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# Impact of Tank Material on Water Quality in Household Water Storage Systems in Cochabamba, Bolivia

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
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Department of Civil & Environmental Engineering
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# ABSTRACT

The importance of water as a mechanism for the spread of disease is well recognized. This study conducted household surveys and measured several physical, chemical, and microbial water quality indicators in 37 elevated storage tanks constructed of different materials (polyethylene, fiberglass, cement) located in a peri-urban community near Cochabamba, Bolivia. Results show that although there is no significant difference in physical and chemical water quality between polyethylene, fiberglass and cement water storage tanks there is a difference in microbial contamination as measured by *E. Coli* counts ($p = 0.082$). Evidence points toward elevated water temperatures that increase along the distribution system (from 10.6°C leaving the treatment plant) to within the black polyethylene storage tank (temperatures as high as 33.7°C) as the most significant factor in promoting bacterial growth. Results indicate that cleaning frequency may also contribute to microbial water quality ($p = 0.102$).

## INTRODUCTION

The importance of water as a mechanism for the spread of disease has long been recognized as seen by the large amount of peer reviewed articles concerning the relationship of health to water quality and sanitation (e.g., Semenza et al., 1998; Craun and Calderon, 2001; Egorov et al., 2002).   In addition, international organizations such as the World Health Organization (WHO), the United Nations (UN) and the World Bank have given much attention to this subject. For example, according to the WHO's World Health Report (2004), approximately 3.2% of deaths and 4.2% of Disability Adjusted Life Years (DALYs) worldwide from diarrheal diseases are attributed to the consumption of contaminated water and lack of sanitation and hygiene practices. This corresponds to 88% of reported diarrheal diseases worldwide with over 99% of deaths occurring in developing countries, 90% of whom are children under the age of 5 (Nath et al., 2006). The UN reports that more than 2.2 million people, most of which reside in developing countries, die each year due to diseases associated with poor water and sanitation. Table 1 provides global and regional data on disease burden from the year 2000 related to diarrheal diseases.

**Table 1: Burden of diarrheal disease by global region, 2000.**

| Deaths and DALY Totals for 2000 | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Global | Africa | Americas | South East Asia | Europe | East Mediterranean | West Pacific |
| Mortality due to Diarrheal Disease | 3.2% | 6.6% | 0.9% | 4.1% | 0.2% | 6.2% | 1.2% |
| DALYs due to Diarrheal Disease | 4.2% | 6.4% | 1.6% | 4.8% | .5% | 6.2% | 2.5% |

**Source: Nath et al., 2006**

Often in developing countries with high morbidity and mortality numbers, the health problems are related to poor water quality, limited water availability, limited sanitation and/or poor hygiene practices. Common interventions in these situations include: improving access to water, providing household treatment options, improving sanitation and hygiene education.

The effect of improving access to water and sanitation services is most easily seen by looking at the under 5 mortality rates. For example, Bolivia has an under 5 mortality rate of 69 deaths per 1,000 live births while, as a region the Americas have an under 5 mortality rate of 25 deaths per 1,000 live births (WHO, 2006). Figure 1 shows how modest increases in access to water and sanitation services can help lower under age 5 mortality.

Figure 1 shows that in 2002, 84% of the population in Bolivia had access to improved water sources and only 59% had access to sanitation services. In 1990, when data for these two parameters began being recorded, under 5 mortality began decreasing at a greater rate. While this alone does not signify correlation, numerous studies have shown that improving access to improved water and sanitation services have shown that a correlation with reducing under 5 mortality rates exists(e.g. Sobsey et al., 2003).

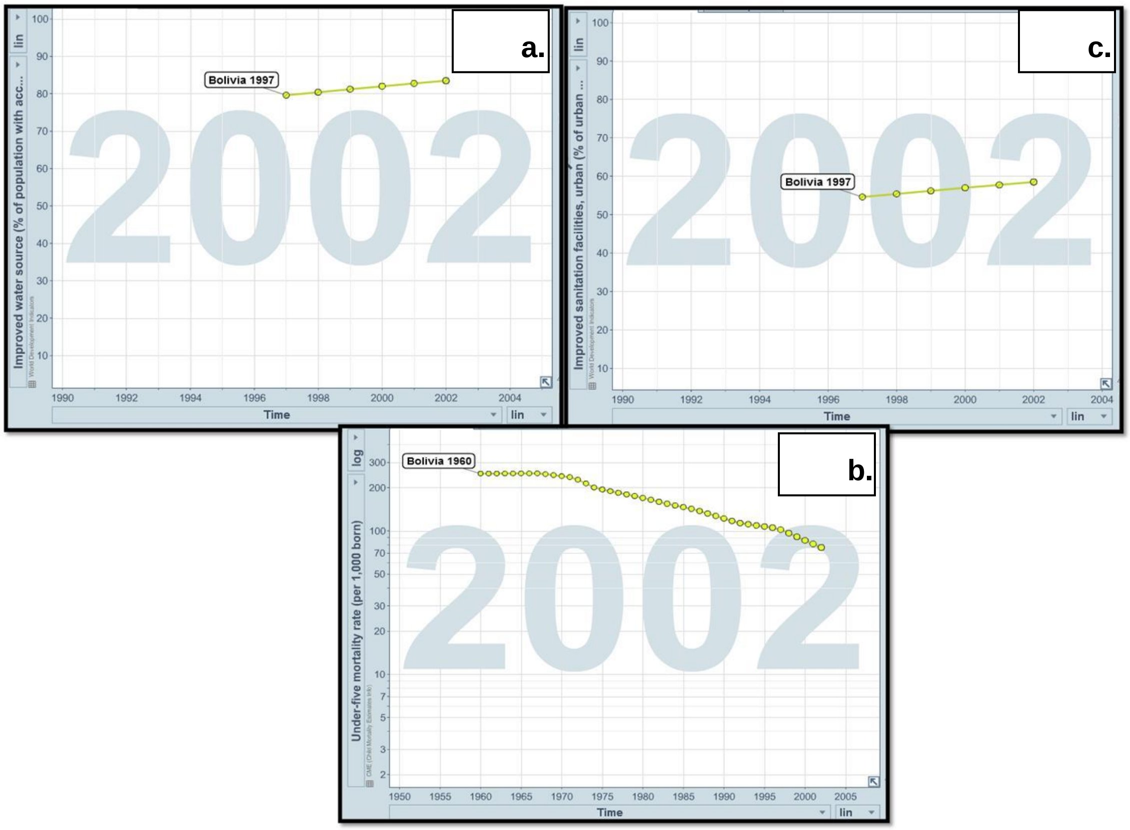
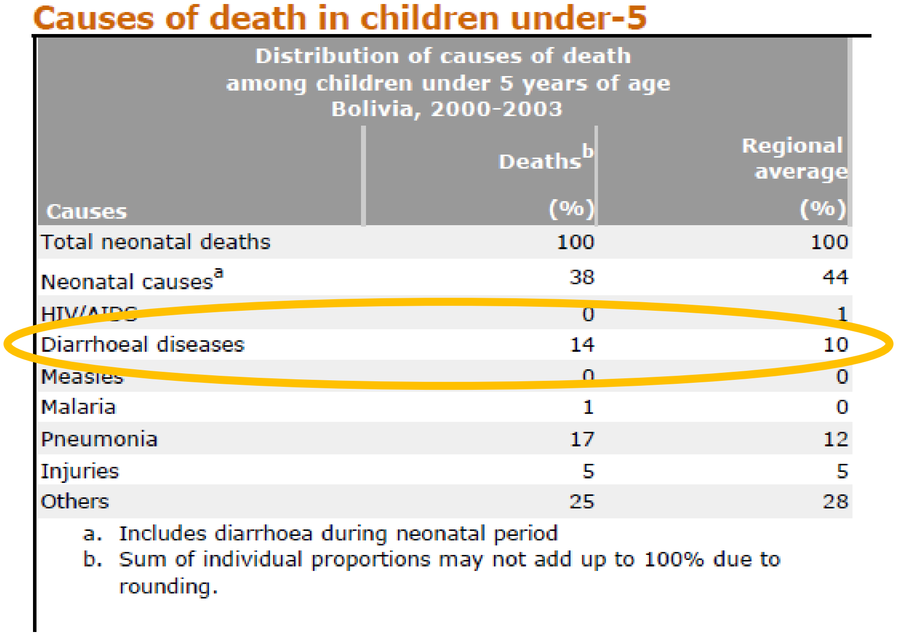


**Figure 1: Access to water and sanitation statistics and child mortality rates for Bolivia. a. Percent of Bolivian population with access to improved water sources; b. Percent of urban Bolivian population with access to sanitation facilities; c. Under 5 mortality per 1,000 births for Bolivia. Source: Visualization from Gapminder World, powered by Trendalyzer from www.gapminder.org. Accessed online April 2010.**

Figure 2 shows the different causes of death for children under 5 years old. This figure shows that more than 10% of deaths for children under 5 are caused by diarrheal diseases. Additionally, although more difficult to measure, early childhood diarrhea has shown to cause stunted growth and lower cognitive function later in life (Berkman, 2002).



Causes of death in children under-5

Distribution of causes of death
among children under 5 years of age
Bolivia, 2000-2003

| Causes | Deaths[b] (%) | Regional average (%) |
|---|---|---|
| Total neonatal deaths | 100 | 100 |
| Neonatal causes[a] | 38 | 44 |
| HIV/AIDS | 0 | 1 |
| Diarrhoeal diseases | 14 | 10 |
| Measles | 0 | 0 |
| Malaria | 1 | 0 |
| Pneumonia | 17 | 12 |
| Injuries | 5 | 5 |
| Others | 25 | 28 |

a. Includes diarrhoea during neonatal period
b. Sum of individual proportions may not add up to 100% due to rounding.

**Figure 2: Causes of under 5 mortality. Source: WHO, 2006.**

The issues discussed above can also be exacerbated by rapid population growth, especially in impoverished areas. While the same organisms that make adults sick also make children sick, children are more susceptible to dying because their immune systems are not as well developed; this effect is exacerbated when children alao suffer from malnutrition (Pelletier et al., 1994).

## Motivation and Hypotheses

The motivation for this study comes from the need for more research into water quality in modern water distribution systems and the causes of microbial contamination of water in household storage tanks. Numerous studies have been done focusing on physical, chemical and microbial water quality of household storage containers in situations where water is collected at a community source and then transported to the home (e.g, Quick et al., 1999, Quick et al., 2002, Clasen and Bastable, 2003, Wright et al., 2004). There have also been studies performed that show how water quality degrades when supply is intermittent and as the residence time associated with distribution and storage increases (Kerneis et al., 1995, Tokajian and Hashwa, 2003). However, few studies have been performed on elevated household storage tanks. In addition, no peer reviewed articles were found by the author on field studies evaluating water quality of elevated household storage tanks commonly found in the developing world.

This study examines the effects of tank material, tank water temperature, and user behaviors on water quality in elevated household storage tanks in the city of Tiquipaya, Bolivia. The overall objective is to determine how the materials used to construct household water storage tanks and user operation/maintenance impact physical, chemical, and microbial quality of water in household storage tanks as well as document water quality as the water travels from the treatment plant through the distribution system to the user. This study will test three hypotheses:

1. Tank material impacts water quality within the household storage tank;
2. Tank material affects water temperature, which impacts microbial water quality; and
3. Tank factors such as cleaning frequency and age impact water quality within the household storage tank.

## PREVIOUS RESEARCH

### Waterborne Diseases

Access to safe water and sanitation facilities (e.g., latrines), as well as knowledge of proper hygiene practices, can reduce the risk of illness and death from waterborne diseases, leading to improved health, poverty reduction, and socio-economic development (CDC, 2010). Water is an important vector for the transport of waterborne diseases, which are generally caused by pathogenic microbes that can survive and often grow in water. Most waterborne diseases cause diarrheal illness and disproportionally affect children. Water can be contaminated by various pathways such as lack of hygiene, inadequate treatment or poorly maintained infrastructure. For example, an outbreak of typhoid fever believed to be due to poor water quality in the distribution system in Dushanbe, Tajikistan, between January 1996 through June 1997 led to 8,901 reported cases and 95 deaths (Mermin et al., 1999). Among a number of variables contributing to the spread of disease was a lack of residual chlorine in the distribution system (Mermin et al., 1999).

The outbreak of cholera that spread to 19 countries in Central and South America in 1991 infected over 533,000 people and caused 4,700 deaths. Drinking unboiled water was associated with becoming infected with *V. cholerae* (Swerdlow et al., 1992). A review published by Gundry et al. (2004) found that samples of stored water contaminated with *V. cholerae* resulted in cholera cases and that treatment and improved storage interventions were successful at preventing cholera.

Numerous studies have found that the consumption of poor quality water is responsible for higher diarrheal incidence (Semenza et al., 1998). However, unlike typhoid fever and cholera, which are each caused by a specific organism, numerous pathogens are responsible for causing diarrhea. As a result, low levels of indicator bacteria may correspond to high numbers of diarrhea cases and high levels of indicator bacteria may not always correspond to an increased number of cases of diarrhea (Gundry et al., 2004). This may be due to indicator bacteria not being a good measure of pathogens; this has been shown to be the case with thermotolerant coliforms (Gleeson and Gray, 1997; Hamer et al., 1998; Gundry et al., 2004). Additionally, diarrhea is a symptom of many illnesses, which makes the association with improved water quality and a reduction of diarrhea incidence difficult to prove (Gundry et al., 2004).

One cause of waterborne pathogens being present in water distribution systems is the failure to disinfect the water (Cardenas et al., 1993; Rab et al., 1997; Craun et al., 2002). The primary reason to maintain a disinfectant residual in a water supply is to guard against the re-growth of pathogens and to neutralize pathogens that enter the system after treatment. Lack of a disinfectant residual in a system in which the water has undergone disinfection by chlorination often indicates that contaminants are entering the system (Agard et al., 2002). It has been shown that low concentrations of free chlorine, less than 0.2 mg/L, in potable water has led to substantially more coliform occurrences than water with higher free chlorine concentrations (LeChevallier et al., 1996). A study done in Trinidad has shown a correlation between the loss of a residual chlorine concentration and an increased prevalence of total coliforms (from 0% to 80%) in water as it travels from the treatment plant to the user (Agard et al., 2002).

### Distribution Systems

In the U.S., recent focus on water quality issues has been on chemical contamination occurring within the distribution system. Evidence has been found indicating that the switch from chlorine to chloramine for disinfection increases corrosion of brass pipe, which leads to elevated lead levels in the water (Edwards and Dudi, 2004). The presence of chlorine has also been implicated in higher rates of copper corrosion (Boulay and Edwards, 2001). Another study has shown that maximum corrosion rates occur at 30°C, which coincides with maximum bacterial growth (Arens et al., 1995).

In developing countries, the focus has been on improving microbial water quality of drinking water supplies. Although the presence of a water distribution system is often seen as a sign of improved water quality, it does not imply that the water is free of pathogens and therefore adequate for human consumption (Lee and Schwab, 2005). Oftentimes, water leaving treatment systems or arriving at community taps is microbiologically safe, however contaminants may enter a distribution system after treatment or during household storage (Nath et al., 2006). In fact, in the United States alone approximately 18% of waterborne disease outbreaks were linked to contaminants entering the distribution system after treatment (Craun and Calderon, 2001). Worldwide, contaminated water has been transported through distribution systems and has been implicated in the spread of outbreaks of typhoid fever, cholera and diarrheal diseases (Semenza et al., 1998; Egorov et al., 2002; Mermin et al., 1999; Swerdlow et al., 1992). These pathogens have been found to be present in unimproved as well as improved water sources (Gundry et al., 2004).

There is also a growing body of evidence that distribution systems can cause a decrease in the quality of water, which can lead to illness in consumers in developed countries (e.g. LeChevallier et al., 1996; Craun and Calderon, 2001), emerging countries (e.g. Gayton et al., 1997; Mermin et al., 1999; Basualdo et al., 2000; Egorov et al., 2002) and developing countries (e.g. Geldenhuys, 1995; Dany et al., 2000; Agard et al., 2002; Lee and Schwab, 2005). Compounding the issue is the common practice in some communities of storing large volumes of water at the household level which enables contaminant organisms to grow and multiply. In many communities, treatment of water for drinking and cooking occurs within the home even when the water is piped to the household. In both rural and urban distribution systems, fecal contamination may enter a piped water supply due to deficiencies such a poor source quality, inadequate treatment or disinfection, and infiltration of contaminated water (e.g. sewage) (Sobsey et al., 2003).This is often due to poor infrastructure maintenance of the distribution system. Old and failing infrastructure leads to stoppages in service, thereby requiring residents to store large quantities of water within the household in large storage tanks. Such storage offers another route for contamination to enter the water before consumption (Nath et al., 2006).

Another way that contaminants can enter the water distribution system is through the addition of untreated water into the distribution network (Ford, 1999; Craun and Calderon, 2001). This can be either intentional, for example, where there is more than one source of water for a distribution system and not all sources are treated; or it can be unintentional, as is the case for leaky systems. The addition of untreated water may result in the presence of microbes, some possibly pathogenic, causing the consumer to become ill (Ford, 1999; Craun and Calderon, 2001). Contaminates can also enter water distribution systems by other pathways; studies have shown that failure to disinfect or to maintain a disinfectant residual (LeChavallier et al., 1996); long residence times (Tokijian and Hashwa, 2004); and changes in pressure within the network (LeChevallier et al., White Paper – No Date) can all lead to the presence of pathogens within a distribution system.

## Health Issues of Stored Water

Microbial quality of potable water supplies is important not only in the developing world but also in developed countries. WHO (2006) guidelines state that water intended for human consumption should contain no microbiological agents that are pathogenic to humans. The WHO (2006) guidelines for *Escherichia coli* (*E. coli*) and thermotolerant coliforms are 0 colony forming units (CFU) per 100 mL because even low levels of fecal contaminants may potentially cause illness. Sobsey (2006) concluded that world wide as well as in the US the greatest risk of waterborne disease is due to microbial contamination of potable water supplies. In developing countries, it is estimated that the consumption of unsafe drinking water is responsible for 15% to 20% of community diarrheal disease, with recent studies indicating that the percentages may even be higher (Sobsey et al., 2003). In developed countries similar issues remain. Between 15% and 30% of community diarrheal disease is a result of contaminated municipal drinking water despite the state-of-the-art treatment technology employed (Payment et al., 1991, 1997 – from Sobsey 2003).

## Environmental Factors Affecting Stored Water Quality

Temperature of the stored water is an important influence on the growth rate of bacteria that have survived treatment processes. Various field studies have shown that significant bacteria growth can occur in water of 15°C or higher (Fransolet et al., 1985; Donlan and Pipes, 1988; Smith et al., 1989; Donlan et al., 1994 – From LeChevallier et al., 1996). For example, Fransolet et al. (1985) showed that a temperature increase from 7.5°C to 17.5°C reduced the lag phase of growth for *Pseudomnas putida* from 3 days to 10 hours

(From LeChevallier et al., 1996). Another study found that coliform bacteria occurred more frequently and in higher concentrations at water temperatures greater than 15°C (LeChevallier et al., 1996). Results from that study indicate that for a temperature increase from 5°C to greater than 20°C, there was an 18-fold increase of coliform occurrence in free-chlorinated systems ($p < 0.0001$) (LeChevallier et al., 1996).

Turbidity in water is usually caused by suspended matter such as clay, silt, organic and inorganic matter, plankton and other microorganisms and is a useful water quality indicator (LeChavallier et al., 1981). These particles can provide either nutrients for bacteria or other pathogens, or they may protect microorganisms themselves from chlorination (LeChavallier et al., 1981). A study by LeChavallier et al. (1981) showed that coliforms in high turbidity water (13 NTU) were reduced by 80% from their original concentration after chlorination, while coliforms in low turbidity water (1.5 NTU) were undetectable after chlorination. Their results also showed that given a constant chlorine dose a turbidity increase from 1 NTU to 10 NTU results in an eightfold decrease in disinfection efficiency.

Residence time has major impact on water quality. Many studies have shown that water quality degrades as the water travels through the distribution system and in some cases is stored before use (e.g., Evison and Sunna, 2001; Tokajian and Hashwa, 2003). A study of a water distribution system in urban Trinidad found that microbial water quality degraded significantly as the water traveled through the distribution system (see Table 2) even though the reservoir repeatedly tested negative for microbial contamination (Agard et al., 2002).  The presence of *E. coli* suggests fecal contamination is occurring within the distribution system.

**Table 2: Percent of positive test results for microbial contaminants from study in urban Trinidad.**

| Drinking Water Samples from Households in Urban Trinidad (n = 104) | | | |
|---|---|---|---|
| | **Total Coliforms** | **Thermotolerant Coliforms** | ***E. coli*** |
| **Treated Reservoir Water** | 0% | 0% | 0% |
| **Distribution System** | 46.9% | 16% | 33.3% |
| **Household** | 80.8% | 53.8% | 67.3% |

Source: Agard et al., 2002

### Water Storage Studies

Microbial re-growth in potable water supplies is often a problem that is intensified by household water storage practices. A laboratory study found that factors such as long retention times of 4 to 7 days, low or no chlorine residual and temperatures above 15°C have all been shown to increase microbial re-growth in commonly used 1000 L fiberglass, polyethylene and cast iron household storage tanks (Evison and Sunna, 2001). This study also found that water temperature inside the tank and tank age were the parameters most important for bacterial growth and were responsible for 77.7% of the heterotrophic plate count values measured for water stored for 4 days (Evison and Sunna, 2001). Additionally, the HPC counts between the water stored for 4 days and the water stored for 7 days were not significantly different which, this author believes indicates that the bacteria in the tank had been shocked initially by the chlorination but had survived in the distribution system and were able to grow in the conditions provided by the storage tank and that an increase in bacterial growth may be observed for shorter residence times. Furthermore, this study did not find significant variations in HPC counts or in physical and chemical parameters between the different tank types tested (polyethylene, fiberglass and cast iron). However, it did find that the bacteria taxa within the different tanks did differ, most likely due to differences in water temperature and light penetration (Evison and Sunna, 2001).

A separate laboratory study looking at the effects of cast iron and black polyethylene household storage tanks (1000 L capacity) found that the stored water deteriorated significantly ($p = \leq 0.05$) microbiologically after 7 days of storage in both types of storage tanks, but did not find a significant difference in HPC counts between the two types of storage tanks (Tokajian and Hashwa, 2003). HPC counts varied seasonally, with the highest levels being measured during the summer months (Tokajian and Hashwa, 2003).

Increased microbial growth in household storage tanks compared to source water may also be due to the design of household storage tanks. It is not possible to completely empty most tanks, and that allows for sediment buildup which can act as a growth medium for microbes in the incoming water (Tokajian and Hashwa, 2004). This leads to persistence of coliforms in the stored water. Increased storage time, water temperature and microbial quality of the incoming water are also significant factors that contribute to poor water quality (Tokajian and Hashwa, 2004).

One study found significant total coliform and E. coli growth in black polyethylene storage tanks in rural Bolivia, however, both total coliforms and E. coli were also detected at the source indicating the problem is occurring prior to point-of-use (Omisca, 2010).

More common are studies on household storage containers used to retrieve water and store it inside the home. For example, a study in Malawi found that fecal coliform levels increased in household storage containers after only 1 hour of storage. Even when investigators chlorinated water in storage containers contamination was only eliminated for the first 4 hours after collection. After 6 hours of storage, there was considerable microbiological growth (Roberts et al., 2001).

A study looking at post-supply drinking water quality in rural Honduras (Trevett et al., 2004) found that source water quality appeared to be a significant factor in determining household water quality and that storage factors such as covering the household storage tank, tank material and residence time did not make a significant difference on the stored water quality. There was also no correlation between storage container type and water quality, although this may be due to the relatively small sample size (43 storage containers). The source water in this study came from hand-dug and bore-hole community wells of varying water quality, but every source saw a deterioration of water quality between collection and consumption. Contamination was measured by the presence of thermotolerant coliforms found in the household storage containers. These containers were either made of plastic or clay and had either wide openings in which water was ladled or dipped out or narrow openings in which water was poured. Residence time was determined simply by asking the female head of household the last time water was collected; no specific times were reported. Due to the small size of the water storage containers (~25 L) this study's author believes the residence times to have been relatively short (< 1 day). This indicates that contamination was occurring between the point of supply and consumption and that the bacteria were able to grow within the household storage container.

Clasen et al. (2003) noted that intervention studies that employ a 3 part intervention program involving 1) narrow mouth storage containers with spigots that prevent hands from entering container; 2) point-of-use disinfection; and 3) community hygiene education have led to reductions in waterborne disease incidence, as can be seen by a 50% reduction in diarrhea incidence in Bangledash (Sobsey et al., 2003), 44% and 50% Bolivia (Quick, 2002 and Sobsey et al., 2003, respectively) and 62% in Uzbekistan (Semenza et al., 1998). Another intervention study using a narrow-neck clay container found that cholera carrier rates were 17.3% in the control group and 4.4% in the intervention group (Deb et al., 1986). These results agree with the results from Trevett et al., (2005), which found that the type of storage container and whether the container allowed contact of hands with the stored water were associated with increased diarrheal disease incidence.

## STUDY LOCATION AND SYSTEM CHARACTERISTICS

The department of Cochabamba is located in the central part of Bolivia on the eastern edge of the Andes Mountains (Figure 4a). It is divided into 47 municipalities and has an area of more than 55,000 km$^2$. While a majority of the residents speak Spanish, there are three additional languages spoken in the area, Quechua, Aymara and Guaraní, the first two with a significant number of speakers. The capital of the department of Cochabamba is also called Cochabamba.  It is the most populated city in the department. The department has 1,455,000 inhabitants with 51% of the population living in urban areas and 49% living in rural areas (Insituto Nacional Estadistica de Boliva, 2009).

This study takes place in the peri-urban municipality of Tiquipaya (Figure 4b) which is located 11 km west of the city of Cochabamba. Due to its proximity to Cochabamba, Tiquipaya is quickly becoming an urban area, as is shown by a yearly population growth rate of over 13% (Insituto Nacional Estadistica de Boliva, 2009). The municipality of Tiquipaya is divided into 6 districts with Districts 1, 2 and 3 are located in the mountains and are sparsely populated and Districts 4, 5 and 6 are located in the valley. Districts 4, 5 and 6 are more densely populated and these districts are also where most agricultural activity in the region occurs (Butterworth et al., 2007). The valley area represents less than 10% of the total area but is where 71% of the population resides (Butterworth et al., 2007).

Within Districts 4, 5 and 6 of Tiquipaya, there are about 40 neighborhoods each with their own water distribution system that provides residents with household water. Approximately 50% of the water distribution systems in the region have been built within the last 15 years (Mejoramiento del Sistema de Agua Potable y Ampliación de la Red de Alcanterillado Sanitario de la Comunidad Colcapirhua-Tiquipaya, 2003). Water for these systems comes from groundwater and rivers; the region is underlain with two aquifers, one at about 45 meters and the other at about 80 meters depth (Ing. Mario Severiche, 2009). The shallower of the two aquifers is said to have been contaminated from nearby septic systems (Ing. Mario Severiche, 2009). Historically, water availability was periodic and as a result, most households have underground cisterns which store water before it is pumped to the water storage tanks located on the roofs of their homes in order to have a constant supply of water. However, many of the water distribution systems within the municipality have been updated in recent years, and now almost 60% of the systems provide service 24 hours a day (Mejoramiento del Sistema de Agua Potable y Ampliación de la Red de Alcanterillado Sanitario de la Comunidad Colcapirhua-Tiquipaya, 2003). The residents say that the water is of poor quality. Figure 3a and 4b show an elevated water storage tank and an underground cistern respectively.

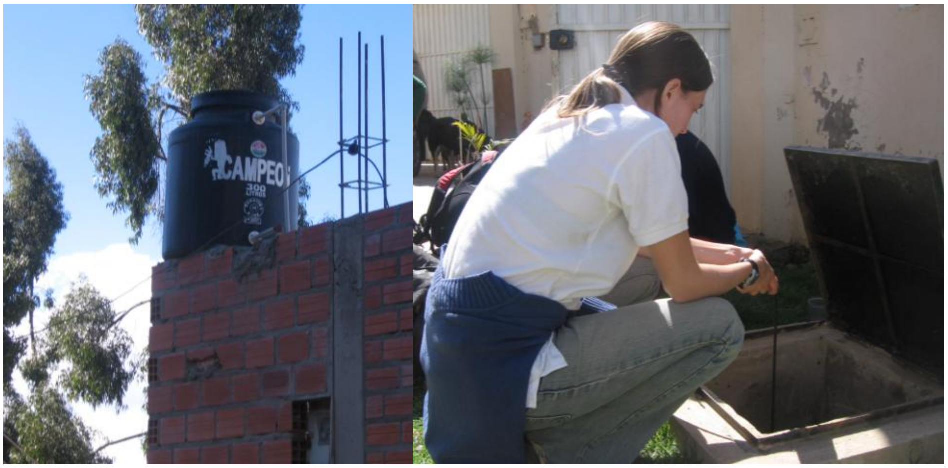


**Figure 3: Elevated storage tank and cistern photos. a) Elevated water storage tank located on the roof of a home; b) Underground cistern located next to home near street.**

There are over 80,000 inhabitants in Tiquipaya (Insituto Nacional de Estadística, 2009). Tiquipaya has an area of 320 km$^2$ (Bustamante et al., no date) and Districts 4, 5 and 6 are divided into about 40 neighborhoods.  Most neighborhoods have their own water distribution system, most of which are operated by community organizations, or in the urban area, a larger association of multiple systems which is operated by the Comité de Agua Potable y Alcantarillado para Tiquipaya (COAPAT). The scope of this study is limited to the Tiquipaya Noreste distribution system which is located near the mayor’s office in District 4 of Tiquipaya. See Figure 4 for study location.

