AN EVALUATION OF HOUSEHOLD DRINKING WATER TREATMENT SYSTEMS IN PERU: THE TABLE FILTER AND THE SAFE WATER SYSTEM

by

Brittany Coulbert

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Abstract

A household water treatment program was implemented in southern Peru in 2003 by CEPIS and the country's Ministry of Health. This program involves the use of two household water treatment systems (HWTSs): the Table Filter and the Safe Water System. The author and a team of researchers from MIT traveled to Peru in January 2004 to assess the program and technologies through water quality tests and personal interviews. This research continued in Peru during March 2004 by local chemical engineering graduates of San Augustine National University.

The Table Filter is a combination filter, involving a geotextile cloth pre-filter, sand, and two Pozzani ceramic candles from Brazil. Table Filters tested in Peru provided an average 99% E.coli removal, 98% total coliform removal, and 67% turbidity removal. Two Table Filters were also tested at MIT, using two different grades of sand. The "Medium Sand Table Filter" demonstrated 98% thermotolerant coliform removal and 91% turbidity removal, and the "Fine Sand Table Filter" showed 98% thermotolerant coliform removal and 92% turbidity removal. Tests performed on the Pozzani ceramic candles alone (without sand) showed similar coliform removal rates and slightly decreased turbidity removal rates, although the difference was statistically insignificant. Previous research shows that this combination of filtration media helps sustain a higher flow rate through the filters (Rojas & Guevara, 2000). Thus the chief advantage of the complete Table Filters, over the Pozzani ceramics candles alone, is a sustained higher flow rate, not coliform or turbidity removal.

The Safe Water System (SWS), designed by the Centers for Disease Control and Prevention, involves local small-scale chlorine generation, household chlorination, safe water storage, and education. Tests on the SWSs in Peru demonstrated 99.6% E.coli removal and 95% total coliform removal. Only 30% of the SWSs tested contained water at or above the WHO-recommended concentration of free chlorine residual (0.2 mg/L).

The author recommends that use of these HWTSs continues and that the program receives increased support. The two HWTSs would be most effective if combined: filtration plus post-chlorination. In order to further distribute these systems in the future, a sustainable funding plan must be created.

Thesis Supervisor: Susan Murcott
Title: Research Engineer, Department of Civil and Environmental Engineering

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List of Abbreviations

CBV	Cerrito Buena Vista
CDC	Centers for Disease Control and Prevention
CEPIS	Pan-American Center for Sanitary Engineering and Environmental Sciences
CFU	Colony-forming units
DGCI	Directorate General for International Cooperation (Belgian International Development Agency)
ET	El Triunfo
FC	Fecal Coliform
FSTF	Fine Sand Table Filter
H_2O-1B!	Clean Water for One Billion People! (MIT's HWTS program)
HWTS	Household Water Treatment System
LS	Lauryl Sulfate
lpcd	Liters per capita per day
LRV	Log Reduction Value
MEng	Master of Engineering Program in Civil and Environmental Engineering at MIT
MIT	Massachusetts Institute of Technology
MSTF	Medium Sand Table Filter
NTU	Nephelometric Turbidity Unit
PAHO	Pan-American Health Organization
S/	*(Nuevo) Soles* (Peruvian currency)
SWS	Safe Water System
TC	Total Coliform
TF	Table Filter
TTC	Thermotolerant Coliform
WHO	World Health Organization
WTP	Water Treatment Plant

1. Introduction

Each year, 1.6 million people worldwide – the vast majority of them children under age 5 – die from diarrheal diseases related to unsafe water, sanitation, and hygiene. In 2002, 15% of worldwide deaths of children under the age of five were caused by diarrhea (WHO website, 2004). Diarrheal disease, one of the most common risks associated with contaminated water, accounts for the 6th highest burden of disease on a global scale (Howard & Bartram, 2003). Unsafe drinking water can lead to community-wide outbreaks of intestinal diseases. Drinking-water-borne diseases can be especially threatening because of the large number of people who can be infected at once if a water source is contaminated. Most of those suffering from water-related diseases are undoubtedly among the 1.1 billion people who lack access to clean or improved water sources worldwide. According to the United Nations and the World Health Organization, <u>access to safe drinking water is a basic human right</u> – a right which 1.1 billion people are being denied (WHO, 2004).

The lack of access to clean drinking water is one of the largest health threats to the world's population. If this problem is to be adequately addressed, organizations, governments, and individuals all over the world must make it a priority to seek ways to increase access to improved water sources, as well as ways to protect these sources and the quality of water consumed at the point of use. It is this problem that, in its small way, this thesis and study attempt to address.

1.1 UN Millennium Development Goals

The United Nations recognizes this water crisis and has addressed it within its Millennium Development Goals. The Goals are presented in the UN Millennium Declaration, in which 189 member states of the United Nations made "a strong commitment to the right to development, to peace and security, to gender equality, to the eradication of the many dimensions of poverty, and to sustainable human development" (UN, 2003).

The UN Millennium Declaration, adopted on September 8, 2000, calls for member states to resolve, in addition to many other goals, "to halve, by the year 2015, the proportion of the world's people whose income is less than one dollar a day and the proportion of people who suffer from hunger and, by the same date, to halve the proportion of people who are unable to reach or to afford safe drinking water" (UN, 2000).

Within the Millennium Declaration are included the following eight goals, known as the Millennium Development Goals, and eighteen targets toward achieving those goals:

Table 1-1: UN Millennium Development Goals & Targets. Source: UN, 2003.

Goal 1: Eradicate extreme poverty and hunger. *Target 1:* Halve, between 1990 and 2015, the proportion of people whose income is less than $1/day.

Target 2: Halve, between 1990 and 2015, the proportion of people who suffer from hunger.

Goal 2: Achieve universal primary education.
Target 3: Ensure that, by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling.

Goal 3: Promote gender equality and empower women.
Target 4: Eliminate gender disparity in primary and secondary education preferably by 2005 and in all levels of education no later than 2015.

Goal 4: Reduce child mortality.
Target 5: Reduce by two-thirds, between 1990 and 2015, the under-five mortality rate.

Goal 5: Improve maternal health.
Target 6: Reduce by three-quarters, between 1990 and 2015, the maternal mortality ratio.

Goal 6: Combat HIV/AIDS, malaria, and other diseases.
Target 7: Have halted by 2015 and begun to reverse the spread of HIV/AIDS.
Target 8: Have halted by 2015 and begun to reverse the incidence of malaria and other major diseases.

Goal 7: Ensure environmental sustainability.
Target 9: Integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources.
Target 10: Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation.
Target 11: By 2020, to have achieved a significant improvement in the lives of at least 100 million slum dwellers.

Goal 8: Develop a global partnership for development.
Target 12: Develop further an open, rule-based, predictable, non-discriminatory trading and financial system.
Includes a commitment to good governance, development, and poverty reduction – both nationally and internationally.
Target 13: Address the special needs of the least developed countries.
Includes tariff- and quota-free access for least developed countries’ exports; enhanced programme of debt relief for HIPC and cancellation of official bilateral debt; and more generous ODA for countries committed to poverty reduction.
Target 14: Address the special needs of landlocked countries and small island developing states (through the Programme of Action for the Sustainable Development of Small Island Developing States and the outcome of the 22nd special session of the General Assembly).
Target 15: Deal comprehensively with the debt problems of developing countries through national and international measures in order to make debt sustainable in the long term.
Target 16: In co-operation with developing countries, develop and implement strategies for decent and productive work for youth.
Target 17: In co-operation with pharmaceutical companies, provide access to affordable, essential drugs in developing countries.
Target 18: In co-operation with the private sector, make available the benefits of new technologies, especially information and communications.

Target 10 addresses the problem of lack of access to clean water: “Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation.” Each target is listed with one to five “indicators” of how the UN proposes this target be evaluated. The indicator dealing with safe drinking water is as follows:

> Indicator #30: “Proportion of the population with sustainable access to an improved water source, urban and rural.”

This indicator is defined as “the percentage of the population who use any of the following types of water supply for drinking: piped water, public tap, borehole or pump, protected well, protected spring, or rainwater. Improved water sources do not include vendor-provided waters, bottled water, tanker trucks or unprotected wells and springs.” The indicator is based on the assumption that these “improved water sources” will be more likely to provide the user with safe drinking water, and thus reduce his or her risk of catching water-borne diseases (UN, 2003).

It should be noted that even if the ambitious UN Millenium Development Goal is achieved, over half a billion people in the world will *still* lack access to improved drinking water. Extremely poor households and remote rural villages are likely to be among those left behind even after the urban *and* rural populations without access to safe drinking water are halved. It is simply easier to provide improved drinking water technologies to denser populations and to those who can afford to pay for all or part of the implementation. This idea of disparity between rich and poor and between urban and rural residents is supported by the findings of the World Health Organization (WHO)/UNICEF Joint Monitoring Program.

1.2 Joint Monitoring Program’s Mid-Term Assessment Report

The UN Millennium Development Goals included, as explained above, a goal to “halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation” (UN, 2003). Although the Goals were adopted in 2000, the baseline values were set at the data available from 1990. In 2004, the WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation (JMP) published a progress report entitled “Meeting the Millennium Development Goals Drinking Water and Sanitation Target: A Mid-Term Assessment of Progress” (JMP, 2004), in which they compared the data from 1990 to that from 2002, essentially the half-way point to the 2015 target. The report serves as a “reality check” on current progress toward the water and sanitation goal by individual countries, regions, and the world, in addition to indicating the areas that will require the most work in order to reach the goal in time (JMP, 2004).

1.2.1 Access to Improved Drinking Water Sources

As stated in Indicator #30 and as defined by the JMP, in order for a family to be considered to have *access*, it must be able to collect at least 20 liters per capita per day (lpcd) from an “improved water supply technology” located within 1 km from its home (WHO, 2004). This is explained in further detail in Section 2.3.3 of this thesis, in the chapter that covers the WHO

Guidelines for Drinking Water Quality. Table 1-2 presents the water supply technologies that are considered improved and unimproved, as listed in the UN Millennium Declaration.

Table 1-2: Classification of Water Supplies as *Improved* and *Unimproved*. Source: JMP, 2004.

Improved Water Supply Technologies	**Unimproved Water Supply Technologies**
Household connection	Unprotected well
Public standpipe	Unprotected spring
Borehole	Rivers or ponds
Protected dug well	Vendor-provided water
Protected spring	Bottled water
Rainwater collection	Tanker truck water

It is much easier and far less costly and time-consuming to note the *type* of water supply that a person uses as opposed to measuring the *quality* of that water, which is why the JMP measures access according to "improved sources." But a drinking water supply that is "improved" is not necessarily *safe*, or free from pathogens or harmful chemicals. In the current survey system used to collect data about water access, water *quality* is not measured. The JMP Mid-Term Assessment states that "the proportion of the population using *safe* drinking water is therefore likely to be lower than that using *improved* drinking water sources" (italics added for emphasis). The WHO and UNICEF are currently conducting a pilot study in six countries on water quality testing at the household level, which could lead to better techniques for the evaluation of water sources in the future (JMP, 2004).

According to the JMP, the world as a whole is on track toward meeting its goal by 2015 for the provision of improved drinking water. In 2002, 5.2 billion people, or 83% of the world's population, had access to improved drinking water, which was an increase from 77% coverage in 1990. 1.1 billion people gained access to improved drinking water sources between 1990 and 2002, and in order to meet the Millennium Development Goal, 1.1 billion more people will need to gain access by 2015 (JMP, 2004).

The world has been split into ten regions for the purpose of monitoring the progress of the Millennium Development Goals. The regions are: the Developed Countries, Eastern Asia, Eurasia, Latin America & the Caribbean, Northern Africa, Oceania, South Asia, South-Eastern Asia, Sub-Saharan Africa, and Western Asia. The region that is furthest behind in providing water coverage is Sub-Saharan Africa, where 42% of the population still lacks access to improved drinking water sources (JMP, 2004).

Peru is part of the Latin America and Caribbean (LA&C) region. LA&C had 89% access to improved drinking water sources in 2002, up from 83% in 1990, which means it is well on its way to halving the proportion of the population without water coverage by 2015. LA&C has the fourth highest coverage of all the regions, trailing only the Developed Regions, Eurasia, and Northern Africa; however there are still 60 million people in the region without access to improved drinking water (JMP, 2004).

This study investigates the safety of the drinking water supplies of several rural communities in southern Peru and the efforts made to introduce two different household drinking water treatment systems into these communities.

1.2.2 Access to Improved Sanitation

Intimately linked to the problem of access to a *safe* water supply is the issue of sanitation. Improved sanitation is defined, according to the JMP, as described in Table 1-3.

Table 1-3: Classification of Sanitation Facilities as *Improved* and *Unimproved.* Source: JMP, 2004.

Improved Sanitation Facilities	Unimproved Sanitation Facilities
Connection to a public sewer Connection to a septic system Pour-flush latrine Simple pit latrine Ventilated improved pit latrine (VIP)	Public or shared latrine Open pit latrine Bucket latrine

The provision of sanitation is occurring at a much slower rate around the world than that of drinking water. If the trend from 1990 to 2002 continues, the world will miss its sanitation target in 2015 by 500 million people. In 1990, only 49% of the world had access to improved sanitation. Sanitation coverage was increased to 58% in 2002, but the goal for 2015 is 75% coverage. 2.6 billion people still do not have access to improved sanitation. In order to reach the goal by 2015, an additional 1 billion urban dwellers and 900 million rural residents will need to gain access to improved sanitation (JMP, 2004).

The Latin America & Caribbean region, however, is on track to meet its sanitation target by 2015. In 2002, it had 75% sanitation coverage, up from 69% in 1990. On the downside, there are still 137 million people in LA&C without any access to improved sanitation (JMP, 2004).

*　　*　　*

It should be noted that even if the coverage for a region or country looks good, there is always disparity between the rich and poor. A selection of Demographic and Health Surveys from 20 developing countries shows that the poorest 20% of the population have only 39% coverage of drinking water compared to the wealthiest 20%, which have 89% coverage. In the same way, the poorest fifth of the population has only 17% sanitation coverage compared to the wealthiest fifth's 75% coverage (JMP, 2004).

The JMP's Mid-Term Assessment also includes ways that improved water and sanitation will help to achieve all eight Millennium Development Goals. For example, improved drinking water and sanitation will help to reduce disease and therefore child mortality, which is goal #4. The report also indicates that in the year 2000, the JMP began to collect coverage information from user-level household surveys instead of from service-providers. This helps to provide a more accurate picture of the actual state of coverage. The JMP has also shifted its definition of access to actual *use*, since households with *access* to an improved source do not necessarily use it (JMP, 2004).

1.2.3 Peru's Assessment

While the LA&C region has relatively good coverage compared to the average for the world, Peru's coverage lags behind the LA&C average, in both water and sanitation. Table 1-4 compares the water and sanitation coverage levels of Peru, the LA&C region, and the world.

Table 1-4: Comparison of Water and Sanitation Coverage between Peru and Its Inclusive Regions. Source: JMP, 2004.

Region	Improved Drinking Water Coverage (%)	Improved Sanitation Coverage (%)
Peru	81	62
Latin America & Caribbean	89	75
World	83	58

Peru's averages are considerably lower than LA&C's averages, as the country has 81% drinking water coverage and 62% sanitation coverage (JMP, 2004). Table 1-5 shows the change in coverage between 1990 and 2002, which indicates that all but urban water coverage have improved.

Table 1-5: Peru's Water and Sanitation Coverage in 1990 and 2002. Source: JMP, 2004.

Year	Improved Drinking Water Coverage (%)			Improved Sanitation Coverage (%)		
	Total	Urban	Rural	Total	Urban	Rural
1990	74	88	42	52	68	15
2002	81	87	66	62	72	33

Indicator #30 of the Millennium Development Goals made the point that water and sanitation coverage should be increased in *both* urban and rural areas. This is important since urban coverage is often easier because the population is denser. For this reason, the JMP has included coverage levels for both urban and rural areas of each country and region. While most of the categories above have improved in Peru since 1990, only rural water coverage is on track to meet its target by 2015. Sanitation coverage has improved but is not halfway to its Millennium Development Goal of halving the proportion of people without access to improved sanitation.

It is concerning that the urban water coverage actually decreased between 1990 and 2002. This is most likely exacerbated by the fact that the Peruvian population is moving to the cities. Between 1990 and 2002, the percentage of Peruvians living in urban areas has increased from 69% to 74%. This means that much more work will need to be done to increase improved drinking water coverage to the population growth in the cities, which has probably occurred largely in peri-urban neighborhoods and slums. At the same time, even though drinking water coverage has increased the most in rural areas to 66%, it is still far behind the urban coverage of 87% (JMP, 2004).

Since this thesis focuses on rural water supply, it is interesting to look more closely at the rural water statistics in Peru. Great improvements have been made in water coverage in the rural areas. In addition to overall improved drinking water access increasing from 42% to 66%, the household water connections have also increased from 16% to 40%, serving an additional 24% of the rural population (JMP, 2004). The residents of the town where most of this thesis' study occurred, Cerrito Buena Vista, not only had "improved access" to drinking water but also had household-level water connections. This means that most of the households included in this study are part of that 40% *with* improved access and household connections to drinking water. As this study will show, the water from these "improved" household connections contained high levels of microbial contamination, which reinforces the warning that "improved access" does not necessarily mean "safe water quality." It is for this reason that it is important to investigate ways to *treat* drinking water in addition to providing more people with improved water supply technologies.

Further evidence that improved water sources do not necessarily produce safe water was provided to the H_2O-1B! team by the Ministry of Health in Arequipa from their microbiological analyses. Water samples were collected from household connections after treatment and subsequent distribution from the small water treatment plants in the towns of Cerrito Buena Vista (CBV), Los Médanos, and Leche Gloria. The water quality results along with the permissible limits for each constituent are listed in Table 1-6.

Table 1-6: Water Quality Tests at Household Connections in Towns with WTPs. Source: Ministry of Health - Arequipa, 2003.

	CBV	Los Médanos	Leche Gloria	Permissible Limits
Total Coliform [CFU/100ml]	1.3×10^3	3.0×10^3	5.0×10^3	0
Fecal Coliform [CFU/100ml]	4.0×10^1	1.1×10^3	1.7×10^3	0
Chlorine Residual[1] [mg/L]	0.0	0.0	0.0	0.2 – 1.0

[1] This limit is based on WHO guidelines (WHO, 2004), while the other limits were provided in the report from the Ministry of Health.

Even though the water samples in the study were collected from an "improved water supply technology," i.e. a household connection, the test results listed in Table 1-6 indicate that their coliform levels were too high and chlorine residual levels were too low. (Chlorine residual should be present in concentrations from 0.2-1.0 mg/L after water treatment by chlorination to ensure that sufficient chlorine was available to inactivate all microbial pathogens.) Fecal coliform in the water indicates the presence of fecal contamination, which can be very harmful if consumed. These results support the idea that "improved access" does not necessarily mean "safe water quality."

1.3 Water-Related Disease

The World Health Organization proclaims that "water is essential to sustain life, and a satisfactory – adequate, safe, and accessible – supply must be available to all" (WHO, 2004). Many diseases can be avoided by the availability of an adequate supply of clean water. These diseases are referred to as "water related" diseases.

Water related diseases fall under four categories: water-borne, water-washed, water-based, and insect-vector. Each type of disease is aided in some way by poor water quality or quantity. Table 1-7 summarizes the four types of diseases as presented in a technical brief entitled "Water: Quality or Quantity?" as prepared by the Water, Engineering, and Development Centre at Loughborough University (House, 2004). The brief stresses the importance of improving both water quality *and* quantity in addition to promoting good sanitation and hygiene for the prevention of disease and illness.

Table 1-7: Water Related Disease Transmission and Preventative Strategies. Source: House, 2004.

Classification	Transmission	Examples	Preventative Strategies
Water-borne (these can also be water-washed)	Disease is transmitted by ingestion	Diarrheas (e.g. cholera) Enteric fevers (e.g. typhoid) Hepatitis A	Improve *quality* of drinking water Prevent casual use of unimproved sources Improve sanitation
Water-washed (water scarce)	Transmission is reduced with an increase in water quantity; includes infections • of the intestinal tract • of the skin or eye • caused by lice or mites	Diarrheas (e.g. amebic dysentery) Trachoma Scabies	Increase water *quantity* Improve accessibility & reliability of domestic water supply Improve hygiene Improve sanitation
Water-based	The pathogen spends part of its life cycle in an animal which is water-based. The pathogen is transmitted by ingestion or by penetration of the skin.	Guinea worm Schistosomiasis	Decrease need for contact with infected water Control vector host populations Improve *quality* of water (some types) Improve sanitation (some types)
Insect-vector	Spread by insects that breed or bite near water	Malaria River blindness	Improve surface-water management Destroy insects' breeding sites Decrease need to visit insects' breeding sites Use mosquito netting Use insecticides

Prevention of water-borne diseases requires improved *quality* of water, while prevention of water-washed diseases requires an increased *quantity* of water. This thesis, then, which focuses on in-home water treatments, is involved with the prevention of mostly water-borne and some water-based diseases.

* * *

It is important to ensure that the quality and quantity of water that people are able to collect prevents them from contracting disease. Unfortunately, many countries and areas of the world do not have the infrastructure or the resources to treat all drinking water to the high quality expected in developed countries nor even the ability to treat water in any way on a community-wide basis. Because of the concern of governments, NGOs (non-governmental organizations), and private enterprises for the health of the people in these particular areas, some groups have begun to focus on household-level systems as an appropriate alternative to drinking water treatment where community-wide treatment plants may not be feasible or may not treat the water adequately.

In order to assist in the provision of safe drinking water, the WHO has established guidelines for drinking water quality as well as advice and information on many topics relating to water quality. The purpose of its publication *Guidelines for Drinking Water Quality* is to provide information and guidelines regarding drinking water so that each country can establish its own appropriate and effective water standards, recognizing that each area has specific circumstances and needs. These *Guidelines* are discussed further in Chapter 2.

1.4 "H_2O-1B!: Clean Water for One Billion People!" Projects through MIT

1.4.1 Purpose of the Projects

The Environmental Engineering Master of Engineering program at the Massachusetts Institute of Technology (MIT) seeks to find technically sound, socially acceptable, low-cost household drinking water treatment options for households in developing countries that either do not have access to an improved water source or do have access but need extra treatment at the point of use to ensure safe drinking water. This goal specifically addresses those households with access to water that is unfit to drink and without the means to purchase expensive household treatment systems. These households are often located in rural areas or peri-urban slums, since the central districts of cities are more likely to have water treatment plants and piped systems that provide clean, or at least improved, water to their urban residents. In rural areas of developing countries, because of the distance between houses or the small size of villages or the lack of money for infrastructure, it may be most reasonable to treat water at the household level. Unfortunately, most household drinking water treatment systems or methods that work well are too expensive for most of the one billion people without access to clean water. It is for these reasons that the MIT Master of Engineering (MEng) Department seeks to find appropriate technically sound and socially acceptable *low-cost* drinking water treatment approaches. The program working toward this goal, and the teams associated with it, are called *H_2O-1B!: Clean Water for One Billion People!*

The program's water and sanitation teams are led by Susan Murcott, Lecturer and Research Engineer in the Civil and Environmental Engineering Department at MIT, and have included MEng students in Civil and Environmental Engineering, business students from the Sloan School of Management, policy and planning students from the Department of Urban Studies, Mechanical Engineering students, and others. These teams have sought to acquire knowledge about possible low-cost household water treatment systems (HWTS) by looking all over the world to learn from the technologies that other countries and companies have already developed. They investigate expensive and inexpensive designs to discover which technologies work and why. Team members look for inexpensive and local methods to manufacture the equipment necessary for the treatment technologies. The participants travel to developing countries where they learn about water treatment programs first-hand and evaluate the technical performance of the various systems to see how well they perform. Sometimes students build upon ideas that were seen in the field, create their own treatment systems, or help to implement or monitor pilot programs with new or existing technologies. All of these experiences, observations, and test data can be combined to help further the investigation and development of low-cost treatment options that may be implemented in new areas without improved or safe drinking water sources. The ultimate goal is to find or produce HWTS that effectively reduce water-related diseases, that are socially acceptable, and that are inexpensive, and then to find ways to disseminate the technology and implement programs so that their use and affordability are sustainable.

1.4.2 History of the Projects

Since the autumn of 1998, fourteen teams of MIT MEng students have investigated safe drinking water and sanitation solutions for developing countries in Nepal, Brazil, Haiti, Nicaragua, the Dominican Republic, and Peru.

Some of the past years' projects include:

- Local manufacture, dissemination, and monitoring of a slow sand filter in Nepal
- Addition of an arsenic removal step to the slow sand filter by Tommy Ngai in Nepal[2]
- Evaluation of the Safe Water System in Nepal and Haiti
- Investigation of solar disinfection ("SODIS") in Nepal and Haiti
- Analysis of the "Potters for Peace" ceramic pot filter in Nicaragua
- Manufacture of a ceramic disc filter in Nicaragua

H20-1B! projects thus far can be categorized into one or more of the following ten areas of investigation (Murcott, 2004):

1. Simplified field-based laboratory methods
2. Water quality and site investigations
3. Technology evaluations (existing household water treatment options)
4. Technology design and innovation
5. Technology comparisons
6. Manufacture, quality control, operation, and maintenance
7. Management, business, and finance
8. Pilot projects
9. Implementation and scale-up
10. Project monitoring, surveys, and overall project assessment

The investigations during the academic year 2003-2004 took place in the Dominican Republic and Peru. They involved the cooperation of civil and environmental engineering students with business students, each investigating different aspects of clean drinking water provision in developing countries. While the engineering students focused on the technical performance and social acceptability of treatment systems, the business students investigated the willingness to pay for the systems and the feasibility of a financially sustainable dissemination of the technologies.

The use of an intermittent slow sand filter, called the Biosand filter, was investigated in the Dominican Republic by Kori Donison[3] (Environmental Engineering MEng '04), Heather Lukacs (Environmental Engineering Lecturer), Teresa Yamana (Environmental Engineering undergraduate '04), and Jeff Cerilles (MIT Sloan School of Management student).

[2] See Ngai's thesis (Ngai, 2002)
[3] See Donison's thesis (Donison, 2004)

In Peru, a household chlorination program, as well as the use of an indigenous sand-and-ceramic filter called the Table Filter, were investigated by Brittany Coulbert (Civil Engineering MEng ’05), Susan Murcott (Environmental Engineering Lecturer), Charlene “Charlie” Lieu (Sloan student), and Anya Obizhaeva (Sloan student).

The technical study that took place in Peru, which this thesis details, was focused on numbers two, three, and five of H_2O-1B!’s investigation categories listed above: site investigation, water quality testing, evaluation of a technology, and the comparison of two technologies. At the same time, the business students investigated numbers six and seven: the manufacturing and financing possibilities associated with the technologies that would increase their sustainability and widen their dissemination.

1.4.3 Invitation to Peru

In 2003, Mauricio Pardón, the director of CEPIS – a regional center of the Pan-American Health Organization (PAHO) located in Lima, Peru – invited Murcott and her students to evaluate its water treatment program and give feedback and recommendations in three areas:

- technical performance,
- social acceptance, and
- economic affordability.

Since Pardón prioritized a technical evaluation of the performance of CEPIS’ two household water treatment technologies, this report (which summarizes the study of the author) focuses on performance tests and data analysis. Research by Coulbert also included a cursory evaluation of user satisfaction and feedback in the form of surveys. Lieu and Obizhaeva, the two business students who accompanied Murcott and Coulbert to Peru, focused on the business aspects: economic affordability, willingness to pay, low-cost manufacturing strategies, and marketing/dissemination practices for sustainability.[4]

CEPIS and Peru’s Ministry of Health hosted the four researchers for three weeks as they traveled to different implementation sites, met with system users and governmental officials, and conducted tests and interviews.

[4] See the business report: “H2O-1B!: Bringing Safe Water to the World” (Cerilles, et. al., 2004).

1.5 An Overview of This Study

1.5.1 Work in Peru

1.5.1.1 The Author's Visit to Peru

During January of 2004, Brittany Coulbert, the author of this report, traveled with a team (listed above) to Peru to study CEPIS' current HWTS: the Table Filter and the Safe Water System (i.e. household chlorination, safe storage, and education). They learned about the HWTS program by talking with CEPIS engineers, Ministry of Health workers, and water treatment system users. They learned about the level of satisfaction with the program and technologies by talking to users and technicians. They also saw first-hand the frustrations regarding the lack of access to safe water as well as the difficulties of collecting information in the field and running a program well when funds are limited.

When they arrived in Peru, Coulbert and Murcott met with engineers from CEPIS in Lima to learn about the program and then, accompanied by Luis Valencia Sifuentes, a senior engineer at CEPIS in charge of this household treatment program, visited sites in Arequipa and Tacna – the two regions of implementation – to gain an overview of the entire program in both geographic areas.

After the week of site visits to towns in Arequipa and Tacna, the La Joya District of Arequipa was selected as the area of focus for the H_2O-1B! team's study. In order to make even greater use of the January field study time, Coulbert interviewed and selected three Peruvians to assist the team from MIT with translation and research. All three women from Peru lived in the city of Arequipa and were chemical engineering students or graduates of San Augustine National University. They helped to translate and interpret since none of the MIT team could speak Spanish well. Ana Luz Gomez Begazo assisted Coulbert with interviewing and testing the HWTS in the La Joya area. Viviana Ruiz Longhi and Patricia Roxsana Ruiz del Carpio assisted Lieu and Obizhaeva in their business research.

Coulbert and Begazo conducted interviews and ran microbial and performance tests on the two types of household water treatment systems for nine days while living in La Joya, a town in the *departmento* (i.e. province) of Arequipa.

1.5.1.2 Further Study in Peru

1.5.1.2.1 H_2O-1B! San Augustine Team
After the MIT team left Peru, Longhi and del Carpio were hired to continue conducting interviews and running microbial and performance tests in CBV for an additional five weeks so that more data could be collected from households that were using the two types of treatment systems. This allowed the MIT researchers and their partners, CEPIS and the Ministry of Health, to receive more feedback on the efficacy of the water treatment systems. Their work, generally referred to as the March 2004 study period in Peru, is considered an extension of the research started by the MIT team in January and therefore is fully included in the data presented in this

thesis. Since their research and testing techniques were nearly identical to those used in January by the author and Begazo, the findings of Longhi and del Carpio are considered part of the same Peru data set. Their report, "Evaluation of Household Systems in La Joya" (Longhi, 2004) was given to Murcott and Coulbert for inclusion in this thesis. The entire report, excluding the accompanying data spreadsheets, is included here as Appendix A. The San Augustine team concluded that the Table Filter is the best HWTS for the town of CBV.

1.5.1.2.2 H_2O -1B! Business Team

Lieu and Obizhaeva, the Sloan business students, with the assistance of Longhi and del Carpio, researched the economics of the HWTS in Peru during January 2004. They investigated the willingness to pay of current and potential users, and they looked for less expensive ways to manufacture or procure the materials needed for the two HWTS. Lieu and Obizhaeva, along with Cerilles, who was part of the H_2O-1B! Dominican Republic team, presented their report in the paper "H_2O-1B!: Bringing Safe Water to the World" (Cerilles, 2004). The executive summary of this report is included here as Appendix B. Their conclusion was that the success of the program related directly to the level of commitment and interaction with the users by the personnel in charge of overseeing the program. They recommend the use of the SWS (household chlorination), as its cost would most likely be completely covered by users, and therefore it would be economically sustainable.

1.5.1.2.3 Agua Peru Team

Additional study of HWTS in Peru took place in the Summer of 2004 as part of the Undergraduate Research Opportunity Program at MIT. A team of three students, who named themselves "Agua Peru," spent two months in Peru, testing water from CBV and comparing four different HWTS. They compared a Household Slow Sand Filter (HSSF – based on the Biosand filter), a pair of Pozzani ceramic candle filters, a pair of Katadyn ceramic candle filters, and the Table Filter. Their evaluation of these systems in Peru is titled "Investigating the Effectiveness of a Variety of Household Water Systems on Microbially Contaminated Water in Arequipa, Peru 2004" (Malies, et al., 2004). They reported that the HSSF, Pozzani, Katadyn, and Table Filters showed average Log Reduction Values[5] (LRVs) of total coliform (TC) of 2.1, 3.0, 3.0, and 2.2, respectively. The average turbidity removal rates were 60%, 87%, 90%, and 82% for the HSSF, Pozzani, Katadyn, and Table Filters, respectively. Their comparison of the Table Filter and the Pozzani candles alone suggested that the inclusion of sand and a geotextile in the Table Filter actually *decreases* its removal efficiency of TC and turbidity. The Agua Peru results also show that the Pozzani candles alone had consistently higher flow rates than the complete Table Filter. Curiously, the Agua Peru findings are opposite to the findings of this report and other previous research by Rojas (Rojas & Sixto, 2000). As this report suggests, further research is needed on all tests before conclusive statements can be made.

1.5.2 MIT Laboratory Studies

When the MIT team left Peru in late January 2004, they brought back with them all the equipment needed to construct two Table Filters, except for the sand. Coulbert assembled both filters in the lab and sifted sand to add to the filters. Two different grades of sand were used for

[5] See Section 7.1.3.2 for an explanation of the Log Reduction Value.

the two Table Filters in order to observe the ways in which differences in sand grade might affect the performance of the filters.

In the Environmental Engineering Water and Sanitation in Developing Countries Laboratory at MIT, the author tested both Table Filters for the presence of coliform bacteria and measured for turbidity for five weeks in the spring of 2004 and for four weeks in the summer. During the spring, the tests were run simultaneously against tests on two "Biosand" filters. Donison, who researched the use and performance of these filters in the Dominican Republic, set up two Biosand filters at MIT for additional testing, run concurrently with Coulbert's tests. Donison tested one BSF *with* and one BSF *without* the addition of the geotextile that is part of the Peruvian Table Filter. The Biosand filter, which Donison tested at MIT, is a relatively low-cost filter using the slow sand filtration method. It was developed in the early 1990s by Dr. David Manz while he was working as a civil engineer at the University of Calgary (Coulbert & Donison, 2004).

During the summer of 2004, Coulbert continued investigation on the two Table Filters in the laboratory at MIT. The Table Filters, which are described in greater detail in Section 4.4, use the combination of ceramic candle filters, sand, and a geotextile cloth to treat water. The only intentional difference between the two filters set up in the MIT lab was the grade of the sands, but coliform tests from the spring produced data that was counter-intuitive to the way that Coulbert and Murcott assumed the two sand types would perform (i.e. that the finer sand would remove more coliform than the medium sand). For this reason, Coulbert decided to test the filters *without* sand to investigate the possibility that there were differences between the ceramic candles themselves. (Without sand, the two filters' data theoretically should have been identical.) After the Table Filters had been sitting unused for two months (after spring testing), Coulbert began running tests again in the summer. She tested them for two weeks with the sand (in order to establish a starting point for the summer data) and then for about two weeks after removing all the sand from both filters.

All of these testing practices are described in Chapter 7 on methodology. The results of the tests and other findings are reported in Chapter 8.

1.5.3 Objectives of This Thesis

The main objectives of this thesis are to:

1. Provide all findings and recommendations to CEPIS and the Ministry of Health in Peru for the benefit of the households using their technologies, and to provide information for CEPIS's further research and implementation of these technologies.

2. Provide information to the academic world regarding a technology about which there is little previous research, that is, the Table Filter, so that others can build upon or learn from its evaluation.

These objectives are addressed in this thesis with the following specific evaluations of the technologies and programs regarding the Table Filter and the Safe Water System (SWS) as used in Peru:

Evaluation of the Technology:

- Report and analyze results of tests for coliform, turbidity, flow rate, and chlorine residual on raw and treated water from Table Filters, Safe Water Systems, and water treatment plants in Peru.
- Report and analyze results of coliform, turbidity, and flow rate from MIT laboratory tests on the use of two different grades of sand in Table Filters.

Evaluation of the Program:

- Report and summarize responses from interviews in Peru regarding these household technologies.
- Provide observations of the Ministry of Health program and the challenges witnessed by the researchers.

1.5.4 Organization of This Thesis

In order to achieve these objectives, this paper is laid out in the following manner:
In the next chapter, the World Health Organization (WHO) guidelines for drinking water quality will be discussed. Section 3.3 provides an overview of the water treatment program that CEPIS and the Ministry of Health have implemented in southern Peru. The following three chapters then go on to describe the three types of water treatment that were evaluated in Peru: household filtration, household chlorination, and water treatment plants. Chapter 7 details all of the procedures that were followed while testing and interviewing in Peru and in the lab at MIT, and Chapter 8 summarizes the results of those procedures. Chapters 9 and 10 provide discussion about the results that were obtained as well as evaluations of the treatment systems and recommendations as to how CEPIS and the Ministry of Health in Peru should proceed in their water treatment program, as well as areas of further possible investigation by other researchers.

2. WHO Guidelines for Drinking Water Quality

"Diseases related to contamination of drinking-water constitute a major burden on human health" (WHO, 2004). The World Health Organization has addressed this concern by providing guidelines and explanatory material in its *Guidelines for Drinking Water Quality* in order to assist countries in providing "satisfactory" water to their residents. The *Guidelines* represent the views regarding drinking water quality and health of the United Nations' group "UN-Water," which coordinates the 24 UN agencies and programs concerned with water. The WHO believes that "every effort should be made to achieve a drinking-water quality as safe as practicable" (WHO, 2004).

2.1 History of the Guidelines

The World Health Organization was founded in 1948 as the UN "directing and coordinating authority" on issues of public health. It produces numerous publications in order to provide information and advice relating to health matters (WHO, 1993).

The WHO published "International Standards" regarding water quality in 1958, 1963, and 1971, which were superceded by the First Edition of the *Guidelines for Drinking Water Quality* in 1983-84 (WHO, 1993). This edition was revamped in the 1990s, and Volumes 1, 2, and 3 of the Second Edition were published in 1993, 1996, and 1997, respectively. In 1995, it was agreed that the *Guidelines* should be continually reviewed and updated as new knowledge was gained. This led to the publication of three addendums to Volume 2 on chemical and microbial issues in 1998, 1999, and 2002, as well as other articles addressing water quality issues. In the year 2000, a plan of work was agreed upon for a completely revised, updated, and expanded Third Edition. Volume 1 of this edition was published in 2004 and contains the most current information on water quality and provision (WHO, 2004).

2.2 Application of the Guidelines

The WHO stresses that national and local water quality standards should be created for the purpose of providing people with safe drinking water, not for the purpose of shutting down poor-quality water systems. To this effect, short- and medium-term goals and expectations can be set for water suppliers whose water quality is below ideal national standards. Given time and intermediary steps, these suppliers could improve their water quality. Based on the circumstances of each country, its national standards may be less stringent than the WHO guidelines and may focus on specific local priority concerns. "Modest but realistic goals," especially when updated periodically, may achieve a larger improvement in the quality of water than "overambitious" goals that seem impossible to reach (WHO, 2004).

The WHO recognizes that some countries or regions have more work ahead of them than others before they can reach high water quality standards. It is for this reason that the *Guidelines* are just that: guidelines, not international *rules*. They provide information on water contamination and water supply surveillance, as well as ideas about ways to establish, monitor, assess, and support water sources and service providers in a manner that will benefit the water-related health of a country. Each country or region is then left free to use this information and these guidelines to establish its own local standards that are appropriate and reasonable to provide effective improvement of drinking water.

2.3 Third Edition of the Guidelines

"Safe drinking water, as defined by the *Guidelines*, does not represent any significant risk to health over a lifetime of consumption" (WHO, 2004). This is the goal of the WHO *Guidelines*: to assist in making possible the provision of safe drinking water so that people can live healthier lives.

2.3.1 Differences Between the 2nd and 3rd Editions

The Third Edition of the *Guidelines* has revised and expanded upon the information contained in the Second Edition. Sections on risk management have been added, as well as applications for specific water situations such as large buildings, ships, disasters, and traveling. Information on some chemicals that were not previously included have been added, as well as additional information on the prevention of microbial contamination, which has been deemed to be the greatest hazard to drinking water. This latest edition has added an evaluation of the roles and responsibilities of different stakeholders in the issues of water supply, as well as different approaches to managing *large* versus *small* community and household water supplies. Since water supplies vary widely between regions, the Third Edition has included methods of evaluation to help countries analyze the status of their water supplies (WHO, 2004).

A specific example of a difference between the Second and Third Editions is given in Section 2.4.1.4 in regard to the treatment of the guidelines for E.coli and thermotolerant coliform presence in drinking water.

2.3.2 General Topics Covered by the 3rd Edition *Guidelines*

The *Guidelines* address microbial, chemical, radiological, and acceptability aspects of drinking water. While this chapter and this thesis focus primarily on microbial contamination in drinking water, all of the components mentioned above are important parts of water quality assessment. Microbial, chemical, and radiological contamination can negatively impact the health of users, and acceptability aspects – appearance, taste, and odor – can influence the willingness of people to use a water source. The *Guidelines* provide information on each type of contamination in addition to threshold levels and possible treatments. The guidelines for specific constituents examined in this study are covered in more detail in Section 2.4 (WHO, 2004).

Ensuring that people have reasonable access to safe water supplies requires more than just source protection and, if necessary, water treatment. It also involves collecting data about waters, suppliers, and users; educating the public about hygienic water practices; fixing and adding quality infrastructure; assisting suppliers in their ability to supply affordable and safe drinking water; establishing ongoing surveillance and maintenance programs; and instituting standards and priorities that are realistic and will accomplish the most good for the people (WHO, 2004).

All of this information is provided so that local governing bodies can make informed decisions about procedures for improving drinking water quality and availability in their respective jurisdictions.

2.3.3 Other Factors Influencing Water's Effect on Health

The WHO has identified that the important health factors concerning water are: **quality**, **quantity**, **accessibility**, **affordability**, and **continuity** (WHO, 2004). The importance of the quality of water is relatively self-explanatory and will be covered in respect to the specific contaminants addressed in this thesis in the following section. The other factors are covered very briefly here.

2.3.3.1 Quantity

Water is required for hydration, food preparation, and hygiene. The WHO claims that a minimum of 7.5 L is adequate for most people per day for hydration and "incorporation into food." Beyond this amount, additional water is generally needed for food preparation, laundry, domestic cleaning, personal hygiene, and can also be used for income generation and household amenities (WHO, 2004).

The amount of water collected and used by a family usually is tied strongly to the amount of trouble that collection requires (e.g. the distance of the water source from the home). The term "service level" often is used as an indicator of household use and is evaluated as an alternative to measuring the actual amount of water that a household collects. The WHO has classified levels of service by describing a household's access to water as *none*, *basic*, *intermediate*, or *optimal*. An explanation of the WHO's classification follows (WHO, 2004):

- *No Access*
  People living over 1 km from a water source, or 30 minutes round trip, are considered to have no access to water. They likely collect less than 5 liters per capita per day (lpcd). It is this population without access to water, in addition to those who only have access to "unsafe" water, that the UN Millennium Goals admonish world leaders to halve by the year 2015 (UN, 2003).

- *Basic Access*
  Those living *within* 1 km, or 30 minutes round trip, from a water source have basic access and probably consume approximately 20 lpcd.

- *Intermediate Access*
  Households with intermediate access have at least one water tap on their plot of land, usually in the yard. This level of access describes the majority of the houses in Peru that were served by the household treatment systems studied in this thesis. A few houses that were visited would be considered to have basic access.

- *Optimal Access*
  Optimal access describes most households in the U.S. and refers to having multiple water taps within the home. It must be remembered that even "optimal access" does not mean access to *safe* drinking water.

2.3.3.2 Accessibility

"From the public health standpoint, the proportion of the population with *reliable access to safe drinking-water* is the most important single indicator of the overall success of a drinking-water supply programme" (WHO, 2004)[6].

"Reasonable access" to improved drinking water sources is "the availability of at least 20 [lpcd] within [1 km] of the user's dwelling," as defined by the WHO/UNICEF Joint Monitoring Programme. It is only considered "reasonable access" if the water source is classified as an "improved water supply technology" (WHO, 2004). As presented in Section 1.2 of this thesis, the JMP's classifications of improved and unimproved water sources are as shown in Table 2-1.

Table 2-1: Classification of Water Supplies as "Improved" and "Unimproved." Source: WHO, 2004.

Improved Water Supply Technologies	Unimproved Water Supply Technologies
Household connection	Unprotected well
Public standpipe	Unprotected spring
Borehole	Vendor-provided water
Protected dug well	Bottled water
Protected spring	Tanker truck water
Rainwater collection	

2.3.3.3 Affordability

It is important that safe drinking water be made *affordable* as well as simply *available*. When poor families cannot afford adequate access to safe drinking water, they may resort to buying water from cheaper sources that may have higher levels of contamination, or they may use less water, which could reduce their defenses against water-washed diseases. When assessing costs

[6] Italics added for emphasis.

of water supplies, ongoing costs as well as capital set-up costs should be considered and measured at the point of user purchase (WHO, 2004).

2.3.3.4 Continuity

Interruptions in a continual supply of water can affect water accessibility as well as quality. Seasonal variance in water availability may cause users to seek out inferior sources. Frequent interruptions in availability through a piped system can increase the chance of contamination or regrowth in the pipes (WHO, 2004).

2.4 Guidelines and Explanations Specific to this Thesis

2.4.1 Microbial Contamination

"The most common and widespread health risk associated with drinking water is microbial contamination, the consequences of which mean that its control must always be of paramount importance" (WHO, 2004). Diseases transmitted through water are caused by the presence of pathogenic bacteria, viruses, and parasites (which include protozoa & helminths). Each of these categories includes many microorganisms that harm our bodies in different ways. They come in different shapes, sizes, and forms, and they react to disinfectants differently (WHO, 2004). The large and numerous variations between pathogens make it impossible to remove or destroy all potential water contaminants with one type of treatment. For this reason, it is beneficial to identify and target the contaminants of largest concern in each specific water source. This is especially true when funds limit the number of successive treatment steps or types that can be performed.

<u>The WHO identifies that the greatest risk from microbes in water is associated with consumption of drinking water that is contaminated with human and animal excreta.</u> This is because pathogens that are easily transported in water often infect the gastrointestinal tract and become transmitted through the feces of humans and animals. For this reason, low-cost household water treatment programs generally focus on the removal of fecal bacteria. Diseases resulting from fecal-oral transmission can also be caused by other poor hygiene practices. General good hygiene and excreta disposal practices are important, as well as an adequate *quantity* of water (to combat transmission of water-washed diseases), in order to halt fecal-oral disease transmission (WHO, 2004).

Instead of measuring disease-causing bacteria directly, it has become standard practice to test for the presence of "indicators." Coliform bacteria are the most commonly-measured indicator bacteria used to test for the presence of fecal contamination since both coliforms and enteric (intestinal) bacterial pathogens are caused by fecal contamination in water. Coliforms were first used as indicator organisms by Phelps in 1909. Indicators are used to test both the level of source water contamination as well as the efficacy of treatment. A list of qualities for the ideal indicator were proposed by Bonde in 1966 as presented in Table 2-2 (AWWA, 1999).

Table 2-2: Characteristics of the Ideal Microbial Indicator. Source: AWWA, 1999.

The ideal indicator must:
1. Be present whenever the pathogens concerned are present;
2. Be present only when the presence of pathogens is an imminent danger, that is, be unable to proliferate to any greater extent in the aqueous environment;
3. Occur in much greater numbers than pathogens;
4. Be more resistant to disinfectants and to the aqueous environment than pathogens;
5. Grow readily on relatively simple media;
6. Yield characteristic and simple reactions enabling, as far as possible, an unambiguous identification of the group;
7. Be randomly distributed in the sample to be examined, or be able to be uniformly distributed by simple homogenization procedures; and
8. Grow widely independent of other organisms present when inoculated in artificial media, that is, not be seriously inhibited in growth by the presence of other bacteria.

Further investigation by the WHO has suggested that a single organism may not be the best indicator of both the presence of fecal contamination in source water *and* the relative effectiveness of treatment processes. For this reason, a differentiation between terms has been suggested: an *index organism* would point to "the presence of pathogenic organisms," and an *indicator organism* would serve to "measure the effectiveness of a process" (WHO, 2004).

Also, researchers have realized that E.coli, the preferred coliform indicator organism, is not effective in indicating the presence of enteric viruses and protozoa. Alternative indicators, such as bacteriophages and bacterial spores, have been suggested for finding the presence of those pathogens (WHO, 2004).

2.4.1.1 Total Coliform

Coliform bacteria are the most common bacteriological indicator for fecal contamination. Coliform refers to a wide range of bacteria that are Gram-negative, non-spore-forming, and "capable of growing in the presence of relatively high concentrations of bile salts with the fermentation of lactose and production of acid or aldehyde within 24 hours at 35-37^{o}C" (WHO, 2004).

Total coliform (TC) concentration is commonly measured in water because "the absence of [total] coliforms ensures the absence of fecal coliforms, which is a conservative standard." It is not the best indicator of fecal contamination, however, as TC may be present when fecal contamination is not. E.coli and thermotolerant coliform are better indicators of fecal contamination (AWWA, 1999).

Total coliform concentration can be used to help assess the effectiveness of water treatment and the general cleanliness of a water system. Total coliform should be *absent* immediately after disinfection. If TC is present in stored water, it could indicate regrowth & biofilm formation. In general, TC should not be present in drinking water. Heterotrophic plate counts (HPC) give a better indication of overall system cleanliness than TC, since HPC detects other microorganisms as well (WHO, 2004).

2.4.1.2 Thermotolerant Coliform

Thermotolerant coliform (TTC), sometimes known as fecal coliform, are those coliform bacteria capable of fermenting lactose at 44-45^{o}C (WHO, 2004). It is a more selective indicator than TC, since those coliform that are not "thermotolerant" cannot survive at the higher incubation temperature (AWWA, 1999). E.coli, a type of TTC, is considered the most reliable indication of recent fecal pollution, and TTC is a good second alternative. Both of these are preferred as indicators over total coliform (WHO, 2004).

2.4.1.3 E.coli

Escherichia coliform, the most prevalent genus of TTC found in water, is more commonly known as E.coli. Only some E.coli strains are harmful, but E.coli in general is an excellent indicator of fecal contamination as well as a good indicator of the general water quality. <u>Any detection of E.coli in drinking water should lead to further action, since it indicates inadequate levels of treatment.</u> Some strains of E.coli can cause acute diarrhea and other symptoms such as vomiting, fever, and malnutrition, all of which can be more severe in children under five (WHO, 2004).

E.coli can also be used as a disinfection indicator, but direct measurement of disinfection (e.g. chlorine) residual is faster and more reliable (WHO, 2004).

2.4.1.4 Guidelines for E.coli and TTC

The absence of E.coli or TTC does not necessarily indicate the absence of enteric viruses or protozoa, which resist disinfection more readily than E.coli. Indicators do, however, provide a margin of safety, because they are usually present in larger concentrations in polluted water than are general enteric pathogens. However, the WHO *Guidelines* instruct that E.coli and TTC should *not* be present in drinking water (WHO, 2004).

