, available at cost. The technical assistance on HWFSs and CTSs include education on maintenance on the HWFs and CTSs, WASH education, and proper safe water storage practices. The projects, goals and vision of the pilot projects written by the NGOs and the Peace Corps volunteers can be found in **Appendix 5.A.4.** They have just begun the pilot of this project in four communities.

5.1.6. National Government-level WASH Priorities:

My research focused on household and community-level drinking water supply and recognized that the availability of water resources places constraints on communities and households—limited water quantity reduces the water available for bathing, household gardens, washing, cleaning, cooking and eventually drinking. In my field research, it was clear that national and local governance were critical to the provision of adequate drinking water services. National policies can guide Water, Sanitation and Hygiene (WASH) strategies, improve access to water and sanitation services, place a high priority on water quality monitoring, and assist in the operation and management of existing drinking water systems, but such supportive policies fail to arise without strong commitment by a government. Little research is available that compares certain political environments or instructional arrangements that are more or less conducive to funding WASH initiatives, and or laws and regulations that support a safe and adequate supply of drinking water to households. In El Salvador, Village Water Committee members suggested that community-level access to piped drinking water facilities was linked to municipal government party affiliation and voting patterns. According to interviews, NGOs often construct rural drinking water systems in El Salvador and municipal governments guide NGO investment in water services. The water systems are, thus, constructed in communities that voted for the mayor (Alcalde), not necessarily in places where need was greatest. Insufficient government commitment and corruption make the goal of sustainable access to safe water that much more challenging, but further research is needed to understand what might improve government commitment and hinder corruption in the WASH sector.

5.1.7. Building on the Millennium Development Goal for Water—A Way Forward

This research presented here reveals that the MDG for water—to halve, by 2015, the proportion of people without sustainable access to *safe* drinking water—cannot be met by tracking just the 'improved' infrastructure criteria. Because improved water is frequently not microbiologically safe, it may still transmit the pathogens which cause diarrheal disease. While the world is on track to meet the MDG for water at a basic infrastructure level, water supply safety and sustainability are not receiving adequate attention. The criteria used to define adequate access to water for the purposes of monitoring progress toward the MDG addresses distance and technology type; it is silent with respect to microbiological water quality at point of consumption, and water supply, quantity, and reliability. As Clasen (2010) states, "using a dichotomous "improved vs. unimproved classification, falls short in measuring progress toward 'sustainable access to safe drinking water.' As Bartram (2008) states, "the MDG targets for drinking water and sanitation represent a limited ambition; smarter targets are necessary; a system that is firmly grounded in health is needed, and testing water safety could be an important step." This shortcoming has significant potential risks to human health (the reduction of waterborne and water-washed disease) with subsequent impacts on poverty reduction and economic development. Gastrointestinal and diarrheal diseases reduce absorption rates of food and micronutrients, decrease childhood growth rates, drain energy levels, contribute to lower attendance levels at school, decrease the number of hours one is physically able and willing to work, and increase rates of morbidity and mortality, especially among children (Checkley et al. 2008; Billig, et al. 1999). Could the focus and subsequent resource allocation post-MDGs, therefore, concentrate more heavily on indicators that actually address safety and sustainability?

Currently the World Health Organization, UNICEF and national health and public works ministries use a "water service ladder" to gauge progress toward MDG access to water at the household level, that accounts only for "unimproved," "improved," and piped water to the household (representing bottom, middle and top rungs of the ladder). This "water service ladder" does not monitor water supply, water quality, accessibility or reliability. For quite some time policies have been based around a water service ladder that incorporates only infrastructure and distance to the user with the assumption that water quality and water supply would improve (UNICEF and WHO 2008). Instead of taking a pass fail approach, however, the goal could be to improve service along indicators that actually improve human health. Water quality, supply, reliability and accessibility could be measured and steps taken to improve these indicators. For example, while some households may have piped water to the household, physical water supply or resources in a certain community may limit a constant supply of piped water to a household tap. Water delivered to the household by pipes but every 8 to 15 days is not reliable or sufficient, and storage of water may compromise water quality. In addition, water source protection or maintenance of the physical water supply through watershed protection is not often a priority in WASH discussions, but could enhance water supply and possible water quality for the users over the longer term.

As populations grow, and agricultural, domestic and industrial demands over scarce water resources increase, this type of planning may become more critical for human and environmental health. The new service ladder in Table II, for example, incorporates quality, quantity, accessibility, reliability, and environmental sustainability, and is a new service ladder that keeps the focus on health and sustainability. This new service ladder, expands on the WHO service ladder, incorporates recommendations from Morarity et al. (2010), Howard and Bartram (2003), and Bartram (2008), and addresses quantity, quality, accessibility, reliability, and environmental sustainability. At the very bottom rungs of the ladder is a very limited service, far from the user, supply is limited, and the water source is not protected. At the very top rung, service level is high, a sufficient quantity of water is provided, quality is of low to no risk, accessibility is in the home, there is a constant supply of water, and the water source is protected for present and future users.

Table II: A New Service Ladder

Rungs of the Water Service Ladder	Quantity (l/c/d)‡	Quality*	Accessibility	Reliability*	Environmental Sustainability	Current MDG Status
High (top rung)	≥60	≤ Low Risk	Home	Constant Supply	Water source protection/watershed plan	Improved
Intermediate	40-59	Intermediate	<10 minutes	Intermittent Supply	Protection of water source	Improved
Basic	20-39	Intermediate- High-risk	10- 30 minutes	Intermittent Supply (≤ 1 hour /day)	Some protection of water source	Improved
Sub-Standard	5-19	Very High - High Risk	31-60 minutes	Intermittent Supply (≤ 1 hour /day)	No protection of water source	Unimproved
Very limited (bottom rung)	<5	Very High Risk	>60 minutes	Intermittent Supply	No protection of water source	Unimproved

Adapted from Moriarty et al. 2010; Howard and Bartram 2003
*Quality of intermediate-very high risk water and intermittent water could be enhanced with household or community-level treatment and safe storage.
‡l/c/d: liters per person per day

5.1.8. Areas for Future Research

Areas for further research were identified in the areas of water policy, field experiments that compare treatment technologies over time, and the effect of environmental protection and planning on water supply over the longer term. Policymakers would benefit from future research that helps identify the institutional WASH policies (at the global, national and service-provision level) that best promote on-going provision of a safe and reliable drinking water (Ahuja, Kremer and Zwane, 2010; Bartram 2008). Few studies compare treatment methods in the field for their water quality or health impacts, and study the methods over a time period that is longer than six months. In future research, I would also like to identify other particularly successful technologies and programs that improve drinking water quality and the sustainability of drinking water systems in the field, and examine whether they improve human and environmental health and are able to generate benefits that are sustained over the longer term. This research has also made it clear that environmental factors of water source and watershed protection seem to be left out of water source planning and development at the local level, and could have devastating impacts on health and the environment as populations grow and water resources become scarcer.

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5.A. APPENDICES

5.A.1. Recommendations for Practitioners

Household Ceramic Water Filter Projects in Honduras: Lessons for Practitioners

This is designed for practitioners in Honduras, for those interested in improving drinking water quality at the household level. These 'lessons' came out of a two-year research project in La Paz and Intibucá, Honduras. The goal of the study was to understand the water quality, household health, and sustainability impacts of the ceramic filters (the Potter for Peace version). 272 female heads of household were interviewed and water quality tests taken in each household before filter distribution, and one and two year years after distribution. In sum, the research the ceramic filters are associated with improved water quality; however, the research suggests that the sustainability of these filters depend on a household's: 1) technical support, 2) community education on the benefits of safe drinking water, 3) access and proximity to a market for replacement parts. A more technical paper will be written with the major results of the study over the next few months.

Overview

A. **Are ceramic filters a good option? Community specific questions to consider**
B. **Filters are a good option for communities with these conditions**
C. **Lessons learned from a three year research project monitoring ceramic filters overtime**
D. **Overcoming challenges for future ceramic filter projects**
E. **Filters may not always be the best option for household water treatment**

Ceramic Filters: Questions, Challenges and Lessons Learned

A. Questions to consider when determining if ceramic filters are a good option for a community or if education, training and capacity building might make the current system better:

1. What is the current drinking water source?
2. Is it improved or unimproved[45]?
3. Is water piped to a household tap or a public community tap?
    a. If it is piped to a household tap, is the tap inside or outside the household?
    b. If water is piped to the household, are there households that are not on the system?
    c. Is water available intermittently or continuously?
    d. If there is piped infrastructure, how old are the pipes and tanks (distribution and intake)?
    e. Is the water microbiologically contaminated?
4. Is the drinking water clear or turbid?
    a. If the water is clear, is it microbiologically unsafe to drink?
    b. Do people who live in the village understand that clear water can be unsafe?
5. Is the water currently being treated?
    a. If yes, is this treatment regular and continuous?
    b. How is the water treated?
        i. Chlorine is inexpensive and widely available
            1. However, is chlorine accepted in the community as a form of drinking water treatment?
            2. If chlorine is used to treat water, how often is it used?
                a. Is it only used to clean the distribution tank once a month?
6. Is there a Junta de Agua (water board or village water committee)?
    a. Are they well organized?
    b. Do they meet regularly?
    c. Are there enough funds (water fees) collected to pay for technical fixes and chlorination in the water system?
    d. Are water fees being collected on a regular basis? What percentage of the community pays their water fees?
7. Is there a drinking water system operator? Is he/she paid a wage for his/her work?

