Integrated Evaluation of a Community-Based

Safe Drinking-Water Project in Rural Guatemala

BY

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THESIS

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LIST OF ABBREVIATIONS

CDPH	Chimaltenango Department of Public Health
GDP	Gross Domestic Product
GPM	Gallons Per Minute
INE	Instituto Nacional de Estadística (National Institute of Statistics)
IRB	Institutional Review Board
JMP	Joint Monitoring Program for Water Supply and Sanitation
kWh	Kilowatt-hour
MDG	Millennium Development Goals
O&M	Operation and Maintenance
POU	Point of Use
RCT	Randomized Control Trial
UIC-EWB	University of Illinois at Chicago Engineers without Borders Chapter
UN	United Nations
UNICEF	United Nations Children's Fund
WHO	World Health Organization
WSH	Water, Sanitation, and Hygiene

SUMMARY

The main impetus for the provision of safe drinking-water in developing nations is to eliminate the health risk posed by enteric pathogens. Often these safe drinking-water programs fail to create long-lasting solutions. Challenges arise due to the frequency of safe drinking-water programs to focus on creating barriers to transmission primarily through engineering solutions by way of water supply and quality. Resulting evaluations from these programs are not able to identify why a program was or was not sustained. Evaluation of these safe water interventions remain limited in scope. Current evaluation practices monitor programmatic goals—such as the duration of the project and the number of wells—and financial goals or exclusive use of summative orientations—which emphasize impact, effectiveness, and quality. Resulting evaluations are also limited as they do not typically account for complex social systems that have a strong bearing on intervention uptake and impact. This linear cause and effect approach is inappropriate. A more appropriate approach is one that focuses on cyclical rather than linear cause and effect; this takes into account complexity and interdependence of factors associated with complex health problems.

This study applied an evaluative lens to what is traditionally considered an engineering intervention in a resource-poor community within the developing nation of Guatemala. It provides an example of a cyclical or holistic approach to conducting an ongoing evaluation of a safe drinking-water intervention. It was successful in documenting intervention content and future directions for the next stages of implementation. It was also successful in developing measures of preliminary and ongoing assessment of efficiency, cost, trends through time, and consumer demand; these factors are often ignored in the drinking water evaluation literature. We were also able to acquire baseline information on diarrhea prevalence in the community and highlight the reliability of the lay community health workers already working there as a data source for assessing future health outcomes, providing support for the idea that the concept of "expert" can be thought of more broadly and sustainably.

I. LITERATURE REVIEW

A. Global Burden of Waterborne Illness

1. Water and health: a brief historical synopsis

From the beginning of civilization to the 16th century, cultures residing in Europe and other parts of the world believed that diseases, such as cholera, were caused by supernatural forces. This concept later evolved into the theory of miasma which lasted until the middle of the 19th century.[1] It was not until the end of the 19th century that the miasma theory was displaced with the introduction of the germ theory of fermentation.[2] The contributions of Liebig, Pasteur, Koch, and Lister helped pave the way for what is known today as the field of bacteriology (Sedgwick, 1902). The advent of bacteriology brought about, as Martin Melosi of the Center for Public History stated, "[the] definitive and physical cause of disease that was plausibly linked to water" (Institute of Medicine of the National Academies (IOM, 2009,p.14). The etiology of water-associated disease and human health was not largely recognized until the middle of the 20th century.

In the early 19th century, the introduction of the first sewage systems and the concept of filtration and use of disinfectants like chlorine with drinking water began in the United States (EPA, 2000). This shift evolved from public demand for large-scale sanitary systems and changed the prevailing attitudes from responsibility at a private or individual level to a public or shared responsibility of water and waste.

In the early 20th century, water system technologies continued to advance; however, because the etiology of water-associated disease was still not well understood, maintenance and replacement of water systems became the focus rather than concerns with public health (IOM,

[1] The term miasma comes from *Μίασμα*, an ancient Greek word for pollution and was referenced in ancient texts as a form of bad air. In the 18th and 19th centuries it was recognized as a form of pollution.

[2] The concept of germ theory was still in its infancy during this time period. While scientists were developing the theory, popular thought and politics was still heavily influenced by the miasma theory.

2009). In the middle of the 20th century, greater attention to environmental health helped spur concern with pollution and human health[3] (EPA, 2000). It shifted public opinion to one that valued preventative medicine and public health as well as preservation of the environment, spawning the environmental movement in the United States. As a result, it led to changes in policy and technology of water systems that included public health within their development (IOM, 2009). This movement continued to spread to the rest of the developed world—it was referred to as the "sanitary revolution" and was considered to play a vital role in reducing illness and death from infectious disease in industrialized countries (McKeown and Record, 1962; Preston and van de Walle, 1978).

The latter half of the 20th century unified global institutions for the advancement of water-associated disease etiology to address the burden of preventable diseases. In 1977, at the United Nations Water Conference in Mar del Plata, it was proclaimed that the "International Drinking Water Supply and Sanitation Decade" would reach 100 percent coverage in water supply and sanitation by 1990 for all countries. Overall, the provision of services did increase; however, many countries could not keep pace with rising populations and the number of people underserved continued to rise (DFID, 1998).

Due to rising populations and increased burden of disease, the United Nations (UN) adopted the Millennium Development Goals (MDG) in 1990. Goals four and seven most reflect the relationship between water and health. Goal four, Target A was to reduce by two-thirds, between 1990–2015, the under-five mortality rate. While this goal is not on target to be met, large strides have been made in diarrhea mortality as diarrhea has declined over the past two decades from an estimated 5 million deaths to 1.5 million in 2004 (You et al., 2009; UNICEF and WHO, 2009). Goal seven, Target C calls to halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation. In 2010, the target for drinking water was met, but the sanitation goal is not on target to be met. Also in 2010, the UN General Assembly recognized water

[3] The popularity of Rachel Carlson's *Silent Spring* and other similar works brought attention to the issue of environmental contaminants which led to increased studies on the subjects and subsequent federal regulations such as Safe Drinking-Water Act of 1974.

and sanitation as a human right. However, 884 million people worldwide still do not have access to safe drinking water and 2.6 billion lack basic sanitation services (United Nations, 2010). History has taught us that global development of safe water and sanitation is more difficult that it may seem and remains a global challenge.

2. <u>Water and sanitation access in developing countries</u>

Prior to 1990, reports on the global status of water supply and sanitation were issued by the World Health Organization (WHO) using information provided by country agencies and ministries of health. The International Drinking Water, Supply and Sanitation Decade of 1982–1990 brought about a mandate for the WHO to report on the progress of access to water supply and sanitation services. Toward the end of the decade, it was recognized that a better monitoring system and management tool for surveying and influencing development was needed. As a result, WHO and the United Nations Children's Fund (UNICEF), created the Joint Monitoring Programme for Water Supply and Sanitation (JMP) (JMP, 2010).

In 1990, the UN established the MDG targets for both water and sanitation to improve access in developing countries. Since its inception, JMP has used methods of data acquisition in which "user-based" data is provided versus "provider-based." The "user-based" method takes survey and population censuses that have been standardized for comparability and allow for disaggregation of data in which categories such as "piped drinking water on premises" can be recorded to determine improvement in access to water and sanitation (UNICEF and WHO, 2011). The metric for improved and unimproved water and sanitation determinations can be seen in Table I.

TABLE I

IMPROVED AND UNIMPROVED DRINKING WATER AND SANITATION ACCESS[a]

	Drinking Water	Sanitation
Improved	Use of: Piped water into dwelling, yard or plot Public tap or standpipe Tubewell or borehole Protected dug well Rainwater collection	Use of: Flush or pour-flush to: Piped sewer system Septic tank Pit latrine Ventilated improved pit latrine Pit latrine with slab Composting toilet
Unimproved	Use of: Unprotected dug well Unprotected spring Cart with small tank or drum Tanker truck Surface water (river, dam, lake, pond, stream, canal, irrigation channel) Bottled water (considered to be improved only when the household uses drinking water from an improved source for cooking and personal hygiene)	Use Of: Flush or pour-flush to elsewhere (that is, not to piped sewer system, septic tank or pit latrine) Pit latrine without slave, or open pit Bucket Hanging toilet or hanging latrine Shared or public facilities of any type No facilities, bush or field (open defecation)

[a] UNICEF, 2012.

Testing water quality for microbial and chemical contaminants at the national level in all countries around the world is complicated and at this time not economical. Therefore a proxy was created to measure “improved” drinking sources and is defined as “that, by the nature of their construction, are protected from outside contamination, particularly fecal matter” (UNICEF, 2012). Simply stated, an improved source of the water is one that through a “technological intervention” increases the likelihood that it provides safe water. For example, if a community uses surface water as its primary source for drinking water, an intervention that constructed a protected well as a primary source of drinking water would be considered an improvement.

The WHO used this methodology for measuring improved access, enabling them to estimate more than 2 billion people had gained access to improved water sources (United Nations, 2010; UNICEF, 2012). The JMP reports that 63 percent of the global population use improved sanitation facilities; this accounts for an increase of almost 1.8 billion people since 1990 (UNICEF, 2012). When considering regions, there are some in which one or both of the targets are not being met (UNICEF, 2012).

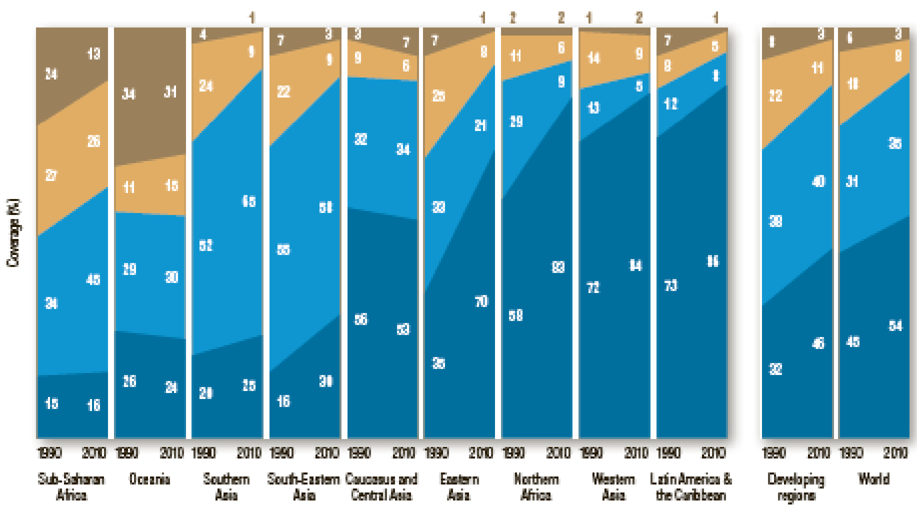

FIGURE 1. Access to improved water supply by access level (UNICEF, 2012).

Figure 1. shows access to water supply by level of access. When considering piped water into dwellings, two clear groupings of regions are identified. The first is a set of regions in which the use of piped water to a dwelling, plot, or yard is low and the second is in which at least 70 percent of the population is using piped water on premises. The first grouping is sub-Saharan Africa, Oceania, Southern Asia, South-eastern Asia; the second grouping consists of Eastern Asia, Northern Africa, Western Asia and Latina America and the Caribbean, respectively.

Figure 2 identifies Southern Asia and sub-Saharan Africa as regions in which large proportions of the population are still utilizing the practice of open defecation. Moreover, these regions have the lowest proportions with access to improved facilities. As with water access, most of the countries with low sanitation coverage are in sub-Saharan Africa, while Southern Asian countries have the lowest rates of improved sanitation.

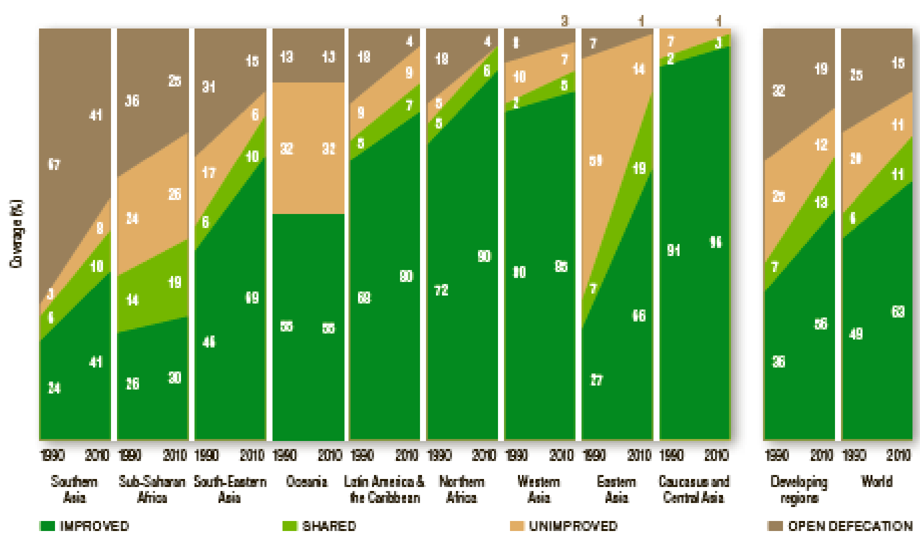

FIGURE 2. Access to improved sanitation by access level (UNICEF, 2012).

Figures 1 and 2 both show that diarrhea burden from lack of access is disproportionately dispersed between developing countries and least developed countries. The JMP's most recent publication identifies the largest disparities existing between rich and poor and those living in rural and urban areas within a country (UNICEF, 2012). The number of the urban population using unimproved water sources actually increased, from 109 million to 130 million. Much of this can be associated with the high growth rates of the urban population during the last two decades (UNICEF, 2012). In this same time period, the number of people using unimproved sources in rural areas decreased from 1.1 billion to 653 million. The number of people in rural areas using an unimproved water source in 2010 was still five times greater than in urban areas (UNICEF, 2012). Disparities between rural and urban sanitation are even more pronounced than those of drinking water. In rural areas, 1.8 billion people lack access to improved sanitation, representing a 72 percent total of those who are unserved globally (UNICEF, 2012).

The "improved" methodology of JMP has further explained types of coverage and given a better idea of identifying regions in which to focus servicing effort. However, improved access to water and sanitation is not necessarily a good indicator of water quality at the point of ingestion nor is improved access to sanitation a good indication of sanitation end use and acceptance (Mara et al., 2010). Improved access does not necessarily meet international engineering and health standards (Montgomery and Elimelech, 2007) and this has most likely overestimated those who have gained access to improved water sources that are safe to consume and basic sanitation services (UNICEF, 2012). In 2011, JMP established a Task Force on Monitoring Drinking Water Quality, which recognized limitations with the current methodology and has pushed for drinking water quality monitoring; however, this will most likely occur at final reporting on the MDG in 2015.

3. Waterborne disease pathology

The priority to identify and prevent water-associated diseases has led to its categorization of transmission into four groups: waterborne, water-washed, water-based, and water-related (IOM, 2009; Bradley, 1974). Further classifications have been made to better understand the relationship between disease and that of water, sanitation, and hygiene (WSH) on human health, including excreta-related, water collection and storage, and toxin-related (Montgomery and Elimelech, 2007; WHO, 2001; WHO, 1999).

Waterborne diseases are caused by organisms that are directly spread through water and can be classified as bacterial, viral, parasitic, or chemical (IOM, 2009). Waterborne pathogens are unique in regard to their ability to survive in the environment outside of the host. This is a primary factor that "largely dictates the possible transmission pathways that can be exploited by a waterborne pathogen in completing its lifecycle" (WHO, 2001). This has several consequences for examining waterborne pathogen pathways and their respective outcomes during an intervention. A major pathway of concern—and primary focus of the international research community—is by the ingestion of water contaminated by human or animal excreta or urine containing pathogenic bacteria or viruses. This includes cholera, typhoid, amoebic and bacillary dysentery, and other diarrheal diseases (Montgomery and Elimelech, 2007). Fecal-oral transmission of disease includes many known and unknown pathogens; in addition, there are shared effects across different pathways that make it difficult to quantify pathogenic contribution to certain health outcomes. For example, though many outcomes have been predicted by chemical or quantitative risk assessment models[4] (WHO, 2001), these models have not been able to identify other factors such as the availability of water to promote hygiene and its effect on a pathway. This provides further challenges when examining pathogen transmission and exposure pathways and identifying their contribution to diarrheal illness (WHO, 2001). While there are many challenges in quantifying pathogenic contribution to diarrhea-related health outcomes, it is has been well documented that prevention strategies such as piped water are effective in reducing diarrhea incidence. However, evidence for the effectiveness of the provision of communal rural infrastructure and latrines is limited (Zwane and Kremer, 2007).

[4] The foundation of many environmental health interventions.