One area of difference between the Second and Third Editions of the WHO *Guidelines* concerns the way in which the E.coli and TTC guidelines are treated. The Third, and current, edition of the *Guidelines* states that *E.coli or TTC should not be detectable in any 100ml sample of drinking water*, but it recognizes that in many developing countries fecal contamination may be largely present in source waters, so it suggests that medium-term goals should be set for the continual improvement of water treatment (WHO, 2004).

In the Second Edition, the guidelines concerning E.coli and TTC are the same as in the Third: they "must not be present in 100-ml samples of any water intended for drinking." The Second Edition also says that some TC in up to 5% of samples over 12 months is acceptable as long as there is no E.coli present. Then it goes on to say that "this criterion is readily achievable by water treatment" (WHO, 1993). This statement seems to imply that all countries should easily be able to meet this goal and that treating the water more effectively should not be a difficult task. This implication does not seem reasonable.

To be fair, the introductory paragraphs of Volume 2 of the Second Edition do assert the flexibility of the guidelines: “The final judgement as to whether the benefit resulting from the adoption of any of the guideline values given here as standards justifies the cost is for each country to decide. What must be emphasized is that the guideline values have a degree of flexibility and enable a judgement to be made regarding the provision of drinking-water of acceptable quality” (WHO, 1996)

But the Third Edition seems to include better recognition of, or at least more advice concerning, the importance of flexibility and realistic (and sometimes intermediary) goals. In contrast to the Second Edition’s “readily achievable” statement, the Third Edition says that “individual values *should not* be used *directly* from the tables”[7] where the guidelines are listed. Instead, the values “should be used and *interpreted* in *conjunction* with the information contained in these *Guidelines*.”[8] In seeking to assist governments in formulating standards, the Third Edition suggests that “national or local authorities may wish to apply specific characteristics of their populations [or local conditions] in deriving national standards” (WHO, 2004)

The Third Edition also provides *alternatives* to strict enforcement of the guidelines. “In many developing and developed countries, a high proportion of small-community drinking-water systems fail to meet requirements for water safety. In such circumstances, it is important that realistic goals for progressive improvement are agreed upon and implemented.” Water sources and treatment facilities can be rated according to degree of treatment so that priority action can be focused on those with the worst contamination (WHO, 2004).

Table 2-3: Categorization of Drinking-Water Systems Based on Compliance with Performance & Safety Targets. Source: WHO, 2004.

Category of Water System Quality	Percentage (%) of Samples Negative for E.coli		
	Population served by system:		
	< 5,000	5,000-100,000	> 100,000
Excellent	90	95	99
Good	80	90	95
Fair	70	85	90
Poor	60	80	85

Table 2-3, from the WHO *Guidelines*, rates the quality of water treatment systems based on the percentage of water samples collected that test negative for the presence of E.coli. Using this system, improvements can be targeted to those water systems that are considered poor or fair. If every community is deemed to have “poor” water quality, a different evaluation method should be created to determine which systems have highest priority. For example, if E.coli is detected

[7] Italics added for emphasis.
[8] Italics added for emphasis.

in every sample, a similar grading method could be applied using instead the *average* amount of E.coli detected in 100ml samples. Priority could also be influenced by the population size affected by the system, by the number of children and elderly users, or by the ease of improving the system (the most efficient impact).

2.4.1.5 HPC

Heterotrophic plate counts (HPC) detect heterotrophic microorganisms, including bacteria and fungi, that are able to grow on rich growth media without inhibitors or selective agents. This includes organisms both sensitive and resistant to disinfection and those able to multiply in the absence of residual disinfectant. Despite this wide range, HPC still includes only a small portion of microorganisms present in water (WHO, 2004).

HPC is not a good indication of pathogens, but it is good for assessing the effectiveness and/or cleanliness of a system. The actual concentration of HPC is not as useful as the change in concentration measured throughout a treatment or distribution system. The general goal is to keep HPC as low as possible in the system (WHO, 2004).

HPC organisms can be affected by treatment processes and may *decrease* from coagulation and sedimentation treatments, but *increase* with activated carbon or sand filtration treatments. They reduce significantly from disinfection and so can also be used as a disinfection indicator (WHO, 2004).

2.4.2 Turbidity

Turbidity, which is explained in more detail in Section 4.1.1, affects both visual acceptability and disinfection ability. The WHO *Guidelines* suggests, regarding visual acceptability, that people are generally willing to drink water that is less than or equal to 5 NTU. When disinfectants are employed, the turbidity ideally should be less than 0.1 NTU for effective disinfection (WHO, 2004).

2.4.3 Chlorine

Chlorine, which is covered in further depth in Chapter 5, is included in the chemical section of the *Guidelines*, which says that the conservative upper limit of chlorine concentration should be 5mg/L. This guideline was set by determining the amount of chlorine that would be unhealthy to consume, treating chlorine as a chemical, not as a disinfectant. It implies that water should be dechlorinated if the concentration is above 5 mg/L. In the context of this study, however, chlorine is added to the water in order to disinfect it. A certain level of concentration is desired after equilibrium is established between the chlorine and the microbes that it inactivates, creating a buffer beneficial to the chlorine and not the pathogens. While the *Guidelines* does not provide a recommended residual concentration for disinfection, it does state that chlorine generally occurs in treated water at 0.2-1.0 mg/L. This range is assumed to be the target residual concentration for this evaluation. At levels of 0.6-1.0 mg/L, users may object to the taste, although some users may taste chlorine at concentrations as low as 0.3 mg/L. Thus, for user acceptability purposes, it is wise to limit the chlorine concentration to 1 mg/L (WHO, 2004).

2.5 Local Guidelines

CEPIS, a technical support agency of the Pan-American Health Organization (PAHO) in Peru, developed a report describing recommended guidelines and water supply surveillance procedures. This report was a result of the cooperation agreement between PAHO and US EPA (Environmental Protection Agency), addressing their commitment toward the Plan for the Improvement of Water Quality in Latin America and the Caribbean. The *Guidelines for the Surveillance and Control of Drinking Water Quality* was drafted by Ricardo Rojas, a CEPIS senior water quality expert, with input from other international experts on drinking water quality. The report instructs that in addition to water *quality*, the quantity, continuity, and reasonable cost of water also must be provided to system users (Rojas, 2002).

Rojas' report provides guidelines through case studies. The section on the "Surveillance of the Quality of Rural Water Supply Services" presents a case study in the province of Cuzco, Peru (north of Arequipa, where this thesis' research occurred). The case study of Cuzco may be viewed as an appropriate locally-specific guideline for comparison to this thesis' study area in Arequipa because both study areas are rural regions of southern Peru. The Cuzco Ministry of Health approved the parameters to be used to evaluate water quality in the Cuzco case study's Drinking Water Quality Surveillance Program. In addition to providing parameters, the case study outlines the frequency of water sample collections required for each type of test. Parameters and sampling frequencies are set for many constituents of drinking water, but only those relevant to this thesis are reported here (Rojas, 2002).

2.5.1 Coliform Parameters

The bacteriological parameters include goals for both total and thermotolerant coliform concentrations. Water sampled at the entrance to the distribution system (exiting the treatment plant) should contain 0 CFU/100ml[9] of TC and TTC in 100% of the samples taken each year. For water samples collected *within* the distribution network, 100% of the samples should result in 0 TTC CFU/100ml. In regard to total coliform, however, at least 95% of the samples tested throughout the year should result in 0 TC CFU/100ml, and the Ministry of Health has agreed to accept up to 10 TC CFU/100ml distributed "sporadically in non-consecutive samples" (Rojas, 2002). This 95% guideline is based on a value given in the Second Edition of the WHO *Guidelines*, as explained above in Section 2.4.1.4.

[9] Coliform test results are presented in CFU/100ml: colony-forming units per 100 ml.

2.5.2 Turbidity Parameters

In order that water be acceptable to users, it is *recommended* that turbidity be a maximum of 5 NTU, although it is *admissible* up to 10 NTU (Rojas, 2002). This is an example of how local standards can be set at lower "admissible" levels while the ideal levels remain in place as "recommended" goals.

2.5.3 Sampling Frequency

The CEPIS report instructs that water at the entrance to the distribution network should be sampled 6 times per year for coliforms and 12 times per year for turbidity. Within the distribution network, coliforms should also be tested from 6 samples per year, and turbidity should be measured in 12 samples per year. While chlorine residual parameters are not provided, the report does instruct that it can be a useful indicator and therefore should be measured in 12 samples per year within the distribution network. The report also indicates that within the distribution network, *one* sample per location should be gathered if the population is under 200, *two* samples per location for a population of 201-800, and *three* samples per location for a population of 801-2,000 (Rojas, 2002). For example, in a town of 500 inhabitants, two samples should be collected each month to test for turbidity.

2.5.4 Chlorine Residual Parameters

In a separate study, in which CEPIS evaluated the 1995-98 chlorination program, the ideal chlorine residual concentration is listed as 0.3-0.5 mg/L for disinfection purposes (CEPIS, 2000). This is assumed to be, for the purposes of this study and evaluation, CEPIS's local guideline for Peru.

Table 2-4 summarizes the limits of indicators used in this study and evaluation as set by the WHO *Guidelines* as well as those provided in the CEPIS report and case study on water quality surveillance in Cuzco, Peru.

Table 2-4: Summary of WHO *Guidelines* and CEPIS Surveillance Guidelines Relevant to This Thesis

Indicator	Indication	WHO Guideline Limit[10]	CEPIS Guideline Limit[11]	CEPIS Sampling Frequency[12]
E.coli & TTC	Fecal contamination	Must not be detectable in any 100-ml sample[13]	TTC: 0 CFU/ 100ml in 100% of samples	6 / year
TC	Coliforms; *may* indicate fecal contamination or inadequate disinfection	Should not be present in drinking water[14]	0 CFU/100ml in 100% of samples entering DN[15] & 95% of samples w/in DN (up to 10 CFU/100ml sporadically)	6 / year
HPC	Heterotrophic microorganisms[16]	As low as possible[17]	N/A	N/A
Turbidity	Suspended particulate matter	5 NTU for acceptability; 0.1 NTU for disinfection[18]	5 NTU recommended; 10 NTU admissible	12 / year
Chlorine Residual	Residual chlorine to protect against regrowth	0.2-1.0 mg/L[19]	0.3-0.5 mg/L[20]	12 / year

[10] These values were taken from the WHO *Guidelines for Drinking Water Quality*, 3rd Edition (WHO, 2004)
[11] These values are taken from the *Guidelines for the Surveillance and Control of Drinking Water Quality* by Ricardo Rojas (Rojas, 2002).
[12] The number of samples collected within a distribution network is affected by the size of the population served by the water supply (see Section 2.5.3). This guideline simply indicates the frequency at which those samples should be taken (Rojas, 2002).
[13] WHO *Guidelines*, 3rd Edition, Volume 1, Table 7.7, page 143.
[14] This is not a strict WHO guideline, but a general recommendation by WHO. WHO *Guidelines*, 3rd Edition, Volume 1, Section 11.6.1, page 283.
[15] DN = distribution network
[16] These organisms are not known to be associated with gastrointestinal infection, but they are useful as treatment and disinfection indicators.
[17] This is not a strict WHO guideline, but a general recommendation by WHO. WHO *Guidelines*, 3rd Edition, Volume 1, Section 11.6.3, page 285.
[18] WHO *Guidelines*, 3rd Edition, Volume 1, Section 10.1.2, page 219.
[19] This is from a WHO slide presentation.
[20] This value is from a separate study by CEPIS (CEPIS, 2000).

3. CEPIS' Water Treatment Program in Peru

Chapter 1 described the reason for such a study as this regarding low-cost household drinking water treatment. This chapter provides additional information about CEPIS, the organization that hosted this study in Peru, as well as basic health and economic statistics about Peru. Here the water treatment program will also be described in greater detail.

3.1 Peru: A Backdrop

In order to set the scene for the water treatment program that is the subject of this thesis, certain basic statistics about Peru are presented. Peru is located on the Pacific coast of South America, bordered by Ecuador, Colombia, Brazil, Bolivia, and Chile (see Figure 3.1).

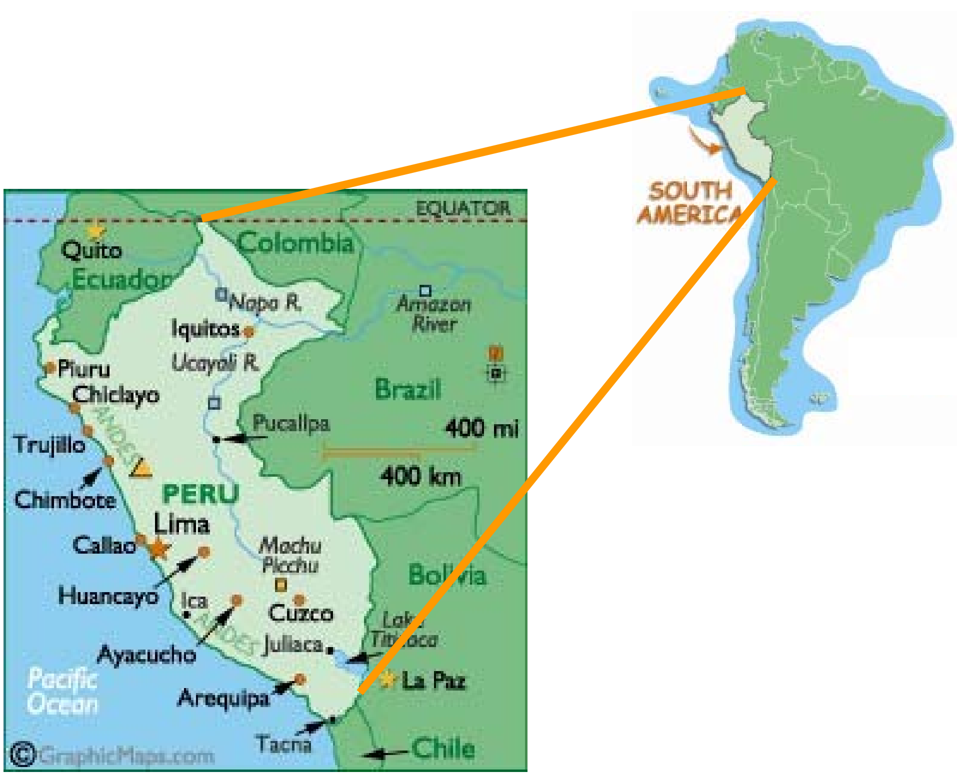


Figure 3.1: Peru and Its Location in South America. Source: GraphicMaps.com.

Peru is a country of 27.5 million people inhabiting 1.3 million square kilometers. This is slightly smaller in size than the state of Alaska, or five times the size of the United Kingdom. The GDP per capita is $5,100, compared to $37,800 in the U.S. 54% of the population of Peru is below the poverty line. The infant mortality rate in Peru is 33 per 1,000 live births. This is the 82nd highest infant mortality rate among the 225 countries listed on the CIA World Factbook website. For comparison, the U.S. has only 7 infant mortalities per 1,000 live births. The average life expectancy in Peru is 69 years compared to the U.S.'s 77 years. The literacy measurement, that is, the percentage of the population 15 years and older who can read and write, was 91% in 2003. Literacy among males in Peru, at 95%, is quite close to the U.S.'s 97% literacy for both males and females (a 1999 estimate); however, the disparity between men and women in Peru is rather notable, as literacy of females is only 87% (CIA, 2004).

Progress has been made over the years, however, as the infant mortality rate in 2000 was 33, a sharp decline from 75 in 1986. The under-five mortality rate in 2000 was 47 out of 1,000 live births, again a large decrease from 110 in 1986. The percentage of children fully immunized rose from 17% in 1986 to 56% in 2000 (Measure DHS, 2004).

The director of the Ministry of Health in Arequipa said that the literacy rate was higher than average in La Joya, the district of this study, such that "everyone" should be able to read the instructional and educational health pamphlets that are distributed with the water treatment systems (Borda, 2004).

As covered in Section 1.2.3, 81% of Peruvians in 2002 had access to improved drinking water sources, but that included only 66% of rural residents. A more thorough analysis of Peru's progress toward the Millennium Development Goals is presented in Section 1.2.3.

3.2 CEPIS: The Pan-American Center for Sanitary Engineering and Environmental Sciences

CEPIS stands for the *Centro Panamericano de Ingenieria Sanitaria y Ciencias del Ambiente*, Spanish for the Pan-American Center for Sanitary Engineering and Environmental Sciences[21]. It is part of the Pan-American Health Organization (PAHO), which serves as the Regional Office of the Americas for the WHO. CEPIS is the Regional Center of PAHO that specializes in environmental sanitation technology (CEPIS, 2004).

3.2.1 CEPIS' History of Water Treatment Projects

CEPIS was established in 1968 and is located in Lima, Peru. CEPIS is part of PAHO's Division of Health and Environment and, therefore, is responsible for undertaking tasks which further the Americas, and specifically western South America toward the UN Millennium Development Goals dealing with health, as described in Section 1.1. "The Mission of CEPIS/PAHO is to cooperate with the countries of the Americas in controlling risk factors related to deficiencies or absence of basic environmental sanitation that, directly or indirectly, affect the health of its populations" (CEPIS, 2004).

[21] www.cepis.ops-oms.org

CEPIS has implemented several drinking water treatment programs in areas outside of the cities, where good water treatment plants do not exist and water contamination can be high.

In January 1991, a cholera epidemic broke out along the northern coast of Peru, killing a reported 66 people in the first 18 days. The diarrhea and vomiting associated with severe cholera can cause the infected person to die within hours from dehydration if he or she remains untreated. Proper oral or intravenous rehydration can reduce death rates from 50% to 1%. The Ministry of Health in Peru responded to this crisis by communicating preventative measures throughout the country by way of the media, including the use of boiled water and the avoidance of undercooked seafood (CDC, 1991).

As a long-term solution to reduce the problem of poor-quality water, CEPIS started a household drinking water chlorination program in 1995. The program was located in five *departmentos* (Peru's provinces or states) of different environments: urban, suburban, rural, jungle, and mountainous. This program was implemented in the following five provinces: Lima, North Lima, Apurimac (Andahuaylas), Ucayali (Pucallpa), and Huanuco. The program involved small-scale, locally-produced chlorine generation in the hands of program participants. At the time of implementation, cholera was a current health problem in the jungle region of Ucayali. The chlorination program was shown to wipe out the incidence of cholera in the place of implementation, while surrounding areas continued to experience the presence of cholera (CEPIS, 2000; Rojas, et al., 2004).

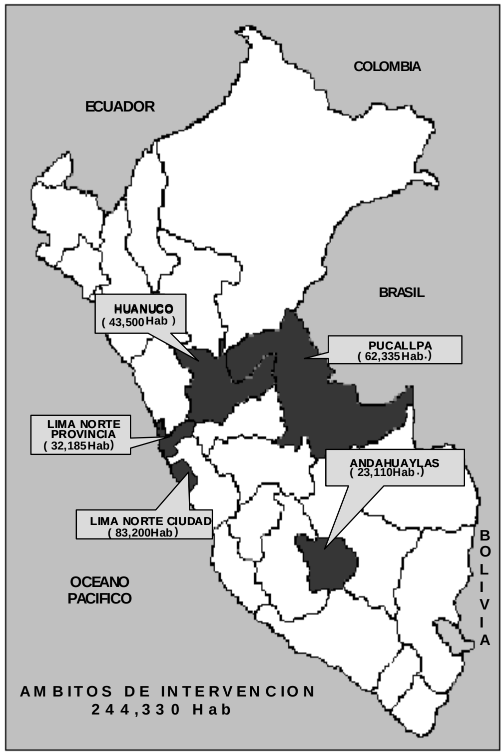


Figure 3.2: The Five Provinces of the 1995 Household Chlorination Program. Source: CEPIS, 2000.

For this program, CEPIS provided technical and social support, while the actual on-site program was run by community groups (such as NGOs and churches) and Peru's Ministry of Health. This large implementation effort involved setting up 163 small-scale chlorine generators and providing approximately 245,000 people in 448 communities with the ability to chlorinate their own water (Pardón, 2003). The chlorine solution was produced through an electrolysis process. The specifications of the chlorine generator that was used are as follows (Pardón, 2003):

- Production rate: 113 g of available chlorine per hour
- Solution: 0.8% chlorine
- Power usage: 5.5 kW per kg chlorine
- Holding tank: 4.1 kg, 18 x 100 cm
- Warranty: 2 years
- Cost: $2,000

Table 3-1 shows the costs per family that this program was estimated to require of PAHO.

Table 3-1: Costs of the Chlorine Generation Program per Family. Source: Pardón, 2003.

Implementation Costs:	**Cost per Family: (in US dollars)**
Electrolysis – Electric Chlorine Generator	$34
Electrolysis – Solar-Powered Chlorine Generator	$55
Operation Costs:	
NaOCl (Chlorine solution)	$0.16 per bottle (approx. 1 month usage)

This program was supported by CEPIS through 1998, at which point it was left in the hands of local citizens. Within a few years, nearly all chlorine generation and use had disappeared in these areas. CEPIS realized that such a program would be more sustainable if the chlorine generation and dissemination was placed in the hands of an organization that was more familiar with administering health programs: namely, the *Ministerio de Salud* (or Peruvian Ministry of Health), which has offices, labs, clinics, and hospitals in cities, towns, and villages all over Peru. It was for this reason that CEPIS partnered with the Ministry of Health to implement its current chlorination and filtration programs in southern Peru. At the time of this research study, CEPIS was also planning to work with the Ministry of Health in the original five regions of the household chlorination program in the hope that their new strategy of allowing the Ministry of Health to generate and distribute the chlorine would make the program more sustainable (Rojas, et al., 2004).

CEPIS has also implemented programs related to other health issues. For example, it established a communal sanitation project in the province of Huanuco, which involved a clean community center where people could come to wash and hang their clothes and use a sanitary toilet. This center was maintained by one worker whose home and office was part of the center (Rojas, et al., 2004).

3.3 CEPIS' Current Water Treatment Program in Southern Peru

3.3.1 Program Background

In June 2001, an earthquake measuring 7.9 on the Richter scale hit southern Peru, causing an immediate decline in the quality of surface waters. Many people living in rural Peru rely on surface waters (e.g. irrigation canals) for their drinking water supply. Also, the water supplied to villages through a piped system often receives little treatment after coming from a river or other surface water source. The surface waters in the southern Peruvian provinces of Arequipa and Tacna were of such poor quality after the earthquake that the government declared it an emergency situation. It called upon CEPIS and the Ministry of Health to help families in these areas treat their water. In response to this request, and with funds from PAHO, 1,000 filters and 400 safe water storage vessels and bottles of chlorine (plus a small-scale chlorine generator for each of the two regions of implementation) were delivered to select families free of charge during June 2003. Figure 3.3 shows a map of Peru indicating the provinces of Arequipa and Tacna.

Figure 3.3: Map of Peru and the Provinces of Arequipa and Tacna. Source: CEPIS.

Families were selected to receive a household treatment system based on their demographics. Preference was given to families with multiple children and/or elderly inhabitants, since children and the elderly are likely to be most severely impacted by the effects of water-related diseases. If a household's water was determined to be of especially poor quality or high turbidity, it was given a Table Filter. If the water seemed of moderate quality and/or low turbidity, the family was provided with a Safe Water System.

This emergency relief effort was the result of the technical, social, and financial support and cooperation of PAHO, the Belgian DGCI, CEPIS, and the Peruvian Ministry of Health. DGCI stands for the Directorate General for International Cooperation and is the Belgian government agency for international development – a Belgian equivalent to USAID. This Belgian agency funded the production of the plastic containers that are used in both treatment systems: Table Filter buckets and SWS *bidones*.

3.3.2 Program Technologies

3.3.2.1 Source Water

In order for household water treatment systems to be fully understood, the context from which system users draw their raw source water must be known. This is the water that some residents collect in their homes and would otherwise be drinking if they did not have these treatment systems. This is the water that their neighbors still drink, or the water that feeds into the (often inadequate) water treatment plants (see Table 1-6 and Chapter 6). Raw source waters were tested for contamination in order to provide a point of comparison with the treated water samples. Results of the source water tests are reported in Chapter 8 along with treated water results.

Residents in the areas of study gathered their drinking water from several different sources. Many of the towns, including Cerrito Buena Vista in Arequipa, were served by a piped distribution system that delivered water from a local treatment plant to on-plot water taps. Figure 3.4 shows an example of an on-plot water tap. Residents of Caleta Vila Vila in Tacna purchased their water from water vendor trucks, such as the one shown in Figure 3.5. Other households gathered their water from irrigation canals, an example of which can be seen in Figure 3.6. Some who could afford it would buy bulk bottled water or bring tap water from Arequipa, which is an hour away but presumably has a better water treatment plant and better quality tap water.

Figure 3.4: A Household Tap in Chucatamani, Tacna with the Town Health Worker and Sosa, in Charge of Monitoring the Tacna Program

Figure 3.5: Water Truck and Customers in La Joya

Figure 3.6: Irrigation Canal in Peru

3.3.2.2 Table Filter

As mentioned earlier, the earthquake in southern Peru caused surface waters – often used for drinking water – to have high turbidity levels caused by suspended solids (Rojas, et al., 2004). High turbidity causes water to be difficult to decontaminate, even with chlorine. To address this problem by filtering out the turbidity, CEPIS developed a sand-and-ceramic-candle filter, which it named the *Filtro de Mesa* or "Table Filter." CEPIS combined the technologies of slow sand filtration and ceramic candle filtration in order to improve upon the respective individual treatment techniques. CEPIS' Table Filter design includes sand to act as a pre-filter in order to prevent two Pozzani ceramic candle filters[22] from quickly becoming clogged by the highly turbid water found in the targeted communities in southern Peru. The combination of sand and ceramic filtration allows the filter to have a flow rate faster than those typically seen in filters with ceramic candles alone. This design also decreases the need for frequent filter maintenance due to clogging. The third component of CEPIS' design is a non-woven polypropylene geotextile cloth manufactured in Peru, which acts as a rough filter. This pre-filter prevents the sand from becoming clogged too quickly with particulate material present in the extremely turbid water. Figure 3.7 shows a labeled cross-section of the upper bucket (which contains the filtering unit) of a Table Filter. The filtration mechanisms and Table Filter design are described in more detail in Chapter 4. These are the filters that were distributed to 1,000 households in Arequipa and Tacna.

The plastic buckets are provided and funded by DGCI, which has a regional office in Lima, Peru. The spouts, geotextile, and rubber tubing required for the Table Filter (TF) are purchased in Lima, although replacement parts may be obtained in the capitol cities of Arequipa and Tacna, if available. The sand for the filters is collected, cleaned, and sifted locally in each region, often by the Table Filter recipients themselves. The ceramic candles are imported from Brazil, where the manufacturing company, Pozzani, is located. They cost $2.50 per candle, including a 10% import tax (Rojas, et al., 2004).

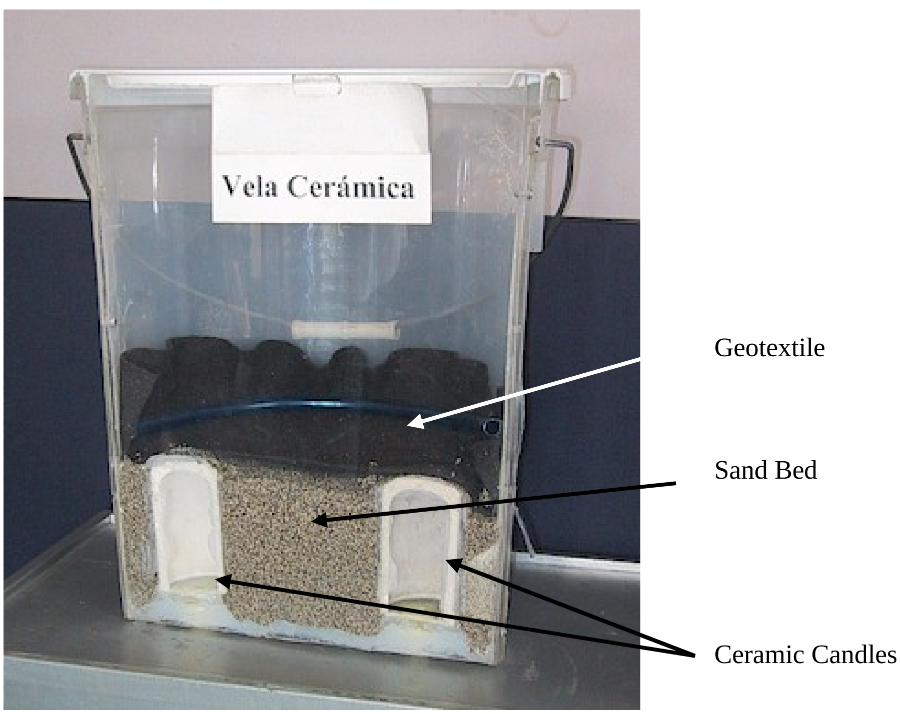


Figure 3.7: Cross-Section of the Top Filtering Bucket of CEPIS' Table Filter. Source: Pardón, 2003.

[22] Ceramic candle filters are described in more detail in Chapter 3.

3.3.2.3 Household Chlorination – the Safe Water System

Household chlorination is the other water treatment being implemented concurrently with, but in different households from, the Table Filter. Families are provided with safe water storage containers for the storage of chlorinated water. The storage containers are called *bidones* in Spanish. This system of household chlorination and safe water storage was developed jointly by the Pan-American Health Organization (PAHO) and the Centers for Disease Control and Prevention (CDC) as the "Safe Water System" (SWS), explained in greater detail in Chapter 5. As in the 1995 program, the chlorine is generated locally and distributed to the families as needed. One SWS container, or *bidon*, costs about $6, but they were distributed for free to the selected users, as were the bottles of chlorine solution, because of the "emergency" situation declared by PAHO (Rojas, et al., 2004).

3.3.2.4 Cost of the Technologies

The MIT Sloan School of Management students, Lieu and Obizhaeva, researched and presented the costs of each technology and its parts and maintenance in their report, "H_2O-1B!: Bringing Safe Water to the World" (Cerilles, et al., 2004). Table 3-2 provides the costs of each element of the Table Filter and Safe Water Systems in U.S. dollars, as reported by the Sloan students.

Table 3-2: Breakdown of Costs for Household Water Treatment Systems. Source: Cerilles, et al., 2004.

	Capital (One-time) Costs	**O&M (Recurring) Costs**
Table Filter:		
2 buckets (incl. spigot)	$6	
2 ceramic candles		$5 / year
Sand	Free	
Geotextile	$0.25	
Plastic tubing	$0.15	
Safe Water System:		
Chlorine generator	$475 / family (when used w/ 400 SWSs)	
Bidon	$6	
250-ml disinfectant bottle	$0.30	
Production of 250 ml of disinfectant		$0.25 / month

Table 3-3: Cost Comparison of the Table Filter and Safe Water System in Peru

Water Treatment Option	Capital Cost	O&M Costs / year
Table Filter (household filtration)	$6.40[23] [TF w/o 2 candles]	$5 [2 candles]
Safe Water System (household chlorination)	$9.80 [$6 (*bidon*) + $0.30 (chl. bottle) + $3.5[24] (chl. generator)]	$3 [$0.25/month for chl. production]

Table 3-3 gives a summary of the capital and yearly operation and maintenance costs of each treatment system, based on certain assumptions. For the Table Filter, it was assumed that both ceramic candles would break or need to be replaced once a year, but in reality they may not need to be replaced that often, depending on use and handling. Also, the candles are listed as yearly O&M (operation and maintenance) costs and excluded from the initial capital costs, assuming that they will not need to be replaced for approximately one year after the Table Filter is purchased or constructed. In other words, the initial cost of the TF is $11.40, and it is approximated that there should be no O&M costs during the first year of use. The O&M cost for the TF does not include the replacement of broken spigots, which seems to be a need for several families in CBV (see survey results in Section 8.3). The assumption made here is that the costs of replacing broken ceramic candles and spigots would eventually average out to approximately $5 per year.

The costs listed here for the Table Filter are lower than those reported by CEPIS. The business students of the H_2O-1B! team found that they could purchase two 20-L buckets and a spigot in Arequipa for $6. CEPIS reported that the Table Filters cost $20 each because they calculated that each 20-L bucket costs $6.25, one spigot costs $2.50, and each candle filter costs $2.50 (Lieu, 2004). It is likely that CEPIS added a factor into the cost to cover transport to the users, or other factors, that the H_2O-1B! team did not. If buckets can indeed be purchased for less than the estimate by CEPIS, this could be good news for the future dissemination of Table Filters. This lower price of $11.40 for a complete Table Filter, including $2.75 for each bucket and $0.50 for a spigot, is used in this thesis.

The SWS is listed as costing $9.80 because this initial cost includes the purchase of a small-scale chlorine generator. The SWS *bidon* itself costs only $6, but a chlorine generator for a community costs approximately $1,200-$1,700 (Cerilles, et al., 2004). In the La Joya area of Arequipa, the chlorine generator is currently serving 400 SWSs, which would cost $3.50 per family for a $1,400 generator. The generator is only being run for production twice a month since that is all that is needed with the number of families that it supports, but if more families were given SWS *bidones*, production cycles could be run more often with no additional equipment cost, only production cycle cost. If the generator supported 1,000 SWS *bidones*, this would only cost each household $1.40 for the initial purchase, for a total of $8 capital cost for the

[23] A Table Filter costs $11.40, which includes two ceramic candles. The capital cost is listed here as $6.40 since the cost of the candles is included in the O&M costs. (It is assumed that only two candles are needed each year.)
[24] This assumes that one $1,400 chlorine generator serves 400 SWSs, as is true in Arequipa, even though one system could generate chlorine for many more or fewer SWSs and change the cost per user.

Safe Water System. The business team estimated a production cycle to cost $0.25 per 250-ml bottle, which is different than CEPIS's estimation of $0.16 mentioned above in Table 3-1. The latter cost may have been calculated several years earlier when CEPIS first started its chlorination program, or the two estimations may have accounted for the cost of different components. Section 10.4 provides recommended methods for financing these two technologies.

3.3.3 Program Management

This water treatment program is run by the Ministry of Health with occasional technical assistance and monitoring by CEPIS. The Ministry of Health has support offices as well as hospitals in every major city and small hospitals and clinics in many towns. Even at the small village level, the Ministry of Health has "health posts" – small clinics where one or two people are employed to attend to health concerns in the town as well as to increase awareness of good health practices. Each of these levels of the Ministry of Health is utilized to help implement this water treatment program.

The program is implemented in two regions: Arequipa and Tacna (see Figure 3.3 in Section 3.3.1). The Ministry of Health headquarters in the capitol city of each region is in charge of the implementation for that region. Since the rural villages that actually use the filters and chlorine containers are generally a couple hours' drive from the capitol cities, smaller towns are used as a local support base for the program. In Arequipa, this local town is La Joya, and in Tacna it is Tarata. These cities and towns are shown on the maps in Figures 3.8 and 3.9. The program is then run locally out of these smaller cities. For example, a technician from Arequipa works in La Joya a few days a week and from there she visits households with the treatment systems in nearby villages. She also generates the chlorine solution in La Joya. (Chlorination was not implemented by CEPIS in Tacna [Rojas, et al., 2004].)

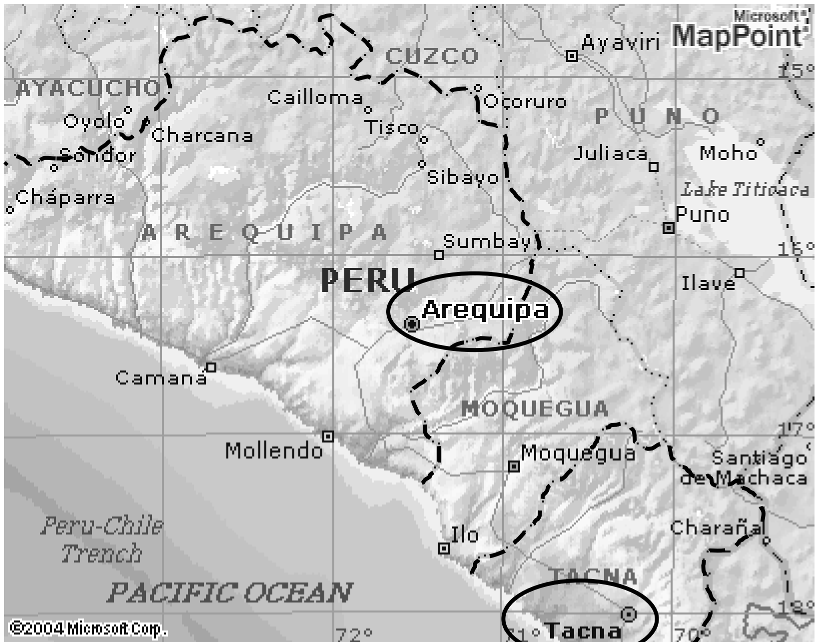


Figure 3.8: Map of the Provinces (Dashed Line Border) and Capitol Cities of Arequipa and Tacna, Peru. Source: MSN Encarta, 2004.

At the next level, almost every village where Table Filters or SWSs were placed has its own "health post," which attends to residents' complaints about the HWTSs and which collects empty chlorine bottles to be refilled. The health post worker is like a clinic nurse for the village. There is also a "motivator" in each village. This person is a resident of the village and volunteers to help with this program. She typically knows everyone in the village, assists the technician in monitoring and visiting the houses, and helps teach and encourage the community in safe health practices.

3.3.4 Program Specifics in Arequipa

3.3.4.1 Study Site: La Joya

In the Arequipa region, the Ministry of Health's HWTS program is centered around the town of La Joya. La Joya is located about an hour's drive from the city of Arequipa.

Approximately 300 Table Filters and 400 SWS *bidones* were distributed to households in 7 towns and villages. Figure 3.9 shows a map of the La Joya area with some of these towns labeled. Table 3-4 shows the number of each system that was distributed to each town or village.

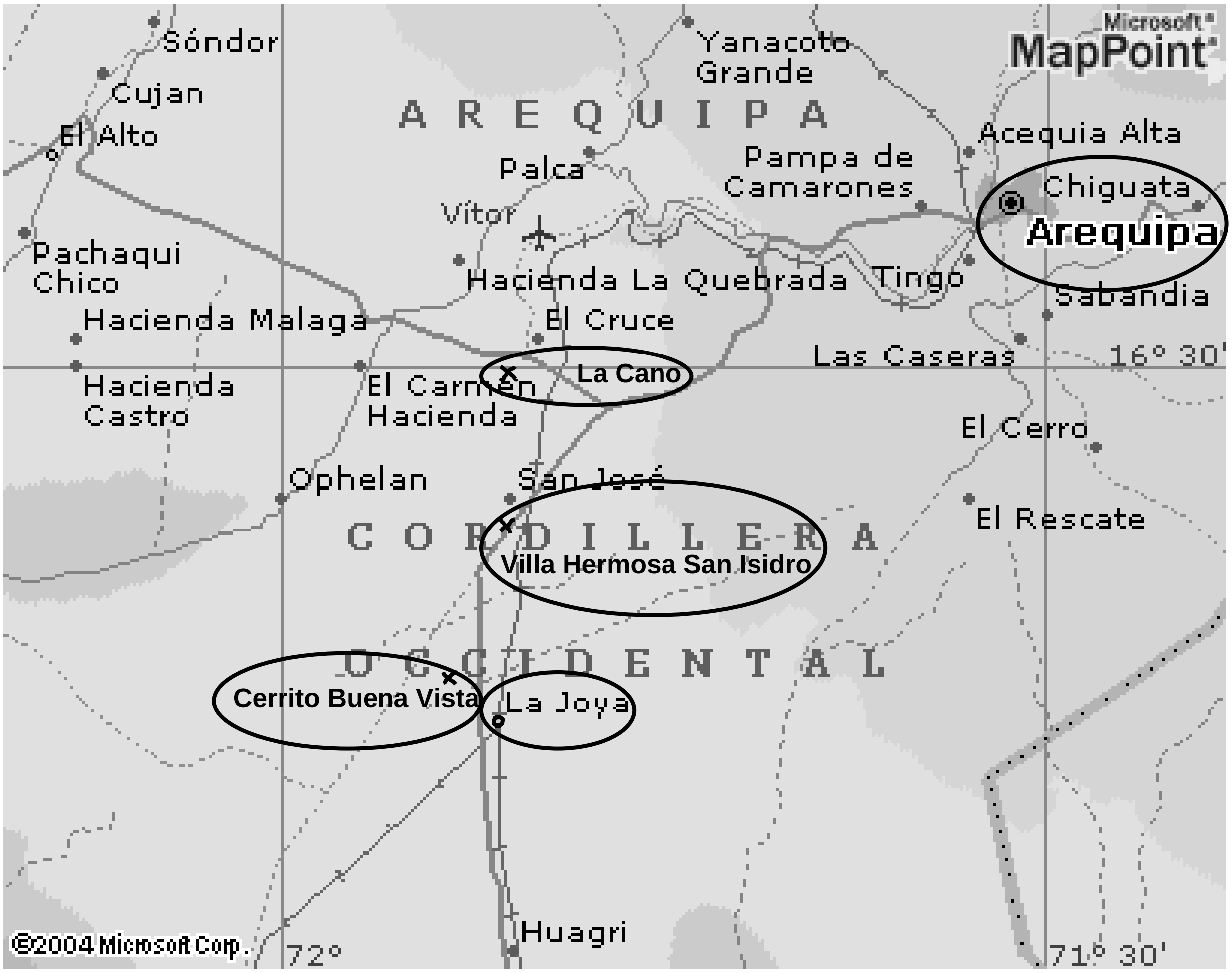


Figure 3.9: Location of Towns in this Study. Source: MSN Encarta, 2004.

Table 3-4: Distribution of Table Filters & SWS *Bidones* in the Province of Arequipa

Town/Village	Table Filters	SWS *Bidones*
Cerrito Buena Vista	30 (used:10)[25]	100
Kilometer 48	0	70
La Cano	50	50
San Camilo 6	50	50
San Camilo 7	50	50
San Isidro	50	50
Villa Hermosa San Isidro	70	30
Total	*300*	*400*

[25] Cerrito Buena Vista actually received 30 Table Filters, but 20 of those Filters were unusable. Instead of 20 upper buckets and 20 lower buckets, they had received 40 upper buckets (which have holes in the bottom) so that the Table Filters could not be constructed.

A majority of the households investigated were located in the village of Cerrito Buena Vista (CBV), a five minute drive from La Joya. CBV, a village of approximately one square kilometer, contains about 250 families, or 1,800 residents. The President of CBV, Clemente Vicente Mamani, as reported by the Agua Peru team, said that 30% of the adults in CBV cannot write their name, and 50% cannot effectively read or write (Malies, et al., 2004). The community is entirely agricultural. Most of the residents work in the surrounding fields, which belong to land owners in La Joya or to the dozen or so land owners from CBV. The average daily wage for women is S/ 13 ($3.75) and S/ 20 ($5.75) for men. The CBV President said that field workers can often only find work four days per week. Other residents graze cattle and sell the milk. In 1985, the CBV local government and residents installed a gravity-fed water distribution system to the town. This is fed by the Vitor River, a branch of the Rio Chili, which is fed by snowmelt and runs through Arequipa (Malies, et al., 2004).

Most families that were visited and interviewed for this study are rural farmers living in small villages of 100 to 200 families in the La Joya area. Many live in small concrete brick houses with a dirt back yard, part of which is covered by woven mats supported by wooden poles or stakes and used for cooking and storage. This area often houses the Table Filter or SWS *bidon*. While nearly all of the water treatment units are kept in some amount of shade, unfortunately most are located in only partial shade, where sunlight can reach them for part of the day or through cracks in construction material.

Many of the families that were visited receive water from a tap as part of a community-wide water treatment and distribution system. Each house generally has only one water tap, which is located outside. Other families collect water directly from a canal or purchase it from a vending truck. A majority of the families have large concrete water storage tanks in their back yards. These are simple open-topped rectangular boxes that hold approximately two cubic meters of water (see Figures 3.10 and 3.11). Families use this tank to settle their water or simply to hold it until they need the water.

Figure 3.10: Coulbert Collecting a Sample from a Household Tank in CBV, Arequipa

Figure 3.11: A Household Tank in Villa Hermosa San Isidro, Arequipa

3.3.4.2 Program Management in Arequipa

In general, but not always, households that received their water from their town's piped infrastructure were given an SWS, and those that used surface waters were provided with a Table Filter to filter out the extra turbidity (Borda, 2004).

As described earlier, the water treatment program in the province of Arequipa is run by the Ministry of Health of Arequipa, whose offices are located in the capitol city of Arequipa.

Claudia Mena Cornejo, a veterinarian by training, is in charge of the day-to-day monitoring of the program in the La Joya area. She is specifically in charge of the villages in the La Joya District: Cerrito Buena Vista and Kilometer 48. She lives in Arequipa and travels about an hour by bus to La Joya three days a week to monitor and support the program in those villages. She visits the "health posts" in each village and tries to address any complaints that people have mentioned to the health worker at the post. She visits houses with HWTSs to make sure that the users are satisfied and using their technologies appropriately (e.g. cleaning regularly and correctly). Cornejo also has chlorine-detection tablets, with which she occasionally tests some SWS *bidones* to ensure that they have the right amount of chlorine residual in the water. The tablets react with the chlorine in a small sample of the water, turning it purple. The amount of chlorine in the water determines the darkness of the purple color. Cornejo compares the shade of purple to a predetermined color chart to see if the water falls within the range of 0.4 to 0.6 mg/L of chlorine. If it does not fall within this range, she instructs the household to add more or less chlorine to their water, as appropriate. Cornejo is also in charge of chlorine generation in La Joya. She generates the chlorine solution at the Ministry of Health clinic in La Joya and then bottles it to distribute to families. The specifications of the chlorine generator and chlorination practices are explained further in Chapter 5.

Jose Vega Chama is another technician, who is specifically in charge of the five communities in the San Isidro District: La Cano (which includes San Luis La Cano and Alto La Cano), San Camilo 6 and 7, San Isidro, and Villa Hermosa San Isidro. While Mena is in charge of chlorine generation, Vega procures, supplies, and monitors ceramic candles and plastic spigots for the Table Filters.

3.3.5 Program Specifics in Tacna

The author spent most of her time in Arequipa and so this thesis does not contain nearly as much information about Tacna as it does about Arequipa. As is true in Arequipa, CEPIS provides technical support while the Ministry of Health of Tacna actually runs the program for its province. The Tacna Ministry of Health received 700 Table Filters to distribute as it saw fit. The communities that received these filters are approximately a two-hour drive north from Tacna, located near the town of Tarata. The towns in Tacna where Table Filters were distributed were: Chucatamani, Potina, Chipispaya, Ilabaya, and Sama Inclan (including other small villages, like Pistala, which were located around these primary towns).

Juana Sosa, the technician from Tacna in charge of monitoring in the region, travels to the different villages to visit households with Table Filters and address any concerns brought to her attention.

The Tacna Ministry of Health boasts that its program is more complete, as it combines household drinking water treatment practices with education about building sanitary ventilated pit latrines (VIPs). The Ministry of Health has pamphlets that encourage and instruct people in how to build their own VIP. This is another good step in safe practices that will help to keep people from getting sick, and the VIP is one of the WHO's recognized "improved sanitation technologies." Tacna also provides Sosa and its other technicians with monitoring sheets to complete as they visit each household that has a Table Filter or latrine. This way they can learn from their detailed records and make improvements to their health program based on their observations.

4. Sand and Ceramic Filters

The filter that CEPIS and the Peruvian Ministry of Health have distributed in southern Peru contains two types of filtration media: sand and ceramic. This chapter introduces these basic water treatment processes and describes the Peruvian Table Filter design.

4.1 Filtration

Filtration is one of the most common processes used to treat water. In essence, it is the process of removing suspended or colloidal particles from water by straining it through a porous medium. These particles can function as food and shelter for microorganisms, protecting them from disinfection or removal; they can also cloud the water, making it visually unattractive. The suspended clay, silt, microscopic organisms, or other organic or inorganic matter causes *turbidity* in water (Clesceri, et al., 1998: Standard Method #2130A). The removal of turbidity and microorganisms are generally the primary goals of filtration.

4.1.1 Turbidity

"Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level through the sample" (Clesceri, et al., 1998: Standard Method #2130A). In other words, turbidity is a measurement of the interference that a light beam experiences when it is directed through the water. Instruments that measure turbidity are called turbidimeters. Nephelometers are a type of turbidimeter that detect the amount of light scattered at a 90-degree angle to the incident light beam. "The higher the intensity of the scattered light, the higher the turbidity" (Clesceri, et al., 1998: Standard Method #2130B). Nephelometers, the type of turbidimeter used in this investigation, report turbidity in nephelometric turbidity units (NTU).

4.1.2 Microorganisms

As explained in Sections 1.3 and 2.4, certain microorganisms can be very harmful to the human body if consumed. It is the goal of filters that are designed for drinking water treatment to remove those harmful organisms. Since bacteria and other microorganisms are so small, their removal can be very difficult. Turbidity can aid in this process as organisms often feed on or take refuge in suspended particles. When this occurs, the removal of turbidity becomes simultaneous with the removal of harmful organisms.

4.2 Sand Filters

Granular bed filters, often composed of sand, are a common type of filter used to remove turbidity and micro- and macroorganisms. The grain size and shape of the filtering media affects how the filter works and what size of particles are removed. Particles and organisms can be removed through biological and physical mechanisms. Biological treatment mechanisms within a sand filter require the growth of a ***schmutzdecke***, or "dirty skin," on the top layer of sand, which biologically breaks down organic matter and microorganisms. Physical treatment mechanisms involve simple **mechanical straining** in which particles are trapped in small openings, as well as **physical adsorption** in which particles are transported and then attached to the surface of the granular material (AWWA, 1999; Rust & McArthur, 1996).

Rapid sand filters (RSFs) primarily rely on the physical removal of particles, while slow sand filters (SSFs) utilize both biological and physical treatment mechanisms (Rust & McArthur, 1996). The Peruvian Table Filter is hypothesized to behave somewhere in between slow and rapid sand filtration. For this reason, both processes are described below.

4.2.1 Slow Sand Filters

Slow sand filters use both mechanisms of filtration: biological and physical. SSFs contain a *schmutzdecke* on the top layer of sand, which consists of dead and living micro- and macroorganisms. This layer develops over time and becomes the primary treatment mechanism of SSFs. The slow sand filter generally has smaller grain size than rapid sand filters and thus a slower flow rate. A shallow layer of water is maintained on top of the sand, which, in addition to the slow flow rate, encourages the development of a small ecosystem in the *schmutzdecke*. This layer uses biological activity to break down bacteria, microorganisms, and other organic matter found in the water that is fed into the filter for treatment. This layer also removes a large amount of particulate matter from the water (AWWA, 1999; Rust & McArthur, 1996).

After traversing the *schmutzdecke*, water reaches the top layer of sand, where it is further physically strained and biologically attacked. The physical straining occurs as suspended particles that are larger than the voids between grains are trapped and as those that are smaller attach to the surfaces of grains. Additional micro- and macroorganisms also live within the sand layers and prey upon organic matter. A slow sand filter's ecosystem generally consists of bacteria, protozoa, rotifers, copepods, and aquatic worms. The larger organisms live deeper in the sand and feed on the smaller organisms (AWWA, 1999).