B. Filters may be a good option for communities with:

[45] A. Improved water source: household connection, public standpipe, borehole, protected dug well, protected spring, rainwater collection. B. Unimproved water source: unprotected well, unprotected spring, rivers or ponds, vendor provided water, bottled water, tanker truck water?

1. Unimproved sources, however, filters do not solve the water quantity problem, and is often considered a temporary solution (by the village) until they can find the funds for a permanent piped system. (Water for cooking, washing dishes and clothing, bathing, and water for agriculture are all important to households),
2. Piped systems with intermittent water service (ceramic filters offer safe storage for times when water is not available),
3. Communities with extremely turbid water (it is difficult to treat extremely turbid water with chlorine and so filters may be a good option),
    a. 96.4% of drinking water in Honduras comes from surface sources[46] -- this water is often very turbid in the rainy season
4. Communities with untreated or irregularly treated piped drinking water that is microbiologically unsafe,
5. Communities where water treatment is not monitored or treatment is not enforced by a health ministry/government official,
6. Communities that detest the taste of chlorine, think it causes illness or disease, and actively deter the operator from treating drinking water with adequate amounts of chlorine,
7. Aging water systems with major leaks--systems that may be too old to be fixed and a new distribution line or new tanks may be too costly),
8. Communities with natural disasters that destroy drinking water infrastructure,
9. Poorly organized Juntas de Agua that cannot raise funds for treatment, or technical and infrastructure fixes.

C. Lessons learned from a two year research project monitoring the health and sustainability impacts of the filters overtime

1. **Water quality**: According to water quality tests, the filters are very good at eliminating microbiological contamination when used properly.
    i. The filters, buckets, and spigots are not always cleaned properly. This can cause filtered water to become contaminated.
2. **Sustainability**: The spigots and filters break overtime
    i. *61% of filters were still in use after one year and 47% were still in use after 2 years with no follow-up and very little access to spare parts*
        1. ***If there is not a market for spare parts, if the community is too far from the market for spare parts, or if households do not understand the critical importance of safe drinking water and, therefore, do not have an incentive to buy spare parts when there are breakages, ceramic filters may only serve as a temporary fix.***

[46] ERSAPS. Datos del Sector de Agua Potable y Saneamiento. Honduras, 2006.

2. ***If households are not reminded of the proper handling of the filters, contamination of filtered water can occur.***
3. ***Households use of the ceramic filter may increase if they see the results of their water quality, and if they are educated on the benefits of the household water filter (improving health, decreasing disease[47], and decreasing the household costs related to disease may improve usage over time.***

ii. Filters do not filter enough water for large households. More than one filter is probably needed for households that have more than 8-10 members.

iii. It is recommended that the ceramic filter filtration piece be replaced every 2 years. If water is very turbid this may have to happen more often as water will filter very slowly.

iv. Subsidized, not free, ceramic water filters may make replacement part purchases more bearable for households.

D. Overcoming challenges and facilitating successful ceramic filter projects:

1. A market for replacement parts. Some ideas for marketplace: tiendas (small store in town), Chlorine Banks, NGOs, Junta de Agua(this changes every few years and may cause some problems). These markets need to be close to households and households need to be aware of their existence.

2. Train female heads of household on how to clean the filters, buckets and spigots. One cannot assume that households can or will read the instructions on the side of the safe storage unit. This training should probably happen more than once.

3. Capacity Building and Education (capacitaciones) seem to be crucial to successful drinking water treatment interventions[48]

a. Capacitaciones can occur with women's groups, in schools and/or with community groups. Capacitaciones may take many different forms and could include:

i. The water quality of the community or household water source

ii. The different options for water treatment, and the advantages and disadvantages of each option,

iii. The diseases caused by unsafe drinking water,

iv. The cost to the household of diarrheal disease: missed school and work, cost of visit to the doctor and transport to the doctor,

[47] Luoto. J. (2009). Information and Persuasion: Achieving Safe Water Behaviors in Kenya. Working Paper.

[48] Ahuja, A., Kremer, M., Zwane, A. (2010). Providing Safe Water: Evidence from Randomized Evaluations. *Annual Review of Resource Economics*. 2: 237-256.

opportunity cost for women- time spent waiting at health center to see doctor that could have been spent working, selling items at market, tending to animals/agriculture/household/other children,

v. The importance of adequate hygiene and sanitation as well as a safe and sufficient supply of drinking water,

vi. The diseases caused by inadequate water, *and* sanitation and hygiene and the cost to the household of these diseases,

vii. Filter maintenance

viii. Some have advised training leaders in the community to check in on households for broken filter pieces, proper hygiene and sanitation.

b. Frequency of capcitaciones:

i. More than one meeting to cover above information,

E. Filters may not always be the best option for household water treatment

1. Other household treatment (HWT) options include: Ceramic filters (disk and candle), Biofilm Fitlers (biodand filters), UV Radiatioin (SODIS, Lamps), Chemical (PUR, clorination), other (moringa Seeds, sari cloth, boiling).
    a. The best option depends on the community water source, community/household resources, access to spare parts, community preference, water availability, and turbidity.
    b. Not all options include safe storage –critical to the consumption of safe drinking water at the point of use.
    c. Research on diarrheal disease reduction suggests that ceramic water filters may be the best HWTS option[49]
2. A new technology may be a quick fix, but it might not be the best fix. Follow-up, education, technical support, and a market for spare parts are critical to sustainability.
3. If there is already a piped system delivering contaminated water to households:
    a. Operators can be trained on how to treat drinking water,
    b. Water boards can be trained in the importance of water fees, educated on how to raise funds for future infrastructure fixes and for water treatment,
    c. Water board members can be trained in the basic elements of accounting so that sufficient funds are available when funds are needed for fixes,
    d. Community members can be educated on the importance of safe drinking water,

[49] Sobsey, M., Stauber, C., Casanova, L., Brown, J., Elliot, M. 2008. Point of Use Household Drinking Water Filtration: A Practical, Effective Solution for Providing Access to Safe Drinking Water in the Developing World. *Environmental Science & Technology*, 42, 4261-4267.

e. Community members can be educated in the importance of chlorine as an inexpensive option for safe drinking water,
f. Ministries of health can be trained to enforce water quality laws and regulations and governments can make it happen.

5.A.2 Practitioner Response

Partnership for Potable Water

Peace Corps y Agua y Desarrollo Comunitario

by PCV David Lee (Honduras, '10-'12)

The key to a fulfilling and productive volunteer experience is very often the work partnerships made between PCVs and host-country organizations. One example of these partnerships is the budding relationship between three volunteers and the Honduran NGO Agua y Desarrollo Comunitario (ADEC). With the support of Fred Stottlemyer of the International Rural Water Association (IRWA), PCVs David Lee, Kristi Krohn, and Zach Neumann have partnered with ADEC to bring potable water to various rural Honduran communities in the departments of Santa Bárbara and Intibucá.

The Players

Agua y Desarrollo Comunitario is directed by Diana Cálix and based in Marcala, La Paz. ADEC provides assistance to rural Honduran families to improve drinking water quality with sustainable treatment technologies while providing education on basic sanitation and hygiene. Their objective is to reduce the incidence of waterborne illness due to poor water quality and bad hygiene practices.

PCVs David Lee and Kristi Krohn are married volunteers serving in Trinidad, Santa Bárbara. David is a Water and Sanitation volunteer with a background in water resources engineering. Kristi is a Health volunteer with a background in school counseling. PCV Zach Neumann serves as a Wat/San volunteer in Camasca, Intibucá and is a recent graduate of Loyola University.

Fred Stottlemyer is a member of the International Rural Water Association and is a RPCV (Pakistan, '62-'64). Fred has been working on a range of potable water projects in Honduras since ADD YEAR.

The Projects

Beginning in February 2011, the PCVs and ADEC will begin implementation of several pilot projects: La Fragosa, Petoa (36 families) in the department of Santa Bárbara, Volcancillo, Camasca (24 families) and La Pintal, Colomoncagua (10 families) in the department of Intibucá, as well as the escuela normal en Camasca. The projects include a combination of the distribution of ceramic water filter systems (manufactured in Sabanagrande, Francisco Morazán) and the installation of mini-drinking water treatment plants (Combined Treatment Units or CTUs). To ensure the sustainability of the projects intensive continuing education will be provided by the PCVs on topics ranging from maintenance of the filters and CTUs to proper hygiene and water storage practices.

ADEC will subsidize the purchase of the ceramic filter systems (about $25) which includes the filter and a drinking water storage bucket with spigot. The PCVs have been working to educate the communities of the benefits of potable water and encourage participation of all families. Each family is required to contribute to the purchase of the filters in the amount of L.50 ($2.65) in Volcancillo and La Pintal and L.100 ($5.30) in La Fragosa. This contribution will be used to purchase replacement parts (filters, buckets, spigots) which will be stored and sold to community members to repair broken filter systems as needed. The ceramic filter treats contaminated water through filtration achieved by fine pore size and disinfection achieved by colloidal silver which is implanted in the ceramic filters during manufacture. The system has a filter rate between 1.5 and 2.5 liters per hour.

ADEC will also purchase the Combined Treatment Units (about $250 for 450L unit) and assist the PCVs with installation in the community schools. The treatment unit will be on loan to the community contingent upon proper maintenance and use. The CTU is a two-tank system (typically 450L to 1000L plastic tanks are used). In the first tank the raw water, typically from a nearby stream, is mixed with the chemical flocculent aluminum sulfate. The microbe carrying sediment coagulates to form heavier masses of sediment called flocs. The flocs, due to their weight, fall to the bottom of the tank where they can be discharged via a cleanout valve. The cleaner water from the first tank is then passed to the second tank where it is disinfected with chlorine. Chemical costs depend on the amount of water treated but should be less than L.30 ($1.59) per month in each of these projects. This treatment process will be taught to school teachers and students alike. The students will have access to treated water while learning the importance and processes of water treatment.