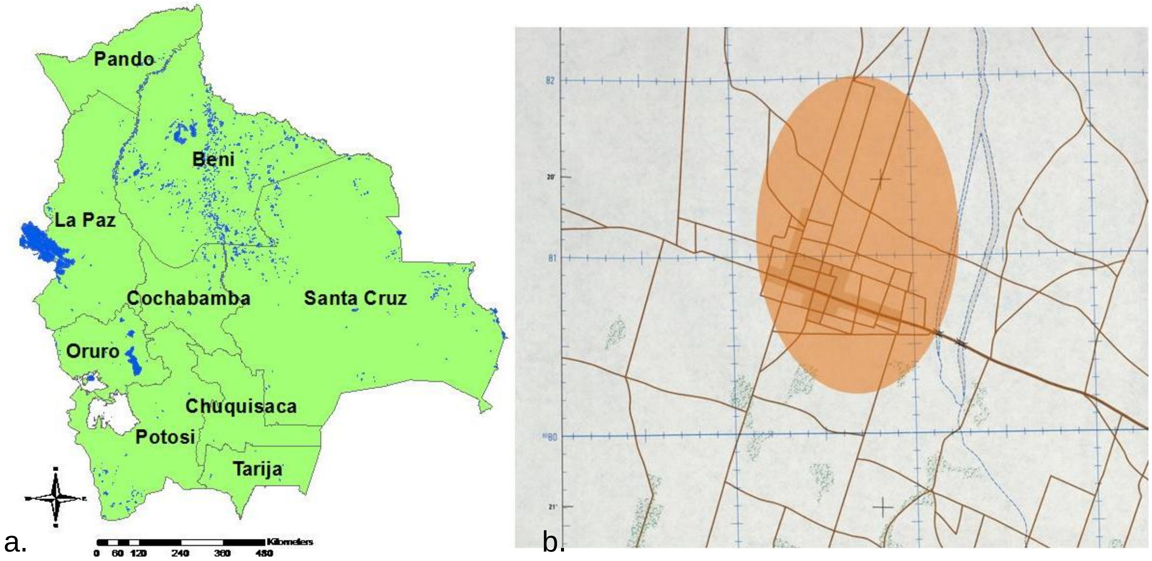


**Figure 4: Study location maps. a) Bolivia and its departments; b) Tiquipaya, study location shown in orange. Each grid represents 1 by 1 km.**

The specific water distribution system under investigation has approximately 500 connections with about 50% of households using an elevated water storage tank (Ing. Hector Escalera Estrad, 2010). The treatment plant was constructed about 15 years ago while the distribution system itself was updated in 2007-2008 to use PVC pipe (Ing. Hector Escalera Estrad, 2010).

The tanks are made of various materials such as fiber cement, fiberglass and polyethylene. In addition to the elevated household storage tank, almost every household also has a below ground cistern for additional water storage. Figure 5 shows that water from the distribution system feeds into the below ground cistern which is then pumped to the elevated storage tank before being used throughout the house.

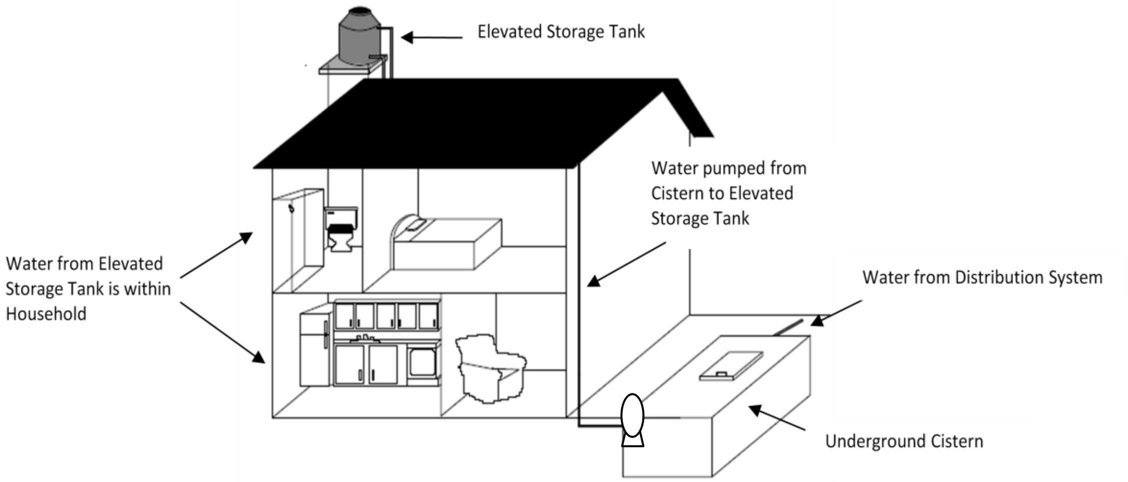


**Figure 5: Diagram of household water system typical of Tiquipaya (Bolivia). Water flows from distribution system to an underground cistern to an elevated storage tank.**

Water for the system comes mainly from the River Khora but is also supplemented by two wells. Water from River Khora is also shared with farmers in the area with approximately 1/6th of the flow going towards irrigation (Butterworth et al., 2007). The river water is treated and then mixed with the well water for distribution. Treatment of the river water consists of a sedimentation basin and storage tank upstream of the main treatment plant. From there, the water is piped to the treatment plant. The water passes through a series of open tanks to encourage sedimentation of suspended solids; the water is then chlorinated and enters a closed storage tank before entering the distribution system. Each day, 2 kg of chlorine in the form of NaOCl (assumed 100% purity) is mixed with 450 liters of water and then combined with water from the river over the course of the day with the goal of achieving an approximate concentration of 0.6 mg/L $Cl_2$ (Ing. Hector Escalera Estrad, 2010). The desired chlorine residual is between 0.6 and 0.7 mg/L as it leaves the treatment plant and 0.2 to 0.3 mg/L when it arrives at homes or other connections (Ing. Hector Escalera Estrad, 2010). Residents generally have water service 24 hours a day; however, service is occasionally interrupted for system cleaning and maintenance and for road and sewer construction.

In order to determine if a sufficient amount of chlorine was being added to the river water, the following calculations were made.

$$\frac{2\ kg\ NaOCl}{450\ L} = 4.44\frac{g}{L}NaOCl$$

$$30\frac{L}{s} * 3600\frac{s}{hr} * 24\frac{hr}{day} = 2592000\frac{L}{day}$$

$$\frac{4.46\ g\ NaOCl}{L} * \frac{450\ L}{2592000\ L} * \frac{1000mg}{g} = 0.77\frac{mg}{L}NaOCl$$

$$0.77\frac{mg}{L}NaOCl * \frac{1\ mol\ NaOCl}{77.4\ g} * \frac{1\ mol\ OCl^-}{1\ mol\ NaOCl} * \frac{51.4g}{mol\ OCl^-} = 0.51\frac{mg}{L}OCl^-$$

Based on this calculation, the amount of free chlorine in the treated water should be about 0.5 mg/L, which does not meet the treatment plant goal of 0.6 to 0.7 mg/L. Additionally, chlorine is a strong oxidant and these calculations do not take into affect reactions of chlorine with reduced species in the water which would reduce the amount of chlorine available for disinfection. In chlorine chemistry, there are three forms of chlorine; total chlorine, free chlorine and combined chlorine. Total chlorine is the sum of free chlorine and combined chlorine, free chlorine is the chlorine available for disinfection in the form of HOCl and $OCl^-$, and combined chlorine is chlorine that has reacted with nitrogen containing compounds to form chloramines. Chloramines can still deactivate microbial contaminants, but the reaction mechanism is slower than with free chlorine. HOCl is a more powerful disinfectant than $OCl^-$; concentrations of HOCl and $OCl^-$ vary with pH.

In the case of the Tiquipaya Noreste water treatment plant, pH varies between 6.5 and 7.8. The associated relation of HOCl to OCl$^-$ is shown by the following equations.

$$NaOCl + H_20 \rightarrow Na^+ + HOCl + OH^-$$

$$HOCl + H_20 \leftrightarrow OCl^- + H_3O^+$$

Assuming the solution behaves ideally (i.e., γ = 1), at 25 °C,

$$\frac{[H_3O^+][OCl^-]}{[HOCl][H_2O]} = 2.5 * 10^{-8} \text{ (Benjamin, 2002)}$$

Rearranging,

$$\frac{[HOCl]}{[OCl^-]} = \frac{[H_3O^+]}{2.5 * 10^{-8}}$$

At a pH of 6.5,

$$\frac{[HOCl]}{[OCl^-]} = \frac{10^{-6.5}}{2.5 * 10^{-8}} = 12.65 \; and \; \frac{12.65}{13.65} = 0.93 \; or \; 93\,\% \; of \; chlorine \; present \; as \; HOCl$$

At a pH of 7.8,

$$\frac{[HOCl]}{[OCl^-]} = \frac{10^{-7.8}}{2.5 * 10^{-8}} = 0.63 \; and \; \frac{0.63}{1.63} = 0.39 \; or \; 39\,\% \; of \; chlorine \; present \; as \; HOCl$$

Figure 6 displays this information graphically.

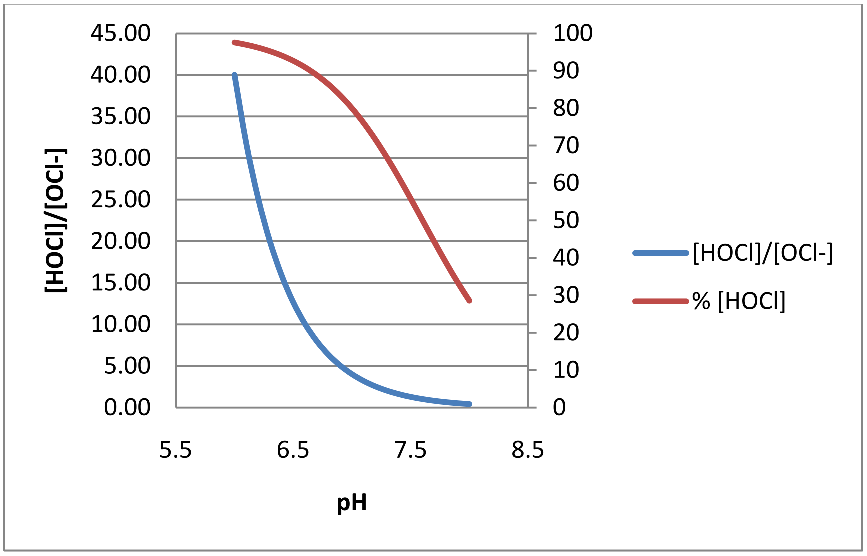


**Figure 6: Speciation plot of [HOCl]/[OCl$^-$].**

Due to the low cost, 10 Bs per 20 $m^3$ or 0.5 Bs per $m^3$ of water ($1.43 USD per 5,283 gallons or $0.27 per 1,000 gallons), water usage is quite high within the community. The engineer that oversees the water distribution system estimated water usage to be between 150 and 200 liters per person per day (~ 40 – 50 gallons per person per day). The low cost of water means that not very much money is collected; improvements to the system can only be made with national government funding. Money collected from users is used to purchase chlorine and electricity for pumps.

In Tiquipaya, the rainy season begins in December and ends in May; the rest of the year it is dry with occasional rainfall. Days are usually warm year round, 24 – 27 °C and nights cool off to about 5 – 12 °C (Weather Underground, 2010). During the dry season, both the wells and the river water are used to provide water to the distribution system. The wells provide 6 – 10 L/s of water and the river supplies about 30 L/s but has the capacity to provide 40L/s. During the rainy season, the river water is too turbid for use and only the wells are used, which causes water shortage problems (Ing. Hector Escalera Espad, 2010).

The following calculations were made based on these numbers.

$$Water\ Demand = 500\ connections * 200\ L/day/person\ * 8\ people/connection$$

$$= 800{,}000\ L/day\ + schools\ + businesses\ + illegal\ connections$$

$$+ leakages$$

$$Water\ Availability = treated\ water\ from\ river + water\ from\ wells$$

$$Treated\ water\ from\ river = 30\ L/s * 3600\ s/hr * 24\ hr/day = 2{,}592{,}000\ L/day$$

$$Water\ from\ wells = 2\ wells * 10\ L/s * 3600\ s/hr * 24\ hr/day = 1{,}728{,}000\ L/day$$

$$Water\ Availability = 2{,}592{,}000\ L/day + \ 1{,}728{,}000\ L/day = 4{,}320{,}000\ L/day$$

The assumptions used in these calculations were that there were 8 people per household (based on results from the household survey) and that the pumps for the well operate on a 24 hour/day basis.

Based on these results, it appears that water demand is much lower than water availability, even in the case when only one source is used. The discrepancy may be due to a number of reasons such as inaccurate production rates of water from the wells or river, a greater number of connections than reported, or significant leakages in the system.

# METHODS

## Background

All data collection occurred during June, July and August of 2010 (winter months in Bolivia) in the community served by the Tiquipaya Noreste water distribution system. There are approximately 500 connections to the distribution system (Ing. Hector Escalera Estrad, 2010). Approximately 150 households in the study site had visible elevated water storage tanks and 37 (25%) of those tanks are included in this study.

Additionally, water samples were taken from 14 different underground cisterns, 7 locations within the distribution system, both wells and at 9 locations within the treatment plant. For the in-depth microbial analysis, 11 tanks, 8 cisterns and 2 locations within the distribution system were revisited for further analysis. Figure 10 in the Results chapter should be consulted for location information related to the various sampling points. All households included in the study are provided water by this distribution system and have an elevated storage tank. The majority of sampling occurred between the hours of 8:00 am and 12:00 pm, however, on two occasions sampling was done between 3:00 pm and 6:00 pm in an attempt to obtain samples from households where homeowners were not present during the earlier sampling period. Measurements for the temperature study were taken every 30 minutes during daylight hours (7:00 am – 7:00 pm).

### General Survey of Tank Type and Availability

Initially, the households, schools and businesses that are provided water by the Tiquipaya Noreste water distribution system were surveyed for the different types of water storage tanks present. The location and tank type of each tank was recorded. This was achieved by walking the streets of the community and noting the types of tanks present in homes, schools and other businesses and marking the locations with a Garmen eTrex ® H GPS (Olathe, Kansas). Tanks found in houses or buildings that appeared to be uninhabited were not counted. From this information the five most common tank types were selected for the study and were assigned numbers. The tanks were then randomly selected by a random number generator and a list of tanks and their corresponding GPS locations was created.

### Sampling Procedures

An initial water quality screening of 37 elevated storage tanks and 14 underground cisterns was performed. Additionally, samples from various locations within the water distribution system, both wells and treatment plant, were taken. In addition to these initial water quality measurements, a subset of 11 elevated storage tanks and 3 cisterns were chosen for in-depth analysis (see next section). The households that were randomly selected were then visited in an attempt to obtain a water sample and administer a survey, however, often times the homeowner was not present and the sample was not obtained. In this situation, the next household on the list of households designated for further analysis was visited. Due to numerous situations in which homeowners were not present, almost every home, school or business with an elevated storage tank in the community served by the Tiquipaya Noreste water distribution system was visited in order to obtain a sufficient number of samples. In the case where water samples were obtained from schools, only survey questions pertaining to storage tank characteristics and behaviors were used. See Figure 10 for a figure showing locations of the elevated storage tanks sampled in this study.

Interviewers obtained informed consent of study participants before conducting surveys or sampling (See Appendix A for the IRB Approval form, Appendix B for Study Information Sheet, and Appendix C for Study Questionnaire). All respondents were of 18 years of age or older. If someone under the age of 18 answered the door, investigators asked if an adult was present. In the event that an adult was not present, the household was visited at a later date when an adult was present.

If the homeowner/school director/business owner agreed to participate in the study a survey asking about use and behaviors related to the rooftop storage tank was administered. The survey was semi-structured and questioned the user about water storage tank age, cleaning and disinfection frequency and practices, see Table 3 for example questions. The detailed survey (i.e., the Study Questionnaire) is provided in Appendix C.

**Table 3: Sample survey questions concerning elevated storage tank properties and household use.**

| **Water Storage Tank Properties and Access to Water** |
|---|
| What material is your tank made of? |
| What is the age of the tank? |
| How many days a week do you have access to piped running water? |
| When you have access to piped running water, how long do you have access? |
| **Household Water Practices & Use** |
| Is the water Stored in the tank used for drinking water? |
| What is the water from the storage tank used for? |
| In general, how frequently do you clean your storage tank? |
| What do you use to clean your storage tank? |

### Initial Water Quality Analysis

Physical/chemical parameters of the water in the rooftop storage tank were measured on site using a Hydro Lab Quanta Probe (Hach, Loveland, CO). The Hydro Lab Quanta Probe measures temperature, conductivity, total dissolved solids, dissolved oxygen, pH, and turbidity. In addition, water samples totaling 350 mL were collected in two separate bottles for further analysis. A 100 mL plastic bottle containing sodium thiosulfate (as provided by Idexx Laboratories) was used to collect the water for analysis of coliforms and *E. coli* and a sterile 250-mL HDPE bottle was used to collect water for free and total chlorine analysis. Sterile sample bottles and all laboratory equipment were purchased and transported to Bolivia. Initially, samples were tested for lead and copper. However because detectable levels of lead or copper were not detected in initial samples, and PVC pipe is used for the distribution system, lead and copper testing was discontinued after an initial round of testing. All samples were stored in a cooler at 4°C and analyzed within 6 hours of collection at our field laboratory.

Whenever possible, physical/chemical parameters were measured and water samples were taken directly from the water storage tank. However, some homeowners were not comfortable allowing someone to climb on their roof in order to collect a water sample directly from the storage tank. Of the 37 elevated storage tanks sampled, 20 (54%) of the samples were taken directly from the tank while 17 (46%) samples were taken from taps connected to the tank. In the case where the sample was collected from a tap it was taken from the tap location closest to the tank. The tap was allowed to run for 30 seconds before the sample was collected. See Table 4 for information regarding the number of samples taken from tanks and taps for each tank type.

**Table 4: Distribution of samples taken directly from storage tanks and samples taken from taps by tank type.**

| Storage Tank Type | Number of Samples Taken Directly from Storage Tanks | Number of Samples Taken from Taps |
|---|---|---|
| Polyethylene | 11 (69%) | 5 (31%) |
| Fiberglass | 5 (45%) | 6 (55%) |
| Fiber Cement | 8 (80%) | 2 (20%) |

Table 5 lists the parameters measured in both the initial and in-depth water quality analysis studies. In order to measure physical parameters with the Quanta Hydrolab probe, a 4-liter glass jar was used to collect water from the tap and then the probe was placed in the jar and results were recorded. Data locations were noted whether the sample was collected directly from the tap or directly from the storage tank.

### In-Depth Water Quality Analysis

In addition to the initial water quality measurements, a subset of 11 elevated storage tanks, 4 cisterns and 2 locations along the distribution system were chosen for a more in-depth microbial analysis. Table 5 lists the parameters measured and the method used to measure them for both the initial study and the in-depth analysis.

Elevated storage tanks were chosen based on accessibility and willingness of homeowner to participate further. At this time of the study 3 samples from distribution system and the water leaving directly from treatment plant were also chosen for in-depth analysis. Samples were collected in 100-mL plastic bottles containing sodium thiosulfate (as provided by Idexx Laboratories) for coliforms and *E. coli* analysis and a sterile 250 mL HDPE plastic bottle was used to collect water for free and total chlorine, iron, nitrate, sulfate, iron related bacteria, heterotrophic aerobic bacteria and slime forming bacteria analysis. Samples were stored in a cooler at 4 °C and analyzed within 6 hours of collection.

**Table 5: Water quality parameters and analytical methods employed.**

| Parameter | Method | Screening Analysis | In-Depth Analysis |
|---|---|---|---|
| **Temperature** | Quanta Probe – in situ measurement | ✓ | ✓ |
| **pH** | Quanta Probe – in situ measurement | ✓ | |
| **Turbidity** | Quanta Probe – in situ measurement | ✓ | |
| **Conductivity** | Quanta Probe – in situ measurement | ✓ | |
| **Dissolved Oxygen** | Quanta Probe – in situ measurement | ✓ | |
| **Total Dissolved Solids** | Quanta Probe – in situ measurement | ✓ | ✓ |
| **Total Coliforms** | Idexx Laboratories Coli-Lert Quanti-Tray/2000 | ✓ | ✓ |
| ***E. coli*** | Idexx Laboratories Coli-Lert Quanti-Tray/2000 | ✓ | ✓ |
| **Total Chlorine** | Hach Test Kit: Smart Colorimeter II Chlorine | ✓ | ✓ |
| **Free Chlorine** | Hach Test Kit: Smart Colorimeter II Chlorine | ✓ | ✓ |
| **Iron** | Lamotte Smart Reagent System | | ✓ |
| **Nitrate** | Lamotte Smart Reagent System | | ✓ |
| **Sulfate** | Lamotte Smart Reagent System | | ✓ |
| **Copper** | Lamotte Smart Reagent System | | ✓ |
| **Lead** | Lamotte Smart Reagent System | | ✓ |
| **Alkalinity** | Hach Alkalinity Test Kit | | ✓ |
| **Iron Related Bacteria** | BART$^{TM}$ Test Kit | | ✓ |
| **Heterotrophic Aerobic Bacteria** | BART$^{TM}$ Test Kit | | ✓ |
| **Slime Forming Bacteria** | BART$^{TM}$ Test Kit | | ✓ |

For Total Coliforms and *E. coli* measurements the Coli-Lert Quanti-Tray system (IDEXX Laboratories, Westbrook, ME) was used which employs a Most Probable Number (MPN) method which is used to enumerate colony forming units (CFU) per 100 mL.

### Temperature Study

Water temperature was measured inside three types of elevated storage tanks for a period of 12 hours. A temperature probe (TDSTestr11+, Oakton Instruments, Vernon Hills, IL) was placed within the tank and measurements were recorded every 30 minutes over a period of 12 hours covering the time of sunrise to sunset (7:00am – 7:00pm). Three tanks were included in the temperature study. Both the fiber cement tank and the fiberglass tank were elevated and remained in direct sunlight throughout daylight hours. The polyethylene tank was located at ground level with a wall located on its west side. This meant that starting at about 2:30pm the tank was in the shade. Since most storage tanks included in this study were located on rooftops, the storage tanks chosen for the temperature study are representative, since they too were exposed to sunlight through most of the day.

### Treatment Plant and Wells

In addition to the water sampling previously mentioned, samples were taken from 8 locations within the municipality's water treatment plant and at both well sources. Temperature, conductivity, total dissolved solids, dissolved oxygen, pH and turbidity measurements were measured using the Hydro Lab Quanta Probe. Total and free chlorine analysis in locations after disinfection was performed at the time of sampling as well as in the field laboratory. Additionally, source water, water after initial sedimentation, water entering treatment plant (Item 1, Figure 7b), within the treatment plant (Items 2 and 3, Figure 7b), water before disinfection (Item 4, Figure 7) water after disinfection (Item 5, Figure 7), water from the storage tank before distribution system, both source wells and 3 locations within the distribution system were analyzed for iron, nitrate, sulfate and alkalinity. The sample taken from the storage tank before the water enters the distribution system was also analyzed for iron related bacteria, heterotrophic aerobic bacteria, and slime forming bacteria. See Figure 7b for treatment plant sampling locations.

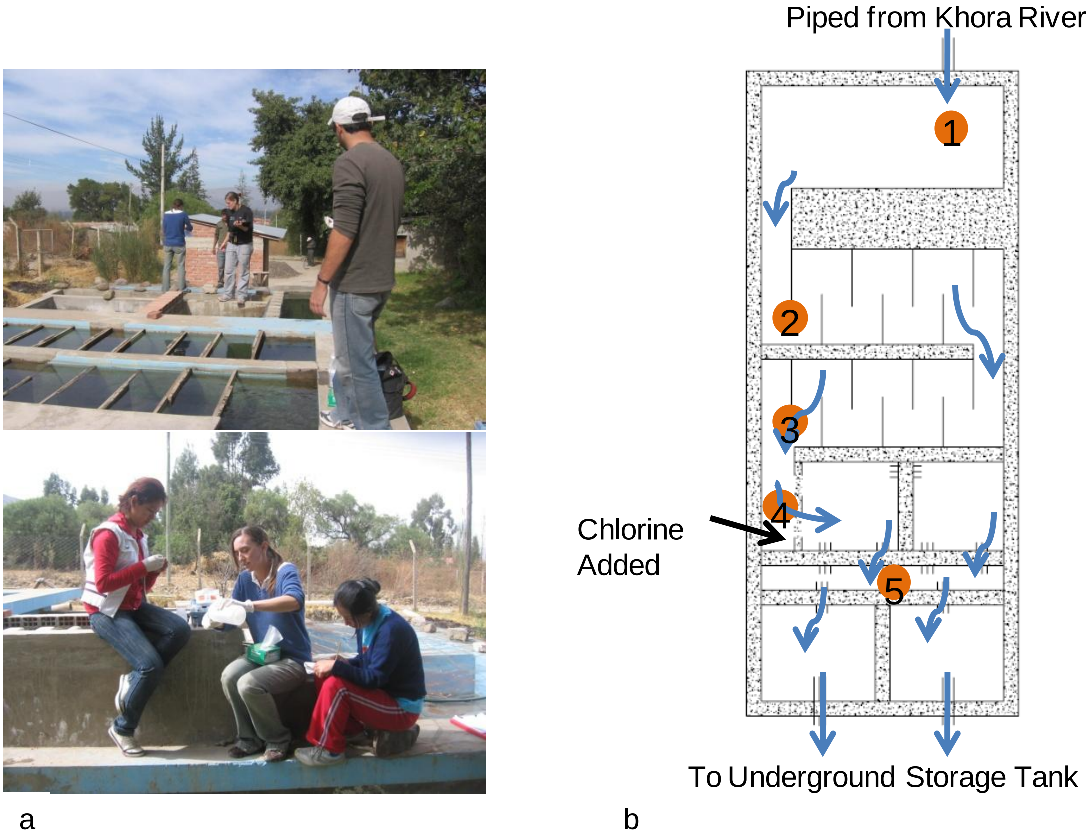


**Figure 7: Tiquipaya Noreste (Bolivia) water treatment plant. a) Photos of Tiquipaya Noreste treatment plant; b) Treatment plant schematic and sampling locations.**

### Statistical Analysis

Statistical analysis included a series of one-way randomized block ANOVAs and general linear MANOVAs as well as multiple regression analysis to determine if correlations and relationships between water quality parameters exist. Two-sample *t*-tests were performed to analyze changes in water quality at different points in the system. Statistical analysis was performed using Minitab 15 software (LEAD Technologies, Inc. State College, PA) and SPSS PASW Statistics, v. 18.0 software (IBM, Somers, NY).

## Removal of Data

Due to measurements of total coliforms and E. coli that were too high to count in one fiberglass tank and associated cistern that were not located within the water distribution system under study, these data were removed from the study for analysis. Additionally, it was found that for fiber cement tanks total chlorine measurements taken from taps were statistically different from measurements taken directly from fiber cement tanks. These data were also removed from the analysis.

## Potential Errors

The potential for errors in sampling arises due to the inability of the researcher to view every elevated storage tank which may have resulted in underreporting of the numbers and types likely storage tanks.

Another potential source of error is related to the detection limits of the equipment. For example, 62% of total chlorine and 75% of free chlorine measurements were reported at or below the lower detection limit (0.02 mg/L as $Cl_2$) . The value from the instrument was coded into three categories as shown in Table 12 and displayed in Figure 12. The values from the instrument were used in the statistical analysis, but it is not known if these values are actually 0. This has the potential to skew the results indicating that chlorine is present in the water when indeed it is not. See Table 6 for the detection limits of all test kits used in this study.

**Table 6: Detection limits of test kits used in laboratory analysis.**

| Parameter | Detection Limit |
|---|---|
| **Total Chlorine** | 0.02 mg/L to 2.00 mg/L as $Cl_2$ |
| **Free Chlorine** | 0.02 mg/L to 2.00 mg/L as $Cl_2$ |
| **Iron** | 0.02 – 6.00 ppm |
| **Nitrate** | 0.02 – 3.00 ppm |
| **Sulfate** | 2 – 100 ppm |
| **Copper** | 0.02 – 6.00 ppm |
| **Lead** | 0.02 – 5.00 ppm |
| **Alkalinity** | 20 – 400 mg/L as $CaCO_3$ |

The timing of sampling is another potential source of error. For example, it was not known how recently the storage tank was filled from the municipal water supply prior to sampling. Agitation of settled particles and microbes may occur during filling and this has been shown to produce significantly higher microbial counts in smaller water storage containers (Roberts et al., 2001).

# RESULTS

## Elevated Storage Tank Types

A general survey of the elevated storage tanks present in the Tiquipaya Noreste community found 145 elevated storage tanks of which 56 (38%) are polyethylene tanks, 50 (34%) are fiberglass tanks and 39 (27%) are fiber cement tanks in the area. Figure 8 shows the locations and tank type of all the elevated storage tanks found within the study area.