Slow sand filters generally have slow flow rates, but as a filter becomes clogged, the rate may slow significantly, indicating that the filter should be cleaned. SSFs usually need to be cleaned every one to six months, or longer, depending on the quality of raw water that is being filtered and the flow rate that is observed. The filter is cleaned by draining the standing water to below the top of the sand and then removing the *schmutzdecke* and 0.5 to 2.0 inches of the top layer of sand. Since much of the treatment process of the SSF relies on the creation of the *schmutzdecke*, a "ripening" time is required for the filter to reach its full treatment potential when first installed and after cleaning. The filter's effectiveness usually improves dramatically over time as the *schmutzdecke* develops. This can take six hours to two weeks, although it often requires less than two days. For this reason, some sources advise that slow sand filters be run for up to two days before the effluent water is consumed. The quality of the filtered water does not generally degrade over the life of the filter, because the *schmutzdecke* becomes more effective as contaminated water continues to feed it (AWWA, 1999).

The slow sand filter has been shown to be effective in removing microorganisms and turbidity from water. A study by the World Health Organization found that 85% of coliform bacteria in water was removed by a bed of sand that had not been allowed to "ripen," while a mature sand bed removed over 99% of coliform bacteria (AWWA, 1999). Donison, an Environmental Engineering student in the Masters of Engineering program at MIT, studied a household-scale SSF in the spring of 2004 and reported that it removed 90% of thermotolerant coliform bacteria and 92% of turbidity (Donison, 2004). The American Water Works Association indicates that slow sand filtration is generally a reliable and effective treatment for high-quality source waters and thus implies that a slow sand filter may not be the most appropriate technology for poor-quality source waters, such as were encountered in Peru (AWWA, 1999).

4.2.2 Rapid Sand Filters

Rapid sand filtration involves both physical filtration mechanisms: mechanical straining and physical adsorption. As described earlier, the removal of particulate matter from water can effectively remove micro- and macroorganisms, which often use particles as food or shelter. Small organisms are removed from water when suspended particles or flocculations of particles attach themselves to the granular filtering material (AWWA, 1999). The filtration media used in an RSF can greatly affect its properties. This material is chosen depending on the properties of influent water, the media available, and the effluent water quality expected (Schmitt & Shinault, 1996).

Flocculation, or the physical grouping together of particles, greatly improves the effectiveness of the physical filtration process. For this reason, pre-treatments involving coagulation and settling are generally employed before water passes through an RSF. Coagulation and settlement are usually used in combination with RSFs. Chemical pretreatment is often used to coagulate or flocculate particles into larger bunches. A large amount of those particle floccs are removed in a settling tank so that RSFs are responsible only to remove any remaining particles (AWWA, 1999; Schmitt & Shinault, 1996).

Unlike a slow sand filter, which may slow due to clogging but often shows *improved* treatment efficacy throughout its "cycle" (the time between cleanings), a rapid sand filter can *deteriorate* throughout its cycle. As the cycle progresses and the sand grains become covered with suspended matter, the "focal point," or most active area, of particle removal moves down through the sand. If the cycle is allowed to continue too long between cleanings, the filter can loose its effectiveness. Thus it is important that the sand be cleaned regularly and thoroughly (AWWA, 1999). RSFs are generally cleaned by backwashing, or forcing water to flow through the sand in the reverse direction in order to dislodge trapped particles. RSFs are cleaned often, even daily, in order to keep them working well (Schmitt & Shinault, 1996).

According to a research study by Gerardo Galvis for his Ph.D. thesis at the University of Surrey in the UK, the removal efficiency of particles is generally much higher in SSF than RSF, as the treatment process in the SSF is further aided by biological removal. Galvis' research found that SSFs remove 90-99.9% enteric bacteria (e.g. fecal coliform) and reduce turbidity to <1 NTU. He recommended that source water have a maximum turbidity of 5-10 NTU and a maximum fecal coliform (FC) concentration of 200 FC CFU/100ml *before* direct SSF treatment. If the source water has higher levels of turbidity or FC, the SSF may not be able to create the "final safety barrier" for drinking water that it should (Galvis, 1999).

4.2.3 Slow and Rapid Sand Filter Comparison

The primary differences between SSFs and RSFs are the loading rates (flow rates), the filtering mechanisms, and the methods of cleaning. Table 4-1 summarizes basic differences between slow and rapid sand filters.

Table 4-1: Summary of Differences Between Slow and Rapid Sand Filters

	Slow Sand Filters	**Rapid Sand Filters**
Loading rate[26]	0.1-0.3 $m^3/m^2/hr$	4-20 $m^3/m^2/hr$
Primary filtering mechanism	Biological (*schmutzdecke*)	Physical straining & adsorption
Secondary filtering mechanism	Physical straining & adsorption	(Often combined with coagulation & settling pre-treatment)
Cleaning method	Scraping off *schmutzdecke*	Backwashing
Cleaning frequency	Months	Days

4.3 Ceramic Candle Filters

Ceramic filters are made of kiln-fired clay containing micro-pores and treat water by straining out particles and microorganisms as water flows through the pores, through the mechanisms of mechanical straining and adsorption (Clasen, 2003). Ceramic filters can be produced from different types of clay and combustible material. When the clay mixture is fired, the fine combustible material disintegrates, creating the micro-pores that are necessary for filtration (Dies, 2003). These pores can be as small as microns or submicrons (0.2μ) in diameter (Clasen, 2003).

[26] These values come from the WHO *Guidelines* (WHO, 2004).

Ceramic filters generally come in three different shapes: pot, disk, and candle (see Figure 4.1). Each type uses the same filtering process, although the different shapes fit into different types of filtering systems, or housing containers (Dies, 2003).

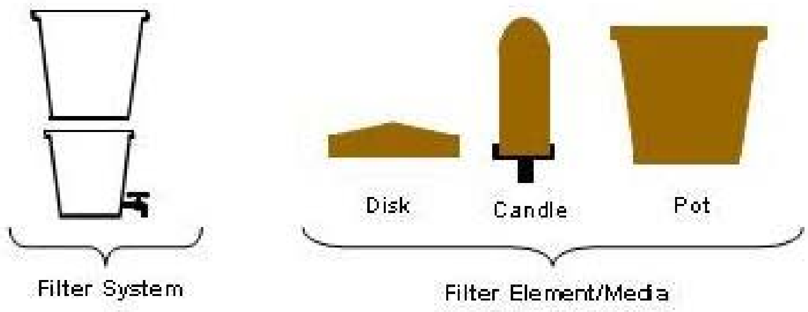


Figure 4.1: Diagram of a Basic Water Filter System and the Three Common Types of Ceramic Filter Elements. Source: MIT, 2004.

Figure 4.2: Example of Ceramic Filters of All Shapes in Nepal. Source: Dies, 2003.

"Candle" refers to the cylindrical shape of one type of ceramic filter. The cylindrical filter is hollow on the inside, which allows water to filter through the outside walls (and sometimes the top) of the cylinder and drain out through a spout at the bottom. The candle filters used in the Table Filter in Peru are made by Pozzani[27] and are imported to Peru from Brazil. They have a pore size of one micron. Pozzani is a British water filter company. Their $2.50 ceramic candle that is made in Brazil is not listed on their website. Several other types of ceramic candle filters are available for purchase through the website for about $20 each. These candles generally have a pore size of 0.9-1.0 microns and are reported to remove 99.8% bacteria and 98% suspended solids. The stages of treatment in each $20 candle consist of ceramic, carbon, carbon block, and in some instances, ion exchange. The candles are listed as needing to be replaced only once

[27] Pozzani: <www.pozzani.co.uk>

every six months. Since these ceramic candles are made by the same company as those used in the Peruvian Table Filters, they may be similar. The candles imported to Peru from Brazil are eight times less expensive and therefore may not be manufactured to as high a quality as those sold over the internet to high-paying customers. Also, they may employ fewer treatment stages and may consist of ceramic filtration media only (Pozzani, 2004).

Figure 4.3: Example of a Pozzani Ceramic Candle Similar to Those Used in the Table Filter (Displayed Upside Down).   Source: Pozzani, 2004.

Candle filtering systems typically consist of an upper and lower water container (see Figure 4.1). The filters are screwed into the bottom of the upper container, which holds the unfiltered water. The ceramic candle filter (or filters – often two or three) then treats the water as it flows through the candle walls down into the lower container, which contains the filtered water.

The ceramic can also be "impregnated" or coated with silver or other substances, which can increase the filter's microbial removal and prevent bacteria from growing within and through the ceramic filter (Clasen, 2003).

In Table 4-2, Thomas Clasen, from the London School of Hygiene and Tropical Medicine, compares the cost and quality of different grades of ceramic candles. The Pozzani candle used in the Peruvian Table Filter would be considered a "Grade C" candle. As shown in the table, generally the better a candle filter performs, the more it costs.

Table 4-2: A Comparison of the Cost and Quality of Ceramic Candles of Different Grades. Source: Clasen, 2003.

Grade	LRV[28] of Bacteria Concentration	Bacteriostasis	Capacity (Liters)	Candle Cost ($ US)
A	>6	Impregnated Silver	50,000	$6 – $9
B	4 – 5	Coated Silver	12,500	$2 – $4
C	2 – 3	None	5,000	$1

[28] LRV stands for the Log Reduction Value of a substance as measured before and after treatment. [LRV = log(untreated/treated)]

Table 4-3 presents the "Advantages of Ceramic Filtration," as presented by Clasen.

Table 4-3: Advantages of Ceramic Filtration. Source: Clasen, 2003.

1. High efficacy in reducing microbial pathogens.
2. Low cost and long life.
3. Easy to use and maintain; minimal instruction or need for behavioral change; also suitable for emergencies, urban applications.
4. Configuration provides safe storage of treated water.
5. Visible improvement in water quality promotes routine use.
6. Operate consistently regardless of level of turbidity, pH, temperature.
7. No chemicals, mixing, batching or contact time.
8. Insert adsorption media in hollow candle to reduce heavy metals, pesticides, and arsenic.
9. Sustainable and transferable technology leading to local production and commercialization.
10. Treated as household asset; portable; opportunity for cost recovery.

Candle filters are simple to use on a day-to-day basis. They require only that the user pours water into the top container and waits for it to filter down through the candle(s) into the bottom container. Table 4-3 presents the advantages to candle filters; however, there are some drawbacks. Because of the nature of the filtering mechanism – water flowing through very small pores (about one micron in diameter) – the flow rate through the filters is generally very low, typically between 0.5 and 4 L/day. Candle filters also require regular cleaning once the pores become clogged with particles. It is important that the brittle filters do not crack or that there be any other failure of the materials that could lead to possible contamination of the filtered water. Also, high-quality filters – those with higher quality control during manufacturing and thus better filtration results – typically cost much more than low-quality filters, as can be seen in Table 4-2 above. The less expensive ones usually do not perform as well and, even at their lower prices, are often too much for poor families in developing countries to afford (Dies, 2003).

4.4 Peruvian Table Filter

4.4.1 General Design

CEPIS and DGCI developed a filter that is made of a geotextile cloth, sand, and two ceramic candles. It is called the *Filtro de Mesa*, or "Table Filter." CEPIS and DGCI combined the technologies of sand filtration and ceramic candle filtration and added a geotextile prefilter. This combination was intended to improve upon each of the respective techniques. The geotextile is a non-woven polypropylene cloth manufactured in Peru, which acts as a rough filter. This pre-filter prevents the sand from becoming clogged with large particulate and organic material. The geotextile also acts as a diffuser to prevent the sand from being greatly disturbed when water is poured into the filter. The sand then filters out much of the particulate and organic matter before the water reaches the candles, which leaves them free to deal with only the smallest particles and microorganisms. The combination of these three filtration media helps to prevent the filter system from quickly becoming clogged by the highly turbid water found in the user communities in Peru.

The hypothesis that the combination of sand and ceramic filtration would improve water treatment was confirmed in a study by Ricardo Rojas and Sixto Guevara of CEPIS (CEPIS, et al., 2001; Rojas & Guevara, 2000). The presence of the geotextile and sand to act as prefilters to the ceramic candles allows the filter to have a flow rate faster than that typically seen in filters with ceramic candles alone. The operation manual for the Table Filter states that the filter will produce approximately 1.5 L/hr, but average flow rates of 3.1 L/hr, and a maximum flow rate of 4.4 L/hr, were measured by the author on Table Filters in Peru (see Section 8.1.2.3). This combination design also decreases the need for frequent filter maintenance due to clogging.

In the study mentioned above, Rojas and Guevara investigated the effect that the addition of sand has on the flow rate of Table Filers. They tested side-by-side TFs containing ceramic candles only and TFs containing ceramic candles and sand. These were also tested alongside a filter containing only sand. Twenty liters of water were added to each filter every day. One of each type of filter was tested with water of 50 NTU turbidity, and the others were tested with water of 500 NTU turbidity. Rojas and Guevara concluded that sand is an important element of the Table Filter in conjunction with the ceramic candle. Their study showed that the sand prevented the candles from clogging quickly with highly turbid water, and helped the TF to maintain a faster flow rate for a longer time. Table 4-4 presents a summary of key data from their study, which demonstrated the large difference that the sand-and-candle combination made in maintaining a higher flow rate (CEPIS, et al., 2001; Rojas & Guevara, 2000).

Table 4-4: Summary of Flow Rates Measured from Different Filters with the Use of 50 NTU Source Water. Source: Rojas & Guevara, 2000.

Days of Study	**Flow Rate [$m^3/m^2/day$]**		
	Candles + Sand **(the full Table Filter)**	**Ceramic candles Only**	**Sand Only**
1	6.2	3.1	1.6
5	6.3	2.2	1.6
10	6.1	3.8	1.6
20	5.4	0.3	1.6

Figure 4.4 shows a labeled cross-section of the upper bucket of a Table Filter[29].

[29] This display TF contains less than the instructed amount of sand, which should reach 5 cm above the top of the ceramic candles.

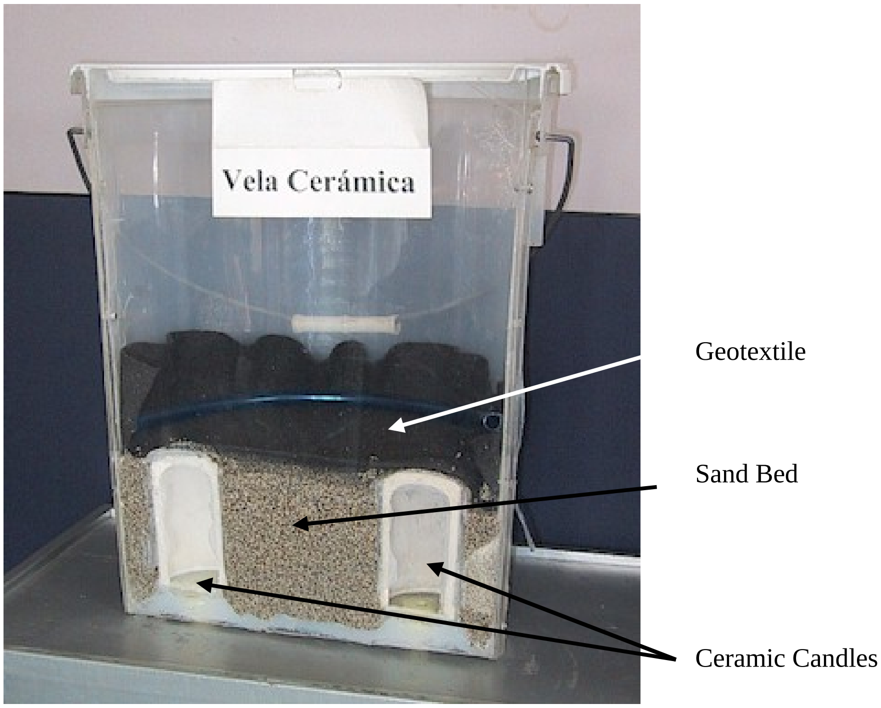


Figure 4.4: Cross-Section of CEPIS' Table Filter

Figure 4.5: Table Filter in Use in a Home in Villa Hermosa San Isidro, Arequipa

An example of the Table Filter in a household in one of the program's towns, Villa Hermosa San Isidro, is shown in Figure 4.5. The filter is made up of two 20-liter buckets with lids stacked on top of each other. The upper bucket contains the filtering materials and the lower bucket catches and stores the filtered water. CEPIS referred to this filter design as the “first generation filter.” They have designed – but not yet implemented – a “second generation filter,” thus all of the Table Filters investigated in this study are “first generation.” Figure 4.6 shows the first and second generation designs.

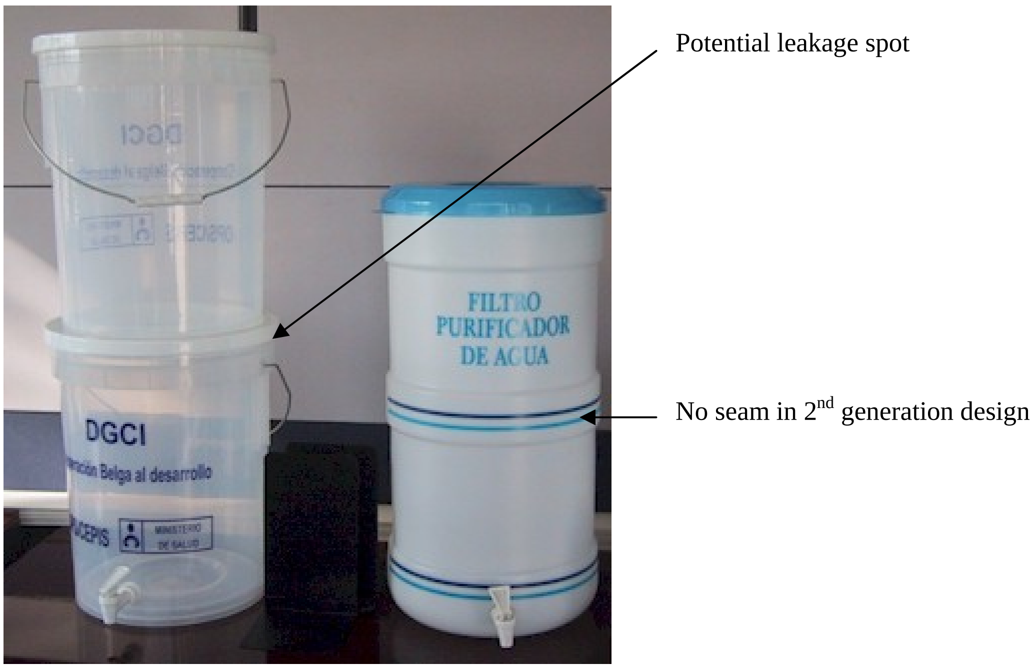


Figure 4.6: First and Second Generation Filter Container Designs

The first generation design, which is the version currently in use by households in southern Peru, is described in more detail in the following Section 4.4.2. Only the outer container is altered between the two “generations,” or designs – the filtering mechanisms remain the same. The second generation design was created because the first design sometimes leaks. When the lower bucket is completely full of water and additional water is added to the upper bucket, water can leak out from between the lower bucket and its lid. The new container, shown in Figures 4.6 and 4.7, is designed such that the filtering unit sits inside the receiving container. This prevents overflow because the water level in the receiving container can never be above that of the filtering bucket and, therefore, will never reach the uppermost lip of the container and leak over.

Figure 4.7: Cross-Section of Second Generation Filter

4.4.2 A Guide to the Table Filter

This section summarizes the instructions for construction, operation, and maintenance of the Table Filter. It is based on the instructions laid out in a pamphlet by CEPIS and the Ministry of Health, as well as the author's experience of the actual steps in Peru. The pamphlet is called "A Guide to the Construction, Operation, and Maintenance of Table Filters with Ceramic Candles and Sand Prefiltration"[30] and is produced and distributed by the joint efforts of DGCI, CEPIS, and the Peruvian Ministry of Health (DGCI, et al., 2003).

In La Joya residents were taught and encouraged to build their own filters. The materials for the filters were provided free to the 300 families whom the Ministry of Health approved to be recipients.

[30] This is the English translation of the actual title: "Guia de Construccion, Operacion y Mantenimiento de filtros de Mesa con Velas Ceramicas y Prefiltro de Arena" (DGCI, et. al., 2003).

4.4.2.1 Construction Materials

4.4.2.1.1 Components:

- Two 20-liter (5-gallon) plastic buckets with lids
- Plastic spigot
- Hollow plastic tubing
    - 84 cm of 3/8 inch diameter tubing
    - 2 cm of 5/16 inch diameter tubing
- Non-woven polypropylene geotextile
    - Dimensions: at least 35 x 35 cm
    - Thickness: 2.0-2.5 mm
    - Permeability: 0.40-0.60 cm/s
    - Permitivity: 2.10-2.28 s^{-1}
    - Pore size: 0.15-0.20 mm
- Two Pozzani ceramic candle filters
    - Dimensions: 9.5 cm tall by 5.5 cm in diameter
    - Pore size: 1 μm
- Sand
    - Fine to medium grade[31]

[31] In Peru, river sand is used. The Rio Chili runs through Arequipa and the Rio Sama runs through Tarata, although sand may be collected locally from smaller tributaries of those rivers.

Figure 4.8: Collecting River Sand in Tacna

4.4.2.1.2 Tools:

- Coarse metal sieve
    - Mesh opening size: approx. 0.85mm (corresponding to ASTM #20 Mesh[32])
- Fine metal sieve
    - Mesh opening size: approx. 0.25mm (corresponding to ASTM #60 Mesh[33])
- Something with which to punch, drill, or melt a 1.3-cm-diameter hole in plastic without causing cracking (e.g. a large metal rod or pipe that can be heated)
- Scissors and/or utility knife
    - To cut geotextile and PVC tubing
- Extra bucket for sand washing
- Water

[32] ASTM Mesh #20 corresponds to a mesh size of approximately 0.85-mm, BS Mesh #18, and Tyler Mesh #20.
[33] ASTM Mesh #60 corresponds to a mesh size of approximately 0.25-mm, BS Mesh #60, and Tyler Mesh #60.

4.4.2.2 Preparation for Construction

4.4.2.2.1 Buckets:

a) Make two 1.3-cm-diameter holes in the base of one bucket (this will become the designated "upper bucket"), each 8 cm from the center and 16 cm apart from each other.

b) In the designated "lower bucket," make a 1.3-cm-diameter hole near the base for the spigot. Make the hole just high enough so that the bucket will sit flat on a table once the spigot is installed.

c) In both buckets, make a 2-mm-diameter hole on each side of the bucket 2 cm from the top of the bucket. This creates necessary ventilation so that the lids can be tightly secured without creating a vacuum as water flows out of each bucket.

4.4.2.2.2 Sand:

a) Pour the sand into the coarse sieve until about 1 cm of sand covers the bottom. Sift this sand into the fine sieve (see Figure 4.9 below). Discard any sand or material remaining in the coarse sieve.

Figure 4.9: Longhi and del Carpio Sifting Sand from Coarse Sieve into Fine Sieve in La Cano, Arequipa

b) Take the sand that passed through the coarse sieve and sift it through the fine sieve. Discard any sand or material that passes through the fine sieve.

c) Wash the sand that is retained on the fine sieve. Small to medium amounts of the sand should be washed with clean water several times in the fine sieve and/or in a bucket. One or both of these processes should be repeated until the effluent or decanted water appears clean (see Figure 4.10).

- When washed in a sieve, water is poured on the sand while moving the sand around by hand until any fine particles remaining in the sand stop flowing out through the sieve.

- When washed in a bucket, 2-4 inches of sand is placed in a bucket, which is then filled with water until it reaches several inches above the level of the sand. The water and sand are mixed by hand for about a minute to encourage any fines or plant particles to become suspended in the water. The water is then poured out, or decanted, while retaining as much sand as possible.

- The author recommends that both cleaning methods should be used in combination when possible since they can both remove different types of unwanted particles. The construction manual for the Table Filters instruct the reader to wash the sand with a lot of water until it is free of dirt, but it does not instruct how this should be done. The technician in Arequipa said that users usually wash the sand in the fine sieve. The sieve washing method is beneficial, as it can remove most of the fine particles, but the author found that when small plant matter was present in the sand, it could not be washed out through the sieve, but it floated and was easily decanted in the bucket washing method.

Figure 4.10: Washing Sifted River Sand in Large Bags in Tacna

4.4.2.2.3 Geotextile:

a) Cut the geotextile cloth into a circle of 35 cm diameter

4.4.2.2.4 Plastic Tubing:

a) Push half of the smaller 5/16” tubing inside one end of the larger 3/8” tubing (see Figure 4.11).

b) Bring the other end of the larger tubing around and push it onto the smaller tubing so that it forms a circle.

Figure 4.11: Inserting the Smaller Plastic Tubing into the Larger Tubing

4.4.2.3 Table Filter Construction

4.4.2.3.1 Lower Bucket:

a) Insert and secure by screwing on the plastic spigot to the side hole of the lower bucket.

4.4.2.3.2 Upper Bucket:

a) Place one rubber washer onto the base of each ceramic candle. (Two rubber washers and one plastic wing nut are provided with each candle.)

b) Insert the spouts of the two ceramic candles into the holes in the bottom of the upper bucket.

c) Place a second rubber washer onto each spout under the bucket’s bottom.

d) Align the lid with holes and fit the spouts into the holes.

e) Place a plastic wing nut (included with the candle) on the bottom of each ceramic candle spout beneath each lid hole and tighten them by hand to secure candles. This seal ensures that all water from the upper bucket will flow into the lower bucket only through the ceramic candles.

4.4.2.3.3 Final Assembly:

a) Fit the lid that is attached to the upper bucket onto the top of the lower bucket.

b) Fill the upper bucket with the prepared sand until it reaches 5 cm above the top of the ceramic candles (see Figure 4.12). This ensures that all water is filtered through the sand before reaching the candle filters. The extra sand also creates a buffer, as users periodically lose some of the sand while cleaning their filter.

c) Place the tubing ring in the middle of the geotextile piece and, keeping it horizontal, push it down into the bucket until it sits on top of the sand.

Figure 4.12: Filling the Upper Bucket with Sand

Figure 4.13: Table Filters after a Day of Construction in Tacna

Figure 4.14: Table Filters Setup During Laboratory Experimentation at MIT

4.4.2.4 Placement of the Filter

a) Keep the filter indoors, preferably in the kitchen or dining room on top of a table or bench.

b) Place the filter so that water flowing out from the spigot is free of any obstacles. For example, extend the spigot over the edge of a table.

c) Be sure to close the spigot completely after each use.

d) Do not use the lower bucket of the filter to transport water from a river or water source, because the spigot can break easily.

4.4.2.5 Operation

a) Fill the upper bucket with water until it reaches 4 cm below the top of the bucket.

b) Check the level of the water periodically, and add more once it recedes below the top of the sand.

4.4.2.6 Maintenance

a) Clean the filter when the flow rate reduces notably. This is generally once a month. During cleaning use filtered water.

b) Carefully remove the plastic tube, the geotextile, and the sand. Place the sand in a bucket or other container for washing.

c) Wash the inside of both buckets with water and soap (see Figure 4.15).

Figure 4.15: Washing the Lower Bucket in Chucatamani, Tacna

d) Wash the geotextile in clean water as if gently cleaning a dirty cloth (see Figure 4.16).

Figure 4.16: Washing the Geotextile and Blue Tubing Ring in CBV, Arequipa

e) Wash the sand with clean water, in the same way as was done in the construction of the filter. Continue washing the sand until the sand is clean and the water is free of turbidity.

f) Remove the ceramic candles and rub the surface with a smooth scrubber. Wash the bottom and the spout with *clean* water, making sure that no water enters the inside of the candle through the spout, which could contaminate it. Do not use soap or detergent while washing. Once the filter is cleaned, the flow should return to its original rate. If it does not, you may need to replace the ceramic candles. These should normally be replaced every 6-12 months.

g) While cleaning the candles, inspect them for any breaks or cracks. If any are found, replace the candles. Handle the candles as carefully as you would handle a piece of fragile ceramic.

h) When you finish cleaning the candles, place them back in the filter in the same manner as during construction. Return the sand to the filter, and make sure that it covers 5 cm above the top of the candles. Extra sand should be sieved, cleaned, and added to the filter once the sand level decreases by a few centimeters.

i) Replace the geotextile and plastic tube back in the filter in the original configuration.

j) Resume regular use of the Table Filter.

5. Water Chlorination

The purpose of disinfection is to reduce the amount of pathogenic microorganisms in water. Disinfection can be accomplished through the use of chemical or physical agents. Water chlorination is a type of chemical disinfection. Disinfection is a separate process from filtration, which reduces pathogens as an effect of removing suspended particulate matter. While chlorine is the most widely used chemical disinfectant, there are several other agents that are often used for disinfection in water treatment plants or systems. Some common chemical disinfectants include chlorine, chlorine dioxide, ozone, metals, extreme pH levels, surfactants (substances reducing surface tension), and permanganate. Physical disinfectant techniques include heat, UV radiation, and electron beam radiation (AWWA, 1999).

This chapter addresses the use of chlorine as a disinfectant. It also introduces the "Safe Water System" of household chlorination and small-scale community chlorine generation. Finally, it describes the chlorination program as it currently exists in southern Peru, as administered by the Ministry of Health and CEPIS.

5.1 Water Treatment using Chlorine

Chlorine was used for waste treatment in France as early as 1825. It was first used as a disinfectant for water in 1908 at Bubbly Creek in Chicago and at the Jersey City Water Company. By 1918, over 1,000 U.S. cities used chlorine to disinfect their water (AWWA, 1999). A study conducted by the American Water Works Association (AWWA) Disinfection Committee in the late 1980s found that chlorine or hypochlorite was employed as the primary disinfectant at over 90% of American water utilities' treatment plants (AWWA, 1999). Today, chlorine is one of the more common ways to treat water in large- and medium-scale water treatment plants, as well as one of the most, if not *the* most, widely used forms of small-scale water treatment in individual homes.

5.1.1 Chlorine's Effects on Microbial Contamination

5.1.1.1 Chlorine Chemistry

Chlorine can be used for disinfection in the form of **elemental chlorine** (Cl_2), **calcium hypochlorite** ($Ca(OCl)_2$), or **sodium hypochlorite** (NaOCl). The three forms are considered "chemically equivalent." Elemental chlorine is naturally found in the form of Cl_2, a dense gas (AWWA, 1999).

Available chlorine refers to the relative amount of chlorine present in chlorine gas or in the hypochlorite salts. The available chlorine in hypochlorite compounds can be determined by finding the electrochemical equivalent amount of Cl_2 to that salt. One mole of hypocholorite ions (OCl^-) is considered to be "electrochemically equivalent" to one mole of elemental chlorine because each molecule reacts with two electrons to form inert chloride (Cl^-) (see equations 5.1 & 5.2); therefore, the amount of available chlorine found in one mole of hypochlorite and in one mole of elemental chlorine gas is 70.91g (the molecular weight of Cl_2) (AWWA, 1999).

$$Cl_2 + 2\ e^- = 2\ Cl^- \tag{5.1}$$

$$OCl^- + 2\ e^- + 2\ H^+ = Cl^- + H_2O \tag{5.2}$$

Calcium hypochlorite ($Ca(OCl)_2$) contains two moles of hypochlorite, and sodium hypocholorite (NaOCl) contains one, as can be seen by their scientific notations, which means they contain 141.8g and 70.91g respectively of available chlorine per mole of compound. Since calcium hypochlorite weighs 143 g/mole and sodium hypochlorite weighs 74.5 g/mole, the pure compounds contain 99.2% and 95.8% by weight of available chlorine. (Chlorine gas, by definition, contains 100% available chlorine.) The large percentage of available chlorine indicates that the hypochlorites are comparable to chlorine gas and can be an effective source of chlorine for water treatment (AWWA, 1999).

When chlorine compounds are added to water, two types of chemical reactions occur: hydrolysis and ionization. *Hydrolysis* of any of the three disinfectant compounds forms hypochlorous acid (HOCl) through the following reactions:

Chlorine gas: $$Cl_2(aq) + H_2O = H^+ + HOCl + Cl^- \tag{5.3}$$

Calcium hypochlorite: $$Ca(OCl)_2 + 2\ H_2O = 2HOCl + Ca(OH)_2 \tag{5.4}$$

Sodium hypochlorite: $$NaOCl + H_2O = HOCl + NaOH \tag{5.5}$$

Hypochlorous acid is a "weak acid" and some of the molecules are quickly broken down into hypochlorite ions and free protons (equation 6). This is called *ionization*.

$$HOCl = OCl^- + H^+ \tag{5.6}$$

Free available chlorine (or just *free chlorine*) refers to the sum of available chlorine present in water in the form of molecular chlorine (Cl_2), hypocholorous acid (HOCl), and hypoclorite ions (OCl^-). A study by Metcalf and Eddy on the destruction of E.coli determined hypochlorous acid to be up to 80 times more effective than hypochlorite ions, depending on concentration and contact time (AWWA, 1999).

When ammonia or amino nitrogen compounds are present in water, free chlorine reacts with ammonium ions to form *chloramines*. The *total*, or *combined*, *chlorine residual* in water consists of the chloramine compounds that have formed as a result of this reaction: monochloramine (NH_2Cl), dichloramine ($NHCl_2$), and trichloramine (NCl_3) (equations 5.7, 5.8, and 5.9). The chloramines, although combined, still contain available chlorine because each chlorine atom is still capable of combining with two electrons and forming chloride. One mole each of monochloramine, dichloramine, and trichloramine contains 71 g, 142 g, and 223 g, respectively, of available chlorine. But while they can help to disinfect the water, chloramines are generally less effective than either hypoclorous acid or hypochlorite ions (AWWA, 1999).

$$NH_4^+ + HOCl = NH_2Cl + H_2O + H^+ \tag{5.7}$$

$$NH_2Cl + HOCl = NHCl_2 + H_2O \tag{5.8}$$

$$NHCl_2 + HOCl = NCl_3 + H_2O \tag{5.9}$$

Total available chlorine refers "to the sum of free chlorine compounds and reactive chloramines" (AWWA, 1999). In other words, it includes both *free chlorine* and *combined chlorine residual*, or:

$$\text{Free + Combined = Total Available}$$

While the amount of residual chlorine may be much larger than that of free chlorine in a water sample, especially when excess ammonia is present, hypochlorous acid (HOCl) is by far the most effective compound at destroying coliform bacteria. For example, Chang reported that relative "biocidal potency" of HOCl : OCl^- : NH_2Cl : $NHCl_2$ is approximately 1 : 0.0125 : 0.005 : 0.0166 for coliforms (AWWA, 1999).

5.1.1.2 The Inactivation of Pathogens

Chlorine reacts with bacteria and, to a lesser extent, with viruses and some protozoa to inactivate them and render them harmless to humans when ingested. When it reacts with organic amines, organic monochloramines form in a similar manner as the formation of inorganic monochloramines. Chlorinated organic by-products are formed when free chlorine reacts with organic constituents. Free chlorine has also been shown to remove tastes and odors caused by the presence of organic sulfur compounds (AWWA, 1999). Metcalf and Eddy explain that chlorine can neutralize pathogenic microorganisms by any of the following activities (AWWA, 1999):

- Damaging cell walls
- Altering the cell membrane, e.g. destroying selective permeability
- Altering the colloidal nature of the protoplasm and causing protein denature
- Inhibiting enzyme activity

Chlorine can inactivate living organisms by interfering with a number of different critical functions. Chlorine can damage respiratory, transport, and nucleic acid activity in bacteria. For example, the viral nucleic acid is inhibited in the bacteriophage f2 when exposed to chlorine. In the poliovirus, the protein coat is harmed by the presence of free chlorine. It is also believed that the combined chlorine in monochloramines is able to inactivate bacteria. Organic chloramines are generally much less effective than inorganic chloramines (AWWA, 1999).

Chlorine demand is the difference between the amount of chlorine added to a water sample and the chlorine residual present after a certain amount of time (AWWA, 1999).

Some studies have shown that organisms that survive the disinfection process can "exhibit inheritable increased resistance to subsequent exposure." This was seen to occur when the poliovirus was exposed to chlorine, but consistent findings have not resulted from similar tests on bacteria (AWWA, 1999).

5.1.1.3 Interference Caused by Turbidity

Turbidity can reduce the effectiveness of chlorine because microorganisms can adsorb to or "hide" within suspended particles or flocs of particles and escape contact with disinfectant compounds. Turbidity can also harbor nutrients to feed microorganisms. Generally, as turbidity in water increases, its chlorine demand is found to increase. LeChevallier, Evans, and Seidler, from the Department of Microbiology at Oregon State University, suggest that high turbidity in water usually indicates poor water treatment. Their "disinfection efficiency" model indicates that drinking water with a turbidity of 10 NTU could be eight times more likely to carry pathogens than water with 1 NTU (AWWA, 1999).

Turbidity has also been found to interfere with membrane filtration (MF) – the coliform detection technique that is utilized in this study. In a study performed by LeChevallier, et al. on the effects of turbidity, MF tests gave more false-negative results when the waters had higher turbidities. A false-negative result occurs when a test *incorrectly* indicates that the water is free of the test coliform. In the LeChevallier study, 17% of the tests gave false-negatives when using water of less than or equal to 1 NTU, the recommended turbidity for disinfection purposes (AWWA, 1999). At 5 NTU, the WHO's recommended threshold for drinking water (WHO, 2004), 45% of the tests resulted in false-negative readings. When the turbidities were greater than or equal to 10 NTU, the false-negative results raised to 80%. These results indicate that turbidity can mask the presence of coliforms (AWWA, 1999).

The reduction of "total organic content" (TOC) in water is another good reason to reduce turbidity. TOC, which is related to turbidity, reacts with chlorine and interferes with its disinfection capabilities. Also, when TOC reacts with chlorine, trihalomethanes are produced as a by-product, and some of these are known to be carcinogenic (AWWA, 1999).

It is for these reasons that a pretreatment, such as settlement (possibly preceded by coagulation) and/or filtration, is recommended before chlorination of waters that have a high turbidity. The WHO suggests that pretreatment before chlorination be designed to reduce the water's turbidity level to less than 1 NTU, or ideally less than 0.1 NTU (WHO, 1993, 2004).

5.1.1.4 General Disinfection Practices

Free chlorine residual refers to the "free (available) chlorine" (in the form of Cl_2, HOCl, or OCl^-) remaining at equilibrium after the original chlorine dose has reacted with the water sample. Some studies suggest that the presence of free chlorine residual can help protect the water against further infection or growth or can indicate a lack of contamination; but other studies claim that there is not necessarily any correlation between the quality of water in a distribution system and the concentration of chlorine residual (AWWA, 1999). The WHO recommends a free chlorine residual concentration of 0.2 to 1.0 mg/L in water to ensure that it is disinfected and protected against biological regrowth (WHO, 2004).

Disinfection is often combined with other treatment processes, such as coagulation, sedimentation, and filtration, which usually occur in that order. Disinfectant can be added at several different points along a series of treatment processes such as those seen in a drinking water treatment plant. When disinfectant is added before coagulation, the process is called *preoxidation* or *predisinfection*. *Prechlorination*, as it is called when chlorine is used as the disinfectant, generally serves to discourage the build-up of “biological slime” on the treatment plant’s infrastructure (AWWA, 1999).

Since disinfection inactivates relatively few pathogens before coagulation, this step is most often placed after coagulation and sedimentation. *Primary disinfection* refers to disinfection that occurs after sedimentation and can occur either before or after filtration. When chlorine is added, especially if it is after filtration, this step can be called *postchlorination*, and often is applied in a holding tank or reservoir where water is stored and given sufficient time to come into contact with the disinfectant before it is distributed to users. If desired, a *secondary disinfection* may be applied after primary disinfection and usually is designed to ensure that some residual of the disinfectant flows with the water throughout the distribution system (AWWA, 1999).

Thiosulfate, hydrogen peroxide, ammonia, sulfite, bisulfite, sulfur dioxide, and activated carbon can be used to “dechlorinate” water if the chlorine residual is higher than desired for human consumption (AWWA, 1999).

5.1.1.5 Choosing a Specific Form of Chlorine for Disinfection

Chlorine for disinfection is generally available in three forms: liquefied chlorine gas, solid calcium hypochlorite, or liquid sodium hypochlorite solution.

Elemental chlorine, a toxic green gas, can be compressed and dissolved into water for disinfection (at which point it is non-toxic). This liquefied gas is generally the least expensive form of chlorine disinfectant, especially in bulk quantities; thus it is often used in large treatment plants in the U.S. (AWWA, 1999). Chlorine gas is not generally recommended for smaller treatment plants, however, because of the hazards of possible toxic gas leaks. In fact, Spellman warns that chlorine gas, even at concentrations as low as 0.1% by volume, can be lethal (Spellman, 2000).

Calcium hypochlorite, sometimes referred to as bleaching powder, can be obtained commercially in a dry powder or tablet form and generally contains about 65% available chlorine (Spellman, 2000). This is the most expensive form of the chlorine disinfectants, but it can be practical for very small treatment plants because it is easy to store and will not lose its potency as quickly as liquid sodium hypochlorite (AWWA, 1999).

Sodium hypochlorite is often chosen by small or mid-size treatment plants because it is less expensive than calcium hypochlorite and less dangerous than chlorine gas. It can also be easily generated on-site, which is especially helpful in places without easy or affordable access to chlorine disinfectant (AWWA, 1999). Commercial sodium hypochlorite solutions, such as household bleach, generally are prepared with 5-15% available chlorine (Spellman, 2000).

Both calcium and sodium hypochlorite are corrosive, and people handling them should be careful to avoid skin contact, inhalation, or ingestion of the substances (AWWA, 1999; Spellman, 2000).

5.1.2 CDC's "Safe Water System"

The Safe Water System (SWS) is a low-cost HWTS that uses chlorination to combat the diseases caused by contaminated water. The Centers for Disease Control and Prevention (CDC) and PAHO developed the SWS in response to the cholera epidemic that broke out in South America in 1992 (CDC, 2001). The system is intended for single-family use, especially in developing countries, as it is a very low-cost and simple technology for disinfecting unsafe water. The Safe Water System has been implemented in 19 countries in Africa, Asia, South and Central America, and the Caribbean (CDC, 2004).

The SWS program is comprised of three components:

1) Point-of-use household chlorination of water using a locally-generated sodium hypochlorite solution
2) Safe storage of treated water in appropriate containers
3) Community education regarding the system, aimed at behavioral modification concerning water and general hygienic practices

5.1.2.1 Chlorination

The main component of the Safe Water System involves the disinfection of drinking water through the use of a sodium hypochlorite solution. The process of disinfection by this chlorine compound is described above in Section 5.1.1. In order to provide a chlorine solution that has a specific concentration of available chlorine and that is cheap, the hypochlorite is generally produced locally specifically for SWS users.

Commercially-available sodium hypochlorite solutions, especially those in developing countries, do not always contain a known or consistent chlorine concentration, and the available concentrations may differ from area to area or product to product. The dose of solution needed to disinfect a certain volume of water depends on the concentration of the chlorine solution, therefore it would be impossible to instruct users on the appropriate volume of chlorine solution to add to their water if there was no consistent chlorine concentration available. Bleaches might also include additives that assist in cleaning laundry but that are not appropriate for drinking (Mintz, 1995; Sullivan, 2002). Another reason to avoid commercially-produced solutions is that many people associate these products with cleaning their clothes or disinfecting their house and may be adverse to the thought of drinking such a substance (CDC, 2001). Also, sodium hypochlorite solutions can usually be locally produced for an entire SWS community of users for less money than it would cost the users to purchase commercially-generated solutions. In some areas of the world, especially in rural or remote communities, SWS users may not be able to find chlorine solutions of any kind. It is for these reasons that the CDC recommends that the sodium hypochlorite solution used with the SWS be generated locally. The CDC also suggests that the most effective solution would be a 0.5-1% sodium hypochlorite solution (CDC, 2001). Small-scale chlorine generation is described in more detail in Section 5.2.

5.1.2.2 Safe Storage

The disinfection of water can only help prevent sickness if the water does not become re-contaminated. The safe storage of water is essential for water to remain sanitary within a house containing many possible sources of contamination. These sources can include dirty water containers, dirty hands, contaminated scoopers or cups dipped into the water, flies or other insects, and things that can fall into an open container of water. The CDC has six criteria for "safe" water storage containers (CDC, 2001):

- 10 - 30-liter capacity for ease of handling, fixed with handle and sturdy base
- Durable, light-weight, translucent, easy-to-clean (e.g. high density polyethylene)
- Opening large enough to allow for refilling and cleaning but small enough to prevent dipping from a cup (6-9 cm ideal), with a screw-on lid, preferably attached with a cord or chain
- Spigot that is durable, easy to close, and allows a flow of 4 L/min.
- Permanent, water-resistant label with instructions on treating, using, and cleaning
- Conforms to local national standards (certified by the local Ministry of Health)

The CDC and PAHO have developed a 20-L safe storage container that meets these criteria. As of the year 2001, these containers, or similar ones designed specifically for the SWS by Oxfam and CEPIS, were available only in South Africa, Bolivia, Ecuador, the UK, and Peru. The container produced by CEPIS for use in Peru will be further described in Section 5.3.2. SWS programs in other countries can import the CDC-designed containers; purchase the molds for $100,000 and manufacture the containers themselves; or they can identify and develop a container from locally available products (Mintz, 1995; CDC, 2001; Sullivan, 2002).

5.1.2.3 Education

Adequate education is essential for this system to be effective and sustainable. Users should understand the health risks associated with untreated water and the benefits that the SWS can offer (Brin, 2003). It is important that the disinfection solution and safe storage container be used appropriately to ensure safe drinking water (Sullivan, 2002). A strong educational program accompanying the SWS's physical components is intended to educate people not only in the use of the SWS but also in good general hygiene practices. Educational material should include instructions such as the importance of washing hands and food in clean water and covering food and water to protect from flies. It could also inform people about how to build and use a ventilated pit latrine (VIP) instead of using exposed waste sites. The CDC refers to this education as "behavior modification" because in order for the program to work effectively and for people's health to improve, the users must not only receive information, but must actually change their habits as they become informed about health issues. The household water treatment program in Peru employed this three-fold strategy, as explained later in Section 5.3.

The educational component of this program could be approached in many different ways. The CDC has listed a large number of formats for presenting the material, as seen in Table 5-1. People developing and preparing the educational material should be cognizant of their intended audience and should make the material understandable, applicable, and attractive to that audience. Audiences that should be considered include people who usually collect water and prepare food for their household, those who make household decisions, mothers with young children, local health workers, school officials, and community leaders (CDC, 2001).

Table 5-1: Potential Communication Channels for Behavior Modification Programs. Source: CDC, 2001.

Interpersonal Channels	**Local Media**	**Mass Media**	**Printed Materials**
Community meetings	Drama	Radio	Posters
Door-to-door visits	Traditional musicians	Television	Brochures
Health worker/Client interactions	Public announcements by local leaders	Videos or films	Labels on storage containers or disinfectant bottles
Shopkeeper/ Customer interactions	Storytelling	Cassettes	Leaflets
Teacher/Student interactions	Puppet shows		Newspapers or newsletters

5.2 Small-Scale Chlorine Generation

Key to chlorination systems is the availability and affordability of chlorine. For reasons stated above, the CDC recommends that chlorine be produced locally in developing countries that use the SWS. Local generation of the appropriate disinfection solution, generally containing 0.5% sodium hypochlorite, can become a micro-enterprise, providing a beneficial health service to the community and a source of income to the enterprise's employee(s) (Gao, 2002).

The disinfection solution is created by running an electric current through saline water for a number of hours. The current causes the salt and water to electrolyze into sodium hypochlorite (Sullivan, 2002). This operation has been practiced since the early twentieth century. The electric current, which may need to be as high as 3.85 volts, causes the oxidation of chloride ions and the reduction of water to hydrogen gas, which results in the formation of sodium hypochlorite, through the reaction shown in equation 5.10. Such high voltages, however, can interfere with the reactions and prevent the systems from being completely efficient. Downs and Adams report that the current efficiencies of typical electrolysis cells can be 97% and the energy efficiencies 58% (AWWA, 1999).

$$NaCl + H_2O = NaOCl + H_2 \tag{5.10}$$

Several different companies manufacture electrolysis cells of different sizes and price ranges. The specific apparatus used in Peru is described in Section 5.3.1.

5.3 Peru's Household Chlorination Program

As predicted by CDC's preference for local chlorine generation, the hypoclorite solutions available in Peru are not regulated. Sodium hypochlorite solutions sold commercially, known in Spanish as *lijia*, are generally 6% solutions but can range from 5 to 10%, and calcium hypochlorite, which comes in a dry powdered form, can range from concentrations of 20 to 25%. With the locally-produced sodium hypochlorite solutions of 0.5% concentration, users can be certain of the dose of solution needed for disinfection (Rojas, et al., 2004).

Although not referred to as such, the household chlorination program, implemented by the Peruvian Ministry of Health and CEPIS is, in effect, the Safe Water System. The program adheres to the goals and components of the CDC's recommended system: small-scale chlorination of water at the household level, chlorine generation, safe water storage, and behavior modification efforts. In an evaluation of its 1995-1998 chlorination program in northern regions of Peru, CEPIS reported that diarrheal sicknesses in children under the age of five were 20-40% lower in areas using household chlorination as compared to a control group without household chlorination (CEPIS, 2000).

5.3.1 Chlorine Generation in La Joya

A chlorine generator was placed in La Joya, the central town out of which the Arequipan household water treatment program is run. The generator is located at the *Centro de Salud*, or Health Center of La Joya, which is run by the Ministry of Health. This generator produces all of the chlorine solution used by those in the SWS program. Four hundred safe water storage containers, known locally in Spanish as *bidones*, were distributed to families and schools in seven neighboring towns and villages. Table 5-2 presents the breakdown of the distribution of *bidones* by town. All towns are located around the town of La Joya, in the La Joya and San Isidro Districts of Arequipa. Small 250-ml bottles of chlorine solution are also distributed for free, as needed, to the families with SWS *bidones*.

Table 5-2: SWS *Bidon* Distribution by Village

Village	*Bidones*
Cerrito Buena Vista	100
Kilometer 48	70
La Cano	50
San Camilo 6	50
San Camilo 7	50
San Isidro	50
Villa Hermosa	30
Total	*400*

The Arequipan Ministry of Health runs the chlorination program through the La Joya Health Center, where the chlorine solution is generated. They refer to the solution as "disinfectant" or *chloro* – the Spanish word for chlorine. The solution that they produce is a sodium hypochlorite solution containing 0.5% chlorine. They use a Yacu Electronic apparatus to generate the sodium hypochlorite solution (see Figure 5.1). CEPIS reported that the generator is Yacu's 5th version, which uses electrolysis cells and runs on 220 volts/15 amperes and produces 25 grams per hour of sodium hypochlorite.