Continuing education will be provided by the PCVs to the community members and students in the weeks and months following project implementation. The PCVs will also be responsible for project follow-up to ensure the proper maintenance and utilization of the filter systems and CTUs.

The Vision

Selection of appropriate technology and community education are the driving forces behind the sustainability of these projects and similar potable water projects in Honduras and the rest of the developing world. Through partnerships with responsible host-country organizations like ADEC, Peace Corps Honduras can reach out to rural communities and elevate the standard of living with low-cost water treatment solutions implemented and supported with basic education on hygiene and sanitation.

5.A.3 – Interview for the Village Water Committee Member, English

Kayser- Tufts- Water System Technical Assistance Model
An Evaluation

To interview the President or Treasurer of the Drinking Water Committee or an official in the Alcaldía with knowledge about the management of the drinking water system.

Name of Interviewee: ____

Date: ______ *(Day)*; ______ *(Month)*, 2009; Time: ____:____ AM / PM *(Circle one)*

INTRODUCTION

Hello. My name is________________ and we are investigating the water quality and management of drinking water committees in El Salvador. As an official en the drinking water committee, we would like to request your participation. The objective of this study is to evaluate the quality of drinking water consumption in your community. In this study we will ask questions about water service, reliability, quality, cost and available technical assistance that you have

received for your system in this community. The benefits of this study are the improvements of human health.
Your participation is voluntary. You can decide to stop the interview anytime. The questionnaire lasts no longer than 30 minutes. Your time is very important and we are very thankful for your participation.

Do you agree to be interviewed? ____ Si; ____ No;

If you do not have time today, we can return at a time that is more convenient.

Before I continue, do you have any questions?

Signature ________________________________ Date_________________

Interview for an Official Representative of the Drinking Water Committee

Name: ____

Department/Municipality/Locality:

____

Country: ______________________

How long have you lived in the Community? _______________________________

A. Drinking Water System

A.1. ¿What type of drinking water system is in your community?

a. Gravity fed b. Rain-fed c. Well

e. Other__________________________________

Percentage of each

A. 2. Where is the water sourced in your community?

a. River b. Spring c. Well (subterranean) d. Other__________

A.3. Is the source protected

a. Yes b. No

A.4. If yes, how is the source protected?

a. fence b. forest c. Protected area d. planting trees

e. have a community tree nursery

f.Other____
____
____
____
____
____

B. Connections

B. 1. How many houses benefit from the drinking water system?

a. < 5 b. 5-10 c. 10-50 d. 50-100 e. 100-500 f. 500-1000

g. 1000-2000 h. 2000-5000

B.2. How many households have a household connection?

a. < 5 b. 5-10 c. 10-50 d. 50-100 e. 100-500 f. 500-1000

g. 1000-2000 h. 2000-5000

B.3.Is this water treated/disinfected?

a. Yes b. No

B.4. What is the treatment process?

____
____
____
____
____
____

B.4 How many houses are not connected?

a. < 5 b. 5-10 c. 10-50 d. 50-100 e. 100-500 f. 500-1000

g. 1000-2000 h. 2000-5000

B.5. Are there zones in the city where no one is connected to the drinking water system?

a. Yes b. No

B.5.b If yes, why?

a. Don't know b. The cost c. The houses are new and were constructed after the system

d. The houses are situated in a place where it is difficult to connect them to the system

e. The houses are above the distribution tank e. Other______________

B.5. How many houses are connected to the system?

a. > 5 b. 5-10 c. 10-50 d. 50-100 e. 100-500 f. 500-1000

g. 1000-2000 h. 2000-5000

B.6 Where do these people without connections get their water?

a. river b. well c. pumpd. other__________________

B.6b. Is this water treated/disinfected?

a. Yes b. No

B.6c. What is the treatment process?

____
____
____
____
____
____
____

B.7. On average, how many houses are not using treated water?

a. > 5 b. 5-10 c. 10-50 d. 50-100 e. 100-500 f. 500-1000

g. 1000-2000 h. 2000-5000

C. Financing

C.1. Who financed the construction of the water system?

a. community with water committee b. mayor c. NGO d. ANDA e. Other________

C. 1.b.How much did each household pay for the initial connection?
___________$ USA

C.2.What was the initial investment in the construction of the drinking water system __________________$ USA

C.3. Who finances the cost of the operation and maintenance of the drinking water system?

a. community/drinking water committee b. mayor c. NGO_______________(name of)

d. other__________

C.4.If the community is responsible for the financing of the operation and maintenance, does every household pay the same amount?

a. Yes b. No

C.5.If yes, what is the monthly fee paid by each household ? _________________$US

C.6. If no, are there meters in each household to measure the volume of water used to determine price?

a. Yes b. No

C.7.What is the annual operating cost of the drinking water system?______________$US

C.8. How are the funds distributed?

C.8.a.____$ operation maintenance
C.8.b.____$ operator
C.8.c.____ $ municipality
C.8.d.____ $ watershed protection
C. 8.e_____$ other ___________

C.9. Do you have a program to protect the watershed for future water users?

a. Yes b. No

C.9b.Please describe the program

____
____
____
____
____

C.10. Are there sufficient funds available for all costs?
a. Yes b. No

C.11. ¿What costs are included in the operation of the plant/distribution tank?
Operations:

Operation	Cost

C.12-19. ¿Who pays for the water in the health center, church, schools, municipality, market and any other public sites?

Place	Who Pays
C.12. Health center	
C.13. Church	
C.14. Grade Schools	
C.15. High School	
C.16. Municipality	
C.17. Market	
C.18. Other___________________	
C.19. Other___________________	

C.20. What is the billing process for the households connected to the system?

C.21. Has the price of water changes with time?

a. Yes **b. No (If no, skip to question C32)**

C. 22. If it changed, what was the price before_______________ $

C.23. What is the price now? ___________________$

C.24. Why did it change?

C.25. Have you received technical assistance in the past 6 months?

a. Yes b. No

C.26.What type of technical assistance did you received in the past 6 months? (circle all mentioned)

a. education b. maintenance c. Treatment/disinfection d. Source protection

e. Watershed protection f. Financial management assistance g. Health/Hygiene

h. Latrine Maintenance i. Other_________________________________

C.27. What foundation gave assistance?

a. ANDA b. ASSA c. other_______________________

C.28. How many times have you received technical assistance in the past 6 months?

a. 1 b.2-5 c. 6-10 d. 11-20

C.29. ¿ Could you indicate what problems you have had in the last 6 months, the duration of the problem, if technical assistance was provided, the cost and what foundation provided the technical assistance?

Problem	Duration of the problem	Technical Assistance	Cost	Foundation

D. Perceptions of the quantity and quality of the water provided

D.1. Is their sufficient water throughout the year in the distribution line?

a. Yes b. No

D.2. If no, when do you not have sufficient quantity of water for every household

a. Rainy season b. Dry Season c. Other

D.3. In the dry season, how many hour/day is their insufficient water available for each household?

______ hours/day

D.4. In the rainy season, how many hour/day is their insufficient water available for each household?

_______hours/day

D.5. Do you think that the piped water is safe to drink?

a. Yes b. No c. Don't Know

E. Chlorination Perceptions

E.1.Do you think it is important to put chlorine in the water?

a. Yes **b . No**

E.1.b Why?

____
____
____
____

E.2. Do the people drink the water treated with chlorine?

a. Yes **b. no**

E.3. If no, why don't they drink it?

a. Taste **b. Cost** **c. Other___________________________**

E.4. If no, could you help me understand the people's thoughts on chlorine?

____
____
____
____

E.5. Do you have any other comments in regard to the quality, quantity and reliability in your community?

____
____
____
____
____

Time: ____:____ AM / PM

5.A.4 Interview for Drinking Water Operator

Kayser- Tufts- Drinking Water Systems, An Evaluation

An interview for the operator of the drinking water system

*** For the Interviewer, please complete this pate before starting the interview. Each interview should have a number and appropriate form of identification) ***

Name of Interviewer: ____

Date: ______ *(day)*; ______ *(month)*, 2009; Hour: ____:____ AM / PM

INTRODUCTION

Hello. My name is _________________ and I am part of study to investigate the quality of drinking water services here in El Salvador and we would like to request your participation. The

questions in this survey are about the drinking water service: the reliability, the quality, the costs and the benefits of the service. The benefits of this study include recommendations for how water services can be improved and, ultimately, the improvement of human health. Your participation is voluntary and you can decide to stop your participation at anytime over the course of the 30 minute questionnaire. I know that your time is valuable and I am very thankful for your willingness to answer a few questions. If you would like, your name can remain anonymous.
.

Will you participate in this study ____ Si; ____ No;

[If you do not have time today, someone can return another day.]

"Before I continue, do you have any other questions about the project?"

Signature________________________________ Date___________________

If you would like, your name will remain anonymous.