4. Burden of diarrhea-related illness in children younger than five

Diarrheal illness is generally associated with transmission of waterborne disease most notably by fecal-oral transmission route; the primary source of diarrhea-related pathogens originates in human feces (Keusch et al., 2006; Trevett et al., 2005; Curtis et al., 2003; Prüss et al., 2002; Curtis and Kanki, 1998; Kolsky and Blumenthal, 1995). Children are recurrently at greatest risk (UNICEF, 2006) based on their higher intake of water (Maughan, 2003; Manz, 2007) and as a result of faster metabolic rate (Hsu et al., 2003), putting them at greater risk than adults of life-threatening dehydration since water constitutes a greater proportion of a child's bodyweight (Black et al., 1984). Bodyweight can be an important indicator of risk for severe diarrhea that leads to mortality. Diarrhea acts synergistically with malnutrition. A dose-response relationship was reported in several studies that found consistent increases in mortality with poorer nutritional status (Boschi-Pinto et al., 2009). While most episodes of childhood diarrhea are generally mild, severe cases can lead to significant fluid loss and dehydration, which may result in death or other severe consequences. For example, rotavirus is the leading cause of severe diarrhea and is responsible for about 40 percent of all hospital admissions due to diarrhea among children younger than five worldwide. Other major bacterial pathogens include *E. coli, Shigella, Campylobacter,* and *Salmonella* (UNICEF and WHO, 2009).

Globally, diarrheal disease, cholera, cancers (Hotez et al., 2006),[5] tooth/skeletal damage from unsafe levels of arsenic and fluoride, and schistosomiasis are the main causes of morbidity and mortality from water-borne illnesses (WHO, 2010). An estimated 88 percent of diarrhea-related deaths are attributable to unsafe WSH. Of all childhood deaths, it has been estimated that 18 percent are due to diarrhea—the second-most common cause of death for children, with pneumonia being first (Bryce et al., 2005; Murray et al., 2007; Boschi-Pinto et al., 2009). This translates to approximately 2 million deaths annually due to childhood diarrhea—75 percent of which are made up of children in developing countries (WHO, 2004; UNICEF, 2004; UNICEF, 2006; UNICEF and

[5] Such as bladder and colorectal.

WHO, 2009; Boschi-Pinto et al., 2009). Globally, diarrhea and pneumonia combined cause more child deaths each year than the annual deaths attributable to smoking in all ages, or twice as many annual deaths as HIV/AIDS, making it a top priority among global health institutions (UN, 2006).

Unsafe water and poor sanitation, including lack of hygiene, account for almost one-tenth of the global burden of disease and 4.1 percent of the total global disability-adjusted life years (WHO, 2004; Prüss-Üstün et al., 2008).[6] Of this burden, children up to 14 years of age, particularly from developing countries, disproportionately share more than 20 percent of this burden (Prüss-Üstün et al., 2008). Further burden has been associated with long-term consequences and can vary depending upon age of exposed person, as well as the severity, duration and frequency of diarrheal episodes. Correlations between impairments of psychomotor and cognitive development (such as limited intellectual capacity and concentration) and diarrheal illness in children have been identified (Niehaus et al., 2002). Unfortunately, long-term consequences of diarrheal disease remain poorly studied and contribute to an underestimation of morbidity (Keusch, 2006).

Global surveillance and longitudinal studies have allowed for trend analysis of mortality and diarrhea incidence, providing a basis for projections and for evaluations of future control strategies. The first published estimate of diarrheal morbidity and mortality among children younger than 5 years of age was in 1982 (Snyder and Merson, 1982). At that time, it was estimated that 5 million children younger than 5 years of age had died due to diarrhea. Globally, diarrhea-related deaths in this age group have been declining from 3.3 million in the 1990s (Bern et al., 1992), 2.5 in early 2000s (Kosek et al., 2003), 1.905 million approximately 3 years later (Bryce et al., 2005), and to 0.801 million in 2010 (Liu et al., 2012). Differences between reports such as those from Parashar et al. (2003) of 2.1million and Boschi-Pinto et al. (2008) of 1.87 million vary significantly from those of Kosek et al. (2003) and Bryce et al. (2005) during the same time periods; methodological variations may account for some of these differences (Keusch et al., 2006). Data for mortality and cause of death data are in vital registration systems and nationally representative studies, both of which can

[6] This measures the years of life lost to premature mortality and the years lost to disability.

vary by country (Boschi-Pinto et al., 2009). Vital registration systems supporting accurate accounts of cause of child deaths usually do not exist in less-developed countries, which account for 98 percent of all under-5 deaths (Rudan et al., 2005). Because of this, the main data concerning cause-specific mortality are from special population epidemiological studies, which can be limited by representativeness, misclassification of cause of death, and possible site bias; however, these are the best sources to date (Boschi-Pinto et al., 2009). While there are variations among studies, the overall trend from the early 1980s to now has been one of significant reductions in global diarrheal deaths in children younger than five (Keusch et al., 2006; Boschi-Pinto et al., 2009; Waddington et al., 2009; Liu et al., 2012).

Estimated median incidence of diarrheal disease in children younger than 5 years of age of approximately three episodes per child per year has remained consistent in developing countries between the early 1990s and the early 2000s as opposed to the decreasing trend in mortality (Kosek et al., 2003; Parashar et al., 2003; Jamison et al., 1993; Bern et al., 1992). Caution should be exhibited when interpreting results of diarrhea incidence taken from demographic and health surveys as they report on diarrhea episodes two weeks prior to survey and may suffer from recall bias, do not take seasonality into account, and as regional surveys might be taken at different periods of time (Boschi-Pinto et al., 2009). To better assess trends of morbidity, the WHO created the Child Health Epidemiology Reference Group in 2001 to conduct systematic literature reviews to identify published articles on diarrhea morbidity rates in children younger than 5 years of age (Bryce et al., 2005; Boschi-Pinto et al., 2009). Countries that were involved were drawn from the six regions of the WHO: Africa, Americas, Eastern Mediterranean, Europe, Southeast Asia, and Western Pacific regions. The median incidence was 3.5 episodes per child per year, which was very similar to the results identified by Kosek et al. (2003) and Parashar et al. (2003). The regions with the slightly higher incidence rates were Africa, the Americas, and Eastern Mediterranean region with approximately five episodes per child per year with the highest rates found in children between 6 and 23 months of age (Boschi-Pinto et al., 2009).

B. Burden of Waterborne Illness in Guatemala

1. Quality of life: health indicators

Guatemala is the most populous nation in Central America, mainly due to the high birth rate (33.8) and fertility rate (4.2, 6.2 in indigenous families) and the low rate of contraceptive use. While Guatemala is the biggest economy in the Central American region, it has one of the lowest expenditures on public health in the Americas region, around 1 percent of Gross Domestic Product (GDP)(U.S. Government Initiative, 2010). However, of all Latin America, Guatemala had the highest outside investment in public health (Programa de las Naciones Unidas para el Desarrollo, 2010). Guatemala also experiences the most unequal distribution of income in Latin America—20 percent of the population consumes 51 percent of the country's GDP (U.S. Department of State, 2012)—with more than half of the population living in poverty and nearly one-fifth in extreme poverty (United Kingdom Foreign & Commonwealth Office, 2012). High levels of poverty, birth, and fertility rates, in addition to inefficient uses of outside private funds, corruption (Drakenberg and Slunge, 2006), and low public expenditure on public health have led to high rates in infant mortality, under-5-years-of-age mortality, maternal mortality, high incidence/prevalence of diarrheal illness, and high incidence/prevalence of respiratory infections (WHO, 2006; Global Health Observatory, 2012; Programa de las Naciones Unidas para el Desarrollo, 2010).

Guatemala's prevalence of malnutrition is seen in children between the ages of 3 and 59 months, with 43.4 percent of this age group suffering from chronic malnutrition—principally found in children of rural and/or indigenous regions and children from mothers lacking formal education (Programa de las Naciones Unidas para el Desarrollo, 2010). This is the highest prevalence of chronic malnutrition (43.4 percent) in the Western Hemisphere (U.S. Government Initiative, 2010). The high prevalence of chronic malnutrition has led to Guatemala having the third highest rate of stunting for children younger than 5 years of age. Food and nutritional insecurity is endemic and much of the malnutrition problems have been exacerbated by poor food utilization (United Kingdom Foreign & Commonwealth Office, 2012).

2. <u>Access to water, sanitation, and their development</u>

Guatemala has abundant water resources and sufficient sources of rainfall to meet water demands of the country (Spillman et al., 2000). Access to improved drinking sources in Guatemala is high; access to sanitation facilities still needs improvement. Large disparities exist between urban and rural populations: 98 percent of the urban and 87 percent of the rural population have access to improved water sources. Eighty-seven percent of the urban and 70 percent of the rural populations have access to improved sanitation facilities (UNICEF, 2012). In 2006, through water access was high, water quality was often poor, with only 15 of 331 municipalities having treatment plants for potable water in working condition and a lack of treatment plants for sewage water. In 2008, it was estimated that only 15 percent of drinking water was disinfected and only 25 percent of municipalities had a system for disinfection (Samper-Rodriguez, 2008). Availability of clean water is also reduced by effluents from industries and municipal or illegal dumps (Drakenberg and Slunge, 2006; Lentini, 2010). Once access is established, continuity of services is a problem (80 percent of systems operate intermittently—on average between 6 and 12 hours per day and an average of 3 to 6 days per month where systems are not in operation) (Lentini, 2010).

Guatemala faces significant challenges for development and ranks 131 out of 187 on the UN Development program's 2011 human development index (Canadian International Development Agency, 2012). To help meet the MDG and to address much of its development deficiencies, Guatemala signed the Paris Declaration on Aid Effectiveness in 2005 and later the Accra Agenda for Action in 2008 (OECD, 2005; OECD, 2008). Since then there have been various investments, both private and public, for water and sanitation projects. For example, in 2010, the department of Chimaltenango had set aside 10 percent of its budget to build five water treatment plants (Central America Data, 2010). That same year the lake Atitlán recovery plan was created and included the construction of 23 sewage treatment plants, 13 to be built in 2010 and the remaining 10 scheduled for 2011 (Central America Data, 2010). In 2012, Guatemala's Municipal Development Institute funded and finalized a total of 148 rural water and sanitation projects with an additional 53 in progress and 62 about to begin (Instituto de Fomento Municipal de Guatemala, 2012).

While progress has been made, past and present analyses point to the same result: water supply and proper management of water resources are lacking (Spillman et al., 2000; del Rosario Navia et al., 2011). In July 2010, Guatemala voted in favor of water as a human right, but has not made it explicit in law. No policy on the water and sanitation sector has been consolidated and at a rural level, projects are planned and concerted with the communities, which ultimately assume their management (del Rosario Navia et al., 2011). Further research by the Inter-American Development Bank (IBD) and the United Nations Program for Human Settlements (UN-Habitat), two major institutional funding arms for Guatemalan development projects, found that "the legal and institutional framework of the water and sanitation sector is practically non-existent" and "the regulatory responsibilities are scarce and scattered" (del Rosario Navia et al., 2011, p.48). The water sector continues to have no financial structure (Guatemala does not have a unified tariff system or subsidy system) and financing still comes from the national budget (del Rosario Navia et al., 2011). Current national funding is not enough to meet the goal of universal coverage by 2020; between 1995 and 2004, the country allocated an average of 0.18 percent of the GDP to the water sector when it has been suggested that the investment required should be 0.38 percent of GDP, excluding investment needed for wastewater treatment (del Rosario Navia et al., 2011).

3. Diarrhea-related illness in children younger than five

In 1997, there was a drastic change to the vital registration system, which increased accuracy and accounted for incidences of diarrhea in the population; between 1997 and 1998 a dramatic increase in incidence occurred due to this change (Moscoso, 2008). Figure 3 shows between the years of 2000 and 2006 there was a gradual decline in incidence of diarrhea in the population; however, the burden of illness was still estimated at 300 cases per 10,000 people of which 60 percent occurred in children younger than 5 years of age (Moscoso, 2008).

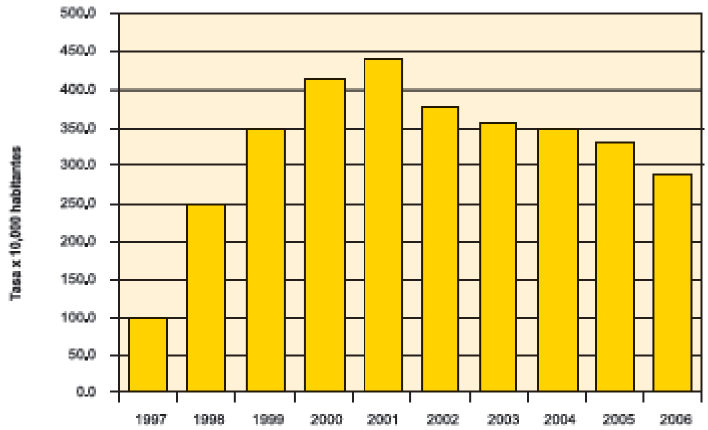

FIGURE 3. Diarrhea Illness per 10,000 inhabitants in Guatemala, 1997–2006 (Moscoso, 2008).

In 2010, diarrheal disease was the 7th highest cause of mortality in children under 5 accounting for 7 percent of all deaths in the age group (WHO, 2012). In developing countries such as Guatemala, those affected most by diarrheal disease are children who live in impoverished conditions and reside in rural communities that lack funds to improve and maintain clean water and provide proper sanitation infrastructure (Lentini, 2010; Moscoso, 2008). Approximately 66.20 percent of the population of Guatemala lives in poverty, with 16 of the 22 states experiencing poverty rates greater than 50 percent; 14 of the 22 states experience 10 percent or higher rates of extreme poverty (Moscoso, 2008). Furthermore, poverty is significantly higher for indigenous groups (76 percent) and rural residents (75 percent). This leaves rural indigenous groups with a higher likelihood of having limited access to safe drinking water and proper sanitation; the risk of exposure to pathogens resulting from distribution systems is greater for those in developing countries, where there is often poor water treatment and management as well as inadequate medical support (Lee and Schwab, 2005).

C. Safe Drinking-Water Programs in Developing Countries

1. Strategies

Strategies for controlling diarrheal disease have remained substantially unchanged since the late 1980s and early 1990s (Keusch et al., 2006). Such strategies include: exclusive breastfeeding, cholera and rotavirus vaccination, improved water and sanitary facilities, and promotion of personal and domestic hygiene. Many strategies largely focus on prevention of severe cases as well as reduction of burden; few aim to create barriers to transmission and exposure. Environmental strategies have largely focused on interventions that act to minimize risks of disease transmission by creating barriers to transmission through WSH. Because most cases of diarrhea illness are linked to WSH the majority of interventions have focused on one or more of those components; WSH interventions can be categorized into five basic groups (Fewtrell and Colford, 2004):

- Hygiene Interventions: including hygiene and health education and the encouragement of specific behaviors, such as hand washing.
- Sanitation Interventions: providing improved means of excreta disposal, usually latrines.
- Water Supply Interventions: including provision of a new or improved water supply and/or distribution, such as the installation of a hand pump or household connection, either at the public or household level.
- Water Quality Interventions: water treatment for the removal of microbial contaminants and/or clean storage, either at the source or at the household level.
- Multiple Interventions: those that introduced a combination of water and sanitation and/or hygiene elements (or health education) to the study population.

Figure 4 is a simplified version of the f-diagram (Nunoo, 2009, unpublished data),[7] which illustrates transmission routes through fecal-oral contamination and Figure 6 considers transmission routes within and between households showing how "indirect exposure to contaminated drinking water can occur as a result of multiple interdependent exposure pathways" (Eisenberg et al., 2007, p.847; Waddington et al., 2009). The dashed arrows in Figure 5 represent the route or routes in which risks are reduced by a water quality intervention.

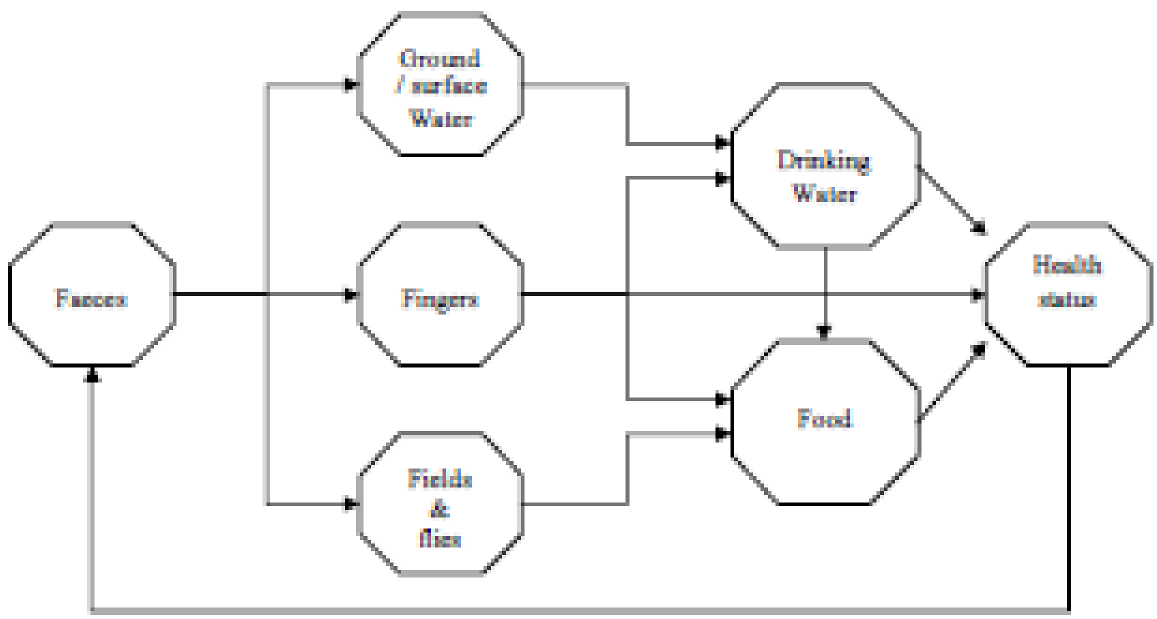

FIGURE 4. F-diagram illustrates transmission routes through fecal-oral contamination (Waddington et al., 2009).

