Examining the Economic Costs and Sources of Potable and Nonpotable Water in Northern Mexico

by

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ABSTRACT

Water availability and the cost of different water sources have been studied at great length. However, information is still needed to determine the policy directions to be undertaken by nations that have not yet achieved universal coverage of an improved water source. To further examine differences in water availability and pricing in the context of the developing world, three communities in Northern Mexico were surveyed to determine the differences in water distribution schemes and associated costs between rural and urban centers. It was observed that rural communities without a piped water supply paid 13 percent more for potable water supplies and 39 percent more for nonpotable water supplies than urban communities with a piped water source. A relationship between access to piped water and the probability of contracting diarrhea was also observed, with households with access to piped water having a lower probability of contracting diarrhea than those households without, and experiencing a lower number of days per month with diarrhea, on average. This leads to the observation that rural communities, who typically are less likely to be able to afford a piped distribution system, are paying more for their water supplies than nearby urban centers, both in terms of the money spent each month for water resources, and the costs associated with contracting and treating diarrhea. Steps should be taken by Mexico and other developing nations to ensure that water is distributed equally and priced fairly, so that the more impoverished subsets of their populations are not paying higher prices for their water.

CHAPTER 1: INTRODUCTION

Water quality and accessibility are topics of concern for many nations, with many developing countries working to provide access to improved sources of water for their citizens. Improved water accessibility to people in the developing world has been identified as one of seven key goals (MDGs) for the UN Millennium Campaign (Millennium Development Goals Report, 2010). Although significant progress has been made towards realizing this goal, it is estimated that 884 million people in the world still lack access to improved water sources (WHO and UNICEF, 2008). Additionally, it is estimated that as many as 2.3 million people die each year from water-related, diarrheal illnesses (Gleick, 2011). The goal of improved water supply and water quality will only become more challenging as water becomes a scarcer resource.

As water scarcity becomes an increasing concern for many world populations, one might begin to wonder if there may be a missing element to current water distribution schemes. Historically, a popular way to relate water rights to the public has been to define bodies of water as 'belonging to all,' meaning that they typically cannot be appropriated by any one person or entity. This key philosophy in water resources management is quite old, dating at least as far back as Roman law, and is visible in many water allocation schemes seen presently (Narasimhan, 2007). However, as current water distribution and availability in many developing nations is more closely examined, a need for a more comprehensive and 'fairer' way of managing water sources can be recognized.

There are many ways to ensure that there is ‘water for all’, including improving available water quality and extending piped service to households whenever possible.

It is thought that at-home, piped water systems can provide the greatest improvement in health, though it is the most expensive form of intervention (Haller et al., 2007). This intervention would have the largest impact on populations that currently store household water in (often uncovered) containers that they fill from off-premises water sources. The time costs associated with obtaining water would also be greatly reduced (Haller et al., 2007). This option is the most expensive, but allows a greater focus to be placed on improving water quantity, which is thought to have a greater impact on reducing waterborne disease by making more water available for hygiene, than focusing exclusively on improving water quality (DCP2, 2007). In the developing world, the number of rural and low-income urban households with access to a piped water source is much lower than the number high-income urban residents in the same countries currently enjoying access (Clarke and Wallsten, 2002). Therefore, it is possible to say that although the key subgroups targeted by the Millenium Development Goal of improved water source could receive the most benefits from a piped water source, extending that water source to them does not often occur.

Currently, there exist notable discrepancies between urban and rural populations in the developing world. For example, children in rural regions are almost twice as likely than children in urban areas to be underweight (Millennium Development Goals Report, 2010). Though the percentage of rural poor is thought to be declining, due in part to rapid migration to urban areas in many developing nations, it is still estimated that three-quarters of poor people in the developing world live in rural areas (Chen and Ravallion, 2007). It has been previously observed that there is much less likelihood of utility coverage in rural areas of developing countries, including but not limited to water utilities (Briceño-Garmendia et al., 2004).

A key issue in extending a comprehensive, piped water distribution scheme to all is the issue of putting a fair price on the water provided by such a system. Contingent valuation, also known as willingness-to-pay studies, is a method of determining the value that a particular community places, or is willing to place, on water or any other resource. Frequently, contingent valuation focuses on finding the amount that participants are willing to pay for clean drinking water. Studies of this nature will often use a survey that includes a bidding system (Whittington et al., 1990b; Whittington, 1998). Participants are asked to determine the value they would be willing to place on being provided a *hypothetical* service scenario. Contingent valuation is especially valuable in the field of water resource management, because it can help to better identify the public's 'key issues' in terms of water resource management, thereby helping to dictate water management policy. Contingent valuation can also help utilities to determine what their levels of service and corresponding prices should be when providing water to the public. For example, willingness-to-pay has been previously used to identify a disjoint between water distribution schemes undertaken by the government of Pakistan and the actual preferences of the rural communities receiving the aid (Altaf et al., 1993). When the results of these studies are summarized, it is often found that populations, particularly those with low water availability, are willing to pay much more for their water supply then they are currently paying (Whittington et al., 1990a; Aguilar, 2009).

Typically, quantifying the current water availability and costs often goes hand and hand with contingent valuation studies to serve as a baseline for the hypothetical component of the study, which can be very illuminating in determining the economic value of a particular water source to its consumers. Although willingness-to-pay studies involving the hypothetical constitute an important part of determining the overall value of water to the people who must share a particular source, it is also beneficial to consider the prices that communities are already paying for their water supplies. This can provide insight into the variety of costs associated with different water sources, as well as the relative costs between economically distinct groups. Determining current water availability and costs is valuable, in that these types of studies help to identify key areas for improvement in the current water distribution scheme.

Studies that determine water sources and costs for communities in the developing world will frequently discover a wide variety of water sources and associated costs, even among members living in the same neighborhood (Crane, 1994). The diversity in water sources and prices is often associated with a lack of access to water supplied by a centralized agency. In the absence of such an agency, people must turn to alternative sources for their water, often at greatly inflated prices, as household demands for water have been generally observed to be in-elastic with respect to both price and income (Crane, 1994; Robinson, 2002; Nauges and Whittington, 2010). These prices, in part, can be due to the perceived costs in time spent collecting water from a distant source being outweighed by the costs of having water delivered to one's household (Whittington, 1990a). Private water vending entities have become a common solution to lack of water access in these types of scenarios, with vending operations ranging anywhere from a large, wide-spread distribution bolstered by fleets of trucks carrying thousands of liters, to an individual using a push-cart to carry a single drum of drinkable water from house to house (Whittington et al., 1991).

Water vending has become an important part of water distribution schemes in many areas of the world lacking universal access to clean drinking water. For example, a case study in Ukunda, Kenya, observed that 45 percent of the total water consumed in Ukunda during the rainy season was provided to consumers by water vendors (Whittington et al., 1989). Typically, water vendors sell treated drinking water to residents of urban areas who lack access to treated drinking water, sometimes at prices much higher than the cost of treated drinking water from the original supplier. In this manner, it is the population that cannot afford to live in the areas with centralized access to drinking water that must pay the higher costs associated with buying from water vendors.

Usually, the poorer segment of the population is forced to pay higher costs for drinking water than the wealthier part of the population (Katko, 1991; McGranahan et al., 2001; Kjellen and McGranahan, 2006). For example, one study investigating the price of water in urban Sudan observed that water vendors sold water at a rate that was between 30 and 120 times the cost of water obtained from a private connection (Cairncross and Kinnear, 1991). Households in the developing world were, at times, observed to spend over 30 percent of their monthly income on vended water, far higher than the 3 percent of disposable income proposed as an affordability threshold by international development organizations, whereas households with access to piped water spent between 1-5 percent (Zaroff and Okun, 1984; OECD, 2003). High water costs can affect other aspects of life;

it has been suggested that increased water prices can lead to malnutrition in some communities, for example a study taking place in Sudan observed that poorer families living in areas with high rates of malnutrition paid up to 56 percent of their income for water (Cairncross and Kinnear, 1992).

Among the rural poor, the problems associated with not having enough money to pay for treated drinking water are further exacerbated by a lack of access to treated drinking water. It has been previously observed in Africa that the drawdown of rural water supplies to exclusively feed distant urban demands, without including nearby rural communities in the water scheme, can further exacerbate water shortages for the rural residents (Showers, 2002).

This study focuses on the issues of water price and availability in selected urban and rural areas of Mexico. As previously mentioned, the issue of improved water access to people in the developing world has been identified as one of seven key goals (MDGs) for the UN Millennium Campaign. A recent report describes the Latin American region of the world as one of the highest performing regions with respect to this goal, as well as the region that made the most relative progress towards achieving this goal (Millennium Development Goals Report Card, 2010). Within this report, the country of Mexico was described as one of the nations "where progress has been achieved," and furthermore as having met the target for the MDG of halving the proportion of people without sustainable access to drinking water by 2015" (Millennium Development Goals Report Card, 2010). Meeting this Millennium Development Goal is a great achievement, but it is important that continuing progress in this area of development does not stop, now that the initial goal has been met.

With an estimated 457.2 cubic kilometers of annual renewable water resources available, as compared to approximately 79.80 cubic kilometers of freshwater withdrawn annually, it would appear that the rate of Mexico's water consumption is well within the margins for sustainable water consumption, and suggests that there should be more than enough water available to meet current demand (Gleick, 2011). However, overall water availability in Mexico is not reflective of regional water availability. It is estimated that 77 percent of Mexico population lives in regions where only 20 percent of the total water resources are located (OECD, 2003). This growth in regions without the water resources necessary to sustain such population expansion has resulted in 102 out of 653 total aquifers in Mexico being listed as overexploited, which frequently leads to salt water intrusion into the aquifer (Asad and Dinar, 2006). Indeed, a need for increased conservation of water resources in water-scarce regions has been previously observed, with respondents to another survey conducted in an arid zone of Mexico indicating a willingness to pay for improved environmental services of natural water supplies (Ojeda et al., 2008).

Water treatment and distribution in Mexico has been the responsibility of individual municipalities since 1991, with access and distribution among municipalities thought to be highly political (Asad and Dinar, 2006; Marañón-Pimentel, 2009). Prior to this year, centralized water distribution was inefficient and costly. It was estimated that, before 1991, losses from irrigation infrastructure were between 50 and 70 percent (Rosegrant and Schleyer, 1996). In urban systems, the amount of water lost due to leakage of the infrastructure was estimated at between 40-60 percent, depending on the city (Rosegrant and Schleyer, 1996). Since the transfer of water distribution responsibilities to individual municipalities, improvements and expansions in the systems have been the general trend, though increased coverage and improved reliability are still necessary in many locations (Marañón-Pimentel, 2009).

Though infrastructure advancements have resulted in a marked improvement of access to water sources in many parts of Mexico, water access is currently not met by providing piped, treated drinking water to all. For example, one study found that the urban periphery of Mexico City seriously lacked adequate water supplies for its inhabitants (Aguilar, 2009). Reliability and potability of water service is a key issue in other areas of Mexico as well, with the respondents of one study reporting willingness to pay an average of nearly 50 percent more than their current water bills in exchange for safer and more reliable service (Vásquez et al., 2009).

One possible solution to water scarcity has been to provide water to communities by truck, though this often cannot meet the normal daily requirements of households due to intermittent and unreliable distribution, with some households reporting an inconsistent drop-off date, and water needs over double what a tanker truck is legally obligated to provide (856 liters vs. 400 liters) (Pike, 2005; Aguilar, 2009). This service is often provided free of cost to the consumer, though 'tips' are sometimes necessary to ensure that a supply truck will bring water to your community on a consistent basis (Aguilar, 2009).

In areas where truck services are limited or incomplete, or the water supplied is not treated to drinking standards, the purchase of drinking water from private entities is often necessary, either from individuals who are capable of transporting water from the source to your house, via pick-up trucks or burros, or from vendors who can provide treated drinking water in large plastic jugs (*garrafónes*), typically from 15-19 liters in size (Aguilar, 2009). An issue in Mexico that is common to other nations with populations that rely on private water vending systems is that the poorest segments of the populations often pay more for the same amount or a lesser amount of water. One estimation of the weekly costs of water for the average individual (making minimum wage) on the outskirts of Mexico City was approximately 5 percent of total income spent on water (Aguilar, 2009). Typically, poorer individuals (as observed in Mexico City) will have less access to water supplies than more affluent segments, though affluent segments may also experience intermittent supply issues (Aguilar, 2009). In Mexico City, significant differences were observed between the water supplies of poorer and more affluent neighborhoods, in terms of water pressure, water quantity, and water quality (Soto Montes de Oca and Bateman, 2003). Perhaps unsurprisingly, the poorest neighborhoods not only reported the lowest satisfaction in water service, but were also the greatest consumers of alternate water sources, in this case bottled water (Soto Montes de Oca and Bateman, 2003).