If you would like this, please sign here _______________________________________

__Interview for the Drinking Water Systems Operator__

Name: ____

Department/Municipality/Locality (indicate if aldea o casaría):

____

Country: ______________________

How long have you lived in this community? _______________________________

Interview #______________________________

A. Drinking Water System

A.1. What type of water system do you have?

a. Gravity b. Pump c. Other______________

A. 2 What is the drinking water source?

a. river, surface water b. Beneath the soil c. well c. Other_______________

A.3. How many houses benefit from this drinking water system?

a. > 5 b. 5-10 c. 10-50 d. 50-100 e. 100-500

f. 500-1000 g. 1000-2000 h. 2000-5000

A.4. What type of distribution is used?

a. Treatment Plant b. Distribution tank c. Other__________________

A.5. What is the volume of water flow from the tank gal/min? _____________

A.6-A.16 For each item mentioned, please tell us if it is part of this drinking water system.

	Physical Water System	Mark those you have	How many do you have
A.6.	Distribution tank		
A.7	Valve before distribution t		
A.8	Hipoclorador		
A.9	Chlorinator		
A.10	Water intake line		
A.11	Conduction line		
A.12	Distribution network		
A.13	Inspection windows on distribution tank		
A.14	Walls		
A.15	Plaster Cement around distribution tank		
A.16	Fence		

A.17. Is the source protected?

a. Yes b. no

A.18. If yes, how is the source protected?

a. fence b. trees c. Protected area d. active tree planting around source

e.Other____
____
____
____

A.19. How much area around the source is protected?

__________________manzanas protected

(1 manzana = 1.68 acres, 1 manzana = .7 hectares, 1 hectare = 2.4 acres)

A.20. Is there are fence around the water source?

a. Yes. b. No

A.21. If yes, how much area is within the fence?

a. _____________ Meters
O
b. _____________manzanas

A.22. Is there sufficient water for all beneficiaries throughout the year?

a. Yes b. No

A.23. Are there interruptions in service?

a. Yes b. No

A.24. How often is water rationed?

a. daily b. weekly c. monthly d. yearly e. seasonally f. never

A. 25. How many hours/week is there water in each household in the rainy season?

_________________ hours/week

A.26. How many hours/week is there water in each household in the dry season?

_________________ hours/week

B. Connections

B.1. How many households have a household connection?

a. > 5 b. 5-10 c. 10-50 d. 50-100 e. 100-500 f. 500-1000

g. 1000-2000 h. 2000-5000

Interview #_______________________________

B.2. Are there zones of the community where household are not connected to the water system?

a. Yes b. No

B.3 If yes, why are these households not connected to the system?

a. Don't know b. Cost c. Homes were built after the system was built

d. The houses are located in a place where it is difficult to connect them to the system

e. Other___________________________________

B.4. On average, how many houses are not connected to the system?

a. > 5 b. 5-10 c. 10-50 d. 50-100 e. 100-500

f. 500-1000 g. 1000-2000 h. 2000-5000 i. Don't know

B.5. Are the pipes in the main conduction line large enough for sufficient water to reach all households in the community?

a. Yes b. No

B.6. Are the pipes along the distribution line large enough for sufficient water to pass through for all households?

a. Yes b. No

C. Treatment

C.1.Generally, what is used to treat the drinking water?

Physical	**Mark those mention**	**Chemical**	**Mark those Mention**
Filtration		Chlorine	
Ultrasound		Hypochlorite	
Osmosis		Chlorine dioxide	
Electrophoretic		Cloramines	
Boiling		Sodium Chlorine	
Heat		Iron	
Ionizing radiation		Bromine	
Solar		Ozone	
Filtration (sand, gravel, y		Hydrogen peroxide	
		Silver	

C. 2. Generally, what is the treatment process?

____
____
____
____
____
____
____

Interview #_______________________________

C.3. If you treat the water with chlorine, have you received training in the use of chlorine for disinfection?

a. Yes b. No

C.4. If chlorine is used, who is responsible for putting the chlorine in the drinking water?

a. You b. Other person, who ____________________

***If* you are not the person responsible for drinking water treatment, could we please talk to the person who is responsible for the treatment?**

C.5. How often do you treat the water with chlorine?

a. ______ times per

b. day or week

C.6. When was the last time you visited the tank to chlorinate the water?

a. today b. yesterday c. Two days ago d. This week e. last week

f. two weeks ago g. This month h. Last month i. never

C.7. When was the last time that you visited the treatment plant/distribution tank?

a. today b. yesterday c. Two days ago d. This week

e. last week f. two weeks ago g. This month h. last month

i. Other ____________________

C.8. When was the last time that you visited the water source?

a. today b. yesterday c. Two days ago d. This week

e. last week f. two weeks ago g. This month h. last month

i. Other _________________

C.9. Where do you keep the chlorine?

a. storage room near the distribution tank b. Storage room near your house

c. in your house d. other___________________________ e. In the treatment plant

Interview #_______________________________

C. 10. If it is close to where you are located, ask you if you can see where the chlorine is stored and mark those that you can see.

Conditions of the Room	***Yes***	***No***
Well ventilated		
Dry		
Away from children		
Away from gasoline		
No oils		

C. 11. From where did you get the chlorine?

a. Purchased it b. Health center c. Alcalde d. NGO

e. Other________________

C. 12. If you bought it, how much was it?_________ $

C.13. for what quantity? ___________

a. pound b. tambo c. tablet d. Other_____________

C. 14. Are there times when there is not sufficient chlorine?

a. Yes b. No

C.15. If yes, how often do you not have enough chlorine?

a. Daily b. Weekly c. Monthly d. Yearly e. Other_____________

C.16.When you do not have sufficient chlorine, what is usually the reason?

a. lack of funds b. it is cultural, the people do not like the taste

d.other____
____

C. 17. Do you test for residual chlorine?

a. Si b. No

Interview #_______________________________

C. 18. If yes, where are the tests run? (do not read, circle what is mentioned)

a. Distribution tank   b. Households close to the distribution tank   c. Households far from the distribution tank

d. Health center   e. Other________________

C. **19. If yes, how often are the residual chlorine tests run in the distribution tank?**

a. Daily   b. Weekly   c. Monthly   d. Yearly   e.Never

f.Other________________

C.20.How often are residual chlorine tests run on the main distribution line, at the hseouholds?

a. Daily   b. Weekly   c. Monthly   d. Yearly   e.Never

f.Other________________

C.21. When was the last time that a residual chlorine test was taken?

a. Today   b. This week   c. Last week   d. Two weeks ago

e. 15 dias – 1 month agof. Last month   g. I do not take the tests

h. Other____________________

C.22. What ppm of clorine should be present in the test ?

a.0   b. 0-.4ppm   c. .5ppm   d. .5-2.0ppm   e. 2.1-5ppm

f. More than 5   g. Other__________________ mg/litro

C.23. Is there anyone here in the community that runs microbiological tests for e-coli?

a.Yes   b. No

C.24. If ues, who ? ____________________________

C.25-26. If yes, how often are the micrbiological tests run?

C**.25 . _________times per**

C.26. a. day   b. week   c.month   d. Year

C. 27. If yes, do you have a copy of the results? May I have a copy of these results?

Interview #_______________________________

D. Maintenance

D.1-2. How often is the distribution tank cleaned?

D.1 ___________times

D.2. every______________ a. day b. week c. month d. year

D.3-4. How often are the pipes and filters in the intake to the distribution tank cleaned?

D.3 ___________times

D.4. every______________ a. day b. week c. month d. year

D.5-6. How often is the hyplochlorinator cleaned?

D.5 ___________times

D.6. every______________ a. day b. week c. month d. year

D.7-8. How often are the air valves inspected?

D.7 ___________times

D.8. every______________ a. day b. week c. month d. year

C.9-10. How often are the connecting valves monitored?

D.9 ___________times

D.10. every______________ a. day b. week c. month d. year

D.11-12. How often are the fences around the water source inspected?

D.11 ___________times

D.12. every______________ a. day b. week c. month d. year

D.13-14. How often is the micro-watershed monitored?

Interview #______________________________

D.13 ___________times

D.14. every______________ a. day b. week c. month d. year

D.15-16 How often are the pipes on the conduction line monitored?

D.15 ___________times

D.16. every______________ a. day b. week c. month d. year

D.17-18 How often does the valves on the conduction line get monitored?

D.17 ___________times

D.18. every______________ a. day b. week c. month d. year

D.19-20 How often do the valves on the distribution line monitored?

D.19 ___________times

D.20. every______________ a. day b. week c. month d. year

D.21-22 How often are the leaks in the distribution line fixed?

D.21 ___________times

D.22. every______________ a. day b. week c. month d. year

D.23-D.27. Could you explain any technical problems you have had in the past three months, if you received any technical assistance, from whom and the cost to fix the problem?

Problem	**Length of problem (Sum up the problems if than one occurred)**	**Technical Assistance (Yes/No)**	**Foundation**	**Cost**
D.23. Source				
D.24. Conduction Line				
D.25. Distribution tank				

D.26. Distribution Line				
D.27. Pressure Break bo				
D. 28. Air Valves				
D.29.Chlorinator				
D.30. Leaks				
D. 31. Other__________				

D.32. If other problems are mentioned, write this below

____
____
____
____

D.33. If you have leaks, how many days, on average do the leaks run?

___________days

D.34. On average, how many leaks do you repair a day?

______________ leaks/week

D.35. How many leaks do you have now that need your attention?

_______________leaks/hour

D.36. When there are leaks, what percent of the system is closed?

_______________% of system

D.37. When there are leaks, for how many hours do you have to close the system to repair the leaks?