[7] This is a diagram which details the fecal-oral transmission route. It is characterized by F's as follows: Fluids, Fields, Fingers, Food, and Flies. All five can be contaminated and spread disease and illness, one of which is diarrhea.

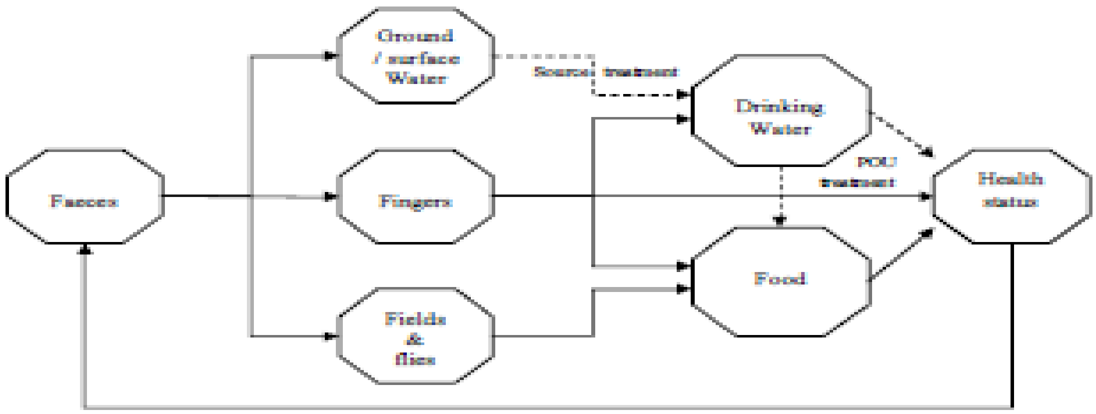

FIGURE 5. Transmission routes within and between households that lead to diarrhea (Waddington et al., 2009).

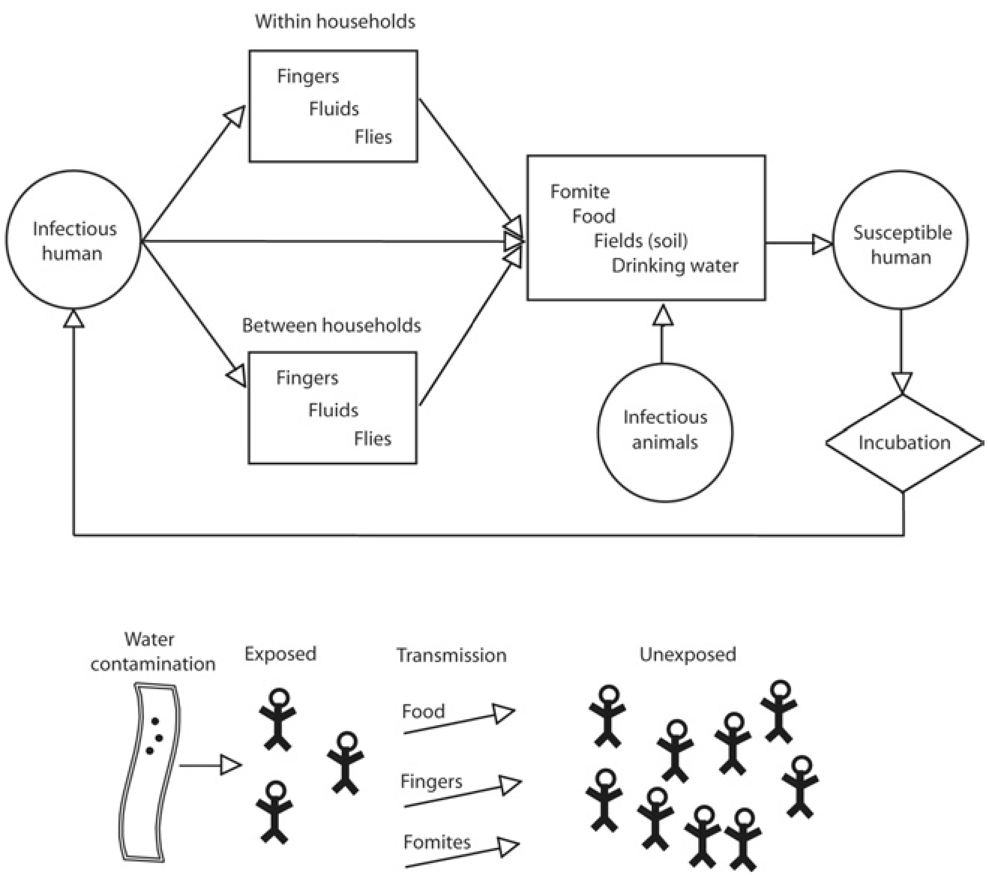

FIGURE 6. Routes by which risks are reduced by water quality interventions (Eisenberg et al., 2007).

These simplified diagrams highlight two major points: interventions can minimize risk by creating barriers to pathways, and enteric pathogens can spread in the household and throughout the community. Although not specifically illustrated, one can draw the conclusion that there are complementary effects on health outcomes by mixing interventions that affect multiple pathways. One major challenge of the last two decades has been in assessing what effects or impact each type of intervention has and where overlap occurs; our current understanding of integrated control strategies remains poor (Eisenberg et al., 2007).

Further challenges arise because interventions are embedded in complex social systems that have a strong bearing on uptake and impact (Waddington et al., 2009). Interventions targeting water quantity, quality at the source, and sanitation require some behavior modification, (e.g., maintenance of facilities in a hygienic manner); however, it is more limited when compared to hygiene and household water quality interventions that require significant behavior change (e.g., soap to washing hands, use of filtration system in the home, boiling water prior to use) (Waddington et al., 2009).

2. Drinking water quality and supply interventions

Water supply interventions are heterogeneous often due to differences in regional availability of water and by differing needs of rural and urban demographics. Interventions can include the provision of an improved source of water (e.g., a protected dug well or spring) or improved distribution (e.g., piped water or standpipes) or an improved source and distribution. Any of these interventions can be provided either at public (source) or household (point-of-use, POU) levels (UNICEF and WHO, 2011). The literature from the 1970–1980s focused on the quantity of water being delivered, from 1990-current literature focused on the availability of water in combination with improved source and distribution or improved distribution.

In Ethiopia, the prevalence of diarrhea among children younger than 2 years old from families with higher water-use rates per person was less than that among comparable children from families with lower rates (Freij, 1977). This suggested health benefits came with increases in water use. Howard and Batram (2003, p.1) highlight that “defining basic needs for water has limited significance as the volume of water used by households depends on accessibility as determined primarily by distance and time, but also including reliability and potentially cost.”

Gorter et al. (1991) showed that in Nicaragua, children living in households with a water supply within 500 meters had 34 percent less diarrhea than children living in households whose water source was more than 500 meters from the house. Gorter et al. (1991) noted that once a water supply is within 500 meters, reducing distance had no further impact. Wang and Hunter (2010) found that research to date suggest that distance to water source may be an important risk factor for diarrheal disease in children. They also highlight observations that are nearly a decade old, have marked heterogeneity in effect sizes, and are sourced entirely from observational data. They call for well-designed studies and suggest that these relationships have important implications for development of policy for appropriate density of water provision where taps at the household are not feasible (Wang and Hunter, 2010).These conclusions are closely tied to a review done by Cairncross (1987), who examined several studies on water use and collection behavior. It was suggested that there is a clearly defined general response of water volumes used by households with accessibility. As accessibility increases, water volumes increase up to a certain point. This suggested that increased volumes resulted in health benefits primarily linked to an increase in personal and domestic hygiene, but also with consumption. Esrey (1996) argues that it is only when the water supply is delivered on-plot (nearest the home) that health gains are found. This is difficult to determine as there is limited published literature on the impact of providing non-piped water supplies on-plot, which would be of particular importance in “determining the fraction of diarrheal disease that is directly attributable to increased service level and the fraction attributable to other factors” (Howard and Batram, 2003, p.13).

Shiffman et al. (1978) examined protection at the supply source in a setting with water treatment and provision of household connections; they did not detect reductions in prevalence of diarrhea following the improvements. Esrey et al*.* (1991) highlighted this same study as an example of why “little to no health impacts from water improvements were found” because of high levels of environmental fecal contamination; a similar conclusion that Eisenberg et al. (2007) came to in their findings identifying poor sanitation conditions and limited improvements to water quality (Eisenberg et al., 2007).

Wang et al. *(*1989) assessed the impact of deep-well tap water through household taps on enteric infectious disease in rural China where control villages had water supply from surface water sources. They found that in the study region, the incidence of infectious disease—including acute watery diarrhea and cholera, in the study region—was 38.6 percent lower than in the control region (Wang et al., 1989). Bukenya and Nwokolo (1991) showed that the presence of a standpipe at households in urban Papua New Guinea was associated with lower levels of diarrhea than users of communal sources and this was found across all socio-economic groups. Tonglet et al. (1992) found that the presence of piped water via standpipes in rural Zaire accounted for a 50 percent reduction in median diarrhea incidence. The intervention population was made up of those living in households with a stand-pipe using more than 50 liters of water per day and/or those using public or communal stand-pipes within a five-minute walk from their respective homes. The study underscored a principal fact that “children in households who used standpipes were exposed to a lower risk of diarrhea”; stressing the importance to investigate access to and use of water among an intervention target population (Tonglet, et al. 1992, p.262). Wang et al. and Tonglet et al. are classified as being of good quality by Fewtrell and Colford (2004) and provide primary evidence to suggest that household connections are a more effective means of reducing diarrhea than standpipe provision. Further evidence from Bukenya and Nwokolo (1991) suggested providing drinking water supply at the household level is more effective than at the communal level.

Good quality water supply interventions have observed reductions in diarrhea mainly through the provision of household connections in settings where water is not stored at the household level. This suggests that provision of household connection should be the ultimate goal of a supply intervention. In cases where this is not economical, evidence suggests that provision should be as close to the home as possible and future research should address the topic of distance to supply source for such provisions.

Water quality interventions often vary based by source of water supply, by the type of treatment, and where the treatment occurs. Surface water in developing countries is often contaminated with pathogens that affect human health. Subterranean sources (groundwater) are typically less contaminated; locations of even small-scale groundwater supplies can be difficult to find and develop, making such locations priority for water supply interventions often due to the higher risks inherent with contaminated surface water supplies (Foster and Chilton, 2003; MacDonald et al., 2005b).

The purpose of a water quality intervention is to improve the microbial quality of drinking water by "removing or inactivating microbiological pathogens and protecting microbiological integrity of water prior to consumption" (Clasen et al., 2006, p.5). The methods to do so depend on where the intervention is taking place—at the household level (POU) or at the source level. Water source interventions can include protection of wells and bore holes; distribution to public tap stands or household connection taps; chemical and non-chemical treatment at the source such as chlorination, filtration, and exposure to electromagnetic radiation in the ultraviolet spectrum. Household interventions can include chemical and non-chemical methods for treatment. Chemical approaches typically include flocculation and chlorination. Non-chemical methods can include physical processes such as filtration, sedimentation, and distillation; biological processes such as sand filtration or active carbon filtration; or electromagnetic radiation such as ultraviolet light referred to as solar filtration. Potentially important differences within groups exist, but are difficult to assess. Chlorination interventions can vary by chlorine source, dose, and contact time; filtration interventions can vary by the pore size of filters and the filter medium (Clasen et al., 2007).

Torun (1982), Gasana et al. (2002), and Jensen et al. (2003) provide some insight into source-based interventions (all of which are quasi-randomized trials). Torun (1982) performed a trial in two small villages in Guatemala that included source protection of a spring, chlorination facilities, adequate storage of water, hygiene education, and water mains with faucets to yards for a total of 12 months. They compared households whose supply came from shallow, unprotected, hand-dug wells with that of the intervention households at water mains with faucets to yard by testing microbial water quality at the source of distribution. They identify a reduction of diarrheal illness of 14 percent following a program to promote health awareness; however, case definitions were not used for diarrhea. This made it not possible to estimate the measure of effect of the water quality intervention arm. Gasana et al. (2002) had three intervention populations for the provision of water treatment infrastructure and one control population in rural Rwanda. They were separated into “sites” as follows: a new source of potable water was built using pipes, a water intake, a sedimentation tank, Katadyn filtration (ceramic filtration), and a storage tank with a communal tap (site A); gravel-sand-charcoal filter was installed at an existing water spring (site B); a protective fence was installed around an existing water spring (site C); and another water spring was selected as a control (site D) (Gasana et al., 2002). Water sampling assessed contamination at the source, during transportation, and at home. At site A, frequency of contamination was 88.6 percent at the source of water (considered very polluted with more than 1100 total coliforms/100ml). After leaving the Katadyn filter, the frequency dropped to 14.6 percent (average of 3 total coliforms/100ml) noting the efficiency of the filter. At site B, it was observed that the gravel-sand-charcoal filter was not working properly and the site ended with one of the highest contamination frequencies of all three sites (it was suggested that population density may have influenced the contamination frequencies). Further observation noted an exponential increase in total coliforms, fecal coliforms, and *E coli* from sites A and B (the least) to sites C and D. Interestingly, site A had frequencies almost identical to site B; however, they were of nominal significance for risk for diarrheal illness. The greatest contributor of contamination was identified as the unsanitary condition of containers as well as the manner of storing and handling containerized water. This further supports the theory presented by Vanderslice and Briscoe (1995) that improving water quality alone will not impact diarrhea seen in children living in highly contaminated neighborhoods (Gasana et al., 2002). A very similar conclusion was made by Jensen et al. (2003), who found that the incidence of diarrhea in a village in Pakistan (7.3 episodes per 10^3 person-days) was not statistically different from that of the poor water quality. They suggest that in non-epidemic conditions chlorination does not seem to be a priority intervention to reduce childhood diarrhea; however the limited size of the study limits its generalizability.

Kirchhoff et al. (1985) conducted a randomized controlled trial (RCT) of POU water treatment using hypochlorite in rural Brazil in which they also considered acceptability by community members of the intervention. They found that people living in homes receiving the placebo treatment had a mean of 11.2 days of diarrhea per year with the highest rate among children younger than 2 years of age at 36.7 days per year. They did not find any significant differences among participants exposed to treatment versus placebo suggesting water quality may only affect morbidity when other variables involved in the fecal-oral transmission are targeted. The results of this trial were similar to that of Gasana et al. (2002) and Jensen et al. (2003), in which no considerable effect was found and where sanitation levels were recorded as low (this study had no homes with sanitary facilities).

Conroy et al. (1996) conducted POU water treatment of solar disinfection in plastic bottles at household level in rural Kenya during a cholera epidemic and repeated the study again in 1999. In the 1999 study they found no significant difference in risk of cholera in adults or older children, but did find a difference between intervention and control groups of children younger than 6 years of age. Their conclusion was that point of consumption interventions using solar disinfection deserve further investigation for the potential to combat chlorine resistant cholera.

Clasen et al. (2006) conducted RCT to assess performance of ceramic filter elements among households in a rural community in central Bolivia. After adjusting for household clustering and repeated episodes, age, and baseline diarrhea prevalence among the intervention group was 51 percent lower than controls. A 9-month follow-up survey found that 67 percent of filters were still being used regularly, 13 percent were being used intermittently, and 21 percent were not used at all (Clasen et al., 2006). This intervention highlights the importance of compliance. Du Preez et al. (2008) also used household commercial ceramic filters assessing their effectiveness in reducing diarrhea. They tested for *E coli* and found that a lower diarrhea incidence among filter users suggested ceramic filters are effective in reduction of diarrheal disease incidence (du Preez et al., 2008).

Reller et al. (2003) conducted a series of four separate RCTs of the following: flocculation-disinfection; bleach only; bleach plus a custom storage vessel; and flocculant-disinfectant in addition to a custom storage vessel. During one year of observation they concluded that intermittent use of flocculant-disinfectant decreased the incidence of diarrhea by 24 percent alone or up to 29 percent with the addition of a storage vessel. Chiller et al. (2006) came to similar findings with an RCT also conducted in rural Guatemala. They report on longitudinal prevalence of diarrhea and find that those receiving the disinfectant had a prevalence of diarrhea 40 percent lower than those using standard water handling practices. Both of these studies suggest that this method of POU treatment is quite effective; however compliance and acceptability should be further assessed.