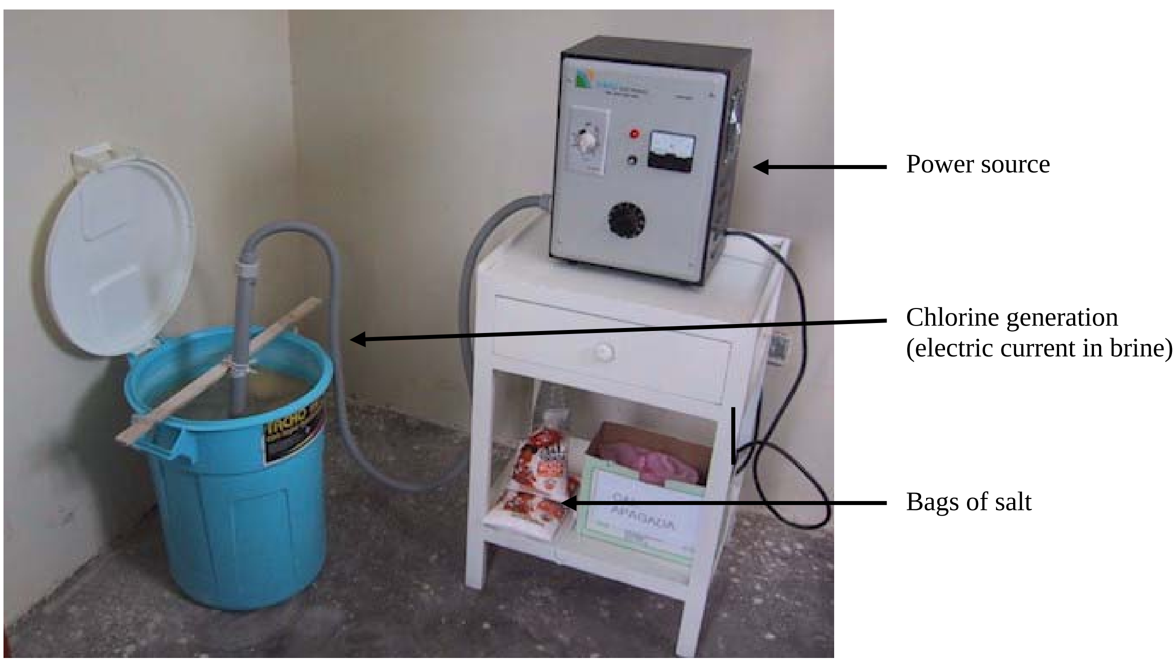


Figure 5.1: Yacu Chlorine Generator Located in the La Joya Health Center

Claudia Mena Cornejo, who is in charge of *chloro* production in La Joya, adds one kilogram of salt (which can be seen in bags at the bottom of Figure 5.1) to 33 liters of water and runs an electric current through the water with the Yacu generator. Cornejo runs a production cycle about twice a month since the 250-ml bottle of *chloro* typically lasts a household one month. Production cycles, with this generation system, can also be run with 40 liters of water, so that up to 160 bottles could be filled per cycle. With two cycles per month, enough solution is produced to supply 320 families with a bottle of *chloro* each month. When a family runs out of *chloro*, they can take their empty bottle to their village's health post to be refilled the next time the solution is produced. Considering that many people do not use their SWS *bidon* or do not chlorinate their water regularly, according to Coulbert's observations while visiting HWTS households, the current production is probably enough to provide those who want it with a continual supply of chlorine solution. After each production cycle, Cornejo fills all of the empty bottles that have been turned in and then gives the rest of the hypochlorite solution to the La Joya Health Center to use for disinfection and cleaning purposes. The bottles are delivered to each village's health post, from whence the local health worker distributes them to families as needed.

5.3.2 Equipment and Procedure for Household Chlorination

An SWS *bidon* and a *chloro* bottle are shown in Figure 5.2. The SWS *bidon* contains a plastic spigot for dispensing water and a medium-sized opening with screw-on lid for refilling. The opening on the top is approximately 10 cm in diameter and is meant to be large enough for easy refilling from water taps or pouring from other containers but small enough to discourage users from dipping anything into the water that might be contaminated (e.g. hands, cups, etc.). This enclosed plastic container is an example of a safe water storage container, as it helps keep the treated water free of contamination while it is being used or stored. Like the Table Filter buckets, these *bidon* containers were manufactured by the Belgian development agency DGCI. The *cloro* bottle has a volume of 250 ml with a screw-on cap that holds approximately 10 ml.

Figure 5.2: SWS *Bidon* and *Chloro* Bottle

In order to disinfect their water, SWS *bidon* users are instructed to add half of the bottle cap of *chloro* (approximately 5 ml) to their empty SWS *bidon*, fill the 20-liter container with water, and then wait 30 minutes before drinking from the container. Since a bottle of *chloro* contains 250 ml, it can be used to treat up to 1,000 L of water before it must be refilled. For a family of five, this allows each person about 6 L per day if the bottle is to last for a month. This is just enough to provide the minimum amount of treated water. The WHO states that a minimum of 7.5 L of water per day is needed for adults. Assuming that some of the household members are children, that some liquids may be consumed away from home during work or school, and that some water may be boiled for cooking instead of chlorinated, then one bottle of *chloro* would be just barely enough to last a family of five one month. However, if they are to consume 20 L each, which is defined as adequate access, they would need more than one bottle per month of *chloro*.

5.3.3 Behavioral Modification Practices

The Ministry of Health distributes educational pamphlets to the households who use the SWS *bidones*. The pamphlets are full of colorful and descriptive pictures and simple phrases so that people without strong literary skills can understand the message that is being conveyed. The English translation of one of the pamphlets follows. It also instructs the readers to use the treated water for all of their domestic household water needs.

Table 5-3: An Instructional Pamphlet on the Use of the SWS Chlorination System

<u>Disinfection and Use of Water</u>[34]

1. Measure half a cap of disinfectant
2. Add the half cap of disinfectant to the empty container
3. Add 20 L of water
4. Wait 30 minutes

Use the disinfected water for:

- Drinking
- Brushing teeth
- Washing vegetables and fruits
- Washing cooking utensils [and dishes]
- Washing hands

Where can you purchase the disinfectant?
In your community's center of administration.
If you have any questions, ask at the center of administration.

[34] Translated from the pamphlet entitled *Desinfeccion y Usos del Agua* produced by DGCI, CEPIS, and the Ministry of Health in Peru.

The Ministry of Health, CEPIS, and DGCI also distribute other pamphlets that describe the use of Table Filters, the construction of pit latrines, and the importance of using these hygienic technologies and keeping a clean house. Here is an example of a pamphlet that the Ministry of Health distributes on general hygienic practices. On the back of this pamphlet are instructions on how to use the Safe Water System chlorine solution and *bidon*. The original Spanish pamphlet can be found in Appendix C.

Table 5-4: Informational Pamphlet on General Hygiene Practices

Our Environment and Our Health[35]

An environment contaminated with
- Excrement in the open air and
- Garbage in the streets,

Contaminates the water
- In the river,
- In water trucks, and
- In storage containers,

And provokes
- Diarrheal illnesses
- Like cholera,
- And even death.

Avoid sickness by:
Disinfecting water that is used for
- Direct consumption,
- Brushing teeth,
- Washing vegetables and fruits,
- Washing kitchen utensils and dishes,
- And washing hands.

Buying food in hygienic places.
Protecting food [that is sitting out].
Constructing and using latrines.
Cleaning the streets of the community.
Maintaining a clean house.

The government of Peru has also launched an educational campaign in certain parts of Peru through the use of radio, and possibly some television, advertisements. This effort may not be connected to CEPIS's chlorination program in the southern parts of Peru, but it does encourage and educate the public concerning the use of chlorine for the disinfection of drinking water.

[35] Translated from the pamphlet called *Nuestro Ambiente y Nuestra Salud* produced by DGCI, CEPIS, and the Ministry of Health in Peru.

6. Water Treatment Plants

In developed countries and urban areas of developing countries, the common solution to contaminated water is the installation of water treatment plants that serve entire towns or cities. A water treatment plant is the third option available to the residents of La Joya and San Isidro Districts to treat their water. Water treatment plants require a substantial investment in infrastructure to treat large volumes of raw water through a variety of processes. These unit processes may include the following treatments: aeration, coagulation/chemical precipitation, sedimentation, filtration, organic and inorganic adsorption, membrane processes, chemical oxidation, and disinfection (AWWA, 1999). The treated water is then pumped to a distribution system which supplies taps or standpipes located in or near individual houses.

People usually prefer treatment plants over household treatment systems because the former frees them from having to treat the water themselves and because the treatment plant distribution system usually includes delivery in pipes directly into the home or its immediate vicinity. Unfortunately, this option is much more expensive than either of the household treatments presented in this paper. It is for this reason that household treatment may be a more realistic immediate to midterm solution to meet the Millenium Development Goal of reducing by half the number of people lacking access to safe drinking water by the year 2015 (UN, 2003). Even assuming that the Millennium Development Goals are met, millions of people will remain without improved access to drinking water, and many of those *with* improved access will not necessarily have *safe* drinking water; therefore, numerous households will stand to benefit from household treatment and safe water storage.

Because of the infrastructure that is required, the option of a water treatment plant is financially feasible only in relatively dense urban areas with customers who are willing and able to pay higher fees for water. A plant could be built in most of the communities in this study, but the cost per family would be extremely high, especially since many communities contain only a few hundred households.

During the January 2004 field study in the La Joya area, we learned of three water treatment plants, but time permitted us to visit only two. The city of La Joya has its own water treatment plant, and most residents believe it provides water of fairly good quality. The small neighboring town of Cerrito Buena Vista (CBV), where most of our water sampling occurred, has its own simple water treatment plant. A nearby town called El Triunfo has a somewhat more sophisticated treatment plant. Also, La Cano, a village of about 250 households, is planning to build a treatment plant over the next couple years if the necessary money can be raised. This chapter reviews the designs of the CBV and El Triunfo treatment plants as well as some of the plans for the La Cano plant.

6.1 Cerrito Buena Vista Water Treatment Plant

The treatment plant at CBV is fairly simple and, while residents are happy to have this facility, the treated water from this plant is of poor quality and therefore residents are instructed to use their household treatment system to further treat the water that comes from the plant to the point of distribution (usually a water tap on the household plot). All water treatment plants in this area use raw water from irrigation canals similar to the El Triunfo canal pictured in Figure 6.1.

Figure 6.1: Typical Irrigation Canal that Feeds La Joya District Water Treatment Plants

The CBV plant's treatment processes consist of sedimentation and a very small amount of chlorination that is administered, it appears, intermittently. The entire treatment plant consists of four tanks of water. Figure 6.2 shows a picture of the plant, with the four tanks labeled.

Figure 6.2: Coulbert & Begazo at the CBV Treatment Plant

In the first tank, raw canal water flows through a rough filtering screen (seen in Figure 6.3), which is meant to trap any large objects and particles. The water then flows through three settling tanks.

Figure 6.3: CBV Treatment Plant - First Tank with Screen

A small amount of powdered chlorine is added in the last tank before the water is delivered through underground pipes to the town. The powdered chlorine is poured into a plastic cylinder which hangs from a string into the last settling tank. This cylinder, which can be seen in Figure 6.4, contains small holes covering the surface, which allow the chlorine to seep out into the water.

Figure 6.4: CBV Treatment Plant – Chlorine Diffuser in Last Tank

6.2 El Triunfo Water Treatment Plant

The El Triunfo plant is newer and utilizes several methods of treatment.

Figure 6.5: El Triunfo Water Treatment Plant (Technician's House on Right)

Raw irrigation canal water is first pre-treated in settling tanks (Figure 6.6) before it enters the main water treatment plant.

Figure 6.6: El Triunfo Pre-Treatment Tanks

As the water first enters the plant after pre-treatment, a 4% solution of aluminum sulfate, commonly known as *alum*, is added drop by drop from a barrel (Figures 6.7 and 6.8). This 50-L barrel is filled with 48 L of water and 2kg of powdered alum, and is refilled twice per day.

Figure 6.7: Barrel Containing Aluminum Sulfate Solution

Figure 6.8: Adding Alum Drop by Drop to Influent Water

The water is then allowed to coagulate with the alum in a small triangular tank (Figure 6.9) before entering a settling tank (Figure 6.10).

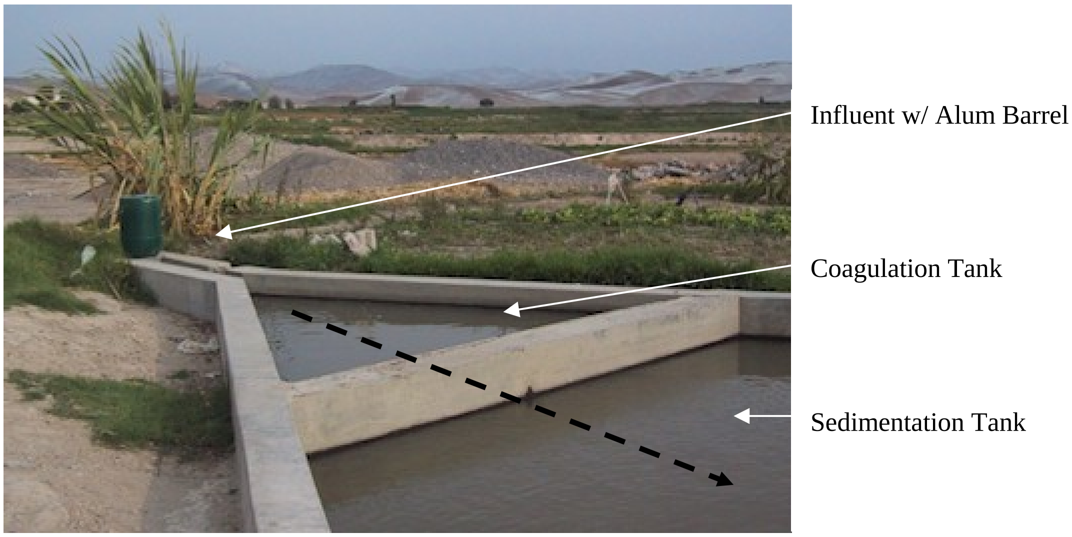


Figure 6.9: Coagulation and Settlement Tanks (Dashed Line Indicates Direction of Flow)

Figure 6.10: Coagulation & Settling Tanks in the Foreground and the Pre-Chlorination Tank & Sand Filtration Beds in the Background

Next, chlorine is added to pre-chlorinate the water before filtration (Figure 6.11). The chlorine used in this plant is a powdered calcium hypochlorite that contains 33% active chlorine. It is manufactured in Peru by Quimpac. Twice a day, 2.5kg are added to a 50-L barrel of water (with 47.5 L of water) to create a 5% solution, and the calcium hypochlorite solution slowly drips out into the water in the same manner as the alum.

Water can then be directed to gravel and sand filters or, when the gravel and sand beds are being cleaned, as was the case when the plant was visited, the water can bypass the filter beds, and go directly to distribution to the town.

Figure 6.11: Pre-Chlorination Tank with Chlorine Barrel (Left Foreground)

When the plant is operating normally, the water is then directed through a series of tanks with coarse gravel, medium gravel, fine gravel, and coarse sand (Figures 6.12 – 6.14). This process is known as multi-stage filtration. Gerardo Galvis' doctoral thesis focuses on multi-stage filtration and explains that the theory accompanying this treatment practice asserts that multiple stages of treatment are necessary to produce clean drinking water. Each stage removes additional contaminants from the water, and the target water quality should be reached before the final stage so that if any one stage or process fails, it will not create a "significant risk of waterborne disease." Each stage of treatment is instrumental in assisting the subsequent treatment processes to reach their full potential. As presented by Galvis, a common structure of a water treatment plant using multi-stage filtration employs dynamic gravel filtration, followed by coarse gravel filtration (often several beds in series), and finally slow sand filtration (Galvis, 1999).

Figure 6.12: Gravel Beds (Dashed Line Indicates Direction of Water Flow)

Figure 6.13: Fine Gravel & Coarse Sand Beds

After the coarse filtration, the water is filtered through large beds of fine sand (Figure 6.14). Each of the two beds contains 4000kg of sand. (The water only looks as dirty as it does in Figure 6.14 because the filters were not in use at the time the photograph was taken. The sand bed was waiting to be cleaned.)

Figure 6.14: Fine Sand Bed (Covered with Water)

Finally, after the multi-stage filters, the treated water is stored in a large tank (Figure 6.15), where additional chlorine can be added and final settlement takes place. The water then flows by gravity into the distribution system, which supplies the homes in El Triunfo. When this plant was visited by the H_2O-1B! team, water in the final tank was temporarily not being distributed because the gravel/sand beds were shut down for cleaning. Since water had been sitting in the final storage tank for at least a day longer than usual, the turbidity, residual chlorine, and coliform level readings taken that day most likely were not representative of the plant under normal operation.

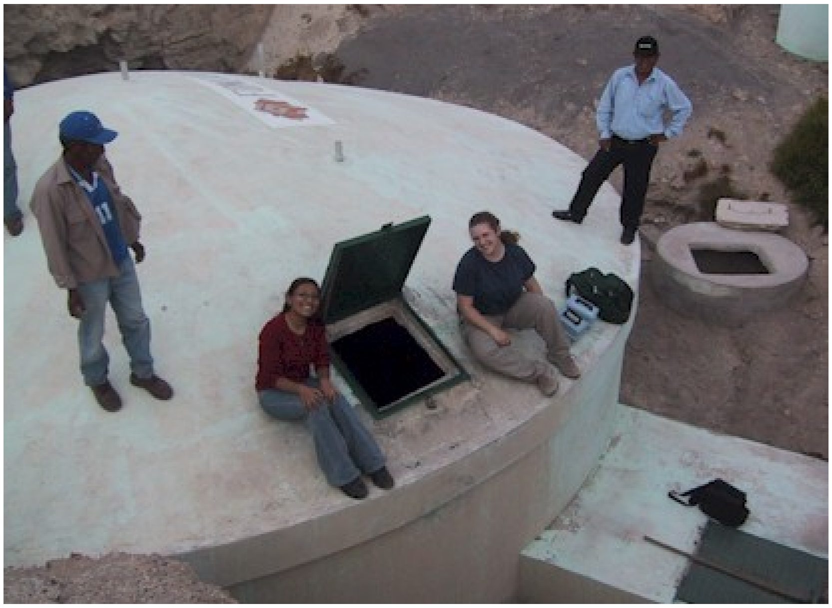


Figure 6.15: Final Settling and Storage Tank
(with WTP Technician on the Left, and Begazo & Coulbert in Foreground)

The people who live in El Triunfo do not receive water from the system every day. The plant's flow rate is about 4-5 L/sec, which is not enough to serve the entire community. In order to address this problem, the town has been divided into three zones, and on any given day, one or two of the zones receive water – about 300 L per family per day. In this way, the plant is able to provide enough water to the town, with everyone receiving water about two-thirds of the time.

The plant was funded by the town residents with a 10% contribution from the Peruvian government agency "Foncodes." The townspeople pay only S/ 2 ($0.57) per month for their water. This pays for the plant operator/technician who maintains and lives at the plant. Residents also contribute to the maintenance of the plant by periodically volunteering their labor.

6.3 Possible Future La Cano Water Treatment Plant

The H_2O-1B! team visited La Cano during January 2004 to conduct an experimental auction. The two purposes of the "auction," which took the form of a town meeting, were: 1) to interact with the citizens to learn about their experience with the two HWTSs distributed by CEPIS and the Ministry of Health and to provide information to those who did not know about them, and 2) to find out which system people preferred and how much they might be willing to pay for one, since the government was no longer providing the HWTSs free of charge nor did the town have very much money to fund their own rural water treatment plant. The team learned, from the Mayor of the La Joya District, that La Cano was already planning to build a treatment plant over the next couple years. While this will cost residents much more than either the household chlorination or Table Filter treatment options would, the La Cano residents prefer the extra convenience and dependability of a treatment plant, even though they cannot afford the full price.

The cost of building the water treatment plant would be S/ 300,000. Table 6-1 shows the costs of each treatment option to families in La Cano, a town of about 250 households. The Mayor said that the town would be expected to raise 20% of the total cost (S/ 240 per family), and then the rest would be funded, presumably, by the government.

Table 6-1: Cost per Family of Each Water Treatment Option

	Initial Cost	Approx. Maintenance Cost / Month
Disinfection *Bidon* (Chlorination)	S/ 40	S/ 0.3
Table Filter	S/ 65	S/ 2
Water Treatment Plant	S/ 1200	S/ 2

During this meeting with the town, we asked people to raise their hands if they would be willing to pay a certain price for a treatment system. Of the 41 people at the meeting, everyone said they would be willing to buy the *bidon* or the Table Filter for S/ 1. Only two people said they would buy the *bidon* for S/ 2, and only five people would buy the Table Filter for S/ 3. Their willingness to pay for these systems was probably dramatically decreased by their desire for and belief that they were already going to get their own water treatment plant. Forty people were willing to pay S/ 20 for the plant and 14 people were willing to pay S/ 50. While they were willing to pay much more for the treatment plant, they still could not pay even 10% of what it would cost. The treatment plant may be a wonderful solution for the town if the government or another organization is willing to fund most of it. However, if the necessary funds cannot be raised, household treatment systems could be the more financially realistic solution.

7. Methodology

In January of 2004, the author traveled to villages in southern Peru, where CEPIS and Peru's Ministry of Health had implemented their HWTS program, to learn first-hand about the actual use of the water treatment systems and about the general water situation that these rural Peruvians face. Coulbert, along with Murcott and Begazo, and with the assistance of the entire H_2O-1B! team, evaluated the treatment programs and technologies through scientific testing, personal observation, and one-on-one interviews of household members. In-depth descriptions of the program and its technologies can be found in earlier chapters. During the January field study in Peru, the researchers also visited two community water treatment plants. More information about the plants can be found in Chapter 6. Water samples from the plants were tested so that the efficacy of the water treatment plants could be approximately compared to that of the Table Filter and SWS.

Longhi and del Carpio continued the research in Peru during the month of March 2004. (This research time period will be referred to as "March" even though the testing occurred from March 10 through April 4.)

The Ministry of Health in Arequipa and its Director, Luis Carlos Arxe Borda, were the local hosts and provided supplies and support to the investigative team. Claudia Mena Cornejo, who worked at the La Joya Health Clinic, a local branch of the Ministry of Health, was in charge of the household drinking water treatment program in La Joya and was instrumental in helping the team collect information and conduct research.

*　　*　　*

This chapter explains the methods that were used to obtain information about the current state of the Ministry of Health's household water treatment program in Arequipa as well as the efficacy of the Table Filter, the chlorination treatment system, and the two water treatment plants visited. The results of these methods are presented in Chapter 7. Most of the research was performed in the province of Arequipa, although the January research period included a brief trip to and a small amount of research in Tacna, the southernmost province of Peru. For the purposes of this thesis, "field tests" are all those tests which were performed in Peru, whether in the laboratory or at the site of water collection (Section 7.1). Further research was performed during the spring and summer of 2004 on two Table Filters that were brought from Peru to the laboratory at MIT. All tests performed at MIT are referred to here as "laboratory tests" (Section 7.2).

7.1 Field Testing Procedures in Peru

Water sample collection and interviews were performed at many houses and a few other places in the provinces of Arequipa and Tacna during the January and March field testing periods. This research study mostly occurred in the La Joya and San Isidro Districts of the Arequipa province of Peru. Most of the houses sampled and interviewed were located in the village of Cerrito Buena Vista (CBV) (see Figure 7.1). Each place where a water sample was collected or an interview conducted received an identification label, often the house's address (e.g. H-3 or LL-12). Unless otherwise noted, all house addresses are located in Cerrito Buena Vista. Whenever possible, flow rate, turbidity, and free chlorine tests were performed at the site of collection. Microbial tests were performed in the laboratory of the La Joya Health Clinic (Figure 7.2).

Figure 7.1: The Town of Cerrito Buena Vista, Arequipa

Figure 7.2: La Joya Health Clinic

7.1.1 Field Laboratory Set-Up

The La Joya Health Clinic allowed the H_2O-1B! team to share part of their laboratory space and use their oven for glassware sterilization. The lab bench was sterilized with isopropenol each day before and after testing. Below is a list of all the tasks that were performed and in general need to be accomplished in order to set up a work space for the types of testing covered in this study.

Figure 7.3: Lab Bench in the La Joya Health Clinic

7.1.1.1 Steps to Initial Laboratory Set-Up

Steps needed for laboratory set-up (not necessarily in order):

1. Place MF broth in refrigerator and non-ice pack in freezer.
2. Create/find a place to throw trash.
3. Find a counter space that can be kept as clean as possible.
4. Clean all surfaces thoroughly, then sterilize with alcohol and/or cover with aluminum foil and then sterilize.
5. Wash with dish soap all equipment bought in-country, and if necessary those brought along.
6. Set out and/or organize all equipment and supplies for ease of use (e.g. the bleach, dish soap, and sponges were kept by the sink; pots, towels, and matches were kept by the stove; MF assembly and glassware was kept on top of the counter; aluminum foil, paper towels, and Petri dishes were kept on shelves beneath the counter).
7. Find a place to keep the incubator.
8. Find/create a clean place to store Petri dishes, filter papers, etc.
9. Create a 10% bleach solution (for used Petri dish disposal).
10. Find small rocks or brick chips to place on the bottom of a pot to elevate the incubator so that the plastic does not melt on the bottom of the pan.
11. Find and clean the stove to be used for boiling water.
12. Sterilize equipment and cover with sterilized foil (wiped with alcohol).
13. Set a metal tray next to the oven to keep sterilized glassware contained.
14. Prepare blank water, if needed (see Section 7.1.4.2.9 below).

15. Sterilize, if necessary, and separate several pipette tips into sterilized aluminum foil inside a sterilized Zip-Lock© bag
16. Standardize turbidimeter
17. Set up lab book for data entry
18. Collect/organize materials needed for sample collection/in-field testing (plastic bottles with screw caps, *Whirl-Pak* bags, paper towels, small water bottles cut off in the middle for water waste in the field when not considerate to throw on the ground, hand sanitizer, lab notebook, permanent pen, bottled water, digital titrator and everything needed for chlorine residual testing, cooler with non-ice pack, turbidimeter

7.1.1.2 Equipment List

Following is a list of all the equipment that was used in this study in Peru, in hopes that others can use this list to help them think through everything that is needed for such a study.

<u>Equipment purchased in Peru:</u>
From the market:
- 2 metal pots for boiling water
- Towels (to use as pot holders, for insulation, and water spills)
- Tongs (to grab glassware out of boiling water)
- Screwdriver (for turbidimeter battery compartment)
- Metal tray (for sterile glassware)

From a store:
- Sponges
- Dish soap
- Matches
- Bottled water
- Candles
- Zip-Lock© bags
- Large garbage bags (for clean work surface, etc)
- Chlorox
- Rubbing alcohol (isopropenol)
- Aluminum foil
- Local maps

From the Ministry of Health lab:
- Methanol
- Distilled water

<u>Equipment brought to Peru:</u>
Membrane filtration:
- Millipore travel MF assembly
- Millipore all metal syringe
- 100 Millipore 47-mm filter papers
- 100 Millipore Petri dishes with pads

- 100 m-ColiBlue24 liquid broth plastic ampoules
- 2 small metal tweezers
- Collapsible cooler (to chill ampoules and water samples during transport)
- Freezable non-ice pack
- Screwdriver (to open MF assembly)

Dilutions:
- Oxford Automatic pipette (1-5 ml)
- 100 pipette tips
- 250-ml glass flask
- 125-ml capped glass flask
- 100-ml glass graduated cylinder
- 25-ml plastic graduated cylinder
- Two 10-ml glass graduated cylinders
- 1000-ml plastic beaker

H_2S P/A tests:
- Nine 100-ml glass bottles
- 150 H_2S P/A PathoScreen Medium for 100-ml samples

Incubators:
- Phase-change MF incubator w/ foam insulation
- Two phase-change 100-ml P/A incubators w/ foam insulation & collapsible cooler
- Metal thermometer
- Plastic handle (for incubator string handles)

Turbidity:
- Hach Pocket Turbidimeter (Cat. No. 52600-00) w/ standards and 2 oil cloths
- Three 4-packs of AAA batteries (none used)

Chlorine tests:
- 100 DPD Total Chlorine reagent
- 200 DPD free chlorine reagent
- 12 FEAS containers (one used)
- Five 25-ml glass flasks (only 2 were necessary)
- Hach digital titrator w/ 5 titration tips

Sample collection:
- Two hundred 100-ml Whirl-*Pak* Thio bags
- Small container of hand sanitizer
- Four 125-ml plastic Nalgene© bottles

Sterilization:
- 2 squeeze bottles (for methanol and blank water)
- Large hand sanitizer bottle

General supplies:

- Permanent pens (for labeling samples and lab tape)
- Lab marking tape
- Duct tape
- 2 rolls of Scotch tape
- Scissors
- Lab notebook
- Copies of instructions for all testing procedures to be used

7.1.2 Sample Collection in Peru

7.1.2.1 Collection Procedures

Samples of water were taken directly from household taps, holding tanks, filter buckets, and *bidones* (storage containers provided to families for use with the chlorination program). As often as possible, samples were collected from the water both before and after treatment (or at several stages of treatment when applicable) to measure how effective the treatment was at decontaminating the water. "Raw," or untreated, water was collected from the top holding bucket whenever possible, and "treated" water was collected directly from the lower bucket's spigot. Raw water used for household chlorination was collected from the household tap when possible, or alternatively from the household water holding tank. When both water sources were tested, the tap water was used for before-and-after comparisons. Treated water samples were collected directly from the SWS *bidon* spigot.

Samples that were to be tested for microbial content were collected in sterile 100-ml *Whirl-Pak*[36] bags that contained a sodium thiosulfate ("de-chlorinating") tablet, which halted the effects of any chlorine in the water so that the microbial conditions of the water samples, when tested, would be as close as possible to the actual conditions at the time of collection. The opening of a *Whirl-Pak* bag is lined with a thin metal wire inside a thick paper strip, much like a "twistie-tie." The *Whirl-Pak* bags were sealed by closing (flattening) the top of the bag and folding over the metal-and-paper rim three time, then folding in the tabs on the side to prevent the top from unrolling *Whirl-Pak* bags are also equipped with pull-tabs on the outside of the top rim so that they can be opened without the user needing to touch the inside or outer edge of the rim (see Figure 7.4). All of these precautions are designed to prevent extraneous contamination. In the field, several *Whirl-Pak* bags were stored together inside the protective sleeve in which they were shipped, which itself had a *Whirl-Pak*-style closure. This package was then kept inside a Zip-Lock© bag. The sample collector would rinse her hands in anti-bacterial hand sanitizer before opening the Zip-Lock© bag and retrieving a *Whirl-Pak* bag. The full *Whirl-Pak* bags were labeled with permanent pen so that each sample could be identified later in the laboratory. The samples for microbial testing were transported in an collapsible insulated cooler with an ice pack to the Health Clinic, where they were then transferred to a refrigerator. Samples were tested within eight hours, as per Standard Method #9060B, which says that samples should be tested as soon as possible after collection, the same day if at all possible, and definitely within 30 hours (Clesceri, et al., 1998).

[36] "Whirl-Pak Thio Bags" by *Nasco*©

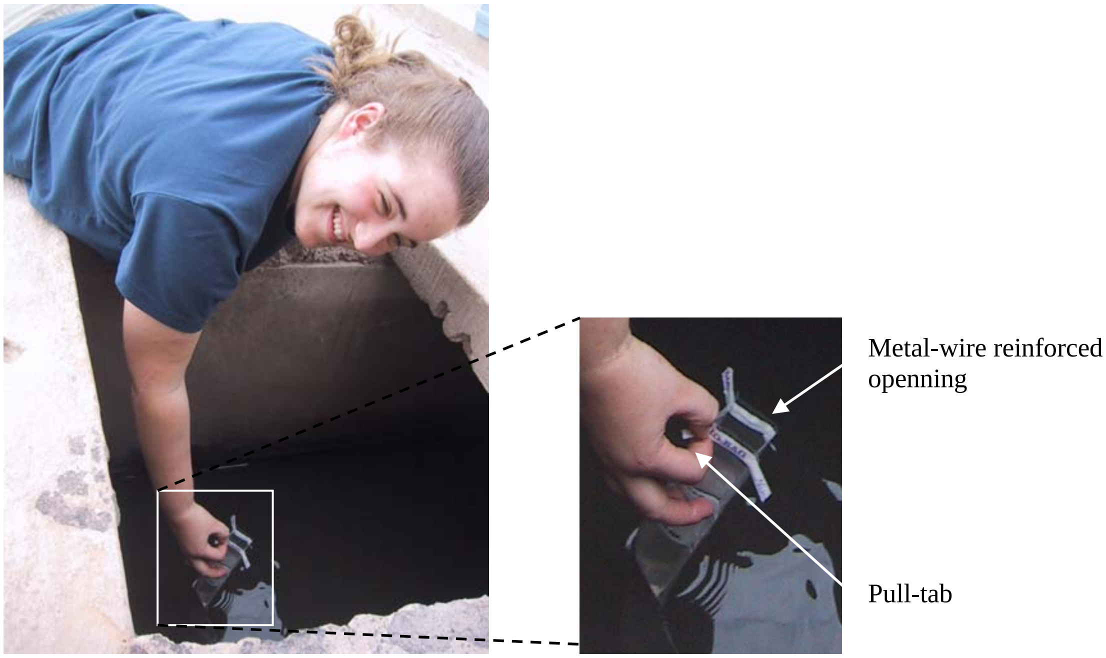


Figure 7.4: Coulbert Sampling from the CBV WTP with a *Whirl-Pak* Bag

Water samples to be used for turbidity and chlorine residual tests were collected in clean *Nalgene*© 125-ml plastic bottles, which were rinsed with bottled water before and after each sample collection. These samples were then immediately tested on-site. Occasionally turbidity was tested in the laboratory, in which case these samples were taken directly from the *Whirl-Pak* bags.

7.1.2.2 Summary of Tests and Locations

Tables 7-1 and 7-2 provide a summary of the tests that were performed in Peru. They are organized according to town, type of water source/treatment system, and type of test/survey. As the tables indicate, a large majority of the research was conducted in Cerrito Buena Vista. Also, more SWSs (38) were tested than Table Filters (21).

Table 7-1: Number of Sample and Survey Locations in Each Town (Peru, Jan. & March 2004)

Town	# TFs Tested	# SWSs Tested	Other Water Sources[37]	# Surveys[38]
Cerrito Buena Vista	13	38	2	53
La Joya			2	2
Villa Hermosa San Isidro	1			4
La Cano	3			1
El Triunfo			1	
Caleta Vila Vila*				6
Miculla*				3
Valles Verdes*				5
Chucatamani*	3			
Pistala*	1			
Total	*21*	*38*	*5*	*74*

* These towns are located in Tacna.

Table 7-2: Number of Tests Performed on Each Type of Treatment System (Peru, Jan. & March 2004)

Treatment System (Raw &/or Treated Water)	MF mColiBlue (E.coli & TC)	MF Lauryl Sulfate (TC)	H_2S P/A Tests	Turbidity	Free Chlorine Residual	Flow Rate
Table Filter	2	11	12	13	n/a	8
SWS	10	25	38	38	37	n/a
WTP	2	4	4	4	5	n/a
Other Sources[39]			3			
Total	*14*	*40*	*57*	*55*	*42*	*8*

7.1.3 Data Reporting Methods

7.1.3.1 Valid Data

Since a limited number of tests were run on each sample and it was often difficult to estimate the ideal volume of sample, the results were not always within the target range of 20 to 80 TC colonies (or 20-60 TTC colonies) per plate. When not within this range, up to 200 colonies per

[37] The other water sources were: the CBV WTP, a house without an HWTS in CBV, an irrigation canal in La Joya, the La Joya Health Clinic, and the El Triunfo WTP.
[38] The two La Joya surveys included a taxi driver and the Mayor of La Joya.
[39] A CBV house without an HWTS, an irrigation canal in La Joya, and the La Joya Health Clinic.

plate is acceptable, although not ideal (Pecchia, 2004). Only those tests considered "valid" were included in the averages and calculations of data in this report.

For the tests associated with this study, whenever possible, only those tests that fell within 20 to 80 (or 60 when appropriate) colonies per plate (Petri dish) were accepted as valid data. Test counts falling outside of this range were accepted only when they were the only test results available for a particular water sample. For counts above the target range, only counts up to 200 CFU were considered valid. Also, as per Standard Method #9222B6, all colonies on the plate had to be 200 at most in order for the test to be considered valid. At ranges above 200 CFU/plate, the colonies can overlap and mask the true number of colonies.

Often CFU plate counts were below 20. While test results between 20 and 200 CFU per plate can be acceptable, results below 20 are very questionable. Unfortunately, many of the test results fell between 0 and 20 CFU per plate. For this reason it was decided that these test results would be accepted as valid only when no other valid data was available, since even they had merit in providing some information about the water samples. (For example, it is significant when a 10-ml water sample produces 12 colonies instead of 200.) Colony plate counts as low as 2 were accepted when deemed necessary. Occasionally counts as low as 1 CFU were accepted on tests where at least 20 ml was tested, and 0 CFU results were considered valid only on 50-ml and 100-ml samples. This leniency on larger sample volumes was due to the fact that Standard Method #9222B6a allows the lower colony limits (i.e. 20 CFU/plate) to be ignored when testing drinking-quality water, which is supposed to be measured in 100-ml samples (Clesceri, et al., 1998). For comparison purposes, the sets of all data considered valid are presented in Appendices F, G, H, and L alongside the same data sets in which *only* 20-200 colonies were considered valid.

Occasionally water samples showed 0 CFU/100ml. These were reported as <1 CFU/100ml since one result of 0 CFU/100ml cannot definitively indicate a complete absence of coliform (Clesceri, et al., 1998: Std. Method: #9222B6). These results were generally included in calculations as 0, for ease of computation.

7.1.3.2 Data Trends/Statistics

For each set of data, the range, average (arithmetic mean), standard deviation, and number of data per set (N) is reported. Often, multiple dilutions or duplicate tests were performed on an individual sample. When multiple results were considered valid (according to the procedure above), they were averaged so that one average value was reported for each water sample. These sample averages were then considered the "data set" and were used in calculations.

When data sets before and after treatment were compared, the percent removals and Log Reduction Values (LRVs) were reported. These values are used to express the treatment efficacy of a system. Most data sets did not match up one-for-one with before and after data; there were often "holes" in the sets due to invalid test results. In these cases, the treatment efficacy indicators could only be computed for those systems with valid data from before and after treatment. The averages of these indicators were found by averaging the values from each pair of untreated and treated water data, as opposed to simply finding the removal efficacy of the *averages* of untreated and treated waters. This is an important difference because the two methods result in different average values. Averaging the actual removal values of each before and after test is more accurate and is the method used in this report. The average of all the data does not directly correspond to the percent removals and LRVs, because some samples included in this average have only untreated or only treated data.

For percent removals, 0 was used in calculations when a test resulted in "<1 CFU/100ml." For this reason, some percent removals are 100.0%. These are reported in summary tables as 99.99%, since a 100% removal rate is not certain. Percent removal is calculated with the following equation:

$$\% \text{ Removal} = [1 - (\text{treated value} / \text{untreated value})] \times 100\% \tag{7.1}$$

LRV is calculated as follows:

$$\text{LRV} = \log_{10} (\text{untreated value} / \text{treated value}) \tag{7.2}$$

Log Reduction Values cannot be calculated when the treated value equals zero; therefore, LRVs are the only case in which "1" is used for calculations with "<1 CFU/100ml" data results.

7.1.3.3 Statistical Analysis

In order to evaluate the significance of the data and its trends, some statistical analysis was performed on the data sets. One of the procedures used was the "t-test." This test (which was calculated with a spreadsheet program) takes two arrays of data and returns the probability that they came from the same distribution, or in other words, the probability that their differences occurred through random chance as opposed to being caused due to some actual difference in the source of the data. The t-test can only be performed when both sets of data contain more than one data point.

When a mean average is calculated from data points of several tests, that mean is only a "guess" at the actual value of the thing that is being tested (e.g. the TTC concentration in a sample of water) or the actual mean that would be found if an infinite number of tests could be performed (e.g. the average % removal caused by all Table Filters). The t-test essentially provides the probability that two sets of data have the same *actual* mean (and distribution).

It is generally accepted that a 5% probability or larger provides enough evidence that the differences between the two sets of data *could have* occurred through random chance. Or, conversely, a less than 5% result to the t-test indicates that the differences between the two sets of data most likely did not occur through random chance. In this case, the difference between the two sources of data is "statistically significant." In this report, the t-test is performed on percent removal values in order to determine whether different types of Table Filters have significantly different removal rates, or whether the differences could have been caused by random chance due to the limited data set size.

7.1.4 Microbial Tests in Peru

Water samples transported back to the lab were analyzed for the presence of microbial contamination using two different methods: Membrane Filtration and H_2S Presence/Absence testing. Membrane filtration tests are comparatively more complicated and more expensive than the Presence/Absence (P/A) test, but they allow for a quantitative and more accurate analysis of the quality of the water.

7.1.4.1 Sterilization

Sterilization of equipment was necessary to ensure that bacterial counts reflected only the bacteria contained in a given water sample and none from external contamination. Possible sources of lab equipment contamination include water from previous samples and contaminants from the work environment.

Glass graduated cylinders, flasks, and bottles were sterilized in an oven at 170ºC for one hour, as per Millipore's Water Microbiology Handbook (Millipore, 1992). Once removed from the oven, glassware that was not needed for immediate use was capped with aluminum foil rinsed in isopropenol to guard against subsequent contamination. Occasionally, glassware was placed in boiling water for ten minutes as a faster and acceptable alternative to dry heat sterilization (Millipore, 1992).

The MF filter holder was sterilized by soaking a rope wick on the base of the device with methanol, according to Millipore's instructions. The methanol was lit with a cigarette lighter. The water receiving cup was placed over the filter holder as a cap for 15 minutes, creating an air-tight seal, which allowed a formaldehyde byproduct of the incomplete combustion of methanol to sterilize the inside of the filter holder (Millipore, 1992) (see Figure 7.5).

Figure 7.5: Millipore Portable Membrane Filtration Filter Holder with Lid Closed for Sterilization

Tweezers were held above a flame for a few seconds to sterilize them before using them to touch the filter paper for the MF procedure. Fingernail clippers were flamed and H_2S powder packets were wiped in alcohol before the clippers were used to cut them open to dispense the powder for H_2S tests. When pipette tips were re-used, they were placed in boiling water for two minutes (it was feared that ten minutes in boiling water would disfigure or alter the plastic), and then they were wrapped in alcohol-rinsed aluminum foil and sealed inside of a Zip-Lock© bag. Hands and counter-tops were constantly rubbed with isopropenol or waterless hand sanitizer (active ingredient: isopropenol). Petri dishes, filter papers, growth medium ampoules, and plastic pipette tips were left in their original containers until needed and were only then touched by sterile hands or tweezers.

7.1.4.2 Membrane Filtration Tests

Membrane Filtration (MF) tests allow direct enumeration of the amount of a certain type of bacteria present in a water sample. The bacteria that is measured is an *indicator* of the presence of disease-causing bacteria, for which it is more difficult and expensive to test directly.

In membrane filtration, water is vacuum pulled through a filter paper, which traps any bacteria in the water onto the paper. The paper is then placed in a Petri dish (or "plate") with growth medium and is incubated until colonies of bacteria can be directly counted with a magnifying glass, a microscope, or the naked eye. A detailed description follows of the actual testing procedures, which followed Standard Method #9222 (Clesceri, et al., 1998) that were used during this study.

7.1.4.2.1 Equipment Preparation

Before the actual filtration of the Membrane Filtration tests can be carried out, the test equipment and supplies must be prepared. The supplies needed and steps for preparation of testing in Peru are listed below. Portable stainless steel MF assemblies made by Millipore and Del Agua were used for all field (and laboratory) MF tests. The preparations steps do not necessarily need to be completed before starting the filtration process but can be done throughout the test as needed.

<u>Supplies Needed for Membrane Filtration</u>

- MF filter holder
- Syringe or pump to pull the water through the filter
- Graduated cylinders and/or pipetters
- Glass flasks or bottles for dilutions
- Petri dishes with absorbent pads
- MF broth
- Tweezers
- Flame source (lighter, candle, oil lamp, etc.)
- Methanol to sterilize filter
- Filter paper (47-mm diameter, 0.45μm pore size)
- Lab tape (to mark dilutions/samples in glassware)
- Incubator

- Thermometer (if using phase-change incubator)

Equipment Set-up

- Sterilize the countertop with alcohol.
- Make sure that the MF filter holder and all the glassware needed for testing have been properly sterilized (as described in Section 7.1.4.1).
- Set out the pipetter, if needed, and place a sterile pipette tip on the end. Place the pipetter in such a fashion that the pipette tip will not touch any surfaces. (For this reason it is best to prepare the pipette immediately before use.)
- Set all supplies for the MF tests on the sterile counter within reach of, but leaving sterile space for, the MF filter holder.
- Create a table in a lab notebook to record the test information.
- Mark the bottom of the Petri dishes with the information about each test to be performed. Generally, the information should include the date, name of the tester, sample identification, and volume of water tested.
- Squeeze one 2-ml ampoule of MF broth onto the absorbent pad in the Petri dish, being careful to avoid dispensing bubbles. Excess broth can be decanted, but one large drop must remain in the bottom of the Petri dish.
- Measure the appropriate volume of sample water to be tested in a graduated cylinder, or create the appropriate dilution. (If a pipette is to be used, water can be pipetted directly into the filter at the time of the test.) Be sure to shake the *Whirl-Pak* bag of the sample thoroughly before measuring out the volume needed to ensure adequate mixing of particles in the water so that a representative sample will be tested.
- Set-up the MF assembly. For the portable Millipore filter, this involves taking off the lid, inverting it, and placing it on the bottom of the filter to act as the receiving cup (see Figure 7.6). For the DelAgua filter, this means removing the lid (since the DelAgua filter has a separate lid and receiving cup).

Figure 7.6: Millipore MF Filter Holder Used in Peru

7.1.4.2.2 MF Broth

The majority of the tests in Peru were performed with Lauryl Sulfate (LS) broth, which allows the enumeration of total coliform in the water sample. Petri dishes with LS were incubated at 35^{o}C +/- 5 ^{o}C for 24 hours, and "well-formed yellow colonies" were enumerated as colony forming units (Longhi, 2004). The LS broth was prepared in the laboratory by Longhi and del Carpio by the following process (Longhi, 2004):

- Add 100 ml sterilized water to a sterile container.
- Add 7.6 grams of powdered Lauryl Sulfate.
- Autoclave the mixture at 120°C for 15 minutes.
- Distribute 2 ml of the broth into each of several sterile test tubes.
- Pour the LS broth directly from the test tubes into the Petri dishes.

Some of the tests (including all of those during January) were performed with mColiBlue-24[40] broth, allowing the enumeration of both TC and E.coli present in the water. MColiBlue broth was incubated at 35^{o}C +/- 5 ^{o}C for 24 hours. MColiBlue broth produces red and blue colonies; E.coli colonies appear blue, and all other coliforms produce red colonies. The sum of the red and blue colonies equals the number of TC present. MColiBlue-24 broth was transported from MIT in a cooler bag with an ice pack in the form of 2-ml plastic ampoules. The broth was emptied directly from the sterile plastic ampoules into Petri dishes.

[40] "mColiBlue-24" broth by Hach©

7.1.4.2.3 Dilution

In order to produce the target number of colonies on each plate, highly contaminated water must first be diluted before it can be tested via the MF method, which was often the case in Peru given the high bacterial contamination of the source water. Dilutions are performed with "blank water," or water that should contain no coliforms. Blank water is described in greater detail in Section 7.1.4.2.9. Dilutions of sample waters should be tested within 30 minutes of creation so that the bacteria does not sit in dilution water for an extended period of time, which could kill or multiply the bacteria.

When trying to reach the best dilution of contaminated water, the goal is to produce 20 to 80 (or 60, depending on whether testing for TC or TTC, respectively) colonies of the bacteria for which the specific growth medium is selected, as well as no more than 200 total colonies of any type of bacteria. Ideally, 100 ml of a drinking water sample will result in no E.coli or TTC colonies (see the WHO guidelines in Section 2.4.1), but when a water source is highly contaminated, it may be necessary to filter much less of the water through the filter paper at one time in order to produce a countable number of colonies. In this case, a smaller volume of the contaminated water is tested; then the number of bacteria colonies found on the plate is multiplied accordingly so that the results can be expressed as the number of bacteria "colony forming units" (CFU) per 100 ml of sample water. For example:

$$\frac{48CFU(Petridish)}{20ml(\,filtered\,)} \times \frac{100ml}{100ml}$$

$$= \frac{4800CFU}{20} \times \frac{1}{100ml}$$

$$= \textbf{240 CFU/100ml} \qquad (7.3)$$

If the desired sample volume to be filtered was less than 1 ml, dilutions were made with blank water so that very small amounts of sample water could be more accurately tested. Dilutions were formed by mixing small amounts of sample water into large amounts of blank water in a sterile glass bottle or flask. Small portions of this mixture were then tested using the usual procedures. The basic methods used for dilutions are outlined in Appendix D. Generally, two to four different dilutions were tested for each sample of water to increase the chances that one or more plate counts would fall within the target range.

7.1.4.2.4 Filtration

The following are the steps required for membrane filtration, which were followed in Peru and which are in accordance with the Millipore Handbook instructions for membrane filtration (Millipore, 1992).

1. Sterilize hands with hand sanitizer or alcohol.
2. Rinse the MF filter funnel (while on the filter assembly) with 30-50 ml of blank water after sterilizing.
3. Remove the filter funnel and place it upside down on the sterile counter. This will expose the filter paper mesh support. (See Figure 7.7, which shows the funnel right-side up.)

Figure 7.7: MF Filter Holder Showing the Filter Mesh Support

4. Sterilize tweezers.
5. Remove a filter paper from its package with tweezers and center it grid-side up on the mesh support of the filter. Replace the funnel and twist to lock in place.
6. Pour or pipette the measured sample or dilution into the funnel on top of the filter paper. If the desired volume of sample water is between 20 and 100 ml, poured it from a *Whirl-Pak* bag into a sterile graduated cylinder for measurement. The correct volume is then poured directly into the Millipore funnel. If the desired volume is between 1 and 20 ml, either pipette or pour it via a graduated cylinder into the funnel *after* approximately 20-30 ml of blank water. For a volume less than 1 ml, prepare the appropriate dilution so that at least 1 ml of the sample dilution can be pipetted into the MF funnel after 20 ml of blank water.
7. Swirl the filter assembly in a circular motion so that the sample water can mix with the blank water and therefore be distributed evenly over the surface of the filter paper once it is vacuum pulled through. This technique, as outlined in the Millipore Handbook (Millipore, 1992) prevents a small amount of contaminated water from touching only a portion of the filter paper and thus prevents an uncountable clump of bacteria.
8. Attach syringe (or hand pump) to the MF filter and pump to create a vacuum in the receiving cup until all the water in the funnel has been pulled through the filter paper.
9. Rinse the funnel/filter with a volume of blank water approximately equal to the sample volume.
10. Rinse the sides of the funnel with blank water from a squirt bottle. This step prevents sample water from sticking to the side of the funnel.
11. Remove pump (to release vacuum) and filter funnel.
12. With sterile tweezers, remove filter paper and place it, with a rolling motion (to avoid trapping bubbles of air underneath), grid-side up into a prepared Petri dish.