The tanks most commonly used are fiber cement, black polyethylene, gray polyethylene round fiberglass and sideways fiberglass. Figure 9 provides photographs of each specific tank type. For purposes of analyzing the results, the tanks have been grouped into three categories: polyethylene, fiberglass and fiber cement.

Polyethylene is a commonly used plastic that is composed of long ethylene chains. Thin fibers of glass are used to form fiberglass. Fiber cement is a composite material that is composed of sand, cement, and cellulose fibers.

**Table 7: Percentages of each tank type found within the Tiquipaya Noreste distribution system and of those included in the study.**

| Storage Tank Type | % of Tank Type Found in Community | % of Tank Type Sampled |
|---|---|---|
| Polyethylene | 38% | 43% |
| Fiberglass | 34% | 30% |
| Fiber Cement | 27% | 27% |

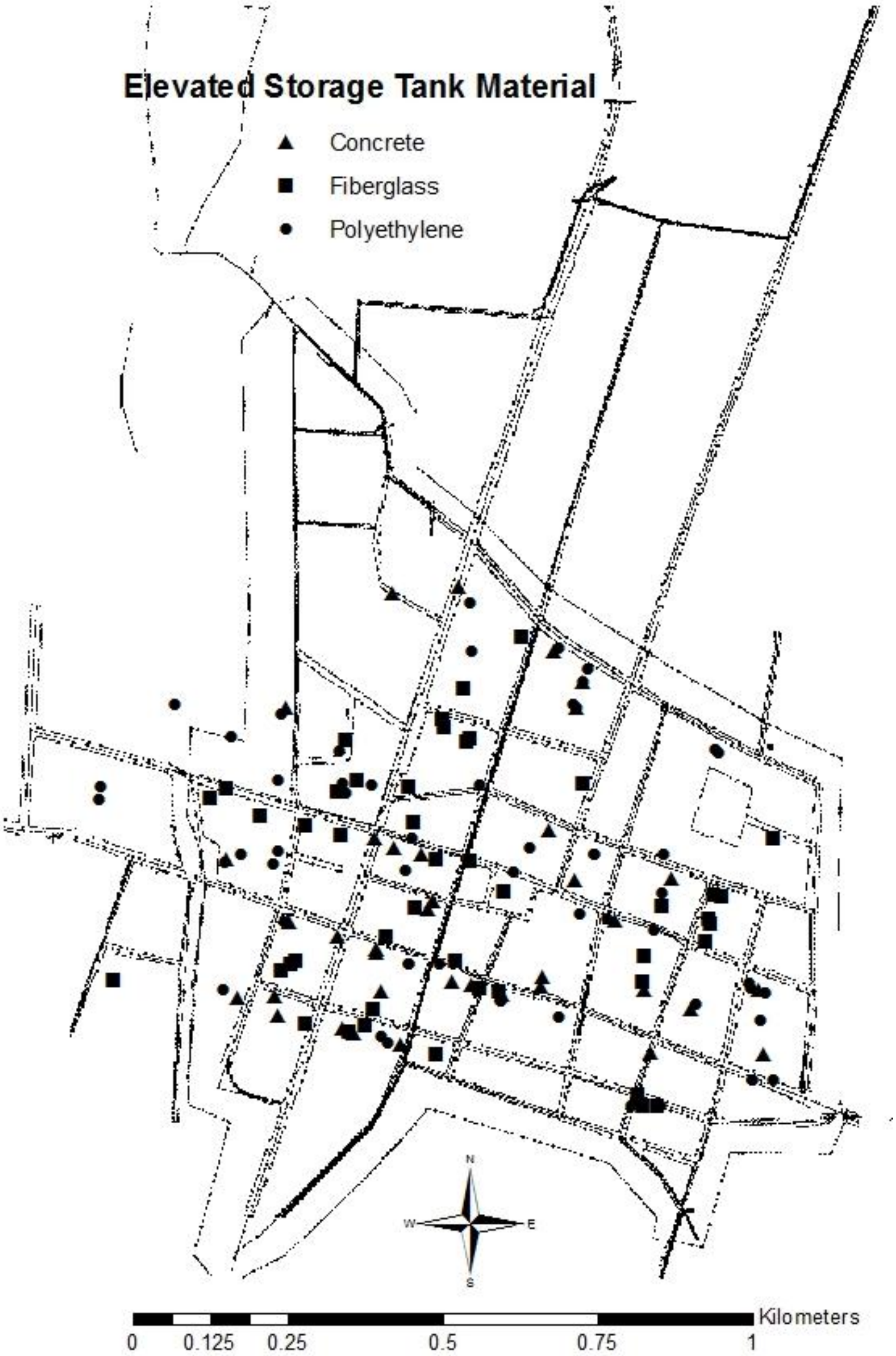


Figure 8: Locations of all elevated storage tanks within study area.

**Figure 9: Five most commonly found elevated storage tanks observed in Tiquipaya Noreste community. Starting from the top left and moving clockwise: gray polyethylene, sideways fiberglass, fiber cement, black polyethylene and round polyethylene.**

### Household Survey

Over the course of one week in June, 2010, a total of 35 surveys were administered, 37 household water storage tanks were sampled (two households had two tanks), and 14 household cisterns and 7 points along the distribution system were sampled. Fourteen of the survey respondents were the female head of household and 21 respondents were the male head of household. A total of 10 fiber cement tanks, 11 fiberglass (6 round, 5 sideways), and 16 polyethylene (9 black, 5 gray, and 2 red) were sampled. Locations of the elevated storage tanks, cisterns and points along the distribution system that were sampled for general analysis are shown in Figure 10.

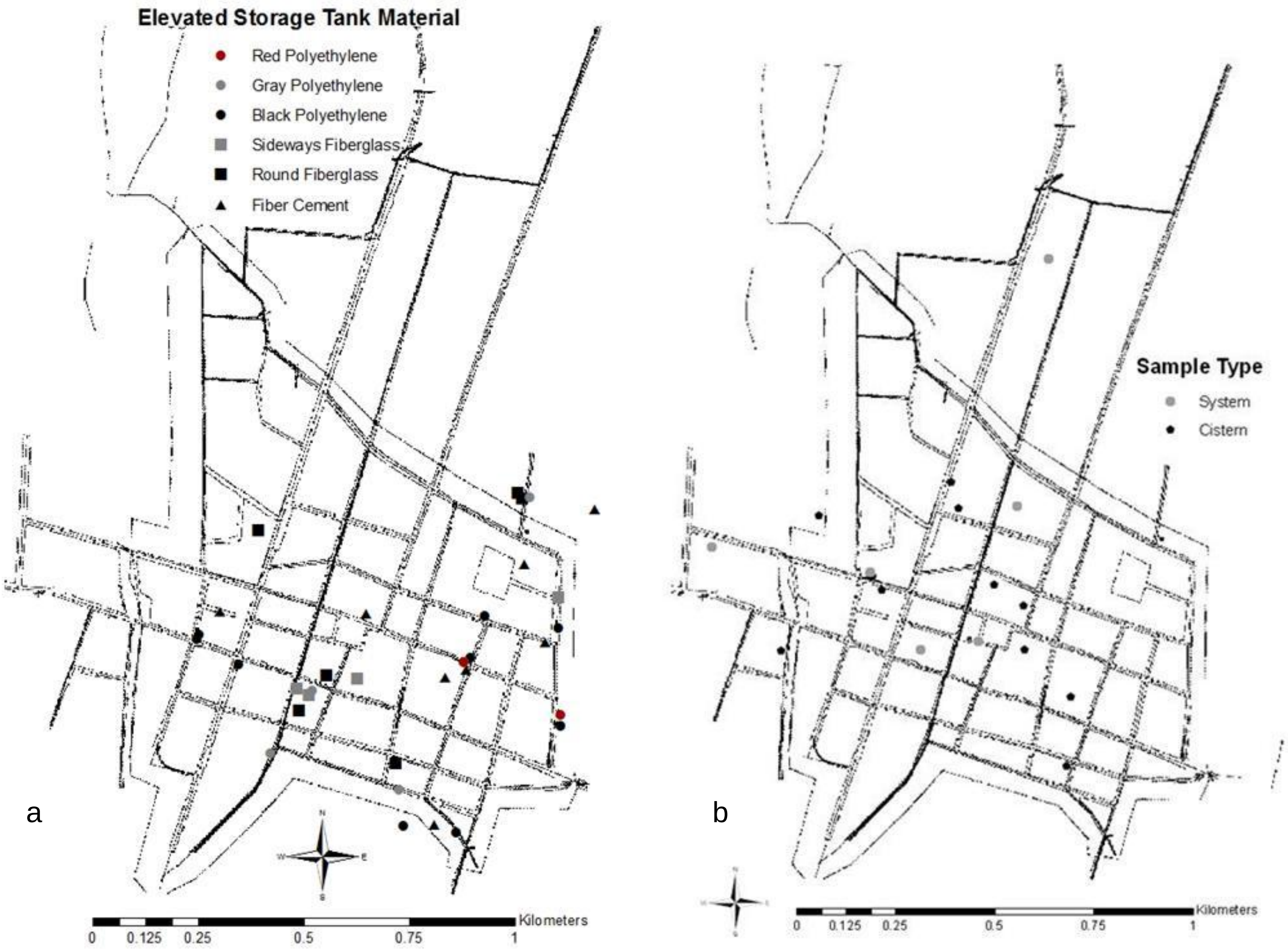


**Figure 10: Sample location maps in Tiquipaya Noreste community. a) Locations of elevated storage tanks included in general study; b) Locations of underground cisterns and samples taken from distribution system.**

Table 8 shows the age distribution of the tanks by tank materials. 32 out of 36 or 89% of the tanks sampled in this study are 10 years old or younger. Generally, storage tanks are sold with a 20 year guarantee.

**Table 8: Age distribution of elevated storage tanks; 37 tanks sampled.**

| **Tank Age** | | | | | | |
|---|---|---|---|---|---|---|
| **Tank Material** | **0 - 3** | **4 - 10** | **11 - 15** | **16 - 20** | **Unknown** | **Totals** |
| Fiber cement | 1 | 6 | 1 | 1 | 1 | **10** |
| Fiberglass | 4 | 5 | 2 | 0 | 0 | **11** |
| Polyethylene | 8 | 8 | 0 | 0 | 0 | **16** |
| **Totals** | **13** | **19** | **3** | **1** | **1** | |

Table 9 shows the frequency in which study participants (n = 37) clean their rooftop tanks. When asked about storage tank cleaning methods,19 study participants said they used bleach, detergent or disinfectant to clean their elevated storage tank. When asked about treating the water from the rooftop tank before use, 23 study participants said they boil their water, 1 participant said s/he disinfects the water in the elevated storage tank, 8 participants said they did not treat the water (including the school) and 2 participants gave no answer because they are owners of apartment buildings in which residents may use various point of use treatment techniques.[1]

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[1] This study's author does not believe that disinfection in the elevated storage tank is taking place due to difficulties encountered in reaching storage tanks. Instead disinfection may be occurring at point-of-use within the household and that there was a miscommunication in either the survey question or in the household answering the survey question. In addition, one participant treats water for all uses while all others who responded stated they treat the water and only use the treated water for drinking or cooking. This study's author does not believe that water is being treated for all uses because treatment method was boiling water and it is unlikely that boiled water for activities such as bathing or washing was used. Once again there was some miscommunication in either the survey question or in the household answering the survey question.

**Table 9: Frequency of rooftop water storage tank cleaning; 36 tanks sampled.**

| How Often Rooftop Tank is Cleaned | | | | | | |
|---|---|---|---|---|---|---|
| Every 2 Years | Annually | Biannually | Every 3 Months | Monthly | Never | Other* |
| 2 | 11 | 3 | 4 | 8 | 5 | 3 |

* Households with no regular cleaning schedule

Thirty six respondents reported they had access to water 24 hours a day and 36 respondents said that they had access to water 7 days a week from the distribution system (different study participant was the lone individual who did not have access 7 days a week). Because all residents are connected to the same distribution system these responses mostly likely reflect occasional cuts in service for maintenance and are not characteristic of the system which generally provides water 24 hours a day, 7 days a week.

### Water Quality – Initial Screening

Before analyzing results for correlations between parameters or for differences in water quality versus tank types, tank properties, and user behaviors, a statistical analysis was performed to see if differences exist between the samples taken directly from the elevated storage tanks and samples taken from household taps. In order to determine this, a series general linear MANOVA was performed. Table 10 provides a summary of results and Appendix I can be consulted for more complete results. These results show that the results for each parameter do not vary significantly between samples taken directly from the storage tanks themselves and samples taken from taps fed by storage tanks,

**Table 10: Results for MANOVA comparing water quality parameters for samples taken directly from elevated storage tanks or from taps. The results show that water samples taken from taps do not differ significantly (sig. < 0.05) from samples taken directly from storage tanks.**

**Multivariate Tests**[b]

| Effect | | Value | F | Hypothesis df | Error df | Sig. |
|---|---|---|---|---|---|---|
| Tank or Tap | Pillai's Trace | .290 | .982[a] | 10.000 | 24.000 | .484 |
| | Wilks' Lambda | .710 | .982[a] | 10.000 | 24.000 | .484 |
| | Hotelling's Trace | .409 | .982[a] | 10.000 | 24.000 | .484 |
| | Roy's Largest Root | .409 | .982[a] | 10.000 | 24.000 | .484 |

a. Exact statistic

b. Design: Intercept + Tank or Tap

Additionally, the data were analyzed to see if there were any differences between parameters for samples taken directly from storage tanks or from taps with various water quality parameters (Table 11). See Appendix I for more detailed results.

**Table 11: Results for tests of between-subject effects using MANOVA. The results show that no significant differences exist for any of the parameters between samples directly from tanks and those from taps.**

| Source | Dependent Variable | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Corrected Model | Temperature | .959[a] | 1 | .959 | .165 | .688 |
| | Conductivity | .006[b] | 1 | .006 | .785 | .382 |
| | TDS | .003[c] | 1 | .003 | .898 | .350 |
| | DO | .378[d] | 1 | .378 | 1.422 | .242 |
| | pH | .000[e] | 1 | .000 | .004 | .951 |
| | Turbidity | 244.647[f] | 1 | 244.647 | 2.572 | .118 |
| | Total Coliforms | 416344.281[g] | 1 | 416344.281 | 2.307 | .138 |
| | E. coli | 92.740[h] | 1 | 92.740 | .040 | .844 |
| | Total Chlorine | .000[i] | 1 | .000 | 1.184 | .284 |
| | Free Chlorine | .000[j] | 1 | .000 | 2.049 | .162 |
| Tank or Tap | Temperature | .959 | 1 | .959 | .165 | .688 |
| | Conductivity | .006 | 1 | .006 | .785 | .382 |
| | TDS | .003 | 1 | .003 | .898 | .350 |
| | DO | .378 | 1 | .378 | 1.422 | .242 |
| | pH | .000 | 1 | .000 | .004 | .951 |
| | Turbidity | 244.647 | 1 | 244.647 | 2.572 | .118 |
| | Total Coliforms | 416344.281 | 1 | 416344.281 | 2.307 | .138 |
| | E. coli | 92.740 | 1 | 92.740 | .040 | .844 |
| | Total Chlorine | .000 | 1 | .000 | 1.184 | .284 |
| | Free Chlorine | .000 | 1 | .000 | 2.049 | .162 |

Data collected from the initial screening indicates that the physical, chemical and initial microbial water quality parameters do not vary significantly between tank types, underground cisterns, and within the water distribution system. There are no statistically significant differences between tank type (Pillai's Trace, *F* = 1.081, *p* = .398), although pH differs between plastic and fiberglass tanks at *p* = .019 (Tukey's HSD post hoc test). Figure 11 and Figure 12 depict the results graphically, for specific values see Table 13 and for detailed statistical analysis see Appendix J.

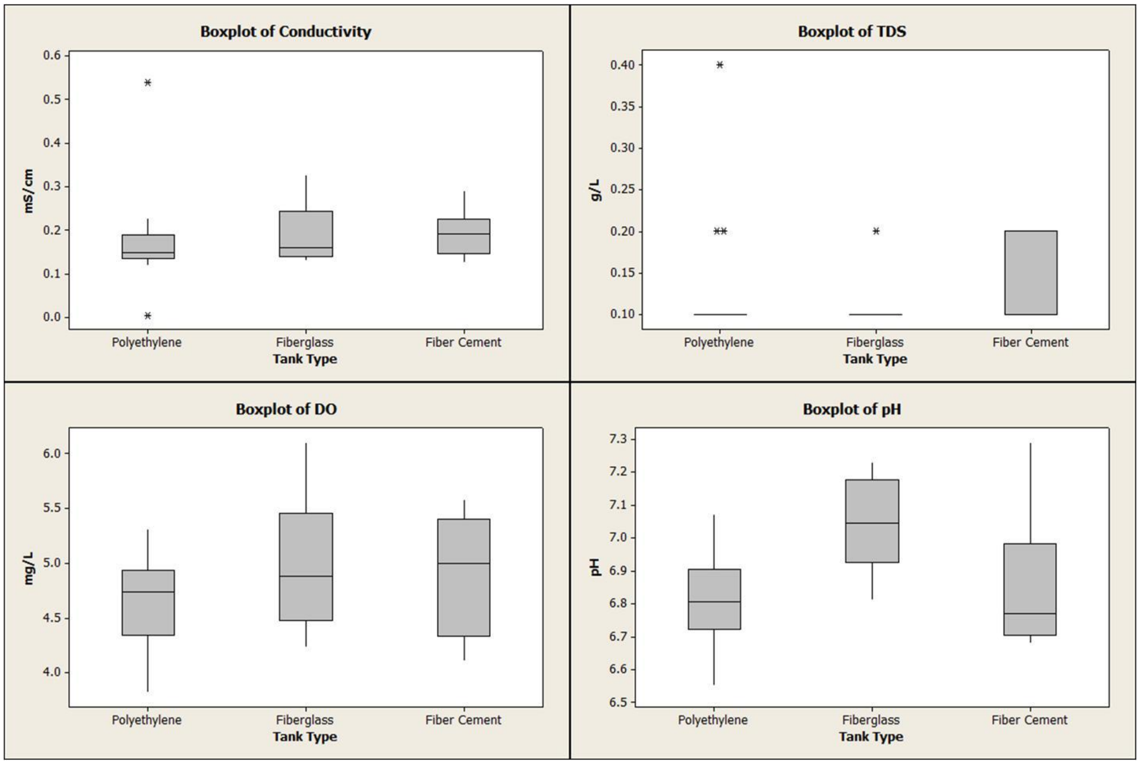

**Figure 11: Results for conductivity, total dissolved solids, dissolved oxygen and pH for water storage tanks in Tiquipaya Noreste (Bolivia).**

Except for a few outliers, results for conductivity, TDS and DO show no difference between tank type. For pH, there is a difference between polyethylene and fiberglass tanks and between fiberglass and fiber cement tanks (*p* = 0.001 and 0.043 respectively); but there is no difference between polyethylene and fiber cement tanks (*p* = 0.722).

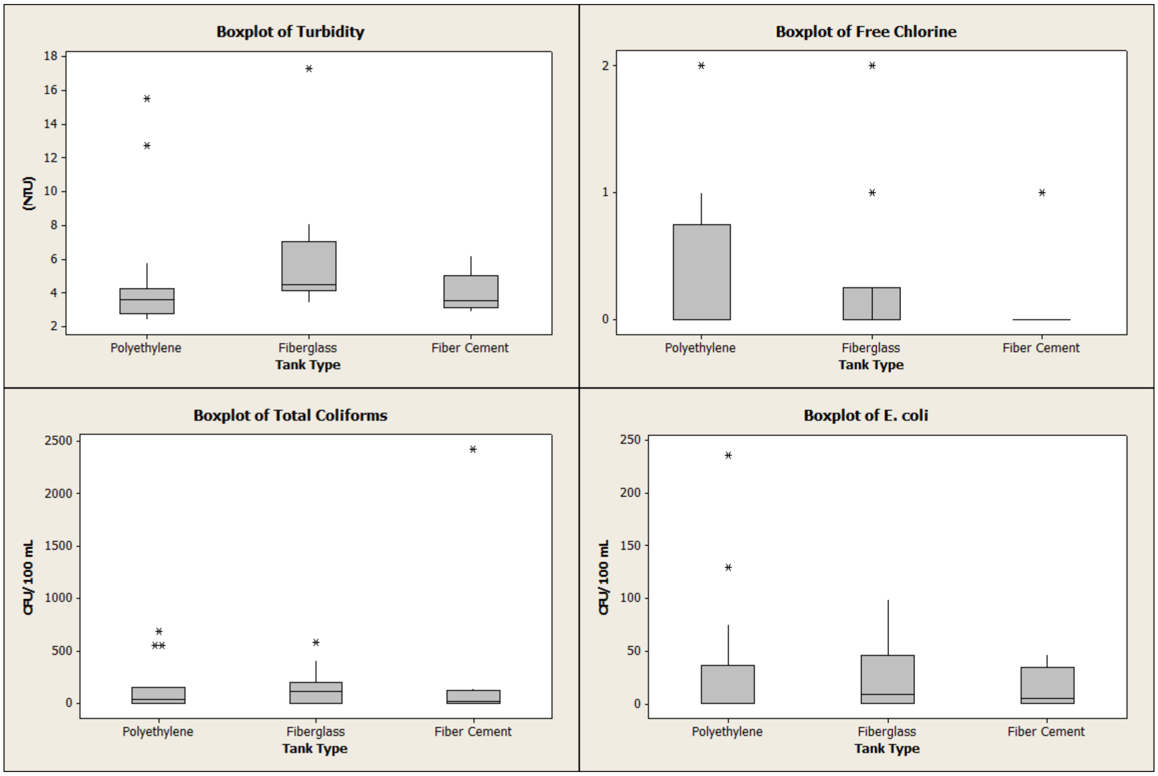

**Figure 12: Results for turbidity, free chlorine, total coliforms and *E. coli* for water storage tanks in Tiquipaya Noreste (Bolivia).**

The outliers for turbidity, total coliforms and E. coli results shown in Figure 12 correspond to storage tanks that are cleaned 2 times a year or less. The results for free chlorine were coded due to a majority of the results were below the detection limit of the instrument. See Table 12 for coding.

**Table 12: Assigned values for coded free chlorine data.**

| Instrument Reading | Assigned Value |
|---|---|
| Below Detection Limit | 0 |
| 0.02 – 0.03 mg/L | 1 |
| > 0.03 mg/L | 2 |

**Table 13: Overall physical and chemical water quality results for each water storage tank type in Tiquipaya Noreste (Bolivia). The listed Bolivian standards apply only to the source water.**

| Parameter | | Tank Type | | | | | | Distribution System (n = 7) | Bolivian Standards[1] |
|---|---|---|---|---|---|---|---|---|---|
| | | Black Plastic (n = 10) | Gray Plastic (n = 5) | Round Fiberglass (n = 5) | Sideways Fiberglass (n = 5) | Fiber Cement (n = 9) | Cistern (n = 13) | | |
| Conductivity (mS/cm) | Max | 0.540 | 0.158 | 0.295 | 0.328 | 0.291 | 0.208 | 0.195 | 1.5 |
| | Min | 0.004 | 0.142 | 0.130 | 0.134 | 0.125 | 0.102 | 0.151 | |
| | Avg | 0.207 | 0.152 | 0.194 | 0.191 | 0.185 | 0.149 | 0.164 | |
| | Std Dev | 0.146 | 0.007 | 0.067 | 0.081 | 0.052 | 0.026 | 0.017 | |
| Total Dissolved Solids (g/L) | Max | 0.4 | 0.1 | 0.1 | 0.2 | 0.2 | 0.1 | 0.1 | 1 |
| | Min | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | |
| | Avg | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | |
| | Std Dev | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | |
| Dissolved Oxygen (mg/L) | Max | 5.31 | 4.94 | 6.10 | 5.36 | 5.58 | 5.80 | 5.51 | > 80% sat. |
| | Min | 4.01 | 4.52 | 4.37 | 4.23 | 4.11 | 4.35 | 4.51 | |
| | Avg | 4.66 | 4.74 | 5.25 | 4.70 | 4.95 | 5.06 | 4.90 | |
| | Std Dev | 0.47 | 0.16 | 0.69 | 0.44 | 0.53 | 0.44 | 0.36 | |
| pH | Max | 7.03 | 7.07 | 7.23 | 7.15 | 7.54 | 7.75 | 7.74 | 6.5 - 8.0 |
| | Min | 6.55 | 6.71 | 7.02 | 6.81 | 6.68 | 6.69 | 6.66 | |
| | Avg | 6.79 | 6.85 | 7.13 | 6.97 | 6.93 | 7.10 | 7.14 | |
| | Std Dev | 0.16 | 0.14 | 0.10 | 0.14 | 0.30 | 0.37 | 0.37 | |
| Turbidity (NTU) | Max | 15.5 | 5.8 | 17.3 | 8.1 | 6.2 | 10.9 | 6.6 | < 10 |
| | Min | 2.1 | 2.5 | 3.4 | 3.8 | 2.9 | 2.7 | 2.8 | |
| | Avg | 5.4 | 3.8 | 7.2 | 5.2 | 4.0 | 4.0 | 4.8 | |
| | Std Dev | 4.7 | 1.3 | 5.8 | 1.7 | 18.8 | 2.1 | 1.2 | |
| Total Chlorine (mg/L) | Max | 0.06 | 0.03 | 0.05 | 0.09 | 0.02 | 0.07 | 0.05 | 0.4 [2] |
| | Min | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| | Avg | 0.02 | 0.01 | 0.02 | 0.03 | 0.01 | 0.02 | 0.03 | |
| | Std Dev | 0.02 | 0.01 | 0.02 | 0.04 | 0.01 | 0.02 | 0.02 | |
| Free Chlorine (mg/L) | Max | 0.05 | 0.03 | 0.03 | 0.05 | 0.10 | 0.05 | 0.06 | 0.2 [2] |
| | Min | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | |
| | Avg | 0.02 | 0.01 | 0.01 | 0.02 | 0.02 | 0.01 | 0.03 | |
| | Std Dev | 0.01 | 0.01 | 0.01 | 0.02 | 0.03 | 0.01 | 0.02 | |
| Total Coliforms (MPN) [3] | Max | 548 | 687 | 579 | 411 | 2420 | 1203 | 178 | 0 |
| | Min | 0 | 8 | 21 | 0 | 0 | 0 | 0 | |
| | Avg | 84 | 268 | 188 | 107 | 295 | 215 | 33 | |
| | Std Dev | 169 | 324 | 222 | 178 | 798 | 345 | 67 | |
| E. coli (MPN) [3] | Max | 236 | 130 | 57 | 99 | 46 | 166 | 46 | 0 |
| | Min | 0 | 0 | 5 | 0 | 0 | 0 | 0 | |
| | Avg | 29 | 48 | 30 | 21 | 14 | 25 | 12 | |
| | Std Dev | 73 | 55 | 22 | 43 | 19 | 51 | 20 | |

[1] **Source: Ley del Medio Ambiente Ley No. 1333, 2007**

[2] **Minimum Standards**

[3] **Results of <1 treated as 0 and results >24120 treated as 2420 for calculation purposes**

Looking at the Bolivian standards provided in Table 13, turbidity occasionally exceeds the Bolivian standards while on average total coliforms and *E. coli* counts exceed the Bolivian standards. Total and free chlorine levels are lower than called for by the Bolivian standards, however, the standards are for water leaving treatment facilities and are not generally used for water at the household level. Average free and total chlorine levels are near the detection limits of the instrument, actual values may be lower.

The results were further analyzed by separating data by cleaning frequency (which was recorded for each tank during the household survey). For the physical and chemical water parameters, the results do not vary significantly between cleaning frequencies (see Figure 13).