_______________hours

D.38. Is there air in the distribution line?

a. Yes b. No

Interview #_______________________________

D.39. Do you have problems with suction in the tubes on the distribution line?

a. Yes b. No

E. Reliability

E.1. Is there sufficient water for everyone connected to the system?

a. Yes b. No

E.2. Is there intermittent service sometimes?

a. Yes b. No

E.3. How often is water cut off?

a. Daily b. Weekly c. Monthly d. Rainy Season e. Dry Season

E.4.Why are there failures in the conduction line?

a. insufficient water at the source b. leaky pipes c. aging system

d. people break into the system to take water e. Seasonality –during the dry season there is not enough water

f.Other____
____
____
____

F. Technical Assistance

F.1 Have you received technical assistance in the past year?

a. Yes b. No

F.2. What was the problem? What was the duration of the problem? Which organization helped you? Was there a cost for the assistance? What was duration of technical assistance?

Problem/ Technical Assistance	**Duration of the problem**	**Organization**	**Cost**	**Duration of technical assistance**

Interview #______________________________

G. Water Samples

G.**1. May we take a residual chlorine test and a water simple for a microbiological test in a house that is close to the distribution tank?**

Result________________________

GPS: Lat________ Long___________________

G.2. May we take a residual chlorine test and a water simple for a microbiological test in a house that is close to the distribution tank?

Result______________________________

GPS: Lat________ Long___________________

H. Sanitation

H.1. Is there a treatment plant for sewage in this com munity?

a. Yes b. No

H.2. If there is no treatment facility, where is the sewage deposited for the community members connected to the system?

a. river b. The ground near the households c. on the ground far from the house

d. pipes to the river e. under the latrines f. Septic tanks

g. no sanitation

H.3 Approximately, how many households have sanitation and how many do not.

a_______________yes b__________________no

H.4 If you have the related information, could you please tell me how many people have each type of sanitation service?

Interview #________________________________

Sanitation Service	# of people
a. without service	
b. Flush toilet with municipally piped drainage	
c. Flush toilet connected to a septic tank	
d. Flush toilet	
e. Composting Latrine	
f. Simple latrine	
g.Other ___________________________	

H.5. If the municipality treats the sewage, please explain how it is treated?
a. treatment plant b. Stabilization ponds c. septic tanks
d. other_____________________________________

H.**6. If septic tanks are the prominent form of disposal of sewage, how are septic tanks constructed?**
____
____
____
____

H.7. If made with cement, how often are they emptied? __________________________

Time: ____:____ AM / PM

Interview #________________________________

5.A.5. Household Survey

Kayser- Tufts- Evaluation of Water Systems, a Household Survey

An interview for the female head of household

*** NOTE for the interviewers: Please complete this page first before beginning the survey. Each interview will have a number specific to the survey. (Please write this number on each page of the surveys). ***

Name of Interviewer : ____

Date: ______ *(day)*; ______ *(month)*, 2008 hour: ____:____ AM / PM *(circle)*

GPS # ________ WayPoint _______ N:________ W: _______

Interview #_______________________________

Introduction

Hello. My name is ______________________ and I work with (name of organization). We are working on a study that investigates drinking water quality in your community and we would like to request your participation. My name is ________________ and I am working with (Name of Organization). The objective of this study is to evaluate the impact of the water quality of the water that you consume in your community. In this interview there are questions about your water service, quality, quantity, costs, disease related to drinking water and sanitation as well as the height and weight of your children under five years of age. The goal of this study is to improve human health.

Your participation is voluntary. You may decide to stop the interview at any time. This interview should not take more than 40 minutes. Your time is valuable and we would very much appreciate your participation. Would you be willing to be interviewed? ____ Yes; ____ No

[If you cannot participate today, may we return in a few days?]

"Before I continue, do you have any questions about the project?"

Signature of the interviewee (a)________________________________
Date___________________

Interview #_______________________________

<u>Interview for the female head of household</u>

What is your name? :____

Department/Municipality/Locality (aldea o caserío):

____

Country: ______________________

How long have your lived in this community? _______________________________

Interview #________________________________

A. Demography

A. 1 What language do you speak in the household?

a. Spanish b. Other______________________ __(specify)

A. 2 Have you ever attended school? ________________________________

a. Yes b. No

A. 3. If yes, until what grade did you complete? _____________________

A. 4. How many people live in your household? ___________

For questions A.5-A.9 , fill in the first 5 columns on the following page

A. 5. What are the names of each person in the household?

A. 6 What are the ages of each member of the household? (Please fill in the table below)

A. 7 ¿What is the sex of each person in the household? (Please fill in the table below)

A. 8 What grade did each person in the household complete? (Please fill in the table below

A. 9 ¿What is the occupation of each adult in the household? (Please fill in the table below)

Interview #________________________________

INSTRUCTIONS: **Respond by filling in Part I.** **You will fill in Part II later.**

PART 1 A5	A6	A7	A8	A9
Name/Number	**Age**	**Sex (male (M), Female (F)**	**Grade in school that you have completed**	**Occupation: Agriculturalist (A), Technical Professional (P), Official (O) Service (V), Manual M), No Calificado (NC), Doméstico (D), Retired (R), Lisiado (L),**
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				

PARTE II:F1-F24						
Vomiting	**Nausea and cramps**	**Diarrhea**	**Diarrhea with cramps**	**Liquid Diarrhea**	**Number of days absent from school in the past two weeks because of any of these symptoms**	**Number of days in lost from work in the last two weeks because of the symptoms**

Interview #________________________________

B. Water Supply

B. 1. Where is the primary drinking water source?

a. piped water in the dwelling b. piped water close to the household

c. community piped water d. Protected well e. a well without protection f. River

g. Truck h. purchase bottled water

B.2. During the rainy season, what is the source of the water that you use for drink?

Source	Mark all that are mentioned
a. Directly from the river	
b. piped water in the dwelling	
c. piped water close to the house	
d. Neighbors private tap	
e. Pila/ public washbin public tap	
f. private dug well	
g. dug well without protection	
h. water truck	
i. rain water	
j. bottled water	
k. Other (______________________	

B.3. ¿During the rainy season, where do you get the water you use to cook?

Source	Mark all that are mentioned
a. Directly from the river	
b. piped water in the dwelling	
c. piped water close to the house	
d. Neighbors private tap	
e. Pila/ public washbin public tap	
f. private dug well	
g. dug well without protection	
h. water truck	
i. rain water	
j. bottled water	
k. Other ______________________	

B.4. During the rainy season, what is your source of water that you use to wash your clothes?

Source	Mark all that are mentioned
a. Directly from the river	
b. piped water in the dwelling	
c. piped water close to the house	
d. Neighbors private tap	
e. Pila/ public washbin public tap	
f. private dug well	
g. dug well without protection	

h. water truck	
i. rain water	
j. bottled water	
k. Other (especificar)_____________________	

B.5. During the rainy season, what is the source of water that you use to wash your dishes?

Source	Mark all that are mentioned
a. Directly from the river	
b. piped water in the dwelling	
c. piped water close to the house	
d. Neighbors private tap	
e. Pila/ public washbin public tap	
f. private dug well	
g. dug well without protection	
h. water truck	
i. rain water	
j. bottled water	
k. Other (especificar)_____________________	

B.6. During the rainy season, what is your source of water that you give your animals?

Source	Mark all that are mentioned
a. Directly from the river	
b. piped water in the dwelling	
c. piped water close to the house	
d. Neighbors private tap	
e. Pila/ public washbin public tap	
f. private dug well	
g. dug well without protection	
h. water truck	
i. rain water	
j. bottled water	
k. Other (Specify)____________________	

B.7. During the rainy season, what is the source of water you use to bathe?

Source	Mark all that are mentioned
a. Directly from the river	
b. piped water in the dwelling	
c. piped water close to the house	
d. Neighbors private tap	
e. Pila/ public washbin public tap	
f. private dug well	
g. dug well without protection	
h. water truck	
i. rain water	
j. bottled water	
k. Other (Specify)___________________	

B. 8-

Interview #________________________________

B.18.During the Rainy season, what is the cost of each source of water you use?

	Source	Cost
B.8	Directly from the river	
B.9	Piped water in the dwelling	
B.10	Piped water close to the house	
B.11	Neighbors private tap	
B.12	Public washing place	
B.13	A private well	
B.14	Dug well without protection	
B.15	Truck	
B.16	Rain water	
B.17	Bottled Water	
B.18	Others (Specify)_________________	

B 19-29. How many liters of water do you use from each source of water that you use?
How many minutes between your house and each source?
If you have to walk to the water source, how many times a day to you go to the source?

	Source	Liters	Time between source and house	Times per day
B.19	Directly from the river	a.	b.	
B.20	Piped water in the dwelling	a.	b.	
B.21	Piped water close to the house	a.	b.	
B.22	Neighbors private tap	a.	b.	
B.23	Public Washing tap	a.	b.	
B.24	A Private Tap	a.	b.	
B.25	A dug well without protection	a.	b.	
B.26	Trucked Water	a.	b.	
B.27	Rain Water	a.	b.	
B.28	Bottled Water	a.	b.	
B.29	Other (Specify)_________________	a.	b.	

Interview #______________________________

B.30. During the dry season, where is your drinking water abstracted?

Source	Mark all that are mentioned
a. Directly from the river	
b. piped water in the dwelling	
c. piped water close to the house	
d. Neighbors private tap	
e. Pila/ public washbin public tap	
f. private dug well	
g. dug well without protection	
h. water truck	
i. rain water	
j. bottled water	
k. Other (Specify)___________________	

B.31. During the dry season, what is the source of the water that you use to cook?