7.1.4.2.5 Incubation

After filtration, the Petri dishes (or "plates") were placed upside down in an incubator at 35ºC for 24 hours. The plates were inverted so that condensation would not drip down onto the growing colonies and smear them.

Two types of incubators were used in Peru: electric and chemical. The electric incubator was part of the DelAgua MF kit and consisted of a cylindrical chamber inside the travel case that could be kept at 35^{o}C when plugged in. This incubator could only hold about ten Petri dishes and was only used during a portion of the January field tests.

Petri dishes were also incubated in a "phase-change incubator," an invention by Amy Smith, Lecturer at the MIT Edgerton Center (see Figure 7.8). The version of this incubator that was used in Peru consisted of a round heavy-plastic food storage container filled with a wax-like substance, ethylene carbonate, which can maintain its heat, when insulated, at approximately $35^{o}C$ for up to 24 hours. In order to activate the phase-change substance, the phase-change incubator was placed in boiling water until the wax-like material melted. It was then allowed to cool until it reached $35^{o}C$, at which point Petri dishes were placed in its cylindrical cavities. The incubator was placed in an outer container of foam insulation, which allowed it to maintain a temperature of $35^{o}C$ +/- $1^{o}C$ for up to 24 hours. Standard Methods specifies that incubators should maintain the target heat within +/- $0.5^{o}C$. After 12 to 18 hours, the temperature was checked and, if needed, the incubator was placed in boiling water to melt the wax-like substance again. The phase-change incubator did not quite meet that specification, but the benefit of the incubator is that it does not require electricity, making it a good alternative for testing in developing countries. The phase-change incubator is also more portable than an electric incubator, which is helpful for traveling researchers who need to provide their own incubator for lab tests. This incubator was used for a majority of the MF tests and all of the H_2S P/A tests during January and for all of both types of tests during March.

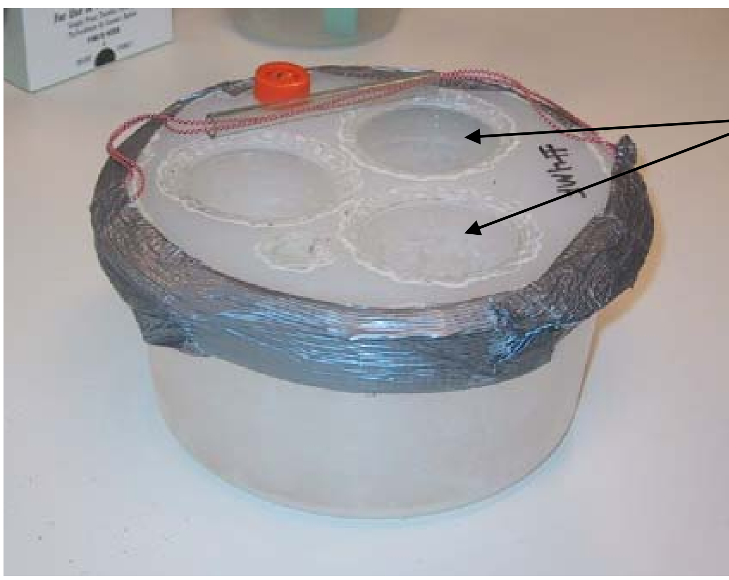


Figure 7.8: The "Phase-Change Incubator"[41]

7.1.4.2.6 Enumeration

After 24 hours, the Petri dishes were removed from the incubator and the appropriate bacterial colonies on each filter paper were counted. (Each growth medium selects for a different type of bacteria and changes those colonies into a certain color; therefore, only the colonies of the specified color are counted.) The volume of sample and the enumeration of colonies were

[41] This incubator, unlike those used in this study, is sealed with duct tape.

recorded for each test so that the results could later be presented in CFU per 100 ml. Plates with more than about 300 colonies were recorded as “too numerous to count” (TNTC) (see Figure 7.10).

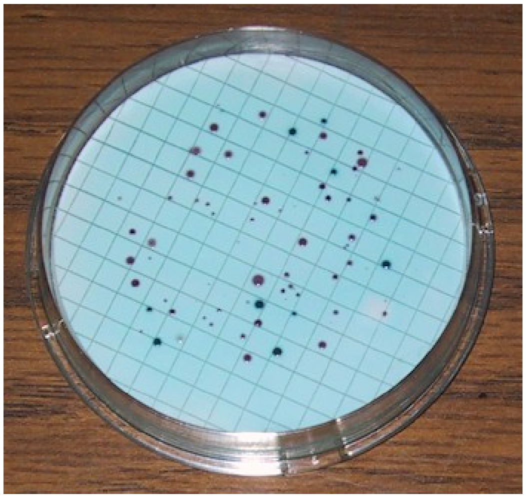


Figure 7.9: An Incubated Petri Dish (mColiBlue Broth) within the Target Range of Colonies, Ready for Enumeration of Coliform

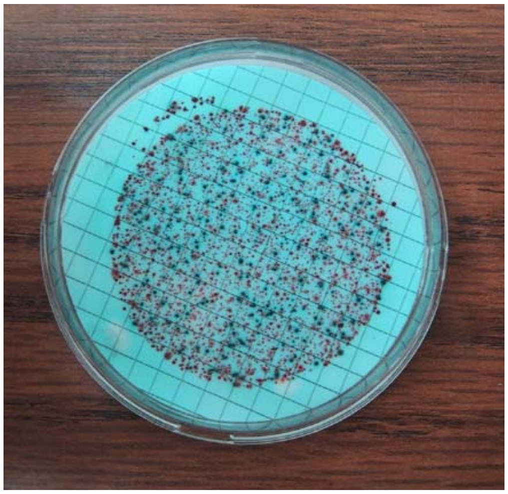


Figure 7.10: Petri Dish with TNTC Coliform Colonies

7.1.4.2.7 Disposal

Once the bacterial colonies had been counted, a few drops of a 10% household bleach solution (diluted with tap water) was dispensed into each Petri dish in order to kill the bacteria on the plate and inhibit the further growth of bacteria. The disinfected plates were then disposed of in a garbage container at the La Joya Health Clinic.

7.1.4.2.8 Duplicate Tests

At least one duplicate test was performed on each day of testing. Duplicate tests are simply the same test of the same volume of the same water sample twice in the same day. They help to verify that the MF procedures being used provide accurate results. Each time a sample is tested, the results of the bacteria count will be slightly different; however, any variations should be statistically insignificant. Otherwise, if two duplicate tests have large differences, then the observed differences between two separate water samples cannot give conclusive evidence.

7.1.4.2.9 Blank Tests and Blank Water

Blank tests are performed to ensure that all colonies growing on an incubated Petri dish were indeed contained in the original sample of water. The results of blank tests indicate whether or not the "blank" water being used for dilutions and rinsing contains any contamination, as well as whether or not the testing and sterilization processes are adding any extraneous contamination to the test results. Blank tests are run just like any other test on a sample of water, except blank water, or water that is assumed to be free of contamination, is used in the test. If a blank test results in positive contamination, the procedures should be analyzed for possible sources of contamination and should be changed accordingly. Blank tests were performed at the beginning of each testing session (usually this meant once each day).

"Blank" water is used for creating dilutions, running blank tests, and rinsing the MF filter holder funnel during each test. Truly distilled (and deionized) water should *not* be used as blank water, since bacteria need the presence of ions to survive. According to a microbiologist at Millipore, the ideal water for dilutions, blank tests, and rinsing is made out of the same type of water that is being tested. This way, the blank water will have similar ions, pH, temperature, and other properties to that being tested, which will best ensure that any bacteria in the test water will survive. Even bottled water should not be used if avoidable since it could have foreign properties that could shock the bacteria in the test sample. The water that is similar to the samples being tested should then be filtered through a 0.22-micron filter (or filter paper) into a sterile container to ensure that all bacteria are removed from the water. Unfortunately, the researchers did not have this information about blank water at the time of research, therefore it is possible that the type of blank water used may have "shocked" or inactivated some of the coliform in the water samples.

Two types of blank waters were used for running blank tests and rinsing the MF filter holder funnel after each test. The Ministry of Health in Arequipa provided five liters of their own distilled water in a plastic jug. Since there was a limited supply of this water during the week of field testing in January, this water was used mainly to rinse the assembly funnel. Larger volumes of clean water were needed for running blank tests and creating dilutions of highly-polluted water samples. For this purpose, bottled water (purchased in a 20-L sealed plastic container) was boiled and then filtered in an MF filter holder through a 0.45-micron filter paper. These two extra steps ensured that any bacteria or other organisms or sediments were killed and/or filtered out of the bottled and boiled water. Similar practices were followed during the March field testing period.

7.1.4.3 H_2S Presence/Absence Tests

The H_2S P/A test is more qualitative in nature. It provides a reading of either presence or absence, essentially a "yes" or "no" to the question of fecal contamination. To perform this test, one packet of powdered growth medium[42] was added to 100 ml of sample water in a sterile glass bottle. The bottle was capped and swirled to mix the medium into the water. It was then incubated for 24 to 48 hours. The chemical phase-change incubators mentioned above (in Section 7.1.4.2.5) were used for these tests. The growth medium for this experiment feeds H_2S-producing bacteria and turns the water black if a sufficient amount of H_2S is formed. If the water remained yellow (the color caused by the addition of the growth medium) after 24 hours, it was left to incubate for another 24 hours. If the water turned black within 24 or 48 hours, it was considered a "presence" reading, which indicated that the water was contaminated. Only if it remained yellow for 48 hours was it considered an "absence" reading.

Figure 7.11: Example of H_2S "Absence" (left) and "Presence" (right) Results

Like the MF test, the H_2S P/A test is an indicator test. It measures the presence of H_2S, which indicates the presence of H_2S-producing bacteria, which in turn indicates the presence of other bacteria. Studies have shown that a variety of bacteria may cause a positive result of an H_2S test. While they are not always coliform bacteria, they are "organisms generally associated with the intestinal tracts of warm-blooded animals" (Sobsey, 2002). Positive results may also be caused by bacteria that are not related to fecal contamination. Sulfides may also be present in groundwater due to natural geological sources" (Sobsey, 2002). Because the H_2S P/A test can result in false positive results, it not recommended to take the place of other more accurate indicator tests like membrane filtration, but it can be an adequate cheaper alternative test, especially since it errs on the side of safety. The H_2S P/A test may be best used as an initial diagnostic test so that water sources which give a positive H_2S result can be identified and

[42] "H2S Presence/Absence PathoScreen Medium for 100ml" by Hach©

further investigated with more precise techniques for measuring the presence of fecal contamination (Sobsey, 2002).

Unlike the MF test, the H_2S test does not allow direct enumeration of bacteria but reports a relative presence or absence of H_2S. This test, therefore, does not give as much information as the MF test. It simply provides “a good idea” as to whether or not contamination is present in the water. Unfortunately it does not reveal the *amount* of contamination in the water, and there is the possibility that low amounts of contamination could result in a false negative reading. The benefits of this test are that it is relatively inexpensive and simple to perform.

7.1.5 Performance Tests in Peru

When possible, turbidity, chlorine residual, and filter flow rate tests were performed on site to determine the quality of the water in Table Filters, SWS *bidones*, water treatment plants, and source waters.

7.1.5.1 Turbidity

Turbidity is a measurement that indicates the amount of particles floating in the water, or its “cloudiness.” This was tested using a “Turbidimeter,” which is an electronic devise that measures the amount of light that is scattered at 90-degrees by particles in a small volume of water. The results are expressed in units of “NTU,” or Nephelometric Turbidity Unit, the U.S. EPA-designated units of turbidimetric measurement. In the field, sample water was measured with a Hach Pocket Turbidimeter, shown in Figure 7.12 below, according to Standard Method #2130 B (Clesceri, et al., 1998). Before testing any samples, the turbidimeter was standardized using Formazin standards of 1 NTU and 20 NTU, as instructed in the enclosed manual. The following steps were followed in testing turbidity of a water sample:

1. Rinse a 125-ml plastic Nalgene© bottle with bottled water.
2. Collect a sample of the water to be tested in the bottle.
3. Rinse the 10-ml plastic sample cell twice with bottled water and once with the sample water.
4. Agitate the sample water by swirling it rapidly in the plastic collection bottle.
5. Pour sample water into the sample cell up to the 5-ml mark.
6. Cap the sample cell, avoiding at all times touching the lower sides of sample cell, through which the beam of light will measure the water’s turbidity.
7. Dispense a few drops of silicone lubricating oil onto the sides of the sample cell and wipe the oil clean with an oil cloth to remove any dust, fingerprints, or smudges and to mask any small surface scratches.
8. Place the cell in the turbidimeter to be read.
9. Place the opaque cover over the sample cell (as shown in Figure 7.12) to block out extraneous light rays.
10. Press and hold the “read” button for several seconds until the reading stabilizes.
11. Record the turbidity from the digital readout of the turbidimeter.

Turbidity was measured as soon as possible after water was placed in the sample cell to avoid settlement of suspended particles. The turbidity was sometimes measured twice with different 5-ml portions of each water sample, and the results were averaged.

Figure 7.12: Hach Pocket Turbidimeter

Turbidity was measured in water from the Table Filters both before and after filtration as well as directly from the water tap and settling tank when applicable. Turbidity measurements were performed on chlorinated water as well. It has been shown that chlorine is much more effective at deactivating microbial contamination when turbidity is low (AWWA, 1999), so it was useful to know the level of turbidity in water that was being treated with chlorine.

Turbidity was generally reported to three significant digits by the turbidimeter. Following Standard Method #2130B5 guidelines, turbidity was rounded and recorded according to Table 7.3 (Clesceri, et al., 1998). Averages and statistics were then computed using the adjusted turbidity values.

Table 7-3: Standard Method for Reporting Turbidity. Source: Clesceri, et al., 1998.

Turbidity Range [NTU]	Report to the Nearest [NTU]:
0-1.0	0.05
1-10	0.1
10-40	1
40-100	5
100-400	10
400-1000	50
> 1000	100

7.1.5.2 Chlorine Residual

Water samples collected from SWS *bidones* were tested for the presence of free chlorine residual using the DPD Ferrous Titrimetric method, as described in Standard Method #4500-Cl F (Clesceri, et al., 1998). The following steps were taken to measure the free chlorine in water samples:

1. Collect water sample in a rinsed (with bottled water) plastic Nalgene© bottle.
2. Measure 25 ml of the sample in a rinsed graduated cylinder.
3. Pour the 25 ml into a rinsed 50-ml flask.
4. Add one "pillow" (or packet) of DPD Free Chlorine Reagent, a powdered indicator chemical (*N*,*N*-diethyl-*p*-phenylene-diamine), which turns the water pink if any free chlorine is present.
5. Swirl the water until most of the DPD crystals are dissolved.
6. If the water shows any pink color, slowly titrate liquid FEAS (Ferrous Ethylenediammonium Sulfate) into the sample while swirling the flask.
7. Stop adding FEAS when the water becomes clear again, with no hint of pink.
8. The amount of FEAS titrated indicates the amount of free chlorine residual in the water in milligrams per liter (mg/L).

7.1.5.3 Flow Rate

The Table Filters were tested for flow rate: that is, the rate at which water is filtered through the combination of geotextile, sand, and two ceramic candles, not the rate at which the spout dispenses water to the user. While the flow rate does not affect the quality of water, it can affect the availability of water. Households, especially those with large families, want clean water to be available when they need it. If a treatment process takes too much time, the intended audience may reject it for conventional practices that allow water to be available immediately.

The flow rate of filters was tested by lifting the top filtering bucket from the bottom storage bucket and placing it between two chairs. The water was filled to the bottom of the white lip of the upper bucket for each test so that the pressure from the height of the water would be the same (and nearly as high as possible) for each test. A 100-ml and a 50-ml graduated cylinder were placed under each of the two ceramic candle outflows (see Figure 7.13). As soon as the smaller graduated cylinder was almost full with water, both cylinders were removed and the time and volumes were recorded. The total flow rate (sum of both candle outflows) was calculated and expressed in liters per hour (L/hr). The calculated flow rates are only approximate, because placing both cylinders under the candle spouts at exactly the same time and without missing any drops was nearly impossible. The results should be considered to be within 0.1 L/hr of the actual flow rate.

Figure 7.13: Measuring the Flow Rate

Figure 7.14 shows Juana Sosa, in charge of monitoring the Table Filters in Tacna, removing water from an upper bucket after measuring the flow. Most of the unfiltered water was generally removed after testing so that the upper bucket could be more easily lifted back onto the lower bucket.

Figure 7.14: Sosa (Tacna Technician) Emptying Water from a Table Filter after Measuring the Flow Rate

7.2 Laboratory Testing Procedures at MIT

This section describes the procedures used in the laboratory at MIT during further investigation of the performance of the Peruvian Table Filter. The objectives of this lab study were four-fold: to obtain more data on the performance of the Table Filter in a consistent and semi-controlled environment; to observe any change in behavior of the same filter used over time; to compare the performance of two Table Filters with different grades of sand; and to compare the performance of these two filters before and after the sand was removed.

The last objective was not actually part of the original plan for lab testing but was pursued after the author noticed that the performance of the two filters with different sand was counter-intuitive – namely that Fine Sand Table Filter filtered out less coliform than did the Medium Sand Filter. It was then speculated that the ceramic candle filters, although supposedly identical may have been the cause of the difference. Thus, during the summer, the geotextile and sand were removed and the performance of the ceramic candles alone was compared over the course of several days.

Between the spring and summer testing periods, the Table Filters sat in the laboratory for two months without being used. Since they had been sitting for so long, 35 L of source water was added to each TF in order to “prime” them, or try to somewhat simulate their continued use.

The treated water was tested after the first 5 L had be filtered and after the entire 35 L had been filtered. After this point, regular testing began with 2 to 5 L of source water being filtered for each round of testing.

When the sand and geotextile were removed from both Table Filters, the insides of each bucket were rinsed with tap water from the MIT lab, and the sides were wiped with paper towels. The outside of the ceramic candles were lightly scrubbed with paper towels to remove some of the build-up of particulate matter.

7.2.1 Table Filter Construction at MIT

Two Table Filters were constructed in the MIT laboratory in the same manner as in Peru, which is described in Section 4.4.2. Any slight variations and specific methods practiced that were not covered in the operation manual (DCGI, 2003) are listed here.

The buckets and lids were purchased in Peru by the MIT researchers. The spigots, geotextiles, and Pozzani candles were provided by CEPIS and the Ministry of Health. Sand was the only component of the Table Filters that was purchased in the U.S.: play sand from Ace Hardware was considered "medium-grade play sand," and "fine-grade play sand" was obtained from a previous MIT class project for 2.009: Product Engineering Processes.

A heated copper pipe (approximately 1.3 cm in diameter) was used to punch holes in the buckets and lids that were necessary to hold the candle filters and spigots.

Two different grades of sand were prepared, one for each of the two filters that were tested. The "fine sand" was prepared to the specifications given in the construction manual from Peru. The "medium sand" was the same as that used in the BioSand filter.

For the filter designated "Fine Sand," a mix of the fine- and medium-grade play sand was filtered through an ASTM #20 Mesh[43] sieve into an ASTM #60 Mesh[44] sieve (this mix of sand was intended to mimic the sand available in Peru). Sand retained in the ASTM Mesh #60 mesh was washed with tap water (which contained chlorine). The washing process consisted of placing a few inches of sand in a 20-liter bucket and filling the bucket with tap water several inches higher than the level of the sand. The water and sand were swirled around by hand for about a minute to encourage any fines or floating particles to become suspended in the water, which was then decanted. This process was followed five times for each small amount of sand until all the sand needed for the filter had been rinsed by hand five times.

For the filter designated "Medium Sand," the commercially available medium-grade sand was filtered through a piece of mosquito netting[45]. The sand that passed through the netting was retained and washed using the process described above.

[43] ASTM Mesh #20 corresponds to a mesh size of approximately 0.85-mm, BS Mesh #18, and Tyler Mesh #20.
[44] ASTM Mesh #60 corresponds to a mesh size of approximately 0.25-mm, BS Mesh #60, and Tyler Mesh #60.
[45] The pores of the mosquito netting are approximately 1-mm wide. A 1-mm pore size corresponds to ASTM Mesh #18, BS Mesh #16, and Tyler Mesh #16.

As an additional cleaning step, several liters of water were run through the completed filters before testing began.

Figure 7.15: Table Filter Setup During Laboratory Experimentation.

7.2.2 Source Water at MIT

The “source water” fed to the Table Filters during the MIT laboratory study was meant to imitate the highly contaminated raw water that was fed into most Table Filters measured during the January 2004 field visit to Peru. In order to create a similar level of contamination in the water, nine parts river water were mixed with one part municipal sewage water (a 1:10 dilution). Charles River water was obtained by lowering a plastic or metal bucket on a rope into the river from the Harvard Bridge or from a spot near the bridge (at the intersection of Massachusetts Avenue and Memorial Drive in Cambridge, MA). This water was brought back to the laboratory to be mixed with the municipal sewage water, which was obtained from the South Essex Sewerage District Wastewater Treatment Plant in Salem, MA. One liter of sewage water was added to a 20-L bucket containing nine liters of Charles River water. The waters were mixed with a large plastic spoon and allowed to warm to room temperature for filtration and analysis the following day.

Five liters of this source water mix was added to each filter every day for the duration of the spring lab tests, even though tests were only performed about twice per week. This semi-continual feeding was designed to mimic the daily use of a Table Filter in Peru.

During the summer lab testing, source water was only added to the filters on each day of testing, which was nearly every weekday during a period of four weeks. The Charles River-to-sewage-water ratio was changed during summer testing because the coliform concentrations of the source water mix were lower than had been measured in the spring. In order to reach the level of coliform concentration used in the spring and seen in Peru, it was determined that the sewage water concentration should be raised from 10% to at least 30%. A smaller volume of water was also added to each TF in order to conserve the limited amount of sewage water available in the lab at the time. Table 7-4 shows the amounts of Charles River water and sewage water added to each Table Filter during the summer test days.

Table 7-4: Amount of Each Type of Raw Water Added to Each Table Filter as "Source Water" During the Summer (MIT, Summer 2004)

Date	Charles River Water (L)	Sewage Water (L)	% Sewage Water
June 1-16 (& Spring)	4.5	0.5	10%
June 18	3	2	40%
June 21	1	1	50%
June 22	1.5	1	40%
June 23	2	1	33%
June 24	2	1	33%
June 28	2	1	33%
June 30	5	0	0%
July 1	3	1	25%
July 2	3	1	25%

On June 25, the sand and geotextiles were removed from each filter, leaving only the Pozzani ceramic candles. After flushing each filter with 18 L of tap water, 3 L of source water was added to each filter on June 27. This water flowed very slowly so it had to be tested on the 28th. After about 24 hours the researcher returned, and only about 1 L of water had filtered in that time! Therefore, since some previously-filtered water always remains in the lower bucket (because of the elevation of the spigot hole), the "treated" water tested on June 28 was only about 50% of the filtered "source" water and about 50% filtered tap water (left from the water that had been used to "flush" the filters).

On June 29 (for testing on June 30), 5 L of pure Charles River water was added to each filter in order find out if the flow would increase due to higher water pressure (head), without wasting the little sewage water that was left. This water flowed much faster but then both filters nearly stopped flowing when they each had about 2 L left. It was speculated that more than 2 L were needed to keep the Pozzani candles alone flowing. For this reason, a total of 4 L was added to each filter for the last two testing days. (Each day the filters nearly stopped flowing when they had about 2.5 L of water left in the upper bucket.)

7.2.3 Sample Collection at MIT

A clean plastic beaker rinsed in tap water was dipped into the source water mix to collect a source water sample and was set aside for analysis. Filtered water samples were obtained directly from the spigot of the Table Filter and were collected in a previously heat-sterilized glass beaker.

In the Table Filter, water drips down from the candle filters into the receiving bucket before it flows out the spigot. Because the hole for the spigot is raised approximately four cm from the bottom of the receiving bucket, the filtered water does not completely drain out. Each day of testing before the source water was added to the top of the Table Filter, the spigot was opened and excess water was allowed to drain out. Sometimes the buckets were tipped on an edge so that more of the leftover water could drain. The one to two liters of water that sat below the spigot level were left in the receiving bucket so as to mimic the practices witnessed in Peru. This meant that the freshly filtered water was able to mix with the previously filtered water before each filtered sample was collected.

7.2.4 Microbial Tests at MIT (Membrane Filtration)

All microbial tests at MIT were performed using the technique of membrane filtration. (No H_2S presence/absence tests were performed.) Three different culture media were used to obtain information about different types of bacteria and to attempt to get the most accurate results possible.

The membrane filtration tests were performed in a very similar manner to the field tests in Peru (see Section 7.1.4). The sterilization techniques and duplicate and blank testing procedures were the same. Any differences from the field test methods are mentioned here:

- "Source water" samples were collected from a 20-L bucket using a clean plastic beaker that had been rinsed in tap water. (The tap water in the lab at MIT showed <1 bacteria when tested with the same MF technique.)
- Filtered water samples were collected using a glass flask that had been sterilized by being placed in an oven at 170°C for one hour.
- Stainless steel travel MF filter holders made by Millipore were used for all the tests.
- Petri dishes were incubated in one of two portable electric single-chamber Millipore incubators.

- Distilled water was used for all dilutions, blank tests, and rinses. For the majority of the time, the water used was obtained from an MIT Civil Engineering lab under the supervision of Dr. John Germaine, which distills its own water, and was stored in gallon jugs from store-bought distilled water. For a brief period of time, while the distilling machine was broken, store-bought distilled water was used.
- Three different growth media were used to test for different types of bacteria. The differences between these tests are mentioned below.

7.2.4.1 Thermotolerant Coliform

The majority of the tests were performed using m-FC broth, which tests for the presence of thermotolerant coliform. This broth was used on all MF tests in the spring and was used on each day of testing in the summer. Tests using m-FC broth were incubated at 44.5^{o}C for 24 hours +/- 2 hours, as per the manufacturer's (Hach's) instructions (Hach, 2004). TTC colonies turn blue for ease of counting. A range of cream to dark blue colonies was seen during these tests, so any dark blue, light blue, or blue-green colonies were considered to be TTC, while the green, yellow-green, yellow, and cream colonies were ignored.

7.2.4.2 E.coli and Total Coliform

MColiBlue-24 broth tests for the presence of E.coli and total coliform. This broth was used in tests alongside the m-FC broth toward the end of the summer testing because of difficulty encountered with obtaining useable results from the m-FC broth. It was hoped that this broth would give more readable and consistant results and therefore aid in the comparison of the filters with and without sand. MColiBlue-24 broth was incubated at 35^{o}C for 24 hours.

7.2.4.3 HPC

HPC broth was used to test for heterotrophic microorganisms, which indicate the general cleanliness of the Table Filter. Only a few days of testing were performed with this broth, which was used to determine whether bacterial growth in the Table Filter was *increasing* the general contamination of the water. Petri dishes with HPC broth were incubated at 35^{o}C for 48 to 72 hours, as specified. (Actual incubation time in this study was usually 48-50 hours.) In HPC tests, the colonies are clear to cream colored.

7.2.5 Performance Tests at MIT

7.2.5.1 Turbidity

Turbidity measurements were performed with the same procedures as in the field (see Section 7.1.5.1), except a Hach 2100P Turbidimeter™ with 10-ml glass sample cells was used instead. Turbidity was measured both in the source water and the filtered waters.

7.2.5.2 Flow Rate

The flow rate of the filters in the lab was only measured once before their sand was removed. This measurement was taken June 22, toward the end of the summer testing and after all of the spring testing. For this reason, the value only gives an indication of the flow rate after a month of testing, two months of being unused, and another month of testing – all without being cleaned – and thus does not necessarily reflect the flow rate of the filters toward the beginning of their use.

After the sand was removed, the flow rate was measured twice. The first measurement was taken after source water had been added on three different days after the sand was emptied, and after the candles had been scrubbed briefly with a paper towel just before the last batch of source water had been added. The second measurement was taken after an additional two days of relatively turbid source water had been added.

Flow rate measurement was performed the same way in the lab as in the field (see Section 7.1.5.3). The graduated cylinders were removed and the time recorded once the volume in the cylinders reached approximately 50 ml. Again, the measurement times and volumes were only approximate because it was virtually impossible to maneuver both cylinders directly under the dripping points simultaneously and without missing a few drops from either side.

7.3 Interviews

Interviews (or surveys) were conducted mostly in houses with a water treatment system (either a Table Filter or a Safe Water System) given to them by Peru's Ministry of Health, while only a few interviews were given to people without systems. The interviews were intended to provide additional information about the water treatment program and how it was perceived by the users. Native Peruvians translated the English questions into Spanish and conducted the interviews in Spanish. Questions in the interview explored the family's use and opinion of the treatment system as well as their willingness to pay for the materials. (All treatment systems in place at that time were distributed free-of-charge by the Ministry of Health after the earthquake of 2001, which caused the low quality of drinking water to be declared an "emergency situation.") The interview consisted of two sets of questions: one general set for all interviewees and another set particular to the type of treatment system given to the household. The interview contained a combination of questions that were adapted from Joe Brown's Master's Dissertation on drinking water treatment in Bolivia (Brown, 2003) and Genevieve Brin's Master's Thesis on the Safe Water System in Haiti (Brin, 2003). The survey questions were then revised by Murcott, Coulbert, Obizhaeva, and Lieu. Various parts of the survey were translated into Spanish by Sifuentes of CEPIS, Longhi, del Carpio, and Begazo. The interviews were conducted by Sifuentes, Longhi, del Carpio, and Begazo. The Spanish and English versions of the interview questions can be found in Appendix E.

A total of 74 individuals or households were interviewed in Peru and are reported in this thesis. During January, Sifuentes, Begazo, Longhi, and del Carpio conducted 30 interviews: 12

households with filters, 15 with *bidones*, and 3 with no treatment system. These interviews took place in seven different towns located in both Arequipa and Tacna provinces of southern Peru. During the March research period, Longhi and del Carpio interviewed 10 households with filters, 32 with *bidones*, and 2 with no system, a total of 44 households. All of those houses were located in Cerrito Buena Vista. The results of the interviews are presented in the following chapter.

Figure 7.16: Viviana Longhi (right) Conducting an Interview in the Town of Villa Hermosa San Isidro

7.4 Field Observations

As the team of researchers visited households to analyze water samples and take surveys, they also made physical observations about the households and the condition and usage of the treatment systems. Physical observations included house construction and condition (indicating relative wealth); placement of the treatment unit (Table Filter or *bidon*); water source and storage equipment and hardware; cleanliness and condition of the container and its water; and appearance of source water. These things were not noted in a systematic way, but were recorded occasionally as observations by the researchers. They serve to complement the interviews that were conducted simultaneously.

7.4.1 “Willingness to Pay Auction”

As described in Section 7.4.1, during January 2004, the entire H_2O-1B! team, led by the business students, held an “auction” in the town of La Cano (near La Joya) in order to help determine residents’ “willingness to pay” for water treatment. The mayors of La Joya and La Cano spread the word and gathered about 40 people from the 200-family village into the town meeting space. During the “auction,” which also took the form of a workshop, the MIT students taught the townspeople about the importance of treating their water and the different household treatment options that were available. Five households with Table Filters and three with Safe Water Systems were represented at the meeting and were asked for their feedback. The Mayor then reminded them about the water treatment plant that they were planning to build for the town.

The MIT students asked what people would be willing to pay for each option. As they presented the options and possible prices (starting low and gradually increasing the price), people at the meeting were asked to raise their hands if they would be willing to pay that price for the HWTS. Since an extra SWS *bidon* was not available, a plain clear bucket was used for demonstration purposes of the Safe Water System. At the end of the auction, the Table Filter, which Obizhaeva had constructed according to instructions, was sold to the highest bidder.

8. Results

This chapter presents the results of the tests that were performed on Table Filters, *bidones*, and other water sources in Peru and at MIT.

8.1 Field Tests in Peru

8.1.1 Microbial Tests in Peru

8.1.1.1 Membrane Filtration

While a number of tests were performed on water samples from households with Table Filters and SWSs in the La Joya area during January 2004, obtaining meaningful results turned out to be rather difficult. People often were not at home when the researchers walked around to collect samples and interview the families, so collection became a rather arduous and time-consuming task. Also, the raw water was much dirtier than had been expected based on the researchers' previous experiences in similar situations in other developing countries (e.g. rural areas in Nepal, Nicaragua, and Haiti), where the total coliform concentrations of raw water was on average one to two orders of magnitude lower than in Peru. The contamination of all water samples fluctuated greatly so that appropriate dilutions were hard to predict, which meant that many test results became unusable because the incorrect volume of water had been filtered. It is for these reasons that relatively little usable data was collected, especially during the short January research period.

During January, the author noticed that it was especially difficult to obtain valid results from the MF tests when using chlorinated water. It seemed as if the chlorine was affecting the growth of the bacteria colonies in some way, even though a sodium thiosulfate (de-chlorinating) tablet was contained in each *Whirl-Pak* bag used for water sample collection. The incubated filter papers from the chlorinated water samples sometimes turned a darker blue than all the other samples (mColiBlue-24 broth was used), or the coliform colonies would come out smeared and impossible to count. These phenomena occurred only during tests of chlorinated water. All of this unfortunately means that less data exists, especially from January, regarding chlorinated water than would be desired.

In January, both filters and *bidones* were tested for E.coli and total coliform (TC) presence using mColiBlue-24 broth. In March, all filters were tested for TC using Lauryl Sulfate broth; some *bidones* were tested with Lauryl Sulfate while others were tested with mColiBlue broth. (This variance was based on the availability of each testing broth at the time of testing.) This means that there are few results for E.coli concentration, which are tested for by mColiBlue, but many tests for TC, which was detected by both mColiBlue and Lauryl Sulfate.

8.1.1.1.1 Source Water

For the Table Filter tests in Peru, the raw water being fed to the filters ranged from 2.0×10^2 to 1.2×10^3 E.coli CFU/100ml from 3 tests, with an average of 5.3×10^2 E.coli CFU/100ml and a standard deviation of 577. From a total of 14 tests, the TC concentration levels ranged from 9.0×10^2 to 9.0×10^4 TC CFU/100ml, showing an average of 3.5×10^3 TC CFU/100ml and a standard deviation of 23,516.

Raw water in households with the SWS ranged in E.coli concentration from 7 to 1.2×10^4 E.coli CFU/100ml from 9 tests, and had an average of 4.5×10^3 E.coli CFU/100ml and a standard deviation of 4,819. TC concentrations in 33 tests ranged from 6.8×10^2 to 1.5×10^5 TC CFU/100ml, averaging 2.1×10^4 TC CFU/100ml with a standard deviation of 31,393.

8.1.1.1.2 Table Filters

Filtered water from the Table Filter tests conducted in Peru ranged from <1 to 4 E.coli CFU/100ml, with an average of 2 CFU/100ml and a standard deviation of 2 from 3 tests. TC in the treated water ranged from <1 to 4.2×10^2 TC CFU/100ml, with an average of 7.2×10^1 CFU/100ml and a standard deviation of 111 from 14 tests.

The Table Filters showed an average percent removal of 99% E.coli and 98% TC. The Table Filters showed an average LRV of 2.3 for E.coli and 2.5 for TC.

Figure 8.1 shows the coliform concentrations for each Table Filter household for which valid results were obtained in Peru during January and March 2004.

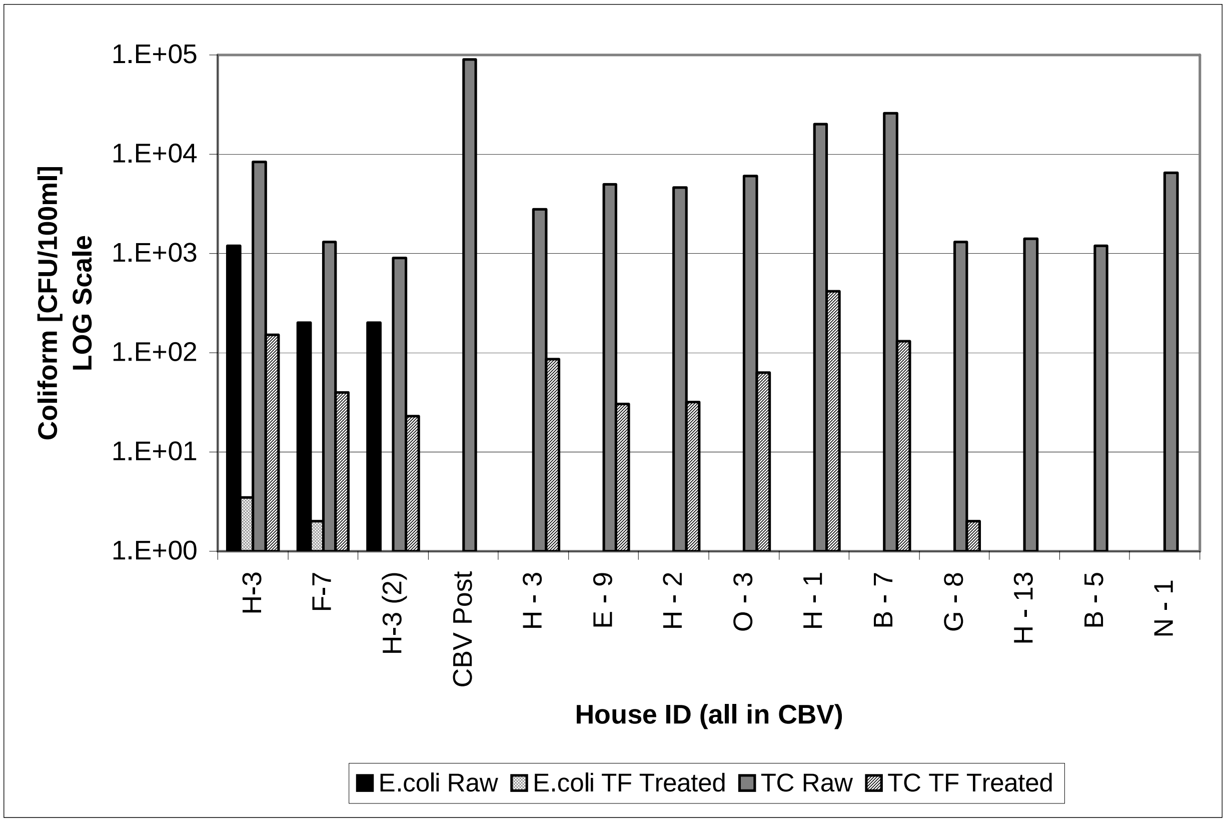


Figure 8.1: All Coliform Concentrations Before & After Treatment by Table Filters (Peru, Jan. & March 2004)

8.1.1.1.3 Safe Water System

Chlorinated water found in 7 SWS *bidones* ranged from <1 to 5 E.coli CFU/100ml with an average of 1 E.coli CFU/100ml and a standard deviation of 2. The TC concentration of 29 SWSs ranged from 5 to 1.1×10^3 TC CFU/100ml with an average of 1.5×10^2 TC CFU/100ml and a standard deviation of 232.

In Peru, SWS *bidones* averaged 99.6% removal of E.coli and 95% removal of TC. They also produced a 2.8 LRV for E.coli and 2.2 LRV for TC.

Figures 8.2 – 8.4 show the concentrations of each coliform before and after household chlorination from all the valid results found while testing in Peru.

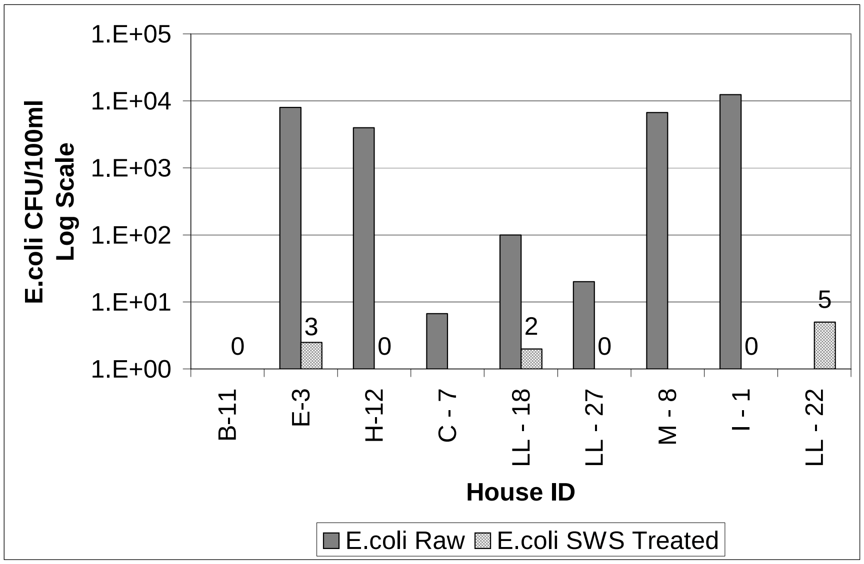


Figure 8.2: E.coli Concentrations Before & After Household Chlorination (Peru, Jan. & March 2004)

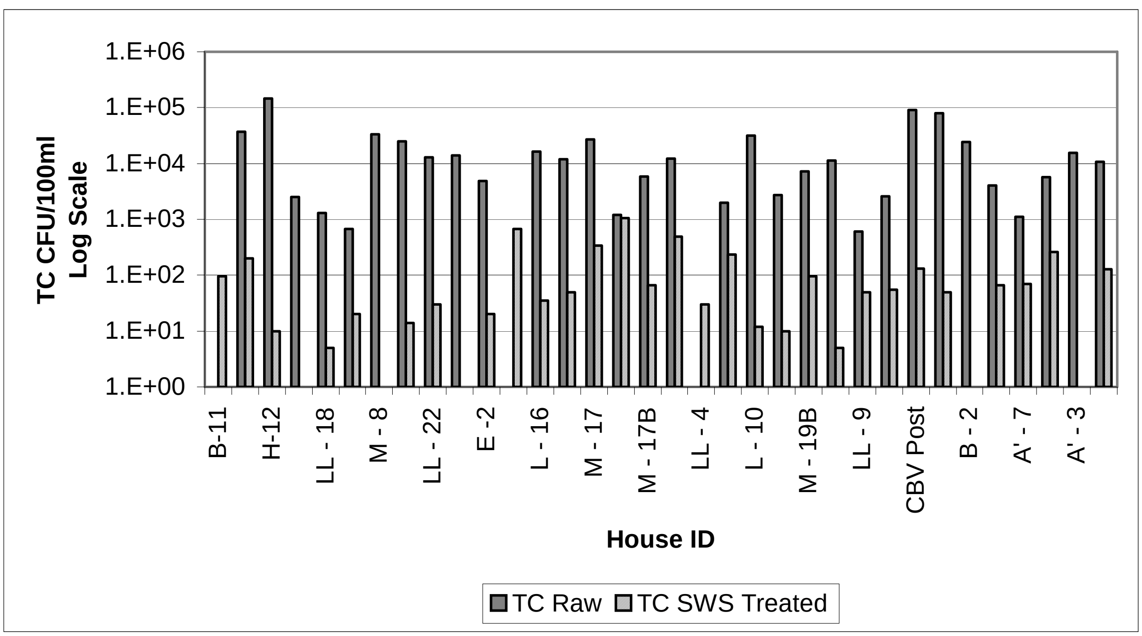


Figure 8.3: TC Concentrations Before & After Household Chlorination (Peru, Jan. & March 2004)

Table 8-1 gives the average percent removal of all microbial data for both Table Filters and SWS *Bidones*. For a complete listing of the microbial data for both systems, see Appendices F and G.

Figure 8.4 graphically compares the average coliform concentrations before and after each type of treatment.

Table 8-1: Summary of MF Data from Filtration & Household Chlorination in Peru (Jan. & March 2004)

Coliform CFU/100ml	Filtration			Chlorination		
	Raw Water	Treated Water	% Removal	Raw Water	Treated Water	% Removal
E.coli	5.3×10^2	2	99%	4.5×10^3	1	99.6%
TC	3.5×10^3	7.2×10^1	98%	2.1×10^4	1.5×10^2	95%

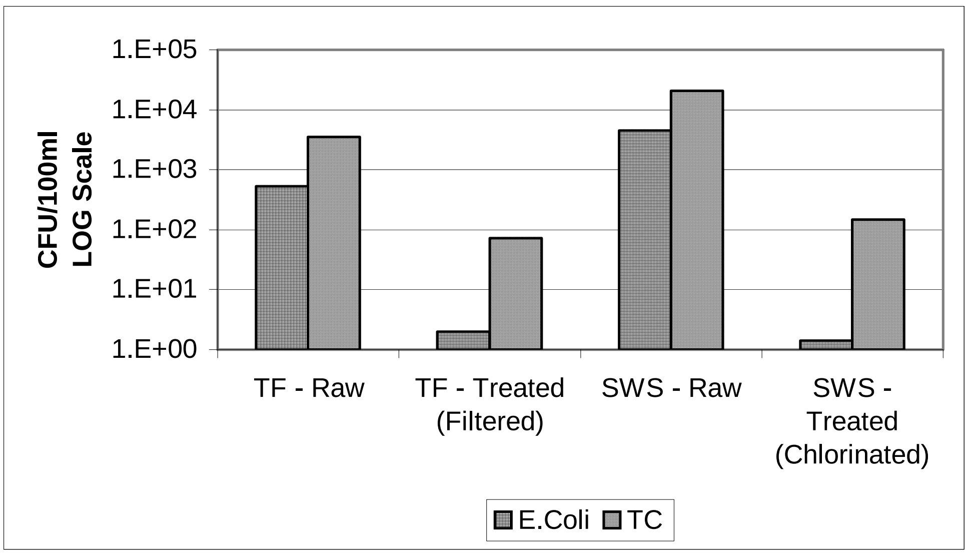


Figure 8.4: Average Coliform Concentrations Before and After Filtration and Household Chlorination (Peru, Jan. & March 2004)

8.1.1.1.4 Water Treatment Plants

During January, two water treatment plants (WTPs) were tested for E.coli and total coliform at three different stages in each plant. The treatment plants were located in the towns of Cerrito Buena Vista (CBV) and El Triunfo (ET). This data is summarized in Table 8-2.

Table 8-2: E.coli and TC Concentrations at Water Treatment Plants (Peru, Jan. 17, 2004)

CBV WTP				El Triunfo WTP		
	E.coli	TC			E.coli	TC
Stage 1	$1.9x10^5$	$3.0x10^5$		Inflow Channel	$1.0x10^5$	$1.8x10^5$
Stage 2	$2.6x10^5$	$8.6x10^5$		Post-Chlorination	$3.0x10^2$	$1.5x10^3$
Stage 3	$1.5x10^4$	$2.3x10^4$		Settling Tank	4	6

The table lists all three sampling locations, but in order to calculate "before and after" results, only two points can be used. For the CBV WTP, Stages 1 and 3 were used as "raw" and "treated" water, since these points of sampling were near the influent and the effluent of the plant. At the El Triunfo plant, the Inflow Channel was considered raw water, and the Post-Chlorination sample was used as a treated water sample. At the time of sampling, the second half of the plant was shut down for cleaning and thus the Settling Tank was not in use. All water was transported to households from the plant directly after the Post-Chlorination step.

During the March research period in Peru, raw water and treated water samples from two visits each to the two WTPs were analyzed for TC. Even when combined with the January samples, the two WTPs were only tested once for E.coli. The CBV WTP raw water showed $1.9x10^5$ E.coli CFU/100ml. During all three testing days, the TC concentration of raw water ranged from $4.5x10^3$ to $3.0x10^5$ CFU/100ml with an average of $1.5x10^5$ TC CFU/100ml and a standard deviation of 201,879.

The treated water at the CBV plant had $1.5x10^4$ E.coli CFU/100ml on the one January day of testing. The TC concentrations, however, ranged from $2.3x10^4$ to $6.1x10^4$ CFU/100ml and averaged $4.4x10^4$ CFU/100ml with a standard deviation of 30,875. This data shows that the CBV WTP produced a 92% removal and a 1.1 LRV for E.coli, and a –258% removal of TC, with an average LRV of 0.3 for TC. The average percent removal of all three days of data collection at the CBV WTP, was calculated to be –258% removal of TC. This is a negative value because on one of the testing days, the raw water was found to have very low contamination, while the treated water was high. This resulted in –944% removal on that day, even though a different day of testing showed 92% removal of TC.

At the El Triunfo WTP, raw water contained $1.0x10^5$ E.coli CFU. The TC concentrations ranged from $1.8x10^4$ to $3.5x10^5$ CFU/100ml and averaged $1.8x10^5$ TC CFU/100ml with a standard deviation of 166,002.

The treated water at the El Triunfo WTP showed $3.0x10^2$ E.coli CFU/100ml. The TC concentrations from all three test days ranged from <1 to $6.9x10^4$ CFU/100ml. They averaged $2.4x10^4$ TC CFU/100ml and had a standard deviation of 39,527. The El Triunfo plant demonstrated an average of 99.7% removal of E.coli and 93% removal of TC. The LRVs were 2.5 and 2.3, respectively, for E.coli and TC removal.

All of the TC concentrations measured at each WTP, including both January and March data, are summarized in Table 8-3. The percent removals and LRVs are also shown.

Table 8-3: TC Concentrations Found at Water Treatment Plants (Peru, Jan. & March 2004)

	CBV WTP				El Triunfo WTP			
	Raw Water CFU/100ml	Treated Water CFU/100ml	% Removal	LRV	Raw Water CFU/100ml	Treated Water CFU/100ml	% Removal	LRV
Jan. 17	$3.0x10^5$	$2.3x10^4$	92%	1.1	$1.8x10^5$	$1.5x10^3$	99%	2.1
March 25	$2.9x10^5$	$6.1x10^4$	79%	0.7	$3.5x10^5$	$6.9x10^4$	80%	0.7
April 4	$4.5x10^3$	$4.7x10^4$	-944%	-1.0	$1.8x10^4$	< 1	99.99%	4.3
Average	**$1.5x10^5$**	**$4.4x10^4$**	**-258%**	**0.3**	**$1.8x10^5$**	**$2.4x10^4$**	**93%**	**2.3**

* * *

Figure 8.5 compares the percent removal of Table Filters and SWS *bidones* to the two WTPs in Peru.

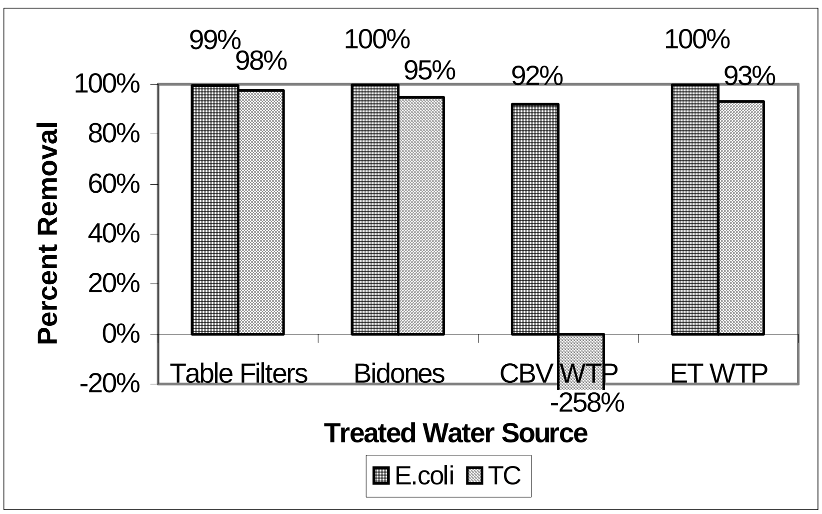


Figure 8.5: Percent Removal of Coliform by Table Filters & WTPs (Peru, Jan. & March 2004)

8.1.1.2 H_2S Presence/Absence

While P/A tests were performed only occasionally during January, they were performed on *every* water source analyzed in March.