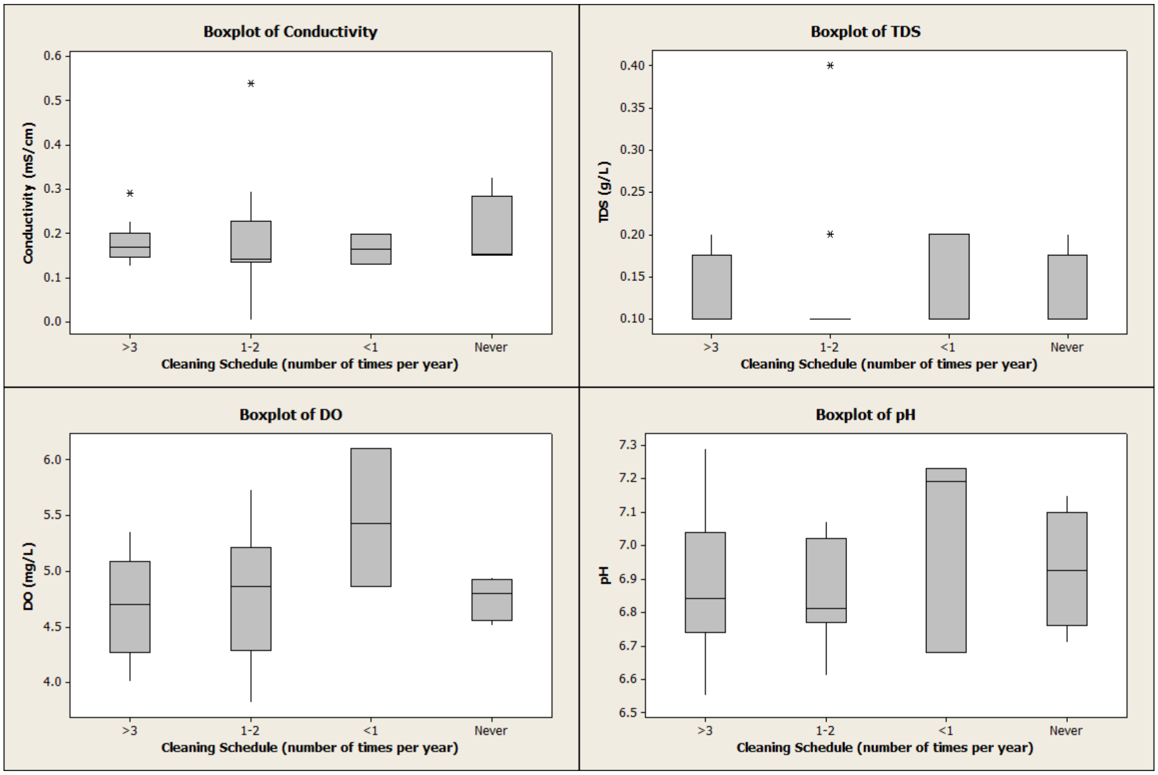

**Figure 13: Results for conductivity, total dissolved solids, dissolved oxygen and pH by cleaning frequency of elevated storage tanks in Tiquipaya Noreste (Bolivia).**

While no significant relationship was seen between cleaning schedule and bacterial growth, Figure 14 shows both total coliform and *E. coli* levels are lower for tanks cleaned more than 3 times a year than for tanks that are never cleaned.

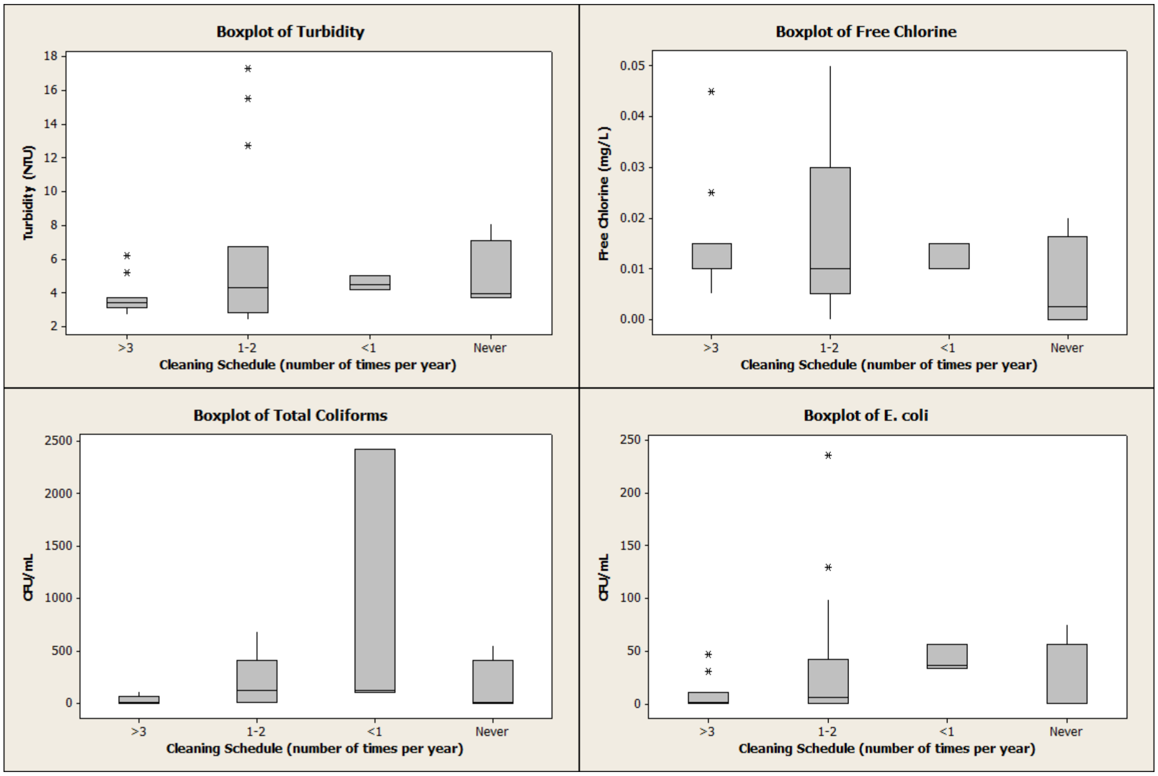

**Figure 14: Results for turbidity, free chlorine, total coliforms and *E. coli* by cleaning frequency of elevated storage tanks in Tiquipaya Noreste (Bolivia).**

Figure 15 and Figure 16 show the results for physical, chemical and microbial water quality parameters for elevated storage tanks grouped by age. These results indicate that storage tank age is not an important factor and that cleaning frequency may have a larger impact on water quality. This may be due to the limited number of storage tanks over 10 years old that were sampled (n = 4) or that 3 of the 4 storage tanks over 10 years old were reported as being cleaned monthly.

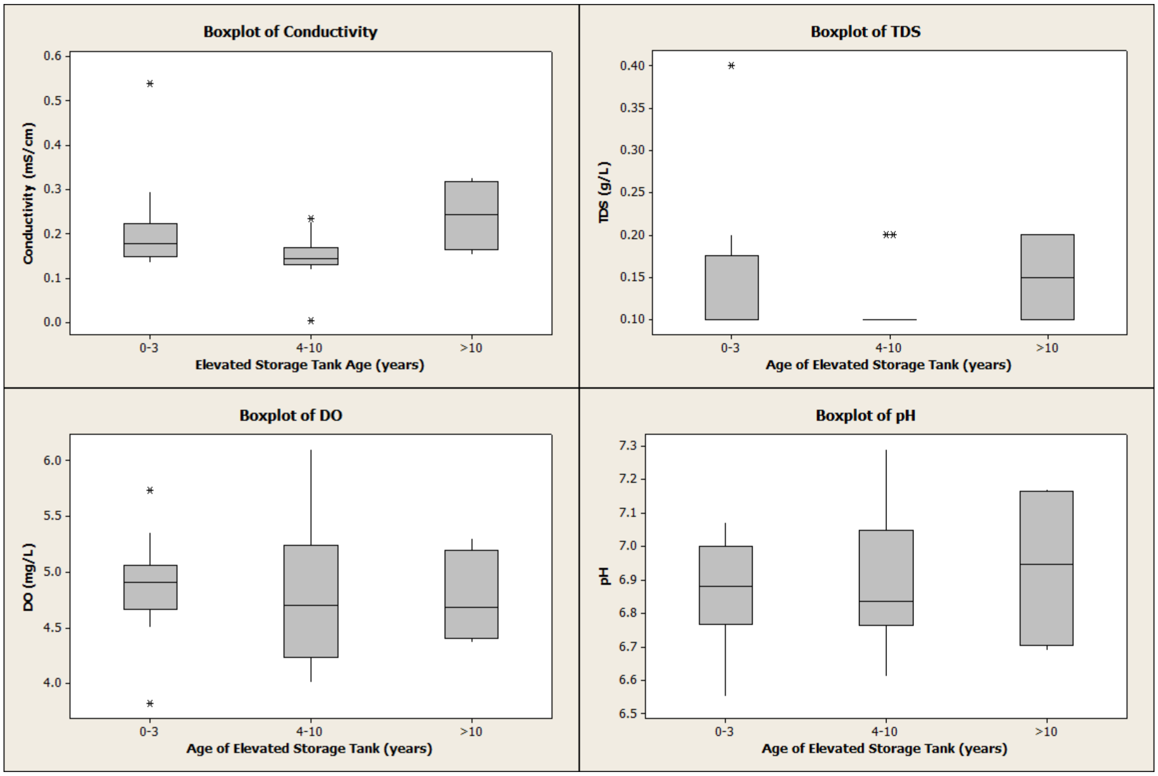

**Figure 15: Results for conductivity, total dissolved solids, dissolved oxygen and pH by age of elevated storage tanks in Tiquipaya Noreste (Bolivia).**

In addition, chlorine measurements were measured near the detection limits of the instrument; it is possible that free chlorine levels are actually lower than reported.

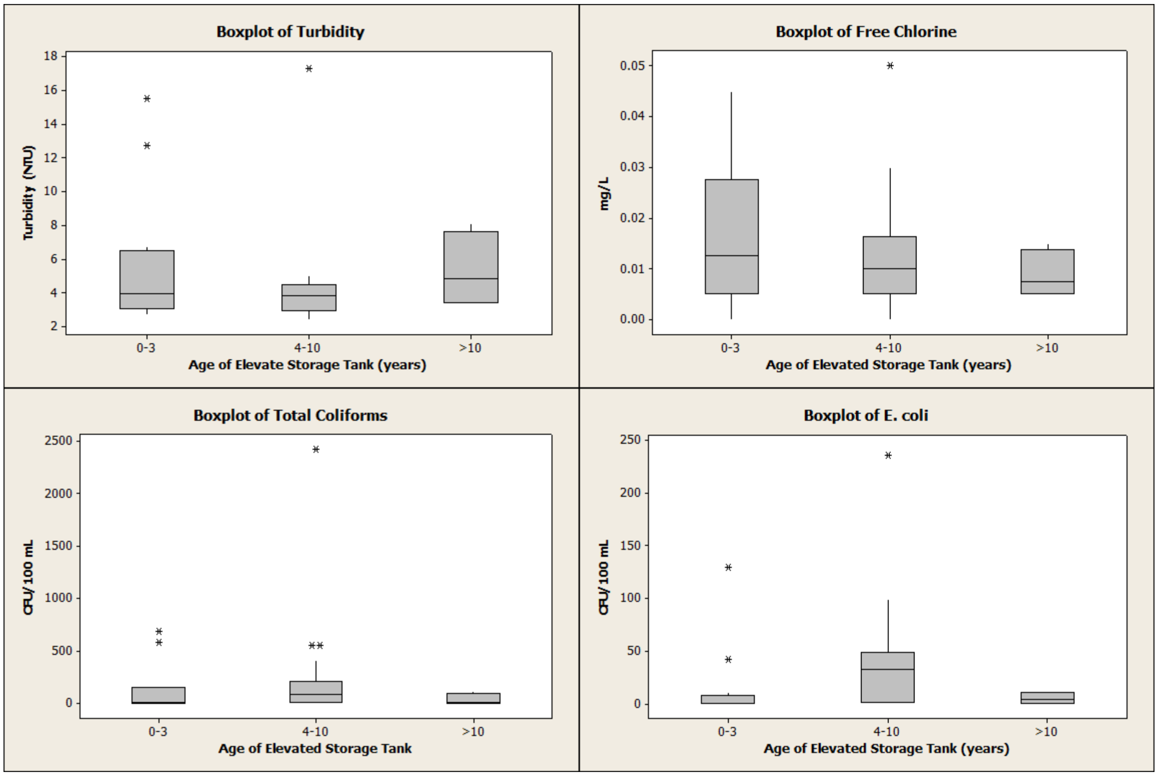

**Figure 16: Results for turbidity, free chlorine, total coliforms and *E. coli* by age of elevated storage tanks in Tiquipaya Noreste (Bolivia).**

Randomized block ANOVAs were used to analyze the effect of tank ages and cleaning schedules on all tanks. Tanks were grouped by age, (0-3 years and >4 years) and cleaning schedule (3 or more times per year, 1-2 times per year and less than 1 time per year). See Table 14 for results.

**Table 14: Results for randomized block ANOVA of various water quality parameters versus tank age and cleaning schedule in Tiquipaya Noreste (Bolivia).**

```
                        E. coli(CFU/100 mL)                                p-value
Tank
Age (years) Mean   --+---------+---------+---------+-------
0-3         20.6667 (------------*------------)
≥4          29.7778          (------------*------------)                    0.396
                   --+---------+---------+---------+-------
                     10        20        30        40
```

## Table 14 Continued

```
Cleaning
Schedule     Mean  -----+---------+---------+---------+----
1          8.1667  (---------*----------)
2         33.1667                   (---------*----------)             0.102
3         34.3333                   (----------*---------)
                   -----+---------+---------+---------+----
                        0        15        30        45

                  Total Coliforms (CFU/100 mL)                        p-value
Tank
Age (years) Mean  --------+---------+---------+---------+-
0-3     136.222  (------------*------------)
≥4      399.889             (------------*------------)                0.328
                  --------+---------+---------+---------+-
                          0       250       500       750

Cleaning
Schedule     Mean     +---------+---------+---------+---------
1          36.000     (----------*----------)
2         202.833         (-----------*----------)                     0.269
3         565.333                    (----------*----------)
                      +---------+---------+---------+---------
                   -350         0       350       700

                      Free Chlorine (mg/L)                            p-value
Tank
Age (years) Mean  --------+---------+---------+---------+-
0-3     0.0136111          (------------*-----------)
≥4      0.0083333  (-----------*-----------)                           0.390
                  --------+---------+---------+---------+-
                        0.0060    0.0120    0.0180    0.0240

Cleaning
Schedule       Mean   -+---------+---------+---------+--------
1         0.0158333              (------------*------------)
2         0.0087500    (------------*-----------)                      0.527
3         0.0083333   (------------*------------)
                      -+---------+---------+---------+--------
                     0.0000    0.0070    0.0140    0.0210

                         Turbidity (NTU)                              p-value
Tank
Age (years)Mean  --------+---------+---------+---------+-
0-3     4.82222     (--------------*---------------)
≥4      4.65556  (---------------*--------------)                      0.828
                 --------+---------+---------+---------+-
                       4.20      4.80      5.40      6.00

Cleaning
Schedule     Mean  --------+---------+---------+---------+-
1         3.73333  (--------*---------)
2         6.11667                     (---------*---------)            0.055
3         4.36667       (--------*---------)
                   --------+---------+---------+---------+-
                         3.6       4.8       6.0       7.2
```

Table 14 shows that while none of the results are significant at the 95% confidence level, ($p$-value $< 0.05$), tanks which are cleaned 3 or more times per year have less *E. coli* than tanks that are cleaned less frequently ($p = 0.102$). Similarly, turbidity is lower in tanks that are reported to be cleaned 3 or more times per year compared to tanks that are reported to be cleaned 1 – 2 times per year ($p = 0.055$), although the difference is less for tanks that are cleaned less than once per year. Tank age appears to have very little effect on water quality for all parameters. Since chlorine levels are near the detection limits (0.02 mg/L) of the equipment, it is difficult to make any specific conclusions about the effects of tank age and cleaning schedule on chlorine concentrations based on the results.

Based on the results from Table 14, one-way ANOVAs were performed to reveal differences between *E. coli* and total coliform counts for various cleaning schedules. The results are shown in Table 15. These results show that there is a significant difference between *E. coli* and total coliform counts in storage tanks that are cleaned three or more times per year compared to storage tanks that are cleaned less than once per year ($p$ = 0.006 and 0.033, respectively). The results also indicate at difference exists between storage tanks that are cleaned three or more times per year and storage tanks that are cleaned once or twice per year, however the difference is not significant at the 95% confidence interval ($p = 0.151$).

### Table 15: Results for one-way ANOVAs comparing *E. coli* and total coliform counts for various cleaning schedules.

```
                                   E. coli                                   p-value

Cleaning
Schedule    N    Mean   StDev   ---------+---------+---------+---------+
≥ 3        11    9.70   15.39   (------------*------------)
1-2        15   40.33   66.79                 (----------*----------)       0.151
                                ---------+---------+---------+---------+
                                         0        25        50        75

Cleaning
Schedule    N    Mean   StDev   +---------+---------+---------+---------
≥ 3        11    9.70   15.39   (-----*-----)
< 1         3   42.17   12.49                  (----------*-----------)     .006
                                +---------+---------+---------+---------
                                0        16        32        48

                              Total Coliforms                                p-value
Cleaning
Schedule    N    Mean   StDev   -------+---------+---------+---------+--
≥ 3        11    29.0    40.3   (-------*------)
> 1         3   882.4  1331.3              (-------------*------------)     0.033
                                -------+---------+---------+---------+--
                                       0       500      1000      1500
```

A series of randomized block ANOVAs were used to analyze the data for differences in water quality while taking into account differences in tank ages and cleaning schedules. The data were divided into the following 6 groups (referred to as “treatments” in following text) and analyzed by tank type (polyethylene, fiberglass and fiber cement):

1. Tanks age 0 – 3 years; cleaned >3 times per year
2. Tanks age >4 years; cleaned > 3 times per year
3. Tanks age 0 – 3 years; cleaned 1 – 2 times per year
4. Tanks age >4 years; cleaned 1 – 2 times per year
5. Tanks age 0 – 3 years; cleaned less than once per year
6. Tanks age 0 – 4 years; cleaned less than once per year

Due to sampling limitations, no fiber cement tanks were sampled for treatment 3 and values were interpolated based on values for group 2 and 4. Table 16 provides the number of samples available for each treatment.

**Table 16: Sample sizes for treatments for randomized block ANOVA design.**

| | Polyethylene | Fiberglass | Fiber cement |
|---|---|---|---|
| Cleaning 1<br>Age: 0-3 | 3 | 1 | 1 |
| Cleaning 1<br>Age: >4 | 1 | 1 | 3 |
| Cleaning 2<br>Age: 0-3 | 4 | 1 | 0 |
| Cleaning 2<br>Age: >4 | 5 | 3 | 2 |
| Cleaning 3<br>Age: 0-3 | 2 | 1 | 1 |
| Cleaning 3<br>Age: >4 | 1 | 3 | 1 |

Table 17 shows the results the randomized block ANOVAs; tank types are analyzed to see if tank age or cleaning schedule affects various water quality parameters. Although none of the results are statistically significant ($p < 0.05$), the results in Table 17 do provide some insight as to what relationships may exist and where further research should focus.

**Table 17: Results for randomized block ANOVA of the effects of tank age and cleaning schedule on various water parameters within different tank types in Tiquipaya Noreste (Bolivia).**

```
                             E. coli                                  p-value
Tank
Type              Mean  ---------+---------+---------+---------+
Polyethylene   40.8333                   (--------*--------)
Fiberglass     20.1667     (--------*---------)                        0.082
Fiber cement   14.6667  (--------*--------)
                        ---------+---------+---------+---------+
                                15        30        45        60

Treatment     Mean  -------+---------+---------+---------+--
1           1.3333  (-------*------)
2          15.0000       (-------*-------)
3          38.6667                 (------*-------)
4          27.6667            (-------*-------)                        0.127
5          22.0000          (-------*-------)
6          46.6667                    (-------*-------)
                    -------+---------+---------+---------+--
                           0        25        50        75

                         Total Coliforms                              p-value
Tank
Type              Mean  --------+---------+---------+---------+-
Polyethylene   204.000   (-------------*------------)
Fiberglass     159.000  (------------*-------------)                   0.647
Fiber cement   441.167           (-------------*------------)
                        --------+---------+---------+---------+-
                                0       300       600       900

Treatment     Mean     +---------+---------+---------+---------
1             5.00     (---------*---------)
2            67.00       (--------*---------)
3           287.67          (---------*--------)
4           118.00       (---------*---------)                         0.300
5           116.00       (---------*---------)
6          1014.67                      (---------*---------)
                       +---------+---------+---------+---------
                    -600         0       600      1200

                          Free Chlorine                               p-value
Tank
Type           Mean  -----+---------+---------+---------+----
Polyethylene   0.0116667           (----------*---------)
Fiberglass     0.0166667                 (----------*---------)        0.230
Fiber cement   0.0045833  (----------*---------)
                     -----+---------+---------+---------+----
                        0.0000    0.0080    0.0160    0.0240
```

**Table 17 Continued**

```
Treatment       Mean  -------+---------+---------+---------+--
1          0.0233333                    (--------*---------)
2          0.0083333       (---------*---------)
3          0.0041667    (--------*---------)
4          0.0133333           (---------*---------)
5          0.0133333           (---------*---------)
6          0.0033333   (---------*---------)
                      -------+---------+---------+---------+--
                           0.000     0.012     0.024     0.036
```

0.346

Turbidity

p-value

```
Tank
Type           Mean    +---------+---------+---------+---------
Polyethylene 4.48333       (-----------*-----------)
Fiberglass   5.56667                  (-----------*-----------)
Fiber cement 4.16667    (-----------*-----------)
                       +---------+---------+---------+---------
                     3.0       4.0       5.0       6.0
```

0.331

```
Treatment     Mean    +---------+---------+---------+---------
1          3.80000     (-------*-------)
2          3.66667    (-------*--------)
3          6.70000                   (-------*--------)
4          5.53333             (--------*-------)
5          3.96667     (--------*-------)
6          4.76667         (--------*-------)
                      +---------+---------+---------+---------
                    2.0       4.0       6.0       8.0
```

0.238

The results show that at the 90% confidence level polyethylene tanks have higher *E. coli* values than fiberglass and fiber cement tanks (*p* = 0.082). Treatment type also appears to have an effect on *E. coli* growth within the tank, although not statistically significant, (*p* = 0.127) showing that tanks aged 0-3 years that are cleaned 3 or more times a year (Treatment 1) have less *E. coli* compared to tanks that are 4 years old or older and cleaned less frequently.

Based on the results from Table 17, one-way ANOVAs were performed to show more specifically the differences in *E. coli* counts between storage tank types and treatments. Table 18 suggests that difference for *E. coli* counts between storage tank types exist, however the differences are not statistically significant at the 95% confidence interval. The results shown in Table 18 also indicate that treatments do effect *E. coli* counts, although from these results it is not clear how great of an affect cleaning schedule or tank age have individually.

**Table 18: One-way ANOVAs for *E. coli* comparing storage tank types and treatments.**

```
                                E. coli                             p-value
Tank
Type                Mean  --+---------+---------+---------+-------
Polyethylene     40.8333                  (-----------*----------)    0.098
Fiber Cement     14.6667  (----------*-----------)
                          --+---------+---------+---------+-------
                            0        16        32        48

Tank
Type                Mean  ---------+---------+---------+---------+
Polyethylene     40.8333                (-----------*-----------)     0.170
Fiberglass       20.1667  (-----------*------------)
                          ---------+---------+---------+---------+
                                  15        30        45        60

Treatment   Mean  StDev  ---------+---------+---------+---------+
1            1.33   2.31  (--------*---------)
6           46.67  24.58                 (---------*--------)          0.034
                         ---------+---------+---------+---------+
                                  0        30        60        90
```

### Water Quality – In-Depth Analysis

In-depth analysis of water quality included measuring iron, sulfate and nitrate levels in 11 tanks, 4 cisterns and 2 locations within the distribution system. These chemical parameters did not vary significantly between the tank types (see Figure 17). Iron is however present in the distribution system in higher concentrations than what was found in the cisterns (*p* = 0.042) and in tanks (*p* = 0.115).

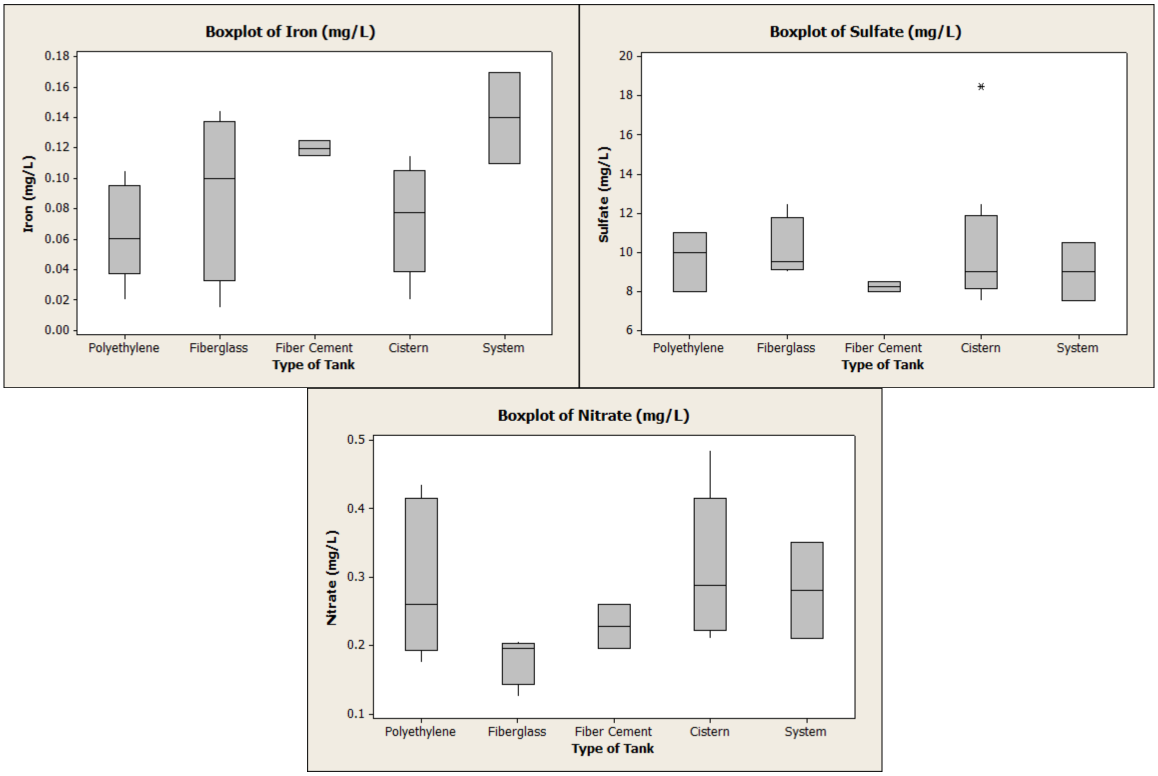

**Figure 17: Results of in-depth analysis of iron, sulfate and nitrate levels in different storage tank types as well as within the distribution system in Tiquipaya Noreste (Bolivia).**

### Microbial Results

*E. coli* results from samples taken from various tank types as well as the distribution system are presented in Figure 18. All samples analyzed from the distribution system meet Bolivian standards (0 CFU/mL) except for two samples. One of these samples was taken from the point furthest from the treatment plant and the other was after water service had been cut off[2] and most likely does not accurately represent true water quality at this location. All samples obtained from household storage tanks (and all tank types)

---

[2] Service was cut-off in a section of the distribution system during sampling one morning. This disconnection of service is not believed to have affected results because samples were taken from storage tanks and cisterns in other parts of the distribution system. Also, storage tanks and cisterns were at or near storage capacity at time of sampling indicating that the cut in service had not significantly impacted water supplies.

had measureable *E. coli* values above Bolivian standards (0 CFU/mL). Round Fiberglass storage tanks appear to have the most samples above Bolivian standards with over 70% of samples failing to meet water quality standards for *E. coli* (Table 19)

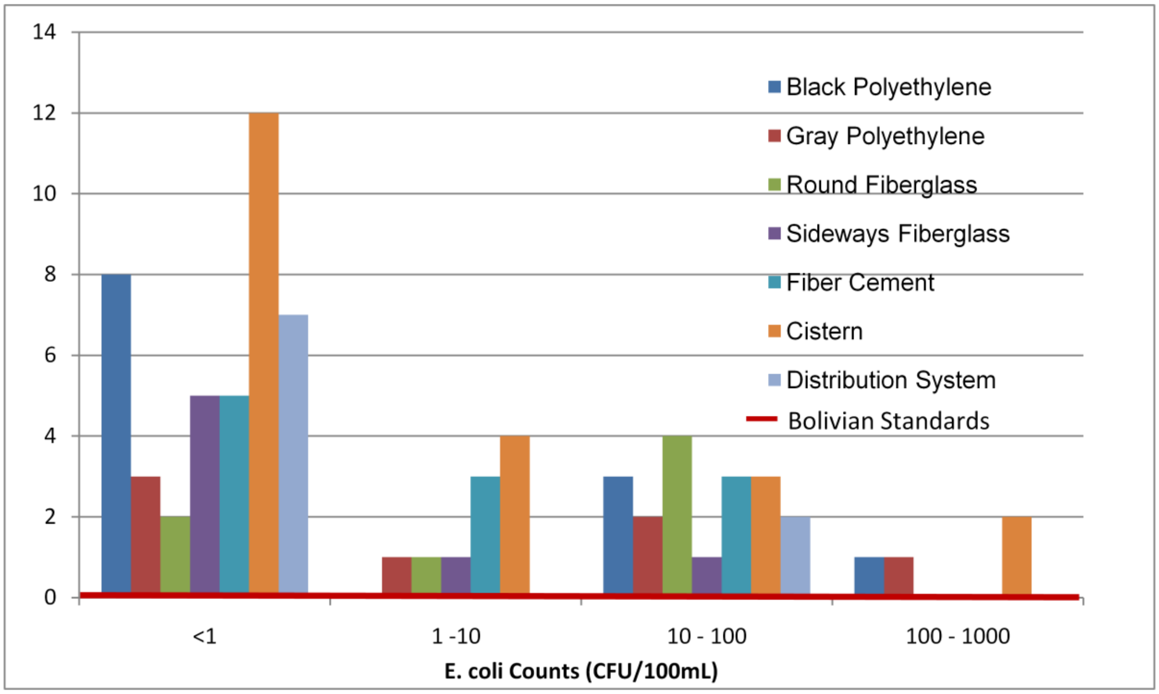

**Figure 18: Histogram of *E. coli* counts. Includes initial and in-depth water analysis from elevated storage tanks, cisterns and the water distribution system in Tiquipaya Noreste (Bolivia).**

**Table 19: Percent of samples that exceed the Bolivian water quality standards for *E. coli* (0.0 CFU/mL).**

| **Tank Type** | | | | | | Distribution System (n = 7) |
|---|---|---|---|---|---|---|
| Black Poly. (n = 10) | Gray Poly. (n = 5) | Round Fiberglass (n = 5) | Sideways Fiberglass (n = 5) | Fiber cement (n = 9) | Cistern (n = 13) | |
| 33.3% | 57.1% | 71.4% | 28.6% | 54.5% | 42.9% | 22.2% |

In addition to testing for total coliforms and *E. coli*, a subset of samples was also tested for iron related bacteria, heterotrophic aerobic bacteria and slime forming bacteria (Table 20). All samples taken from the distribution system, cisterns and storage tanks were positive for iron related bacteria suggesting widespread prevalence of these bacteria in the distribution system. All cisterns tested positive for all three types of bacteria. A sample taken of effluent water from the treatment plant tested negative for all three types of bacteria.