Rural communities in Mexico are reported to be experiencing similar issues with access to and costs of available water supplies (OECD, 2003; Kolb deWilde et al., 2008). Although, as noted earlier, Mexico is on track to successfully complete the goals set forth by the UN Millennium Development Campaign, gaps can still be identified in water accessibility and improved sanitation measures among Mexican citizens. For example, in 2008, 96 percent of the urban population in Mexico was classified as having access to improved drinking water. The corresponding fraction for Mexico's rural population in 2008 was 87 percent, considerably lower than their urban counterparts (Gleick, 2011).

Similar results can be seen under the improved sanitation category, with 90 percent of Mexico's urban population claiming access to improved sanitation, in comparison with 68 percent of its rural population claiming similar access in 2008 (Gleick, 2011). Although rural water treatment schemes have been promoted in Mexico, these were previously observed to be met with limited success, possibly due to the preference of bottled water over locally treated water or the inconvenience of transporting water to households (Kolb deWilde et al., 2008).

1.1 Study Motivation, Objectives, and Hypotheses

This study is concerned with the issues of water price and availability in selected sample of urban and rural areas of Mexico. The objective is to contribute to the empirical literature by focusing on a nation already thought to have met its Millennium Development Targets in terms of providing access to improved water supplies. In addition, the sample populations include both rural and urban subsets. The rural subsets are *ejidal* communities, a type of community not previously well-covered in available Mexican water resource literature, and all communities sampled are located in regions previously identified as water-stressed. This study attempts to compare communities with different water distribution schemes, each located in three different but adjacent municipalities, in an attempt to quantify observable differences between municipalities. Accordingly, the goal of this study is to analyze differences in costs of potable and nonpotable water to families across economic and demographic spectrums. To achieve these objectives, this study surveyed a sample of households in both rural and urban settings to determine monthly costs to households for both potable and nonpotable water supplies. Multiple hypotheses are addressed.

The first hypothesis is that water constitutes a significant expenditure for many people in Mexico, and that its cost is greater for rural, impoverished Mexicans who still have to purchase treated drinking water (at a higher rate due to the associated transportation costs), but do not have the option of drinking or cooking with tap water. Additionally, it is thought that there is a significant reduction in the monthly costs of nonpotable water once a piped source becomes available. To further examine the differences between households with and without piped water, additional parameters are examined, including the number of days per month someone in the household reports having diarrhea, perceived confidence in potable and nonpotable water quality, and whether or not household water demands are being met by current water availability. It is hypothesized that participants with access to a piped water source report a lower incidence rate of diarrhea, be more confident in the potability of their nonpotable water source, and have a higher level of satisfaction in their current water availability.

The second hypothesis examines whether or not potable water needs are being met in a community without access to a piped water source. It is hypothesized that actual water demands are higher for potable water than actual water availability currently provides for. To test this hypothesis, a free source of potable water that is capable of generating an additional 2.5 extra liters of drinking water/day to a family will be provided to participating families. It is not currently known whether this additional water will help to reduce the weekly costs of treated drinking water for a family (demand stays the same, but available supply is increased), or if it will increase the amount of water consumed by each family (demand for clean drinking water increases as the supply is increased), while the costs paid weekly by each family remain the same. With average estimated daily household consumption rates of 3 liters for cooking and 6 liters, for some families this will constitute a major access point to potable water.

CHAPTER 2: METHODS

2.1 Study Location and Characteristics

All study communities are located in the northernmost tip of the state of San Luis Potosi, in Mexico. This region of Mexico is considered to be within the southern region of the Chihuahuan Desert, and is commonly referred to as high plane desert. This area of the Chihuahuan Desert is dominated by the presence of gobernadora, a shrub known as creosotebush in the United States, as well as Mesquite trees, graminoids, several *Yucca* species and numerous cacti genera (personal observation).

The study area consists of three municipalities: Matehuala (study focus: the city of Matehuala), the municipality of Cedral (study focus: the village of Ejido Hidalgo), and the municipality of Vanegas (study focus: the village of El Gallo). Each municipality provides some or most inhabitants of its principal population (the population living in the city that the municipality is named for) with piped water. In the municipalities of Cedral and Matehuala, the water for the urban populations is provided by *Servicios de Agua Potable Alcantarillado y Saneamiento de Matehuala* (SAPSAM). In the municipality of Vanegas, where El Gallo is located, some piped coverage is provided to inhabitants of the town of Vanegas, though the total number of those with coverage in the town is unknown.

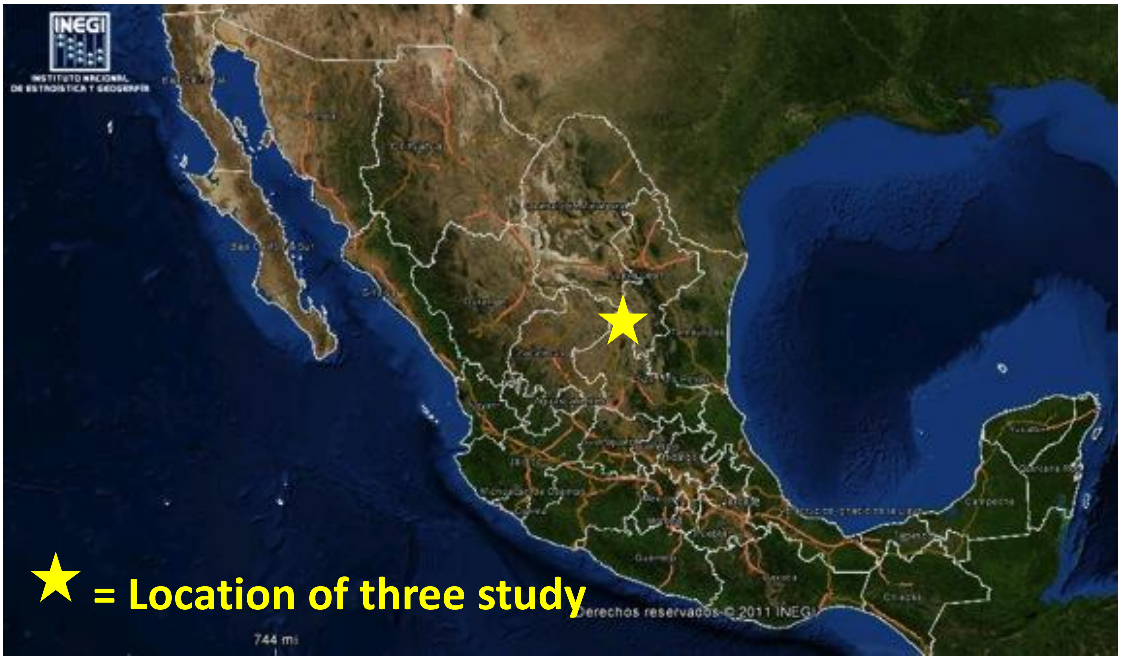

Figure 1. Study locations, Mexico. Map generated courtesy of INEGI data (www.inegi.org.mx).

Figure 2. A map showing the three selected study sites and their geographical proximity to one another. Map generated courtesy of INEGI data (www.inegi.org.mx).

2.1.1 Site Description: Municipality of Vanegas: The Village of El Gallo

El Gallo, as is common in many small communities in rural Mexico, is an *ejido*-based land management community. In *ejido*-run communities, every family owns a part of the land surrounding the community, but major decisions involving land management are taken by a governing group, the *ejidetario*, in this case consisting of most of the elderly men of El Gallo. Widowed women are allowed the opportunity to participate, provided that they are the owners of land within the *ejidetario*. Leadership positions within the *ejidetario* are decided by vote every three years. The *comisariado* is the elected leader of the *ejido*, and his job is to settle disputes among other members of the *ejiditario*. He is also responsible for securing money and jobs from the government for the other members of the *ejido*. In this way, although each family has a claim to their individual parcel of land, the actual management of the surrounding lands is in a style more similar to a cooperative. For example, a family may make unique choices for their house location and style and a small area immediately adjacent to their house (some have family gardens, some have repair sheds, some have chicken coops or pig sties), but everyone sends their livestock to a communal grazing area. The vegetation in heavily-grazed areas is creosote-dominant, a common environmental issue in the Chihuahuan Desert, also with populations of various *Yucca* species and *Opuntia* (personal observation). The grazing areas are commonly occupied by donkies, cows, horses, and goats. Goats are very abundant in this region of the Chihuahua, as goat milk is frequently consumed as either milk or cheese and suckling goats (‘cabritos’) are considered a good source of income to farmers who are able to sell them in more urban areas.

Residents of these small communities typically live in one or two-room houses, usually constructed of adobe, but sometimes of concrete block. Multiple generations frequently live within one housing unit, with each married couple/family sharing a bedroom, and everyone sharing a kitchen and bathroom. Typical status items include indoor electricity, televisions (with satellite), cars, washing machines, and refrigerators. Homes in El Gallo can have all of these amenities, or none of them. With very few exceptions, sanitation needs are met at each house by an outdoor pit latrine. Most families have small areas or containers to grow vegetables and chiles for personal consumption, and many have pigs and chickens for the same reason.

Women from El Gallo and the surrounding communities tend to marry at a young age. The author of this thesis has met women that were married as early as 13 years old, though 15 to 18 seems to be a more common age. The average household in El Gallo is typically supported by all capable males over the age of 15. In addition to the yearly subsidies provided by the federal government for farming their individual plots of land, and the profits resulting by selling their produce from these fields, males can expect to earn around 50 pesos a day as farm workers, shepherds, or laborers on government-sponsored projects. For example, a current government project pays men in El Gallo to fill all of the potholes in the road leading to their town with stones. Another example of government assistance is represented by the financial incentive each family receives to keep every child under the age of 15 in school. Through this same program, adult women who did not previously finish school up to the ninth grader level are paid to continue their education up to this grade. Another source of income for many community members is remittances, sent from anywhere in Mexico (it is common for people to leave rural areas to find jobs in larger cities as unskilled laborers and send a share of their wages back home), or from relatives living and working in the United States or Canada.

The onsite water resources of El Gallo are heavily-drawn from aquifers. The water table is high enough that many families are able to dig personal wells in their yards, though the costs associated with putting in a private well are unaffordable for the majority of community members (approximately 10,000 pesos/$830 USD). This is uncommon in the municipality of Vanegas, where drilling depths of up to 1,000-m have been reported in (unsuccessful) attempts to dig wells in other small communities. Though every community depends at least partially on the use of treated water from an outside source, typically the small communities in this region rely on communal rainwater collection systems to supplement household water needs. Common water resource issues in the communities near to El Gallo include high turbidity and the presence of numerous pathogens, due in part to community members collecting their water from sources that are frequently surrounded by livestock and used as communal watering holes (based on personal observation and communication with community members, local community development workers).

In contrast, El Gallo does not usually rely on rainwater retention ponds to fulfill household water needs beyond the provision of water to livestock, although they do exist within their *ejido*. This is probably due to two reasons: 1) the rainwater pond in El Gallo is a considerable distance from the community (approximately 10 km), and 2) other rainwater retention ponds in the area are well-developed, concrete-and-plastic-lined projects sponsored by the federal government, whereas the pond in El Gallo is much smaller,and does not retain much water outside of the rainy season. The water in the rainwater collection ponds during the rainy season is also visually unappealing. For these reasons, El Gallo utilizes several pumps on the outskirts of the community that provide shared access to all. These wells/pumps were put into place by the Mexican government, and are principally for irrigation purposes. When enough water is available, the pumps can send water to public tapstands located throughout El Gallo, currently no more than 100 meters from any given household. Additionally, some families have the resources to put private wells in their yards (to my knowledge, no one in El Gallo has indoor plumbing). The electricity and maintenance costs associated with using the public wells are determined by a household's water consumption, and may vary greatly. A family that uses the pumps to irrigate crops (typically only done for saleable crops such as alfalfa) will pay substantially more per month to use the pump than a family that has no land and is only buying water for household use. However, it is important to not that, due to a lack of actual water availability, irrigation of crops in El Gallo is currently not performed (communication with *ejido* members). Typically, the costs of water use for younger or poorer families will be 'covered' by more senior members of the household who have already paid to use the pump to irrigate. If a household is unable to pay then it does not receive access to the pumps (although exceptions are made for older individuals). Access to the pumps is controlled by a key, which is in the possession of the *comisariado*. These wells have 'memberships', and are evenly spaced so that (hypothetically) each individual who owns land close to a given well pays for the right to access that particular well for his crops, and for his household needs. Though a total of 12 wells were put into place by the government, the costs associated with maintaining the pumps have been the sole responsibility of community members in El Gallo. Currently, most of the pumps are not functional, and residents rely solely on the two still-functioning pumps for their water. Water availability at the pumps is not constant, as community members are not able to keep them from breaking down on a frequent basis. This means that, in reality, probably farmers are not using the pumps for irrigation, and the majority of the water being taken from the pumps is being used in households. Commonly, people in El Gallo will go to either of these two wells in a truck or a donkey cart once or twice a week to fill 200- or 400-liter containers, then bring the containers back to their houses.