The results of all the P/A tests are presented in Appendices F, G, and H. Of all the filtered water samples from Table Filters tested for H_2S presence in both January and March, 25% were negative (or gave an "absence of H_2S" result). Of those treated with chlorine solution in SWSs, only 8% were negative. The water treatment plants were each tested twice. The CBV WTP was positive twice, and the El Triunfo plant was negative once and positive once. Again, a negative or “absence” result is desirable, as “presence” indicates that the water is contaminated. Table 8-4 gives the breakdown of the number of each result. Figure 8.6 shows an example of absence and presence results.

Table 8-4: Summary of H_2S P/A Test Results for Treated Waters (Peru, Jan. & March 2004)

	# of “P” Results	# of “A” Results	% “A” Results
Table Filter Treated	9	3	25%
SWS Treated	35	3	8%
Total Household Treated	*44*	*6*	*12%*
CBV WTP	2	0	0%
ET WTP	1	1	50%
Total Water Treatment Plants	*3*	*1*	*25%*

Figure 8.6: Example of H_2S Results (Peru, January 2004)
“Presence” (#14) Appears Black and “Absence” (#15) Appears Dark Yellow

8.1.2 Performance Tests in Peru

8.1.2.1 Turbidity

8.1.2.1.1 Table Filters

Fourteen Table Filters were tested for turbidity before and after filtration during the January and March field testing periods. Figure 8.7 shows the turbidity of water samples, before and after filtration, from these filters. The Table Filters reduced the average of the raw water from 10 NTU to 2.4 NTU in the treated water, a 67% removal.

Three of the 14 filters were reported as "not working." Of the 11 "working" Table Filters tested in Peru, the average turbidity reduced from 12 NTU to 2.4 NTU. These filters showed an average of 70% removal of turbidity.

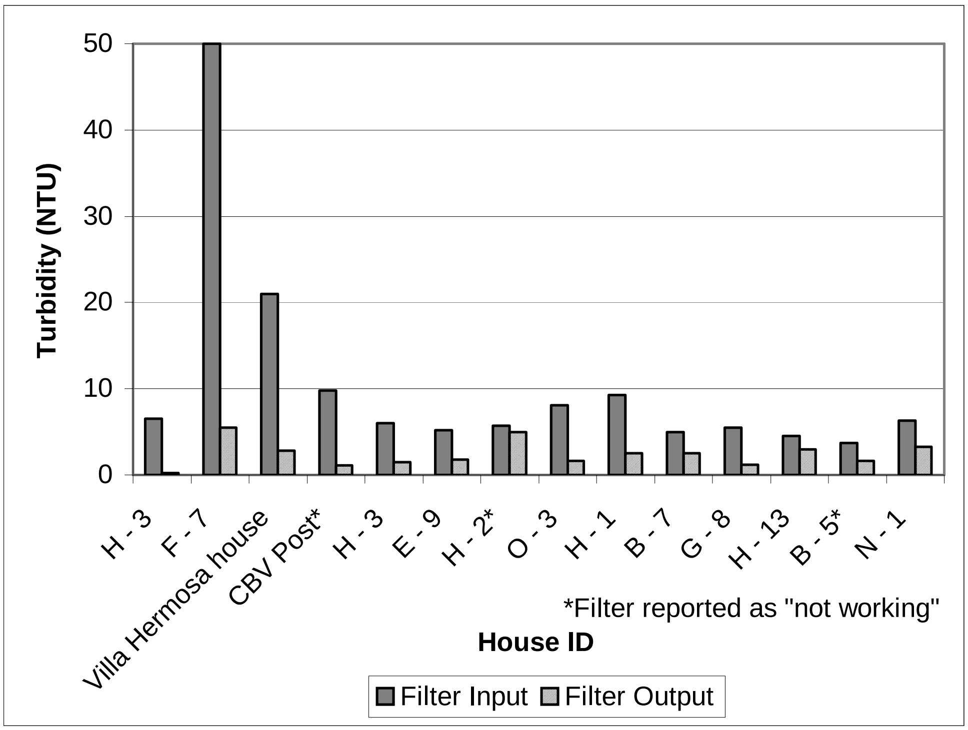


Figure 8.7: Turbidity Concentration Before & After Filtration (Peru, Jan & March 2004)

8.1.2.1.2 Safe Water System

Chlorination is not intended to reduce turbidity, however it is useful to note the turbidity in chlorinated water, as high turbidity could interfere with the effects of chlorine. The average turbidity measured in *bidones* was 38 NTU. Most households with *bidones* were measured for turbidity both before chlorination (that is, water directly from the tap) and after chlorination (that is, water located in the *bidon*). Curiously, household waters measured at both of these stages showed an average 37% *increase* in turbidity from 20 to 28 NTU.

8.1.2.1.3 Water Treatment Plants

The turbidity data from water samples collected from two water treatment plants is presented in Figure 8.8. The turbidity in the water only decreased slightly as a result of treatment at the two WTPs. As was explained in Section 6.2, the samples taken from the final stage of the El Triunfo plant were not representative of the typical state of the plant. At that time, the post-chlorination water was being pumped directly to households instead of the water from the final holding tank.

Turbidity was measured again at these two water treatment plants on April 4 in two places: raw water was collected at the influent, and treated water was collected at the final effluent point just before entrance into the distribution system.

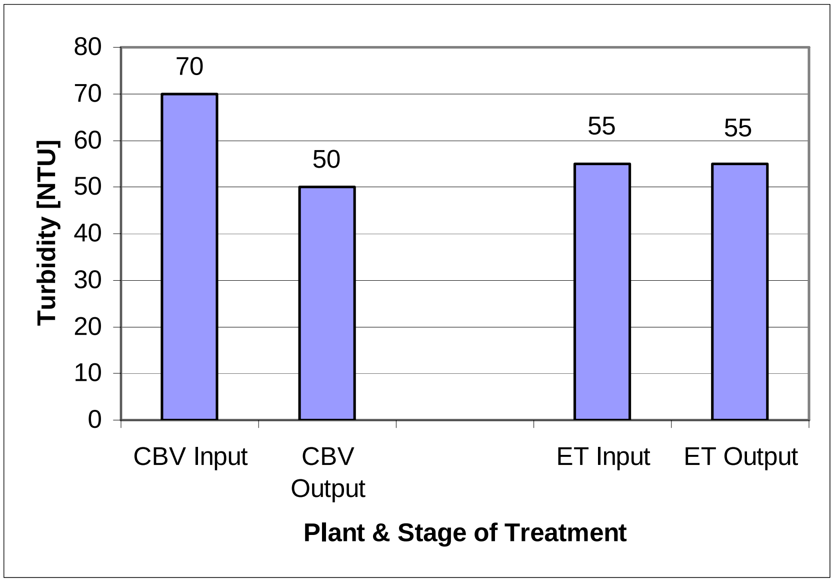


Figure 8.8: Turbidity at Cerrito Buena Vista & El Triunfo WTPs (Peru, Jan. & March 2004)

Figure 8.9 compares the average reduction in turbidity by Table Filters in Peru versus each water treatment plant. This percent removal combines both January and March data. The Table Filters reduce the amount of turbidity in the water much more than the community water treatment plants that were visited.

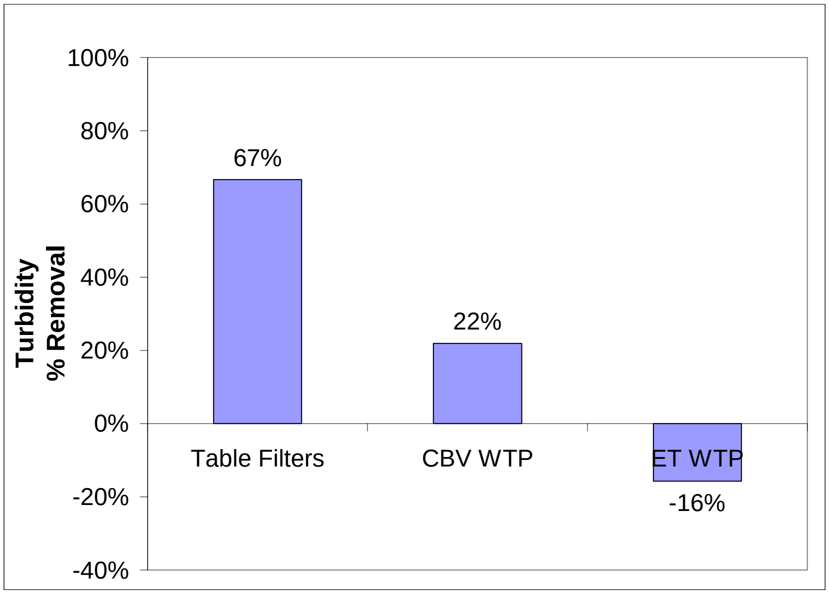


Figure 8.9: Average % Removal of Turbidity by Table Filters & WTPs (Peru, Jan. & March 2004)

8.1.2.2 Chlorine Residual

During January and March 2004, 37 SWS *bidones* were successfully measured for chlorine residual. Figure 8.10 shows the concentrations measured in each *bidon*. The average *free chlorine* found in all *bidones* tested in January and March in Peru was 0.18 mg/L. This average is just below the WHO recommended range of 0.2 to 1.0 mg/L chlorine residual for disinfection purposes. Eleven of the 37 SWS *bidones*, or 30%, fell within the recommended range.

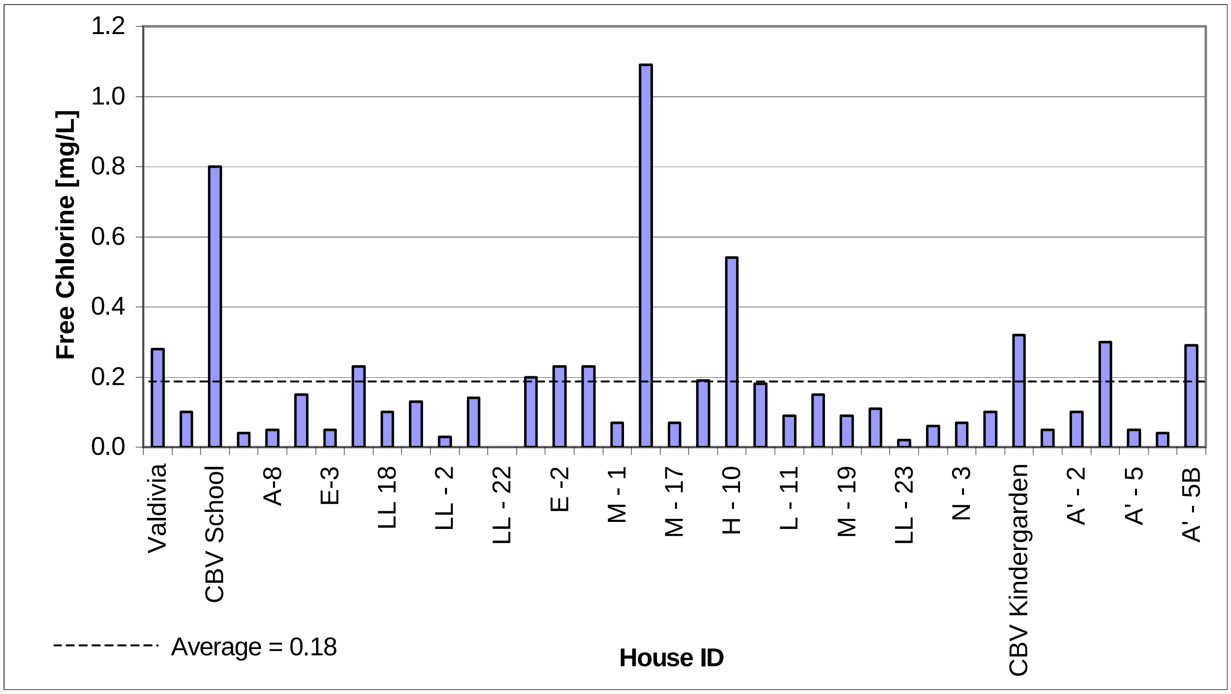


Figure 8.10: Free Chlorine Residual in SWS *Bidones* (Peru, Jan & March 2004)

Free chlorine residual was also measured at the "output" of each WTP. CBV's showed an average of 0.41 mg/L chlorine residual. El Triunfo's average chlorine residual concentration at the "output" was 0.53 mg/L. Both of these were within the WHO recommended range. However, the fact that chlorine residual was never found at the household level in CBV indicates that the chlorine demand throughout the distribution system is higher than the amount being added at the treatment plant (Malies, et al., 2004).

8.1.2.3 Flow Rate

Flow rate was measured in 16 different Table Filters in the Arequipa and Tacna regions. The average flow rate for the eight filters was 2.2 L/hr. The average flow rate of the 12 Table Filters from the Arequipa region was 1.7 L/hr (with a standard deviation of 1.1), while the average flow rate of the 4 from Tacna was 3.8 L/hr (with a standard deviation of 0.5). Figure 8.11 shows the flow rates measured from the 16 Table Filters. The first 12 filters graphed were located in Arequipa, and the last 4 were in Tacna.

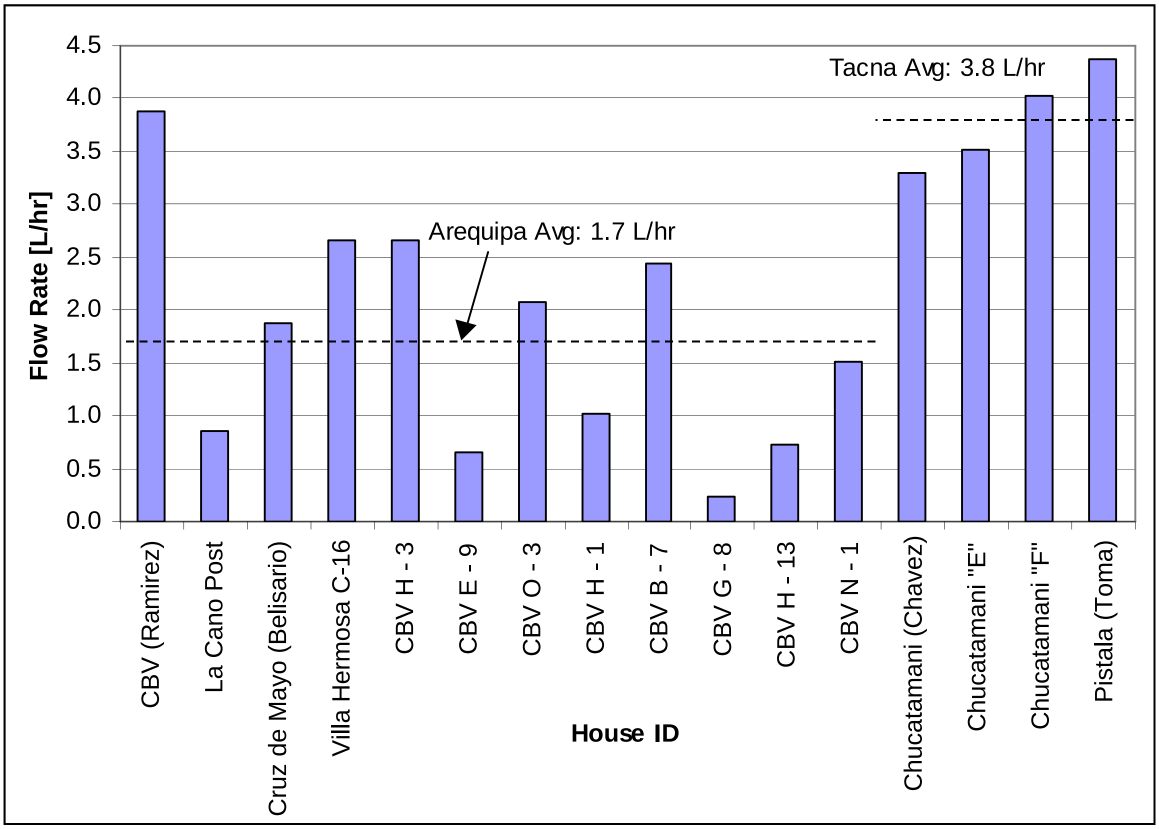


Figure 8.11: Table Filter Flow Rates

8.2 Laboratory Tests at MIT

8.2.1 Microbial Tests at MIT (Membrane Filtration)

8.2.1.1 Thermotolerant Coliform

8.2.1.1.1 Table Filters with Sand

The average concentration of thermotolerant coliform (TTC) in the 8 source water samples tested during the spring lab work averaged 1.9×10^4 TTC CFU/100ml. During the summer laboratory testing period, the Table Filters were tested for TTC both before and after the geotextile and all of the sand were removed from the filters. The source water that was used in Table Filters before their sand was removed averaged 1.3×10^3 TTC CFU/100ml during 5 test days. When the 15 spring and summer tests are combined, the source water ranged from 2.0×10^2 to 6.7×10^4 TTC CFU/100ml with an average of 1.2×10^4 TTC CFU/100ml and a standard deviation of 19,295.

The Medium Sand Table Filter produced treated water averaging $7.2x10^1$ TTC CFU/100ml during 8 testing days in the spring. During summer testing, the Medium Sand Table Filter reduced its treated water to concentrations averaging 1 TTC CFU/100ml. During the spring, the MSTF removed an average of 98% of TTC and produced an LRV of 2.6, while it removed 99.9% and gave an LRV of 2.6 during the summer.

The 17 tests on treated water from the Medium Sand Table Filter ranged from < 1 to $2.1x10^2$ TTC CFU/100ml, which averaged $4.1x10^1$ TTC CFU/100ml with a standard deviation of 72. The MSTF showed an average 98% removal of TTC and a 2.6 LRV.

During the spring, the Fine Sand Table Filter reduced the levels of TTC to an average of $4.3x10^2$ TTC CFU/100ml. The FSTF treated water in the summer showed an average of $1.4x10^1$ TTC CFU/100ml. In the spring, the FSTF performed at an average of 97% removal and 1.8 LRV. During the summer, the FSTF gave an average of 99% removal of TTC and an LRV of 2.3.

When the 16 FSTF treated water tests are combined, they ranged from < 1 to $1.3x10^3$ TTC CFU/100ml and averaged $2.2x10^2$ TTC CFU/100ml with a standard deviation of $4.0x10^2$. The FSTF had an overall average percent removal of 98% and a LRV of 2.0.

Figure 8.12 presents, in graphical form, the TTC concentrations in each type of water sample for each day of testing.

The t-test shows that the percent removals of TTC caused by the MSTF and the FSTF have a 62% chance of being from the same data distribution. This indicates that the two Table Filters with different sand grades do not demonstrate a statistically significant difference in turbidity removal.

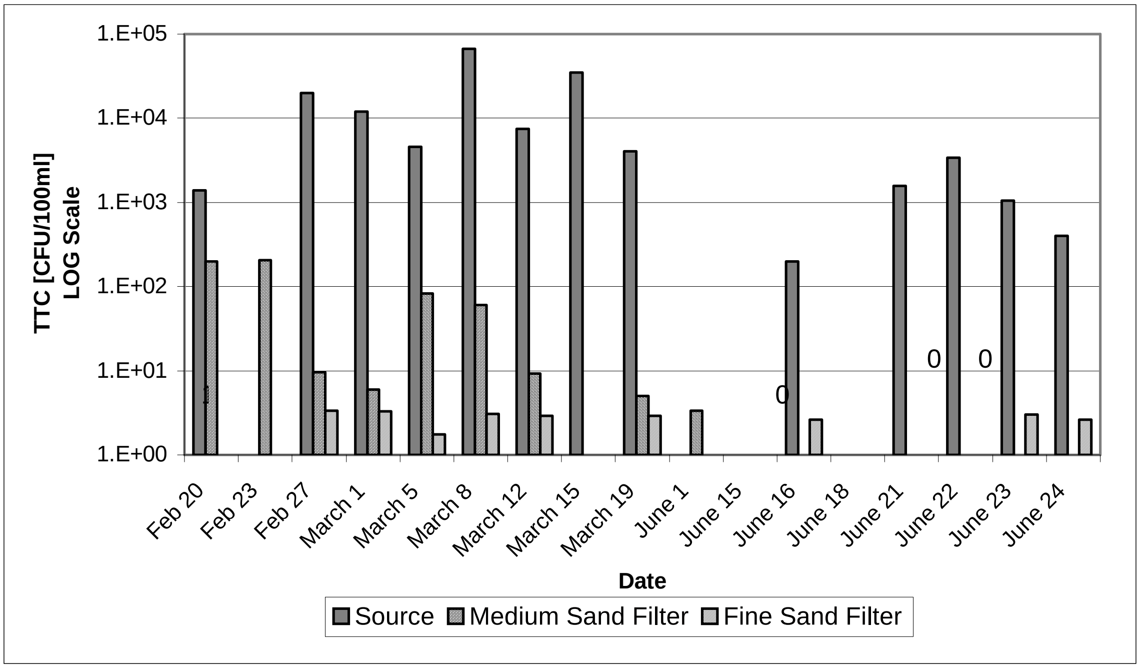


Figure 8.12: TTC Concentrations Before & After Filtration by Medium and Fine Sand Table Filters (MIT, Spring & Summer 2004)

8.2.1.1.2 Table Filters without Sand

After removing sand from both filters, the source water concentration ranged from 1.1×10^3 to 3.0×10^3 TTC CFU/100ml during 3 test days and averaged 1.9×10^3 TTC CFU/100ml with a standard deviation of 1,002.

After the sand was removed, the MSTF was able to reduce the TTC concentration to 5 and 1.5×10^2 CFU/100ml on two different testing days, which averaged 7.7×10^1 CFU/100ml and had a standard deviation of 103. The ceramic candles alone in the former MSTF were able to produce 97% TTC removal and an average LRV of 1.9.

The FSTF without sand produced concentrations of 8 and 5.9×10^1 TTC CFU/100ml, which averaged of 3.3×10^1 TTC CFU/100ml and a standard deviation of 36. The ceramic candles in the former FSTF showed an average of 99% removal and a 1.9 LRV.

Figure 8.13 shows the daily TTC concentrations after the sand was removed from the Filters.

Without sand, the percent removals caused by the two Table Filters have a 67% chance of resulting from the same data source (according to the t-test). This means that the ceramic candles in the two TFs do not behave significantly differently.

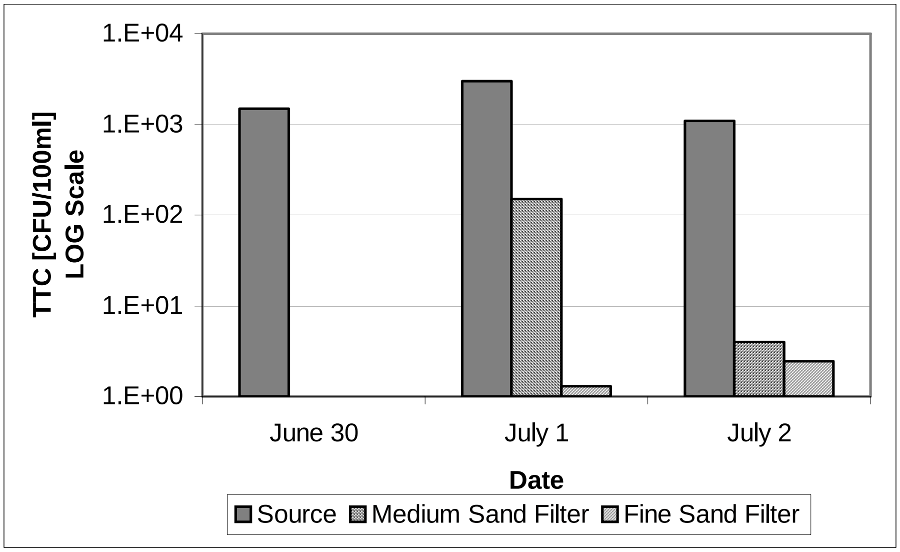


Figure 8.13: TTC Concentrations Before & After Filtration – ***After Sand Removal (Ceramic Candles Only)*** **(MIT, Summer 2004)**

8.2.1.2 E.coli and Total Coliform

As stated in Section 7.2.4.2, the tests for E.coli and total coliform (TC), performed with mColiBlue-24 growth media, were added late during the summer testing period in an effort to produce additional useful data regarding the comparison of the Table Filters before and after their sand had been removed. Due to time constraints, only one set of tests with this medium occurred before sand was removed from the filters, and four sets of tests occurred afterward.

8.2.1.2.1 Table Filters with Sand

Before removal of sand from the filters, the source water, during the one day of testing with mColiBlue-24, contained $1.8\text{x}10^3$ E.coli CFU/100ml and $6.5\text{x}10^3$ TC CFU/100ml.

The MSTF reduced the coliform levels during the one day of testing before the sand was removed to < 1 E.coli CFU/100ml and 3 TC CFU/100ml. The FSTF brought the levels to $1.0\text{x}10^1$ E.coli CFU/100ml and $6.4\text{x}10^1$ TC CFU/100ml. Thus the Medium Sand Filter produced a 99.99% removal of E.coli (3.3 LRV) and 99.95% removal of TC (3.3 LRV), and the FSTF showed 99.5% removal of E.coli (2.3 LRV) and 99% removal of TC (2.0 LRV).

8.2.1.2.2 Table Filters without Sand

After the geotextile and all of the sand were removed from the TFs, and only the ceramic candles were left to filter the water, the source water that was used during the 4 days of testing ranged from $4.7\text{x}10^1$ to $2.0\text{x}10^3$ E.coli CFU/100ml and averaged $8.9\text{x}10^2$ E.coli CFU/100ml, with a standard deviation of 838. TC concentrations ranged from $2.3\text{x}10^3$ to $1.5\text{x}10^5$ TC CFU/100ml with an average of $5.0\text{x}10^4$ TC CFU/100ml and a standard deviation of 65,425.

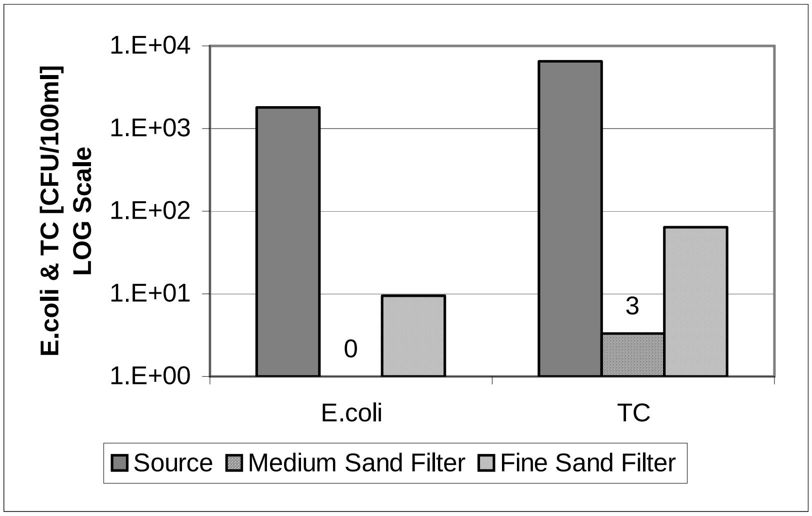


Figure 8.14: E.coli & TC Concentrations Before & After Filtration (MIT, June 24, 2004)

The water produced from the MSTF after sand was removed produced < 1 E.coli CFU/100ml during each of the three tests. The MSTF ranged from 7.9×10^{1} to 5.4×10^{3} TC CFU/100ml in three tests and averaged 2.0×10^{3} TC CFU/100ml with a standard deviation of 2,979. This means that the Medium Sand Table Filter without sand showed an average percent removal of 99.99% E.coli and an LRV of E.coli of 2.6, and 23% TC removal with a 1.6 LRV.

The low average removal of TC by the Medium Sand Filter was caused by one day of testing in which the tests showed that the bacterial contamination in the filtered water was higher than that in the source water. Valid data could not be collected from the water filtered by the Fine Sand Filter so the two filters could not be compared on that day, and therefore, the average values and percent removal are not truly comparable between the two filters. See Section 9.2.1.2 for further commentary on this one day of testing.

The FSTF ranged from < 1 to 5 E.coli CFU/100ml and averaged 3 E.coli CFU/100ml in 3 tests, with a standard deviation of 3. The FSTF also ranged in 3 tests from 7 to 2.7×10^{2} TC CFU/100ml with an average of 1.2×10^{2} TC CFU/100ml and a standard deviation of 136. The FSTF gave an average of 99.8% removal and 2.6 LRV of E.coli, and 99.8% removal and 2.9 LRV of TC.

Figures 8.15 and 8.16 show the E.coli and TC concentrations in water before and after being filtered. The Raw Water coliform concentrations on June 30 are lower than the other days because the “source” water on that day consisted solely of Charles River water (and no sewage), as explained in Section 7.2.2.

The t-test performed on the data from the MSTF and FSTF with ceramic candles only shows a 19% chance that the E.coli percent removals come from the same data distribution, and a 42% chance of the same with the TC percent removal values. While differences in removal by the two TFs seem to have more evidence here than in other sets of data, there is still not a statistically significant difference. (The percent chance would have to be 5% or less.)

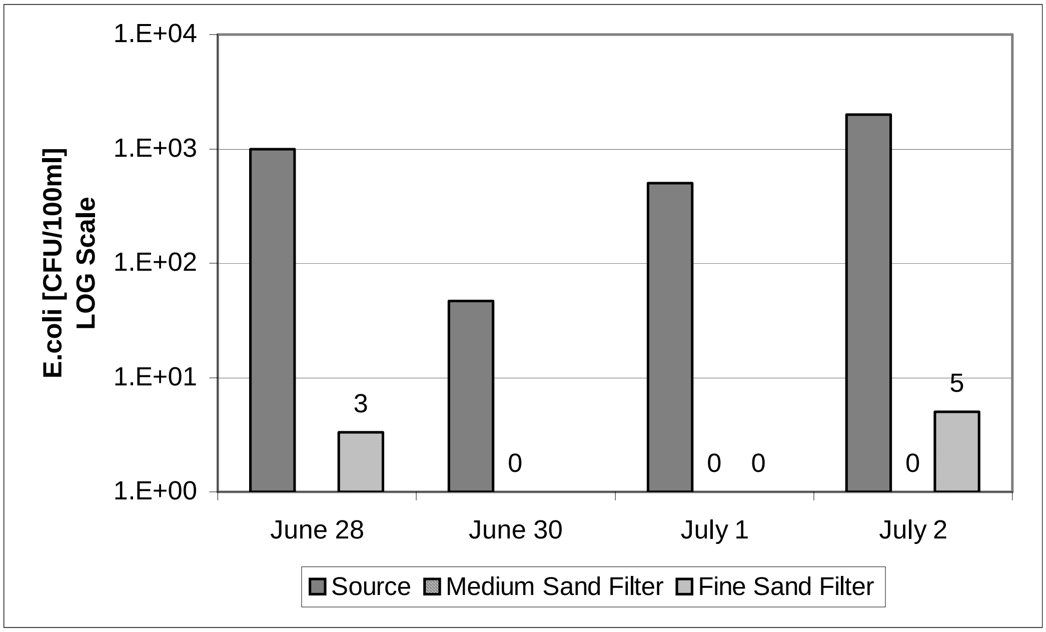


Figure 8.15: E.coli Concentrations Before & After Filtration – After Sand Removal (MIT, Summer 2004)

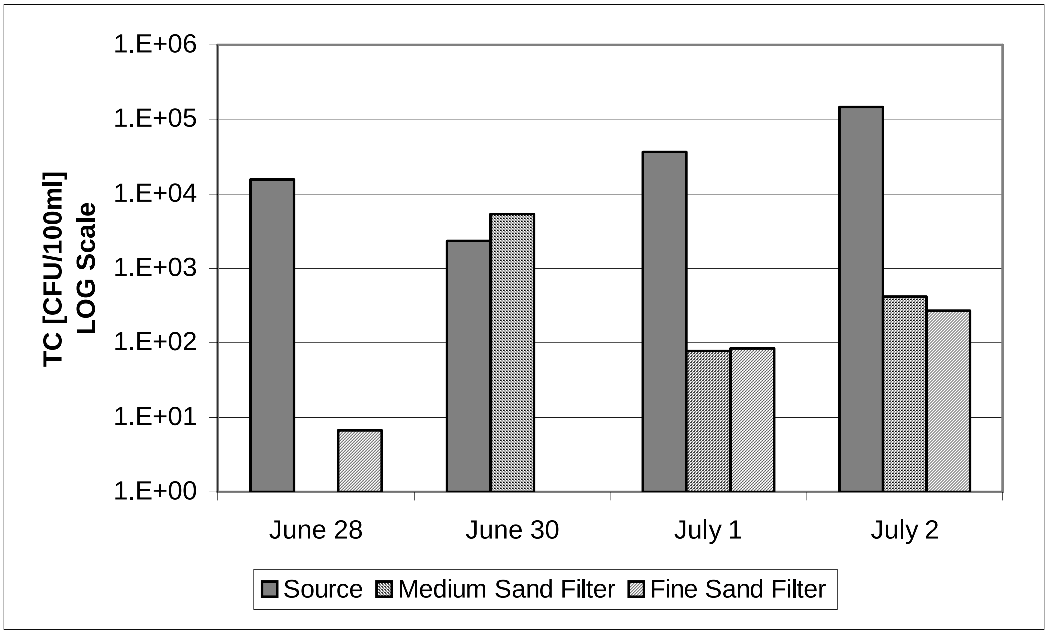


Figure 8.16: Total Coliform Concentrations Before & After Filtration – *After Sand Removal* (MIT, Summer 2004)

8.2.1.3 HPC

HPC tests were performed three times before sand was removed from the filters. Source water concentration ranged from $2.4\text{x}10^5$ to $7.7\text{x}10^6$ HPC CFU/100ml and averaged $3.1\text{x}10^6$ HPC CFU/100ml with a standard deviation of 4,029,962.

The HPC concentration in treated water from the Medium Sand Table Filter was $9.0\text{x}10^2$ and $1.1\text{x}10^5$ CFU/100ml on two separate test days. This averages $5.3\text{x}10^4$ HPC CFU/100ml and has a standard deviation of 73,610. When both days with raw and treated water results for the MSTF are averaged, it performed at an average of 99% removal of HPC with a 2.1 LRV.

The Fine Sand Table Filter was $1.3\text{x}10^6$ HPC CFU/100ml on one day of testing. The FSTF removal of HPC was 83% on its one valid test day. The FSTF demonstrated an LRV of 0.8.

It is also important to note that "blank water" was not absent of HPC bacteria. The two days that data fell within the 0 to 200 ($2.0\text{x}10^2$) range for 100ml samples, the blank water showed < 1 and $6.6\text{x}10^1$ HPC CFU/100ml. These two days averaged $3.3\text{x}10^1$ HPC CFU/100ml with a standard deviation of 47. A third day of testing resulted in $2.5\text{x}10^2$ HPC CFU/100ml, which is out of the "valid" range but certainly provides information about the concentration of HPC in blank water. If this result was added to the average, it would raise to $1.0\text{x}10^2$ HPC CFU/100ml in blank water.

Also, to get a more accurate comparison between the water before and after filtration, one can look at the data from June 23 – the one day that all four water samples produced valid/useable results. On that day, the source water reduced from $7.7\text{x}10^6$ HPC CFU/100ml to $1.1\text{x}10^5$ HPC

CFU/100ml with the MSTF, a reduction of 99%, and to $1.3x10^6$ HPC CFU/100ml with the Fine Sand Filter, a reduction of 83% HPC.

These concentrations can be compared to the blank water on that day, which produced $2.5x10^2$ HPC CFU/100ml. This would be a 99.997% reduction from the source water, or a 99.8% reduction from the MSTF's treated water.

All HPC results are shown in Figure 8.17.

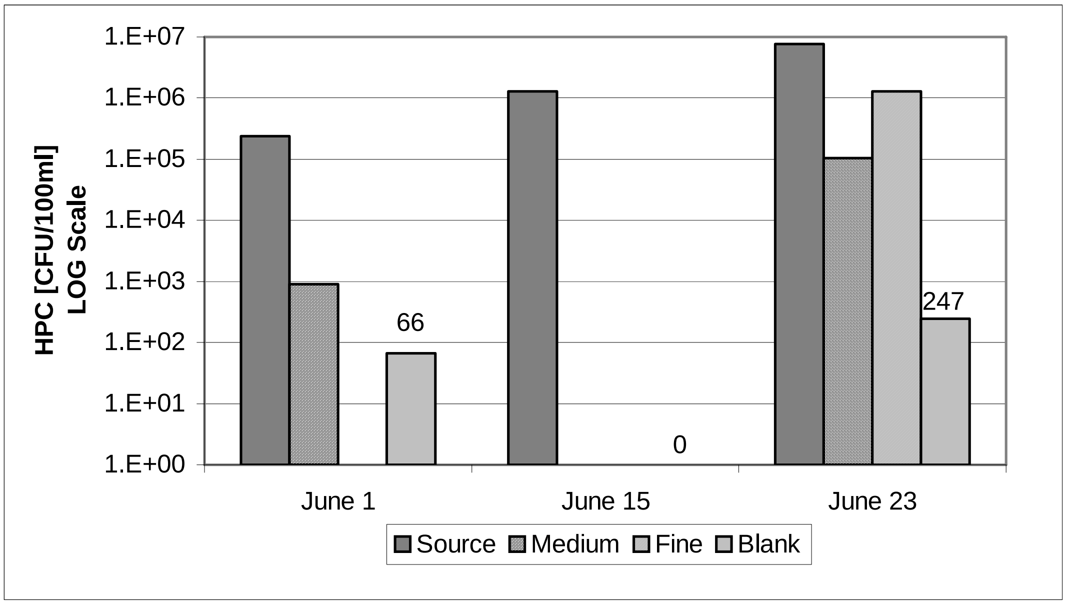


Figure 8.17: HPC Concentrations Before & After Filtration (MIT, Summer 2004)

* * *

Table 8-5 and Figures 8.18 – 8.20 summarize the concentrations of each type of coliform both before and after filtration as well as before and after the sand was removed from the Table Filters.

Table 8-5: Summary of All Average Coliform Concentrations (CFU/100ml) and Percent Removals of Table Filters (MIT, 2004)

Broth	Table Filter Media	Source Water	MSTF Treated Water	FSTF Treated Water	MSTF % Removal	FSTF % Removal
TTC	**Sand**	1.2×10^{4}	4.1×10^{1}	2.2×10^{2}	98%	98%
	No Sand	*1.9×10^{3}*	*7.7×10^{1}*	*3.3×10^{1}*	*97%*	*99%*
E.coli*	**Sand***	1.8×10^{3}	< 1	1.0×10^{1}	99.99%	99.5%
	No Sand	*8.9×10^{2}*	*< 1*	*3*	*99.99%*	*99.8%*
TC*	**Sand***	6.5×10^{3}	3	6.4×10^{1}	99.95%	99%
	No Sand	*5.0×10^{4}*	*2.0×10^{3}*	*1.2×10^{2}*	*23%*[46]	*99.8%*
HPC	**Sand**	3.1×10^{6}	5.3×10^{4}	1.3×10^{6}*	99%	83%

* These tests were only performed once.

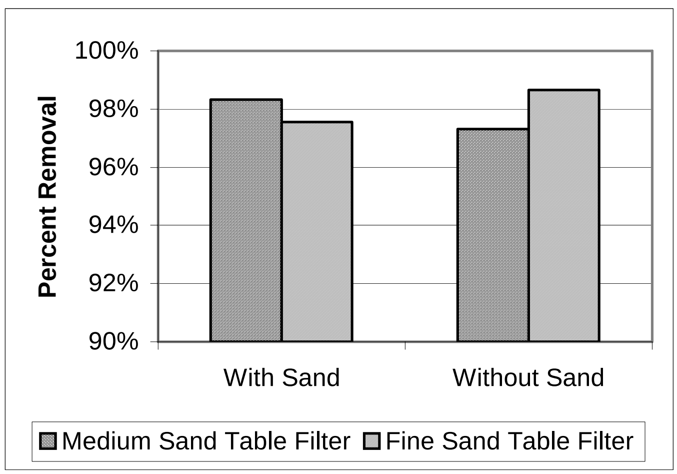


Figure 8.18: Percent Removal of TTC With & Without Sand (MIT, Spring & Summer 2004)

[46] For explanation of this low percent removal, see Section 9.2.1.2.

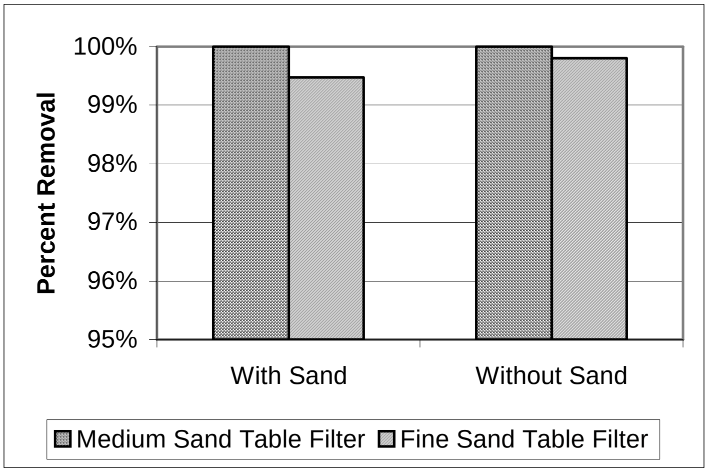


Figure 8.19: Percent Removal of E.coli With & Without Sand (MIT, Summer 2004)

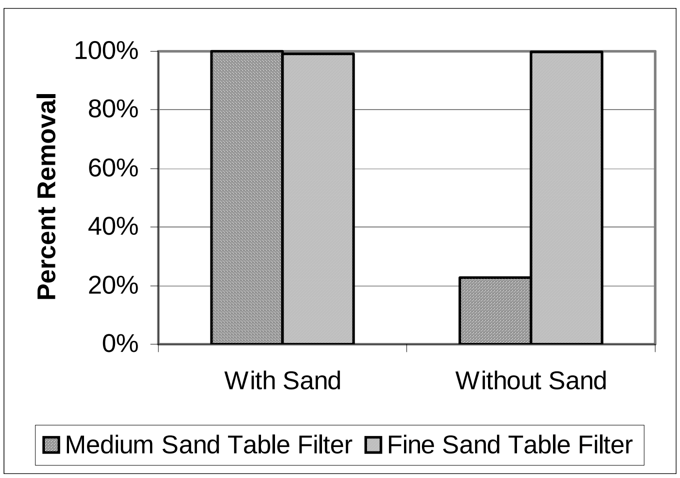


Figure 8.20: Percent Removal of TC With & Without Sand (MIT, Summer 2004)

8.2.2 Performance Tests at MIT

8.2.2.1 Turbidity

The average turbidity of the source water that was used on the days the Table Filters were tested in the lab during the spring was 8.1 NTU. Filtered water samples from the Medium Sand Table Filter had an average turbidity of 0.55 NTU, and those from the Fine Sand Table Filter had an average turbidity of 0.60 NTU. The average percent removal of turbidity was 90% for the MSTF and 91% for the FSTF.

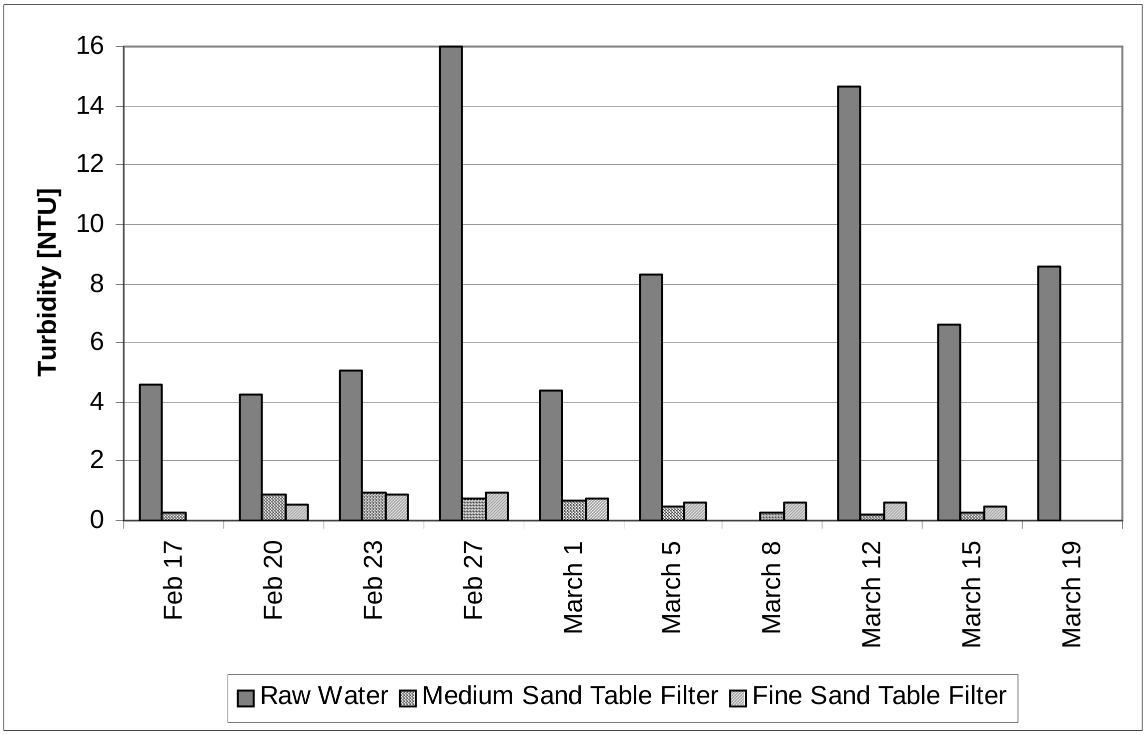


Figure 8.21: Turbidity Concentrations in Source and Table Filter Water (MIT, Spring 2004)

During the summer, the turbidity was measured once before the sand was removed, after which it was measured on four separate test days. The source water on the one day that water was tested while the filters still had sand was 75 NTU. The MSTF produced water with a turbidity of 0.95 NTU, which is 99% removal. The FSTF water was 2.0 NTU, a 97% removal.

When the average turbidity readings from the ten spring and summer test days are combined, the source water readings range from 4.3 to 75 NTU and average 15 NTU, which has a standard deviation of 22. The MSTF treated water ranged from 0.20 to 0.95 NTU and had an average of 0.60 NTU and a standard deviation of 0.3. The FSTF ranged from 0 to 2.0 NTU and averaged 0.75 NTU with a standard deviation of 0.5. The average percent removal of turbidity in the MIT lab was 91% by the MSTF (the LRV was 1.2) and 92% by the FSTF (with a LRV of 1.1).

After the sand and geotextiles were removed from the Table Filters, they showed slightly worse removal rates of turbidity during four days of tests. The source water during these tests ranged from 4.5 to 28 NTU, with an average of 19 NTU and a standard deviation of 10. The MSTF treated water ranged from 0.80 to 1.6 NTU and averaged 1.0 with a standard deviation of 0.3. The FSTF was very similar in that it ranged from 0.75 to 1.5 and averaged 1.1 with a standard deviation of 0.3. The MSTF without sand demonstrated 89% removal of turbidity with a 1.2 LRV. The FSTF showed 88% removal and a 1.2 LRV. A summary of the turbidity values of the water samples and percent removals by the Table Filters is presented in Table 8-6.

Table 8-6: Average Turbidity of Raw and Table Filter Treated Waters at MIT (Spring & Summer 2004)

Date	Average Turbidity [NTU]			% Removal	
	Raw Water	MSTF	FSTF	MSTF	FSTF
Feb 17	4.6	0.30	0.00	93%	100%
Feb 20	4.3	0.90	0.55	79%	87%
Feb 23	5.1	0.95	0.85	81%	83%
Feb 27	16	0.80	0.95	95%	94%
March 1	4.4	0.65	0.75	85%	83%
March 5	8.3	0.45	0.60	95%	93%
March 8		0.30	0.60		
March 12	15	0.20	0.60	99%	96%
March 15	6.6	0.30	0.50	95%	92%
March 19	8.6				
June 22	75	0.95	2.0	99%	97%
Average	**15**	**0.60**	**0.75**	**91%**	**92%**
(sand removed)					
June 28	22	0.80	0.75	96%	97%
June 30	4.5	1.6	1.5	65%	66%
July 1	28	0.95	1.1	97%	96%
July 2	23	0.90	1.1	96%	95%
Average	**19**	**1.1**	**1.1**	**89%**	**88%**

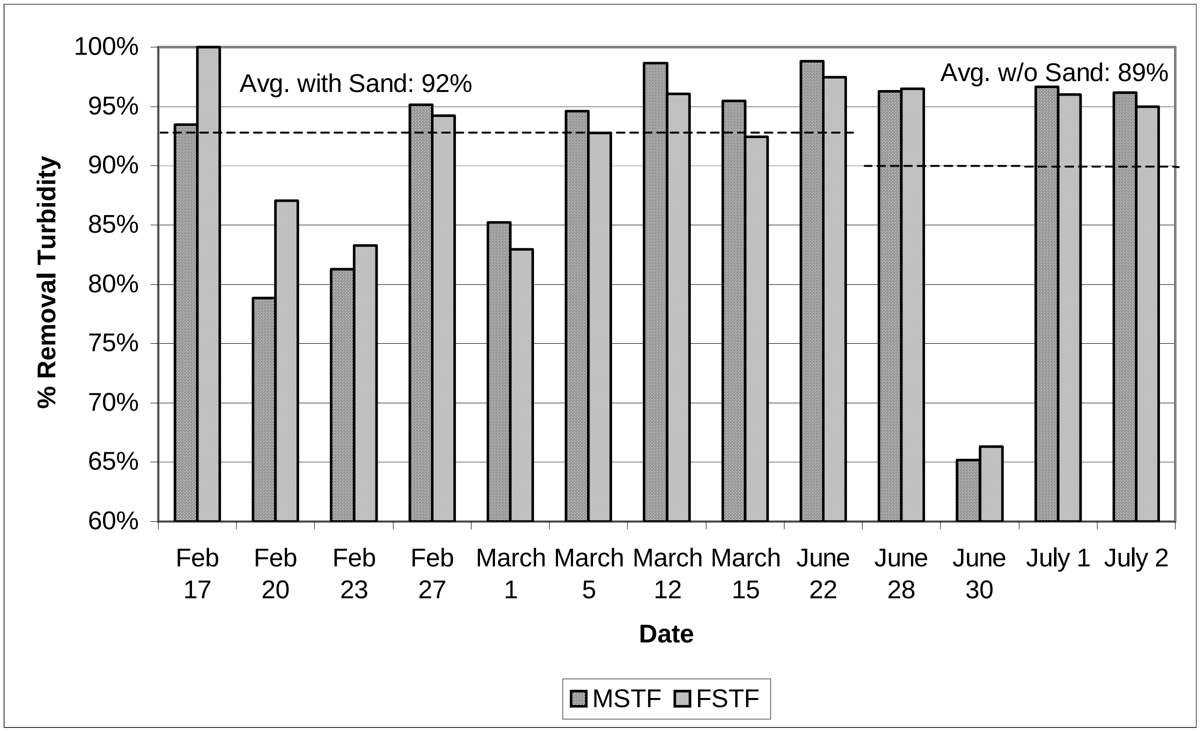


Figure 8.22: Turbidity Removal by the MSTF & FSTF With and Without Sand (MIT, Spring & Summer 2004)

While these removal rates are less than those seen in the Table Filters *with* sand, the "t-test" shows a 76% chance for the MSTF and 69% chance for the FSTF that the percent removals without sand come from the same distribution as the filters with sand. Therefore, the difference in percent removal seen in these tests is not statistically significant.