In Guatemala, the provision of unlimited potable water to homes increased water consumption, but had no appreciable effect on morbidity, a phenomenon attributed to poor water storage practices within the household (Shiffman et al., 1978). Lindskog et al. (1987) found improved water supplies had no impact on diarrheal disease, even though overall morbidity was significantly reduced. The author attributes this finding to continuing contamination from poor water storage practices and use of traditional water sources that were accessible during the rainy season (Lindskog et al.,1987). These studies set the groundwork for studies like Roberts et al. (2001) who, in Malawi, assessed effectiveness of a water container and cover in preventing water contamination at a refugee camp using a randomized intervention trial methodology. Water sources had little-to-no microbial contamination prior to storage; however hand contact with drinking water quickly contaminated it. Analysis of samples demonstrated a 69 percent reduction of fecal coliform levels in household water and attributable 31 percent reduction in diarrheal disease in children younger than 5 years of age. This provides evidence that health benefits can result without chemical disinfection and offers an opposing view to that of Vanderslice and Briscoe (1993), which indicates that bacterial contamination from sources distant from the home pose threats to human health, but does agree with the theory formed in their (1995) study implying sanitation conditions undermine drinking water interventions aimed at quality. Trevett et al. (2005) provide a conceptual framework of principal factors that determine pathogen load in household drinking water. They conclude re-contamination of drinking water exists and suggest that sanitary conditions in the domestic environment, cultural norms, and poverty play a role on pathogen load of household stored water that represents significant health risks to infants and those with secondary immunodeficiency (Trevett et al., 2005). It is further suggested that stored drinking water quality becomes important as a major source of diarrheal risk when the stored water is grossly contaminated—a finding supported by observational data such as Lacey et al. (2011), where they find gross contamination in drinking water storage containers in rural Guatemala (Lacey et al., 2011). This has important implications on household interventions as a larger proportion of communities in developing countries depend upon systems that require the collection and storage of drinking water (Trevett et al., 2005).

Next steps for POU (household) treatment is to determine whether people are willing to permanently adopt or pay for systems that affect the taste of water, slow the rate at which water can be consumed, or require that traditional storage containers be abandoned (Makutsa et al., 2001). Clasen et al. (2007) suggests that household interventions are limited by opportunities of non-compliance that lead to reduced effectiveness. He calls for more assessment of target population's potential uptake of household interventions to examine sustainability of household based projects (Clasen et al., 2007).

3. Cost and sustainability of safe drinking-water projects

It has been difficult to associate all costs and benefits from improved water projects. Hutton et al. (2007) provide a cost-benefit analysis of water interventions and their global economic impact. It has been estimated that for every US dollar invested, the return is five US dollars in economic benefit per capita. The annual cost of increasing access to basic improved water supply and sanitation to all is less than 10 USD per person reached in all developing areas. This assumes such direct economic benefits consist partly of costs averted due to the prevention or early treatment of disease. These include and are not limited to costs avoided by healthcare, such as avoided costs due to “care and hospitalization, estimated at 500 million USD per year if the water Millennium Development goal is met” (Hutton et al., 2007, p. 489). Indirect economic benefits relate particularly to productivity as it increases due to improved health (Gold et al., 1996). Another area impacts children’s ability to attend school, creating education benefits due to fewer missed school days. It is important to note the difficulty in quantifying lost productivity due to persistent diarrhea’s effect on cognitive abilities, and this issue has not been included in any cost-benefit analysis to date (Lorntz et al., 2006). Most often highlighted is time saved, which benefits women and can include time savings from collection of water; an average family of eight received an estimated 25 minutes of saved time per day and an average sized family of four received one hour of saved time per day (Hutton et al., 2007). Further evidence supporting this claim is found in a study by Crow et al. (2012), where they suggest that community organized piped water projects allow women to spend less time collecting water and more time sleeping in comparison with women from communities without piped water supplies (Crow et al., 2012).

Evaluations of WSH interventions remain limited in scope and the most prevalent evaluation practices monitor programmatic goals, such as the duration of the project, the number of wells, and financial goals. The lack of a standardized mechanism to evaluate projects continues to be one of the most challenging barriers to overcome in providing sustainable water (IOM, 2009). Understanding and responding to consumer demand for water and sanitation services is tantamount to the sustainability of improvement projects. Problems relating to unaccounted-for water and distribution system deficiencies remain overlooked in developing countries. Miguel and Gugerty (2005) report that in western Kenya nearly 50 percent of borehole wells dug in the 1980s, and subsequently maintained using a community-based maintenance model, had fallen into disrepair by 2000 (Miguel and Gugerty, 2005). Lee and Schwab (2005) link distribution system inadequacies (inadequate disinfectant residual, low water pressure, intermittent service, and ageing infrastructure) to cross-contamination of clean water supplies and outbreaks of waterborne and water-related disease, noting that often a combination of failures in a system results in poor water quality (Lee and Schwab, 2005). Hunter el al. (2009) suggest that poor reliability of drinking water interventions in developing countries could be undermining much of the intended public health benefits, noting that even a few days of interrupted supply of drinking water may be sufficient to destroy the health benefit from the provision of clean drinking water (Hunter et al., 2009).

An important topic that has arisen in more recent literature is the availability of reliable fresh water resources as it is a vital first step towards a sustainable supply of water for domestic uses (Hunter et al., 2010). Fresh water resources are not spread evenly across the globe as can be seen in Figure 7. The figure highlights greater levels of rainfall occurring in most of the wealthier areas of the world. Higher levels of rainfall are more likely to replenish rivers, reservoirs, and aquifers (MacDonald et al., 2005). Wealth and higher rainfall often equate to a higher capacity to store and transfer water and can lessen the hardship from water stress presented by climate change and drought (Grey and Sadoff, 2007).

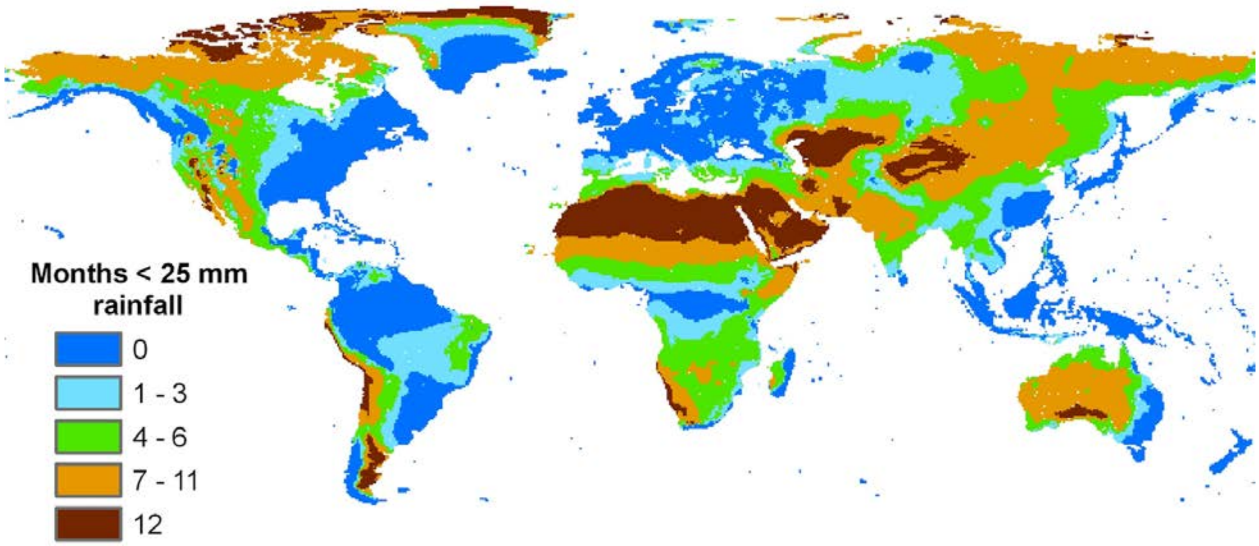

FIGURE 7. Global distribution of rainfall: The number of dry months a year (Hunter et al., 2010).

It has been estimated that a minimum of 7.5 liters of water per person per day is required in the home for drinking, preparing food, and personal hygiene; at least 50 liters per person per day is needed to ensure all personal hygiene, food hygiene, domestic cleaning, and laundry needs are met under most conditions (Howard and Batram, 2003). On many occasions, domestic water consumption is dwarfed by demands from agriculture and eco systems (Hunter et al., 2010). To cover all consumption use and avoid water stress, approximately 1,000 cubic meters of freshwater per capita per year is needed (Rijsberman, 2006). Populations in regions that experience long dry seasons and who have no reliable water supply are often required to find a groundwater source (MacDonald et al., 2005a). Groundwater resources rely heavily on rainfall for renewal and are strongly affected by climate variability and climate change (Carter and Parker 2009). High levels of water extraction from water sources that are already stressed by climate change, population growth, and urbanization can lead to exhausting of water resources, which is considered a global problem (Foster and Chilton, 2003). Sustainability is an important issue not adequately addressed. The scalability of water quality interventions, as well as a need for better understanding of what determines use and performance in the long term should be considered in future projects and evaluations.

D. Evaluation in Environmental Health

1. Purposes and approaches

Evaluations are periodic, objective assessments of a project, policy, or program. They can be carried out at any point and are used to answer specific questions related to design, implementation, and results (Gertler et al., 2010). Program evaluation can be further separated into three main categories: formative, process, and summative (Van Marris and King, 2007). Imas and Rist (2009) broadly address three types of questions asked in these categories (Imas and Rist, 2009):

- Descriptive questions: Formative evaluations are used in the planning stages of a program. They determine what is taking place and describe processes, conditions, organizational relationships, and stakeholder viewpoints (i.e., needs assessments, evaluability assessment, pre-testing program materials).
- Normative questions: Process evaluations are used when programs are already underway. They examine procedures and tasks to compare what is taking place to what should be taking place; they assess activities and whether or not targets are accomplished. Normative questions apply to inputs, activities, and outputs (i.e., implementation evaluation, quality of services provided, tracking quantity, and narrative of individuals and program effect).
- Cause-and-effect questions: Summative evaluations are used when programs are already underway or completed. They examine outcomes and try to assess the intended and unintended effects a program has on outcomes (i.e., impact evaluation; outcome evaluation; changes in attitudes, knowledge, or behavior; changes in morbidity or mortality rates).

Traditionally in environmental health the fundamental approach is that of risk assessment. Risk assessment is meant to identify the presence of toxic substances and to evaluate risks posed to the environment and human health. Four basic steps are used to assess risk (hazard identification, dose-response assessment, exposure assessment, and risk characterization) and if significant risk is present, an appropriate risk management strategy is imposed (control at source, control along pathway, control at level of person, and a form of secondary prevention) (Bailar and Bailer, 2001).

However, risk assessments are often laden with scientific uncertainty and controversy and this leads to difficulty in taking action for stakeholders—i.e., public health professionals, elected officials, and communities (Howze et al., 2004). Bailar and Bailer (2001) highlight six areas that raise uncertainty of risk in assessments. First, differences in human physiology and genetic makeup that dictate exposure to hazards may or may not result in an adverse response. Second, how often and to what degree one is exposed to a hazard reflects on the frequency and the magnitude of an adverse response. Third, individual variation in response can occur at the same level of dose or exposure. Fourth, direct measurement data of human risk are often inadequate or absent. Fifth, risks can be deemed acceptable by individuals and communities and depend on the level of acceptance, which is often complex. Sixth, when it comes to the balance of risk, criteria are often unclear (Bailar and Bailer, 2001).

Because the relationship of risk to dose is generally unknown and often controversial, accurate estimation of most risks is not possible.[8] Further uncertainty arises when exposure to other agents may intensify effects or have a synergistic effect associated with the hazard of concern. These reasons, among others, reflect upon the controversial nature of risk assessment once risk management techniques come into play.

[8] Reports on the same hazards often differ by a factor of a thousand or more.

Accounting for “public perception of risk must become more a part of risk management decision making and environmental health action planning” (Howze et al., 2004, p.431). As communities become aware of their exposure to environmental hazards, calls for action to reduce or mitigate these exposures have increased (Parker et al., 2004). In the United States and in other countries in the world, insufficient capacity of health infrastructure to document the links between environmental exposures with disease creates barriers for stakeholders in taking action to prevent or reduce these health problems (Pew Environmental Health Commission, 2000). Complex health problems such as water pollution are strongly connected to the communities in which they occur, which are diverse in social, economic, political, cultural, and value systems (Kreuter et al., 2004). This complexity is not likely to be accounted for in an expert-driven problem-solving strategy.

Rittel and Webber (1973) first made this distinction in their landmark article “Dilemmas in a General Theory of Planning,” in which they categorized complex problems dichotomously as “tame” and “wicked” (Rittel and Webber, 1973). Tame problems can be defined and solved by expert-driven approaches in controlled settings—e.g., a toxicologist who assesses the potential health impacts of a chemical hazard by studying route, concentration, and duration of exposure (Kreuter et al., 2004). Problems are wicked in the sense that there are conflicting interpretations by stakeholders, and sole expert-driven approaches to solve the problem fall short (Kreuter et al., 2004). The four characteristics for determining between tame and wicked are: the problem, the role of stakeholders, the “stopping rule” (the end is defined by stakeholders, political forces, and resource availability), and nature of the problem. With tame problems the following exist: a clear definition to a problem; causes are determined by experts using scientific data; the task is complete when the problem is solved; the problem has clearly written protocols that guide the choice to a solution. With wicked problems the following exist: disagreement about problem definition, involvement of multiple stakeholders often with differing ideas about the problem and causes of it, lack of a stopping rule, and standard approaches are ruled out.

Kreuter et al. (2004) and Conklin (2002) both suggest that wicked problems are “best resolved through a planned process with input from multiple sources in an atmosphere where scientific certainty is tempered by the perspective of community stakeholders” (Kreuter et al., 2004, p.433; Conklin, 2002). This process is widely used in health promotion and known as the PRECEDE-PROCEED model (Predisposing, Reinforcing, and Enabling Constructs in Educational/Ecological Diagnosis and Evaluation; Policy, Regulatory, and Organizational Constructs in Education and Environmental Development) (Green and Krueter, 1991). This model assumes that the community is usually the most appropriate focus for population health programs. It sets out to build a strong relationship with community and as a result an environment of sustained collaboration through trust and mutual respect (Kreuter et al., 2004).

A planning strategy that has been promoted in addressing wicked problems has been that of systems thinking. The key to the systems thinking approach is the focus on cyclical rather than linear cause-and-effect; this takes into account complexity and interdependence associated with wicked problems. An application of this approach in a wicked problem context is that of the Great Lakes Basin. The Great Lakes Basin was a center of commerce and industry in the United States and vulnerable to accumulation of pollutants released as by-product by commerce and industry. The basin shared borders with Canada and more than one state, quickly making this a wicked problem with international and intrastate reach. There was great concern among the environmental public health community about newly developed evidence from the wildlife biology field (reproductive and developmental deficits, cancer, and disrupted endocrine function in a wide range of animal species) and how this may affect human health. The approach was “built on traditional elements of health protection and disease prevention (i.e., surveillance, evaluation, interventions and control strategies, infrastructure development, and impact assessment” and a success as elevated body burdens of persistent toxic substances (PCBs, dioxins, furans, and chlorinated pesticides such as DDT and mercury) decreased dramatically in six years; at the core was “ongoing problem-solving dialogue, research to answer gaps in the knowledge base, and the use of targeted health communication (advisories) on fish consumption without compromising fish as an essential element in the diets and cultures of those lining in the base” (Kreuter et al., 2004, p.448; Hicks et al., 2000, p.12).

The Great Lakes Basin is an example of how systems thinking was able to separate a wicked problem into more approachable tame problems; most importantly, a mixed-methods (quantitative and qualitative) approach combining traditional environmental health, community health, and health promotion sciences was identified by Kreuter et al. (2004) as central to the successful outcome. Health promotion has been largely absent from the environmental health field with a few notable exceptions (NIEHS/EPA and NIEHS directly) (Howze et al., 2004).

Health promotion, with its ecological and systems approaches, has much to offer in the struggle to solve environmental health problems (Howze et al., 2004). Essential skills such as health and social assessments that consider diverse stakeholder viewpoints, implementation of theoretically sound programs and strategies, collaboration across sectors, and process and outcome evaluation all have a major place in addressing environmental health problems (Kreuter et al., 2004). To bridge the gap in effectively addressing these complex health problems there is a need for an integration of environmental health with that of health promotion sciences (Howze et al., 2004; Kreuter et al., 2004; Oakley et al., 2006; Stokols,1992; Goodman, 2000; Gertler et al., 2010).