Figure 3 is a photograph taken in El Gallo of a family collecting water from the irrigation pump located outside of El Gallo. Typically, families will bring as many containers as can be carried to the well, and fill each of them using a series of tubes connected to the pump and flowing into the containers. Fill times for each container depend on the size of the container and whether or not the pump is functioning properly.

Figure 3. A resident of El Gallo collects water for use in his house from a pump located several kilometers from his residence.

Figure 4 shows a family (and fellow Peace Corps volunteer) transporting water from the well outside of El Gallo to their home. The barrel in the cart needs to be filled several times a week, if not every day, for the average family in El Gallo to meet their household needs.

Figure 4. If a family does not have transportation to and from the agriculture pump, they can obtain water by hauling barrels back and forth in a cart.

With the usage of these pumps comes a different water-resource issue, that of high salinity. It is suspected that the aquifer they have tapped into has been drained significantly by the large-scale agriculture in the area, contributing to the salinity problem. An alternate theory is that the aquifer they can access is simply naturally salty. Whatever the reason, the water that people in El Gallo are drawing from their pumps is not potable, and is used primarily for hand-washing, cleaning (laundry and household), and watering crops and livestock. The residents of El Gallo currently rely principally on the import of purified water from an outside source to meet their cooking and drinking needs. Typically, a truck filled with *garrafónes* (large plastic jugs capable of holding up to 19 liters) will pass through El Gallo once every eight days. These trucks come from water treatment sources many kilometers away (the closest is Cedral, approximately 50 km away). These garrafónes cost about 18 pesos each, or about $1.50 USD, which is very costly, considering that the average male can expect to earn between 50 and 100 pesos a day. If water needs are not planned correctly, then the options are to access a pump that has potable water located over an hour's drive away in the town of Tanque Lopez, purchase garrafónes from the local small shops at an inflated rate, or to drink from the pump water, though increasing the likelihood of falling sick. Alternatively, a water truck comes from the nearby town of Vanegas, and fills the water tower in El Gallo with treated water every 15-30 days (this water is provided free of charge to whoever wants it), but there are issues with the reliability of the truck, as sometimes it does not come for months. There are also issues with the potability of the water they bring, as many times the water tower has dead animals or other contaminants in it.

In an effort to make potable water more available to the residents of El Gallo, interested participants received training workshops and necessary resources to construct solar distillers at each of their homes. Through the process of evaporation, solar distillers work to remove any dissolved solids from the well pump, and in this manner make the previously undrinkable well water fit for consumption. It is estimated that, if operated and maintained correctly, each solar distiller can provide up to an additional 2.5 liters of potable water/day for each family (Manser, 2012). Construction of the solar distillers finished in August 2011, with additional maintenance/construction issues resolved by October 2011.

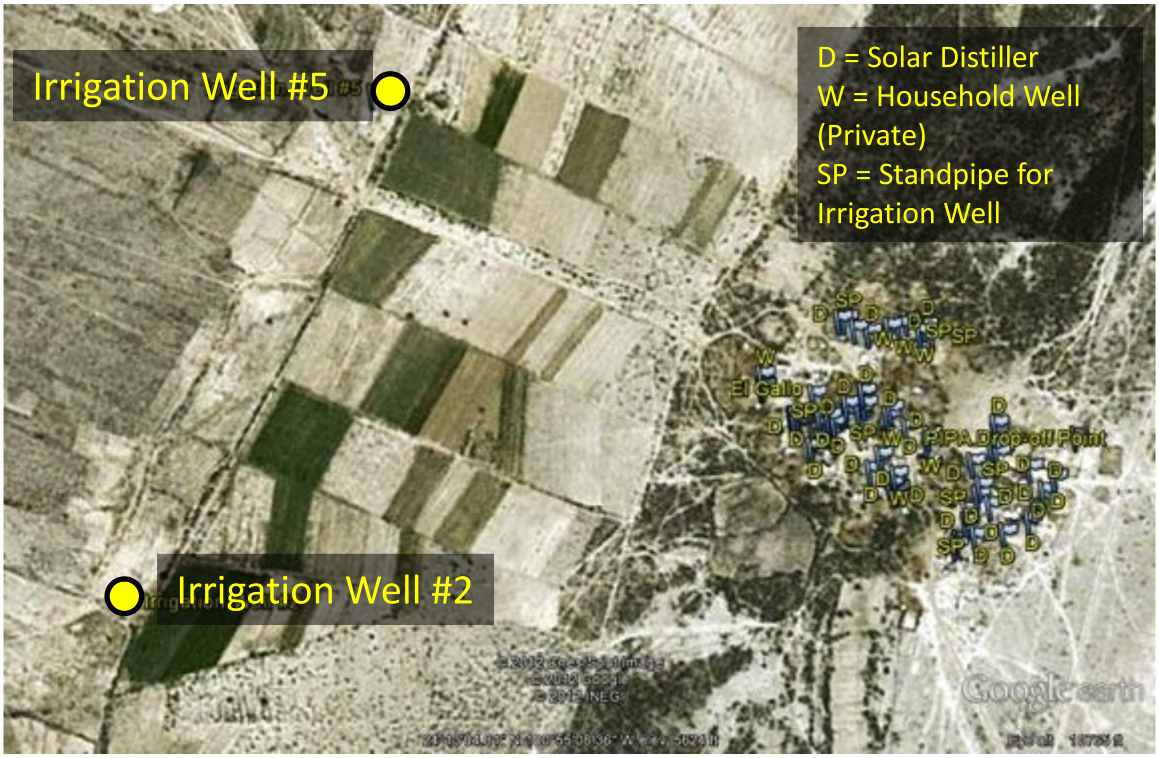

Figure 5. Locations of the irrigation wells, tapstands, private wells, and solar distillers in El Gallo. Information courtesy of INEGI (www.inegi.org.mx) and Google Earth (www.googleearth.com).

2.1.2 Site Description: Municipality of Cedral: The Village of Ejido Hidalgo

The small community of Ejido Hidalgo is similar to the community of El Gallo in many ways. Like El Gallo, Ejido Hidalgo is governed by an *ejido* system. It is also located a great distance from its municipal center of Cedral, and is largely dependent on agricultural industry and subsistence farming as means of living.

The important distinction between El Gallo and Ejido Hidalgo, for the purposes of this study, is that the residents of Ejido Hidalgo have access to both a low-cost supply of potable water and a piped source of nonpotable water. Each participating household can pay for 40 liters/day of drinkable water (the old or the poor are exempted from paying for their water). This water is provided by a water treatment system located in the center of the community. The center was originally put into place over a decade ago by SEDUE, a federal government agency (now non-existent). A local resident has been trained in its operation, and is paid to oversee the distribution of potable water among community members. The water treatment is accomplished via filters (provided by the president of the municipality of Cedral every 1-3 years), and the additional of several chemicals, also provided by the president. Any unexpected maintenance issues are paid for by the residents of Ejido Hidalgo. In this community, people leave 20-liter containers outside of the treatment center to be filled every morning and then recollect them throughout the day, as shown in Figure 6. This provision of drinking water has created a community that relies only occasionally (about once/year for up to a week, when the treatment system needs to be repaired) on *garrafónes* for drinking water.

In addition to having a source of potable water, almost every resident has indoor plumbing providing immediate access to as much (untreated) water needed. The untreated water comes from the same source as the treated water, and residents share the costs of electricity to operate the pump. People who use this water source for livestock and crops are expected to pay a small amount more each month in addition to their normal household costs. When residents temporarily lose piped water service , they are able to fill containers from a nearby rainwater collection and storage pond or *aljibe* as seein in Figure 7. Those that do not have indoor piping are therefore provided with a dependable source of untreated water, and may choose to hire a truck to transport the water to their house for a small fee.

Figure 6. The treatment center for potable water in Ejido Hidalgo.

Figure 7. An *aljibe* in Ejido Hidalgo that can provide unimproved water.

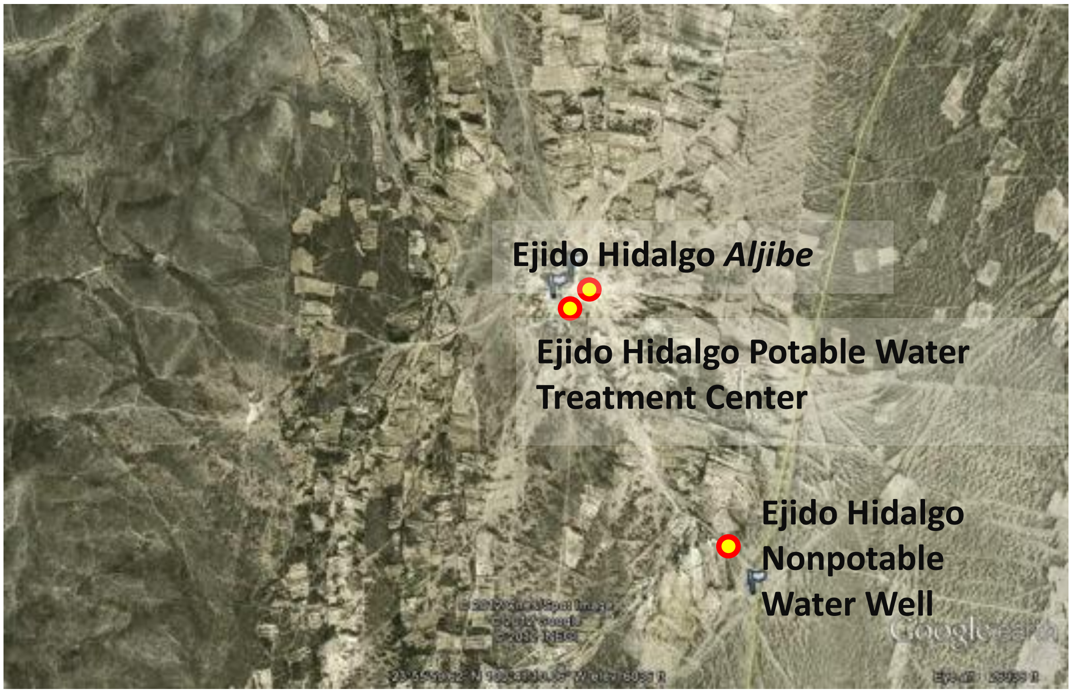

Figure 8. Locations of the pump supplying nonpotable piped water, the water treatment center, and the *aljibe* in Ejido Hidalgo. Information courtesy of INEGI (www.inegi.org.mx) and Google Earth (www.googleearth.com).

2.1.3 Site Description: Municipality of Matehuala: The City of Matehuala

The city of Matehuala is located approximately 1.5 hours south of El Gallo and one hour south of Ejido Hidalgo by car. This municipal seat is substantially larger than those of Vanegas and Cedral, and boasts several supermarkets, a movie theater, and a university. The people in Matehuala (both in the city and in the municipality) have almost universal access to piped, treated drinking water, and also have access to garrafón - providing water treatment centers.

The water provided to the city of Matehuala comes from a nearby community, La Paz, and is a combination of rainwater and groundwater. Along the distribution route, there are treatment centers or *pilas* that chlorinate the water before sending it along. Anecdotally, there appears to be a substantial division in public opinion over the potability of this water. Some believe that the water provided by the city of Matehuala via the agency SAPSAM is potable, and drink from the tap on a daily basis. However, other people believe that the tap water is contaminated by heavy metals, a byproduct of the mining industry in the area, and drink water almost exclusively from garrafónes. Others believe that the water has been polluted by other contaminants, such as sediment and salts.

The services of SAPSAM can be extended to residents without a connection, but it requires a small upfront investment of time and money. Typically, residents are responsible for all of the costs associated with plumbing the interior of their homes, but SAPSAM will assist them in connecting their household pipes to the system, and will also help them to install a water meter. If a resident is outside of the existing network, SAPSAM expects them to pay to have the network extended, but this cost is usually partially, if not entirely, subsidized by the municipality.

In addition to the water provided by SAPSAM, residents of the city of Matehuala have access to a variety of different water vendors. These vendors treat piped water, typically by osmosis filtration, bottle and sell it in garrafónes. These garrafónes are cheaper when they are purchased directly from the vendor, but are also made available to customers in stores, including gas stations, corner stores and supermarkets. There are also trucks that sell garrafónes by driving up and down streets. This sales method is the standard for a variety of products, including tanks of gas, ice cream, dirt and brooms. Trucks drivers can be provided directly by a particular water vendor, or they can be freelance.

The majority of small rural communities of Matehuala also have access to piped water, though whether or not this water comes directly into their homes or they collect their household water from watering stations varies by community. Typically, there is a big measurer or *macro medidor* next to a valve at a point in the pipe that can be shut on or off by SAPSAM, depending on whether or not the community has paid their last water bill. This *macro medidor* keeps track of the total liters consumed by the community in a month, and it is up to the community members to self-report this quantity to SAPSAM officials, and to pay (collectively) what they owe. SAPSAM does not authorize its water to be used for agricultural purposes, though this can be difficult to enforce.