8.2.2.2 Flow Rate

The flow rate measured toward the end of the summer testing and shortly before the sand was removed from the filters was 1.0 L/hr in the Medium Sand Filter and 0.8 L/hr in the Fine Sand Filter. Table 8-7 shows the flow rates before and after the sand was removed from the filters. The flow rates of the TFs experienced a sharp increase after the geotextile and sand were removed from the filters and the candles were lightly scrubbed with a paper towel. The flow rate then quickly decreased over time as source water clogged the candle pores more quickly without the pre-filtering sand in place. The average flow rate of the two measurements after the sand was removed was 4.0 L/hr in the Medium Sand Table Filter and 4.1 L/hr in the Fine Sand Table Filter.

Table 8-7: Table Filter Flow Rate Before & After Sand was Removed (MIT, Summer 2004)

Date	Flow Rate [L/hr]	
	MSTF	FSTF
22-Jun	1.0	0.8
Sand removed		
30-Jun	7.1	6.7
2-Jul	0.8	1.5
Avg. (no sand)	**4.0**	**4.1**

While sand was still present in the Table Filters, they were generally observed to filter 5 L within a few hours. (Five liters were added to each TF for testing, and at least 2 L had generally filtered through within an hour, allowing the treated water to be tested the same day.) After the sand and geotexile were removed from the Table Filters, they were filled with 3 L of source water each, but drained extremely slowly. The author decided to wait until the next day to test the water in order to give the filters time to drain. After 24 hours, only about 1 L of source water had drained through the filters, as mentioned in Section 7.2.2.

The next day, the ceramic candles were lightly scrubbed with a paper towel, and 5 L of Charles River water was added to each filter. This time the flow rate was much faster, but both filters almost stopped flowing again when about 2 L remained in their upper buckets. As mentioned in Section 7.2.2, it was speculated that more than 2 L in the upper bucket were needed to maintain a higher flow rate with the Pozzani candles.

This sensitivity of the flow rate was noticed only with the candles alone, and not with the complete Table Filters, probably because in the latter case, the sand helps elevate the water and creates a higher pressure. The sand also transports small amounts of water to flow into every portion of the ceramic candle. Without sand present, 1-2 L of water have very little space to flow into the side of the candle, since the Pozzani design includes a plastic lip on the bottom half inch of the candle (see Figure 4.3 in Section 4.3).

8.3 Interviews

8.3.1 General Questions

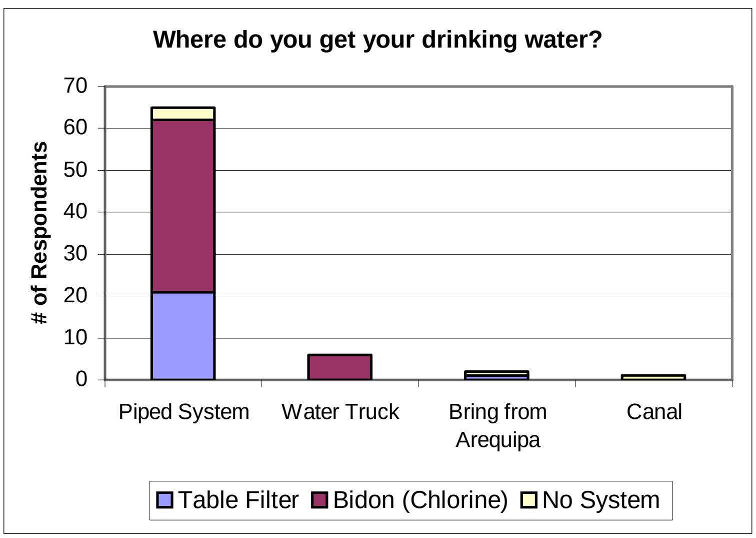
Of the 74 households or individuals interviewed, 22 had a Table Filter, 47 had a Safe Water System, and 5 had neither of those treatment systems. The households that were interviewed had an average of 5.4 people, including an average of 1.3 children under the age of 5, the ages most susceptible to water-borne diseases. To get a feel for their standard of living, those interviewed were asked how much money they spend each month on everything they need. The 74 households interviewed spent an average of S/ 341 per month on all expenses; although, the 69 households who had received the water treatment systems for free spent about S/ 325 per month.

This is equal to approximately $93 per month for the entire household (which averaged 5.4 people), which boils down to about $0.56 per person per day. All the households had electricity, and they reported on average that they spent S/ 23 (about $6.6) per month to receive electricity.

All 30 of those interviewed in March were from Cerrito Buena Vista. Surveys in January were conducted in both regions where the treatment programs were implemented: Arequipa and Tacna. In addition to CBV (where both TF and SWS were located), interviews in Arequipa took place in the towns of La Joya (no systems), Villa Hermosa de San Isidro (TF), and San Luis La Cano (TF). In Tacna, respondents lived in the towns of Valles Verdes (TF), Miculla (SWS), and Caleta Vila Vila (SWS).

8.3.1.1 Water Supply

88% of the households interviewed, including almost all the residents of Cerrito Buena Vista, received their water into their household compound, typically located in their yard, through a piped system from their town's reservoir or small water treatment plant. All of those interviewed who lived in Caleta Vila Vila – 8% of the total interviewed – bought their water from a water truck. Two households (3%) brought their water from Arequipa, and one household drew its water from a canal.



8.3.1.2 Water Treatment

Each person was asked if and how they treated their water before receiving a treatment system, or how they currently treated their water if they had no system. Several households combined settling the water in a tank before boiling it or adding *lejia* to it. *Lejia* is the Spanish word for commercially-available liquid chlorine solution. The engineers at CEPIS said that *lejia* is usually a 6% solution of sodium chloride, but its use as a disinfectant is discouraged because its concentration is not standardized. Of the 64 people who answered this question about treating their water, 61% boiled their water, 33% added *lejia*, 27% allowed it to settle, and 8% said they did nothing to their water.

8.3.2 System Usage

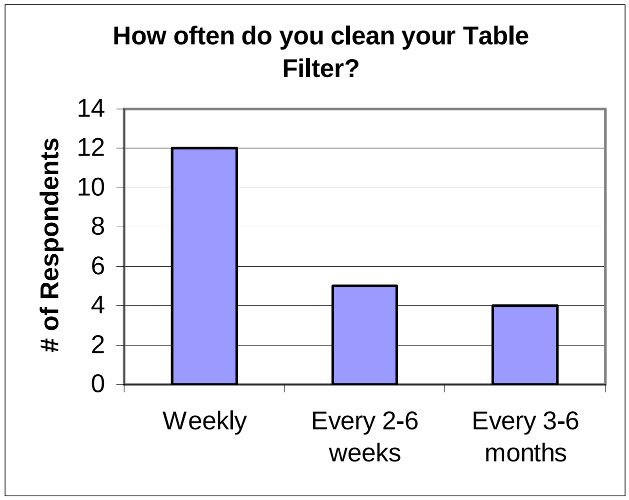
8.3.2.1 Water Quantity Used

Of the 69 people interviewed who had a Table Filter or *bidon*, 57% said they used more water after than before they had the treatment system, and only 1% said they used less. The other 42% said they used approximately the same amount of water as before. It is interesting to note that 66% of people with *bidones* said they drink more water now that they treat it with a chlorine solution, while only 36% of those with filters said they drink more water now.

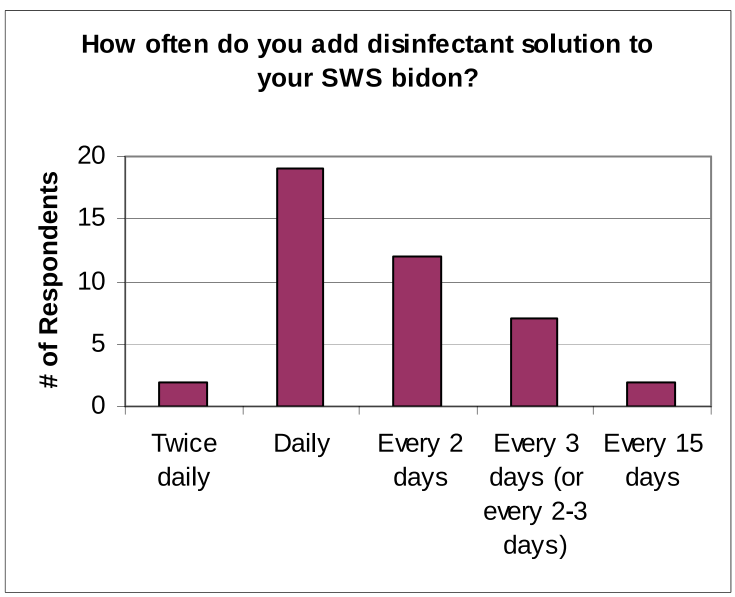
8.3.2.2 Beverage Consumption Away From Home

62% of people with water treatment systems said they never drink untreated water. However, when asked what they drink when away from home, 13% said they drink soda, 28% drink water, and 66% drink *chicha*. *Chicha* is a Peruvian drink made from corn and water. Because of the beverages that are consumed while away from home, the number of people who drink untreated water is probably higher than reported. This is discussed further in the discussion Section 9.3.2.

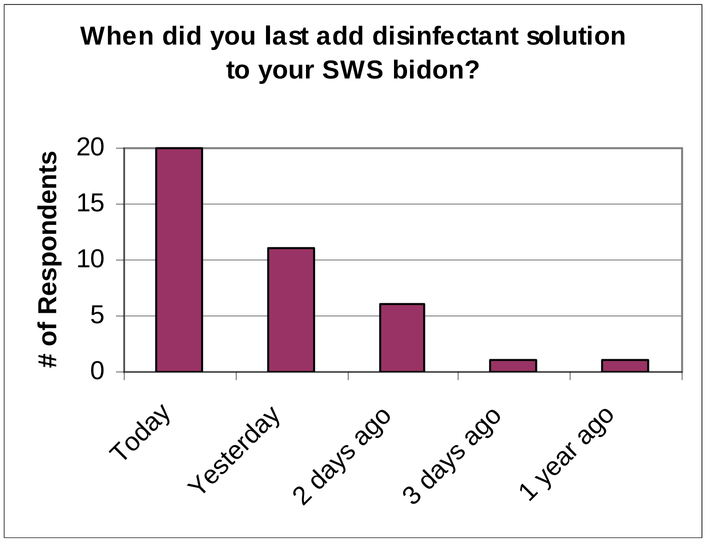
When asked how often the families clean their Table Filters, the answers varied widely, based on location. In January, answers ranged from “weekly” to “every six months,” with the average being every 60 days, or about once every two months. (The average cleaning frequency time was calculated by averaging the number of days that families allowed between cleanings, setting “weekly” equal to 7 days and “monthly” equal to 30.5 days.) In March, every respondent answered “weekly,” thus the average frequency of cleaning their Table Filters was every 7 days, or “weekly.” All households interviewed in March were located in the town of Cerrito Buena Vista. Only one of the households from January were in CBV, and they answered “weekly.” This means that every one of the 11 households that responded from CBV reported that they cleaned their Table Filter weekly. The average number of days between cleanings reported by all the towns other than CBV was 65 days, indicating that CBV residents clean their Table Filters much more frequently than other towns.



Households with Safe Water Systems were asked how often they treat their water by adding "*chloro*" (the local term for the disinfectant solution), as well as when was the last time they had added it to their SWS *bidon*. 45% of the respondents answered that they treat their water every day. Another 45% reported that they treat it every two or three days. Two of the 42 respondents add *chloro* to their water twice a day, and two said they only treat it twice a month. The average treatment frequency of all respondents was every 2.2 days.



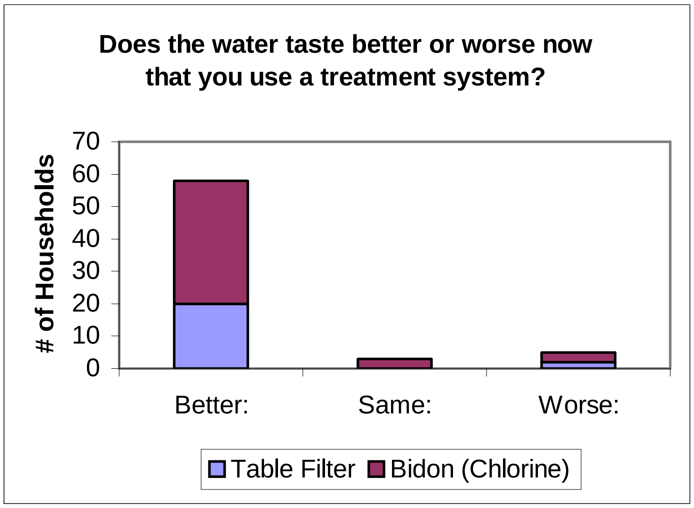
When asked when SWS users last treated their water, 51% of those who responded said "today," and another 28% said "yesterday."



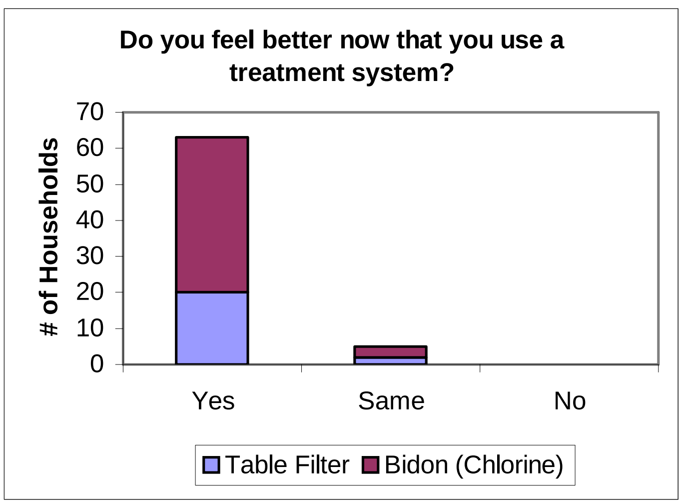
When calculating the average number of days since users had last treated their water, the value of zero was assigned to the response "today." Also, one user said the last time she had treated her water with *chloro* was "one year ago," so it can be safely assumed that she was not using the Safe Water System. Of the 41 people who were currently using the SWS, the average was 0.7 days (or somewhere between "yesterday" and "today") since the users had last treated their water with the disinfection solution.

8.3.3 User Satisfaction

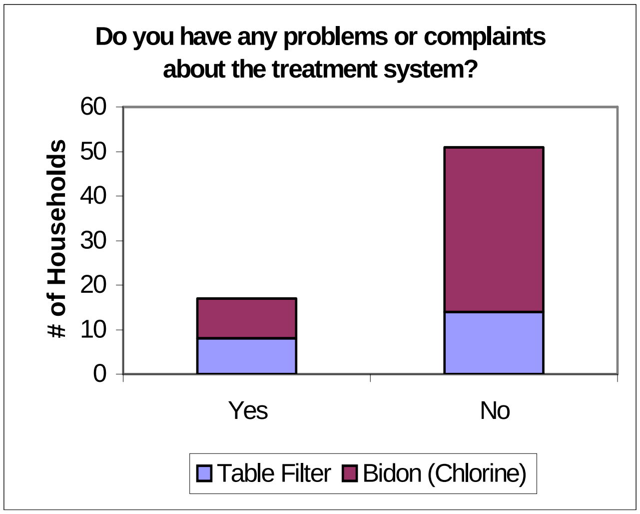
When asked if their water tastes better or worse now that they use either a Table Filter or the SWS, 88% of the 66 people who answered said it tastes better (91% of those with Table Filters and 86% of those with *bidones*). 5% said it tastes the same and 8% said it tastes worse. (9% of those with Table Filters and 7% of those with *bidones* said their water tastes worse now.)



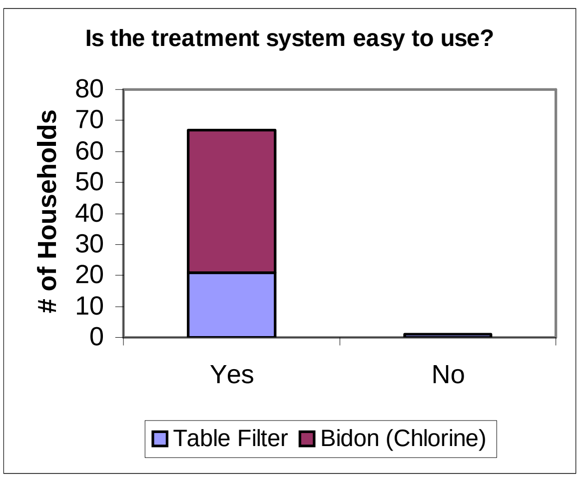
When asked if they feel better physically since using the system, 93% said yes. The other 7% said they feel the same as before.

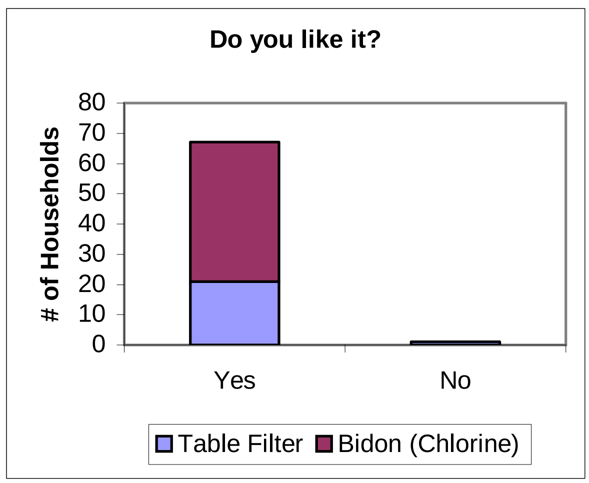


25% said they had complaints or problems with their system. 36% of those with Table Filters had problems or complaints while only 20% of those with *bidones* reported any. 30% of HWTS owners from Arequipa voiced complaints, compared to only 7% of those interviewed from Tacna. Two of the 22 people with Filters and 7 of the 47 people with *bidones* (53% of those who reported problems) complained of problems with the spigot: broken, hard to turn, or produces a slow flow. Three Filters and two *bidones* (29% of the complaints) were reported as being "too small" or not producing enough water. However, 91% of the 22 Table Filter owners said that it did produce enough water for their family. Other people complained of the water having a bad taste or of the filter being difficult to wash.



100% of those interviewed said they believed using the system was beneficial for their family. Only 1 out of 68 people said the system was not easy to use, and 1 other person said they did not like it. Both of these people owned Table Filters; every one of the *bidon* owners said it was easy to use and they liked it.

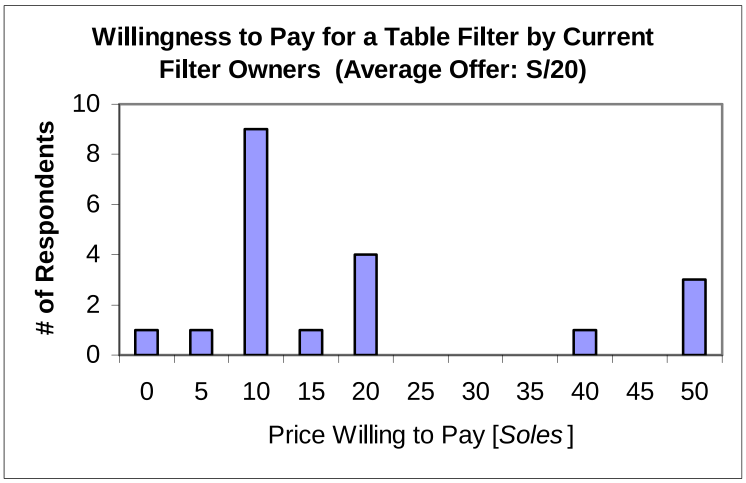




8.3.4 Willingness to Pay

8.3.4.1 Table Filters

At the time of research, the exchange rate was 3.5 Peruvian *soles* (S/) to one U.S. dollar. The Table Filter cost about S/ 40, or $11, for CEPIS to construct. Filter owners were asked the following question: "Imagine that your filter is broken and filters are no longer distributed for free. Would you buy a new one, and if so, how much would you be willing to pay for it?" 91% of respondents said they would be willing to pay for a filter. The average price offered was S/ 20, and offers ranged from S/ 5 to S/ 50.



Filter owners were then asked, "Would it be better if the filters were [paid for by way of] monthly payments? If so, how much should the monthly payment be?" 72% of the 18 respondents said that monthly payments would be better. S/ 7.6 was the average monthly cost that they would be willing to pay. The monthly payment suggestions ranged from S/ 2 to S/ 20.

Filter owners were also asked how much they thought the Table Filter cost. S/ 42 was the average of the 20 answers, which ranged from S/ 10 to S/ 100.

8.3.4.2 Safe Water System

SWS *bidon* owners were asked similar questions to find their willingness to pay for a new *bidon* (plastic container with spigot for safe water storage) and for a bottle of chlorine solution that would last the family one month. Only 73% of current *bidon* owners said they would be willing to pay for a new one if they lost their current one. S/ 12 was the average offer, although they ranged from S/ 5 to S/ 20. The SWS *bidones* actually cost about $6 each, or S/ 21 (Cerilles, 2004).

93% of *bidon* owners said they would pay for a bottle of "disinfection solution." The average offer for one bottle of solution was S/ 2.0. It is interesting to note that the *bidon* owners interviewed in January were willing to pay S/ 0.5 to S/ 15, giving an average of S/ 6.5, while those interviewed in March offered S/ 0.2 to S/ 0.5, with an average of S/ 0.3. The actual cost of a disinfection bottle is about $0.30, or S/ 1, according to the business students involved in this trip, and it costs about $0.25 to produce enough disinfection solution to refill one bottle (Cerilles, 2004).

8.3.4.3 Households Currently Without a Treatment System

Three people were interviewed who had neither a Table Filter nor a *bidon*. They were asked how much they would be willing to pay for a water treatment system, and the average price was S/ 40.

Table 8-8: Average Willingness to Pay for Different Water Treatment Systems (Peru, 2004)

Average Willingness to Pay:	***Soles***	**Actual Cost**
For a Filter by Current Filter Owners	20	40
For a *Bidon* by Current *Bidon* Owners	12	21
For Chlorine Solution by *Bidon* Owners	2	1
For any System by Non-Owners	40	n/a

8.4 Field Observations

8.4.1 Arequipa

Additional observations about the households with HWTSs are listed in the description of the study site in Section 3.3.4.1.

One problem with the Table Filters was that green algae often was observed growing inside the sand and occasionally in the corners of and around the spigot of the treated-water holding bucket. Many spigots were also broken, leading to frustration by the users. While some people created makeshift spigots or stoppers, others discontinued use of their filter while they awaited a new spigot from the health post. All of the filters contained less sand than the specification that the local staff gave to us, but still more than enough to cover the ceramic candles. The washing process, which is required for appropriate maintenance of the filters, causes sand loss, little by little, throughout the filter's life.

One problem that was noticed with the SWS *bidones* was that they lack a handle for easy transport. These *bidones* hold twenty liters, which would be hard enough to carry or move even if a handle was present. The author witnessed a couple people take off the top lid and carry the SWS *bidon* by sticking their hand inside and holding on to the upper rim. This practice allows for recontamination of the chlorinated water. Safe storage practices require that the introduction of anything besides chlorine into the water inside of the container be avoided at all times. This could result in an increase in the amount of contamination in the drinking water.

Also, it is unclear as to whether the amount of chlorine generation in La Joya is sufficient for the number of households that must be served. Several people whom the H_2O-1B! team visited in the town of CBV reported that they were not currently using their SWS *bidon* because the health post was out of *chloro*. As explained in Section 5.3.1, with two production cycles per month, the chlorine-generation system in La Joya could produce 320 bottles of chlorine solution per month. This is not enough to supply all 400 households with 250-ml bottles, which presumably last one month. As observed in La Joya, the production cycles are generally run at less than full capacity, producing 132 bottles per cycle, and sometime these cycles were run only once a month.

8.4.1.1 "Willingness to Pay Auction"

At the auction/workshop that was held in La Cano, residents who currently owned an HWTS were asked for their feedback on the system. They complained that the spigots and candles break easily and that the Table Filters clog (while the latter may be true, it also may be that the TF flow rate is too slow for their liking).

People in the meeting were asked to raise their hands if they would be willing to purchase each HWTS at a stated price. The price started low and then was raised slowly until no one left was willing to pay it. Table 8-9 shows the prices asked for each HWTS and the number of people out of the 41 people at the meeting who were willing to pay it.

Table 8-9: Number of People Who Were Willing to Pay Each Price for Each HWTS at the La Cano "Auction"

Price	Table Filter	SWS
Free	41	41
S/ 1	41	41
S/ 2	n/a	2
S/ 3	5	0
S/ 5	3	n/a
S/ 6	0	n/a

The highest bid for the Table Filter was S/ 5, or about $1.40, compared to the S/ 40 that the materials cost. The Table Filter was sold to the one person who bid S/ 5 and was actually willing to pay it.

Figure 8.23: Begazo Explaining the Use of an HWTS to a La Cano Resident

8.4.2 Tacna

There are fewer field observations from Tacna because considerably less time was spent there than in Arequipa. According to a conversation with the Director of the Ministry of Health in Tacna, their technicians/monitors visit all of the Table Filter households each month to monitor their use. They seemed very systematic about their monitoring as they had sheets that needed to be filled out during the monitoring visits. These record sheets were kept on file in Tacna. They reported only about 6 to 7 broken spigots and no broken candles, an apparent improvement from the reports and complaints in Arequipa. Only 7% of those interviewed from Tacna voiced complaints about their Table Filters, while 30% of HWTS owners in Arequipa complained of problems with their system.

9. Discussion of Results

9.1 Field Tests in Peru

9.1.1 Microbial Tests in Peru

9.1.1.1 Membrane Filtration

9.1.1.1.1 Positive Blank Tests
As discussed in Section 7.1.4.2.9, blank tests are performed to ensure that the blank water used in testing, as well as the equipment and test procedures, do not add contamination to the MF coliform tests. When blank tests are positive (i.e. they contain coliform CFU), it indicates that the blank water, equipment, or procedures are not sterile. Some of the blank tests in this study were positive for coliform. Positive blank tests occurred on January 15, when the Millipore filter holder resulted in 2 E.coli CFU/100ml and a total of 3 TC CFU/100ml (including both red and blue colonies, i.e. this includes the E.coli colonies) and the Del Agua filter holder produced 3 E.coli CFU/100ml and a total of 12 TC CFU/100ml. January 16 showed 1 E.coli CFU/100ml on the blank test. The blank test on January 18 had 3 E.coli CFU/100ml and 4 TC CFU/100ml. Blank tests during March 2004 in Peru were performed but not reported by Longhi, so it is assumed that these were all negative for coliform contamination.

Also, positive blank tests in the laboratory at MIT included 1 E.coli CFU/100ml on June 24, and 1 TTC CFU/100ml on June 28. All other blank tests using m-FC and mColiBlue-24 broth tested negative for coliform. Some blank tests using HPC broth were positive, but this is discussed separately in Section 9.2.1.3.

When coliform colonies are found on blank tests, the results from the remaining tests during that day of testing are not adjusted in any way (Pecchia, 2004), since the contamination may not have occurred in any subsequent test (e.g. the contamination could have been due to unsterilized tweezers which were later sterilized). Also, not subtracting any CFU from subsequent tests due to positive blank tests errs on the side of caution when analyzing drinking water. If anything, it overestimates the contamination in the water, causing additional precautions to be made before the water is considered safe for drinking.

9.1.1.1.2 Source Waters
The average E.coli concentration in raw water before being filtered was 5.3×10^2 CFU/100ml, as measured in three Table Filters. Fourteen Table Filters were tested successfully for TC in March and showed an average of 3.5×10^3 CFU/100ml in raw water.

The average raw water of nine SWS *bidones* had a concentration of 4.5×10^3 E.coli CFU/100ml. Thirty-three households with SWS *bidones* used raw water with an average of 2.1×10^4 TC CFU/100ml.

These concentration levels were on average one to two orders of magnitude higher than had previously been recorded in studies of other countries done by previous students of the same MIT program. Because the presence of coliform was so high in the source waters measured in Peru, the Membrane Filtration procedure was much more complicated to perform. It required many tests to determine the correct range of dilution needed for valid colony counts both for untreated and treated water, and even once that range was found, the results varied greatly so that multiple dilutions needed to be performed on each water sample. This caused many of the colony counts to fall outside of the target range so that some results were determined to be *invalid* (i.e. outside of the valid range as described in Section 7.1.3.1) and others were accepted with reservations (e.g. counts under 20 CFU/plate). The treatment of data is described in Section 7.1.3.1. While the author has attempted to present the data in a reasonable and representative way, the microbial data sets that were used can be found in Appendices F, G, H, and L so that other interpretations can be made.

9.1.1.1.3 Table Filters

As stated in Section 2.4.1.4 of this thesis, the WHO recommended guidelines for coliform indicators state that E.coli "must not be detectable in any 100-ml sample" of drinking water because they indicate the presence of fecal pollution (WHO, 2004). This guideline value was not reached by the Table Filters: treated water from Table Filters showed an average of 2 E.coli CFU/100ml. All five of the tests with valid data that were used in this average involved filtering only 20 or 50 ml of sample water. If a full 100 ml had been used, the E.coli count *may* have been higher.

Although 100-ml tests are standard for drinking water, sometimes tests of lower volume were conducted when the CFU/100ml count was guessed to be higher than appropriate for 100-ml MF tests. Unfortunately, the researcher must predict an appropriate volume of water to be tested so that the CFU per Petri dish will fall in the target range of 20-80. This prediction may be made based on prior tests performed on similar water samples, but it cannot be known if the appropriate volume was used until after the test has finished, 24 hours later. For this reason, tests of several different volumes or dilutions were often performed, but even this did not always guarantee that results within the desired range would be found. Also, when mColiBlue broth is used, the upper CFU count is targeted for TC, which is generally one or two orders of magnitude larger than the E.coli CFU count. This means that when TC is in the correct range, the E.coli count is generally between zero to five. Since this is below 20, the E.coli counts may not be a very accurate representation of the state of the water, especially when volumes of less than 100 ml were used. For this reason, the author speculates that *TTC MF tests may actually be better indicators of fecal contamination than E.coli MF tests*, not because the TTC bacteria itself is a better indicator but because the only MF broth which is currently available to test for E.coli (mColiBlue) gives preference to *total coliform* detection.

The average of 2 E.coli CFU/100ml in treated water samples includes only *three* Table Filters, which is not a very reliable indicator of the state of all 700 Table Filters distributed in Peru.

While the *Guidelines* state that "immediate investigative action must be taken if E.coli are detected," they also leave room for *intermediate* relaxed standards for areas where fecal contamination is widespread and where excellent, high-end water treatment is not affordable

(WHO, 2004). Since this is the case in the program site in Peru, these intermediate standards should be set and used as mid-term goals for treated waters.

While they were not perfect, the Table Filters were effective in dramatically reducing contamination in the water. They removed approximately 99% of E.coli and 98% of TC.

While E.coli is considered to be the superior indicator, it was necessary to perform most of the tests in Peru with Lauryl Sulfate, prepared from a powder, which tests for the presence of TC. Because of this, only 3 Table Filters gave valid results for E.coli concentration, but 14 different Table Filters are included in the TC concentration average. For this reason, the TC data is probably more representative of most Table Filters in La Joya. Total coliform (TC) is not an accepted indicator of fecal contamination or even "the sanitary quality of water supplies," but it can give an idea of the general cleanliness of the water (WHO, 2004).

9.1.1.1.4 SWS Bidones

The SWS *bidones* showed similar results. The treated water from SWS *bidones* that were tested for E.coli contained an average of 1 E.coli CFU/100ml and an average of 99.6% removal. Since the water from only 5 households contributed to the 99.6% removal, the actual average removal, or concentration, of E.coli from the 400 SWS *bidones* distributed throughout La Joya could be fairly different. The LRV of 2.8 did indicate that the SWS was slightly better at removing E.coli than the Table Filter's 2.3 LRV.

The volume size of the tests may have produced a lower average E.coli concentration than is representative of the true state of the SWS *bidones*. The tests included in this average ranged from 1 to 100 ml, so although no E.coli CFU may have been found in a 1-ml or 20-ml test, it might have been found if 100 ml had been tested directly.

The 29 SWS *bidones* tested for TC showed an average of $1.5\text{x}10^2$ TTC CFU/100ml and 95% removal. Again, the larger sample size may make the TC data a better representation of the actual effectiveness of the household chlorination system. This relatively low removal rate of 95% could partially be due to the presence of turbidity in the water. The WHO *Guidelines* state that disinfectants work best when the turbidity is less than or equal to 0.1 NTU (WHO, 2004). The average turbidity of the 26 SWS *bidones* that are included in the 95% TC removal calculation have an average turbidity of 25 NTU. Although it cannot be wholly due to turbidity concentrations, however, because the SWS *bidon* with the lowest percent removal of TC:[47] 13%, had a turbidity of 11 NTU, while a different SWS *bidon*[48] was measured with 270 NTU turbidity and achieved a 99% removal of TC. Another explanation for the low percent removal of TC could be that SWS *bidon* users need to put more chlorine in their water. We do not know whether they are putting the prescribed amount of chlorine into their water, but we do know that the chlorine residual concentration found in households is almost uniformly too low. The average free chlorine residual concentration of 24 of the 26 SWS *bidones* that are included in the 95% TC removal calculation is 0.19 mg/L and all but 6 of them contained water below 0.2 mg/L. Chlorine residual and turbidity will be discussed further in later sections.

[47] CBV house L-1
[48] CBV house A'-5B

As with the Table Filters, these data indicate that *the household chlorination procedure does not reach the high guidelines set by the WHO, but does inactivate a considerable amount of pathogenic bacteria.*

9.1.1.1.5 Water Treatment Plants

During January, water treatment plants at Cerrito Buena Vista and El Triunfo were each tested for E.coli and TC on a single day. During March, the two WTPs were tested for TC on two different visits each.

At the CBV plant, samples were collected at three different "stages," the last of which was most representative of the water delivered through the town's distribution system. The "Stage 3" (or "output") coliform concentrations were on average 1.5×10^4 E.coli CFU/100ml and 4.4×10^4 TC CFU/100ml. The E.coli concentration from January is four orders of magnitude larger than the concentrations resulting from treatment by Table Filters or household chlorination, and the TC concentrations are two and three orders of magnitude larger than those treated by the household-level methods. In fact, the CBV WTP removed only 92% E.coli, while the Table Filter and SWS removed an average of 99% and 99.6% E.coli, respectively. *This indicates that the household treatment systems are much more effective at pathogen removal than the CBV water treatment plant.*

During one day of testing in March, the CBV WTP showed 79% removal of TC, but the other day's tests resulted in a –944% removal of TC. This negative removal was probably most affected by the abnormally low TC concentration in the raw water of 4.5×10^3 CFU/100ml (compared to 2.9×10^5 TC CFU/100ml earlier in March and 3.0×10^5 TC CFU/100ml in January). Why this sample's concentration was so low is unclear. It could have been due to human error in testing or recording data, or could have been caused by the settling tank mechanics, such that the sample skimmed off the top of the initial settling tank was not representative of the water continuing through the rest of the WTP, where perhaps any pollution was well-mixed and present at the surface of the final sampling point. If the first two days of testing, which showed 92% and 79% removals, are considered to be the "best case scenario," they can be compared to the 98% and 95% removal of TC due to Table Filters and household chlorination, which affirms that household treatment systems are more effective than the CBV WTP.

The concentration of the water "treated" by the CBV WTP is one and two orders of magnitude larger for E.coli, and about four times larger but on the same order of magnitude for TTC, than the "raw water" that was used by households with Table Filters and SWS *bidones*. All the households that were tested using the Membrane Filtration technique are located in the town of CBV. This would suggest that *the contamination levels of the water decrease somewhere between leaving the CBV WTP and actual household usage*. The reasons for this decrease could be many things: there may be some die-off in the distribution pipes; the chlorine added at the final stage of the plant has, by that point, more time to inactivate the pathogens present in the water; many people allow their water to settle in large concrete water tanks before using it, which helps remove contamination; some people have created their own pre-treatment devices; or the water measured at the final stage of the treatment plant may not actually be representative of the water being delivered to the town.

The El Triunfo WTP was being cleaned during the January visit, so that the filtering sand beds and final settling tank were not in use. The water was therefore collected just after chlorination and before it was released through the distribution system to the community. “Raw water” was sampled in the “inflow channel” at the entrance to the main section of the WTP but after being routed through several pre-settling tanks. Finally, a water sample was collected from the final settling tank with the understanding that this water had sat in the tank for longer than usual and was not being sent through the distribution system at that time. In March, samples were taken at the “input” and “output” of the plant, and probably most closely correspond to the waters from the “Inflow Channel” and “Post-Chlorination” stages. For more details on the layout of the El Triunfo WTP, see Section 6.2.

In January, the El Triunfo WTP showed 99.7% removal and 3.0×10^2 E.coli CFU/100ml concentration of treated water (which had only gone through half of the treatment plant due to cleaning at that time). While the concentration is two orders of magnitude higher than the average 2 and 1 E.coli CFU/100ml measured in Table Filters and SWS *bidones*, respectively, the removal efficacy of the WTP is slightly higher than the 99% and 99.6% removals caused by the household treatment systems, respectively. This is due to the fact that the raw water from the inflow channel of the treatment plant was two and three orders of magnitude higher than the raw water fed to the household treatment systems in CBV. The 93% removal of TC at the WTP was slightly lower than the 98% and 95% caused by Table Filters and household chlorination, respectively.

While the El Triunfo WTP seems to be much more effective at water treatment than the CBV plant, neither one compares to the high level of treatment demonstrated by the Table Filter and SWS chlorination program.

9.1.1.2 H_2S P/A

The ten concurrent, split-sample P/A and MF E.coli tests in Peru indicate that a “presence of H_2S” result does not necessarily indicate the presence of fecal contamination, nor does an “absence of H_2S” result accurately reflect the *absence* of fecal contamination. In Table 9-1, the P/A test results are compared to E.coli concentration, which is supposed to be the most reliable indicator of fecal contamination.

Table 9-1: Comparison of E.coli and H_2S P/A Test Results (Peru, Jan. 2004)

Source / House ID	Sample Description	E.coli CFU/100ml	H_2S P/A
CBV H-12	SWS *Bidon*	< 1	A
CBV E-3	SWS *Bidon*	< 1	A
CBV B-11	SWS *Bidon*	< 1	A
La Joya Hospital	Tap	4.5×10^1	A
CBV E-3	Household Tap	5.0×10^3	P
La Joya Canal	Canal	8.5×10^3	P
CBV LL-18	SWS *Bidon*	2	P
CBV LL-27	SWS *Bidon*	< 1	P
CBV I-1	SWS *Bidon*	< 1	P
CBV LL-11	SWS *Bidon*	5	P

As explained in the methods section about H_2S P/A tests, a positive result should indicate the presence of fecal contamination but can sometimes be caused by other substances present in the water. The H_2S P/A test method is reported, however, to err on the side of caution by giving false positives but generally not false negatives (indicating that the water is safe to drink when it is not). So it is important to note that some of these tests did actually result in false negatives, which *do not* err on the side of caution. Only 20 ml of each water sample was tested at a time for E.coli from three of the SWS *bidones* listed as having < 1 E.coli CFU/100ml, so while it can be assumed that the contamination level was very low, it cannot be concluded that fecal contamination was absent from the water. A 100-ml sample should have been tested for better accuracy.

Other possible reasons for the false negative results could be that the incubator was not warm enough to encourage the growth of H_2S-producing bacteria. The researchers did have some problems with the phase-change incubator losing heat because they did not know of the crucial step of whacking the incubator on the table in order for it to hold its heat for 24 hours.

9.1.2 Performance Tests in Peru

9.1.2.1 Turbidity

9.1.2.1.1 Table Filters

The Table Filters reduced the average turbidity of water to 2.4 NTU. All but 1 of the 14 Table Filter contained filtered water at or below the recommended WHO guideline of 5 NTU in order to be visually acceptable. The one Table Filter above 5 NTU,[49] was only as “high” as 5.5 NTU because the water had started out at 50 NTU, much higher than the average source water turbidity of 10 NTU. While the average percent removal of turbidity by the Table Filters was only 67%, this was adequate to bring the turbidity down to a level acceptable for drinking

[49] CBV house F-7

(although not acceptable if the water was to be post-chlorinated). The 11 Table Filters that were reported as "working" when they were tested showed an average 70% removal of turbidity. *The Table Filters have shown to be very effective at reducing the turbidity of water to the correct level.*

9.1.2.1.2 SWS Bidones

The average turbidity found in SWS *bidones* was 38 NTU, which is much higher than the recommended 5 NTU. It is two orders of magnitude higher than the 0.1 NTU guideline to allow for the most effective disinfection. As discussed in Section 5.1.1.3, this large amount of turbidity can interfere with the effectiveness of disinfection by chlorine. It is interesting to note that four of the 38 SWS *bidones* contained water with turbidity over 100 NTU. This was uncharacteristically high, and if the other 34 values are averaged, the result is only 9.8 NTU, which may be a more accurate indicator of the general turbidity level in most SWS *bidones*.

9.1.2.1.3 Water Treatment Plants

The CBV WTP reduced turbidity by only 22%. The "treated" water at the last stage of the plant showed an average of 50 NTU. This value is far too high above the 5 NTU guideline. The low average reduction of turbidity measured at the plant is especially concerning since settlement is the main treatment process at the CBV plant. *As long as there are high levels of turbidity and coliform coming from the WTP, it is important that the residents of CBV continue to treat their water through household treatment.*

The turbidity problem at the El Triunfo WTP is similar. The "treated" water had an average of 55 NTU, which again is much higher than the goal of 5 NTU for visual acceptability and 0.1 NTU for disinfection effectiveness. When analyzing the turbidity value, however, it is important to remember that, at least for the January measurement of 60 NTU and possibly for the March measurement of 55 NTU, the plant's sand bed filters were not working and so the sample was taken before being filtered. Under normal operation, the El Triunfo WTP may achieve higher turbidity removal than the 17% removal in January and the 49% *increase* in March.

* * *

It is interesting to note that the houses with HWTSs measured for turbidity, all of which were located in CBV, received water of lower average turbidity than was measured in the final stage of the CBV treatment plant. The average "raw water" turbidity measured at houses with an HWTS was 17 NTU, considerably lower than the average of 50 NTU measured in the final stage of the CBV WTP. It is possible that additional settling occurred at the plant between the point of sample collection and distribution to the town. Also, the average turbidity of source waters for Table Filters was only 10 NTU, which could indicate the settling of water in a household tank before adding it to the Table Filter as well as additional settling within the upper bucket of the filter such that water samples taken from the upper buckets of filters may not have included all the turbidity that the filters needed to remove but which had already settled down to the geotextile.

9.1.2.2 Chlorine Residual

Of the 37 SWS *bidones* tested in January and March, 70% contained less than the WHO's target concentration of 0.2 to 1.0 mg residual chlorine per liter of water. Figure 9.1 below shows the graph of all chlorine residual concentrations measured in Peru along with dark solid lines that indicate the goal concentration. The dashed line shows the overall average concentration.

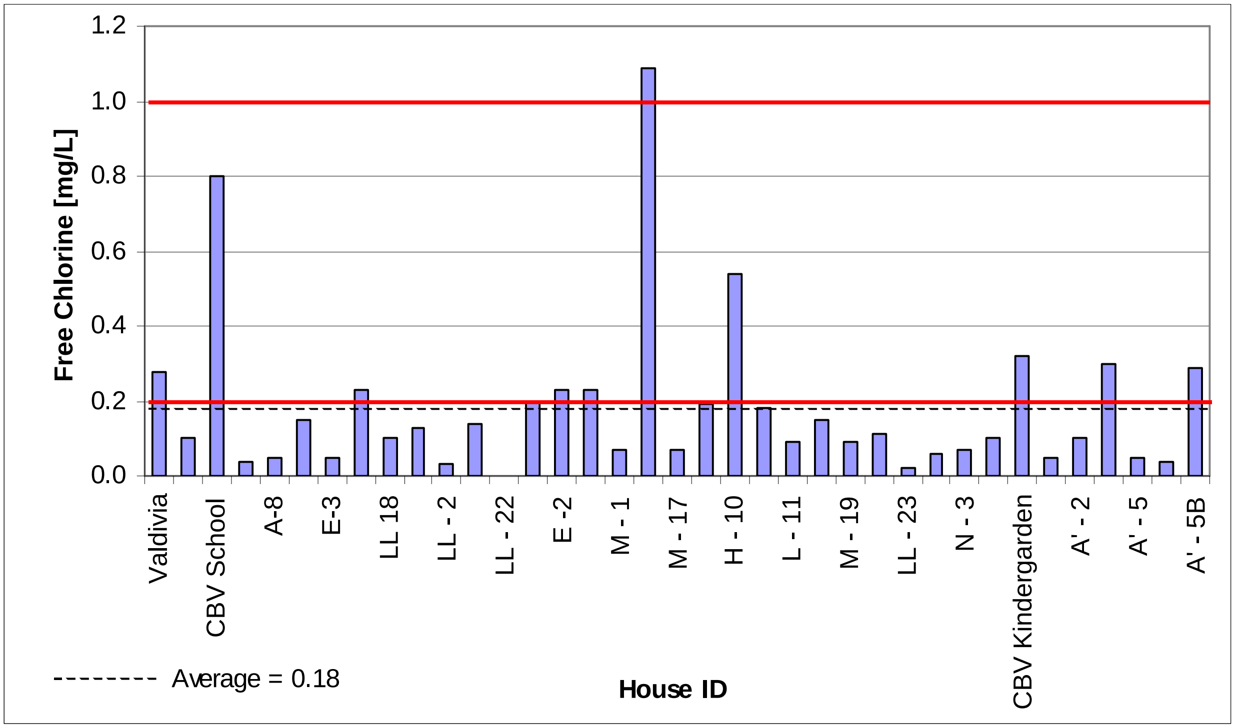


Figure 9.1: Free Chlorine Residual in SWS *Bidones* (Peru, 2004)

The WTPs had higher residual chlorine levels at 0.41 mg/L at CBV and 0.53 mg/L at El Triunfo, but these levels obviously did not last very long throughout the distribution system, because the level of chlorine residual was usually much lower than this even after SWS *bidones* users had added additional chlorine to their water.

9.1.2.3 Flow Rate

The average flow rate of the 16 Table Filters measured in Peru was 2.2 L/hr, with the 12 in Arequipa producing an average of 1.7 L/hr and the 4 in Tacna producing 3.8 L/hr. All but five of these filters produced a flow rate higher than the 1.5 L/hr that is quoted in the Table Filter operations manual (DGCI et al., 2003).

There was a relatively large variance in flow rates from 0.2 to 4.4 L/hr. Many things could have caused this wide spread of flow rates. Higher turbidity of the raw water used in the Table Filters could have caused the filters to become clogged quickly and slow the flow rate. (Turbidity was not measured from the same Table Filters tested for flow rate.) Those Table Filters that had been washed more recently before being measured would likely have faster flow rates than those that had not been washed for a longer time. The height of the sand above the filter's ceramic candles could affect how quickly they become clogged as additional sand may prevent more suspended particles from reaching the candles.

The differences in flow rate witnessed between the two regions of Arequipa and Tacna may be insignificant and due to random combinations of the reasons above (especially since only four Table Filters were tested in each location), or the contrast may indicate a critical difference in performance between the Table Filters in Arequipa and Tacna. Since all of the other tests performed in this study occurred in Arequipa and we do not have information about the effectiveness of the Table Filters from Tacna, it would be interesting to run microbial tests in Tacna to see if the results are comparable to those found in Arequipa. If consistent differences are detected, there may be an opportunity for one region to learn from the other's practices. The two regions use sand that is from two different river beds (local to each program site). Perhaps the differences in the sand affect the efficacy of the Table Filters even though they were sifted through the same sizes of mesh. Alternatively, Table Filter users in Tacna may have been instructed to clean their filters more often or in a more thorough way, or perhaps the raw water collected in the Tacna communities is less turbid than that found in the La Joya area.

It may be assumed that a faster flow rate is "better," but it is also possible that a slower flow rate is better, as the water may have a chance to be more thoroughly purged of turbidity and microbes.

9.2 Laboratory Tests at MIT

9.2.1 Microbial Tests at MIT

9.2.1.1 Thermotolerant Coliform

At the MIT laboratory, two different versions of the Table Filter were analyzed: the Medium Sand Table Filter and the Fine Sand Table Filter.

During the spring testing period, the Medium Sand Table Filter reduced raw water with 2.0×10^4 TTC CFU/100ml down to 7.2×10^1 TTC CFU/100ml, and the Fine Sand Table Filter brought it down to 4.3×10^2 TTC CFU/100ml. The Table Filters removed an average of 98% and 97% TTC respectively, which is a large majority of the contamination, but which does not reach anywhere near the suggested WHO guidelines of "should not be detectable" (WHO, 2004).

The data from MIT during the spring indicates that there may be a "cleansing" or "priming" period for the Table Filters, since the removal rates of TTC dramatically changed during the first two weeks of testing. Further testing could be done on this subject, but this may mean that new filter owners should allow dozens of liters of water to pass through the filter before expecting it to be operating at its long-term performance level. (Only five liters of water were added to each filter per day in the MIT laboratory, so this priming period could be shortened to one day if the user has access to large amounts of water.) The percent removal rates by the two Table Filters over time are shown in Figure 9.2.