**Table 20: BART test results for three different microbial indicators reported as percent of positive tests recorded for each tank type.**

| | Iron Related Bacteria | Heterotrophic Aerobic Bacteria | Slime Forming Bacteria |
|---|---|---|---|
| **Polyethylene (n = 5)** | 100% | 40% | 80% |
| **Fiberglass (n = 4)** | 100% | 75% | 75% |
| **Fiber cement (n = 2)** | 100% | 0% | 100% |
| **Cistern (n = 4)** | 100% | 100% | 100% |
| **System (n = 2)** | 100% | 0% | 50% |
| **Treatment Plant (n = 1)** | 0% | 0% | 0% |

Figure 19 and Figure 20 show that there is no observable spatial correlation found for the iron related bacteria, heterotrophic aerobic or slime forming bacteria ($p$ = 0.245, 0.847, and 0.934 respectively). This indicates that while the distribution system may be responsible for transporting the bacteria to the household, the cisterns and elevated storage tanks are providing habitat for bacteria to growth. This idea is supported by the lower prevalence of heterotrophic aerobic and slime forming bacteria found in the distribution system.

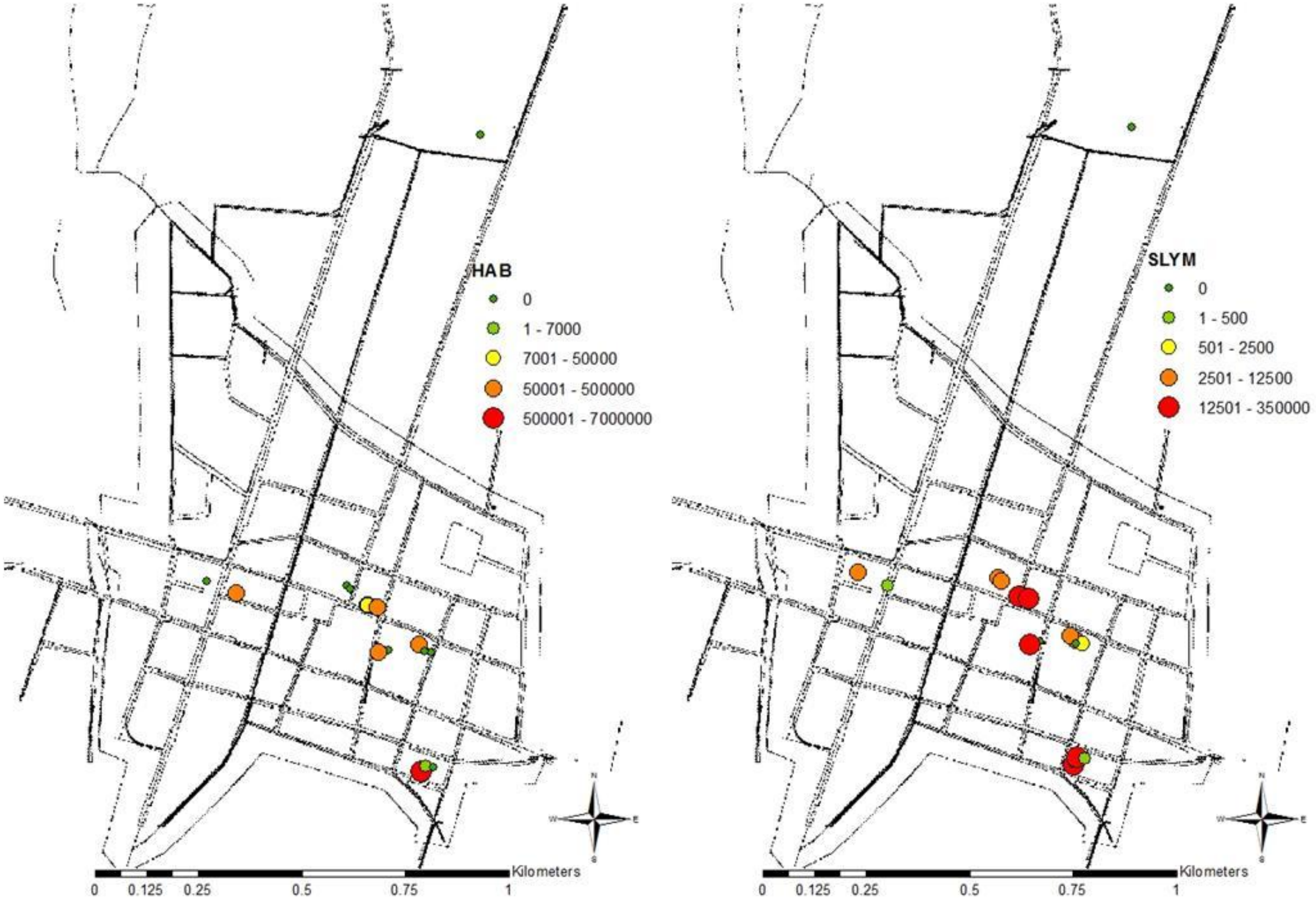

**Figure 19: Levels of heterotrophic aerobic and slime forming bacteria measured in distribution system and household cisterns and water storage tanks in Tiquipaya Noreste (Bolivia).**

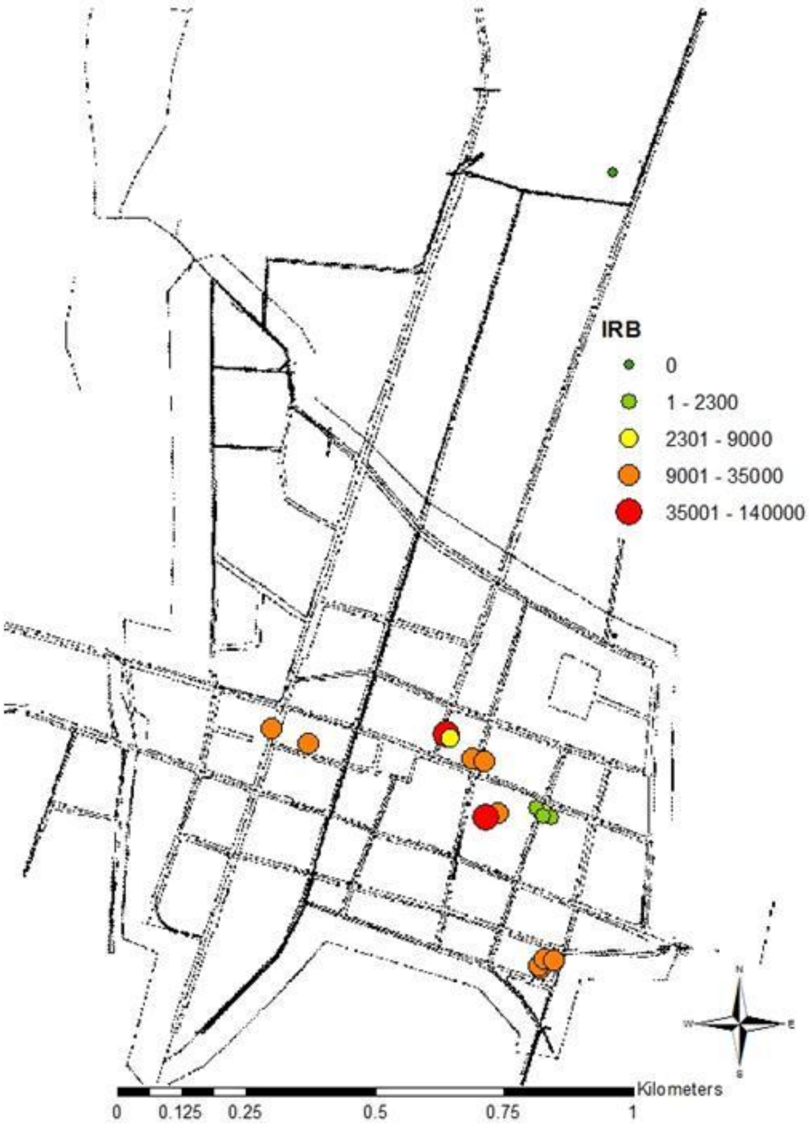

**Figure 20: Levels of iron related bacteria measured in distribution system and household cisterns and water storage tanks in Tiquipaya Noreste (Bolivia).**

**Temperature Study**

Figure 21 and Figure 22 show the results from the temperature study. Temperatures were greatest and had the highest variability in the black polyethylene tank; temperatures were lowest and had the lowest variability in the fiberglass tank.

Temperatures in all three tanks were greater than 15 °C, indicating that significant bacteria growth is possible (LeChevallier et al., 1996).

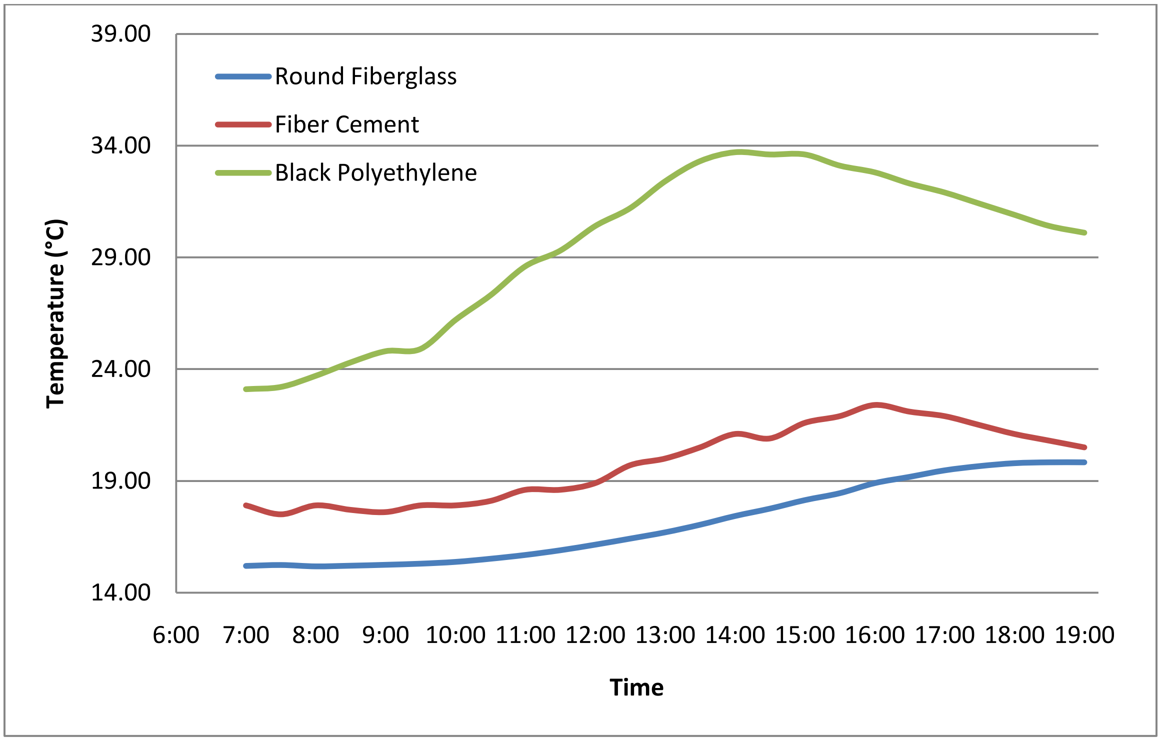

**Figure 21: Water temperature within three types of elevated storage tanks in Tiquipaya Noreste (Bolivia).**

Figure 21 shows that water temperature in the black polyethylene tank peaks earlier than the other two tanks due to shading of the black polyethylene tank around 14:30 while the other 2 tanks remained in direct sunlight until sunset.

**Table 21: Maximum and minimum water temperatures (°C) recorded in elevated storage tanks in Tiquipaya Noreste (Bolivia).**

| | Fiberglass (n = 1) | Fiber cement (n = 1) | Black Polyethylene (n = 1) |
|---|---|---|---|
| **Maximum Water Temperature (°C)** | 19.83 | 22.40 | 33.70 |
| **Minimum Water Temperature (°C)** | 15.18 | 17.50 | 23.10 |
| **Difference (°C) Between Max and Min Temperatures** | 4.65 | 4.90 | 10.60 |

Temperatures in the black polyethylene tank were greater than the ambient air temperature during the entire measurement period, shown by the positive values in Figure 22. Both the fiberglass and fiber cement tank had temperatures greater than the ambient air temperature in the morning, but had cooler water temperatures during the days as shown by the negative values in Figure 22.

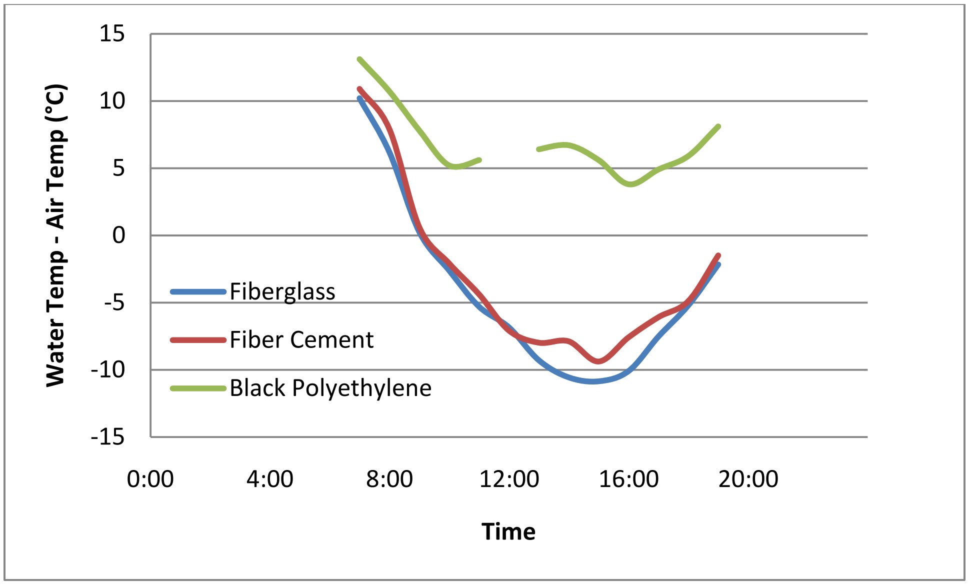

**Figure 22: Difference between ambient air temperature and stored water temperature in storage tanks in Tiquipaya Noreste (Bolivia).**

One implication of the warm water temperatures found in all elevated storage tanks, but especially in the black polyethylene tank is that there is the potential for increased bacterial growth. The climate in Cochabamba (11 km east of Tiquipaya) is moderate with average monthly temperatures between 13°C and 19°C (climate-zone.com). The average temperature for August, when the temperature study took place, is 16°C. This implies that the results of this temperature study are representative of year-round water temperatures found inside the storage tanks.

### Effect of Residence Time

Water samples analyzed from treatment plant, locations within the distribution system, cistern and storage tanks show a loss of chlorine residual (almost immediately), an increase in total coliforms and *E. coli*, and an increase in temperature as the water travels from the treatment plant to the household cisterns and storage tanks.

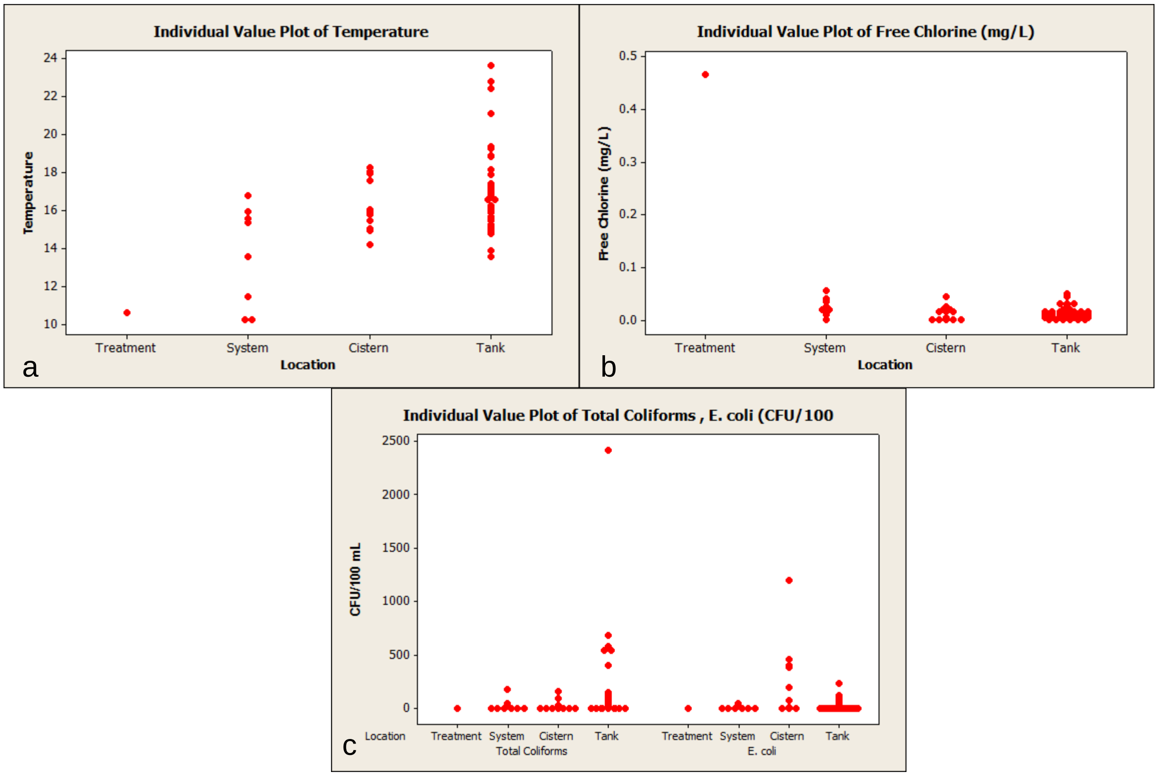

**Figure 23: Water quality changes as water travels from the treatment plant through the system to household cisterns and storage tanks. a) Temperature (°C); b) Free chlorine (mg/L $Cl_2$); c) Total coliforms and *E. coli* (CFU/100 mL).**

As shown by p-values less than 0.05 in Table 22, significant differences in E. coli counts can be found between water from the distribution system and cisterns and between the distribution system and storage tanks. For total coliforms, significant differences can be found between cisterns and storage tanks and between the distribution system and storage tanks.

**Table 22: P-values for two-tail independent t-tests comparing *E. coli* and total coliform counts within the distribution system, cisterns and elevated storage tanks in Tiquipaya Noreste (Bolivia).**

| Pair t-test | *E. coli* | Total Coliforms |
|---|---|---|
| System vs. Cistern | 0.026 | 0.548 |
| Cistern vs. Tank | 0.964 | 0.020 |
| System vs. Tank | 0.049 | 0.024 |

### Treatment Plant and Wells

Analysis of water samples from the Tiquipaya Noreste water treatment plant showed that treatment was sufficient to inactivate bacteria in the drinking water supply leaving the treatment plant. Free chlorine was measured at 0.47 mg/L $Cl_2$ in the effluent water from the treatment plant. Total coliforms were detected in Well 2 (534 CFU/100 mL) but were not detected in Well 1. Neither *E. coli* nor total coliforms were detected at locations in the distribution system near the respective wells. Well water is not chlorinated and low free chlorine levels were detected in the water at locations in the distribution system near the wells (0.04 mg/L $Cl_2$ for Well 1 and 0.05 mg/L $Cl_2$ for Well 2).

## DISCUSSION

This study found evidence of microbiological contamination of the potable water supply in Tiquipaya Noreste (Bolivia) that could potentially have negative health consequences for users. Based on previous studies potential sources of the contamination include: 1) the addition of untreated well water, 2) leakages within the distribution system, 3) inadequate treatment of source water, 4) long residence times, 5) elevated water temperature and 6) low chlorine residual. The addition of untreated well water creates an additional chlorine demand thereby lowering the amount of chlorine in the water that would otherwise provide protection against bacterial re-growth. The existence of leakages in the distribution system were not detected during this study, however, extensive testing of the system was not done. Leakages could potentially allow contaminants to enter the distribution system. Water leaving the Tiquipaya Noreste treatment facility meets Bolivian water quality standards, therefore inadequate treatment is not believed to be responsible for the increased bacterial growth found between water in the distribution system and water in household cisterns and elevated storage tanks ($p = 0.026$ and 0.049 for *E. coli*, respectively).

Multiple studies have shown that increases in storage time lead to decreases in water quality (Evison and Sunna, 2001; Roberts et al., 2001; Agard et al., 2002; Tokajian and Hashwa, 2003). While this study did not directly measure residence time, by storing water at the household level residents are increasing water residence time prior to use. This study also found that water temperature increases as the water travels from the treatment plant through the distribution system to the household cisterns and finally to the elevated storage tanks. This result is supported by studies that suggest that in countries where access to water is unreliable the problem of microbial re-growth is intensified by long water storage times (Evison and Sunna, 2001). This study also found that the water temperature inside the elevated storage tanks is above the threshold level of 15°C cited by other studies as causing increased microbial growth (Fransolet et al., 1985; Donlan and Pipes, 1988; Smith et al., 1989; Donlan et al., 1994 – From LeChevallier et al., 1996). Low to no chlorine residual detected in the water from this study may be allowing microbes to overcome the initial shock of chlorination and to grow. This observed increase in microbial growth also corresponds to an increase in water temperature as the water moves from the source to household water storage tanks. Long retention times, low or no residual chlorine and high water temperatures within the household storage tank are found to increase the likelihood of microbial growth (Schoenen, 1990; Schoenen and Scholer, 1985; LeChevallier et al., 1981; Schoenan and Dott, 1977; Grabow et al., 1975).

Previous studies have shown that storage tank materials do not contribute significantly to differences in microbial water quality of stored water (Evison and Sunna, 2001; Tokajian and Haswa, 2003). This study found, however that there may be a difference in microbial water quality between polyethylene storage tanks and fiberglass and fiber cement tanks (*p* = 0.082). However, physical and chemical water parameters were not found to differ significantly between the storage tank types.

One possible cause for the difference in microbial water quality observed in different storage tank types may be water temperature inside the storage tanks. A longer duration study that measured water temperature in three representative storage tank types found that water temperatures inside black polyethylene tanks reach upwards of 34°C as opposed to 20°C and 23°C in fiberglass and fiber cement tanks respectively. Increased microbial growth has previously been documented in water with temperatures exceeding 15°C (Donlan and Pipes, 1988; Fransolet et al., 1989; Smith et al., 1989; Donlan et al., 1994 – From LeChevallier et al., 1996). The temperatures found in three different storage tank types indicate the potential for increased bacterial growth which is a health concern because even low levels of bacterial growth have the potential to cause illness in users (WHO, 2006).

This study also showed that water temperature and total coliforms and E. coli counts increased as the water travels from the treatment plant through the distribution system to household cisterns and elevated storage tanks. This result agrees with other studies that have shown increased microbial growth as residence time increases (Evison and Sunna, 2001; Roberts et al., 2001; Agard et al., 2002; Tokajian and Hashwa, 2003).

Storage tank cleaning frequency also appears to impact the microbial water quality of the stored water. Although not statistically significant, storage tanks that are reported to be cleaned 3 or more times per year have less *E. coli* than tanks cleaned less frequently ($p$ = 0.102). Additionally, no correlation between storage tank age and *E. coli* or total coliform counts was found indicating that storage tank age does not significantly impact water quality. This study encountered storage tanks that were over 10 years old, but were cleaned monthly and as a result no coliforms were detected in the stored water.

According to a report released in 1996, 72.4% of water distribution systems in Bolivia practice disinfection (Espana et al., 1996). However, this study has found that the chlorine residual present in water that reaches the household to be at or below the analytical detection level of 0.02 mg/L, indicating that although chlorine is added to the water supply it is not added in sufficient quantities to provide users with protection against pathogens. Since sampling is usually done immediately after treatment, the report may be misleading about the safety of potable water supplies in Bolivia.

One study found significant growth of total coliforms in waters where the free chlorine concentrations were less than 0.2 mg/L (LeChevallier et al., 1996). In the Tiquipaya Noreste distribution system, free chlorine levels that are one-tenth of that are commonly found in the system, cisterns and storage tanks. A lack of free chlorine in the supply water may also be an indication that contaminants are entering the system after treatment. For example, a study by Agard et al., (2002) found post-treatment contamination to be the cause of microbial contamination of the drinking water supply. The addition of untreated well water being blended into the Tiquipaya Noreste system may also be causing the decrease in chlorine residual into the system due to reactions of the chlorine with the additional microbes and other compounds introduced into the system. Studies have shown that the addition of untreated water into a distribution system reduces chlorine residuals and increases the likelihood of illness in consumers (Ford, 1999; Craun and Calderon, 2001).

**Community Perceptions**

During multiple instances during this study's sample collection, the investigators were told by residents that the water provided by the system was contaminated by the time it reached their homes. While this may be the case during different parts of the year, the study's investigators did not find conclusive evidence to confirm these claims. Contaminants may be entering the distribution system or the cisterns and storage tanks may be seeding the influent water, either way it appears that the cisterns and storage tanks are providing habitat for bacterial growth. Many community members also did not appear to understand the connection between not cleaning their storage tank and reduced water quality.

## CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The objectives for this study was to look at physical, chemical, and microbial water quality inside household storage tanks commonly found in the developing world and to document water quality changes as the water travels from the source to the user. Few studies have looked at microbial water quality in household elevated storage tanks in laboratory settings but this author was unable to find field studies concerning physical, chemical and microbial water quality in elevated storage tanks. Studies done in the US and other developed countries have looked at physical, chemical and microbial water quality but few studies measuring more than microbial water quality have been done in developing countries.

The first hypothesis that this study investigates is that tank material impacts water quality of water inside household storage tanks. This study found that the *E. coli* was present in higher concentrations inside polyethylene storage tanks compared to fiberglass and fiber cement storage tanks ($p = 0.082$). Physical and chemical water quality parameters were not found to vary significantly between storage tank types.

The second hypothesis is that the water temperature inside storage tanks affects water quality. This study found that temperature was highest in black polyethylene storage tanks and that temperatures in each of the storage tank types investigated reached levels previously shown to induce increased bacterial growth and that polyethylene tanks had higher *E. coli* counts ($p = 0.082$).

The third hypothesis is that storage tank use factors also affect water quality. This study found that storage tanks cleaned 3 or more times per year had lower *E. coli* counts and turbidity than storage tanks cleaned less frequently ($p$ = 0.102 and 0.055, respectively). However, tank age was not found to have a significant difference in water quality indicating that maintenance (i.e. cleaning) is more important to water quality.

Additionally, this study provided evidence that as the water travels from the treatment plant through the distribution system to elevated storage tanks that water *E. coli* and total coliform counts increase ($p$ = 0.049 and 0.024, respectively) as does temperature.

Currently, guidelines for water quality are for source water/water leaving treatment facilities and not at the point of consumption. Evidence presented in this study as well as by other researchers has shown that there is potential for contamination of water supplies during transport from the source/treatment to occur in the distribution system and during storage and that the potential for illness exists. Generally speaking, the risk for developing waterborne illness is relatively unknown since the water quality of consumed water is often unknown.

Based on the results of this study, it is recommended that homeowners discontinue their use of cisterns and storage tanks. Water service is provided 24 hours a day every day of the week thereby negating the necessity for storage in this instance. For communities where service is intermittent and water storage is necessary, it is recommended that elevated storage tank owners clean their tanks 3 or more times per year. This study's results also suggest that the age of the elevated storage tank is not as important as maintenance (cleaning) on water quality. Also, when cost is not an issue fiberglass and fiber cement storage tanks are preferred over polyethylene storage tanks because of lower water temperature in the fiberglass and fiber cement tanks. In instances where polyethylene storage tanks are used, they should be sited in shady areas to mitigate increases in water temperature. Additionally, it is recommended that the well water is chlorinated in the Tiquipaya Noreste distribution system to increase chlorine residual in order to provide more protection of users against waterborne diseases.

Further research into the effects of tank material on water quality could look at water temperatures inside the elevated storage tanks to find more conclusive evidence linking increased microbial growth to temperature. This study provides a snapshot of the water quality inside elevated storage tanks, but more research should be done to investigate seasonal effects.