Environmental health promotion intervention strategies need to target a range of outcomes and occur at multiple levels using social ecological frameworks (Howze et al., 2004). These frameworks draw from the fields of medicine, public health, and behavioral and social sciences (Stokols, 1992). Environmental health requires explicit analysis of the interplay between the environmental resources available in an area and the particular health habits and life-styles of the people who occupy the area. This includes a range of individual and environmental factors that influence behavior and ultimately health. These can be organized into the following levels of influence: intrapersonal/individual (e.g., knowledge, attitudes, and behaviors), interpersonal (e.g., family, social networks), institutional (e.g., voluntary organization, workplace), community (e.g., local, state, and national laws and policies) (Parker et al., 2004; McLeroy et al., 1988; Hancock, 1993). The Stress Process model builds on this concept taking the complexity inherent in environmental health issues into consideration (Parker et al., 2004). Parker et al. (2004, p. 501) found that “this model focuses attention on stressors, conceptualized as environmental demands that tax or exceed the adaptive capacity of an organism resulting in psychological and biological changes that may place persons at risk of disease” making it ideal for complex environmental health problems.

2. State of evaluation science in drinking water projects in developing countries

Summative evaluations on impact and outcome became the primary focus of research since the inception of the MDG. The global trend was part of a broader agenda of evidence-based policy making that shifted attention from inputs to outcomes and results (Gertler et al., 2010). Evaluation was directed to improve quality, efficiency, and effectiveness of interventions. One way to measure impact is to perform an effectiveness evaluation which determines if an intervention has external validity (generalizability). External validity allows for further program implementation across beneficiaries beyond the evaluation sample—e.g., if an intervention is proven to be effective, policymakers can implement programs to address the issue at a larger scale (Gertler et al., 2010).

The evidence that improving access to safe drinking water reduces the risk of diarrheal disease in children is strong (Hutton et al., 2007; Haller et al., 2007; Clasen et al., 2007; Hutton and Batram, 2008; Hunter et al., 2010). Meta-analyses performed by Esrey and colleagues (1985, 1991, 1996) have created much debate among the research community on the relative importance (effectiveness) of water quantity and water quality in reducing incidence of diarrheal disease—for examples, see Prüss et al. (2002); Fewtrell and Colford (2004); Clasen et al. (2007); Hutton et al. (2007); Independent Evaluation Group (2008); Waddington et al. (2009); Cairncross et al. (2010)—(Hunter et al. 2010; Clasen et al. 2007).

Of interest is the meta-analysis conducted by Esrey et al. (1991), which reviewed 144 studies looking at various single and multiple water and sanitation interventions. The conclusion from the data suggested median reduction in morbidity was relatively low from all water improvements unless they were combined with sanitation improvement. The 1991 meta-analysis contradicted the 1985 meta-analysis, suggesting that the impact of combined improvements in water quality and quantity resulted in a lower reduction of morbidity than water quantity interventions alone. Benefits from the increase in water availability were not necessarily felt in all age groups, a finding highlighted in a previous study (Herbert, 1985). This revealed that impact depends strongly on the dominant route of exposure under local circumstances (Howard and Batram, 2003). In 2004, WHO re-evaluated existing interventions (i.e., breastfeeding promotion, improved feeding practices, rotavirus immunization, cholera immunization, measles immunization, improved WSH) to determine “the extent to which they have been effectively implemented and their effect” (Keusch et al., 2006, p.375). This led to the Fewtrell and Colford (2004) study, which was a systematic review and meta-analysis of WSH and diarrhea. Using the same data for 17 of the studies considered by Esrey et al. (1991), Fewtrell and Colford (2004) found all interventions to be effective and at greater levels than reported by Esrey et al. (1991). The most significant differences were found in water quality interventions in developing countries (Fewtrell and Colford, 2004). It has been suggested that the confidence intervals for this study and the other estimates were so wide as to show that the new figures were not significantly different from the Esrey et al. (1991) estimates. This variance was linked to differences of treatment locations, further suggesting exposure outcomes depend on local conditions. Most importantly, the Fewtrell and Colford (2004) study suggested that supply interventions seemed to reduce diarrheal levels, but this reduction was heavily reliant on studies that included provision to household connection without household storage. Specific to water quality interventions, POU treatment at the household level seemed to reduce diarrheal illness levels and the authors suggest that water quality interventions may have a larger impact than previously thought. Multifactorial interventions consisting of WSH and hygiene education acted to reduce diarrhea but were not more effective than individual interventions (Fewtrell and Colford, 2004). Many of the interventions reviewed may have had long-term impacts related to quality of life, however these studies did not attempt to quantify long-term impacts; these impacts may even have a possible distal consequence leading to a decrease in diarrhea levels. Secondary health effects have been identified by some studies, such as those on household income, children's education, and gender equity (Webb et al., 2010; Crow et al., 2011; Hutton et al., 2007).

Clasen et al. (2007, p.1) conducted a systematic review and meta-analysis specific to water quality selecting only randomized and quasi-randomized controlled trials "to improve the microbial quality of drinking water for preventing diarrhea in both adults and children in settings with endemic disease." Building upon the Fewtrell and Colford (2004) study, Clasen et al. (2007) examined the role interventions at the household level had to reduce the occurrence of diarrhea. The household interventions comprised improved water storage, chlorination, solar disinfection, filtration, combined flocculation, and disinfection. They found that interventions to improve microbial quality were generally effective in reducing the occurrence of diarrhea in adults and children. Clasen et al. (2007) highlight the heterogeneous nature of water quality projects and suggest that the magnitude of effectiveness may depend on a variety of conditions that research has yet to explain. One explanation is argued by Eisenberg and colleagues (2007), who suggested that the benefits of a water quality intervention depended upon sanitation and hygiene conditions. They found when sanitation conditions were poor, water quality improvements may have had minimal impact regardless of amount of water contamination, noting "each transmission pathway alone is sufficient to maintain diarrheal disease, single-pathway interventions will have minimal benefit, and ultimately an intervention will be successful only if all sufficient pathways are eliminated" (Eisenberg et al., 2007, p.846). Additional evidence supporting the Eisenberg (2007) perspective can be found with the increasing evidence linking the efficacy of household water quality interventions with that of the level of community sanitation (Esrey, 1996; Gundry et al., 2004; VanDerslice and Briscoe, 1995). Of the 42 controlled trails in the Clasen et al. (2007) meta-analysis pooled estimates from 12 suggest household-based interventions were more effective than water source based interventions.

However, they excluded two water source studies (used different measures of effect and could not be pooled) which had efficiency levels as high as household interventions. The first was a quasi-RCT using household-level chlorination with calcium hypochlorite in rural Saudi Arabia over six months (Mahfouz et al., 1995). The second was a quasi-RCT with multiple arms involving improved water supply, sanitation, hygiene education, and oral rehydration therapy for those with diarrhea in rural villages on the Ivory Coast over a five-year span—the longest of all studies reviewed (Messou et al., 1997). Across all interventions, POU treatment was generally considered effective when positively associated with compliance.

Point-of-use water treatment is difficult to implement with respect to compliance both during and post-intervention; this difficulty in compliance was echoed in more recent studies (Ram et al., 2007; Luby et al., 2008; Arnold et al., 2009). Ram and colleagues (2007) found that while a large proportion of participants (73 percent) reported use of a household-level chlorination method, a minority of families (15 percent) purchased safe water storage containers; they did not track the study group post intervention (Ram et al., 2007). Luby and colleagues (2008) indicated that POU water treatment was difficult to get to scale in rural Guatemala, even after efficacy was demonstrated and an aggressive marketing approach was pursued. Arnold and colleagues (2009) evaluated a pre-existing POU and hand-washing intervention, finding that modest gains in water treatment behavior resulted and no change in hand-washing behaviors were found. The World Bank's Independent Evaluation Group's (IEG, 2008) review suggested that water treatments at the source did not appear to have health gains and health impacts of combined methods did not appear to have a greater impact than any single approach—similar to the conclusions of Fewtrell and Colford (2004) (Independent Evaluation Group, 2008). Schmidt and Cairncross (2009, p.990) recommend caution when interpreting the results from POU studies, concluding that "widespread promotion of household water treatment is premature given the available evidence." Arnold and Colford (2007) provide further evidence that widespread POU promotion may be premature, pointing out that the length of the trails was linked to reduced effectiveness, meaning that POU efforts may be difficult to sustain over time.

Nearly all reviews to date have focused on incidence and morbidity versus death as an outcome (for examples, see Fewtrell and Colford, 2004; Clasen et al., 2007; Hutton et al., 2007; Independent Evaluation Group, 2008; Waddington et al., 2009). Cairncross et al. (2010) present the most recent review of the literature focusing on mortality from diarrheal disease. Their key messages were the following:

- The effect of hand washing with soap is most consistent with a 48 percent reduction in diarrhea mortality.
- The effect of water quality improvements in mortality found in RCTs seems to be affected by bias and is not seen in blinded studies.
- The evidence for effect of sanitation on mortality is weakest—randomized trials are needed—but there may be a 36 percent reduction.
- Though evidence is weak compared with clinical RCTs, it is enough for action.

De Wilde et al. (2008) utilized an integrated method for evaluating safe water programs. This is a rare, perhaps the only, example of an integrated method using both process and impact evaluation in the drinking water literature. The researchers created a three-step framework that considers the technical performance of the safe water system, community preferences, and re-contamination through transport, storage, or hygiene practices. The framework was used to evaluate the performance and impact of a community-based water purification program in rural Mexico five years after program implementation. It was found that only two of the 21 communities met all requirements for effective program performance. Of the villages where diarrhea was caused by poor drinking water quality, only six consistently had a supply of safe water and only eight communities reported that they obtained water from the water treatment system.

Their process evaluation revealed that the intervention was unlikely to have an effect on gastro-intestinal illness; household preferences, constraints, and choices were the main factors that determined whether the water treatment system was used. Community members were aware of the value of safe drinking water and believed this was provided by the water treatment system. The cost of using it in terms of time, money, and labor, in addition to the availability of alternative sources of drinking water, determined water-use decisions, leading households to choose water sources that were seen to be more convenient. By combining impact and process evaluations the authors were able to identify that a primary leverage point for program improvement was user convenience. Rural water programs assessments typically attribute program failure to poor maintenance; De Wilde and colleagues (2008) were able to identify convenience was the factor that led *to* poor maintenance.

II. SAFE DRINKING-WATER PROJECT

A. Introduction

The main impetus for the provision of safe drinking water in developing nations is to eliminate the health risk (e.g., diarrhea) posed by enteric pathogens (IOM, 2009; WHO, 2001). Unfortunately, a large number of safe drinking-water programs fail to create long-lasting solutions (Hunter et al., 2009; Zwane and Kremer, 2007; Miguel and Gugerty, 2005; Lee and Schwab, 2005). This is the case in the developing country of Guatemala.

Guatemala has designated a large percentage of international investment into their water infrastructure, but continues to struggle to maintain safe drinking-water programs. At a rural level, projects are planned and concerted with communities, which ultimately assume their management (del Rosario Navia et al., 2011). High poverty rates, low public expenditure on public health, and no financial structure in the water sector have resulted in a population with a high level of access to improved drinking sources, but with water quality that is often poor and water supply and management of water resources that are often lacking (Spillman et al., 2000; Moscoso, 2008; del Rosario Navia et al., 2011). The current developments are insufficient and unsustainable, leading to high rates of diarrhea morbidity; most affected are children and the rural poor (Drakenberg and Slunge, 2006; WHO, 2006; Global Health Observatory, 2012; Programa de las Naciones Unidas para el Desarrollo, 2010; Moscoso, 2008).

While the case of Guatemala is not a sole example, these challenges arise because safe water programs are strongly based in environmental health where risk assessment and risk management are focused on creating barriers to transmission primarily by engineering solutions in water supply (e.g., piped water, hand pumps) and quality (e.g., covered wells, chlorination). These solutions are often focused on a linear cause-and-effect dichotomy and do not take into consideration complexity and interdependence of factors outside the scope of engineering outcomes (Waddington et al., 2009; Howze et al., 2004; Kreuter et al., 2004). Resulting evaluations from these programs are not able to identify why a program was or was not sustained (De Wilde et al., 2008).

The lack of understanding can be attributable to the tunnel vision created when one focuses solely on evaluation of engineering outcomes and programmatic goals (e.g., the duration of the project, the number of wells, and financial goals).

This tunnel vision is inappropriate as safe drinking-water programs are complex and require a different approach—traditional expert-oriented approaches are often inappropriate, yet are the focus of the majority of safe drinking-water programs (Kreuter et al., 2004; Howze et al, 2004). Part of the solution is to consider the complicatedness of programmatic implementation. The other is accounting for complexity and the interdependence of factors.

Attributable to complicatedness of interventions is the implementation of safe drinking-water infrastructure. Inadequacies in distribution systems, reliability, drinking water storage, ability to meet and maintain consumer demand, and continuous supply are infrastructure elements often disregarded in evaluation and should be considered (Lee and Schwab, 2005; Hunter et al., 2010; IOM, 2009). Complexity can be associated with the multiple transmission pathways of enteric pathogens and their appropriate barriers as well as the social, economic, political, cultural, and value systems of those being benefited by a safe drinking-water program. These factors of complexity are often disregarded in safe drinking-water evaluations and the resulting literature (Eisenberg et al., 2007; Krueter et al., 2004; Howze et al., 2004). It is important to consider the complicatedness of programmatic implementation, but most ignored are the societal factors (e.g., patriarchal decision making, cost of infrastructure maintenance, state-run water subsidies, and distrust of outside groups) involved in the complexity, which have a strong influence on programmatic uptake (Waddington et al., 2009).

De Wilde et al. (2008) authored a study that is an example of how evaluation can provide insight into why or why not a safe drinking-water program was sustained. In their specific analysis, they were able to identify that a primary leverage point for program improvement was lack of user convenience, which led to poor maintenance. De Wilde et al. (2008) came to this conclusion because they applied an evaluative lens to what is typically considered to be only an engineering project.

A similar approach is used with an engineering project conducted by the Engineers without Borders University of Illinois at Chicago chapter (UIC-EWB) in the rural community of Cerro Alto, Guatemala. This evaluation presents early portions of an ongoing evaluation effort that provides a useful aide to other service groups on how to set up more holistic and feasible evaluations of safe water projects traditionally focused on engineering outcomes.

B. Context

This project was carried out in central Guatemala, in the province of Chimaltenango, in the village of Cerro Alto. It is a rural population of approximately 1,040 residents mainly of Kackchiquel decent, an ethnic subgroup of the Maya. The village is located on a semi-remote mountainside approximately 1820 meters above sea level. It is identified as semi-remote because only one road connects the village to a main road approximately 3 kilometers distant and the nearest urban center, Chimaltenango, is approximately 7.5 kilometers distant. This road is not paved and takes between 30 and 45 minutes (by car) to reach Chimaltenango.

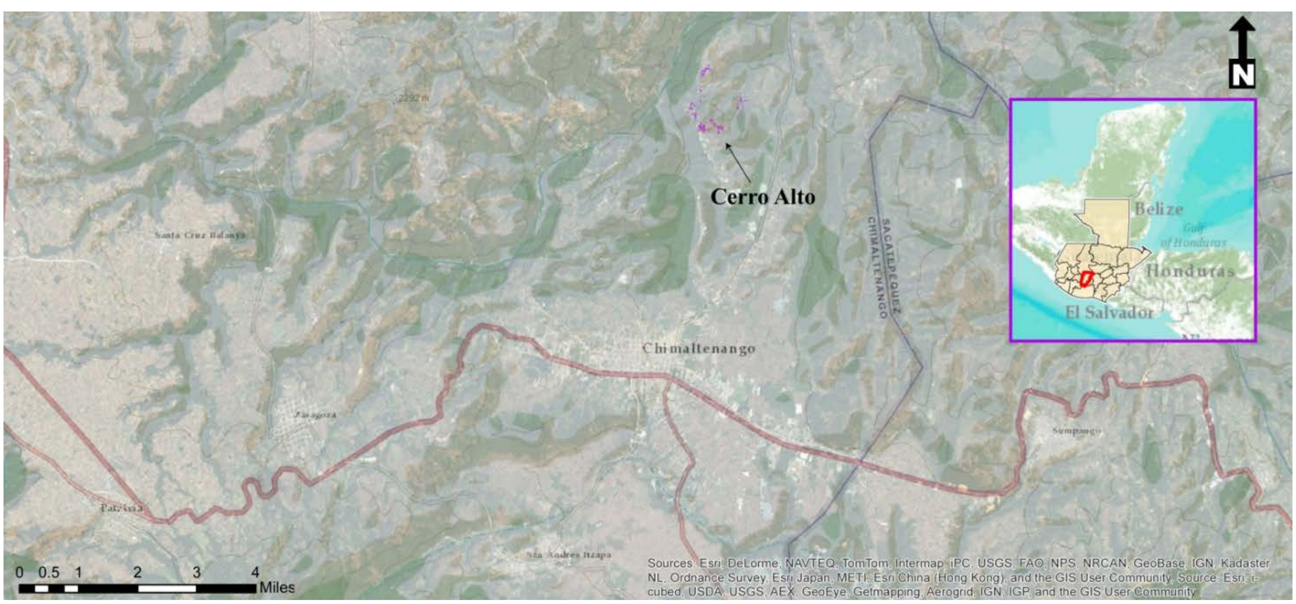

Figure 8. Intervention location.