Figure 9. Distribution of surveyed sampling points in Matehuala. *Information courtesy of INEGI (www.inegi.org.mx) and Google Earth (www.googleearth.com).*

Every ten years, a nation-wide census is conducted by the *Instituto Nacional de Estadistica y Geografia* (INEGI). Table 2 summarizes some of the key demographic information for each of the three study sites, according to the 2010 findings of INEGI.

Table 1. A summary of the different study sites, and their access to different water sources.

Location	*Population*	*Daily Access to Garrafónes*	*Access to Community Wells*	*Water Provided to Community by Trucks*	*Access to Piped Water*
El Gallo	220	X	X	X	
Ejido Hidalgo	194		X		X
Matehuala	77,328	X			X

Table 2. Descriptive statistics of each of the three study sites, as reported by INEGI.

Variable	*Matehuala*	*Ejido Hidalgo*	*El Gallo*
Total Size of Population	77,328	194	220
Total Number of Households	18,933	49	50
Average Number of School Grades Completed by Women	9.04	6.43	5.6
Average Number of People per Household	4.07	3.96	4.40
Average Number of People per Household Room	0.95	1.3	1.24
Percentage of Households with Electricity	99%	94%	98%
Percentage of Households with Plumbing	96%	71%	0%
Percentage of Households with a Television	97%	84%	86%
Percent of Households with a Refrigerator	94%	47%	56%
Percentage of Households with a Washing Machine	86%	53%	42%
Percent of Households with an Automobile	58%	37%	20%

2.2 Calculation of Sample Size

The results of the 2010 nationwide census conducted by the Instituto Nacional de Estadistica y Geografia (INEGI, www.inegi.org.mx), in addition to the website http://www.surveysystem.com/sscalc.htm#one, were used to calculate the appropriate sample sizes in each community, with a 95-percent confidence level and a confidence interval of +/- 10 percent. In calculating the appropriate sample size for each community, the total number of residences (not the total population) was used to define the number of residences needing to be sampled. Table 3 summarizes the calculated sample sizes.

Table 3. A summary of population sizes, number of residences, and calculated sample sizes for each community.

Location	*Total Population of Municipality*	*Total Population of Sampled Community*	*Total Number of Residences in Sampled Community*	*Calculated Sample Size*
Matehuala	91,522	77,328	18,933	96
Ejido Hidalgo	18,933	194	49	33
El Gallo	2,728	220	50	38

2.3 Surveying Process

Prior to the beginning of the survey period, the study protocol was approved by Institutional Review Board at the University of South Florida (see Appendix A). Two detailed surveys were developed to answer the research questions of this study (see Appendices B and C). Questions focused on the water-use habits of residences, opinions on various water sources, and also the relative economic status of participants. All water costs and economic status surveys were conducted over a 2-month time period within each community. In El Gallo, this surveying period began in June and ended in July. In Matehuala, this period began in September, and ended in October. In Ejido Hidalgo, survey began and concluded in September. All water use surveys in El Gallo were conducted over a four-month time period, beginning in June and ending in September.

2.3.1 Water Costs and Economic Status Survey

Prior to the beginning of each survey, the survey questions were reviewed by native Spanish speakers to confirm that the questions were correctly translated into the native language and did not contain subject matter or questions that might be considered culturally inappropriate. With the exception of the participants in El Gallo, all households were randomly selected. Surveyed households in El Gallo were the participants in the solar distillers project. Participants in the solar distillers project represented some 80-90 percent of the total households in El Gallo. Expanding the sampling pool to include the households who did not wish to participate in the distillers project was believed to not be practical. The majority of these households had already previously informed the researchers that they did not wish to participate in any project that might happen, and in the initial canvassing of El Gallo, these same households also declined to participate in a general questionnaire about the needs of El Gallo, so it is very likely that these same households would decline to be interviewed during this study.

To meet the needs of the first hypothesis, the 38 households that participated in the construction of solar distillers in the community of El Gallo were surveyed. This survey collected information on the general characteristics of each family, estimations of their annual income, their weekly and monthly water consumption rates, their sources of potable and nonpotable water, and their opinion of the safety and availability of these water sources. GPS coordinates were collected for each non- garrafónes water source. Additionally, survey respondents were asked to provide estimates of the distances from their houses to each source of nonpotable water, and the average waiting times that they experience while filling their containers.

For the remainder of the study, households were randomly selected for surveying. In the case of Ejido Hidalgo, it was necessary to first have a meeting of all of the (female) heads-of-households to explain the author's purpose in their community. To randomly select households in Ejido Hidalgo, Google Earth (www.googleearth.com) was used to number visible streets, then a random number generator was used to select streets for surveying (www.random.org). In the larger city of Matehuala, it was first necessary to divide the city by the existing neighborhoods or *colonias*, assign each a number, and then use the random number generator to identify the *colonias* in which to sample. After the *colonias* were selected, the streets within them were assigned numbers, and the random number generator was used once more to the identify streets on which to conduct the survey. In both communities, streets were canvassed by starting on one side of the street, and continuing on that side until the end of the *colonia* (or the town, in the case of Ejido Hidalgo). Surveys were conducted at every other house along the street, the next door was not skipped if someone didn't answer the door.

Additionally, it was necessary to survey from the hours of 10 a.m. to approximately 8 p.m., to include those households that had all adults working outside of the home. Working schedules can be similar to the 9-to-5 schedule of the U.S., or they can be based on the more traditional Mexican work schedule, which will see employees typically stopping work around 1 or 2 in the afternoon, going home for an extended lunch and rest, and then returning to work around 3 or 4, completing the work day around 7 or 8 in the evening. Surveying for an extended period of time each day allowed for a sampling of the households that were out of the house until 5 (sampled from 5-7); of households that took a break in the afternoon (sampled from 1-4), and, of households where not everybody worked outside of the house (sampled continuously throughout the day).

At all but three of the households in Matehuala, the female head of the household was surveyed. In the instances where the male head of household was surveyed, this was due to there being no female head of household to survey. An effort was made to speak to female heads of household because it was thought that they might be more aware of the rates of diarrhea in their household, since they are typically responsible for caring for the sick. Since the topic of diarrhea can be sensitive, it is possible that households in Mexico were under-reporting, but it is thought that this is probably more of an issue in the more conservative, rural communities that it is in the urban communities. Additionally, due to the depth of pit latrines located in rural communities, it was not possible to visually confirm the presence/absence of diarrhea in a household at the time of the survey.

All information regarding monetary values that was collected during this survey is reported here in pesos unless otherwise stated.

2.3.2 Water Use Worksheets

To address the second hypothesis, families located in El Gallo who participated in the solar distillers projects were given the opportunity to complete water usage worksheets each week. Solar distillation, a passive solar technology, is the process of using solar energy to produce purified water from an impure source. The solar distillers project was jointly sponsored by Peace Corps and the regional branch of La Comision Nacional de Areas Naturales Protegidas (CONANP), and seeks to provide all interested participants with the education and resources necessary to successfully construct their own household solar distillers. These solar distillers will treat a previously-unpotable water source through the processes of evaporation and condensation so that the water becomes potable. It has been estimated that each solar distiller will be capable of producing approximately 2.5 Liters of potable water each day (Manser, 2012).

Beginning in June 2011, water-use worksheets (see Appendix C) were distributed to the participants of the solar distillers project. These worksheets asked participants to document their daily water needs for different household categories (drinking, cooking, bathing and hygiene, cleaning or washing clothes, livestock, and gardens) in liters. The worksheet also asked participants to list the source of water for each activity (garrafón, well, pipa, truck, and eventually distiller). A community mapping exercise in April identified no major, overlooked sources or uses of water. The timeline for completing the worksheets to collect the baseline water usage data spanned from June to the end of July. After the completion of the distillers in September, worksheets were distributed for another two weeks to collect information about how the addition of a distiller affected each family's water consumption. Prior to distributing the first worksheet to each household, it was explained in detail how to fill out the worksheet correctly. To minimize confusion on what the exact volume of a liter is, 3.5-liter volume pitchers with marked increments of 0.5 liters on the sides were provided to every participating household, so that they were able to measure more exactly the quantity of water taken each time from the garrafón, community well, pipa or the distiller. On a weekly or biweekly basis, the previous week's worksheet was collected, and a new worksheet for the coming week was provided. The worksheets were checked while still in each household to confirm that the information had been entered properly, and to provide time to answer any questions there might be about filling in the worksheets. For certain categories, the use of water pitchers for estimating volume was impractical, for example estimating the amount of water used for watering gardens. For these categories, the volumes of larger containers were recorded. These containers were all of a standard size in the community, either 240 liters or 400 liters, and their volumes were already well-known by participants.

2.4 Statistical Analysis

Results from both surveys were recorded in an Excel spreadsheet to obtain the averages and other basic descriptive statistics. Further statistical analysis was conducted using Minitab v. 16.2.1 software.

2.4.1 Water Costs and Economic Status Survey

While reviewing the data for inclusion in statistical analysis, one outlier was identified in the Matehuala subset, based on the variable ‘yearly income.’ This outlier was removed from the dataset before proceeding with the statistical analysis. Additionally, it became apparent that information from Ejido Hidalgo regarding average costs of both potable and nonpotable water supplies needed to be excluded from further statistical analysis, as the prices in Ejido Hidalgo were based on set tariffs and provided a fixed monthly supplied quantity, rather than the monthly consumption rates available in El Gallo and Matehuala. All other information from the surveys conducted in Ejido Hidalgo was included in further statistical analysis.

To determine the differences, if any, in means for selected variables, two sample t-tests were performed at the $\alpha = 0.05$ level of significance. Selected variables included yearly income, the perceived access to sufficient quantities of water for daily needs, the number of days per month with diarrhea, the cost of garrafón water ($/liter) (El Gallo and

Matehuala only), and the cost of nonpotable water per month (El Gallo and Matehuala only).

Linear regressions were performed on the variables observed to have significantly different means among the three communities, as determined by the two sample t-tests, in order to further examine the relationship between the variables and their possible influencing factors. The independent variables, as identified by the t-tests, were the cost of potable water ($/liter) in El Gallo and Matehuala only, the cost of nonpotable water ($/month) in El Gallo and Matehuala only, the probability of contracting diarrhea (coded as presence or absence in the dataset), the number of days/month with diarrhea, and the perceived access to sufficient quantities of water for household needs (coded as 1 = sufficient, 0 = insufficient). In some cases, the log of the dependent variable was taken to obtain results that could be quantified in terms of percentage change. Again all analyses were conducted at the $\alpha = 0.05$ level of significance. In addition to the variables available from the survey, several other variable were created, including the presence or absence of a piped water source and the average monthly nonpotable water costs. The presence or absence of a piped water source variable was based on information taken from the survey (source of nonpotable water), and coded as 1 (have piped source) or 0 (do not have piped source) in the dataset. The average monthly nonpotable water cost was the sum of the reported costs of the nonpotable water source and the average reported monthly maintenance costs associated with this nonpotable water source.

2.4.2 Water Use Worksheets

When reviewing the results of the water use worksheets, it was determined that 10 out of a total of 38 participating households had provided enough data that could be included in further statistical analysis. Households in this data subset provided at least three weeks of information related to pre-distiller water consumption rates, and at least one week of information related to post-distiller water consumption rates. The mean consumption rates pre- and post-distiller were compared using a paired t-test with significance at the $\alpha = 0.05$ level.

CHAPTER 3: RESULTS

3.1 Issues During the Survey of Water Costs and Economic Status

A number of issues became obvious during the surveying process, mostly related to the confidence in participants of the 'legitimacy' of the study. 'Legitimacy' in this case refers to whether or not respondents believed that the surveyor represented a legitimate establishment, or was working in conjunction with a criminal enterprise to gather information regarding the finances of households. To alleviate these concerns, the surveyor presented identification that identified them as a Peace Corps volunteer to all possible respondents, and also provided all possible respondents with contact information for the surveyor and the affiliated university.

Even with these measures in place, several survey questions were deemed to be fairly sensitive in certain sites, for example in some communities there is concern that reporting of any remittances poses a threat of kidnapping. For these reasons, the question about remittance rates was skipped if a participant seemed especially reluctant to share financial information. Still, many households felt comfortable enough to provide this type of information, and it is included where available. With all of the fear and suspicion that is currently gripping Northern Mexico, it is realistic to assume that some respondents were nervous about questions regarding finances, and may have had motivation to downplay actual income due to fears of the threats of extortion, kidnapping, etc.

Table 4 compares demographic information gleaned from INEGI 2010 census findings and the survey findings for this study. Based on the comparison provided in Table 4, the respondents in Matehuala for this study are the most similar to the city-wide averages obtained during the 2010 INEGI census, suggesting that the data from this study is representative of the city of Matehuala, in terms of these predetermined economic indicators. For both the village of Ejido Hidalgo and the village of El Gallo, survey information obtained during this study mostly averaged higher than the data obtained during the 2010 INEGI census. This suggests that, if anything, the estimated economic status of residents in these communities is higher than it should be.