More research into the chlorine residual levels in water distribution systems that use chlorine for disinfection since this study found that chlorine levels were not sufficient at preventing microbial growth. Although at least 72% of water distribution systems in Bolivia chlorinate their potable water supplies, chlorine residuals may be too low to prevent microbial growth resulting which could potentially lead to illness in users.

Results from the bacteria study show that numerous bacteria are present in the water in the distribution system, cisterns and elevated storage tanks. Further research could attempt to identify more specifically what bacterial species are present and evaluate the potential health concerns.

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# APPENDICES

## Appendix A: IRB Approval Letter

USF
UNIVERSITY OF SOUTH FLORIDA

DIVISION OF RESEARCH INTEGRITY AND COMPLIANCE
Institutional Review Boards, FWA No. 00001669
12901 Bruce B. Downs Blvd.. MDC035 • Tampa, FL 33612-4799
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June 10, 2010

Cynthia Schafer
Civil and Environmental Engineering

RE: **Expedited Approval** for Initial Review
IRB#: Pro00001177
Title: Impact of Tank Material and Residence Time on Water Quality in Household Water Storage Systems in Cochabamba, Bolivia

Dear Cynthia Schafer:

On 6/10/2010 the Institutional Review Board (IRB) reviewed and **APPROVED** the above referenced protocol**.** Please note that your approval for this study will expire on 6-10-2011.

Approved Items:
Protocol Document(s):

| | |
|---|---|
| Study Protocol.docx | 0.01 |

Consent/Assent Document(s):

Waiver of Informed Consent Documentation for the Verbal English and Spanish Information Sheet/Consents

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

**Appendix A Continued**

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.

Please note, the informed consent/assent documents are valid during the period indicated by the official, IRB-Approval stamp located on the form. Valid consent must be documented on a copy of the most recently IRB-approved consent form.

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 813-974-9343.

Sincerely,

Krista Kutash, PhD, Chairperson
USF Institutional Review Board

Cc: Various Menzel, CCRP
USF IRB Professional Staff

## Appendix B: Study Information Sheet for Survey Participants: Cochabamba, Bolivia

**Interviewer:________________ Date:______________Survey #: ______________**

You are being asked to participate in a research study described below:

**STUDY TITLE:** Impact of Tank Material and Residence Time on Water Quality in Household Water Storage Systems in Cochabamba, Bolivia

**PERSON IN CHARGE:** Dr. James Mihelcic **PHONE NUMBER:** 1-813-974-9896

**EMAIL:** jm41@eng.usf.edu

**LOCAL CONTACT:** Nathan Reents **PHONE NUMBER:** 591-722-38444

**EMAIL:** nreents@gmail.com

**PURPOSE:** The purpose of this research is to understand how water quality within household storage tanks is affected by tank type and individual practices relating to storage tank usage.

**RISKS, BENEFITS, AND ALTERNATIVES:** There are no known risks or benefits to participation in this study. You have the alternative to choose not to participate. Your participation is voluntary. You may withdraw at any time without penalty.

**CONFIDENTIALITY:** We will not collect any information about you that could be used to identify you. The information we will collect will be combined with information from other sources to meet the research objectives. Results of the study may be published, but will not contain any personally identifiable information about you. All information that you provide will be stored in a secure location in which only the primary investigator has access to.

**CONSENT:** Your consent to participate in this study was obtained verbally. If you decide at any time that you want your information to be excluded from this research study, please contact any of the people listed above and provide your survey number (in the top right corner of the information sheet) so that your information can be removed from the study.

**QUESTIONS OR COMPLAINTS:**

If you have any concerns, do not hesitate to call the numbers listed above.

If you have questions about your rights, general questions, complaints, or issues as a person taking part in this study, call the Division of Research Integrity and Compliance of the University of South Florida at 1-813-974-9343.

## Appendix C: Household Survey Questionnaire

Date:

ID:

Interviewer:

Interviewee: Male Female

## Impact of Tank Material and Residence Time on Water Quality in Household Water Storage Systems in Cochabamba, Bolivia

### Community Survey

### Demographic Information

1. What is your age?
    a. 18-35
    b. 36-50
    c. 50-65
    d. Over 65

2. How many persons live in your household? __________

3. How many are adults aged 18 and above? ____________

4. How many children aged 5 – 17? _______________

5. How many children under 5 years? ____________

**Appendix C Continued**

6. What is the occupation of male head of household? ___________

7. What is the occupation of female head of household? ___________

## Water Storage Tank Properties and Access to Water

8. What material is your tank made of?
    a. Plastic
    b. Metal (aluminum, tin)
    c. Fiber fiber cement
    d. Ceramic
    e. fiberglass
    f. Other __________________________

9. What is the age of the tank?
    a. 0-3 years
    b. 4-10 years
    c. 11-15 years
    d. 16-20 years
    e. Older than 20 years

## Appendix C Continued

10. How many days a week do you have access to piped running water?

    a. 1 day per week
    b. 2 days per week
    c. 3-4 days per week
    d. 5-6 days per week
    e. everyday

11. When you have access to piped running water, how long do you have access?

    a. All day
    b. 12 hours a day
    c. 6-11 hours a day
    d. 2-5 hours a day
    e. 1 hour a day

12. How often is your tank filled?

    a. Every day
    b. Every 2 days
    c. Every 3-5 days
    d. Every 6-7 days
    e. Less than once a week

**Appendix C Continued**

13. How is the tank filled?

    a. Pumped by a pipe network directly connected to municipal system

        i. (Do you share a pump? Yes _____ No _____)

    b. By municipal system using gravity

    c. Using a hose connected to an outside tap (Do you share a tap? Yes ______ No ______)

    d. Other ___________________________________

## Household Water Practices & Use

14. Is the water stored in the tank used for drinking water?

    a. Yes

    b. No

15. If no, what is the source for drinking water? __________________________

16. What is the water from the storage tank used for? (circle all that apply)

    a. Drinking

    b. Washing food/cooking

    c. Hand washing

    d. Bathing

    e. Brushing teeth

    f. Clothes washing

    g. Other _____________

**Appendix C Continued**

17. What methods do you use to treat your water before use?

    a. Storage tank disinfection (What kind of disinfection?

       ____________________________)

    b. Point of use disinfection (What kind of disinfection?

       _____________________________)

    c. Boiling

    d. Filter (what type? ____________)

    e. Other ___________

    f. None

18. Is water treated for all uses or only for drinking?

    a. Yes

    b. No

    c. Treated for drinking and _________________

19. Does someone disinfect the water in the storage tank? (If answer is NO, skip to Question 23)

    a. Yes

    b. No

**Appendix C Continued**

20. If yes to disinfection, how frequently is the water disinfected?

    a. Daily
    b. Weekly
    c. Monthly
    d. Every 6 months
    e. Annually
    f. Rarely
    g. Other _____________

21. If yes to disinfection, when was the last time of disinfection?

    a. Within the last two weeks
    b. Within the last month
    c. Within the last six months
    d. Within the last year

22. Who is the main person responsible for disinfecting the water in the storage tank?

    a. Male head of household
    b. Female head of household
    c. Child
    d. Other __________

**Appendix C Continued**

23. In general, how frequently do you clean your storage tank? (If answer is NEVER, skip to Question 27)
    a. Never
    b. Daily
    c. Weekly
    d. Monthly
    e. Every 6 months
    f. Annually
    g. Other ____________

24. What do you use to clean your storage tank? ________________________

25. When was the last time the tank was cleaned?
    a. Within the last two weeks
    b. Within the last month
    c. Within the last six months
    d. Within the last year
    e. Other _____________

26. Who is the main person responsible for cleaning the water storage tank?
    a. Male head of household
    b. Female head of household
    c. Child
    d. Other__________________________

**Appendix C Continued**

## Health Effects

27. In the last 2 weeks have you or someone in the household experienced an illness resulting from drinking the water in your storage tank?

    a. Yes

    b. No

28. If yes to the illness, who was ill?

    a. Male head of household

    b. Female head of household

    c. Child (Under 5: yes ____  no ____)

    d. Other _________________________

29. If yes to the illness, what symptoms were present (circle all that apply)?

    a. Diarrhea b. Stomach pains/cramps c. Fever

    d. Nausea e. Skin rash/infection f. Loss of appetite

    g. Other________________________

**Thank you for your time.  The survey is now complete.**

## Appendix D: Household Survey Questionnaire Responses

**Table D1: Demographic information.**

| Gender of Respondents | |
|---|---|
| **Female** | **Male** |
| 14 | 21 |

| # of People in Household | | |
|---|---|---|
| **1 – 5** | **6 – 10** | **> 10** |
| 13 | 15 | 6 |

| Ages of People in Households | | |
|---|---|---|
| **> 18 Years** | **5 – 17 years** | **Under 5** |
| 194 | 42 | 23 |

**Table D2: Storage tank properties.**

| Tank Material | | |
|---|---|---|
| **Polyethylene** | **Fiberglass** | **Fiber Cement** |
| 16 | 11 | 9 |

| Tank Age | | | | |
|---|---|---|---|---|
| **0 - 3 Years** | **4 -10 Years** | **11 - 15 years** | **16 - 20 Years** | **Unknown** |
| 13 | 19 | 3 | 1 | 1 |

| # of Days per Week with Access to Water | | | |
|---|---|---|---|
| **< 2 Days** | **3 - 4 Days** | **5 -6 Days** | **7 Days** |
| 0 | 0 | 1 | 35 |

| # of Hours per Day with Access to Water | | | |
|---|---|---|---|
| **< 6 Hours** | **6 -11 Hours** | **12 - 23 Hours** | **24 Hours** |
| 0 | 1 | 0 | 35 |

| Method Used to Fill Tank | |
|---|---|
| **Gravity** | **Pump** |
| 9 | 27 |

**Appendix D Continued**

**Table D3: Uses and practices of storage tank.**

| Water from Tank is Used for Drinking | | |
|---|---|---|
| Yes | No | NA |
| 28 | 5 | 2 |

| Other Sources of Drinking Water | | |
|---|---|---|
| Bottled Water | SODIS | Directly from System |
| 11 | 1 | 2 |

| Other Uses of Water from Storage Tank | | | |
|---|---|---|---|
| Cooking | Washing Clothes | Bathing | Brushing Teeth |
| 27 | 34 | 34 | 30 |

| Method of Treating Water | | | |
|---|---|---|---|
| Boil Water | Disinfect With Chlorine | No Treatment | NA |
| 23 | 1 | 8 | 2 |

| Frequency of Cleaning Storage Tank | | | | | | |
|---|---|---|---|---|---|---|
| Every 2 Years | Annually | Biannually | Every 3 Months | Monthly | Never | Other |
| 2 | 11 | 3 | 4 | 8 | 5 | 3 |

| What is Used to Clean Storage Tank | | | | |
|---|---|---|---|---|
| Disinfectant | Detergent | Broom | Brush | Rag |
| 7 | 10 | 9 | 15 | 5 |

| Person Responsible for Cleaning Storage Tank | | |
|---|---|---|
| Male Head of Household | Female Head of Household | Other |
| 18 | 1 | 12 |

**Table D4: Health effects of stored water**

| Illness Experience Within Last 2 Weeks | | |
|---|---|---|
| Yes | No | NA |
| 3 | 27 | 6 |

| Symptoms | | | | | |
|---|---|---|---|---|---|
| Diarrhea | Stomach Ache | Fever | Nausea | Headache | Chills |
| 2 | 3 | 1 | 2 | 1 | 1 |

# Appendix E: Raw Data for Elevated Storage Tanks in Tiquipaya Noreste (Bolivia)

## Table E1: Elevated storage tank location and material and age characteristics.

| Sample ID | Date | Location | | | | Tank Brand Name | Tank Material | Tank Color | Materials Used in Household System | Type of Tank | Age of Tank |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Southing | | Westing | | | | | | | |
| CBBA001 | 22/06/2010 | 17 | 20.036 | 66 | 13.111 | Tinabol | Plastic | Black | PVC | C | 0-3 |
| CBBA002 | 22/06/2010 | 17 | 20.245 | 66 | 13.325 | Tinacos | Plastic | Black | PVC | C | 0-3 |
| CBBA003 | 22/06/2010 | 17 | 20.284 | 66 | 13.377 | Tank Burg | Plastic | Black | PVC | C | 4-10 |
| CBBA004 | 22/06/2010 | 17 | 20.278 | 66 | 13.379 | Tank Burg | Plastic | Black | PVC | C | 0-3 |
| CBBA005 | 22/06/2010 | 17 | 20.420 | 66 | 13.299 | Plastec | Fiberglass | White | PVC | B | 4-10 |
| CBBA006 | 23/06/2010 | 17 | 20.312 | 66 | 13.159 | Duralit | Cement | | | A | 4-10 |
| CBBA008 | 23/06/2010 | 17 | 20.308 | 66 | 13.005 | Tinacos | Plastic | Black | PVC/Indoors | C | 4-10 |
| CBBA010 | 23/06/2010 | 17 | 20.254 | 66 | 13.024 | Campeon | Plastic | Black | Rubber Hose | C | 0-3 |
| CBBA011 | 23/06/2010 | 17 | 20.238 | 66 | 13.029 | Duralit | Cement | | PVC | A | 4-10 |
| CBBA012 | 24/06/2010 | 17 | 20.376 | 66 | 12.954 | Duralit | Cement | | PVC and Rubber Hose | A | 4-10 |
| CBBA015 | 24/06/2010 | 17 | 20.469 | 66 | 12.962 | Tanqueplast | Fiberglass | White | PVC | B | 4-10 |
| CBBA016 | 24/06/2010 | 17 | 20.461 | 66 | 12.956 | Tanqueplast | Fiberglass | White | PVC | B | 4-10 |
| CBBA017 | 24/06/2010 | 17 | 20.447 | 66 | 12.863 | Duralit | Cement | | PVC | A | 4-10 |
| CBBA018 | 24/06/2010 | 17 | 20.293 | 66 | 12.910 | Campeon | Plastic | Black | PVC | C | 4-10 |
| CBBA019 | 24/06/2010 | 17 | 20.274 | 66 | 12.927 | Duralit | Cement | | PVC | A | 16-20 |
| CBBA020 | 24/06/2010 | 17 | 20.037 | 66 | 13.071 | Duralit | Cement | | PVC | A | 11-15 |
| CBBA021 | 24/06/2010 | 17 | 20.185 | 66 | 13.247 | Fiberglast | Fiberglass | White | PVC | B | 0-3 |
| CBBA022 | 24/06/2010 | 17 | 20.231 | 66 | 13.211 | Fibraplast | Fiberglass | White | PVC | B | 4-10 |
| CBBA024 | 25/06/2010 | 17 | 20.228 | 66 | 13.056 | | Cement | | PVC | A | 0-3 |
| CBBA026 | 25/06/2010 | 17 | 20.249 | 66 | 13.032 | Tigre | Plastic | Gray | PVC | A | 4-10 |
| CBBA027 | 25/06/2010 | 17 | 20.249 | 66 | 13.032 | Tinacos | Plastic | Red | PVC | C | 4-10 |
| CBBA029 | 25/06/2010 | 17 | 20.13 | 66 | 13.284 | Duralit | Plastic | Gray | PVC | A | 4-10 |
| CBBA031 | 25/06/2010 | 17 | 20.314 | 66 | 13.349 | Duralit | Cement | | PVC | A | unknown |
| CBBA033 | 26/06/2010 | 17 | 20.227 | 66 | 13.171 | | Fiberglass | White | PVC | D | 0-3 |
| CBBA034 | 26/06/2010 | 17 | 20.214 | 66 | 13.250 | Fiberplast | Fiberglass | White | PVC | D | 11-15 |
| CBBA036 | 26/06/2010 | 17 | 20.211 | 66 | 13.23 | Duralit | Plastic | Gray | PVC | A | 0-3 |
| CBBA039 | 26/06/2010 | 17 | 20.205 | 66 | 13.234 | Fiberglast | Fiberglass | White | PVC | D | 0-3 |
| CBBA041 | 28/06/2010 | 17 | 20.463 | 66 | 12.946 | Duralit | Plastic | Gray | PVC | A | 4-10 |
| CBBA043 | 28/06/2010 | 17 | 20.333 | 66 | 12.909 | | Fiberglass | White | PVC | D | 4-10 |
| CBBA044 | 28/06/2010 | 17 | 20.180 | 66 | 12.906 | Tinacos | Plastic | Red | PVC | C | 0-3 |
| CBBA046 | 28/06/2010 | 17 | 20.027 | 66 | 13.043 | Agua Sol | Plastic | Black | PVC | C | 0-3 |
| CBBA047 | 28/06/2010 | 17 | 20.083 | 66 | 13.117 | Duralit | Plastic | Gray | PVC | A | 0-3 |
| CBBA049 | 28/06/2010 | 17 | 20.117 | 66 | 13.121 | Fibraplast | Fiberglass | White | PVC | B | 11-15 |
| CBBA052 | 28/06/2010 | 17 | 20.330 | 66 | 12.368 | Duralit | Cement | | PVC | A | 4-10 |
| CBBA053 | 28/06/2010 | 17 | 20.330 | 66 | 12.368 | Tinacos | Plastic | Black | PVC | C | 4-10 |
| CBBA054 | 28/06/2010 | 17 | 20.722 | 66 | 12.300 | | Fiberglass | Orange | PVC | D | 0-3 |

## Appendix E Continued

### Table E2: Physical-chemical water quality data for elevated storage tanks.

| Sample ID | Date | Time of Sampling | Temp (°C) | Conductivity (mS/cm) | TDS (g/L) | DO (mg/L) | pH | Turbidity (NTU) | Comments |
|---|---|---|---|---|---|---|---|---|---|
| CBBA001 | 22/06/2010 | 11:20am | 22.4 | 0.200 | 0.2 | 4.50 | 6.55 | 3.5 | From Tank |
| CBBA002 | 22/06/2010 | 12:25pm | 22.77 | 0.54 | 0.4 | 4.92 | 6.63 | 15.5 | From Shower |
| CBBA003 | 22/06/2010 | 12:50pm | 21.07 | 0.004 | 0.1 | 4.88 | 6.61 | 4.3 | From Shower |
| CBBA004 | 22/06/2010 | 13:13pm | 18.82 | 0.212 | 0.1 | 5.09 | 6.88 | 12.7 | From Tap |
| CBBA005 | 22/06/2010 | 13:30pm | 16.23 | 0.227 | 0.1 | 5.21 | 7.02 | 17.3 | From Tap |
| CBBA006 | 23/06/2010 | 10:55am | 15.22 | 0.234 | 0.2 | 5.58 | 6.81 | 5.0 | From Tap |
| CBBA008 | 23/06/2010 | 11:16am | 15.9 | 0.13 | 0.1 | 5.31 | 6.81 | 3.8 | From Tank (Indoor) |
| CBBA010 | 23/06/2010 | 12:34pm | 18.84 | 0.227 | 0.2 | 4.95 | 6.79 | 3.7 | From Tank |
| CBBA011 | 23/06/2010 | 12:45pm | 18.13 | 0.125 | 0.1 | 4.11 | 6.74 | 60.4 | From Tap |
| CBBA012 | 24/06/2010 | 8:03am | 16.54 | 0.198 | 0.2 | 5.43 | 6.68 | 5.0 | From Tap - rubber hose |
| CBBA015 | 24/06/2010 | 9:22am | 15.88 | 0.164 | 0.1 | 4.86 | 7.19 | 4.2 | From bathroom sink |
| CBBA016 | 24/06/2010 | 9:29am | 15.07 | 0.13 | 0.1 | 6.1 | 7.23 | 4.5 | From bathroom shower |
| CBBA017 | 24/06/2010 | 10:05am | 14.90 | 0.185 | 0.1 | 5.13 | 7.29 | 3.1 | From Tank |
| CBBA018 | 24/06/2010 | 10:35am | 17.03 | 0.118 | 0.1 | 4.07 | 6.86 | 2.4 | From Tank |
| CBBA019 | 24/06/2010 | 15:08pm | 17.28 | 0.291 | 0.2 | 4.86 | 6.74 | 3.5 | From Tank |
| CBBA020 | 24/06/2010 | 16:03pm | 19.24 | 0.197 | 0.1 | 5.30 | 6.69 | 6.2 | From Tank |
| CBBA021 | 24/06/2010 | 16:27pm | 17.87 | 0.295 | 0.1 | 5.73 | 7.02 | 6.7 | From Tap |
| CBBA022 | 24/06/2010 | 17:05pm | 23.59 | 0.141 | 0.1 | 4.51 | 7.07 | 4.3 | From Tank |
| CBBA024 | 25/06/2010 | 9:10am | 15.10 | 0.145 | 0.1 | 4.63 | 6.8 | 2.9 | From Tank -Hospital |
| CBBA026 | 25/06/2010 | 9:38am | 15.65 | 0.142 | 0.1 | 4.52 | 6.8 | 2.5 | From Tank |
| CBBA027 | 25/06/2010 | 9:42am | 17.30 | 0.141 | 0.1 | 4.29 | 6.89 | 2.6 | From Tank |
| CBBA029 | 25/06/2010 | 10:53am | 16.63 | 0.156 | 0.1 | 4.7 | 6.71 | 3.7 | From Tank |
| CBBA031 | 25/06/2010 | 11:49am | 17.18 | 0.148 | 0.1 | 5.31 | 7.54 | 3.1 | From Tank |
| CBBA033 | 26/06/2010 | 9:00am | 13.55 | 0.202 | 0.1 | 5.36 | 6.88 | 5.2 | From Tap |
| CBBA034 | 26/06/2010 | 9:36am | 16.06 | 0.328 | 0.2 | 4.51 | 7.15 | 8.1 | From Tap |
| CBBA036 | 26/06/2010 | 9:54am | 16.54 | 0.150 | 0.1 | 4.94 | 6.91 | 4.1 | From Tap |
| CBBA039 | 26/06/2010 | 10:27am | 14.78 | 0.150 | 0.1 | 4.89 | 6.94 | 3.8 | From Tap |
| CBBA041 | 28/06/2010 | 8:46am | 15.45 | 0.156 | 0.1 | 4.7 | 6.77 | 2.8 | From Tank |
| CBBA043 | 28/06/2010 | 9:53am | 19.36 | 0.134 | 0.1 | 4.23 | 6.81 | 4.5 | From Tank |
| CBBA044 | 28/06/2010 | 10:31am | 16.99 | 0.134 | 0.1 | 3.82 | 6.76 | 2.8 | From Tap |
| CBBA046 | 28/06/2010 | 11:15am | 17.40 | 0.148 | 0.1 | 4.77 | 7.02 | 2.7 | From Tank |
| CBBA047 | 28/06/2010 | 11:25am | 15.55 | 0.158 | 0.1 | 4.86 | 7.07 | 5.8 | From Tap - kitchen |
| CBBA049 | 28/06/2010 | 11:45am | 13.85 | 0.154 | 0.1 | 4.37 | 7.17 | 3.4 | From Tank |
| CBBA052 | 28/06/2010 | 4:45pm | 17.04 | 0.146 | 0.1 | 4.23 | 7.04 | 3.3 | From Tank |
| CBBA053 | 28/06/2010 | 4:48pm | 16.79 | 0.146 | 0.1 | 4.01 | 7.03 | 3.3 | From Tank |
| CBBA054 | 28/06/2010 | 5:23pm | 20.43 | 0.161 | 0.1 | 3.55 | 6.86 | 24.9 | From Tank |

**Appendix E Continued**

**Table E3: Total and free chlorine water quality data for elevated storage tanks.**

**Detection level is 0.02 mg/L.**

| Sample ID | Date | Time of Sampling | Total Chlorine (mg/L) | | | Free Chlorine (mg/L | | | Time Analysis Finished |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1st Test | 2nd Test | Average | 1st Test | 2nd Test | Average | |
| CBBA001 | 22/06/2010 | 11:20am | 0.02 | 0.02 | 0.02 | 0.01 | 0.02 | 0.015 | 4:00pm |
| CBBA002 | 22/06/2010 | 12:25pm | 0.05 | 0.03 | 0.04 | 0.00 | 0.03 | 0.015 | 5:30pm |
| CBBA003 | 22/06/2010 | 12:50pm | 0.01 | 0.01 | 0.01 | 0.07 | 0.03 | 0.05 | 6:45pm |
| CBBA004 | 22/06/2010 | 13:13pm | 0.04 | 0.08 | 0.06 | 0.04 | 0.02 | 0.03 | 6:50pm |
| CBBA005 | 22/06/2010 | 13:30pm | 0.02 | 0.05 | 0.035 | 0.04 | 0.02 | 0.03 | 7:30pm |
| CBBA006 | 23/06/2010 | 10:55am | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2:22pm |
| CBBA008 | 23/06/2010 | 11:16am | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2:55pm |
| CBBA010 | 24/06/2010 | 12:34pm | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 3:20pm |
| CBBA011 | 24/06/2010 | 12:45pm | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.01 | 3:34pm |
| CBBA012 | 24/06/2010 | 8:03am | 0.01 | 0.01 | 0.01 | 0.10 | 0.10 | 0.10 | 12:03pm |
| CBBA015 | 24/06/2010 | 9:22am | 0.00 | 0.00 | 0.00 | 0.02 | 0.01 | 0.02 | 12:36pm |
| CBBA016 | 24/06/2010 | 9:29am | 0.04 | 0.06 | 0.05 | 0.02 | 0.01 | 0.02 | 12:53pm |
| CBBA017 | 24/06/2010 | 10:05am | 0.03 | 0.00 | 0.02 | 0.02 | 0.01 | 0.02 | 1:07pm |
| CBBA018 | 24/06/2010 | 10:35am | 0.02 | 0.01 | 0.02 | 0.01 | 0.02 | 0.02 | 1:16pm |
| CBBA019 | 25/06/2010 | 15:08pm | 0.02 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 5:55pm |
| CBBA020 | 25/06/2010 | 16:03pm | 0.04 | 0.00 | 0.02 | 0.01 | 0.02 | 0.02 | 6:05pm |
| CBBA021 | 25/06/2010 | 16:27pm | 0.02 | 0.02 | 0.02 | 0.00 | 0.00 | 0.00 | 6:18pm |
| CBBA022 | 25/06/2010 | 17:05pm | 0.00 | 0.01 | 0.01 | 0.00 | 0.02 | 0.01 | 6:26pm |
| CBBA024 | 26/06/2010 | 9:10am | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 1:02pm |
| CBBA026 | 26/06/2010 | 9:38am | 0.03 | 0.01 | 0.02 | 0.00 | 0.01 | 0.01 | 1:28pm |
| CBBA027 | 26/06/2010 | 9:42am | 0.00 | 0.00 | 0.00 | 0.02 | 0.02 | 0.02 | 1:40pm |
| CBBA029 | 28/06/2010 | 10:53am | 0.03 | 0.01 | 0.02 | 0.00 | 0.00 | 0.00 | 2:10pm |
| CBBA031 | 28/06/2010 | 11:49am | 0.00 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 2:40pm |
| CBBA033 | 28/06/2010 | 9:00am | 0.11 | 0.07 | 0.09 | 0.05 | 0.04 | 0.05 | 11:40am |
| CBBA034 | 28/06/2010 | 9:36am | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 11:52am |
| CBBA036 | 28/06/2010 | 9:54am | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 12:17pm |
| CBBA039 | 26/6/2010 | 10:27am | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 12:55pm |
| CBBA041 | 28/6/2010 | 8:46am | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 12:55pm |
| CBBA043 | 28/6/2010 | 9:53am | 0.00 | 0.02 | 0.01 | 0.00 | 0.01 | 0.01 | 1:20pm |
| CBBA044 | 28/6/2010 | 10:31am | 0.02 | 0.00 | 0.01 | 0.00 | 0.01 | 0.01 | 1:45pm |
| CBBA046 | 28/6/2010 | 11:15am | 0.02 | 0.02 | 0.02 | 0.01 | 0.00 | 0.01 | 2:10pm |
| CBBA047 | 28/6/2010 | 11:25am | 0.02 | 0.03 | 0.03 | 0.04 | 0.02 | 0.03 | 2:22pm |
| CBBA049 | 28/6/2010 | 11:45am | 0.01 | 0.02 | 0.02 | 0.00 | 0.01 | 0.01 | 2:48pm |
| CBBA052 | 28/6/2010 | 4:45pm | 0.01 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 7:12pm |
| CBBA053 | 28/6/2010 | 4:48pm | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 7:25pm |
| CBBA054 | 28/6/2010 | 5:23pm | 0.01 | 0.01 | 0.01 | 0.00 | 0.02 | 0.01 | 7:53pm |