This project was comprised of six assessment trips from 2008–2011, an implementation trip in 2012, and is ongoing. The impetus behind the implementation trip in 2012 and the focus of our evaluation came from a health assessment conducted between 2007 and 2008. This identified gastrointestinal related illness (specifically diarrhea) as a major concern and contributor to health burden within the village; those with greatest risk were identified as younger children. It was further discovered that the community believed burden was related to the installment of a water piping system in 2006. To address this, multiple system and health analyses were conducted between 2008 and 2011. Analyses included community planning surveys, community health surveys, and engineering and technical analysis of the water system.

Primary findings concluded that water was easily accessed (delivered to taps at the household level), however delivery was intermittent and necessitated storage. The intermittent nature of the system was due to bad water system design, limited knowledge of infrastructure maintenance techniques, lack of funding for maintenance, and varying pressure within the system.

Bad water system design was due to varying pipe diameter throughout the system; likewise the pressure required to service all taps was insufficient. Further limitations were a result of the capacity of the pumping system to fill the water reservoir. The time it took the pump to fill the reservoir required separating the supply into sectors. This limited the number of hours and days in which water could be distributed to sectors of the community and led to storage of drinking water.

Initially, water quality problems were believed to be a result of economic hardship and acceptability of treatment techniques. The community's main source of providing safe water was a chlorinator installed in April of 2008 that was in disrepair six months later. Availability of chlorine tablets was found to be dependent on a government subsidy that was inconsistent and led to rationing of tablets (the community claimed to use three tablets rather than the Department of Public Health's recommendation of five). Upon further investigation it was found that tablet use had been lowered to two tablets because residents complained of resulting smell and taste from chlorine.

Water testing in 2009 found insufficient chlorine concentrations throughout the water system to meet acceptable levels to deter negative health impacts.

Microbial testing conducted during 2008 and 2009 determined that chlorination may not be vital to maintain water quality as the main source of water was from a protected deep well (244 meters) which had non-detectable levels of indicator bacteria. Further microbial testing throughout the water system found that drinking water storage containers had elevated levels of indicator bacteria for diarrhea and determined a source of contamination (Lacey et al., 2011).

C. Materials and Methods

1. Process evaluation

Process evaluation looks at how program activities are delivered. It helps determine the degree to which an intervention was implemented as planned and the extent to which it reached the community. Most important, it identifies implementation quality and is important for demonstrating effectiveness.

Data for the process evaluation were comprised of existing documents and primary data. For content measures the following were considered: extent to which what was done matched what was said would be done; if the water system fit with community desires; the attractiveness to community; relevance to community intervention reflects best practices. For implementation the following were taking into account: basic ethical considerations; financial accountability; respect for cultures and views; the implementation of sustainable practices.

2. Intervention content

An important aspect to a successful intervention is to compare planned work with completed work. A 2010 memorandum of understanding between the UIC-EWB group and the community of Cerro Alto was compared to an Engineers without Borders report and to documented telephone and email communications leading up to and through the implementation. Data were organized by date, time, and communication narrative.

Another important component of a successful intervention is that the intervention is keeping with community desires and is attractive to the community. We assessed community desires through a community planning survey where residents were asked about their concerns and needs in the community. Community survey data were organized by responses to the following questions: use and design of cooking stoves, types of latrines used, methods of garbage disposal, methods for waste water disposal, biggest concerns in the community, and what the next UIC-EWB project should be. To identify the attractiveness to the community, documented communications from meetings between UIC-EWB and community leaders were reviewed. Data were organized by meeting date, time and meeting narrative.

The final component of a successful intervention is implementation of industry best practices. To assess best practices, we reviewed a UIC-EWB report with expert input from a professional engineer and an alternative intervention analysis. Data in the alternatives analysis were organized by intervention alternatives and by category topics. Alternative interventions were organized by ceramic filters, chlorination, larger tank, and larger pump. Categories were organized by complexity, cost, operation and management issues, constructability, availability of materials, acceptance from the community, sustainability, and effectiveness of alternative options for improving water quality and supply. Data from expert input were organized in narrative form. The two documents were compared to see if recommendations matched.

3. <u>Implementation of the intervention</u>

When working with communities it is vital to make sure that basic ethical considerations are in place prior, during, and after intervention implementation. Documentation of telephone, email, and written communications were kept during the entire duration of the 2012 implementation project. We reviewed these documents in addition to UIC-EWB reports that had documented community relationships and institutional review board (IRB) approval to assure approval was granted prior to study of human subjects for study purposes. Data in reports were organized by date and then analyzed using thematic analysis of gender roles, governance, and non-governmental committees. The communications were compared to the community profile to determine if the intervention adhered to the community's culture and views.

To assure sustainability of the intervention we considered the community's ability to operate and maintain the water system pre-intervention and four months post-intervention. Water system operation and maintenance (O&M) documentation was reviewed from UIC-EWB reports. Data were organized in narrative form and examined through thematic analysis documenting meeting minutes with water committees and local government. Particular attention was given to how the community paid its water system bills and how they allocated funding for maintenance. In addition to O&M documentation, we reviewed the community's ability to afford and pay its utility bills. Particular interest was given to determining a payment schedule and identifying delinquencies in payments. We requested electricity bills for 2012 and were able to attain electricity bills from April to October of 2012. For successful long-term O&M of a water system it is important to have funding set aside for upkeep and governance to delegate the necessary tasks to keep the system operating optimally. As a preliminary first step we reviewed documented communications to determine if a water committee and maintenance fund had been implemented in the community 2011–2012.

4. <u>Development of outcome measures</u>

We assessed existing and newly collected data to inform our recommendations for metrics to assess outcomes over time. To develop outcome measures we considered measures of health and water supply measures of energy efficiency and cost. Outcome measures were separated into health and water supply-related metrics. Health related measures are intended to monitor change in burden of diarrhea illness by creating a baseline measurement of diarrhea illness.

Water supply-related metrics considered conversion of the supply system from intermittent to continuous; energy efficiency of new pump technology versus old pump technology; cost of the new pump; current capacity and future capacity to meet consumer demand.

The Chimaltenango Department of Public Health (CDPH) has a passive surveillance system of reportable diseases, similar to the system in the United States. Information on reportable diseases is documented by town, and observed for overall case counts for the entire year. Cases are reported to CDPH from clinics in Cerro Alto, which are run by a government-hired non-governmental organization. Every week they notify cases of diarrhea to the central government. It was unclear whether or not these cases were laboratory confirmed, what tests were performed, or if case definitions were used.

A standardized data extraction form was created and data were acquired from an epidemiologist at the CDPH on aggregated cases of diarrhea occurrence by year, month, and age group for Cerro Alto. The same process was repeated with a lay health worker in the community of Cerro Alto. The lay health worker data came from an informal active surveillance program (IASP) the community had in place. The IASP was instituted by particular members in the community known as *promotor/a* and *vigilantes* who practice natural and or traditional medicine. All medical records are maintained by one community member. This community member provided records in aggregate on cases of diarrhea occurrence by year, month, age group, sex, and severity. Age groups were organized by newborn to 6 years, 7 years to 15 years, and greater than 15 years. Sex variables were male and female. Severity variables were mild, moderate, and severe. Case definitions were determined for children as follows: mild—non-continuous watery stools were identified; moderate—dehydration is obvious; severe—unable to keep in liquid and foods. Case definitions for adults of severity were identified by the patient. Diarrhea cases were examined using simple counts and measures of central tendency to conduct trend analysis. These data were used as numerator data for prevalence estimations.

To measure prevalence, population data were acquired from the Instituto Nacional de Estadística (INE) and UIC-EWB. The INE conducts a national census in which the most recent census was 2002 (the 2012 census had been conducted but the data was still not available). Data are acquired by INE by household surveys identifying number of people in each household, age, gender, ethnic group, literacy level, education, and employment by gender. The UIC-EWB carried out two separate surveys to use in population growth estimation. The first was conducted in 2009 by random sample of 27 in-home surveys identifying head of household, number of people in each household, age, gender, and family relationship of each member of household. This methodology was repeated in 2012 with a sample size of 32. All census and survey data were then combined and linear and exponential regression were used to predict population and proportion of population in their respective age groups from 2009–2012. These data were used as denominator data for prevalence estimation. There were some inconsistencies in the community health data. In 2010 there were 55 more cases reported by age group than by severity. In 2011, there were 46 more cases reported by severity than by age group. In 2012, there were three more cases reported by age group then by severity.

When creating prevalence rates for age groups, census data and lay community health worker data were used. The community source data had the youngest population group separated at the 6-year age mark and in census data it was separated by 5-year age mark. We used the census data up to the 5-year age mark for prevalence estimates in the 0–6 year age group and this could affect both the 0–6 year and 7–14 year age groups. All statistical analysis was done on Microsoft Excel 2010 and graphs were created with Adobe Illustrator CS5.

Review of communication between UIC-EWB and the water committee and local leaders was conducted to ascertain if the following had been installed: high capacity pump, two transformers, a float tank switch, pressure reducing valves. Further review of the same documentation was conducted to ascertain if the following objectives had been met: water pipe burial; residents had been informed of the purpose of the project, to close taps when not in use, to watch for leaks, and to report if no water was reaching their taps during initial testing. The final objective was to test and document problems in the supply system post-continuous change. This was done by reviewing the UIC-EWB post-implementation report for 2012 for documented communications three months post continuous system implementation.

To measure the energy efficiency of the newly installed pumping system we considered whether the new pumping system used less overall energy than the old pumping system, taking total active energy consumption over time also known as kilowatt-hours(kWh). Electricity data were acquired from local utility, EnerGuate. Data were organized by bill date and active consumption (kWh) per month, and were analyzed using trend analysis of active consumption from December of 2010 through October of 2012 measuring mean monthly difference among years. All statistical analysis was done on Microsoft Excel 2010 and graphs were created with Adobe Illustrator CS5.

Most important to the community was installing a new system that would incur less overall monthly electricity costs. To consider the cost benefit of the pump, photocopied electricity bills were requested from a community leader. We attained six months of electricity bills from April through September of 2012. Data was organized by monthly cost in quetzals and converted to US dollars using exchange rates from March 4, 2013; 1 USD was equivalent to 7.84 quetzals.

In addition to understanding if the community had sustainable practices in place—i.e., the ability to pay for and maintain their water system—it is just as important to estimate current and future water demand to assure the pump had capacity to meet long-term demands. We used data from household demand calculations, flow rate of old pump, estimated flow rate of new pump, number of water taps, and reservoir volume. Data were attained from UIC-EWB engineering and technical documents. Census and survey data used to predict population for diarrhea prevalence data were used to predict population growth to 2022; demand was estimated using the average daily use estimates of water predicted in UIC-EWB technical documents and multiplied by population.

Table II

DATA SOURCES BY METRIC

Metric	Source
What was done matched what was said would be done	UIC-EWB
Water system fit with community desires	UIC-EWB
Attractiveness to community	UIC-EWB
Project reflected best practices	UIC-EWB
Basic ethical considerations	UIC-EWB
Financial accountability	UIC-EWB
Respect for cultures and views	UIC-EWB
Implementation of sustainable practices	Communications with Community Leader
Conversion of the supply to continuous	Community Leadership
Energy efficiency of new pump technology vs. old pump technology	Energuate (electric utility)
Cost of the new pump	Energuate (electric utility)
	Utility Bills (Community Leader)
Current and future capacity to meet consumer demand	UIC-EWB
Baseline measurement of diarrhea illness	Lay Community Health Worker
	Chimaltenango Department of Public Health
	Instituto de Estadísticas

Approval from the IRB was obtained under expedited review and was granted on May 3, 2012 by the Office for the Protection of Research Subjects at the University of Illinois at Chicago (Protocol #2012-0376).

D. Results

1. Intervention content

Our group had discussed and received approval from community leaders for design upgrades which included installation of a larger more efficient pump and an improved piping network in various locations. During the 2012 implementation trip community members identified the need to improve the water system and approved of UIC-EWB intervention. Communications during community meetings on the 2012 implementation trip identify UIC-EWB presenting the new pumping system as being more efficient and should reduce overall electricity costs.

Expert input from a professional engineer determined the prior system was “undersized“ and unable to meet the “demand conditions of the system.” The installation of a more efficient and powerful pump in combination with a reduced voltage motor starter would “reduce motor runtime” and result in lower electrical usage through an “increase in pumping rate.” The alternatives analysis identified a larger pump as the best option for an intervention matching the expert recommendations.

The high-capacity pump did not arrive during the implementation trip in January, testing of continuous flow did not occur. Further challenges occurred in late January early February when the pump was held at Guatemalan customs due to insufficient documentation. Delays in approval for electrical contracting work held back the project until May. Figure 9 is a timeline of events in 2012 from the implementation trip to the full function of the pump.

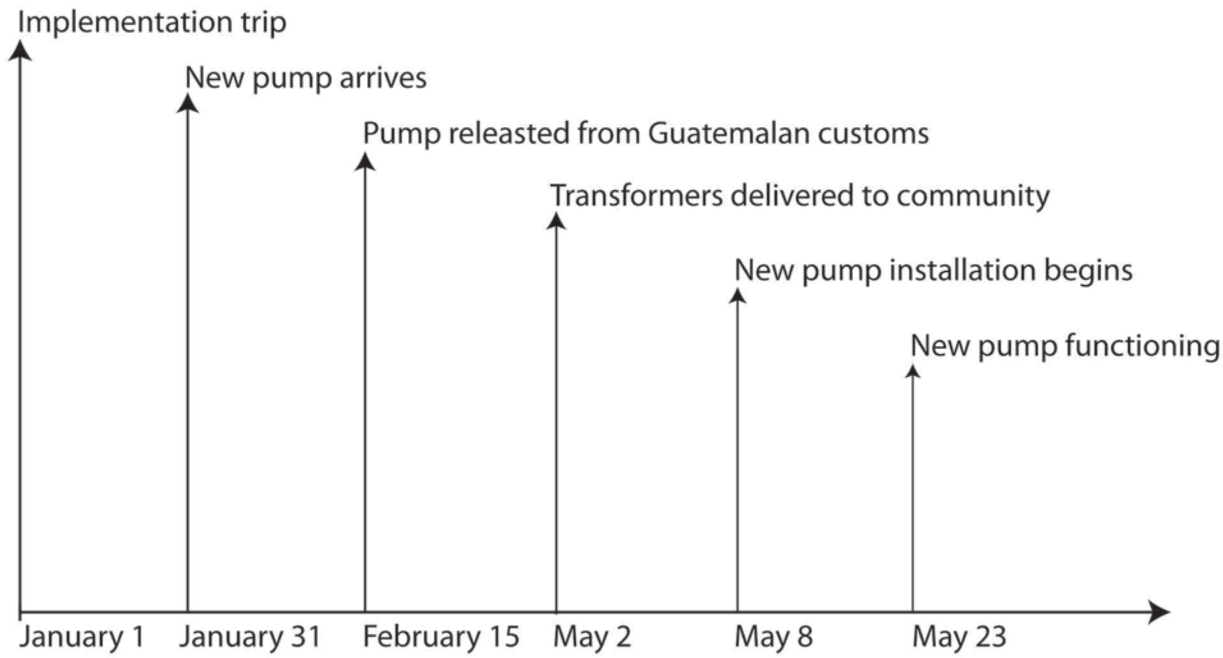

Figure 9. Timeline of events leading to fully functioning water pump in Cerro Alto, Guatemala.

2. <u>Implementation of the intervention</u>

Approval from the IRB was attained prior to requests, and surveys were done to be used for study purposes. Relations between UIC-EWB and the community were documented as “professional and respected” while relations within community leadership were explained as “strained.” A specific case was documented in which male leadership respectfully declined to offer assistance in acquiring public health data on diarrhea from the CDPH on grounds this was what the water committee was responsible for— the water committee was led by a woman. This case occurred after signing a letter of support stating this male in leadership would assist in acquiring these public data.

The community depended “heavily on government subsidies” to pay for electricity for the water system. Communications with community leadership in 2012 identified three tiers for a monthly payment structure—full payment for service at $10.20, shared service at $7.40, and full service at 50 percent of cost for widows and special cases at $5.10—with a total of 162, 31, and 11 users, respectively. This totaled $1,938.52 per month.

Community leadership met several times and had begun planning development of an O&M fund. Legality of the fund was the main challenge identified. The agreed upon funding scheme was a monthly addition of $0.64 per user to be paid at time of billing; as of October of 2012 the O&M fund had not been created though a water committee had been created.

Further examination of bills from April to October of 2012 showed that the community owed an additional $1,340.31 for previous bills which had grown to $1,766.84 by October. Official seals were stamped on each bill when payment occurred; all bills were stamped two months past due.

3. Outcome measures

Health outcome data showed that there was reasonable agreement between CDPH's total monthly cases of diarrhea and severe diarrhea cases reported by the lay community health worker (Figure 10 and Figure 12).