Additionally, when examining the different job categories reported in this survey, the survey contained very similar reported wages for each type of labor across communities and households. For example, the average daily and monthly wage for a farm laborer in El Gallo was equal to that reported for a farm laborer in Ejido Hidalgo (usually $100 pesos per day, but dependent on the type of labor). Although there were far fewer farm laborers in Matehuala, the surveyed households all reported very similar wages for the same job, for example teachers at each household all made about the same wage per month, as compared to other households with teachers, and none of these reported wages seemed unrealistic to the surveyor. For these reasons, it can be assumed that the reported values for sensitive subjects regarding wages, etc., were relatively accurate.

From the literature, although no information was found regarding average monthly wages specific to this study region, it has been previously observed that the hourly wages in different professions are often twice as high or more for urban dwellers, compared to rural dwellers (Verner, 2005). This ratio is approximately consistent with our finding that urban dwellers in Matehuala earn a little over twice what the rural participants earned in a month ($10,523.83 (Matehuala) vs. $4,425.90 (Ejido Hidalgo) and $3850.85 (El Gallo)). Based on all of the above information, it is probable that the financial information regarding annual income is representative of all sample populations in this study.

Table 4. A comparison of information reported by 2010 INEGI census, and results from this study.

Variable	*Matehuala (Reported by INEGI in 2010)*	*Matehuala (Survey Results from this Study)*	*Ejido Hidalgo (Reported by INEGI in 2010*	*Ejido Hidalgo (Survey Results from this Study)*	*El Gallo (Reported by INEGI in 2010)*	*El Gallo (Survey Results from this Study)*
Average Number of People per Household	4.07	4.00	3.96	3.94	4.40	4.03
Average Number of People per Household Room	0.95	0.84	1.3	1.71	1.24	1.27
Percentage of Households with Electricity	99%	100%	94%	88%	98%	97%
Percentage of Households with Plumbing	96%	100%	71%	97%	0%	8% (Bathrooms Only)
Percentage of Households with a Television	97%	97%	84%	94%	86%	92%
Percentage of Households with a Refrigerator	94%	94%	47%	58%	56%	76%
Percentage of Households with a Washing Machine	86%	92%	53%	58%	42%	50%
Percentage of Households with an Automobile	58%	66%	37%	27%	20%	31%

3.2 Remittance Rates and Average Incomes

Initially, there was some concern that, due to the ongoing wave of crime and violence in northern Mexico, respondents would be reluctant to share financial information honestly during the survey. This was particularly true for reporting remittance rates, as many people believe that kidnappers have specifically targeted households receiving remittances in the past. Therefore, it was necessary to compare the results of the survey regarding financial information with previous findings to confirm that the information from this study was consistent with previous observations.

Table 5. A comparison of the number of households (%) receiving remittances.

Variable	*Matehuala*	*Ejido Hidalgo*	*El Gallo*
Percentage of Households Reported Receiving Remittances	14.6%	33.3%	36.8%
Previously Reported Percentage of Households Receiving Remittances (de la Fuentes, 2008)	7.88%-10.62%	7.88%-10.62%	7.88%-10.62%
Previously Reported Percentage of Households Receiving Remittances (Demirgüç-Kunt et al., 2011)	4.7%-12.4%	12.4%-13.8%	12.4%-13.8%

Based on the above comparison in Table 5, the respondent rates from this study were very high, compared to the national and regional averages. This suggests that the number of respondents reporting receiving remittances was not impacted by the current state of security in Mexico.

3.3 Water Costs and Economic Status Survey

3.3.1 A Description of El Gallo

Of the three communities sampled, El Gallo had the highest percentage of respondents (55%) who reported an insufficient quantity of water to meet their daily needs, respondents reported a need for more water in all provided categories, including drinking (16% reported a need for more drinking water daily), cooking (11%), bathing (21%), cleaning (29%), washing clothes (34%), livestock (24%) and crops (21%). Interestingly, the categories with the highest expressed need are all categories that typically use untreated water. This is complementary to the lowest level of satisfaction reported among the three groups, with 55 percent, and 34 percent reporting that they were satisfied with the dependability of the nonpotable communal well and the water tanker truck, respectively, compared to 88 percent satisfied with the dependability of the well providing piped nonpotable water in Ejido Hidalgo and 97 percent of respondents in Matehuala satisfied with the dependability of their tap water source. While there is an expressed need for more drinking and cooking water, the actual weekly usage rates per person of garrafón water in El Gallo is very similar to the weekly usage rates per person in Matehuala, a city with much more accessibility to water vendors (0.70 garrafónes (13.3 liters) per person per week in El Gallo vs. 0.78 garrafónes (14.8 liters) per person per week in Matehuala).

The average cost of a garrafón in El Gallo was $17.39, with 68% of respondents reporting that they had purchased garrafónes from a truck, and 50% of respondents reporting that they had purchased garrafónes from a local store. No one reported buying garrafónes directly from a treatment center, which is not surprising considering the distance to a treatment source. All respondents reported using garrafón water for drinking, and 53 percent used garrafón water additionally for cooking. With regards to perceived water quality, 74 percent reported that they felt that garrafón water was either ‘very safe’ or ‘pretty safe’ to drink. Generally speaking, in all three communities there appears to be at least a significant minority of the population concerned with the quality of garrafón water, probably in part due to existing rumors that unscrupulous vendors have packaged untreated water in garrafónes to sell to unsuspecting consumers.

Of the other available sources of water in El Gallo (communal or private well, truck, rainwater retention pond, and rainwater collection), 89 percent of respondents reported using water from a well, with a further 16 percent of respondents reporting the use of a private or familial well. Eighty-four percent reported using the water truck, and only 3 percent used the rainwater retention pond. It is possible that, due to unobserved social dynamics, the 3 percent reported to use the retention pond do not feel comfortable using the communal well. There are a lot of inter-community social dynamics in El Gallo that could possibly preclude an ‘outcast’ from using a community well. Rainwater harvesting was relatively popular in El Gallo, with 74 percent reporting that they collected rainwater when possible.

With respect to perceived water quality, 11 percent of El Gallo residents felt that untreated well water was either ‘very safe’ or ‘pretty safe’ to drink, with 5 percent of participants stating that they or someone in their household drank untreated well water regularly. The water brought in by truck was more popular for consumption, with 26 percent of respondents thinking that this water was safe to drink, and 37 percent reporting actually drinking it. Reasons for thinking that the well or truck water was unsafe to drink included the presence of bacteria (11% for both well and truck water), the presence of other pollutants (42% and 34%), bad taste (82% and 18%), bad smell (11% and 0%), and appearance (11% and 5%). Water costs for untreated well water were approximately $228 pesos a month per household.

From an economic standpoint, El Gallo is a community that consists mostly of day-laborers working in the fields of large farms, though some unusual reported forms of employment include hand-making goat cheese and scraping cactus pads for the strong inner fibers (used to make rope and some tough fabrics). Houses overwhelmingly consist of adobe walls, cement floors, and ceilings of *garrocha* (garrocha is a term used to describe a mixture of long, straight poles (typically the dried, dead flowers of agave or maguey plants) and dirt or adobe. The average house has 3.5 rooms, which is approximately 1 room per resident. The majority of bathrooms in survey households were outside and not plumbed, although a few houses reported having an outdoor bathroom with plumbing. In this instance, 'plumbing' should not be interpreted to mean that the bathroom is connected to any type of sewer service. Nearly ¾ of homes (74%) owned farm land, and 97 percent of homes had a reliable source of electricity. During the survey, a list of 11 'status' items was created to help determine the amount of money that surveyed households had for nonessentials. The items on this list included television, satellite or cable connection for the television, car or truck, radio, stereo, gas (for cooking), refrigerator, washing machine, motorcycle, phone, and computer. The participants in El Gallo had, on average, 5.39 of the total 11 items on the list, with the most common being possession of a television with satellite connection, followed by gas for cooking.

When comparing the average monthly salary of a household in El Gallo to the average monthly water costs (including nonpotable well sources and the purchase of garrafónes), it is observed that the average household spends approximately 15 percent of their monthly income on water.

3.3.2 A Description of Ejido Hidalgo

No survey participants in Ejido Hidalgo reported buying garrafónes with any regularity. Respondents generally replied that they might buy one or two garrafónes a year if the treatment plant has temporarily broken. Ninety-seven percent of participants stated that they used the treated well water for drinking, with a further 76 percent using treated well water for cooking, 6 percent used the water for bathing, and 3 percent used the water for washing clothes. Interestingly, 88 percent of respondents expressed confidence in the safety of treated well water for drinking, this confidence rate is higher than either of the expressed confidences in the safety of garrafón water by El Gallo (74%) or Matehuala (78%).

Ninety-four percent of participants in Ejido Hidalgo used a private well to meet the rest of their water needs, with an additional 79 percent using the rainwater retention pond regularly and 6 percent using shared tap stands. A few household reported drinking (6%) and cooking (9%) with the untreated well water, but the majority used this water for bathing (73%), cleaning (88%), washing clothes (88%), watering livestock (61%) and tending to crops (36%). Lower usage rates in general were reported for rainwater pond usage, but it is important to note that the most common usages of water from the rainwater pond were bathing (33%) and washing clothes (30%), these relatively high rates, especially when considering that bathing and washing clothes are two household chores that could be accomplished much more easily with a piped source of water should be considered a reflection of the water quality coming from the piped source. Many participants concern that the untreated well water was ‘salty’, full of minerals, and did not really clean things as well as rainwater. This is probably why taking a bucket shower using rainwater is preferable to taking a piped water shower using well water for some participants.

The average monthly cost varied little from household to household in Ejido Hidalgo, almost all respondents paid 50 pesos a month for 40 liters/day of potable water, and an additional 50 pesos per month for the electricity bill of the water pump that provides nonpotable water to households (the very elderly and very poor were exempted from paying this). Some households reported paying a little more than this basic cost, due to the extra needs of their livestock, or due to having to hire a truck to bring them water from the rainwater pond when the pump was not working.

Economically speaking, Ejido Hidalgo is similar to El Gallo, but a little lower on the economic scale, despite have a slightly higher average reported monthly wage. Houses again mostly consist of cement floors, adobe walls, and *garrocha* (a mixture of dirt and the dried stalks of agave flowers) ceilings, though they are a little smaller in Ejido Hidalgo (an average of 3 rooms per house or 0.85 room per inhabitant). Interestingly, although a higher percentage of respondents in Ejido Hidalgo reported having a plumbed bathroom (24%) when compared to the participants in El Gallo (8%), a higher percentage of respondents in Ejido Hidalgo also reported having no bathroom or a shared bathroom (12%) than those in El Gallo (0%). A higher percentage also reported having no electricity (12%) in Ejido Hidalgo as compared to El Gallo. The average amount of status items owned by a household in Ejido Hidalgo was similar to that of El Gallo, approximately 4.9 items/household.

The percentage of monthly water costs to average monthly income was lowest in the community of Ejido Hidalgo, with 3 percent of average monthly income being spent on obtaining water.

3.3.3 A Description of Matehuala

Surveyed residents of the city of Matehuala universally had access to piped water. For the purposes of this paper, we will refer to this source of water has their untreated source of water, though the water is actually treated with chlorine drops. It is unknown whether the addition of chlorine drops treats the water in any significant way, in terms of pathogen removal. Additionally, there was no treatment to remove heavy metals, which is a major concern for many people living in Matehuala due to the mining industry nearby. Five percent of residents stated that they or a member of their family drank from this source of water, which is equal to the proportion of residents in El Gallo drinking from their untreated source of water. Garrafón consumption rates were also similar in Matehuala compared to El Gallo, with Matehualans drinking approximately 1.5 liters more per person/week of garrafón water on average. Garrafón price and availability possibly influenced this difference, with residents in Matehuala paying, on average, over two pesos less per garrafón than the residents of El Gallo. Matehualans were also able to buy directly from the treatment center (20% stated that they did this) in addition to the trucks (54% bought from trucks) and stores (34% bought from stores) commonly available in places like El Gallo.

Of the three groups, residents in Matehuala expressed the highest level of satisfaction (99%) with their current water availability. They also expressed the highest level of satisfaction with the dependability of their untreated water source of the three groups (97%). The average monthly cost of this water source was $69.9 per household, lower than the average reported in El Gallo. Rainwater collection was at the lowest rate of the three communities in Matehuala (21%), unsurprisingly. The average economic level of residents in Matehuala was higher than residents in either El Gallo or Ejido Hidalgo, with an average of 5.3 rooms per house (1.61 rooms per person). From the list of 11 status items, Matehualans possessed an average of 8.0 items.

When the average monthly cost of water per household (including water from SAPSAM and the purchase of garrafónes) is compared to the average monthly income in Matehuala, it is observed that residents of Matehuala spend, on average, 4.4 percent of their monthly income on water.