## Appendix E Continued

### Table E4: Microbial water quality data for elevated storage tanks.

| Sample ID | Date | Total Coliforms (CFU/100 | E. coli (CFU/100 mL) |
|---|---|---|---|
| CBBA001 | 22/06/2010 | <1 | <1 |
| CBBA002 | 22/06/2010 | 131 | <1 |
| CBBA003 | 22/06/2010 | 38 | 15 |
| CBBA004 | 22/06/2010 | <1 | <1 |
| CBBA005 | 22/06/2010 | 21 | 5 |
| CBBA006 | 23/06/2010 | 142 | 35 |
| CBBA008 | 23/06/2010 | 548 | 236 |
| CBBA010 | 23/06/2010 | 3 | <1 |
| CBBA011 | 23/06/2010 | <1 | <1 |
| CBBA012 | 24/06/2010 | >2420 | 34 |
| CBBA015 | 24/06/2010 | 122 | 57 |
| CBBA016 | 24/06/2010 | 105 | 36 |
| CBBA017 | 24/06/2010 | 11 | 2 |
| CBBA018 | 24/06/2010 | 1 | <1 |
| CBBA019 | 24/06/2010 | 2 | <1 |
| CBBA020 | 24/06/2010 | 14 | 8 |
| CBBA021 | 24/06/2010 | 579 | 42 |
| CBBA022 | 24/06/2010 | 122 | 99 |
| CBBA024 | 25/06/2010 | <1 | <1 |
| CBBA026 | 25/06/2010 | 11 | <1 |
| CBBA027 | 25/06/2010 | 1 | <1 |
| CBBA029 | 25/06/2010 | 548 | 75 |
| CBBA031 | 25/06/2010 | 1 | 1 |
| CBBA033 | 26/06/2010 | <1 | <1 |
| CBBA034 | 26/06/2010 | <1 | <1 |
| CBBA036 | 26/06/2010 | 8 | <1 |
| CBBA039 | 26/06/2010 | <1 | <1 |
| CBBA041 | 28/06/2010 | 86 | 38 |
| CBBA043 | 28/06/2010 | 411 | 6 |
| CBBA044 | 28/06/2010 | 157 | <1 |
| CBBA046 | 28/06/2010 | 41 | 11 |
| CBBA047 | 28/06/2010 | 687 | 130 |
| CBBA049 | 28/06/2010 | >2420 | 1046 |
| CBBA052 | 28/06/2010 | 68 | 46 |
| CBBA053 | 28/06/2010 | 78 | 31 |
| CBBA054 | 28/06/2010 | 114 | 11 |

## Appendix F: Raw Data for Underground Cisterns in Tiquipaya Noreste (Bolivia)

### Table F1: Underground cistern characteristics.

| Sample ID | Date | Location | | | | Tank Type | Tank Material |
|---|---|---|---|---|---|---|---|
| | | Southing | | Westing | | | |
| CBBA009 | 23/06/2010 | 17 | 20.312 | 66 | 13.018 | Cistern | Cement |
| CBBA013 | 24/06/2010 | 17 | 20.376 | 66 | 12.954 | Cistern | Cement |
| CBBA014 | 24/06/2010 | 17 | 20.471 | 66 | 12.961 | Cistern | Cement |
| CBBA023 | 24/6/2010 | 17 | 20.231 | 66 | 13.211 | Cistern | Blue Plastic |
| CBBA025 | 25/6/2010 | 17 | 20.224 | 66 | 13.059 | Cistern | Cement |
| CBBA028 | 25/6/2010 | 17 | 20.252 | 66 | 13.019 | Cistern | Cement |
| CBBA030 | 25/6/2010 | 17 | 20.129 | 66 | 13.297 | Cistern | Cement |
| CBBA032 | 25/6/2010 | 17 | 20.314 | 66 | 13.349 | Cistern | Cement |
| CBBA035 | 26/6/2010 | 17 | 20.209 | 66 | 13.229 | Cistern | cement |
| CBBA037 | 26/6/2010 | 17 | 20.212 | 66 | 13.224 | Cistern | Cement |
| CBBA042 | 28/6/2010 | 17 | 20.457 | 66 | 12.595 | Cistern | Cement |
| CBBA045 | 28/6/2010 | 17 | 20.166 | 66 | 12.907 | Cistern | Black Plastic |
| CBBA048 | 28/6/2010 | 17 | 20.083 | 66 | 13.117 | Cistern | Cement |
| CBBA050 | 28/6/2010 | 17 | 20.119 | 66 | 13.108 | Cistern | Cement |
| CBBA055 | 28/6/2010 | 17 | 20.728 | 66 | 12.302 | Cistern | Cement |

### Table F2: Physical-chemical water quality data for underground cisterns.

| Sample ID | Date | Time of Sampling | Temp (?C) | Conductivity (mS/cm) | TDS (g/L) | DO (mg/L) | pH | Turbidity (NTU) | Comments |
|---|---|---|---|---|---|---|---|---|---|
| CBBA009 | 23/06/2010 | 11:27am | 14.92 | 0.184 | 0.1 | 5.13 | 7.52 | 4.3 | From Cistern |
| CBBA013 | 24/06/2010 | 8:12am | 17.92 | 0.102 | 0.1 | 4.64 | 9.53 | 3.9 | From Cistern |
| CBBA014 | 24/06/2010 | 9:17am | 17.55 | 0.121 | 0.1 | 5.67 | 6.79 | 3.5 | From Cistern |
| CBBA023 | 24/06/2010 | 17:09pm | 15.96 | 0.143 | 0.1 | 4.92 | 7.24 | 10.9 | From Cistern |
| CBBA025 | 25/06/2010 | 9:20am | 15.92 | 0.134 | 0.1 | 4.6 | 6.69 | 2.8 | From Cistern |
| CBBA028 | 25/06/2010 | 9:54am | 18.24 | 0.142 | 0.1 | 5.16 | 6.8 | 2.7 | From Cistern |
| CBBA030 | 25/06/2010 | 11:02am | 18.01 | 0.146 | 0.1 | 5.35 | 6.72 | 3.4 | From Cistern |
| CBBA032 | 25/06/2010 | 11:59am | 15.79 | 0.154 | 0.1 | 5.48 | 6.92 | 3.5 | From Cistern |
| CBBA035 | 26/06/2010 | 9:41am | 15.04 | 0.145 | 0.1 | 5.03 | 7.29 | 3.2 | From Cistern |
| CBBA037 | 26/06/2010 | 9:57am | 15.76 | 0.152 | 0.1 | 4.95 | 7.49 | 3.7 | From Cistern |
| CBBA042 | 28/06/2010 | 8:55am | 15.44 | 0.153 | 0.1 | 4.65 | 6.73 | 2.8 | From Cistern |
| CBBA045 | 28/06/2010 | 10:39am | 17.23 | 0.34 | 0.1 | 4.05 | 6.73 | 2.1 | From Cistern |
| CBBA048 | 28/06/2010 | 11:30am | 16.03 | 0.208 | 0.1 | 4.35 | 7.75 | 3 | From Cistern |
| CBBA050 | 28/06/2010 | 11:55am | 14.18 | 0.154 | 0.1 | 5.8 | 7.20 | 4.2 | From Cistern |
| CBBA055 | 28/06/2010 | 5:35pm | 20.19 | 0.161 | 0.1 | 2.71 | 6.76 | 27 | From Cistern |

## Appendix F Continued

**Table F3: Total and free chlorine water quality data for underground cisterns.**

**Detection level is 0.02 mg/L.**

| Sample ID | Date | Time of Sampling | Total Chlorine (mg/L) | | | Free Chlorine (mg/L | | | Time Analysis Finished |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1st Test | 2nd Test | Average | 1st Test | 2nd Test | Average | |
| CBBA009 | 23/06/2010 | 11:27am | 0.02 | 0.02 | 0.02 | 0.00 | 0.00 | 0.00 | 3:04pm |
| CBBA013 | 24/06/2010 | 8:12am | 0.05 | 0.08 | 0.07 | 0.00 | 0.00 | 0.00 | 12:11pm |
| CBBA014 | 24/06/2010 | 9:17am | 0.06 | 0.06 | 0.06 | 0.02 | 0.01 | 0.02 | 12:23pm |
| CBBA023 | 24/06/2010 | 17:09pm | 0.00 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 6:40pm |
| CBBA025 | 25/06/2010 | 9:20am | 0.02 | 0.02 | 0.02 | 0.03 | 0.02 | 0.03 | 1:15pm |
| CBBA028 | 25/06/2010 | 9:54am | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1:55pm |
| CBBA030 | 25/06/2010 | 11:02am | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2:25pm |
| CBBA032 | 25/06/2010 | 11:59am | 0.03 | 0.02 | 0.03 | 0.02 | 0.01 | 0.02 | 2:52pm |
| CBBA035 | 26/06/2010 | 9:41am | 0.03 | 0.00 | 0.02 | 0.02 | 0.02 | 0.02 | 12:05pm |
| CBBA037 | 26/06/2010 | 9:57am | 0.01 | 0.02 | 0.02 | 0.05 | 0.04 | 0.05 | 12:30pm |
| CBBA042 | 28/06/2010 | 8:55am | 0.02 | 0.03 | 0.03 | 0.00 | 0.01 | 0.01 | 1:07pm |
| CBBA045 | 28/06/2010 | 10:39am | 0.01 | 0.02 | 0.02 | 0.00 | 0.01 | 0.01 | 1:57pm |
| CBBA048 | 28/06/2010 | 11:30am | 0.00 | 0.02 | 0.01 | 0.04 | 0.00 | 0.02 | 2:35pm |
| CBBA050 | 28/06/2010 | 11:55am | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 3:01pm |
| CBBA055 | 28/06/2010 | 5:35pm | 0.01 | 0.02 | 0.02 | 0.01 | 0.02 | 0.02 | 8:40pm |

**Table F4: Microbial water quality data for underground cisterns.**

| Sample ID | Date | Total Coliforms (CFU/100 | E. coli (CFU/100 mL) |
|---|---|---|---|
| CBBA009 | 23/06/2010 | 201 | 5 |
| CBBA013 | 24/06/2010 | <1 | <1 |
| CBBA014 | 24/06/2010 | 79 | 35 |
| CBBA023 | 24/06/2010 | 411 | 102 |
| CBBA025 | 25/06/2010 | <1 | <1 |
| CBBA028 | 25/06/2010 | 12 | <1 |
| CBBA030 | 25/06/2010 | 10 | <1 |
| CBBA032 | 25/06/2010 | 14 | <1 |
| CBBA035 | 26/06/2010 | <1 | <1 |
| CBBA037 | 26/06/2010 | 15 | <1 |
| CBBA042 | 28/06/2010 | 387 | 166 |
| CBBA045 | 28/06/2010 | 1 | <1 |
| CBBA048 | 28/06/2010 | 1203 | 16 |
| CBBA050 | 28/06/2010 | >2420 | >2420 |
| CBBA055 | 28/06/2010 | 461 | 6 |

## Appendix G: Raw Data for the Tiquipaya Noreste (Bolivia) Water Distribution System

### Table G1: Tiquipaya Noreste water distribution system characteristics.

| Sample ID | Date | Location | | | | Comments |
|---|---|---|---|---|---|---|
| | | Southing | | Westing | | |
| CBBA007 | 23/06/2010 | 17 | 20.312 | 66 | 13.159 | From System |
| CBBA038 | 26/06/2010 | 17 | 20.207 | 66 | 13.228 | From System |
| CBBA040 | 26/06/2010 | 17 | 20.300 | 66 | 13.080 | From System |
| CBBA051 | 28/06/2010 | 17 | 20.330 | 66 | 12.368 | From System |
| CBBA065 | 1/7/2010 | 17 | 19.779 | 66 | 12.985 | Water from system before it mixes with well water |
| CBBA067 | 1/7/2010 | 17 | 20.172 | 66 | 13.443 | Water from Well 2 mixed with river water |
| CBBA068 | 1/7/2010 | 17 | 20.116 | 66 | 13.027 | Water from Well 1 mixed with river water |

### Table G2: Physical-chemical water quality data for the Tiquipaya Noreste water distribution system.

| Sample ID | Date | Time of Sampling | Temp (?C) | Conductivity (mS/cm) | TDS (g/L) | DO (mg/L) | pH | Turbidity (NTU) | Comments |
|---|---|---|---|---|---|---|---|---|---|
| CBBA007 | 23/06/2010 | 11:00am | 16.75 | 0.000 | 0.1 | 5.00 | 6.66 | 2.8 | From Tap |
| CBBA038 | 26/6/2010 | 10:01am | 15.33 | 0.157 | 0.1 | 4.51 | 7.74 | 4.3 | From System |
| CBBA040 | 26/6/2010 | 10:30am | 13.56 | 0.151 | 0.1 | 4.58 | 7.12 | 4.2 | From System |
| CBBA051 | 28/6/2010 | 4:15pm | 15.55 | 0.154 | 0.1 | 4.84 | 6.93 | 6.6 | From System - Cistern was filling |
| CBBA065 | 1/7/2010 | | 10.24 | 0.195 | 133.4 | 5.51 | 7.04 | 5.5 | Chlorinated water from treatment plant |
| CBBA067 | 1/7/2010 | | 11.45 | 0.174 | 116.2 | 5.18 | 7.51 | 5.5 | Chlorinated water mixed with well water |
| CBBA068 | 1/7/2010 | | 15.94 | 0.154 | 104.9 | 4.70 | 6.97 | 4.7 | Chlorinated water mixed with well water |

### Table G3: Total and free chlorine water quality data for the Tiquipaya Noreste water distribution system. Detection level is0.02 mg/L.

| Sample ID | Date | Time of Sampling | Total Chlorine (mg/L) | | | Free Chlorine (mg/L | | | Time Analysis Finished |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1st Test | 2nd Test | Average | 1st Test | 2nd Test | Average | |
| CBBA007 | 23/06/2010 | 11:00am | 0.00 | 0.00 | 0.00 | 0.02 | 0.05 | 0.04 | 2:42pm |
| CBBA038 | 26/6/2010 | 10:01am | 0.03 | 0.03 | 0.03 | 0.01 | 0.01 | 0.01 | 12:45pm |
| CBBA040 | 26/6/2010 | 10:30am | 0.03 | 0.03 | 0.03 | 0.03 | 0.02 | 0.03 | 1:10pm |
| CBBA051 | 28/6/2010 | 4:15pm | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 6:59pm |
| CBBA065 | 1/7/2010 | 11:30am | 0.03 | 0.03 | 0.03 | 0.01 | 0.03 | 0.02 | 5:02pm |
| CBBA067 | 1/7/2010 | 11:55am | 0.03 | 0.03 | 0.03 | 0.05 | 0.06 | 0.055 | 5:23pm |
| CBBA068 | 1/7/2010 | 12:05pm | 0.05 | 0.04 | 0.045 | 0.05 | 0.03 | 0.04 | 5:23pm |

**Appendix G Continued**

**Table G4: Microbial water quality data for the Tiquipaya Noreste water distribution system.**

| Sample ID | Date | Total Coliforms (CFU/100mL) | E. coli (CFU/100mL) |
|---|---|---|---|
| CBBA007 | 23/06/2010 | 178 | 46 |
| CBBA038 | 26/6/2010 | <1 | <1 |
| CBBA040 | 26/6/2010 | <1 | <1 |
| CBBA051 | 28/6/2010 | 51 | 35 |
| CBBA065 | 1/7/2010 | <1 | <1 |
| CBBA067 | 1/7/2010 | <1 | <1 |
| CBBA068 | 1/7/2010 | <1 | <1 |

## Appendix H: Raw Data for the Tiquipaya Noreste (Bolivia) Water Treatment Plant

### Table H1: Tiquipaya Noreste water treatment plant characteristics.

| Sample ID | Date | Location | | | | Comments |
|---|---|---|---|---|---|---|
| | | Southing | | Westing | | |
| CBBA056 | 29/06/2010 | 17 | 19.023 | 66 | 12.686 | Collection tank at river (source) |
| CBBA057 | 29/06/2010 | 17 | 19.275 | 66 | 12.743 | Storage tank after sedimentation tank |
| CBBA058 | 29/06/2010 | 17 | 19.636 | 66 | 12.868 | Equalization Basin |
| CBBA059 | 29/06/2010 | 17 | 19.636 | 66 | 12.868 | Before Baffled Section |
| CBBA062 | 29/06/2010 | 17 | 19.636 | 66 | 12.868 | Tank after baffled Section |
| CBBA060 | 29/06/2010 | 17 | 19.636 | 66 | 12.868 | Tank before weir (where cloro is added) |
| CBBA061 | 29/06/2010 | 17 | 19.636 | 66 | 12.868 | Tank after weir |
| CBBA063 | 29/06/2010 | 17 | 19.636 | 66 | 12.868 | Storage tank that feeds distribution system |
| CBBA064 | 1/7/2010 | 17 | 20.155 | 66 | 12.886 | Well 1 |
| CBBA066 | 1/7/2010 | 17 | 20.068 | 66 | 13.440 | Well 2 |
| CBBA065 | 1/7/2010 | 17 | 19.779 | 66 | 12.985 | Water from system before it mixes with well water |
| CBBA067 | 1/7/2010 | 17 | 20.172 | 66 | 13.443 | Water from Well 2 mixed with river water |
| CBBA068 | 1/7/2010 | 17 | 20.116 | 66 | 13.027 | Water from Well 1 mixed with river water |

### Table H2: Physical-chemical water quality data for the Tiquipaya Noreste water treatment plant.

| Sample ID | Date | Time of Sampling | Temp (?C) | Conductivity (mS/cm) | TDS (g/L) | DO (mg/L) | pH | Turbidity (NTU) |
|---|---|---|---|---|---|---|---|---|
| CBBA056 | 29/06/2010 | 9:43am | 10.07 | 0.150 | 0.1 | 5.36 | 6.80 | 6.3 |
| CBBA057 | 29/06/2010 | 10:01am | 9.60 | 0.156 | 0.1 | 5.43 | 6.94 | 4.7 |
| CBBA058 | 29/06/2010 | 10:30am | 9.98 | 0.156 | 0.1 | 5.56 | 6.92 | 4.2 |
| CBBA059 | 29/06/2010 | 10:34am | 9.99 | 0.155 | 0.1 | 5.62 | 7.20 | 4 |
| CBBA062 | 29/06/2010 | 10:43am | 10.03 | 0.154 | 0.1 | 5.48 | 7.45 | 4.5 |
| CBBA060 | 29/06/2010 | 10:40am | 9.98 | 0.154 | 0.1 | 5.67 | 7.36 | 3.8 |
| CBBA061 | 29/06/2010 | 10:48am | 9.97 | 0.156 | 0.1 | 5.67 | 7.67 | 4 |
| CBBA063 | 29/06/2010 | 10:53am | 10.60 | 0.156 | 0.1 | 5.37 | 7.70 | 4.4 |
| CBBA064 | 1/7/2010 | 11:20am | 17.47 | 0.256 | 127.7 | 3.50 | 6.63 | 22.2 |
| CBBA066 | 1/7/2010 | 11:45am | 14.20 | 0.191 | 128.9 | 3.85 | 6.84 | 4.4 |
| CBBA065 | 1/7/2010 | 11:30am | 10.24 | 0.195 | 133.4 | 5.51 | 7.04 | 5.5 |
| CBBA067 | 1/7/2010 | 11:55am | 11.45 | 0.174 | 116.2 | 5.18 | 7.51 | 5.5 |
| CBBA068 | 1/7/2010 | 12:05pm | 15.94 | 0.154 | 104.9 | 4.70 | 6.97 | 4.7 |

## Appendix H Continued

**Table H3: Total and free chlorine water quality data for the Tiquipaya Noreste water treatment plant. Detection level is 0.02 mg/L.**

| Sample ID | Date | Time of Sampling | Total Chlorine (mg/L) | | | Free Chlorine (mg/L | | | Time Analysis Finished |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1st Test | 2nd Test | Average | 1st Test | 2nd Test | Average | |
| CBBA056 | 29/06/2010 | 9:43am | NA | NA | NA | NA | NA | NA | 2:42pm |
| CBBA057 | 29/06/2010 | 10:01am | NA | NA | NA | NA | NA | NA | 3:41pm |
| CBBA058 | 29/06/2010 | 10:30am | NA | NA | NA | NA | NA | NA | NA |
| CBBA059 | 29/06/2010 | 10:34am | NA | NA | NA | NA | NA | NA | NA |
| CBBA062 | 29/06/2010 | 10:43am | NA | NA | NA | NA | NA | NA | NA |
| CBBA060 | 29/06/2010 | 10:40am | NA | NA | NA | NA | NA | NA | NA |
| CBBA061 | 29/06/2010 | 10:48am | 0.00 | 0.00 | 0 | 0.01 | 0.01 | 0.01 | 4:41pm |
| CBBA063 | 29/06/2010 | 10:53am | 0.47 | 0.48 | 0.475 | 0.5 | 0.43 | 0.465 | 4:28pm |
| CBBA064 | 1/7/2010 | 11:20am | NA | NA | NA | NA | NA | NA | 4:21pm |
| CBBA066 | 1/7/2010 | 11:45am | NA | NA | NA | NA | NA | NA | 5:02pm |
| CBBA065 | 1/7/2010 | 11:30am | 0.03 | 0.03 | 0.03 | 0.01 | 0.03 | 0.02 | 5:02pm |
| CBBA067 | 1/7/2010 | 11:55am | 0.03 | 0.03 | 0.03 | 0.05 | 0.06 | 0.055 | 5:23pm |
| CBBA068 | 1/7/2010 | 12:05pm | 0.05 | 0.04 | 0.045 | 0.05 | 0.03 | 0.04 | 5:23pm |

**Table H4: Microbial water quality data for the Tiquipaya Noreste water treatment plant.**

| Sample ID | Date | Total Coliforms (CFU/100m | E. coli (CFU/100mL) |
|---|---|---|---|
| CBBA056 | 29/06/2010 | 32 | 4 |
| CBBA057 | 29/06/2010 | 131 | 69 |
| CBBA058 | 29/06/2010 | 127 | 40 |
| CBBA059 | 29/06/2010 | 142 | 24 |
| CBBA062 | 29/06/2010 | 649 | 77 |
| CBBA060 | 29/06/2010 | 104 | 32 |
| CBBA061 | 29/06/2010 | 166 | 45 |
| CBBA063 | 29/06/2010 | <1 | <1 |
| CBBA064 | 1/7/2010 | <1 | <1 |
| CBBA066 | 1/7/2010 | 534 | <1 |
| CBBA065 | 1/7/2010 | <1 | <1 |
| CBBA067 | 1/7/2010 | <1 | <1 |
| CBBA068 | 1/7/2010 | <1 | <1 |

## Appendix I: Results for MANOVA Comparing Water Quality Parameters for Samples Taken Directly from Storage Tanks with Those Taken from Taps

**Table I1: Multivariate tests for water quality parameters for samples taken directly from storage tanks compared to those taken from taps.**

| Effect | | Value | F | Hypothesis df | Error df | Sig. |
|---|---|---|---|---|---|---|
| Intercept | Pillai's Trace | .999 | 4229.953$^a$ | 10.000 | 24.000 | .000 |
| | Wilks' Lambda | .001 | 4229.953$^a$ | 10.000 | 24.000 | .000 |
| | Hotelling's Trace | 1762.480 | 4229.953$^a$ | 10.000 | 24.000 | .000 |
| | Roy's Largest Root | 1762.480 | 4229.953$^a$ | 10.000 | 24.000 | .000 |
| TankorTap | Pillai's Trace | .290 | .982$^a$ | 10.000 | 24.000 | .484 |
| | Wilks' Lambda | .710 | .982$^a$ | 10.000 | 24.000 | .484 |
| | Hotelling's Trace | .409 | .982$^a$ | 10.000 | 24.000 | .484 |
| | Roy's Largest Root | .409 | .982$^a$ | 10.000 | 24.000 | .484 |

**Table I2: Tests of between-subjects effects for water quality parameters for samples taken directly from storage tanks and those taken from taps.**

| Source | Dependent Variable | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Corrected Model | Temperature | .959$^a$ | 1 | .959 | .165 | .688 |
| | Conductivity | .006$^b$ | 1 | .006 | .785 | .382 |
| | TDS | .003$^c$ | 1 | .003 | .898 | .350 |
| | DO | .378$^d$ | 1 | .378 | 1.422 | .242 |
| | pH | .000$^e$ | 1 | .000 | .004 | .951 |
| | Turbidity | 244.647$^f$ | 1 | 244.647 | 2.572 | .118 |
| | Total Coliforms | 416344.281$^g$ | 1 | 416344.281 | 2.307 | .138 |
| | E. coli | 92.740$^h$ | 1 | 92.740 | .040 | .844 |
| | Total Chlorine | .000$^i$ | 1 | .000 | 1.184 | .284 |
| | Free Chlorine | .000$^j$ | 1 | .000 | 2.049 | .162 |

## Appendix I Continued

## Table I2 Continued

| | | | | | | |
|---|---|---|---|---|---|---|
| Intercept | Temperature | 9620.269 | 1 | 9620.269 | 1650.834 | .000 |
| | Conductivity | 1.119 | 1 | 1.119 | 152.208 | .000 |
| | TDS | .538 | 1 | .538 | 143.819 | .000 |
| | DO | 767.924 | 1 | 767.924 | 2889.429 | .000 |
| | pH | 1561.052 | 1 | 1561.052 | 32619.806 | .000 |
| | Turbidity | 1739.403 | 1 | 1739.403 | 18.288 | .000 |
| | Total Coliforms | 1494181.007 | 1 | 1494181.007 | 8.278 | .007 |
| | E. coli | 21652.959 | 1 | 21652.959 | 9.226 | .005 |
| | Total Chlorine | .010 | 1 | .010 | 27.318 | .000 |
| | Free Chlorine | .006 | 1 | .006 | 43.895 | .000 |
| Tank or Tap | Temperature | .959 | 1 | .959 | .165 | .688 |
| | Conductivity | .006 | 1 | .006 | .785 | .382 |
| | TDS | .003 | 1 | .003 | .898 | .350 |
| | DO | .378 | 1 | .378 | 1.422 | .242 |
| | pH | .000 | 1 | .000 | .004 | .951 |
| | Turbidity | 244.647 | 1 | 244.647 | 2.572 | .118 |
| | Total Coliforms | 416344.281 | 1 | 416344.281 | 2.307 | .138 |
| | E. coli | 92.740 | 1 | 92.740 | .040 | .844 |
| | Total Chlorine | .000 | 1 | .000 | 1.184 | .284 |
| | Free Chlorine | .000 | 1 | .000 | 2.049 | .162 |
| Error | Temperature | 192.308 | 33 | 5.828 | | |
| | Conductivity | .243 | 33 | .007 | | |
| | TDS | .123 | 33 | .004 | | |
| | DO | 8.770 | 33 | .266 | | |
| | pH | 1.579 | 33 | .048 | | |
| | Turbidity | 3138.721 | 33 | 95.113 | | |
| | Total Coliforms | 5956374.322 | 33 | 180496.192 | | |
| | E. coli | 77450.511 | 33 | 2346.985 | | |
| | Total Chlorine | .012 | 33 | .000 | | |
| | Free Chlorine | .005 | 33 | .000 | | |

## Appendix I Continued

## Table I2 Continued

| | | | | | | |
|---|---|---|---|---|---|---|
| Total | Temperature | 10547.668 | 35 | | | |
| | Conductivity | 1.403 | 35 | | | |
| | TDS | .680 | 35 | | | |
| | DO | 822.090 | 35 | | | |
| | pH | 1673.454 | 35 | | | |
| | Turbidity | 4904.010 | 35 | | | |
| | Total Coliforms | 7567820.210 | 35 | | | |
| | E. coli | 101516.280 | 35 | | | |
| | Total Chlorine | .022 | 35 | | | |
| | Free Chlorine | .011 | 35 | | | |
| Corrected Total | Temperature | 193.268 | 34 | | | |
| | Conductivity | .248 | 34 | | | |
| | TDS | .127 | 34 | | | |
| | DO | 9.148 | 34 | | | |
| | pH | 1.579 | 34 | | | |
| | Turbidity | 3383.367 | 34 | | | |
| | Total Coliforms | 6372718.603 | 34 | | | |
| | E. coli | 77543.251 | 34 | | | |
| | Total Chlorine | .013 | 34 | | | |
| | Free Chlorine | .005 | 34 | | | |

a. R Squared = .005 (Adjusted R Squared = -.025)

b. R Squared = .023 (Adjusted R Squared = -.006)

c. R Squared = .026 (Adjusted R Squared = -.003)

d. R Squared = .041 (Adjusted R Squared = .012)

e. R Squared = .000 (Adjusted R Squared = -.030)

f. R Squared = .072 (Adjusted R Squared = .044)

g. R Squared = .065 (Adjusted R Squared = .037)

h. R Squared = .001 (Adjusted R Squared = -.029)

i. R Squared = .035 (Adjusted R Squared = .005)

j. R Squared = .058 (Adjusted R Squared = .030)

## Appendix J: Results for MANOVA Comparing Water Quality Parameters for Each Tank Type (Polyethylene, Fiberglass, and Fiber Cement)

**Table J1: Multivariate tests for water quality parameters for each tank type.**

| Effect | | Value | F | Hypothesis df | Error df | Sig. |
|---|---|---|---|---|---|---|
| Intercept | Pillai's Trace | 1.000 | $4764.810^{a}$ | 10.000 | 23.000 | .000 |
| | Wilks' Lambda | .000 | $4764.810^{a}$ | 10.000 | 23.000 | .000 |
| | Hotelling's Trace | 2071.656 | $4764.810^{a}$ | 10.000 | 23.000 | .000 |
| | Roy's Largest Root | 2071.656 | $4764.810^{a}$ | 10.000 | 23.000 | .000 |
| Tank Type | Pillai's Trace | .621 | 1.081 | 20.000 | 48.000 | .398 |
| | Wilks' Lambda | .469 | $1.058^{a}$ | 20.000 | 46.000 | .421 |
| | Hotelling's Trace | .940 | 1.034 | 20.000 | 44.000 | .446 |
| | Roy's Largest Root | .641 | $1.538^{b}$ | 10.000 | 24.000 | .186 |