Figure 11 shows that the newborn through less than 6-year age group were disproportionally affected at a higher rate than other groups; over the past three years this group was approximately 20 percent of the population and suffered 70 percent of the diarrheal burden. Furthermore, a majority of cases reported by the lay community health worker were mild (Figure 12) and there is reasonable agreement between mild cases and the number of cases in the newborn through younger than 6 years age group (Figure 11). It can also be observed that prevalence in the community fluctuated year to year with peaks during the wet seasons (Figures 10, 12).

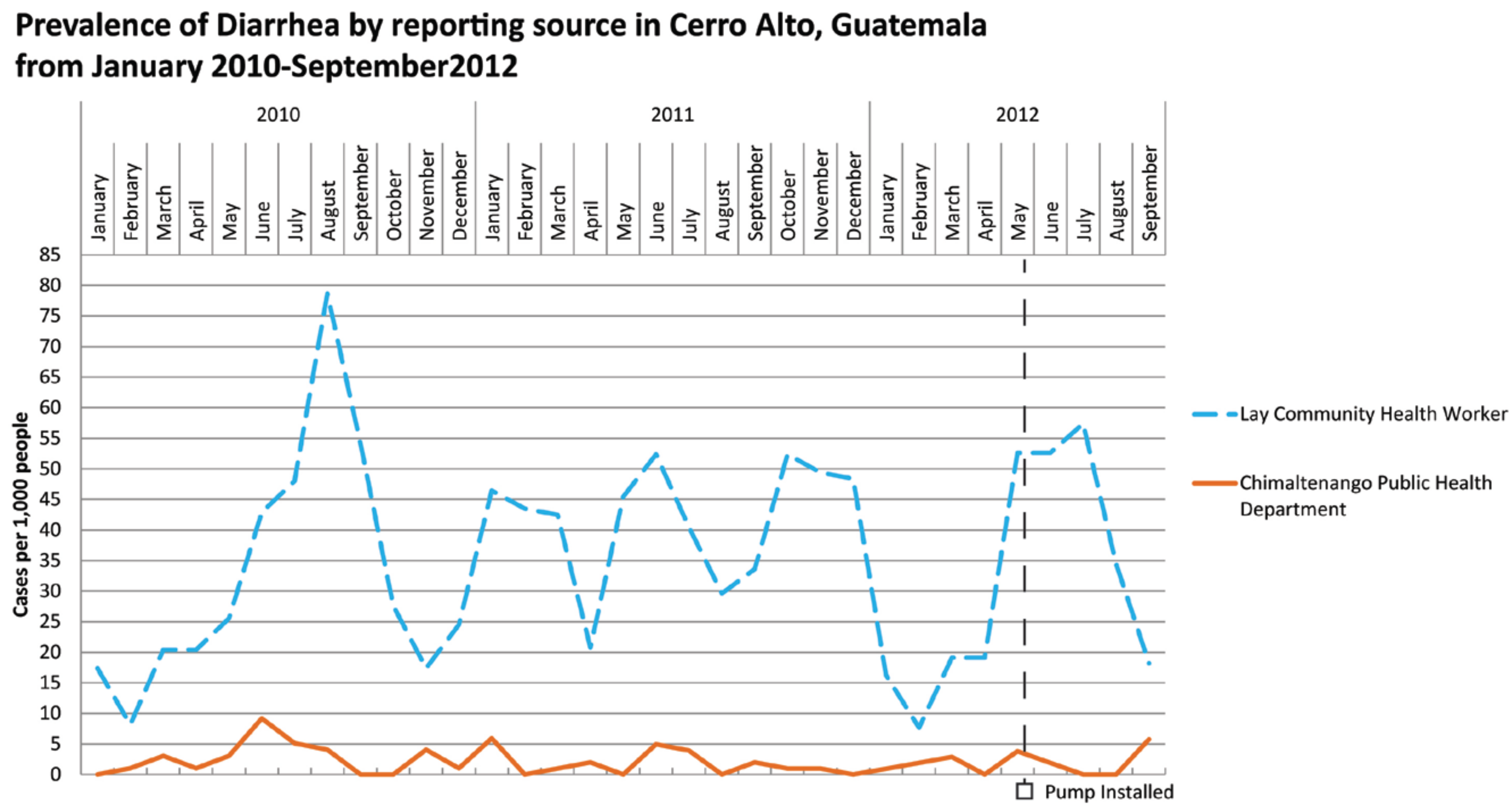

Figure 10. Diarrhea prevalence by two different reporting sources in Cerro Alto, Guatemala.

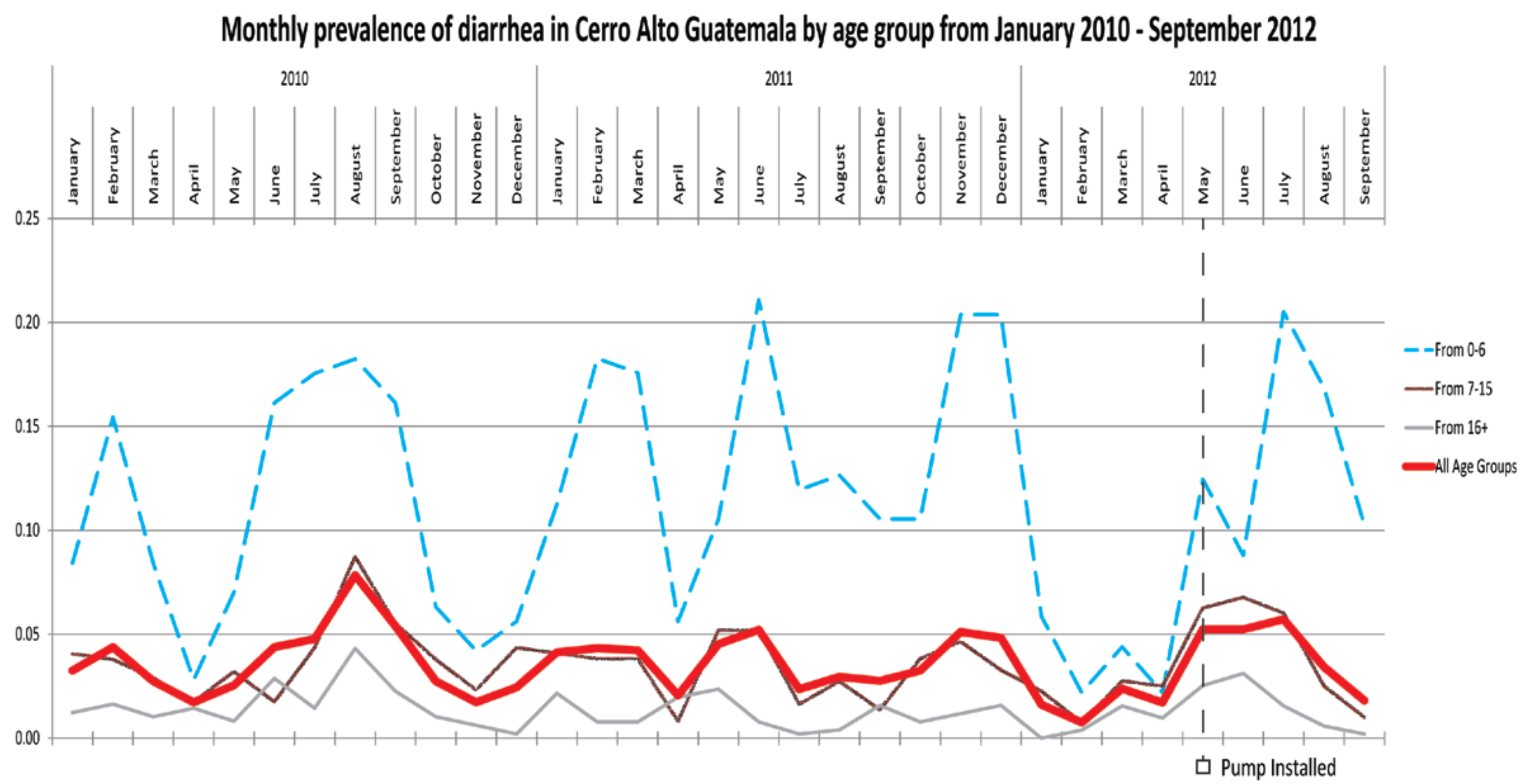

Figure 11. Prevalence of Diarrhea by Age Group reported by lay community health worker.

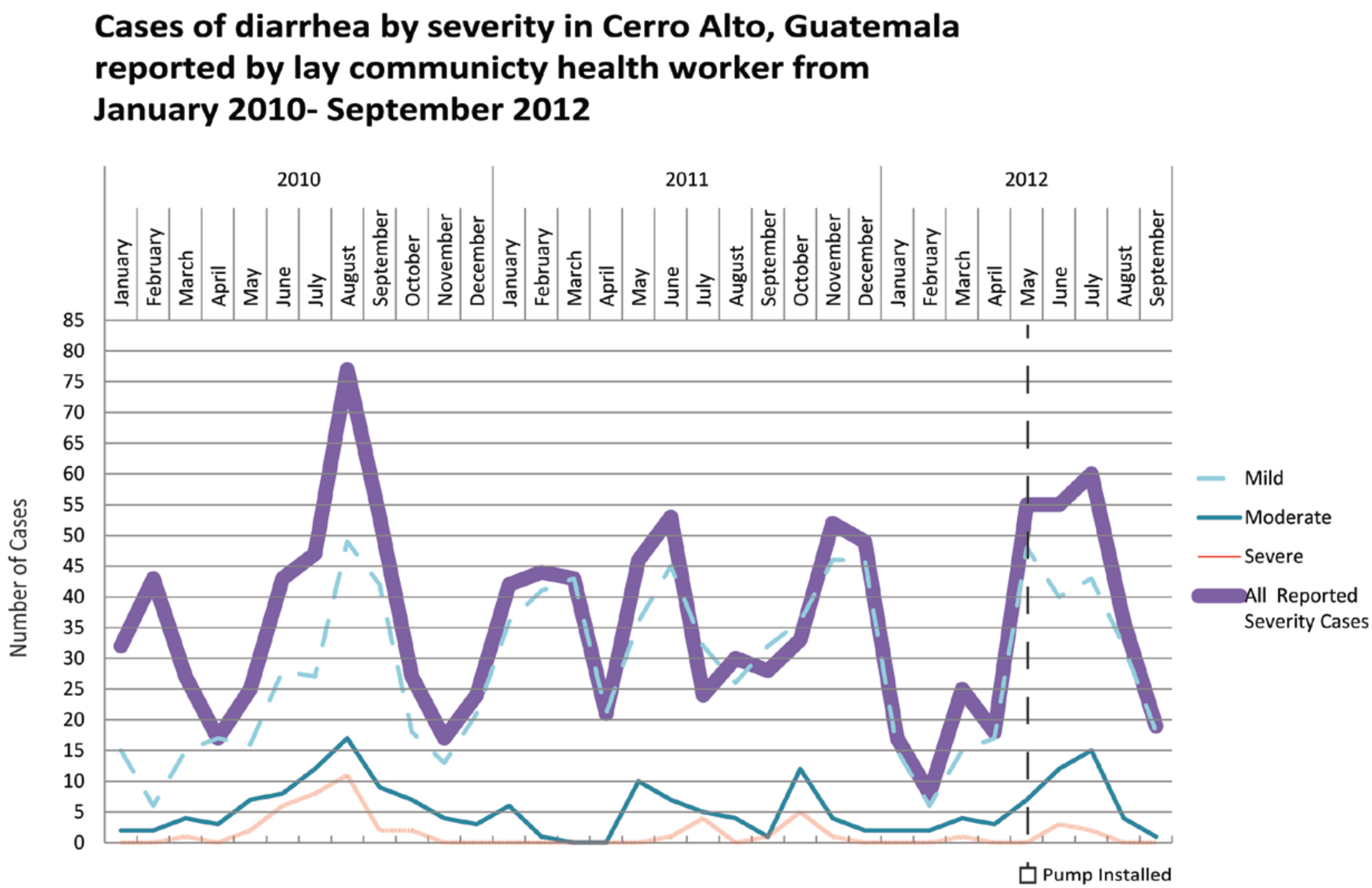

Figure 12. Severity of diarrhea cases reported by lay community health worker.

As of October of 2012, the high-capacity pump and two transformers had been installed; the float tank switch was not installed, the pipes were not buried, and the pressure reducing valves were not installed. Telephone conversations during August of 2012 confirmed that water was still being supplied intermittently.

Energy consumption of the newly installed pump was lower than overall and annual averages (Figure 13). While energy consumption went down, monthly costs went up and are at the highest since January of 2011 (Figure 14). Bills from April to September revealed that the rate at which energy consumption was charged (dollars/kWh) increased from $0.12 to $0.14 to $0.16.

In 2012, there were 204 connections with an estimated 1,050 residents. On average, 26 gallons are needed daily for consumption per person. To fulfill current needs of the community a minimum of 27,300 gallons would be needed per day. In 2022, an estimated population of 1,385 would require 36,010 gallons per day.

The original pump system was comprised of two pumps that had a combined flow rate of 109.2 gallons per minute (GPM). Often only one pump was used with a flow rate of 67.6 GPM; the newly installed pump's flow rate is 150 GPM. The original pumping system (when combined) could meet daily demand in 4.17 hours. In 2022, it could meet demand and would take 5.5 hours. The new pumping system could meet daily demand in 3.03 hours. In 2022, it could meet demand and would take 4 hours.

The water reservoir has an estimated capacity of 11,477.8 gallons. Outflow from the reservoir is 112.65 GPM. The original pump systems combined had a flow rate which was insufficient—inflow into the water reservoir was less than outflow. The new pumping systems flow rate was sufficient—inflow into the water reservoir was more than outflow and allows for 24 hour use.

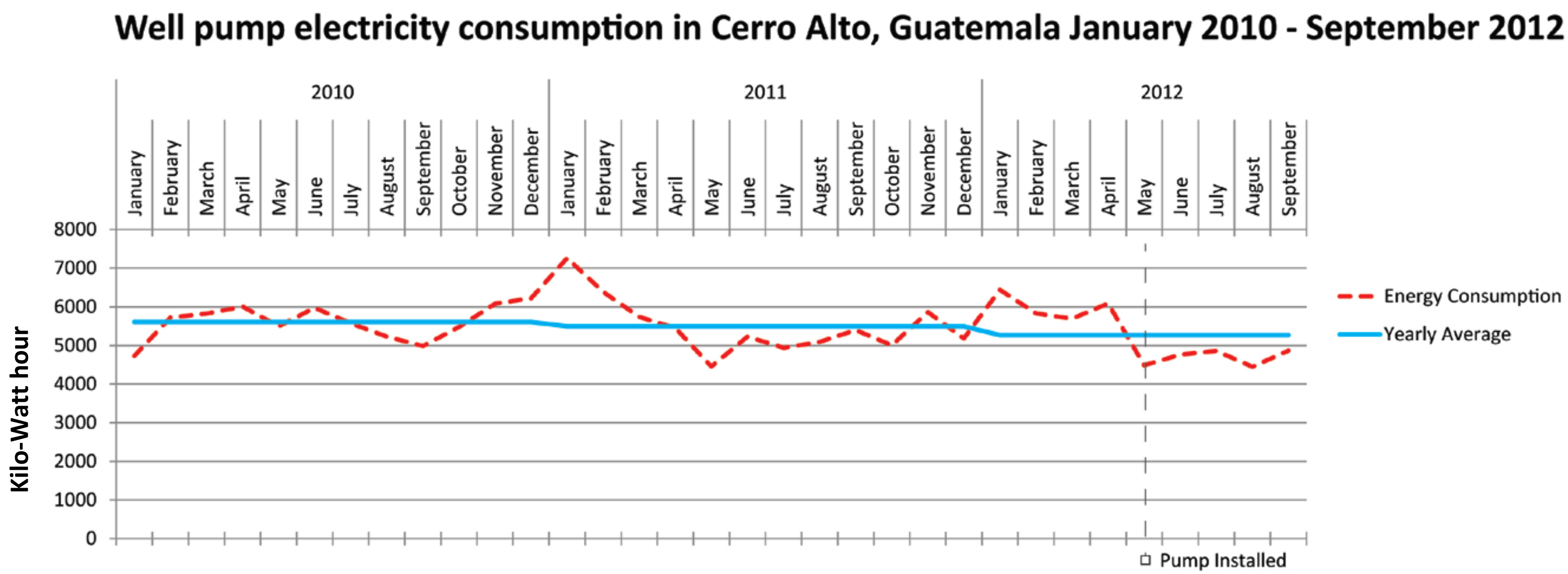

Figure 13. Electricity consumption in kilowatt hours in Cerro Alto, Guatemala.