Although no rural communities within the municipality of Matehuala were surveyed during this study, it is possible to paint a rough picture of their water habits, based on conversations with the head SAPSAM office in Matehuala. SAPSAM estimates that it has been able to provide coverage to 95 percent of residents within the municipality of Matehuala, with the remaining 5 percent of residents electing not to receive coverage. SAPSAM reported that the eight ejidos within the municipality of Matehuala all used significantly less water than their urban counterparts (an average of 607 cubic meters/month for a house of 4 residents vs. and average of 12 cubic meters/month for a house of four residents in the city). SAPSAM is also able to offer residents of rural communities a significantly discounted monthly rate on water; residents of the city of Matehuala pay $52.4 for the first 10,000 liters of water per month, but the rate for the first 10,000 liters of water for rural residents is $23.0 per month, less than half of what city residents pay.

Table 6. A summary of demographic results from the surveys in each community.

Variable	*Matehuala*	*Ejido Hidalgo*	*El Gallo*
Household Size	4.0	3.9	4.0
Literacy Rate (%)	94%	91%	89%
Respondent's Age at Marriage	22	18	18

Table 6 compares some of the results from the demographic information section of the survey. The average number of people per household are the most similar, with literacy rates being slightly higher in Matehuala than they are in either Ejido Hidalgo and El Gallo, and the average age of the wife at marriage being slightly younger in Ejido Hidalgo and El Gallo than it is in Matehuala.

Table 7. A summary of water costs and water sources in each community.

	Matehuala	Ejido Hidalgo	El Gallo
Do you feel that your household has sufficient access to water? (% responding 'yes')	99%	94%	45%
Average number of garrafónes consumed in a household per week	2.85	0	2.75
Average number of garrafónes/per person/per week	0.78	0	0.70
Average cost of one garrafón	$15.09	-	$17.39

Table 7 (Continued)

Access to SAPSAM network (Percentage w/access)	100%	0%	0%
Access to shared potable water source (Percentage w/access)	-	97%	0%
Access to shared, nonpotable well (Percentage w/access)	-	97%	89%
Access to private, nonpotable well (Percentage w/access)	-	6%	16%
Access to pipa (water tanker truck)	-	0%	84%
Access to aljibe (rainwater retention basin)	-	79%	3%
Percentage collecting rainwater at least once a year	21%	82%	74%
Average cost per household per month (pesos)			
SAPSAM connection	$69.91	-	-
Shared potable water source	-	$48.48	-
Shared, nonpotable well	-	$0	$228.42
Private, nonpotable well	-	$48.48	$0
Pipa (water tanker truck)	-	-	$0
Aljibe (rainwater retention basin)	-	$0	$0
% of Households Satisfied with dependability of each available source			
SAPSAM connection	97%	-	-
Shared potable water source	-	88%	-
Shared, nonpotable well	-	N/A	55%
Private, nonpotable well	-	N/A	42%
Pipa (water tanker truck)	-	-	34%
Aljibe (rainwater retention basin)	-	-	3%

Table 7 (Continued)

Average Liters/wk. consumed per household			
SAPSAM connection		-	-
Shared potable water source	-	271.6	-
Shared, nonpotable well	-	N/A	831.9
Private, nonpotable well	-	N/A	1122.5
Pipa (water tanker truck)	-	-	132.9
Aljibe (rainwater retention basin)	-	N/A	1397.1
Average Yearly Maintenance Costs			
SAPSAM connection	$75.13	-	-
Shared potable water source	-	$192.24	-
Shared, nonpotable well	-	-	$266.56
Private, nonpotable well	-	-	-

Table 8. A summary of water consumption rates in each community.

	Matehuala	Ejido Hidalgo	El Gallo
Drinking Water Consumed (liters/month)	235.0	n/a	226.4
Untreated Water (liters/month)	10,000	n/a	6,054.1

Table 9. A summary of water quality perceptions in each community.

	Matehuala	Ejido Hidalgo	El Gallo
Percentage of Households Reporting that Garrafón Water is Safe to Drink	73%	88% Responded that their treated alternative to garrafón water was safe to drink	74%
Percentage of Households Reporting that Untreated Well Water is Safe to Drink	n/a	9%	11%
Percentage of Households Reporting that Water from the Pipa (Water Truck) is Safe to Drink	n/a	n/a	26%
Percentage of Households Reporting that Aljibe (Rainwater Retention Pond) Water is Safe to Drink	n/a	9%	3%
Percentage of Households Reporting that Piped Water via SAPSAM is Safe to Drink	16%	n/a	n/a
Most Common Response to "Why is Well Water Unsafe to Drink?"	n/a	Funny Taste (85%)	Funny Taste (82%)
Most Common Response to "Why is Pipa Water Unsafe to Drink?"	n/a	n/a	Contains Pollutants Other than Bacteria (34%)
Most Common Response to "Why is Aljibe Water Unsafe to Drink?"	n/a	Funny Taste (58%)	Appearance (50%)
Most Common Response to "Why is Piped Water via SAPSAM Unsafe to Drink?"	Funny Taste (55%)	n/a	n/a

Table 9. (Continued)

Percentage of Households Reporting at Least One Resident Drinking Well Water	n/a	9%	5%
Percentage of Households Reporting at Least One Resident Drinking Pipa Water	n/a	n/a	37%
Percentage of Households Reporting at Least One Resident Drinking Aljibe Water	n/a	9%	3%
Percentage of Households Reporting at Least One Resident Drinking Piped Water via SAPSAM	15%	n/a	n/a
Average Number of Days with Diarrhea in a Month per Household	0.16	0.52	2.82
Percentage of Households Who Felt that Their Untreated Source of Water Was Salty	21%	88%	100%
Percentage of Households Who Feel that Drinking Well Water Causes Diarrhea or Stomach Pain	n/a	85%	63%
Percentage of Households Who Feel that Drinking Pipa Water Causes Diarrhea or Stomach Pain	n/a	n/a	8%
Percentage of Households Who Feel that Drinking Aljibe Water Causes Diarrhea or Stomach Pain	n/a	75%	0%
Percentage of Households Who Feel that Drinking Piped Water via SAPSAM Causes Diarrhea or Stomach Pain	53%	n/a	n/a

Table 10. A summary of income results from the surveys in each community.

	Matehuala	Ejido Hidalgo	El Gallo
Average number of rooms per home	5.25	3.03	3.5
Average number of rooms per person per home	1.61	0.85	1.02
Most common floor construction material	Mosaico/Tile	Cement/Concrete	Cement/Concrete
Most common wall construction material	Cement	Adobe	Adobe
Most common ceiling construction material	Cement	Garrocha	Garrocha
Percentage of homes with an indoor, plumbed bathroom	90%	15%	5%
Percentage of homes with an outdoor, plumbed bathroom	9%	9%	3%
Percentage of homes with an outdoor, unplumbed bathroom	1%	64%	92%
Percentage of homes with a bathroom shared with another household	-	3%	-
Percentage of homes with no bathroom	-	9%	-
Percentage of homes with regular electricity	100%	88%	97%
Average number of 11 'status' items per household	7.97	4.94	5.39
Average monthly income per household	$10,523.83	$4,425.90	$3,850.85
Minimum monthly income per household	$300.00	$1,203.33	$708.33
Maximum monthly income per household	$108,333.33	$11,183.89	$10,266.67

Table 11. A summary of key results by community.

	Matehuala	Ejido Hidalgo	El Gallo
Average Number of Days/Month a Household has Diarrhea	0.16	0.52	2.82
Average Number of Liters/Month of Potable Water Consumed	235.0	1,179.8	226.4
Average Number of Liters/Month of Nonpotable Water Consumed	10,000	n/a	6,054.1
Average Monthly Cost of Potable Water ($/L)	$9.52	$0.04	$10.69
Average Monthly Cost of Nonpotable Water ($/L)	<$0.01	n/a ($50/Mo for unlimited supply)	$0.07
Average Monthly Maintenance Costs of Water Supply	$6.26	$14.08	$10.52
Average Monthly Income	$10,523.85	$4,425.90	$3,850.85
Monthly Percentage of Income Spent on Water (Potable+Nonpotable+ Maintenance Costs)	4.4%	3%	15%

3.4 A Comparison of Subset Means Using Two Sample T-Tests

From the above descriptive statistics the following five variables were selected for further comparison among the communities: 1) yearly income, 2) perceived access to sufficient quantities of water for daily needs, 3) number of days per month with diarrhea, 4) cost of potable water ($/L) (El Gallo and Matehuala only), and 5) cost of nonpotable water ($/month) (El Gallo and Matehuala only).

Table 12. Two sample t-tests comparing the differences in means of key variables in El Gallo, Ejido Hidalgo, and Matehuala.

Variable	*Yearly Income*	*Cost of Potable Water ($/L)*	*Cost of Nonpotable Water ($/Month)*	*Average Number of Days Per Month with Diarrhea*	*Perceived Access to Sufficient Quantity of Water*
El Gallo Reported Mean	$46,210	$0.92	$69.71	0.16	99% Yes
Ejido Hidalgo Reported Mean	$53,110	n/a	n/a	0.52	94% Yes
Matehuala Reported Mean	$113, 931	$0.78	$228.42	2.82	45% Yes
El Gallo vs. Ejido Hidalgo Calculated p-value	0.314	n/a	n/a	0.001	0.000
El Gallo vs. Matheuala Calculated p-value	0.00	0.000	0.002	0.000	0.000
Ejido Hidalgo vs. Matehuala Calculated p-value	0.00	n/a	n/a	0.450	0.257

The results shown in Table 12 indicate that the average yearly incomes in Ejido Hidalgo and El Gallo are both significantly different from the average yearly incomes in Matehuala ($p = 0.000$ and $p = 0.000$, respectively). The average yearly incomes in Ejido Hidalgo and El Gallo are not significantly different from one another ($p = 0.314$).

Additionally, it is observed that the average costs of potable water are significantly different between El Gallo and Matehuala, with a calculated p-value of 0.000. The average monthly costs of nonpotable water are significantly different between El Gallo and Matehuala, with a calculated p-value of 0.002. The average number of days per month with diarrhea in El Gallo is significantly different in El Gallo than it is in either Ejido Hidalgo or in Matehuala ($p = 0.001$ and $p = 0.000$, respectively). The average number of days per month with diarrhea in Ejido Hidalgo and Matehuala are not significantly different from one another ($p = 0.45$). Finally, the average number of respondents reporting that they felt they had access to a sufficient quantity of water for their daily needs is significantly different in El Gallo, as compared the averages of both Ejido Hidalgo and Matehuala ($p = 0.000$ and $p = 0.000$, respectively). The averages were not significantly different between Ejido Hidalgo and Matehuala ($p = 0.257$).

3.5 Further Examination of Statistically Different Means Using Linear Regression

The following linear regressions were obtained using the key variables, as identified by the results from the two sample t-test (Table 12) as the independent variables. The dependent variables were then identified as household size, household size squared, ownership of automobile (yes/no), ownership of land (yes/no), weekly water consumption, log of annual income, access to sufficient quantity of water, access to piped water source (yes/no), total number children, someone in household drinking from untreated source, total number of livestock owned, participation in the OPORTUNIDADES program, and rainwater collection (y/n).

Table 13. Linear regression results: cost of potable water ($/liter) in the communities of El Gallo and Matehuala.

Variable	*Coef.*	*Std. Err.*	*t*	*P>t*	*[95%Conf.*	*Interval]*
Household Size	0.167	0.052	3.22	0.002	0.065	0.270
Household Size Squared	-0.019	0.005	-3.48	0.001	0.030	0.008
Automobile	0.056	0.050	1.12	0.266	0.043	0.156
Own Land	0.046	0.054	0.84	0.401	0.061	0.153
Weekly Water Consumption	-0.095	0.041	-2.32	0.022	0.176	0.014
Log of Annual Income	0.026	0.034	0.76	0.449	0.042	0.093
Access to Sufficient Quantity of Water	-0.080	0.041	-1.97	0.052	-0.160	0.001
Access to Piped Water	- 0.132	0.052	-2.57	0.011	0.234	0.030
	-0.350	0.353	-0.99	0.324	-1.050	0.350

Number of observations: 132, F (8, 123) = 5.66, Prob. > F = 0.00, R-squared = 0.225, Root MSE = 0.23

In Table 13, it is observed that the variables household size (p = 0.002), the square of households size (p = 0.001), weekly water consumption (p = 0.022), and presence of a piped water source (p = 0.001) are all significantly correlated to the costs of potable water at the $\alpha = 0.05$ level.

Specifically, in terms of household size, it was observed that a 10 percent increase in household size leads to a 1.8 percent reduction in the price of potable water, this suggests that the consumers of larger quantities of garrafónes may be either getting a discount on garrafónes when they purchase them, or it may be that respondents who consume a lot of garrafón water are finding the cheapest sources to purchase garrafónes.

The presence of a piped water source leads to a 13.2 percent decrease in the price of potable water. Since the only respondents in this analysis with a piped water source were from Matehuala, and the only respondents without a piped water source were from El Gallo, it is possible to confer that the urban residents of Matehuala are paying, on average 13.2 percent less for their potable water source than their rural counterparts in El Gallo.

Table 14. Linear regression: cost of nonpotable water ($/month), in the communities of El Gallo and Matehuala.