Source	Mark all that are mentioned
a. Directly from the river	
b. piped water in the dwelling	
c. piped water close to the house	
d. Neighbors private tap	
e. Pila/ public washbin public tap	
f. private dug well	
g. dug well without protection	
h. water truck	
i. rain water	
j. bottled water	
k. Other (Specify)___________________	

B.32. During the dry season, what is the source of water that you use to wash your clothing?

Source	Mark all that are mentioned
a. Directly from the river	
b. piped water in the dwelling	
c. piped water close to the house	
d. Neighbors private tap	
e. Pila/ public washbin public tap	
f. private dug well	
g. dug well without protection	
h. water truck	
i. rain water	
j. bottled water	
k. Other (Specify)___________________	

Interview #______________________________

B.33. During the dry season, what is the source of the water that you use to wash your plates and silverware?

Source	Mark all that are mentioned
a. Directly from the river	
b. piped water in the dwelling	
c. piped water close to the house	
d. Neighbors private tap	
e. Pila/ public washbin public tap	
f. private dug well	
g. dug well without protection	
h. water truck	
i. rain water	
j. bottled water	
k. Other (Specify)__________________	

B.34. During the dry season, what is the source of water that you give the animals?

Source	Mark all that are mentioned
a. Directly from the river	
b. piped water in the dwelling	
c. piped water close to the house	
d. Neighbors private tap	
e. Pila/ public washbin public tap	
f. private dug well	
g. dug well without protection	
h. water truck	
i. rain water	
j. bottled water	
k. Other (Specify)__________________	

B.35. During the dry season, what is the source of water that you use to bathe?

Source	Mark all that are mentioned
a. Directly from the river	
b. piped water in the dwelling	
c. piped water close to the house	
d. Neighbors private tap	
e. Pila/ public washbin public tap	
f. private dug well	
g. dug well without protection	
h. water truck	
i. rain water	
j. bottled water	
k. Other (Specify)__________________	

Interview #______________________________

B. 36-B.46.During the dry season, what is the cost of each source of water that you use?

	Source	Cost
B.36	Directly from the river	
B.37	Piped water into the dwelling	
B.38	Piped water close to the house	
B.39	Neighbors private tap	
B.40	Pila/public washbin public tap	
B.41	A private well	
B.42	Dug well without protection	
B.43	A water truck	
B.44	Rainwater	
B.45	Bottled Water	
B.46	Other (Specify)________________	

B 47-57. During the dry season, how many liter of water do you use from each source?
How many minutes between each source and your house?
How many times a day do you go to each source during the dry season?

	Source	Liters	Time from the House	Times per day
B.47	Directly from the river	a.	b.	
B.48	Piped water into the dwelling	a.	b.	
B.49	Piped water close to the house	a.	b.	
B.50	Neighbors private tap	a.	b.	
B.51	Pila/ public washbin public tap	a.	b.	
B.52	A private well	a.	b.	
B.53	Dug well without protection	a.	b.	
B.54	A water truck	a.	b.	
B.55	Rainwater	a.	b.	
B.56	Bottled Water	a.	b.	
B.57	Other (Specify)________________	a.	b.	

B. 58 ¿Do you disinfect or filter your water before your drink it?

a. yes b. no

B.58b. ¿If yes, how to you filter or disinfect it? (Do not read the options below, mark those that are mentioned)

a. Boil b. Chlorinate c. filter with a towel

d. Filter with a ceramic filter e. Leave the water to filter

f. Other treatment _____________ g. Do not filter h. Do not know

B. 59. If you or someone in your family walks to get your water, who carries the water the majority of the time?

a. Interviewee b. Girls less than 15 years c. Boys less than 15 years

d. women older than 15 years old e. men older than 15 years old

e. Other person (Circle all mentioned)

B.60. If you use piped water, who is responsible for the maintenance of this water?

a. Municipality b. Water committee c. Household d. Other_____________

B. 61. If you have piped water to the household, who is responsible for the maintenance of the household connections?

a. Municipality b. Water committee c. Household d. Other_____________

C. Water Quantity

C. 1. If you have piped water into the household, do you have a meter that measures the amount of water that you use?

a. Meter b. No Meter

C. 2. If you have piped water into your house, do you have sufficient quantity water throughout the year?

a. Yes b. No

C. 3. If you do not have sufficient water throughout the year, what part of the year do you not have sufficient water during the year?

a. The rainy season b. The dry season

C. 4. In the dry season, how many hours per day do you not have water in your house?

______ hours per day

C. 5. En the rainy season, how many hours per day do you have not water in the household?

______ hours per day

Interview #______________________________

C. 6. When you do not have sufficient water, do you have to reduce the frequency of any of the following activities?

Activity	Yes or No
a. Drinking	
b. Cooking	
c. Bathing	
d. Sanitation	
e. Garden	
f. Cleaning	
g. Irrigation	
h. Business	

C. 7. Do you have a place where you store your water that you drink?

a. Yes b. No

C. 8. How do you store the water in your house? (Circle all mentioned)

a. Bucket b A plastic receptacle with a top

c. Tinaje d. pila/ cement holding tank

e. Other__________________

C. 9. Of the recepticals that you use, which receptacle do you use for your drinking water?

a. Bucket b. A plastic receptacle with a top

c. Tinaje d. pila/ Cement holding tank

e. Other__________________

C. 10. Does this receptacle have a wide enough mouth top ut your hands in?

a. Yes b. No

C. 11. Do you cover the receptacle?

a. Yes b. No [If the answer is no, continue with C12]

C. 12. ¿What do you use to cover this receptacle? (Circle the response)

a. A topb. Something that you can screw on and off c. A piece of material

d. Other__________________

C. 13. If your answer is yes, what are the other activities that you use the water for in the receptacle you use for drinking? (do not read the answers, circle what is mentioned)?

a. Cooking	Yes	No	Don't know
b. Wash fruit and vegetables	Yes	No	Don't know
c. Wash plates and utensils	Yes	No	Don't know
d. Personal Hygiene	Yes	No	Don't know
e. Hand Washing	Yes	No	Don't know
f. Other: ____________________			

C. 14. What do you use to take the water out of the receptacle? (Circle all that are mentioned)

a. Cup b. Cántaro c. Tazón de arcilla d. Bucket

e. Hands f. Pour directly from the receptacle g. Other____________

C. 15. Do some in the household use their hands to take water from the receptacle?

a. Yes b. No

D. Water Quality

All of the subsequent questions are for households with a tap inside the house or in the yard.

D.1. Es the water in your faucet safe to drink?

a. Yes b. No c. Do not know (Circle one)

D. 2. Is the water you receive, treated before you receive it?

a. Yes b. No c. Do not know (Circle one)

D. 3. Do you do anything in the household to ensure that the water is safe to drink?

a. Yes b. No c. Do not know (Circle one)

D. 4. If yes, what do you do? (don't read the answers, circle those that are mentioned)

a. Boil the water b. Use a disinfectant c. chlorine

d. Lemon juice e. Other________________________

D. 5. If you use a disinfectant, what is the name of the disinfectant?__________________________

D. 6. If you use bleach, what quantity of bleach do you put in one liter of water? _________________

D. 7. Does the water from the tap have a good or bad taste?

a. Good b. Bad (Circle one)

D. 8. Are there some occasions, when the quality prevents you from drinking the water in the tap

a. Yes b. No c. Do not know (Circle one)

D. 9. If yes, why?

a. Too much chlorine b. A Brown color (turbidity) c. Other ________________

D. 10. If the water is sometimes turbid, or the color of coffee, do you do anything to get rid of the particles/turbidity?

a. No b. Decant c. Use additives d. Other_______

D. 11. During the rainy season, how often is the water in the tap the color of café/turbid? (Circle one)

a. Every day b. Every week c. Every month d. Never

D. 12. If you have to leave the water for any reason, what do you do? (circle the options that are mentioned)

a. Buy water b. Neighbors house c. River d. Well

e. Spring f. Other __________________

E. Perceptions

E. 1. Which characteristic of your water service, would you like to improve in your community? Which? (check all that are mentioned)

Activity	Check the options mentioned
a. Infrastructure (tubes, connections, etc.)	
b. Quality (soil in the water, turbidity, smell, taste)	
c. Quantity (sufficient for all of your needs)	
d. Purification (microbiology of the water, safety)	

E. 2. If the water service was improved, could you pay more?

a. Yes b. No (Circle)

E. 3-E.6.. If yes, how much could you pay for each activity mentioned? (Write the answers on the table)

Interview #________________________________

Activity	Write the price mentioned
E. 3. Infrastructure	
E. 4. Quality	
E. 5. Quantity	
E. 6. Purification	

F. Health

Return to page five to fill out the table for each household member (F1-F24).