**Table J2: Tests of between-subjects effects for water quality parameters for each tank type (polyethylene, fiberglass and fiber cement).**

| Source | Dependent Variable | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Corrected Model | Temperature | $11.413^{a}$ | 2 | 5.706 | 1.004 | .378 |
| | Conductivity | $.003^{b}$ | 2 | .001 | .170 | .844 |
| | TDS | $.003^{c}$ | 2 | .002 | .452 | .641 |
| | DO | $.893^{d}$ | 2 | .446 | 1.731 | .193 |
| | pH | $.328^{e}$ | 2 | .164 | 4.187 | .024 |
| | Turbidity | $177.354^{f}$ | 2 | 88.677 | .885 | .423 |
| | Total Coliforms | $147746.201^{g}$ | 2 | 73873.100 | .380 | .687 |
| | E. coli | $2189.369^{h}$ | 2 | 1094.684 | .465 | .632 |
| | Total Chlorine | $.001^{i}$ | 2 | .001 | 1.451 | .249 |
| | Free Chlorine | $9.613E-5^{j}$ | 2 | 4.806E-5 | .310 | .735 |

## Appendix J Continued

### Table J2 Continued

| | | | | | | |
|---|---|---|---|---|---|---|
| Intercept | Temperature | 9573.897 | 1 | 9573.897 | 1684.665 | .000 |
| | Conductivity | 1.108 | 1 | 1.108 | 144.262 | .000 |
| | TDS | .513 | 1 | .513 | 133.011 | .000 |
| | DO | 776.498 | 1 | 776.498 | 3009.901 | .000 |
| | pH | 1579.958 | 1 | 1579.958 | 40387.919 | .000 |
| | Turbidity | 1648.871 | 1 | 1648.871 | 16.458 | .000 |
| | Total Coliforms | 1266567.432 | 1 | 1266567.432 | 6.511 | .016 |
| | E. coli | 19446.248 | 1 | 19446.248 | 8.258 | .007 |
| | Total Chlorine | .009 | 1 | .009 | 25.243 | .000 |
| | Free Chlorine | .006 | 1 | .006 | 35.865 | .000 |
| Tank Type | Temperature | 11.413 | 2 | 5.706 | 1.004 | .378 |
| | Conductivity | .003 | 2 | .001 | .170 | .844 |
| | TDS | .003 | 2 | .002 | .452 | .641 |
| | DO | .893 | 2 | .446 | 1.731 | .193 |
| | pH | .328 | 2 | .164 | 4.187 | .024 |
| | Turbidity | 177.354 | 2 | 88.677 | .885 | .423 |
| | Total Coliforms | 147746.201 | 2 | 73873.100 | .380 | .687 |
| | E. coli | 2189.369 | 2 | 1094.684 | .465 | .632 |
| | Total Chlorine | .001 | 2 | .001 | 1.451 | .249 |
| | Free Chlorine | 9.613E-5 | 2 | 4.806E-5 | .310 | .735 |
| Error | Temperature | 181.855 | 32 | 5.683 | | |
| | Conductivity | .246 | 32 | .008 | | |
| | TDS | .123 | 32 | .004 | | |
| | DO | 8.255 | 32 | .258 | | |
| | pH | 1.252 | 32 | .039 | | |
| | Turbidity | 3206.013 | 32 | 100.188 | | |
| | Total Coliforms | 6224972.402 | 32 | 194530.388 | | |
| | E. coli | 75353.883 | 32 | 2354.809 | | |
| | Total Chlorine | .011 | 32 | .000 | | |
| | Free Chlorine | .005 | 32 | .000 | | |

## Appendix J Continued

### Table J2 Continued

| | | | | | | |
|---|---|---|---|---|---|---|
| Total | Temperature | 10547.668 | 35 | | | |
| | Conductivity | 1.403 | 35 | | | |
| | TDS | .680 | 35 | | | |
| | DO | 822.090 | 35 | | | |
| | pH | 1673.454 | 35 | | | |
| | Turbidity | 4904.010 | 35 | | | |
| | Total Coliforms | 7567820.210 | 35 | | | |
| | E. coli | 101516.280 | 35 | | | |
| | Total Chlorine | .022 | 35 | | | |
| | Free Chlorine | .011 | 35 | | | |
| Corrected Total | Temperature | 193.268 | 34 | | | |
| | Conductivity | .248 | 34 | | | |
| | TDS | .127 | 34 | | | |
| | DO | 9.148 | 34 | | | |
| | pH | 1.579 | 34 | | | |
| | Turbidity | 3383.367 | 34 | | | |
| | Total Coliforms | 6372718.603 | 34 | | | |
| | E. coli | 77543.251 | 34 | | | |
| | Total Chlorine | .013 | 34 | | | |
| | Free Chlorine | .005 | 34 | | | |

a. R Squared = .059 (Adjusted R Squared = .000)

b. R Squared = .011 (Adjusted R Squared = -.051)

c. R Squared = .027 (Adjusted R Squared = -.033)

d. R Squared = .098 (Adjusted R Squared = .041)

e. R Squared = .207 (Adjusted R Squared = .158)

f. R Squared = .052 (Adjusted R Squared = -.007)

g. R Squared = .023 (Adjusted R Squared = -.038)

h. R Squared = .028 (Adjusted R Squared = -.033)

i. R Squared = .083 (Adjusted R Squared = .026)

j. R Squared = .019 (Adjusted R Squared = -.042)

## Appendix J Continued

### Table J3: Multiple comparisons using MANOVA and the Tukey HSD test statistic

| Dependent Variable | Tank Type | Tank Type | Mean Difference | Std. Error | Sig. | 95% Confidence Interval Lower Bound | 95% Confidence Interval Upper Bound |
|---|---|---|---|---|---|---|---|
| Temperature | 1 | 2 | 1.196625 | .9609798 | .436 | -1.164859 | 3.558109 |
| | | 3 | 1.083958 | .9932906 | .526 | -1.356926 | 3.524842 |
| | 2 | 1 | -1.196625 | .9609798 | .436 | -3.558109 | 1.164859 |
| | | 3 | -.112667 | 1.0953253 | .994 | -2.804288 | 2.578955 |
| | 3 | 1 | -1.083958 | .9932906 | .526 | -3.524842 | 1.356926 |
| | | 2 | .112667 | 1.0953253 | .994 | -2.578955 | 2.804288 |
| Conductivity | 1 | 2 | -.019875 | .0353261 | .841 | -.106684 | .066934 |
| | | 3 | -.012819 | .0365138 | .934 | -.102547 | .076909 |
| | 2 | 1 | .019875 | .0353261 | .841 | -.066934 | .106684 |
| | | 3 | .007056 | .0402647 | .983 | -.091890 | .106001 |
| | 3 | 1 | .012819 | .0365138 | .934 | -.076909 | .102547 |
| | | 2 | -.007056 | .0402647 | .983 | -.106001 | .091890 |
| TDS | 1 | 2 | .021 | .0250 | .676 | -.040 | .083 |
| | | 3 | -.002 | .0259 | .996 | -.066 | .061 |
| | 2 | 1 | -.021 | .0250 | .676 | -.083 | .040 |
| | | 3 | -.023 | .0285 | .695 | -.093 | .047 |
| | 3 | 1 | .002 | .0259 | .996 | -.061 | .066 |
| | | 2 | .023 | .0285 | .695 | -.047 | .093 |
| DO | 1 | 2 | -.3314 | .20475 | .253 | -.8345 | .1718 |
| | | 3 | -.3077 | .21163 | .326 | -.8278 | .2124 |
| | 2 | 1 | .3314 | .20475 | .253 | -.1718 | .8345 |
| | | 3 | .0237 | .23337 | .994 | -.5498 | .5971 |
| | 3 | 1 | .3077 | .21163 | .326 | -.2124 | .8278 |
| | | 2 | -.0237 | .23337 | .994 | -.5971 | .5498 |
| pH | 1 | 2 | -.2299* | .07973 | .019 | -.4258 | -.0339 |
| | | 3 | -.1074 | .08241 | .404 | -.3099 | .0951 |
| | 2 | 1 | .2299* | .07973 | .019 | .0339 | .4258 |
| | | 3 | .1224 | .09088 | .380 | -.1009 | .3458 |
| | 3 | 1 | .1074 | .08241 | .404 | -.0951 | .3099 |
| | | 2 | -.1224 | .09088 | .380 | -.3458 | .1009 |

## Appendix J Continued

### Table J3 Continued

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Turbidity | 1 | 2 | -1.438 | 4.0349 | .933 | -11.353 | 8.478 |
| | | 3 | -5.515 | 4.1706 | .393 | -15.764 | 4.733 |
| | 2 | 1 | 1.438 | 4.0349 | .933 | -8.478 | 11.353 |
| | | 3 | -4.078 | 4.5990 | .652 | -15.379 | 7.224 |
| | 3 | 1 | 5.515 | 4.1706 | .393 | -4.733 | 15.764 |
| | | 2 | 4.078 | 4.5990 | .652 | -7.224 | 15.379 |
| Total Coliforms | 1 | 2 | -1.508750 | 177.7953 | 1.00 | -438.41800 | 435.40050 |
| | | 3 | -149.2298 | 183.7733 | .698 | -600.82922 | 302.36950 |
| | 2 | 1 | 1.508750 | 177.7953 | 1.00 | -435.40050 | 438.41800 |
| | | 3 | -147.7211 | 202.6512 | .748 | -645.71052 | 350.26830 |
| | 3 | 1 | 149.2298 | 183.7733 | .698 | -302.36950 | 600.82922 |
| | | 2 | 147.7211 | 202.6512 | .748 | -350.26830 | 645.71052 |
| E. coli | 1 | 2 | 7.838750 | 19.56160 | .916 | -40.231386 | 55.908886 |
| | | 3 | 19.47430 | 20.21932 | .605 | -30.212082 | 69.160693 |
| | 2 | 1 | -7.838750 | 19.56160 | .916 | -55.908886 | 40.231386 |
| | | 3 | 11.63555 | 22.29632 | .861 | -43.154812 | 66.425923 |
| | 3 | 1 | -19.47430 | 20.21932 | .605 | -69.160693 | 30.212082 |
| | | 2 | -11.63555 | 22.29632 | .861 | -66.425923 | 43.154812 |
| Total Chlorine | 1 | 2 | -.009188 | .0076405 | .460 | -.027963 | .009588 |
| | | 3 | .005313 | .0078974 | .781 | -.014094 | .024719 |
| | 2 | 1 | .009188 | .0076405 | .460 | -.009588 | .027963 |
| | | 3 | .014500 | .0087087 | .234 | -.006900 | .035900 |
| | 3 | 1 | -.005313 | .0078974 | .781 | -.024719 | .014094 |
| | | 2 | -.014500 | .0087087 | .234 | -.035900 | .006900 |
| Free Chlorine | 1 | 2 | -.001563 | .0050178 | .948 | -.013893 | .010768 |
| | | 3 | .002882 | .0051865 | .844 | -.009863 | .015627 |
| | 2 | 1 | .001563 | .0050178 | .948 | -.010768 | .013893 |
| | | 3 | .004444 | .0057193 | .720 | -.009610 | .018499 |
| | 3 | 1 | -.002882 | .0051865 | .844 | -.015627 | .009863 |
| | | 2 | -.004444 | .0057193 | .720 | -.018499 | .009610 |

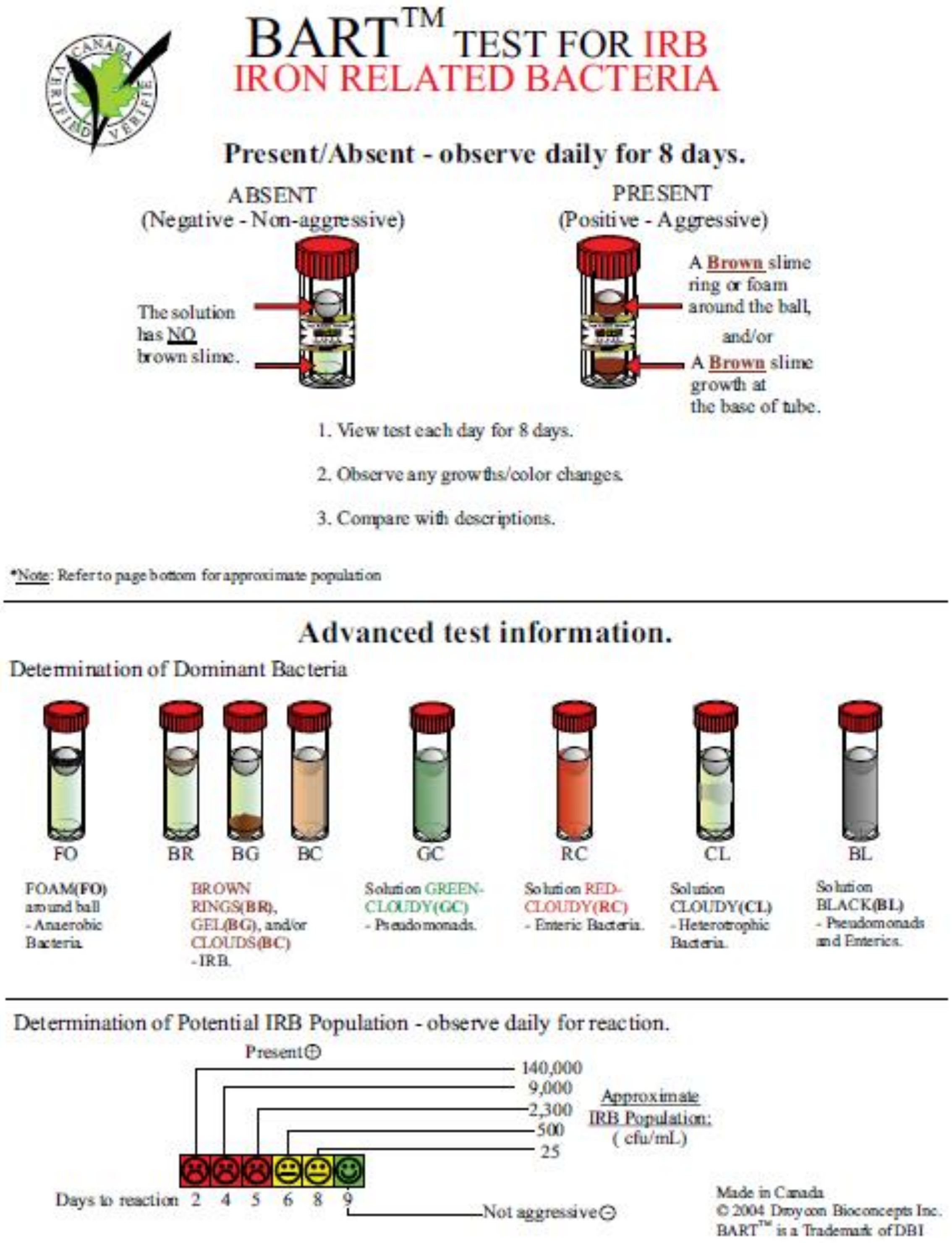
Based on observed means.

## Appendix K: BART Results

### Table K1: Raw data for in-depth microbial testing.

| Sample ID | IRB | | HAB | | SLYM | | Sample Type | Other Notes |
|---|---|---|---|---|---|---|---|---|
| | Day Present | Comments | Day Present | Comments | Day Present | Comments | | |
| CBBA063 | Absent | | Absent | | Absent | | from treatment plant | |
| CBBA072 | Day 1 | Solution yellow - BC | Absent | | Day 4 | TH then Day 5 CL - glows under UV light | System | All one system |
| CBBA073 | Day 5 | Orange ring - BR | Absent | | Day 4 | CL - glows under UV light | Cement tank | |
| CBBA074 | Day 4 | Orange ring - BR | Absent | | Day 4 | CL - glows under UV light | Black plastic tank | All one system |
| CBBA075 | Day 5 | Solution yellow - BC | Absent | | Day 5 | TH - glows under UV light | Cement tank | |
| CBBA076 | Day 5 | Solution yellow - BC | Day 2 | UP - aerobic bacteria | Day 4 | CL - glows under UV light | Cistern | |
| CBBA077 | Day 5 | Solution yellow - BC | Absent | | Absent | | System | |
| CBBA078 | Day 3 | Orange ring - BR | Day 2 | UP - aerobic bacteria | Day 1 | CL - glows under UV light | Gray plastic | All one system |
| CBBA079 | Day 3 | Orange ring - BR | Day 3 | UP - aerobic bacteria | Day 1 | CL - glows under UV light | Red Plastic | |
| CBBA080 | Day 3 | Solution Orange/brown - RC | Day 2 | UP - aerobic bacteria | Day 1 | CL - glows under UV light | Cistern | |
| CBBA081 | Day 3 | Solution Orange/brown - RC | Day 2 | UP - aerobic bacteria | Day 1 | CL - glows under UV light | Cistern | All one system |
| CBBA082 | Day 3 | Solution yellow - BC | Day 1 | UP - aerobic bacteria | Absent | | Round Fiberglass | |
| CBBA083 | Day 3 | Orange ring - BR | Day 4 | UP - aerobic bacteria | Day 2 | CL - glows under UV light | Round Fiberglass | |
| CBBA085 | Day 3 | Orange ring - BR | Absent | | Day 4 | CL - glows under UV light | Sideways Fiberglass | |
| CBBA087 | Day 3 | Solution yellow - BC | Day 2 | UP - aerobic bacteria | Day 6 | CL - glows under UV light | Sideways Fiberglass | |
| CBBA088 | Day 3 | Solution yellow - BC | Absent | | Absent | | Black plastic tank | All one system |
| CBBA089 | Day 2 | Orange ring and solution dark yellow - BR and RC | Day 2 | UP - aerobic bacteria | Day 2 | CL - glows under UV light | Cistern | |
| CBBA090 | Day 3 | Orange ring - BR | Absent | | Present | CL - glows under UV light | Gray plastic | |

## Appendix L: BART Test Information Sheets



# BART™ TEST FOR IRB
# IRON RELATED BACTERIA

### Present/Absent - observe daily for 8 days.

ABSENT
(Negative - Non-aggressive)

The solution has NO brown slime.

PRESENT
(Positive - Aggressive)

A **Brown** slime ring or foam around the ball,

and/or

A **Brown** slime growth at the base of tube.

1. View test each day for 8 days.
2. Observe any growths/color changes.
3. Compare with descriptions.

*Note: Refer to page bottom for approximate population

---

### Advanced test information.

Determination of Dominant Bacteria

| Code | Description |
|---|---|
| FO | FOAM(**FO**) around ball - Anaerobic Bacteria. |
| BR<br>BG<br>BC | BROWN RINGS(**BR**), GEL(**BG**), and/or CLOUDS(**BC**) - IRB. |
| GC | Solution GREEN-CLOUDY(**GC**) - Pseudomonads. |
| RC | Solution RED-CLOUDY(**RC**) - Enteric Bacteria. |
| CL | Solution CLOUDY(**CL**) - Heterotrophic Bacteria. |
| BL | Solution BLACK(**BL**) - Pseudomonads and Enterics. |

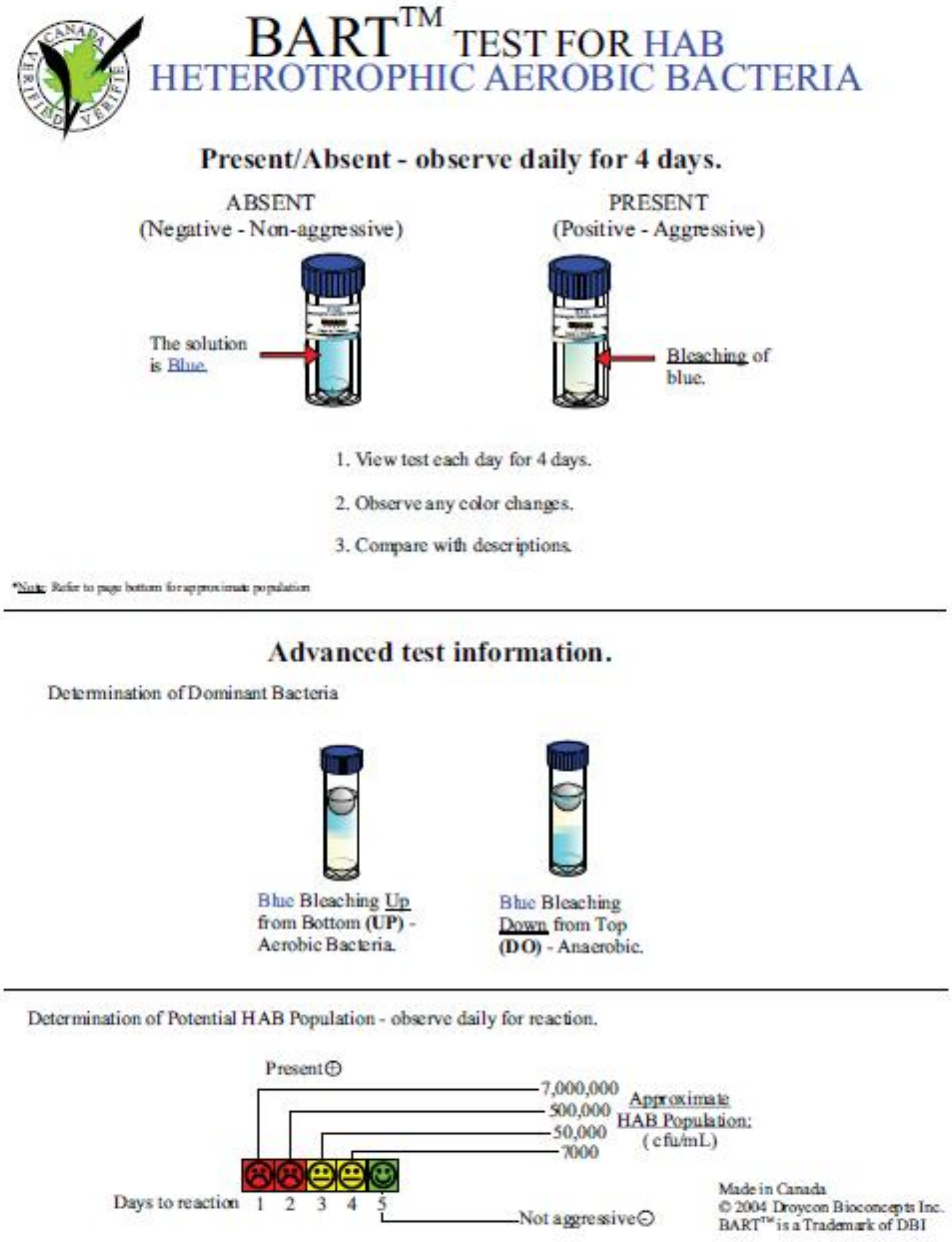
---

Determination of Potential IRB Population - observe daily for reaction.

Present ⊕

| Days to reaction | Approximate IRB Population: ( cfu/mL) |
|---|---|
| 2 | 140,000 |
| 4 | 9,000 |
| 5 | 2,300 |
| 6 | 500 |
| 8 | 25 |
| 9 | Not aggressive ⊖ |

**Appendix L Continued**



# BART™ TEST FOR HAB HETEROTROPHIC AEROBIC BACTERIA

## Present/Absent - observe daily for 4 days.

ABSENT (Negative - Non-aggressive)

The solution is Blue.

PRESENT (Positive - Aggressive)

Bleaching of blue.

1. View test each day for 4 days.
2. Observe any color changes.
3. Compare with descriptions.

*Note: Refer to page bottom for approximate population

## Advanced test information.

Determination of Dominant Bacteria

Blue Bleaching Up from Bottom **(UP)** - Aerobic Bacteria.

Blue Bleaching Down from Top **(DO)** - Anaerobic.

Determination of Potential HAB Population - observe daily for reaction.

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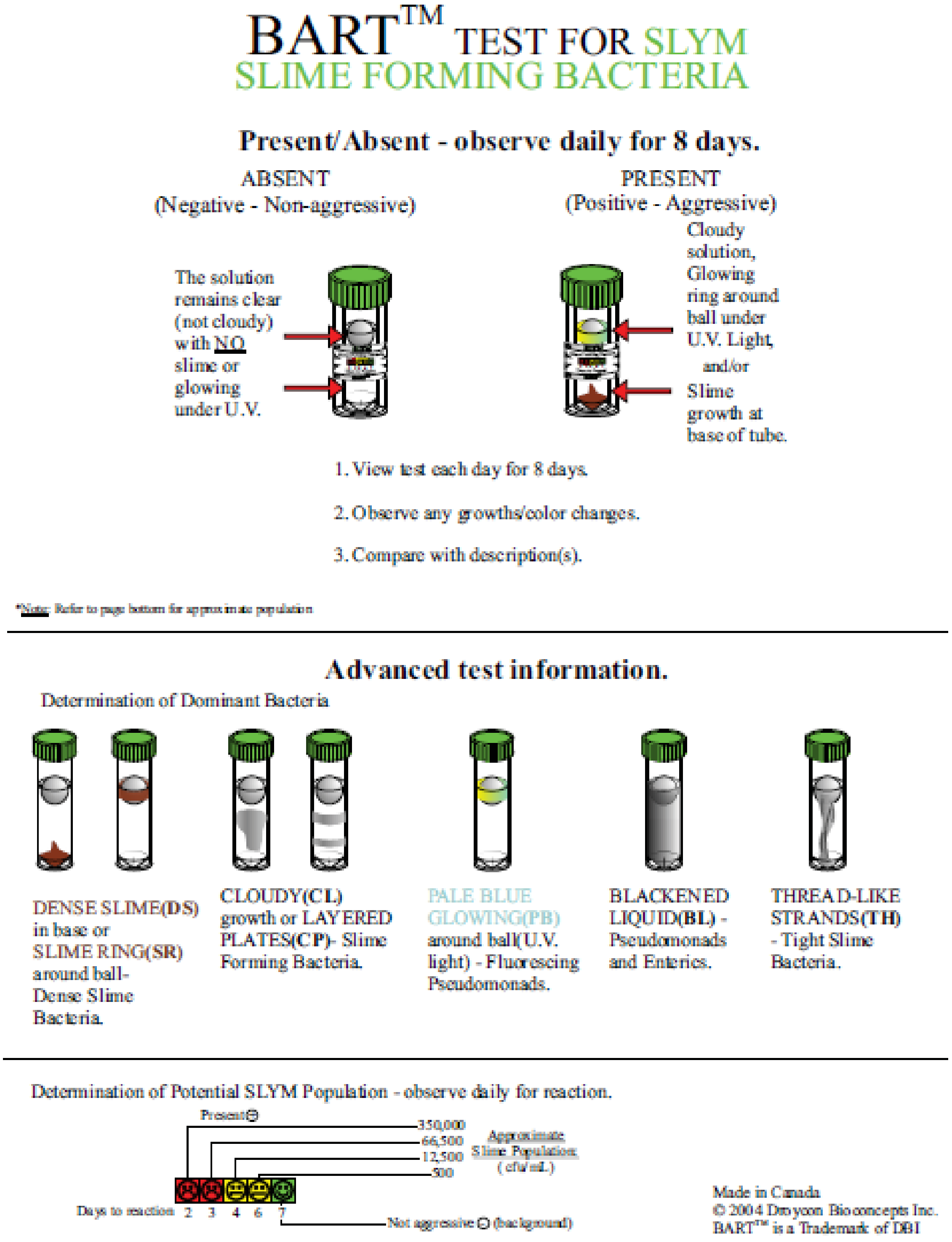
**Appendix L Continued**



# BART™ TEST FOR SLYM SLIME FORMING BACTERIA

## Present/Absent - observe daily for 8 days.

ABSENT
(Negative - Non-aggressive)

The solution remains clear (not cloudy) with NO slime or glowing under U.V.

PRESENT
(Positive - Aggressive)

Cloudy solution, Glowing ring around ball under U.V. Light,
and/or
Slime growth at base of tube.

1. View test each day for 8 days.
2. Observe any growths/color changes.
3. Compare with description(s).

*Note: Refer to page bottom for approximate population

## Advanced test information.

Determination of Dominant Bacteria

DENSE SLIME(**DS**) in base or SLIME RING(**SR**) around ball- Dense Slime Bacteria.

CLOUDY(**CL**) growth or LAYERED PLATES(**CP**)- Slime Forming Bacteria.

PALE BLUE GLOWING(**PB**) around ball(U.V. light) - Fluorescing Pseudomonads.

BLACKENED LIQUID(**BL**) - Pseudomonads and Enterics.

THREAD-LIKE STRANDS(**TH**) - Tight Slime Bacteria.

Determination of Potential SLYM Population - observe daily for reaction.

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## ABOUT THE AUTHOR

Cynthia A. Schafer received her B.S. in Environmental Engineering from Michigan Technological University, where she was awarded the 2008 Nicole Roth Award for Leadership in Environmental Sustainability. At Michigan Tech, she served as a member of the Environmental Sustainability Committee and worked for the Carbon Academic Quality Improvement Program to inventory and offset carbon dioxide emissions on the Michigan Tech campus. She spent 2006 and 2007 as a participant in the U.S. Department of Energy's Global Change Education Program – Summer Undergraduate Research Experience, working with faculty and graduate students to study the role of biological soil crusts in alpine ecosystems and carbon dioxide flux over Lake Superior. While at the University of South Florida, Cynthia was the 2009 – 2010 Sustainability Fellow. During her spare time, Cynthia volunteered with the Gulf Coast Jewish Family Services helping refugee children and their families adjust to life in the US.