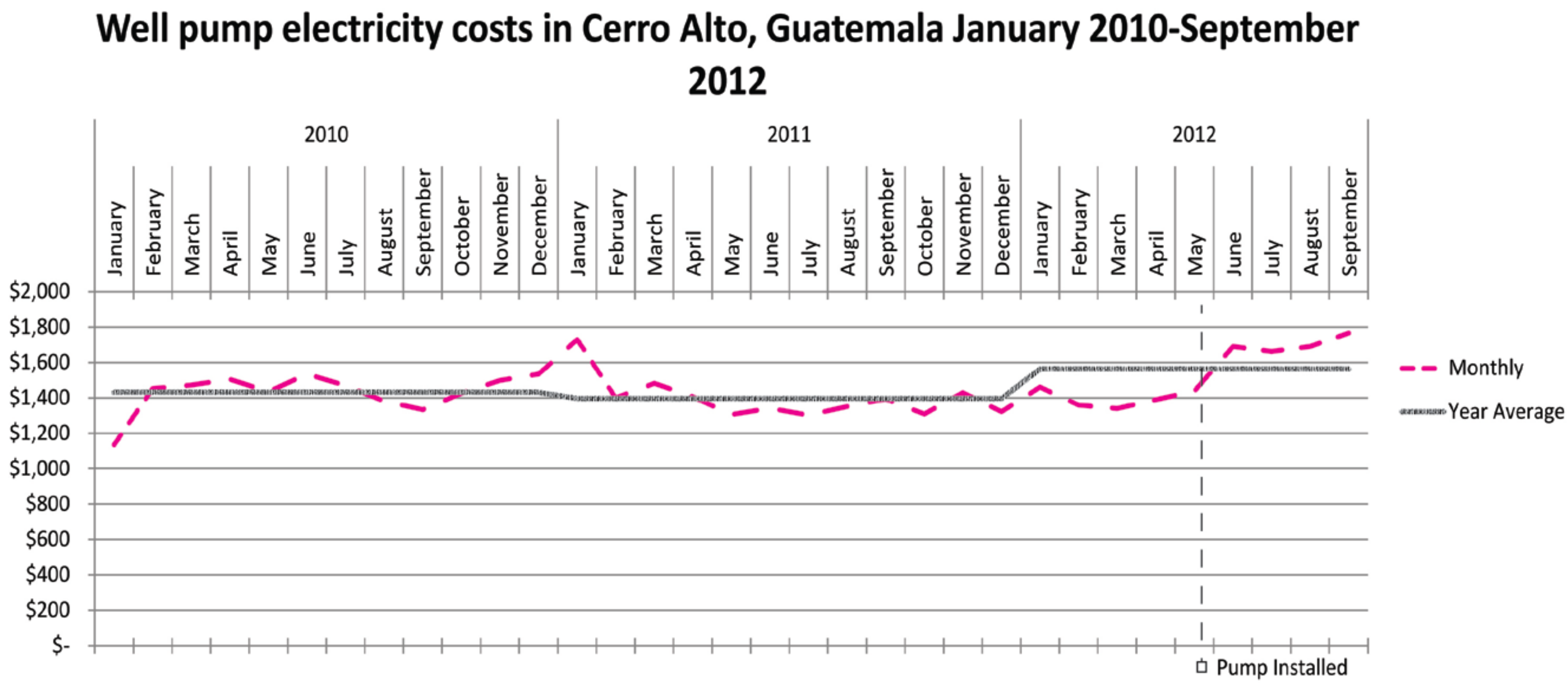

Figure 14. Monthly electricity costs of well pump in Cerro Alto, Guatemala.

E. Discussion

1. Discussion of results

The process evaluation revealed the community supported the implementation of a safe and continuous system; however, there were challenges in how to manage and maintain it after implementation. Strained relationships in leadership tied to gender roles challenged the provision of continuous water in this community. The process evaluation also revealed that the expectation of the new pumping system was to reduce electrical costs associated with pumping water and to do so at a higher capacity. While the system was considered more efficient and had a higher capacity, early outcome measures revealed costs were the highest they had been during the past three years. Ongoing efforts in education and communication will need to address the increases in cost as community satisfaction will be strongly tied to maintenance going forward. Special attention and strategy will also need to address gender roles in the next stages of implementation and monitoring.

A major strength of employing explicit process evaluation was its ability to document both content and implementation related topics in a dynamic setting. During the implementation of this project many unintended events occurred that required adaptation of the intervention; to date, a continuous system has not been attained.

We were successful in developing measures of preliminary and ongoing assessment of efficiency, cost, trends through time, and consumer demand. These factors are often ignored in the drinking-water evaluation literature (Lee and Schwab, 2005; Hunter et al., 2009). We were able to acquire baseline information on diarrhea prevalence in the community and highlight the reliability of the community *promotoras* (lay community health workers) as a data source for assessing future health outcomes. This directly links to points made by Kreuter et al. (2004) and Howze et al. (2004) on limitations of expert oriented approaches. Here we show that “expert” can be thought of more broadly and sustainably.

In this instance, the UIC-EWB group created and implemented a census to determine current and future demand. To ensure sustainability, the promotoras could also be used for ongoing population estimates. Having an accurate population estimate can be used to measure the rate at which diarrhea is affecting the community, instead of having to rely on UIC-EWB or a government census every 10 years. Rates are more useful than simple counts because they are tied to population and growth, thus a more accurate account of diarrhea prevalence can be determined in the community. Ongoing efforts should focus on training community members, especially the promotoras, to conduct their own census and how to plot rates to measure prevalence and ideally incidence. This will assure long term sustainability of the intervention and transfer of knowledge to enable the community to link future health outcomes with the continuous water system.

2. Limitations

Much of the data presented here were obtained through months of follow-up via email and telephone conversations with community leaders. In an ideal setting, data would be acquired mostly while in the field as opposed through email and telephone. This delayed the overall evaluation by months due to delays in acquiring data from community and government sources. It also limited the number of years we could consider from the lay community health source—time constraints in completing and returning the data extraction form limited the years we could consider (we originally asked for six years of data). In regard to costs, we were not able to ascertain why costs went up as high as they did. The community has informed us that electricity bills are only for the well pump, however kilowatt demand is higher than the maximum demand of the pump signifying another source is adding to the kWh use. Because of the need to protect personal and medical information we were only able to attain data in aggregate form. This means that while cases are generally high, there is no way of knowing how many repeat cases could have occurred and how much this effects overall monthly prevalence.

3. Future directions

The work described here was an essential first step in ongoing evaluation of the provision of a continuous water supply system in a rural setting poor in material resources, and it contributes to existing literature by emphasizing process. Future evaluations should consider the following:

- Challenges in implementing sustainable practices. This should include setting up water committees, maintenance funds for operations of water systems, and metering of both individual and communal water use as a way to control use.
- Once continuous supply begins, assess community perspectives on the new system, their ability to financially maintain it, and water conservation education.
- Education programs to promote knowledge transfer of conducting a census, using rates and measuring diarrhea, and mapping incidence of diarrhea in a community.

4. Conclusion

There are many challenges in implementation of international safe drinking-water projects, even in cases where community support, technical ability, and funding are in place. Safe drinking-water programs are often both complex and complicated. This intervention is an example of how complex problems can be approached and how to apply an evaluative lens to what is traditionally considered an engineering intervention. The evaluative lens applied here was able to reveal processes, how these can be improved upon, and how to begin measuring outcomes during the implementation phase of an intervention to ensure long-term sustainability, effectiveness, and impact.

Future evaluations should focus on assessments of community acceptance, development of legally recognized water committees, development and implementation of water conservation education programs, and in-depth measurements of current and future water demand.

III. CONCLUSION OF THESIS

Diarrhea continues to be a major public health concern in developing countries. The impact it has on human health is substantial enough to make it a key priority of the MDG of the UN. We also know that drinking water is a transmission pathway for enteric pathogens; diarrhea is most often the result of infection from an enteric pathogen. Thus the mantra has been, provide clean drinking water free of enteric pathogens and diarrhea burden should decrease; unfortunately it is not this simple.

The past 40 years have provided much insight into how complex and often difficult providing safe drinking water can be. Evaluation is a key component of understanding how and why a program does or does not succeed in reaching desired outcomes. Thus far, the focus has mostly been on desired outcomes, which are based on engineering and programmatic outcomes; these are limited in scope and are what I refer to as a form of tunnel vision. Examples of expected outcomes are: “has diarrhea increased or decreased since the program implementation,” “was the well functional and is the water safe to drink,” “can people access the well,” and “was the project at, under, or over budget.” This tunnel vision has not only limited, but often made it impossible to explain, the processes that led to and were part of the implementation of a safe drinking-water program and to later explain why it had or had not been sustained.

To address this tunnel vision, one should consider a more cyclical approach as opposed to the often linear and dichotomous approach used by many evaluations in the safe drinking-water community. This cyclical approach takes into consideration complexity and the interdependence of factors as well as documenting the complicatedness involved in programmatic implementation (these factors are often outside engineering and programmatic scopes). By taking this approach you can begin to document and understand how, for example, social and economic factors affect an outcome such as diarrhea by way of a safe drinking-water program. By considering factors that have been identified as vital components of programmatic uptake, you begin to tackle the challenge of program sustainability.

The research and resulting evaluation provide an approach that considers complicatedness and complexity of an ongoing safe drinking-water project. Most importantly, it provides a real life example of how to apply an evaluative lens to what is typically considered an engineering project. The result is an evaluation that provides vital information during the implementation stage of a safe drinking-water program. This vital information guides the next steps for the safe drinking-water program and creates outcome measures that address programmatic sustainability.

APPENDICES

APPENDIX A

No.	Age	Date (day, month, year)	Diagnosis of Diarrhea (mild, moderate, severe)
1			
2			
3			
4			
5			
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24			
25			
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29			
No.	Age	Date (day, month, year)	Diagnosis of Diarrhea (mild, moderate, severe)
30			
31			
32			
33			
34			
35			
36			

APPENDIX B

No.	Edad	fecha	Diagnostico de Diarrea (leve, moderado, grave)
1			
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27			
28			
29			
No.	Edad	fecha	Diagnostico de Diarrea (leve, moderado, grave)
30			
31			
32			
33			
34			
35			
36			

APPENDIX C

NO.	FECHA	DE 0 A 6 AÑOS		DE 7 A 15 AÑOS		DE 15 ENDEL ANTE.		DIAGNOSTICO	LEVE	MODERADO	GRAVE	TOTAL
		M	F	M	F	M	F	DIARREA				
2010	ENERO	5	7	4	10	4	2	DIARREA	15	2	0	17
2010	FEBRERO	9	13	6	7	3	5	DIARREA	6	2	0	8
2010	MARZO	8	4	2	8	2	3	DIARREA	15	4	1	20
2010	ABRIL	3	1	2	4	4	3	DIARREA	17	3	0	20
2010	MAYO	4	6	4	7	3	1	DIARREA	16	7	2	25
2010	JUNIO	13	10	2	4	9	5	DIARREA	28	8	6	42
2010	JULIO	11	14	9	6	4	3	DIARREA	27	12	8	47
2010	AGOSTO	14	12	16	14	11	10	DIARREA	49	17	11	77
2010	SEPTIEMBRE	12	11	9	10	7	4	DIARREA	42	9	2	53
2010	OCTUBRE	6	3	5	8	4	1	DIARREA	18	7	2	27
2010	NOVIEMBRE	4	2	5	3	2	1	DIARREA	13	4	0	17
2010	DICIEMBRE	5	3	7	8	1	0	DIARREA	21	3	0	24

NO.	FECHA	DE 0 A 6 AÑOS		DE 7 A 15 AÑOS		DE 15 ENDEL ANTE.		DIAGNOSTICO	LEVE	MODERADO	GRAVE	TOTAL
		M	F	M	F	M	F	DIARREA				
2011	ENERO	7	9	2	13	7	4	DIARREA	36	6	0	47
2011	FEBRERO	10	16	9	5	1	3	DIARREA	41	1	0	44
2011	MARZO	11	14	8	6	3	1	DIARREA	43	0	0	43
2011	ABRIL	3	5	1	2	7	3	DIARREA	21	0	0	21
2011	MAYO	6	9	10	9	5	7	DIARREA	36	10	0	46
2011	JUNIO	16	14	5	14	3	1	DIARREA	45	7	1	53
2011	JULIO	7	10	2	4	1	0	DIARREA	32	5	4	41
2011	AGOSTO	10	8	6	4	1	1	DIARREA	26	4	0	30
2011	SEPTIEMBRE	6	9	5		6	2	DIARREA	32	1	1	34
2011	OCTUBRE	9	6	9	5	1	3	DIARREA	36	12	5	53
2011	NOVIEMBRE	18	11	9	8	6	0	DIARREA	46	4	1	50
2011	DICIEMBRE	12	17	9	3	1	7	DIARREA	46	2	0	49

APPENDIX C (continued)

NO.	FECHA	DE 0 A 6 AÑOS		DE 7 A 15 AÑOS		DE 15 ENDEL ANTE.		DIAGNOSTICO	LEVE	MODERADO	GRAVE	TOTAL
		M	F	M	F	M	F	DIARREA				
2012	January	3	5	2	7	0	0	DIARREA	15	2	0	17
2012	February	2	1	1	2	0	2	DIARREA	6	2	0	8
2012	March	4	2	4	7	3	5	DIARREA	15	4	1	20
2012	April	2	1	4	6	1	4	DIARREA	17	3	0	20
2012	May	9	8	14	11	6	7	DIARREA	48	7	0	55
2012	June	5	7	12	15	7	9	DIARREA	40	12	3	55
2012	July	19	9	14	10	5	3	DIARREA	43	15	2	60
2012	August	13	10	7	3	1	2	DIARREA	32	4	0	36
2012	September	6	8	3	1	0	1	DIARREA	18	1	0	19

APPENDIX D

Jan-10

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Feb-10

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Mar-10

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Apr-10

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

May-10

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Jun-10

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	1	3	4	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0

APPENDIX D (continued)

Jul-10

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Aug-10

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Sep-10

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Oct-10

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Nov-10

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
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Dec-10

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX D (continued)

Jan-11

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	2	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Feb-11

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Mar-11

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Apr-11

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

May-11

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0

Jun-11

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX D (continued)

Jul-11

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Aug-11

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Sep-11

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Oct-11

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Nov-11

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Dec-11

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX D (continued)

12-Jan

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

12-Feb

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

12-Mar

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

12-Apr

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

12-May

CIE-10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	0	0	0	0	0	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Jun-12

CIE -10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas							1	1																				

APPENDIX D (continued)

Jul-12

CIE -10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	sin movimiento																											

Aug-12

CIE -10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	sin movimiento																											

Sep-12

CIE -10	DIAGNÓSTICO	< 1m		1 a 2m		2m < 1a		1 a 4		5 a 9		10 a 14		15 a 19		20 a 24		25 a 39		40 a 49		50 a 59		60 a 64		65 a 69		70 +	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
A:09:X	Diarreas	1						1	2	1		1																	

APPENDIX E

Fecha facturacion	consumo	Potencia facturada	Potencia leida	Consume reactiva	importe
10/22/2012	5171	55000	49414	3528	Q 14,302.00
9/22/2012	4865	55000	49363	3266	Q 13,852.00
8/22/2012	4450	55000	49504	3005	Q 13,256.00
7/23/2012	4863	55000	49759	3301	Q 13,028.00
6/21/2012	4764	50040	50040	3181	Q 13,247.00
5/22/2012	4487	40507	40507	2067	Q 11,271.00
4/21/2012	6085	38884	31187	2430	Q 10,899.00
3/22/2012	5695	38884	30939	2277	Q 10,508.00
2/22/2012	5829	38884	31176	2331	Q 10,662.00
1/23/2012	6438	38884	31345	2578	Q 11,453.00
12/22/2011	5182	38884	38548	2072	Q 10,357.00
11/22/2011	5866	38884	38884	2386	Q 11,206.00
10/21/2011	5004	37555	31590	2014	Q 10,258.00
9/22/2011	5397	37555	37496	2219	Q 10,924.00
8/22/2011	5092	37555	37555	2117	Q 10,586.00
7/21/2011	4937	37433	37433	2080	Q 10,203.00
6/21/2011	5226	37267	37203	2182	Q 10,516.00
5/20/2011	4453	37267	37267	1953	Q 10,237.00
4/20/2011	5453	28000	22670	4481	Q 11,027.00
3/22/2011	5739	28000	23151	5079	Q 11,614.00

APPENDIX E (continuted)

2/18/2011	6385	28000	23425	5729	Q 10,979.00
1/20/2011	7257	28000	16981	6357	Q 13,559.00
12/20/2010	6224	28000	17359	5310	Q 12,029.00
11/19/2010	6077	28000	17572	5085	Q 11,744.00
10/21/2010	5476	28000	17687	4419	Q 11,181.00
9/21/2010	4985	28000	17658	3998	Q 10,456.00
8/20/2010	5228	28000	17737	4214	Q 10,830.00
7/22/2010	5574	28000	18029	4455	Q 11,520.00
6/22/2010	5975	28000	18554	4695	Q 12,024.00
5/20/2010	5493	28000	18872	4087	Q 11,247.00
4/21/2010	6004	28000	19541	4384	Q 11,793.00
3/22/2010	5826	28000	19793	4208	Q 11,542.00
2/19/2010	5726	28000	19995	4092	Q 11,387.00
1/21/2010	4728	28000	20153	3367	Q 8,903.00

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