F. 1. Have any of the children under 5 experienced vomiting in the past two weeks?

a. Yes b. No

F. 2 If your answer is yes, which of those under 5 have experienced vomiting? (Read the list from page 4)

F. 3 Have any of the children under 5 experienced cramps and nausea during the past two weeks?

a. Yes. b. No

F. 4 If yes, which of the children under 5 have experienced cramps or nausea in the past two weeks? (Read the list from page 4)

F. 5 Have any of the children under 5 in the household experienced diarrhea in the past two weeks?

a. Yes b. No

F. 6. If yes, which children under 5 experienced diarrhea in the past two weeks? (Read the list on page 4)

F. 7. Have any children under 5 experienced diarrhea with cramps in the past two weeks?

a. Yes b. No

F. 8. If yes, which children under 5 have experienced this in the past two weeks? (Read the list on page 4)

F. 9. Have any of the children under 5 in the house experienced liquid diarrhea in the past two weeks?

a. Yes b. No

F. 10. If yes, which children under 5 have experienced this? (Read the list on page 4) Mark those children mentioned

F. 11. Is there anyone five years or older in the house that has experienced cramps and nausea in the past two weeks?

a. Yes b. No

F. 12. If yes, who? (mark the rows in the table)

F. 13. Is there anyone in the household over five who has experienced diarrhea in the past two weeks?

a. Yes b. No

F. 14. If yes, which people in the household? (mark the rows in the table)

F. 15. Is there anyone in the household over the age of five who has had liquid diarrhea in the past two weeks?

a. Yes b. No

F. 16. If yes, which household members? (mark the rows in the table)

F. 17. Is there any member of the household over the age of five who has experienced diarrhea with cramping in the past two weeks?

a. Yes b. No

F. 18. If yes, which household members? (mark the rows in the table)

F. 19. Have any of those household members mentioned not attended school in the past two weeks because of any of these symptoms? (Read all of the names of those identified with the symptoms.)

F. 20. How many days of school did each person miss? (Specify for each person.)

F. 21. Have any of those household members mentioned, been unable to attend work in the past two weeks because of the symptoms mentioned? (Read the names of those adults with the prior mentioned symptoms.)

Resume the interview here.

F. 25. When your kids have diarrhea, what do you do to help them? (Don't read the list, mark only what is mentioned)

Action	Check if mentioned
a. Medicinal remedies	
b. Medicine from the health center/pharmacy	
c. Sugar/Salt Solution	
d. Rehydration salts	
e. Give less liquid	
f. Give more liquid	
g. Reduce breastfeeding	
h., Give more food	
i. Give less food	
j. Increase breastfeeding	
k.Other ________________________	

F. 26.How much money have you spent in medicines to stop diarrhea or vomiting in the past two weeks?

__________ Lempiras

F. 27. ¿Have you taken any of your children to a doctor or hospital in the past two weeks because of diarrhea or vomiting?

a.Yes b. No

F. 28. How much time does it take to get to the health center from your house?

a. 0-10 minutes b. 11-30 minutes c. 31-60 minutes d. 61-120 minutes

e. more than 120 minutes

F. 29-31. How much money have you spent in visits to the health center or hospital in the past two seeks to control diarrhea or vomiting?

Symptoms related to waterborne disease	Cost
F. 29. Diarrhea	
F. 30. Vomiting	
F. 31 Other _______________________	

G. Children under 5

The following questions correspond to each child in the family under five.

Complete the table n the following page with the following questions.

G. 1-G4 Could you please give me the birthdates of all children under five in your house. If you have an identification card for your children, could you show it to me.

G. 5. Indicate the name and sex of each child on the table below.

G. 6 Is ________________(Name) completely or partially breastfed? (Read the list and note a T of the child is totally breastfed, a P if partially breastfed and and N if the child is not breastfed)

G.7. Ask if any of the children who are totally breastfed ever eat or drink liquids.

G. 8-G.10. May be take the weight of your children under five?

G.11-G13 May we measure the height of your children under 5 years old?

Interview #_______________________________

G.1. Code for each child	G.2.Name of child under five	G.3 Birth Date (Day/ Month /Year)	G.4 Age		G.5 Sex (M/F)	G.6. Totally Breastfed (T), Partially breastfed (P),Not breastfed (N)	G.7. Does child consume any food or water (Y/N)	G.8. Weight in kgs, (ex. 4.623 kg)	G.9. Weight in kgs, (ex. 4.623 kg)	G.10. Weight in kgs, (ex. 4.623 kg))	G.11 Height in cm,(with a decimal point 51.3)	G.12. Height in cm,(with a decimal point 51.3)	G.13 Height in cm,(with a decimal point 51.3)
			Y	M									

H. Sanitation

H. 1. ¿What type of sanitation do you have in the house? (Don't read the list, mark only what is mentioned)

Type of Sanitation	Check what is mentioned
a. No service	
b. Toilet connected to sewerage system	
c. Toilet connected to septic tank	
d. Latrine with flush toilet	
e. Composting latrine	
f. Simple latrine	
g.Other ______________________________	

H. 2. Where do children in the household defecate? (Don't read the list, check only what is mentioned)

Type	Mark what is mentioned
a. Any where around the house	
b. A bathroom in the house that is connected to drainage	
c. Septic tank	
d. Latrine outside the house	
e. Composting latrine	
f. Other ______________________________	

H. 3. If there is a latrine, what is the distance between the house and the latrine?

a.___________meters from the house

b. ___________uphill from the house _________downhill from the house

H. 4. If threre is a bathroom, where does the drainage empty? (don't read the list, mark what is mentioned)

Where is the sewage deposited	Check what is mentioned
a. To the river in tubes	a.
b. On the subsoil	b.
c. Latrine – below the soil	c.
d. In tubes to the street, close to the house	d.
e. In tubes to the street, far from the house	e.
f. Septic tank	f.
g. In tubes to a municipal system	g.
h. En tubes to a treatment tank	h.

H. 5. If you have a septic tank, how often do you empty it? Every _________ years

H. 6. If you have a septic tank, what is the floor made of?

a. Cement b. Rocks c. Earth d. Other _______

I. Hygiene

I. 1. Did you use soap yesterday or today?

a. Yes b. No

I. 2. If yes, what did you use it for? (Don't read the list, mark what is mentioned)

Use soap for:	**Check what is mentioned**
a. Wash clothing	a.
b. Wash dishes	b.
c. Bathe	c.
d. Bathe children	d.
e. After using the bathroom	e.
f. After changing the diaper of a child	f.
g. Before eating	g.
h. After preparing the food	h.
i. Before preparing the food	i.
j. Other______________________	J

I. 3. What is your best source of information about your hygiene and personal health in the house? (Do not read, mark only what is mentioned)

I..4 Which do you trust the most?

I.3.Source	**Check**	**I.4.Trust most**
a. TV	a.	a.
b. Radio	b.	b.
c. Newspaper	c.	c.
d. Health worker	d.	d.
e. School/teacher	e.	e.
f. Family	f.	f.
g. Social worker	g.	g.
h. Books	h.	h.
i. Other __________________	i.	i.

Interview #______________________________

J. Household Characteristics

J.1. How many rooms do you have in the household?

_________# of rooms

J. 2 How many bedrooms do you have in the house?

_________# of rooms for sleeping

J.3. Do you have electricity?

a. Always b. Sometimes c. Never

J. 4. What source of energy for you use for cooking?

a. Wood b. Coal c. Kerosene d. Propane gas

e. Other_____________

J. 5. Do you have animals?

a. Yes b. No

J. 6-J.10. If yes,

a. How many of each type of animal do you have?
b. Where do these animals live? (in the house, in the patio, within 10 meters of the house, far from the house)?

Type of Animal	a. Number of animals of each type	b.Where do the live? (in house, patio, closet o house, far from the house)
J.6. Cows		
J.7. Pigs		
J.8 Sheep		
J.9. Goats		
J. 10. Chickens/birds		

J.11. What is the roof of your house made of in your house?

a. Tin b. Tiles c. Cane/reed d. Concrete e. Other____________

J.12. What are the walls made of in your house?

a. Earth b. Adobe c. Cane/reed d. Concrete e. Wood

J. 13. What is the floor made of in your house?

a. Earth b. Adobe c. Concrete d. Wood

J. 14-J25. Which of the following amenities do you have in the house?

	Amenities	**Circle**
J14	Refrigerator	**a. yes b. no**
J15	Television	**a. yes b. no**
J16	Radio	**a. yes b. no**
J17	Table	**a. yes b. no**
J18	Telephone	**a. yes b. no**
J19	Chairs	**a. yes b. no**
J20	Bed	**a. yes b. no**
J21	Bicycle	**a. yes b. no**
J22	Motorcycle	**a. yes b. no**
J23	Car/Truck	**a. yes b. no**
J24	Armoire	**a. yes b. no**
J25	Cellular Telephone	**a. yes b. no**

J. 26. How many manzanas (100 meter x 100 meters) do you own?

a. 0 b. 0-1 c.1-2 d. 3-5 e. 6-10 f. < 10

J. 27. How long does it take you to get to the closest market?

a. 0-14 minutes b. 15-29 minutes c. 30-44 minutes d. 45- 59 minutes

e. 1 – 2 hours f. 2 -3 hours

J.28 How long does it take to get to the main road?

a. 0-14 minutes b. 15-29 minutes c. 30-44 minutes d. 45-59 minutes

e. 1 – 2 hours f. 2-3 hours

J.29. How long does it take to get to the health center?

a. 0-14 minutes b. 15-29 minutes c. 30-44 minutes d. 45-59 minutes

e. 1-2 hours f. 2-3 hours

Interview #______________________________

K. Observations

K. 1-K7. Ask the interviewee if you can use their bathroom:

	Conditions	Circle		
K.1	Smell	a. Very bad smell	b. Ok	c. No smell
K.2	Cleanliness	a. Very dirty	b. Ok	c. Clean
K.3	Ease of use	a. Could a child under five use it easily and not fall in	b. Ok	c. Easy to use
K.4	Toilet Paper is present	a. No toilet paper	b. Paper/newspaper	c. Toilet paper
K.5	Soap is close? (ask where you can wash your hands)	a. No	b. Yes, but not close	c. Yes close
K.6	Is there a lock?	a. Yes	b. No	
K.7	Is there a door?	a. Yes	b. No	

K. 8. Is there soap in the bathroom or close to the bathroom (did you see it)?

a. Yes b. No

K. 9. Is there human excrement on the patio or close to the house?

a. Yes b. No

K.10. What quantity?

a.. none b. a little (1-3 excrement) c. . a lot (>4 excrement)

K. 11. Are there animals in the house? (this does not include cats or dogs)

a. Yes b. no

K. 12. Can you see excrement on the patio?

a.. none b. (1-2 excrement) c. many (>5 excrement)

Time: ____:____ AM / PM

Interview #________________________________

5.A.6 HWFS Survey Follow-up

Kayser-Tufts

Follow-up research in Honduras

Household Ceramic Water Filter and Safe Storage (HWFS)

Sustainability questions

A. Filter Status

A.1 Were you aware of *the opportunity to buy a household ceramic water filter last year?*

Yes No (If no, your interview is over, if yes, continue)

A.2 Did you buy a filter through the program__________________________?