Variable	*Coef.*	*Std. Err.*	*t*	*P>t*	*[95%Conf.*	*Interval]*
Household Size	-0.015	0.074	-0.20	0.842	-0.161	0.132
Household Size Squared	0.005861	0.008	1.41	0.460	-0.010	0.022
Log of Annual Income	0.121	0.086	1.41	0.163	-0.050	0.292
Access to Safe Water (H20 Access?)	-0.206	0.114	-1.82	0.072	-0.431	0.019
Access to Piped Water	-0.390	0.092	-4.25	0.000	-0.572	-0.208
	1.78	0.424	4.20	0.000	0.942	2.62

Number of observations: 121, R-squared = 0.32

In Table 14, it is observed that the only variable significantly correlated to nonpotable water cost at the $\alpha = 0.05$ level is the presence of a piped water source, with the presence of a piped water source resulting in a 39.0 percent reduction of the monthly costs of nonpotable water. The variable 'perceived access to sufficient amount of water for daily household needs' was correlated to the cost of nonpotable water at the $\alpha = 0.10$ level.

Table 15. Logistic regression results: probability of contracting diarrhea in the communities of El Gallo, Ejido Hidalgo, and Matehuala.

Variable	*Coef.*	*Std. Err.*	*t*	*P>t*	*[95%Conf.*	*Interval]*
Access to piped water source	-1.63	0.505	-3.24	0.001	0.20	0.07
Total number of children	-0.226	0.186	-1.21	0.225	0.80	0.55
Someone in household drinking from untreated water source	-0.062	0.514	-0.12	0.905	0.94	0.34
Total Number of Livestock	-0.019	0.012	-1.54	0.123	0.98	0.96
Participation in the OPORTUNIDADES program	2.33	0.421	5.54	0.000	10.29	4.51
	-0.160	0.566	-0.19	0.851		

Number of observations: 166, G = 50.079, DF = 5, P-Value = 0.000

In Table 15, a statistically significant relationship is observed between the probability of having diarrhea at least once per month and both the variable 'access to piped water' and the variable 'participation in the OPORTUNIDADES program'. More specifically, access to a piped water source was negatively correlated to a household's probability of having diarrhea, and participation in the OPORTUNIDADES program, here a measure of the poverty of a household, was positively correlated to the probability of having diarrhea at least once in a month.

It is likely that the number of children had no observed effect because the number of children in each household was fairly uniform across the sampling pool. Interestingly, whether or not someone in a household was drinking from an untreated source had no effect on the probability of someone in that household having diarrhea, nor did the total number of livestock owned by a household. An additional regression was performed to examine the differences in diarrheal rates in El Gallo and Matehuala alone, but this regression did not produce any observed relationships of statistical significance.

Table 16. Linear regression results: monthly number of household diarrhea occurrences in the communities of El Gallo, Ejido Hidalgo, and Matehuala.

Variable	*Coef.*	*Std. Err.*	*t*	*P>t*	*[95%Conf.*	*Interval]*
Access to piped water source	-0.398	0.143	-2.78	0.010	-0.693	-0.103
Total number of children	-0.062	0.075	-0.83	0.414	-0.216	0.092
Someone in household drinking from untreated water source	0.116	0.166	0.70	0.491	-0.226	0.458
Total Number of Livestock	0.003	0.005	0.51	0.616	-0.008	0.013
Participation in the OPORTUNIDADES program	0.194	0.140	1.39	0.177	-0.094	0.481
	0.484	0.157	3.09	0.005	0.161	0.807

Number of observations: 31, R-squared = 0.41

The results shown in Table 16 were similar to the regression of the probability of contracting diarrhea in a month. Neither the total number of children, the presence of someone in the household drinking from an untreated water source, nor the total number of livestock owned by the household were correlated to the log of the total number of days with diarrhea in a month. Participation in the program OPORTUNIDADES, although increasing the probability of contracting diarrhea in the previous logistic regression (Table 15), is not significantly correlated to the number of days with diarrhea in a month, interestingly.

From the correlated variable, ‘access to a piped water source’, it is possible to infer 2.4 percent reduction in the number of days with diarrhea if there is access to a piped water source.

Table 17. Logistic regression results: perceived access to sufficient amount of water for daily needs in the communities of El Gallo, Ejido Hidalgo, and Matehuala.

Variable	*Coef.*	*Std. Err.*	*t*	*P>t*	*[95%Conf.*	*Interval]*
Access to piped water source	3.89	0.723	5.37	0.00	48.74	11.81
Participation in the OPORTUNIDADES program	-0.253	0.581	-0.44	0.663	0.78	0.25
Someone in household drinking from untreated water source	0.126	0.618	0.20	0.839	1.13	0.34
Rainwater Collection (y/n)	-0.180	0.631	-0.29	0.776	0.84	0.24
	-0.020	0.690	-0.03	0.977		

Number of observations: 166, G = 56.763, DF = 4, P-Value = 0.000

The results shown in Table 17 indicate that the only recorded variable statistically correlated to a respondent answering 'yes' when asked if they felt that they had enough water to meet their daily needs was positively correlated 'presence or absence of a piped water source'. All other variables were not correlated at the $\alpha = 0.05$ level.

3.6 Water Use Worksheets

A total of 30 of the 38 participating households provided enough information for a relevant pre-distiller water use profile, though several sampling difficulties were encountered during this section of the study, primarily they were due to the distillers not producing as much water as initially expected. This is probably due in part to the fact that the distillers were completed when the hot season was beginning to diminish. Additionally, although there were 38 participants, there were not 38 working distillers when we finished in September, there were a lot of issues with the construction of the distillers that led to leaking and diminished production rates. While most of these issues were ultimately resolved, they were not resolved in time to distribute the 'post' water use worksheets for any meaningful period of time. Finally, there was some trepidation initially about using the distilled water for cooking or drinking, further follow-up sessions with households on an individual basis were needed to instill confidence in the quality of the distillate (though once these issues were resolved, many positive reports about the water taste were received).

In all, 37 households participated in some capacity in the pre-distiller segment of the study. Of these 37 households, a total of 10 households were able to provide at least three weeks of pre-distiller information regarding water consumption rates, and an additional weeklong post-distiller water profile. The uses of the distilled water were varied; the worksheets indicated that this new source of potable water is being used for drinking and cooking (most commonly), but also for watering livestock.

Table 18. Results of a paired t-test comparing average weekly consumption rates of water before and after implementation of solar distillers in El Gallo.

	Calculated T-Value	Calculated P-Value
Consumption of Water for Drinking Before and After Distiller	-0.51	0.62
Consumption of Water for Cooking Before and After Distiller	0.30	0.77
Consumption of Water for Livestock Before and After Distiller	-0.73	0.48

Table 18 shows the calculated t-and p-values for paired t-tests comparing the average weekly consumption rates of the three water usage categories that solar distiller water was used for, at an $\alpha = 0.05$ level. In each of the categories, there is no observable difference in consumption rates pre-and post-distiller, suggesting that the study participants are not limited by the amount of water available to them (there was no perceived increase in water consumption), but by the associated costs of each water source (weekly consumption rates stayed the same, which means that the amount paid weekly for potable water decreased).

It is important to note that the distillers in each household produced less than what was initially expected (~ 1 Liter/day actual vs. 2.5 Liters/day expected), this is probably due to several factors. First, the sampling was conducted during the time of year when the least amount of sunlight was available, it is probable that the yields will be higher during other times of the year. Also, there were initially some leakages of potable water from some of the distillers, while these leakages were repaired prior to the end of the project, they were not repaired prior to the beginning of sampling period. Therefore, it is possible that the results from this study can not accurately predict the behavior of participants should a larger quantity of water be made available to them.

CHAPTER 4: DISCUSSION AND RECOMMENDATIONS

4.1 Discussion

The small, rural communities of El Gallo and Ejido Hidalgo were more similar to one another, both in terms of the respective sizes of their communities, and in terms of their economic level, than either was to the urban center of Matehuala. Both of these communities had similar housing size and construction, and both relied primarily on agricultural labor or government-supported projects as key sources of income. Both small, rural communities had average monthly earnings approximately half of those earned on average on Matehuala, with the average monthly incomes of these two communities both being statistically different from Matehuala, but not from one another.

In comparing the water distribution schemes among the three municipalities, we find that all three provide some form of intervention or aid to their residents, with the most basic level being experienced in the community of El Gallo (their municipality brings water to them in a tanker truck every 2-4 weeks), to a more involved water system in Ejido Hidalgo (a now-defunct agency put in a well, the responsibilities of which are now shared by the municipality of Cedral and the residents of Ejido Hidalgo), to the most evolved system in Matehuala (the municipality of Matehuala covers the costs associated with connecting a household to the centralized water system, subsidizes the costs associated with extending the network to residents currently outside of the reach, provides chlorinated water to all households within the network consistently and reliably, and provides piped water service to small, rural communities in the municipality at a heavily-subsidized rate).

Based on the observed results from the earlier linear regressions, it is found that rural communities without access to a piped water source pay the greatest amount for their water resources. The small, rural community of El Gallo was observed to be paying 13.2 percent and 39.0 percent more for their potable and nonpotable water sources than the urban community of Matehuala. A key reason for this price difference may be that the community that pays less (Matehuala) is under the care of a centralized water distribution system, while El Gallo manages its water supply strictly at the *ejido* level (the wells were put in by the government, but there has been no follow-up care provided since the initial installation, and residents are responsible for all of the costs associated with running the pump, including electricity).

Taking the currently available distribution schemes in each municipality into consideration, it is interesting to observe that the communities that paid the least amount for their water sources were Matehuala and Ejido Hidalgo, based on the water costs as a percentage of monthly wage (4.4% and 3%, respectively, vs. 15% in El Gallo). Although statistical analysis of the differing percentages of income allotted to water every month was not feasible with the available dataset, the percentages are noteworthy because they suggest that the prices for current water distribution schemes which include a piped water source are within reason (<5% of monthly income), when the salary of residents is taken into consideration. Whether or not the present tariffs in Ejido Hidalgo and Matehuala have been established by taking the average monthly income of each community into consideration is not known. The location that does not have a piped water source is paying a larger percentage of monthly income for water sources, well above the recommended 3-percent threshold.

There are additional costs to the rural users of a nonpiped water source that were not quantified by this study but should be mentioned. First, the associated time costs with collecting water on a weekly or biweekly basis can be a significant burden to households. Secondly, the costs associated with experiencing diarrhea can include lost time in wages, and increased medical costs. Therefore, it is probable that this study underestimated the differences in costs between urban and rural communities, with rural communities (without piped access to water) paying even more in reality for their water than urban communities as estimated by this study.

Among the three study sites, there was an observed decrease in both the probability of contracting diarrhea and the actual number of days per month with diarrhea in households with access to a piped water source ($P = 0.001$ and $P = 0.010$, respectively). The other variable correlated to the probability of having diarrhea was participation in the OPORTUNIDADES program. The OPORTUNIDADES program is an outreach program sponsored by the Mexican federal government to help impoverished, mostly rural families keep their kids in school until the age of 15 (Winters and Chiodi, 2011). Additionally, the program provides incentives for participating women to finish school (up to the 9th grade), and offers free health classes and sometimes medical care (Braine, 2006). Participation in the program OPORTUNIDADES can be seen as a proxy for poverty, therefore it is possible to say that the probability of having diarrhea and the number of days per month with diarrhea in the three sample sites is positively correlated to having low income. Though no attempt was made to quantify the costs related to the burden of having diarrhea, there is sufficient evidence in the literature to suggest that there are real, observed costs associated with having diarrhea, which means that the poorer respondents in this survey are probably shouldering the extra costs of having diarrhea disproportionately (Gadgil, 1998).

In trying to explain the observed differences between diarrheal incidences and presence of a piped water source, the role of water supply should be considered. Numerous times, it was observed in El Gallo that inhabitants were conserving water by cutting back on the amount of water used for washing hands, either by not washing their hands at all, or by using the same bucket to wash their hands in for several days at a time. The same can be said for dishwater, laundry water and cleaning water in El Gallo, as compared to household with piped water sources. Therefore, it is very likely that a piped source of nonpotable water would decrease the rates of diarrhea currently observed in El Gallo. Additionally, the prolonged storage of water for household daily needs may be contributing to elevated rates of diarrhea in communities without a piped source of water. Typically, water is stored in the sunlight in plastic containers, which have been previously identified as having greater *E. coli* levels as compared to concrete household storage containers, though the volume of previously studied containers was much larger (Schafer, 2010).

The presence or absence of a piped water source was the only variable significantly correlated to respondents feeling that they had access to enough water to meet their daily needs. This suggests that the addition of a piped water source to a community greatly improves water accessibility, which could have a number of related health benefits, including a reduction in incidences of diarrhea.