Yes No (If no, proceed to A.2.b)

A.2.b If no, why not

a. It cost too much (distinguish too expensive from not having cash?)
b. I did not have the money required at the time
c. could not get to distribution location that day
d. did not want one
e. bought it through another program ________________________________(name of)
f. Other_________________________

A. 3. If you do not have a filter, do you do anything to your water to make it potable, or safe to drink?

a. boil b. solar treatment c. chlorinate d. use a disinfectant

e. other___________________

B. Breakage

B. 1. Do you use the drinking water filter?

a. Yes b. No (if yes, skip to question B.3)

B.2. If not, why not?

a. Filter Breakage b. Spigot leakage c. Bucket breakage

d. Didn't filter enough water e. Sold it f. Gave it away

g. Other _______________

B.3. If the filter broke, did you replace it?

a. Yes b. No

B.4. If no, why not?

a. Cost b. Could not find replacement c. PFP filtration unit was not useful
d. OTHER ____________________

B.5. If the spigot broke, did you replace it?

a. Yes b. No

B. 6. If no, why not?
a. Cost
b. Could not find replacement
c. Ceramic filtering unit was not useful
d. OTHER ____________________

B.7. If the bucket broke, did you replace it?

a. Yes b. No

B.8. If no, why not?
a. Cost b. Could not find replacement c. filter was not useful

d. Other ____________________

C. Household Usage

C. 1. For what purposes do you use the filtered water? (do not read, circle all mentioned)
a. drinking b. cooking c. handwashing

d. Other___________________

C. 2. Do you store the filtered water in a place other than the bucket?

a. Yes b. No

C.3. Could you please show me where you store the drinking water from the filter (direct observation only, do not read answers)

a. capped b. not capped

C.4 Where do your children get their drinking water? (list all and circle all that apply)

a. household tap b. the filter c. neighbor
d. school e. tienda (store) f. stream
g. other________________________

Interview #________________________________

C.4.b. If your children drink from the filter, how often do they drink from the filter ?

a. seldom   b. often   c. every day

d. only from the filter

C. 5. Do the adults get their drinking water? (list all and circle all that apply)

a. household tap
b. the filter
c. neighbor
d. school
e. store (tienda)
f. stream
g. other_________________________

C.5.b. If the adults drink from the filter, how often do they access their water from the filter?

a. seldom   b. often   c. every day   d. only from the filter

C.6. If yes to any source besides the filter, why do household members not drink only filtered water

a. Not enough water is filtered for everyone
b. Lack of knowledge - children
c. do not believe the water is contaminated
d. other_______________________

C. 7. Do you use any additional treatment for the water in the filter?

a. yes   b. no

C. 7b. If yes, what method do you use? (do not read, circle those mentioned)

a. chlorine   b. boiling   c. solar   d . other ________________

C. 8. Do you use any additional treatment for the unfiltered water that household members drink?

a. yes   b. no

C.8 b. If chlorine is mentioned, ask: how much chlorine do you apply to each liter of water?

_____________________drops/liter

C. 9. How much water does the PFP filter per hour? Is it liters or gallons? Use whichever one they are used to using.

a. > 1 liter   b. 1 liter   c. 1.5 liters   d. 2 liters

e. 2.5 liters   f. 3 liters   g. 3-5 liters   h. don't know

C. 10 How much water does your household use from the filter on average, each day?

a. < 1 liter b. 1-3 liters c. ~ 1 gallon d. 1.1-3 gallons

b. 3.1-5 gallons f. 5.1-9 gallons g. > 10 gallons

C.11. Does the HWFS filter enough for drinking for all HH members?

a. Yes b. NO

C.12. How often do you fill the filter with water?

a. None (not in use) b. Once a week c. Every 3-6 days

d. Every 1-3 days e. Once a day (24 hour period) f. Twice a day

g. Three times a day h. Four times a day i. Other__________

Observation:

C.13. Is the filter in a place that is at arms length for a child?

a. Yes b. No

D. **Maintenance**

D.1. In the past year, how often did you clean the filter? (do not read through answers)

__________times in the past year

D. 2. If you cleaned the filter, how did you clean the filter (do not read answers, circle all mentioned).

a. Just the top of the filter
1. With a brush
2. With soap
3. Chorine
4. hands
4. other____________________

b. The top and bottom of the filter
1. With filtered water
2. With unfiltered water
3. brush
4. soap
5. hands
6. chlorine
7. other___________

D. 3. How many times in the past year did you clean bucket?

________________________times in the past year

D.4. If you cleaned the bucket, where did you put the filter when you cleaned the bucket?
(do not read answers, circle those mentioned only)

a. on the table b. in a dish with purified water

c. in a dish with unfiltered water c. on a towel d. on the floor

d. other_______________________

E. **Economics**

E.1. How much did you pay for the filter?

___________________lempiras

E.2. Since you have had the filter, have you purchased bottled water?

a. Yes b. No

E. 2b. If yes, why?

a. not enough water b. quality of water from filter c. filter broke

d. other____________________

F. Perceptions

F.1 Do you believe your piped water is safe to drink?

a. Yes b. No

F.2.
Do you believe water from your filter is safe to drink?

a. Yes b. No

Time: ____:____ AM / PM

Interview #______________________________

5.A.7 Community Treatment System (CTS) Follow-up Interview

Kayser-Tufts
Addendum for follow-up research in Honduras
CTS (Depuridor in Spanish)

Sustainability questions

C. CTS Status

A.1. Do you access your drinking water from the community treatment system (depuridor)?

a. Yes b. No (if yes, skip to section B)

A. 2. If no, why not?

a. distance to depuridor
b. buy water
c. don't trust that the water is safe in the depuridor
d. other______________________

A. 3. If no, do you do anything to your water to make it potable, or safe to drink?

a. boil b. solar treatment c. chlorinate d. use a disinfectant

e. other__________________

(If answer no to A.2., end interview here)

B. Household Usage

B. 1 For what activities do you use the water from the depuridor? (do not read, circle all mentioned)

a. drinking
b. cooking
c. handwashing
d. other

B.2. Could you please show me where you store the drinking water from the depuridor? (direct observation only, do not read answers)

a. capped b. not capped c. some capped, some not capped

B.3. Do the children ever drink water that is not collected from the depuridor?

a. Yes b. No

B.3.b. If yes, how often?

a. seldom b. often c. every day

B.3.c If yes, from where do they access the unfiltered water?

a. faucet b. school c. stream d. Other_________________

B.4. Do adults ever drink unfiltered water?

a. Yes b. No

B.4.b. If yes, how often?

a. seldom b. often c. every day

B.4.c If yes, from where do they access the unfiltered water?

a. faucet b. work c. stream d. Other_________________

B.5. If yes to B3or B4, why do household members not drink only filtered water?

a. Not enough water is filtered for everyone
b. Lack of knowledge - children
c. do not believe the water is contaminated
d. other______________________

B.6. Do you use any additional treatment for the water from the depuridor?

b. chlorine
c. boiling
c. other ______________________

B.7. How much water does your household use per day from the depuridor?

a. < 1 liter
b. 1liter-3 liters
c. 1 gallon
d. 1.1 gallon-3 gallons
e. 3.1 gallons-5 gallons
f. 5.1 – 10 gallons
g. < 10 gallons

B. 8. How often do you walk to the depuridor to collect water?

a. None (not in use)

b. Once a week
c. Every 3-6 days
d. Every 1-3 days
e. Once a day (24 hour period)
f. Twice a day
g. Three times a day
h. Four times a day
i. Other___________

B. 9. If yes, why?

a. Not enough water for everyone
b. Lack of knowledge - children
c. do not believe the water is treated
d. there is not always water in the depurdior
e. Other _______________________

C. Maintenance

C. 1. How often is the depuridor cleaned?

a. Once a month
b. Once every 3 months
c. Once every 6 months
d. Once a year
e. not at all
f. never
g. I don't know

C.2. Is the water from the depuridor ever muddy or full of particles?

a. Yes b. No

D. Economics

D.1. How much did you pay for the depuridor?

a. $0 b. $1-$5 c.$6-$15 d. > $15

D.2. Did you purchase bottled water while you have had the depuridor in your community?

a. Yes b. No

D. 3. If yes, why?

a. not enough water b. quality of water from depuridor

c. depruidor was not in operation d. other___________________

D.4. Did you purchase bottled water when you did not have the filter?

a. Yes b. No

E. Perceptions

E. 1. Do you believe the water from your piped source is contaminated?

a. Yes b. No

E.2. Do you believe the water from the depuridor is safe to drink?

a. Yes b. No

Time: ____:____ AM / PM