When looking at the results of the weekly consumption rates of water in El Gallo, it is apparent that cost is a more pressing issue than overall water availability; after constructing distillers, participants consumed the same amount of water, resulting in a lower price per liter, rather than a greater number of liters for the same price. However, when interpreting the results of this study, it is important to consider that the observed relationship may not be the same when greater quantities of free potable water are made available. For example, the results may change during the hotter months, when the distillers are capable of producing nearly 3 times as much water as they are currently producing (1 liter vs. an estimated 2.5 liters). Additionally, the final sample size of 10 out of a total of 38 participants is small, and may not be representative of all participating households. It is for these reasons that we find that there is not sufficient evidence to accept or reject the second hypothesis, though the preliminary results generated by this study were very interesting.

4.2 Conclusion and Recommendations

At the time of this writing, an additional intervention to provide more water to the town of El Gallo is underway. Specifically, the government has announced that it will be putting in another well that will pump water from a potable aquifer. Notably, this well will be located several kilometers outside of town, a distance that is even further away from the town than the currently available nonpotable water well. The actualization of this well will continue to make access very time-consuming for residents. There are also growing doubts among community members that the government will be able to complete its promise any time soon. Even if this well is installed in the near future, residents will still be obligated to pay the electricity bill to run the pump. It has been estimated by the governing ejido that the costs of electricity every month will be around $8,000 pesos, or about $160 pesos per month per household, still higher than the average monthly costs paid by citizens in Ejido Hidalgo or Matehuala, and not likely to affect the overall percentage of monthly income devoted to water resources. Additionally, based on the findings of this study, it is unlikely that continuing to utilize a water system that relies on prolonged storage of water and truncated periods of collection will produce any real health benefits for the people in El Gallo.

Based on the above observed results, then, it is possible to infer that, despite the best of intentions, the government intervention of a source of potable water is unlikely to have little effect on the rates of diarrhea and the monthly water costs for the people living in El Gallo. The best form of intervention in this community is likely to be a water source that is piped directly to households. Additionally, steps should be taken by the municipality of Vanegas to reduce the costs of water to the community of El Gallo, so that the average percentage of monthly income spent on water is lowered to the comparable 5 percent paid in the nearby communities of adjacent municipalities.

In terms of costs, a community-based treatment center similar to the center in Ejido Hidalgo, capable of providing 40-liter of potable water per household per day to residents for only 50 pesos a month (on average) may be a better fit for the cost-limited families in El Gallo, rather than the more expensive well that is currently being considered, and may result in a greater percentage of families in El Gallo being able to afford potable water. Similarly, the solar distillers, after the initial investment, (approximately 500 pesos per distiller (Manser, 2012) may be an attractive option to families unable to afford the price of treated garrafón water, provided that enough distillers are constructed to meet their daily needs. Notably, both of these options provide treated water either in the household or at a centralized location in the community, rather than from a location far away from the community.

It is therefore recommended that the municipality of Vanegas rethink its current intervention scheme in favor of a scheme that will provide piped water at the household level to residents of El Gallo. To further reduce the monthly costs to El Gallo residents, it is recommended that a treatment center similar to the one put in place for the community of Ejido Hidalgo be considered, or possibly the construction of more solar distillers to allow households to treat their own water supplies, but in sufficient quantities to cover all potable water needs.

Additionally, steps must be taken to educate families on ways to reduce the probability of contracting diarrhea, possibly with a focus on educating the female heads of households, as they are primarily responsible for the sanitation and hygiene measures undertaken in each household (personal observation). It is interesting to note that approximately 86 percent of all households in El Gallo own a television, but none of the households have access to piped water (Table 2). Providing piped water to all communities must be made a greater priority, so that water costs are manageable and fair.

Although cost and availability are almost always closely related in pricing schemes, it is important to determine which of the two drives consumption rates in natural resource management projects. If cost is the most important factor, it may be necessary to consider a cheaper water source to extend coverage to a greater proportion of the population. Therefore, it is recommended that further data be gathered in the case of the solar distillers to determine if cost really is the determining factor in potable water consumption in El Gallo, or if it may actually be availability.

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APPENDICES

Appendix A. IRB Approval Letter

UNIVERSITY OF SOUTH FLORIDA

DIVISION OF RESEARCH INTEGRITY AND COMPLIANCE
Institutional Review Boards, FWA No. 00001669
12901 Bruce B. Downs Blvd., MDC035 • Tampa, FL 336124799
(813) 974-5638 • FAX (813) 974-5618

06/8/11

Kathryn Marlor
Civil and Environmental Engineering
316 Quintana Roo

RE: Expedited Approval for Initial Review
IRB#: Pro00004359
Title: Examining the relationship between improved water supply and the economic costs of water in rural, semi-rural, and urban Mexico.

Dear Kathryn Marlor:

On 6/7/2011 the Institutional Review Board (IRB) reviewed and APPROVED the above referenced protocol. Please note that your approval for this study will expire on 6/7/2012.

Approved Items:
Protocol Document(s):

IRB Application Study Protocol Marlor amended.doc	5/23/2011 5:23 PM	0.01

It was the determination of the IRB that your study qualified for expedited review which includes activities that (1) present no more than minimal risk to human subjects, and (2) involve only procedures listed in one or more of the categories outlined below. The IRB may review research through the expedited review procedure authorized by 45CFR46.110 and 21 CFR 56.110. The research proposed in this study is categorized under the following expedited review category:

(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

Your study qualifies for a waiver of the requirements for the documentation of informed consent as outlined in the federal regulations at 45CFR46.116 (d) which states that an IRB may approve a consent procedure which does not include, or which alters, some or all of the elements of informed consent, or waive the requirements to obtain informed consent provided the IRB finds and documents that (1) the research involves no more than minimal risk to the subjects; (2) the waiver or alteration will not adversely affect the rights and welfare of the subjects; (3) the research could not practicably be carried out without the waiver or alteration; and (4) whenever appropriate, the subjects will be provided with additional pertinent information after participation.

As the principal investigator of this study, it is your responsibility to conduct this study in accordance with IRB policies and procedures and as approved by the IRB. Any changes to the approved research must be submitted to the IRB for review and approval by an amendment.

We appreciate your dedication to the ethical conduct of human subject research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

John Schinka, Ph.D., Chairperson
USF Institutional Review Board

Cc: Olivia Hart
USF IRB Professional Staff

Appendix B: Water Costs and Economic Status Survey

Demographic Information

1. Are you the head of this household? If not, who do you consider to be the head of the household?

2. How many people reside in this house? What is their relationship to you? And how many years of school did each individual complete?

Person and gender	Adults: 18+ years	Adolescents: 12-18 years	Children: 3-12 years	Infants: Under the age of 3	Years in Primary School (up to the age of 15)	Years in Secondary School (15-18)	Years in college or university	Years in post-graduate education

Appendix B. (Continued)

3. Could you please read to me the following sentence? Could your husband/wife read this sentence for me?

"Agua potable me puede mejorar mi salud, por que no contiene enfermedades ni pollutantes."

4. At what age were you married? If there are other married couples in the residence, at what age were they married?

5. Are you originally from El Gallo? If not, where are you originally from?

Other Questions About the Household

1. How many rooms does this household contain?

Construction information about each room in the house:

Room Number and Classification (bedroom, kitchen, bathroom, etc.)	Floor material	Wall material	Ceiling material

Appendix B. (Continued)

2. What kind of bathroom does this household have?

Indoor/Plumbed	Outdoor/Plumbed	
Outdoor/Unplumbed	Communal/Public	None

3. Do you own a garden or milpa?

Size:	< 1 m^2	1-10 m^2	10-50m^2
	>50 m^2		

4. Do you participate in a community garden program?

# of hours/week:

Appendix B. (Continued)

Water Use and Cost

1. Do you feel that your household has access to a sufficient quantity of water to meet all of its daily needs?

2. If you do not feel like your household has access to a sufficient quantity of water, imagine that you are provided access to a sufficient quantity of clean, drinkable water. What would you use this water for?

Drinking Cooking Bathing Cleaning Laundry

Livestock Crops

3. How many garrafónes does this household use in a week? How much do you pay per garrafón?

4. Does this household buy their own garrafónes or do you wait for a delivery truck?

5. What does this household use garrafón water for?

Drinking Cooking Bathing Cleaning Laundry

Livestock Gardens

Appendix B. (Continued)

6. How do you feel about the safety of the garrafón water that is available to you?

Very safe to drink   Somewhat safe to drink

Somewhat unsafe to drink   Very unsafe to drink

7. Other than garrafónes, where does this household get the water that it uses every day?

Private indoor plumbing (tap)

Private outdoor plumbing (yard pipe or well)

Public outdoor plumbing (communal wells or standpipe)

Rainwater collection

8. Who put in the tap/yard pipe/well?

9. How much did this household pay to have the tap/yard pipe/well put in?

10. How much does this household pay on a monthly basis for water from the tap/yard pipe/well? Is this amount based on the number of Liters that you use in a month?

11. Are you satisfied with the reliability of the service provided?

Very Satisfied   Somewhat Satisfied

Somewhat Unsatisfied   Very Unsatisfied

Appendix B. (Continued)

12. Are there any maintenance costs associated with your tap/yard pipe/well? Approximately how much does this cost, and how frequently?

13. If you are accessing a community well, is everyone allowed to use it, or is it exclusive to members only?

14. If you are using a community well, how far do you estimate this well is from your house?

15. How much time to you estimate it takes to fill a container at the community well? How many times a day do you fill the container? Are there other people in this household that also fill containers on a daily basis? What is the volume of the container that is used at the well?

16. What do the people in this household use tap/yard pipe/well water for?

Drinking Cooking Bathing Cleaning Laundry

Livestock Gardens

17. How do you feel about the potability of the tap water/well water that is available to you?

Very safe to drink Somewhat safe to drink

Somewhat unsafe to drink Very unsafe to drink

Appendix B. (Continued)

18. Does anyone in this household drink water from the well/tap?

19. Do the people in this household avoid drinking well water/tap water?Why?

Health (Bacterias) Health (Heavy Metals)

Taste Odor Appearance

20. Do you believe that the water from the tap/yard pipe/well is salty?

21. Why do you think it is salty?

22. Does anyone in this household experience any side effects from drinking water from the well/tap?

I am now going to ask you a question about diarrhea. Diarrhea is defined as loose or watery stool three or more times within a 24-hour period.

**23. Do any of the people in this household frequently have diarrhoea?
How many times a week? Approximately how many times a month?**

Appendix B. (Continued)

24. When you are suffering from a water-bourne illness (diarrhea), how do you seek treatment? Where do you go?

Nothing, stay at home

Go to a *Curador(a)*
Location and cost:

Go to a doctor
Location and cost:

25. Do you collect rainwater (estimate volume of cistern if applicable)? How frequently does the cistern fill?

Appendix B. (Continued)

Assessment of Income/Wealth

1. How many people in this household are currently employed and what do they do?

2. Approximately how much does each employed person make in a day? And approximately how many days does each person work per week?

3. Does this household receive monetary aid from any of the following outside sources, and approximately how much in a month?

a. Remittances from people employed outside of the residence (can be from a foreign country or in Mexico)

b. Government programs (ie. PET and PROCODES community employment projects, OPORTUNIDADES, PROGAN)

c. Government subsidies to farm their land (PROCAMPO).

4. If you are currently farming land, how much do you estimate you make from the sale of your crops each year?

Appendix B. (Continued)

5. Does this household own any livestock?

Sheep:

Goats:

Cows:

Burros:

Horses:

Pigs:

Chickens:

Other:

6. Does this household have access to a regular source of electricity?

7. Does this household own any of the following items?

TV (satellite or cable connection?)

Car or Truck

Radio or Stereo

Gas for cooking, heating water

Refrigerator

Washing Machine

Motorcycle

Appendix B. (Continued)

8. Could you estimate for me your monthly expenditures on the following items?

Food

Transportation

Doctor + Medicine

Fixed payments (debts)

Clothing

Gas for cooking, heating water

Candles

Electricity

Escuela (Secundaria o Universidad, o otra)

9. Do you own your home, or do you rent?

10. Do you sell things from your house? What do you sell? Approximately how much do you make in a month from selling things in your house?

11. Do you sell livestock? How many times a year do you sell livestock? What kind of livestock do you sell? How much are you able to sell each animal for?

12. Do you have any other sources of income that I have not mentioned?

Appendix B. (Continued)

13. Could you estimate for me the total yearly income for this household?

0-24,000 pesos	24,000-50,000 pesos	50,000-100,000 pesos
100,000-250,000 pesos	250,000-500,000 pesos	500,000-750,000 pesos
>750,000 pesos		

Appendix C. Water Use Worksheet

DAY	QUANTITY (LITERSLITERS)	SOURCE (GARRAFÓN, PIPA, WELL, DISTILLER)	DRINKING	COOKING	BATHING	CLEANING OR WASHING	ANIMAL (TYPE)	GARDEN (TYPE)

1. What is your opinion of your solar distiller?

Very satisfied   Somewhat satisfied

Somewhat unsatisfied   Unsatisfied

2. In the future, do you think that you will construct another solar distiller, so that you will be able to treat a greater quantity of water for drinking?