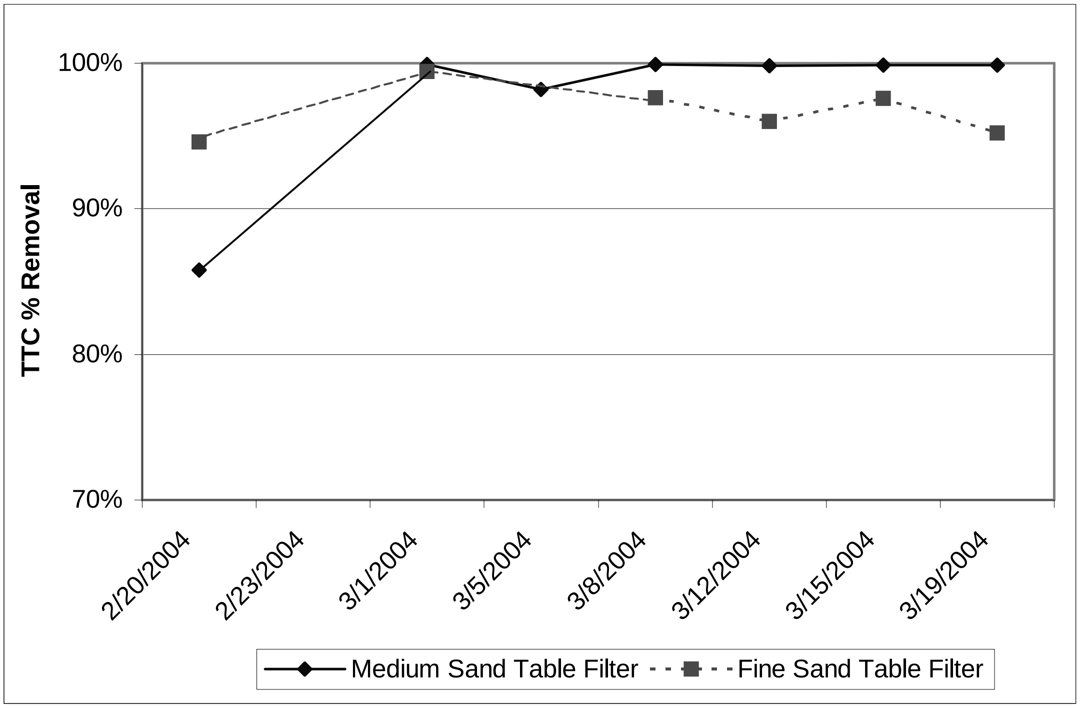


Figure 9.2: Percent Removals Over Time of TTC by the Table Filters (MIT, Spring 2004)

This "priming" phenomenon particularly expresses itself in the Medium Sand Table Filter performance, as the percent removal of all the tests that occurred *after* the first two weeks, beginning with March 1 (thus simulating two weeks of filter priming at 5 L/day, or a total of approximately 70 L, before use), was 99.5% removal of TTC, a considerable change from 98% removal when all weeks are included. This statistic helps to show the difference in performance that was often observed between the Medium and Fine Sand Table Filters, specifically that the MSTF often had lower TTC concentration levels, often by one or two orders of magnitude, than the FSTF. (The FSTF's removal rate remains at about 97% when leaving out the first two weeks of filter use.)

Results were fairly different during the summer round of testing, probably due largely to the lower contamination levels of the raw source water used during that time: 1.3×10^3 TTC CFU/100ml. Since the fecal contamination started out relatively low in the source water, the Table Filters had a chance to reduce the contamination levels much further during the summer: to an average of 1 TTC CFU/100ml in the MSTF and 1.4×10^1 TTC CFU/100ml in the FSTF, for an average removal of 99.9% and 99%, respectively. This performance is better than that seen in

Peru, however the source water contamination levels were not as high at MIT and therefore not as comparable as the spring lab data is to the Peru data. However, this *does* show that the Table Filters, especially the “Medium Sand” may be extremely effective at treating raw water with lower levels of contamination.

After the removal of sand from the Table Filters at MIT, the percent removal was reduced and the TTC concentration in the treated water was increased in both filters, meaning that they were more effective when the sand was present. Although the difference between the percent removals by the Table Filters with and without sand was not as large as may have been expected. They were still performing at an average of 97% and 99% TTC removal by the Medium and Fine Sand Table Filters, respectively, compared to their previous 99.9% and 99% TTC removals during the Summer and 98% and 97% TTC removals during the Spring. *This indicates that most of the microbial removal of the Table Filters occurs in the ceramic candle filters. However, slightly more TTC was removed when the sand was present, so we know that it may be helpful in some way.* It is likely that the geotextile and sand primarily serve the purpose of removing large particles and, as a result, increase the water flow rate through the ceramic candles and lessen the frequency of cleaning required by the candles.

In addition to comparing the Table Filters with and without sand, the purpose of the removal of the sand was also to investigate the reason that the Medium Sand Table Filter generally seemed to perform better than the Fine Sand Table Filter. Table 9-2 gives a summary of the test results from all of the Table Filters investigated in this study. The Medium Sand Table Filter’s averages are consistently better than the Fine Sand Table Filter in terms of TTC concentration, percent removal, and LRV. The only known and intended difference between the two filters was the grade of sand. Since only one of each type of filter was tested in the laboratory, there could have been any number of unknown differences between the two filters. The sand was removed to investigate the possibility that the ceramic candles were irregular and causing some or all of the difference between the two filters. *The two Table Filters performed relatively similarly to each other once their sand was removed, so while further investigation would be necessary to confirm this, it has been supported by this study that the difference in sand grades could cause differences in the performance of Table Filters.*

Table 9-2: Summary of the Averages of All Table Filter Tests for Thermotolerant Coliform (MIT, 2004)

Test Description	TTC Concentration (CFU/100ml)			Percent Removal		Log Reduction Value (LRV)	
	Raw Source Water	*Treated Water*					
		Medium	*Fine*	*Medium*	*Fine*	*Medium*	*Fine*
MIT, Spring	2.0×10^4	7.2×10^1	4.3×10^2	98%	97%	2.6	1.8
MIT, Summer	1.3×10^3	1	1.4×10^1	99.9%	99%	2.7	2.3
MIT, Avg. Spr. & Sum. *with* Sand	1.2×10^4	4.1×10^1	2.2×10^2	98%	98%	2.6	2.0
MIT, Summer *without* Sand	1.9×10^3	7.7×10^1	3.3×10^1	97%	99%	1.9	1.9

As before the sand was removed, the MSTF without sand did perform better than the FSTF without sand, but only slightly. In the experiments with sand, the MSTF produced treated water with TTC concentrations that were one and two orders of magnitude smaller than that from the FSTF. However, with the sand removed, the TTC concentrations of the treated water from the two Table Filters were in the same order of magnitude.

Much of the TTC test data is questionable because the incubated Petri dishes were often covered with other non-TTC colonies that did or may have masked the true presence of TTC colonies. This may have been due to high bacterial growth occurring in the sand while the Table Filters were not in use for ten weeks between the spring and summer testing periods. Green, gray, cream, and clear colonies were often present on the Petri dishes along with the blue colonies formed by TTC. Often blue and cream colonies overlapped to form green, making the blue TTC colonies difficult to distinguish between the green non-TTC colonies. The best judgements as to the number of TTC colonies were made whenever possible. As described in the methods section, the blue and blue-green colonies were counted as TTC CFU, and any other green, light green, cream, or clear colonies were noted, as can be seen among the data in Appendix L. Whenever the non-blue colonies were TNTC or the total number of colonies exceeded 200, the data was considered invalid.

Virtually every test was covered to some extent with non-TTC colonies, so it was not possible to simply discount these tests. There were often “patches” of cream that seemed like they masked the presence of blue TTC colonies that were otherwise evenly spread over the Petri dish. An example of this can be seen in Figure 9.3. This picture shows the Petri dish of a 10-ml test of the source water on June 24. The contrast between dark and light colonies shows that certain areas of the blue TTC colonies were allowed to grow while others were completely taken over by cream colonies. Because of the fairly even distribution of large and small colonies throughout the plate, it can be speculated that there may have been more TTC CFU evenly spread across the plate that were masked by the abundance of other bacterial colonies. Another possible explanation for these patches of cream colored broth and colonies is that the m-FC broth had degraded, which can happen with time, excessive heat, or for other reasons (Pecchia, 2004). While the broth should not have degraded, since it was less than five months old and kept refrigerated constantly, this phenomenon could explain the poor results of the TTC tests.

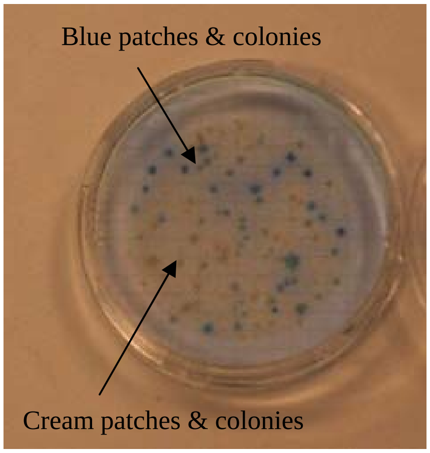


Figure 9.3: TTC Test Result Showing Blue Colonies Taken Over by Large Areas of Cream Colonies (MIT, Summer 2004)

9.2.1.2 E.coli and Total Coliform

MColiBlue-24 broth was used in the laboratory only during the summer as an additional indicator because the TTC tests were often overrun with other bacterial colonies. MColiBlue is better at allowing only the target coliforms to grow on the Petri dishes.

Because mColiBlue was added late in the summer testing period as a back-up indicator, only one test was run with this broth before the sand was removed from the Table Filters. This test showed the presence of < 1 E.coli CFU/100ml and 3 TC CFU/100ml in the treated water from the Medium Sand Table Filter. It is interesting to note that this average of 3 TC CFU/100ml was the result of one single TC colony found on a 10-ml test of the Medium Sand Table Filter (averaged with two other tests with 0 CFU). No colonies were found on the 50-ml test or the 100-ml test. The blank test performed before these tests showed 1 E.coli CFU/100ml of blank water, so the water or equipment may have been slightly contaminated. But these results may also indicate that a single 100-ml test with zero CFU does not mean there is absolutely no contamination in the water nor that zero CFU will always result from multiple 100-ml tests of the same water. A 100-ml test resulting in no CFU, however, certainly does indicate a very clean water source even if some small amounts of contamination may be present.

The Fine Sand Table Filter showed 1.0×10^1 E.coli CFU/100ml and 6.4×10^1 TC CFU/100ml on the one day of testing with mColiBlue broth before the sand was removed, indicating that the Fine Sand version does not filter out fecal and non-fecal contamination as well as does the Medium Sand Table Filter.

After the sand was removed from the filters, the ceramic candles of the MSTF treated the water to < 1 E.coli CFU/100ml and 2.0×10^3 TC CFU/100ml, and the FSTF's water had an average of 3 E.coli CFU/100ml and 1.2×10^2 TC CFU/100ml. While very few tests were performed with the mColiBlue broth, the results may indicate that the ceramic candles are comparably effective at removing E.coli with and without the presence of sand, but are less effective without sand at removing TC. The comparable removal of E.coli may also be a result of the fact that the E.coli concentration was so low. Since the E.coli concentrations were < 1 and 3 CFU/100ml, they could not get much lower to create very large differences in the LRVs.

Table 9-3 gives the LRVs for both filters for E.coli and TC before and after the sand was removed. The values support the possibility stated above (that ceramic candles alone were less effective at removing TC than when sand is present but that they are relatively equivalent in the removal of E.coli) only for the Medium Sand Table Filter. The Fine Sand Table Filter seems to have been more effective at removing TC without sand than it was with sand. This may, however, be attributed to the fact that the source water had much higher contamination during the tests performed on the filters without sand.

Table 9-3: Comparison of LRVs of Coliforms by Table Filters Before and After the Removal of Sand (MIT, Summer 2004)

	E.coli LRV		**Total Coliform LRV**	
	MSTF	FSTF	MSTF	FSTF
With Sand	3.3	2.3	3.3	2.0
Without Sand	2.6	2.6	1.6	2.9
Difference in LRV Caused by Sand	0.7	-0.3	1.7	- 0.9

Below, Tables 9-4 and 9-5 present a summary of all the tests for E.coli and TC that were performed in Peru and in the MIT laboratory.

Table 9-4: Summary of the Averages of All Table Filter Tests for E.coli (Peru & MIT, 2004)

Test Description	**E.coli Concentration (CFU/100ml)**			**Percent Removal**		**Log Reduction Value (LRV)**	
	Raw Water	**Treated Water**					
Peru	$5.3x10^2$	2		99%		2.3	
		Medium	*Fine*	*Medium*	*Fine*	*Medium*	*Fine*
MIT, Summer	$1.8x10^3$	< 1	$1.0x10^1$	99.99%	99.5%	3.3	2.3
MIT, Summer *without* Sand	$8.9x10^2$	< 1	3	99.99%	99.8%	2.6	2.6

Table 9-5: Summary of the Averages of All Table Filter Tests for Total Coliform (Peru & MIT, 2004)

Test Description	TC Concentration (CFU/100ml)			Percent Removal		Log Reduction Value (LRV)	
	Raw Water	Treated Water					
Peru	$3.5x10^3$	$7.2x10^1$		98%		2.5	
		Medium	*Fine*	*Medium*	*Fine*	*Medium*	*Fine*
MIT, Summer	$6.5x10^3$	3	$6.4x10^1$	99.95%	99%	3.3	2.0
MIT, Summer *without* Sand	$5.0x10^4$	$2.0x10^3$	$1.2x10^2$	23%	99.8%	1.6	2.9

The Table Filters were tested for coliforms on only four different days *after* their sand had been removed. This means that, just as with the sets of data from before the sand was removed and those from the Table Filters in Peru, the average numbers are not necessarily representative of how the filters would have behaved if given more time.

The data from June 30 was quite different than the other days' data. The E.coli concentration of the raw water that day was measured at an average of $4.7x10^1$ CFU/100ml. This brought the average raw water concentration for that whole testing period down to $8.9x10^2$ CFU/100ml, even though the other three days averaged $1.2x10^3$ E.coli CFU/100ml.

Also, the total coliform measurements from June 30 seem to indicate that the Table Filters without sand *raised* the level of contamination in the water. This may have been *partially* due, again, to the fact that the source water was relatively "clean." That day's water had a concentration of $2.3x10^3$ TC CFU/100ml, while the other three days averaged $6.6x10^4$ TC CFU/100ml, a full order of magnitude larger. The Medium Sand Table Filter-without-sand's treated water showed $5.4x10^3$ TC CFU/100ml, which was a *negative* 131% removal, i.e. an addition. This lowered the otherwise 99.7% TC removal average down to a mere 23%. The result from the Fine Sand Table Filter test on that day was "too numerous to count," but it was visually apparent that the concentration was between $1x10^3$ and $5x10^3$ TC CFU/100ml. This result, too, was much higher than the other days, but since it was "TNTC," it could not be included in the averages. Thus the Fine Sand Table Filter without sand maintained an average 99.8% in contrast to the Medium Sand Table Filter's 23%. Although as stated above, the Medium Sand Table Filter's average would have been 99.7% if the same days were included in the calculation as were for the Fine Sand Table Filter's 99.8% removal. This day's unusually large MSTF treated water TC concentration also contributed to the low LRV of 1.6, which otherwise would have been 2.6, comparable to other LRVs.

9.2.1.3 HPC

HPC tests are used to indicate the general cleanliness of a system or sample of water, since it measures the presence of many different types of microbes. On June 23, when all four water samples – raw source water, Medium and Fine Sand Table Filter treated waters, and "blank" distilled water – gave valid results, the MSTF removed 99% and the FSTF 83% of HPC. *This* *indicates that the Medium Sand Table Filter is more effective in removing general contamination from the water than is the Fine Sand Table Filter.*

It is interesting that the blank water had a concentration of 2.5×10^2 HPC CFU/100ml that day. This concentration seems high, although it is equivalent to a 99.997% "removal" from the contamination found in the source water. This reinforces the fact that many HPC-detected microbes are harmless and certainly not caused by fecal contamination. On the flip side, the HPC concentration in the treated waters was three and four orders of magnitude higher than that in the blank water, indicating that the "treated" water contains much more contamination than blank water and thus the treatment process could still be improved.

9.2.2 Performance Tests at MIT

9.2.2.1 Turbidity

The turbidity of the treated water from both Medium and Fine Sand TFs was always under 1 NTU during the spring tests and less than or equal to 2 NTU during the summer, both with and without the sand. This means that the Table Filters were always able to reduce the water to levels beneath the WHO recommended maximum of 5 NTU for visual acceptability of drinking water (WHO, 2004). The MSTF and FSTF provided 91% and 92% removal of turbidity, respectively, before the sand was removed. Without the sand, the Medium and Fine Sand Table Filters removed only 89% and 88% turbidity, respectively. *This suggests that the sand present in Table Filters may help turbidity removal to be more effective than if ceramic candles alone were used.* While the differences in percent turbidity removal appear relatively large, unfortunately the t-test indicates that these differences are statistically insignificant. The t-test values for the MSTF and the FSTF are 76% and 69%, respectively, much higher than the 5% needed to confirm significant differences in turbidity removal performance.

In general, the two types of Table Filters performed comparably to each other. They also performed better than the average percent removal of turbidity by Table Filters measured in Peru of 70%, even though the raw water found in Peru and used at MIT had similar turbidity levels. The average raw water turbidity in Peru was 10 NTU, and the source water used at MIT was 15 NTU before the sand was removed and 19 NTU after the sand was removed. The slightly lower starting turbidity may partially explain why the percent removal of turbidity was lower in Peru: there was not as much turbidity for the Table Filters to remove.

9.2.2.2 Flow Rate

In the MIT laboratory tests, the flow rate increased dramatically after the sand was removed from the Table Filters and the candles were lightly scrubbed with paper towels. Immediately following the removal and cleaning, the Medium Sand Table Filter increased from 1.0 to 7.1 L/hr, and the Fine Sand Table Filter changed from 0.8 to 6.7 L/hr.

The initial flow rates of 1.0 and 0.8 L/hr were measured in the summer and so were most likely slower than the initial flow rates of the Table Filters during the spring testing. But once the sand was removed, the flow increased immediately but then began to quickly decline. Within two days, the flow rates were back down to 0.8 and 1.5 L/hr for the Medium and Fine Sand TFs respectively. *This suggests that although the sand may prevent the large flow rate that could occur with clean ceramic candles, it does prevent them from quickly becoming clogged from turbid water.* This supports the theory that CEPIS acted upon when combining the two technologies. They believed that the addition of sand would help filter out some of the turbidity before it reached the ceramic filters so that they would not become as easily clogged with particles.

9.3 Interviews

9.3.1 General Questions

88% of the houses interviewed receive their drinking water through a piped system. *Therefore it is possible that for better water treatment for communities that already have a central water distribution system, the level of treatment at the plant could be raised instead of or in addition to household water treatments.* One possible step that could require little ongoing resources (e.g., from the ongoing addition of disinfectant) would be to increase turbidity removal at the plant level so that chlorination alone would be needed at the household level, which is cheaper than Table Filters.

When asked what, if anything, the interviewees did to treat their drinking water before receiving a treatment system from the Ministry of Health, 33% said they added household chlorine. *This would indicate that chlorination is already an acceptable practice among many people in those communities and therefore, as is always a concern, it can provide a culturally-sensitive and community-accepted water treatment.*

9.3.2 System Usage

When asked if they drink more water now that they have a household treatment system, people with SWS *bidones* were more likely to respond positively (66%), than those who have Table Filters (36%). The reason for this difference is not immediately clear. There could be a number of factors causing this difference, including the relatively small sample size of 22 Table Filters and 47 SWS *bidones*. It may be because the Table Filters have a much slower flow rate than do the SWS *bidones*, which would force families to wait longer for treated water. However, if the Table Filter is continually filled, the flow rate should not be a problem when collecting small amounts of filtered water. One would only have to wait a long time for the treated water to slowly drip from the ceramic candles if all the water in the lower bucket was completely drained out. But if it were the case that several liters of water were needed at once, the same would be true of the SWS *bidon*. If all the water in the *bidon* was used at once, the family would have to wait 30 minutes before a newly chlorinated batch of water was ready for consumption.

It could be that people are more likely to enjoy drinking the water from an SWS *bidon* than from a Table Filter. This does not seem to fit with the assumption that people will be more likely to complain about the taste of chlorinated water than that of filtered water. However that assumption was not supported by the survey data, which seems to indicate that people generally like treated waters from each system about equally. 91% of households with Table Filters and 86% with SWS *bidones* reported that their water tastes better after treatment, while 9% with TFs and 7% with *bidones* said it tastes worse.

62% of people with water treatment systems said they never drink untreated water, but they may have answered this question thinking only of their time at home. Most of the men and some of the women work on the farm for many hours each day. While 13% said they drink soda when away from home, which is generally sealed and contamination-free, 28% reported that they drink water. Of these 20 people who said they drink water when away from home, only 2 indicated that it was boiled water and 1 that it was mineral (bottled) water. Since the water drunk away from home by those interviewed is usually not boiled or bottled, many of the farmers most likely are drinking contaminated water while on the farm. A large 66% of the respondents reported drinking *chicha* while on the farm. *Chicha* is a Peruvian drink made from corn and water. Depending on where and how this chicha is made, it could be made from bottled water or untreated tap water. Therefore, *more* than the 38% of people indicated by the survey may actually drink untreated water when away from home. In all, only 18% indicated that they drink soda or boiled or bottled water, so according to the survey, *up to 82% of the people who responded to the question could be drinking untreated water on a regular basis when away from home.*

CBV residents uniformly reported cleaning their Table Filters every week, while the average time between cleanings for TF owners from other towns was more than two months. This means that CBV residents clean their TFs an average of nine times more often than people from other towns interviewed. This may be because they were instructed to clean their TFs more often than people in other towns or because their filters needed cleaning more often due to properties of the water in that location. It is statistics like these that show that systems can function differently based on location or a change in condition. *Since most of the data in this report was collected from CBV, it should be noted that it may not be representative of the same treatment systems in other locations.*

SWS users add *chloro* to their water an average of every 2.2 days. Two SWS *bidon* owners reported that they add *chloro* only twice a month, which does not really include them as regular or ongoing SWS users. If these two households are taken out of the average, it is reduced to every 1.6 days that *chloro* is added, which is probably more representative of responsible users of the system. This number is still concerning. The SWS is designed so that users will treat all of the water they consume. According to the user's manual (see Table 5-3), treated water is always supposed to be used for drinking, brushing teeth, washing hands, and washing dinnerware and fruits and vegetables. The WHO's definition of "basic access" to water includes the assumption that each person should be able to collect and consume 20 liters per day (see Section 2.3.3). While this entire amount may not need to be treated, a minimum of 7.5 lpcd (liters per capita per day) is assumed to be needed for hydration and "incorporation into food" (WHO, 2004). If teeth brushing and food and dish washing is added, it can be assumed that a minimum of 10 lpcd of *treated* water is needed. For a family of 5, which is the average household size of those interviewed, this would mean that they should be disinfecting at least 50 liters per day. Assuming that two of those family members are children and they can consume less water, the average household consumption of treated water should be at least 40 liters per day. Since the SWS *bidon* holds only 20 liters, users should be treating a *bidon*-full of water an average of at least twice per day, or every 0.5 days. Now, of course, not all water may be consumed in the household, as people often drink chicha or soda when working outside of the house during the day. Also, water used in cooking may be treated by boiling instead of chlorination. For these reasons, a full 10 liters may not need to be treated per person each day. *Depending on use, each household should treat one full bidon of water daily for every two to four residents.* Of the 42 SWS owners interviewed, only two, or 5%, were treating their water twice a day. One of these households contained four members and one contained eight. It is good to note, however, that all of the households with seven or more members were treating their water at least once daily.

9.3.3 User Satisfaction

Questions about taste were discussed above in Section 9.3.2.

93% of respondents said that they feel better physically since they have begun to use their Table Filter or SWS. It is important to keep in mind that surveys are not objective but subjective. Answers could change each time the same person is asked the same questions. Their answers may be influenced by who the interviewer is (they may try impress or give the "right" answer, especially if a free service or object is in question); how the interviewer asks the questions (the questions themselves may imply the "correct" response or previous questions may lead in a certain direction); who is present at the interview (a foreigner, a representative of the benefactor, a "friend" or "enemy"); who answers the questions (man or woman, involved in the actual gathering and treating of the water or not); and so on. Therefore, the 93% of people who said they feel better using treated water may have told the truth; or said it to assure the interviewer that they like, are grateful for, and want to keep the treatment system; or responded with what they thought the answer *should* be (e.g. their thoughts might be something like: the water is "treated," so I *should* feel better…why yes, of course I feel better). This is not stated to discount their answers but so that readers can be aware of the subjective nature of personal surveys.

As another example, 88% of respondents said that their water tastes better after treatment, but that may not be realistic. Chlorinated water generally tastes worse. They may have unconsciously translated "Does the water taste better now?" into "Do you think you have better water now?" Most respondents would naturally answer yes to the latter question, since they were all grateful for receiving the treatment systems.

More people with Table Filters (36%) reported problems with them than did those with SWS *bidones* (20%). This indicates, at least on one level, *that general user satisfaction is greater with the SWS than with the Table Filter*.

Also, 53% of the complaints related to the spigot. Many of the HWTSs had broken spigots, which often meant that the users could not use their system or had to create their own method for plugging the spigot hole. During January, it was explained to the researchers that many people wanted spigots so they were being ordered and would be replaced as soon as possible. However, during the interviews in March, an even larger percentage of people complained of broken spigots, which suggests that the replacement spigots had not arrived or that the quantity was not sufficient. The simple replacement of broken spigots would address the complaints of many of the treatment system owners.

While 100% of the people with each type of system said they believed it to be beneficial for their family, there was not a total consensus among Table Filter owners about liking the system. 5% of households with Table Filters (that is, *one* house that was surveyed) said that the Table Filter was not easy to use, and the same percentage (but a different household) said they did not like the Table Filter. This can be contrasted to the SWS *bidon* owners who agreed 100% that they liked the SWS and found it easy to use. One data point does not give a very reliable percentage representation of the entire population. The one house that did not like the Table Filter could have been one of five interviews, in which case it would have represented 20% of the population, or it could be the only one who would complain out of a hundred interviews, making it only 1% of the total population. On the other hand, more people may have been unhappy with their systems than reported, but because they were grateful for their Table Filter and did not want it to be taken away, stated that they liked it. Also, the question "Do you like it?" is very open to interpretation by the respondent. In this case, it may be more informative to look at the fact that 25% of HWTS owners reported complaints or problems with their system.

9.3.4 Willingness to Pay

As explained above, surveys can be a very subjective means of collecting information. The amount of money that a person or population may be able and willing to pay for a product is even more subjective because it is often based on a conjecture about the future instead of a quantitative evaluation of the past. In this survey, respondents' "willingness to pay" was investigated through contingent valuation, meaning that the interviewees were asked, in essence: "*Contingent* upon receiving this product, how much would you pay for it (what *value* would you place on it)?" Sometimes people responded with their own price and sometimes they were asked about a range of values to find out where their cut-off point was.

The technique of asking different possible prices of the interviewee is called the "split-case method." The instructions written on the survey to the interviewer were written by the business student Obizhaeva as follows:

> For surveyor: We will try to obtain more accurate "willingness to pay" information by using a split-case method. Each time you give an interview, start with different initial prices (e.g. $5, $10, $15) then try to find the maximum price the respondent is willing to pay. For example in one case you might ask:
> "Will you pay $10?" *Yes.* "Will you pay $12?" *Yes.* "Will you pay $14?" *No.* Stop here. The actual price is something in between, in this case, $13. So you will write down the last price as $13 in the answer section.

When this method is used, the respondent's answer may depend on the starting price offered. Just as in an auction, if the price starts high, the interviewee may think that the product is worth a lot of money and offer more. If the price starts low, she may think that it is not very valuable and refuse to pay much money. This is the reason that the interviewer is supposed to change his starting price with this method, in hopes that this effect will average out over time.

9.3.4.1 Table Filters

The average price offered for a Table Filter was S/ 20, roughly equal to $6, not nearly enough to cover the approximate $11 that the Table Filter costs to produce. Table Filter owners guessed, on average, that it cost S/ 42, or $12, which means that they know they cannot or are not willing to pay for the full price of the filter.

The average *monthly* price offered, however, was S/ 8. 72% of TF owners said that monthly installments would be a better way of paying for the filter, and probably more than that would be *willing* to pay monthly installments. When the question about monthly installments was asked of owners, no timeline was given for the length of those payments, which means that respondents did not necessarily provide their answers thinking it would only be for a limited amount of time. Therefore, it may be a good idea to pursue monthly payments for the TFs, if they are to be sold to families. If families were charged only S/ 2.5, about $0.70, per month for two years, they would pay S/ 60, or $17, enough to cover the $11 for the TF and $5 for 2 extra ceramic candles, with $1 left over to help fund the program (e.g. the technicians who support TF owners) or make up for other families who are not able to pay every month.

9.3.4.2 SWS Bidones

Only 73% of SWS *bidon* owners said they would be willing to pay for a new one if their current one was lost, as opposed to the 91% of TF owners who said they would purchase a new one. The average offer for a *bidon* was S/ 12, or about $3.50. This is a lower price than was offered for the TFs, which is logical because the SWS *bidon* is simply a container and the owners would also have to purchase disinfection solution.

There was a notable difference between the prices offered for a bottle of disinfectant solution in January and March. The average price given in January was S/ 6.5 while the average in March was S/ 0.3. It is possible that the question was stated differently during these two rounds of interviewing or that respondents understood the questions differently. For example, the interviewers may have offered different starting prices between the two months. It could also be possible that the time of year affected the answer, a different season of farming could cause different strains on finances.

The difference between the prices offered for disinfection solution could also be a function of where respondents lived. Some towns may have been poorer than others or the residents may have been informed of a certain price for the disinfection solution. All 32 SWS *bidon* owners from March lived in CBV, whereas only 6 of the 15 owners from January were from CBV. The average offer from March was S/ 0.3, ranging from S/ 0.2 to S/ 0.5. If it were a function of location, the CBV respondents from January would also be expected to average about S/ 0.3. But the four *bidon* owners who actually responded offered an average of S/ 3.9, ranging from S/ 0.5 to S/ 5, which does not support the location-based theory.

9.3.4.3 Households without a CEPIS-Provided Treatment System

The average price offered for a “water purification system that gives you safe drinking water” (which, by the way, is not an accurate description of either the Table Filter or the SWS because they do not guarantee *safe* drinking water but simply *treat* water so that it is *improved*) was S/ 40, or $11, which happens to be the cost of the Table Filter.

It must be noted that only *one* of the *three* people who were asked this question was from Cerrito Buena Vista. His price was S/ 20, which would only cover the cost of the SWS *bidon* without any disinfectant. Each of the other interviewees, who offered S/ 50, lived in La Joya, a larger town, and were employed as a taxi driver and the Mayor, respectively, which means that they probably had much more money than the families initially provided with a water treatment system. It appears that people with more money may be willing to pay more than the average offer from CBV, and may even be able to pay full price or more for a low-cost treatment system. If households with more resources are able and willing to pay more money for these systems, they may be able to help subsidize a lower price for lower-income families. This is an important finding, but the average S/ 40 offer must not be taken to apply to all households. It is important to keep in mind that poor families – those most likely to drink poor-quality water (because they cannot afford bottled or treated water or because they live in towns with lower quality water treatment plants) – may not be able or willing to pay full price for the systems.

9.3.4.4 Cost Comparison for Economic Affordability

In view of the willingness to pay values of the target households in Peru, it is informative to compare the actual costs of each water treatment option. Table 9-6 compares the capital and maintenance costs of each option. These costs are taken from the report written by the MIT business students, Lieu and Obizhaeva. They are explained in further detail in Section 3.3.2.4.

Table 9-6: Cost Comparison of Water Treatment Options in Peru. Source: Cerilles, et al., 2004.

Water Treatment Option	Capital Cost	O&M Costs / year
Table Filter (household filtration)	$6.40[50] [TF w/o 2 candles]	$5 [2 candles]
Safe Water System (household chlorination)	$9.80 [$6 (*bidon*) + $0.30 (chl. bottle) + $3.5[51] (chl. generator)]	$3 [$0.25/month for chl. production]
Water Treatment Plant (w/ piped system)	$475 [per family of 5]	$36

It should be noted that the O&M costs do not include the salary of a technician to keep the program running.

It would be a good idea to see if the chlorine generator could be donated to poorer villages so that SWS users need only cover the cost of the *bidon* itself.

The water treatment plant costs are calculated assuming that a treatment plant, piped delivery system, and household taps will cost at least $95 per person served. Since the typical Peruvian family has five people, as reported from the household surveys, this is estimated to cost $475 per household. The operation and maintenance costs of $36 per household per year includes servicing and a "long-term budget for equipment upgrade" (Cerilles, et al., 2004). This option is by far the most expensive. A community-wide water treatment plant and distribution system can be a good option for a community as it may treat the water more thoroughly than a household treatment will, and it provides easy access to clean water by delivering it directly to the house and erasing the need for household treatment steps. These benefits must be weighed against the cost and practicality. (Water distribution systems may be impractical for widely-scattered houses.)

For many rural villages and scattered households, household water treatment systems will be the most practical and cost-effective way to treat water.

9.4 Field Observations

There seemed to be fewer technical problems with the HWTSs in Tacna than in Arequipa. Fewer broken spigots were observed and fewer owners complained of problems (7% in Tacna versus 30% in Arequipa). This could be due to better education about the handling of the systems or better staff support or resources to replace broken spigots.

[50] A Table Filter costs $11.40, which includes two ceramic candles. The capital cost is listed as $6 since the cost of the candles is included in the O&M costs, and they will not need to be replaced (on average) until the second year.
[51] This assumes that one $1,400 chlorine generator serves 400 SWSs, as is true in Arequipa, even though one system could generate chlorine for many more or fewer SWSs.

The amount of chlorine solution being generated each month in Arequipa does not seem to be enough to serve all 400 SWS owners. However, it may be that the author is mistaken, and this one chlorine generator does not serve all seven of the towns in Arequipa that were supplied with SWSs. Also, the low level of chlorine generation may actually be in response to a low user-demand for *chloro*. If this is the case, however, families with SWS *bidones* should be encouraged to chlorinate their water regularly.

During the "willingness to pay auction" in La Cano, the amount of money that attendees were willing to pay for an HWTS was very low, much lower than the average offer of people in all regions who were interviewed. Most people at the auction were only willing to pay S/ 1, while current owners of the system who were interviewed offered an average of S/ 20 for the Table Filter and S/ 12 for the SWS *bidon*. In hindsight, the willingness to pay that people offered was probably affected by first having current HWTS owners air their concerns about the systems and having the Mayor remind them about the WTP that was planned for the town. Both of these factors probably caused residents to devalue the HWTSs.

10. Evaluation & Recommendations

Mauricio Pardón, director of CEPIS, requested that the MIT research team provide to CEPIS technical, social, and economic evaluations regarding their household water treatment program, in that order of importance (Rojas, et al., 2004). This chapter summarizes these evaluations as well as provides recommendations as to how CEPIS and the Peruvian Ministry of Health could proceed with their program. Suggested topics for further evaluation and research of these household water treatment technologies are also presented here. Further economic evaluation and recommendations can be found in the MIT business team's report by Lieu, Obizhaeva, and Cerilles: "H_2O-1B!: Bringing Safe Water to the World" (Cerilles, et al., 2004).

10.1 Technical Performance of Treatment Systems

Nearly all of the coliform and turbidity tests performed on Table Filters and SWSs in Peru were from households located in the town of Cerrito Buena Vista (CBV), so it is an important finding of this report that both of the household treatment systems were much more effective at treating the water than was the CBV water treatment plant. As illustrated in Figure 8.5 in Section 8.1.1.1, the CBV WTP removed only 92% E.coli from the water, while the Table Filters removed 99% and the SWS removed 99.6%. Due to a single test day that indicated an *addition* of TC to the water by the CBV WTP, the treatment plant showed an average *increase* of 258% TC, while the TF removed 98% TC and the SWS removed 95% TC. Therefore, unless the CBV WTP is dramatically improved in its ability to remove pathogens from water, **the CBV citizens should continue to use (or start using) household drinking water treatment systems.**

The CBV WTP could and should be improved to remove much more fecal contamination and turbidity, but that could be 10-50 times as expensive, depending on the upgrade, as the community-wide implementation of an HWTS program. (According to the business team, as presented in Table 10-1 in Section 10.4, the installation of a *new* WTP would cost over 50 times as much per family as an HWTS.) As one small step to improved microbial removal, sufficient chlorine should be added at the plant so that pathogens are inactivated before reaching the household level, but since the water has such high turbidity, this may not be entirely effective. A coagulation process step combined with enhanced sedimentation is also needed to aid in the removal of turbidity.

The prospect of improving every WTP or every HWTS can be overwhelming. Instead, improvements can be made one step at a time, focusing on the systems of highest priority. As stated in Section 2.4.1.4, priority levels for improving water supplies and treatment technologies should be set according to a rating system. The priority ratings could be based on the current level of contamination, the size of population that would be affected by the improvement, the type of population affected (age, health, etc.), or the cost of the improvement. As systems are improved, intermediate goals of coliform concentration or other constituents can be set if it is not immediately feasible to meet ideal WHO guideline values.

10.1.1 Table Filters

The Table Filters tested in Peru proved to be very, though not completely, effective in treating water for drinking. They removed 99% E.coli and 98% TC from raw water. They reduced turbidity by 67% to an average of 2.4 NTU, which is below the WHO guideline value of 5 NTU. (The CBV WTP only reduced turbidity by an average of 22%.) **It is therefore recommended that Table Filters continue to be used in homes and schools to treat drinking water.**

While the Table Filters are effective, they do not meet WHO guideline values for E.coli removal (i.e. E.coli should not be present in 100-ml samples of drinking water [WHO, 2004]), so the technology could and should be improved. While the 2.4 NTU average turbidity does meet drinking water guidelines, it is above the 0.1 NTU turbidity recommended for water that is to be chlorinated. If chlorine treatment is to be combined with the Table Filter, as suggested below, it would be best if the filter could have higher levels of turbidity removal than it does currently. **Further research should address ways to increase coliform and turbidity removal by Table Filters.**

The average flow rate of the Table Filters measured in Tacna (3.8 L/hr) was faster than that of Arequipa's filters (1.7 L/hr). **Further investigation should measure the flow rates of more Table Filters in both provinces to learn if this average difference truly exists. Microbial and turbidity tests could also be run on more Table Filters from each province to look for any differences between the two regions.** If there are differences in performance of the Table Filters between the two provinces, perhaps there are aspects of the materials, water, education, or program support in one region that could help improve the performance of the filters in the other region.

As for the laboratory study on Table Filters at MIT, the Medium Sand Table Filter was *slightly* more effective at coliform removal than the Fine Sand Table Filter, which was supposed to most closely imitate the sand used in Peru, although the difference was not enough to be statistically significant. While this study does not provide significant differences in the Table Filter behavior due to different grain sizes, it does present the possibility that **it may be beneficial to investigate the effect that different grades of sand have on coliform and turbidity removal in Table Filters in order to discover the most effective grain size.**

The laboratory studies also supported the theory that the addition of sand to ceramic filters aids the removal of turbidity. The MSTF removed 91% turbidity with sand and candles and 89% with candles alone. The FSTF showed 92% turbidity removal with the sand, which reduced to 88% removal after the sand was removed. Data provided in Section 8.2.2.2, as well as previous data reported by Rojas & Guevara (2000), indicates that the combination of sand with the ceramic candles also helps to sustain a higher flow rate for a longer period of time. **The combination of geotextile, sand, and ceramic candles should continue to be used in Table Filters in Peru.**

Other organizations involved in producing low-cost drinking water filters may also be interested in investigating the effect of the combination of sand and ceramic filters in order to apply this technique to other filter designs.

On the other hand, there may be some significant, but as yet unresearched, drawbacks to using the combined ceramic candle and sand filtration media, for example:

1. The ceramic/sand combination may provide media for bacterial growth. **Therefore it is recommend that far more comprehensive HPC testing be performed to research bacterial growth within the Table Filter.**
2. The ceramic/sand combination makes the Table Filter difficult to clean because it requires the separate removal and cleaning of the sand and the ceramic candle.

10.1.2 Household Chlorination System (SWS)

Like the Table Filters, the Safe Water Systems were effective at removing much, but not all, of the coliform contamination in the water. They removed 99.6% E.coli and 95% TC. Unlike with the Table Filters, SWS *bidon* owners *do* have a direct way to affect the coliform removal of their systems: they can alter the amount of chlorine solution that they add to each batch of raw water. The average chlorine residual concentration found in water in SWS *bidones* in Peru was 0.18 mg/L, slightly below the WHO-recommended 0.2 mg/L. **Thus it is recommended that those households with less than adequate residual chlorine levels be instructed to add more disinfectant than they normally use.** Since each household with an SWS *bidon* was only tested once for residual chlorine levels, it would be best if, before the houses are advised accordingly, each household was tested several times to ensure that the one low test result was not an anomaly. Additionally, before instructing SWS owners to add more than the prescribed dose of chlorine (a half capful per 20 L), it should be made certain that this amount is indeed being added by the users in the first place. In other words, a low residual chlorine level could be caused either because the prescribed dose of chlorine is too small or because that dose is not being added correctly by the user.

If it is determined that the free chlorine residual is too low in SWS *bidones* of households that do add one half capful of chlorine solution to a full 20-L container, then the prescribed dose may need to be increased. The CDC describes a process for determining this dose in its SWS Handbook (CDC, 2004). In a controlled environment, using the same type of water that households add to their SWS *bidones* daily, a technician should fill the container with 20 L of water and then one half a capful of chlorine solution (the current prescribed dose). After 30 minutes, the free chlorine residual should be between 0.5 to 2.0 mg/L. (This CDC-instructed concentration may be higher than the WHO guideline value because chlorine could continue to be used up in the water over time, since some households only create a new batch of chlorinated water every 24-48 hours). If the concentration is below 0.5 mg/L after 30 minutes, the CDC recommends that the dose be increased and the same evaluation procedure be followed until the correct dosage has been determined. The CDC states that the correct dose will generally be 5 – 10 ml for a 20-L container of water (CDC, 2004), and the CEPIS *chloro* bottle cap holds approximately 10 ml.

The household interviews revealed that SWS users were adding *chloro* to their water on average only once every two days. **In order for there to be an adequate supply of treated water in the house so that residents do not consume untreated water, disinfection solution should be added to a full *bidon* of water at least once daily or, preferably, once per day for each 2-4 members of the household, depending on consumption.**

The second problem with the water found in SWS *bidones* was that the turbidity was very high. In order for disinfectants to be most effective, turbidity levels should ideally be at or below 0.1 NTU, and in order for water to be visually acceptable for drinking, the turbidity should be reduced to at most 5 NTU (WHO, 2004). The water measured in SWS *bidones* in Peru, however, averaged 38 NTU, which is extremely high for drinking water. These high turbidity levels likely contribute to the ineffectiveness of the chlorine.

Finally, **the addition of a handle to the SWS *bidon* should be considered.** It may be difficult to carry this container full of 20 L of water without a handle. If this is not currently a feasible option, or at least until it is, SWS users should be reminded to *never* put their hand inside the *bidon* unless they are cleaning it. Once the water inside the SWS *bidon* has been chlorinated, the lid should be kept closed at all times until the water is used up and the *bidon* needs to be refilled or cleaned.

*   *   *

Because of the problems with turbidity and chlorine effectiveness seen in the SWS *bidones*, the option of combining filtration and post-chlorination should be seriously explored. Filtration would remove much of the turbidity that would otherwise hinder the disinfection process and could remove much of the microbial contamination, depending on the type of filtration. Post-chlorination, or adding chlorine to water that has been filtered, would provide an extra step of disinfection and presumably inactivate most of the remaining microbes. **Further laboratory and/or field studies should investigate the effect that post-chlorination has on the effectiveness of the Table Filter.**

The combination of the Table Filter and post-chlorination would provide the best treatment, and therefore should be implemented if possible, but unfortunately it is also more expensive than either option alone. Alternatively, or as an intermediate solution until a way to fund the Table Filter-plus-chlorination can be found, a simpler way to remove turbidity from raw water before chlorination by SWS users should be pursued. Even a small amount of turbidity removal could make a large difference in the effectiveness of the disinfectant. There are many different types of pre-filtration techniques. For example, SWS *bidon* users could be instructed to settle their water in a series of containers over a period of one to three days (water in each container is allowed to settle then decanted into the next container for further settling), or water could be filtered through several layers of locally-available cloth. Also, water treatment plants could be improved to remove more turbidity before the water is delivered to the entire town. This could be a much more efficient way of removing excess turbidity so that household chlorination can be more effective.

An alternative to chlorination post-treatment for the Table Filter is solar disinfection. Many advanced-technology water treatment plants use UV-A rays for water disinfection. A low-cost version of this treatment has been developed and is known as SODIS. This technology consists of placing water in clear plastic containers, often 2-liter soda or water bottles (with labels removed) and placing them in the sun for 1-2 days. This technology works best in areas that receive large amounts of direct sun, as in Peru. A study by Oates, an MIT Master of Engineering student, showed that the SODIS system in Haiti "achieved complete bacterial inactivation" on 52% of the samples left in the sun for one day and on 100% of the samples left in the sun for two days (Oates, 2001). Cervantes, another MIT Master of Engineering student who studied SODIS, outlines the basic steps that should be followed to treat water using the SODIS system (Cervantes, 2003):

1. Reduce the water to below 30 NTU, which can generally be achieved by running it through a cloth. (The average turbidity of water treated by Table Filters was 2.4 NTU.)
2. Place the water in a clear plastic container. In order to increase the effectiveness of the solar radiation, Cervantes recommends that the water containers have a diameter no larger than 10-cm, and that they be placed on a reflective surface or half of the bottle be painted black or covered with tin foil (see Figure 10.1).
3. Aerate the water by vigorous shaking. Cervantes recommends that the bottle be filled part-way, shaken for 20 seconds, then filled to the top (avoiding the formation of a large air bubble, which can reduce sunlight penetration). This shaking increases dissolved oxygen and improves the effectiveness of the treatment.
4. Expose the container to the sun for up to two days (see Figure 10.1).

Since the only equipment needed for this technology are reused and cleaned soda or water bottles, the option of combining the Table Filter and SODIS requires essentially no extra cost beyond the cost of the Table Filter.

Figure 10.1: Experiment on the Effectiveness of SODIS using Different Bottles, Some with Black Backs. Source: Khayyat, 2000.

Chlorination alone is the lowest-cost option, but the high turbidity of source water in the study region presents a large problem, so pre-treatment turbidity removal steps should be pursued as mentioned above.

10.2 Program Evaluation

As additional testing and monitoring of the HWTSs continues, **the programs in Arequipa and Tacna should be compared and contrasted.** If there are consistent differences between the two regions, perhaps techniques or procedures from one region could be implemented to improve the program in the other region.

If families are not using the correct amount of *chloro* in their water or are not chlorinating their water on a regular basis, they should be re-educated or encouraged to do so. If a family does not wish to use its SWS *bidon*, it should be given to another family who would be glad to use it. Once SWS *bidon* owners are chlorinating their water regularly, **chlorine production cycles should be run often enough to supply all users with enough *chloro*.** Also, SWS users should not have to wait for the next production cycle when their *chloro* runs out. Fresh bottles of the chlorine solution should be kept on hand at each village's health post. Each production cycle of *chloro* should be distributed before the next batch since chlorine can lose its effectiveness over time.

Families with Table Filters who frequently see algae growth in their filters should be instructed to clean them more often. Other possible causes of this problem should be investigated as well. For example, their Table Filter must be kept out of the sun.

HWTS systems should continue to be monitored. As the WHO recommends, since perfect water quality standards (0 E.coli CFU/100ml) are not able to be met immediately, **the Ministry of Health should set intermediary water quality goals** for the treated water from WTPs and/or from the Table Filter and SWS. The household and community-wide systems should then continue to be improved, through technical advances and/or program support until they can reach those intermediary goals.

The Table Filter and SWS program should be implemented in other villages and towns. These technologies offer valuable treatment of drinking water. Priority could be placed on areas with the most highly contaminated water or those that collect water directly from surface waters without any treatment. Households with children and elderly could be prioritized. They could be placed in schools and hospitals for a wide-spread effect on some of the most vulnerable populations.

10.3 Social Acceptance (User Satisfaction)

User satisfaction with both the Table Filter and the Safe Water System is high. 95% of Table Filter owners and 100% of SWS *bidon* owners said they liked their treatment system and thought it was easy to use. 91% of Table Filter owners and 93% of SWS *bidon* owners said they feel better physically since using the treatment system. 100% of all HWTS owners interviewed said they thought using the system was beneficial for their family.

The main concern regarding acceptance of these systems is the fact that many people reported problems with them. 36% of those with Table Filters and 20% of those with SWSs reported problems or complaints. **These complaints, as reported in the results Section 8.3.3, should be addressed by those who run the program**, particularly if multiple people report similar problems. For example, 53% of those who reported problems with their system, either Table Filter or SWS, complained that the spigot was broken or too difficult to turn. As discussed in the previous chapter, keeping extra spigots on hand to replace those that are broken would address most of the complaints about the two systems. When technicians visit the houses regularly, which they are reported to do, they could help address any maintenance concerns that the families may have.

Also, since the current spigots are plastic, alternate spigot types such as metal could be investigated, although they would undoubtedly be more expensive. That touches on another problem of who pays for replacement parts and maintenance of the systems. Since the households received the treatment systems for free, they did not seem to expect to have to pay for their maintenance. This will be discussed further in the affordability section.

A different way of measuring user satisfaction is to monitor the number of HWTS owners who continue to use their systems. A survey should be conducted of all households that originally received an HWTS from CEPIS and the Ministry of Health to determine whether or not that household, or another household to which it was passed on, is still using that HWTS on a regular basis. (This comprehensive survey would also give the local technicians an opportunity to address any problems with the system that are preventing the household from using the HWTS if they want to.) Then, in the future, perhaps every five years, this comprehensive survey can be repeated and compared to the original (baseline) survey. This would indicate the sustained usage levels and, therefore, one aspect of the success of the program.

10.4 Economic Affordability and Financing

The families for whom the low-cost household water treatment systems are designed, that is, those who are least likely to have access to clean drinking water, are also usually the ones who can least afford to pay for the treatment systems. They are designed to be low-cost so that the households may be more likely to afford them, but often the families still cannot cover the entire cost of the system. **For this reason, it may be necessary to find alternate strategies to allow the users to be able to afford and pay for the cost of the systems.**

All of the systems currently in Arequipa and Tacna were distributed for free due to the water quality crisis caused by the earthquake of 2001. One option for funding the household treatment systems is to have the government or PAHO (of which CEPIS is a part) continue to fund the program. However, if these treatment systems are to be distributed widely to thousands and even millions of homes in Peru, it would be best to find a way for the program to cover all or at least some of its own costs.

The information gathered from the household surveys indicates that **the target population for the treatment systems may be willing to pay *half* of the capital costs**, that is, of either the Table Filter or the SWS *bidon* and disinfectant bottle (not including the capital cost of the chlorine generator). **The Peruvian government, PAHO, or some outside donor organizations could then cover the other half of the capital costs plus the costs of a chlorine generator** (if the Safe Water System was to be used in a community). The SWS *bidon* owners were also generally willing to pay the full price, or half the price according to March survey results, of the disinfectant solution. O&M costs for the Table Filters could either be covered by families, if they were able, or by other funders.

Table 10-1 presents the costs of each treatment option mentioned here. (See Table 9-6 for more detailed cost information.)

Table 10-1: Cost Comparison of Water Treatment Options in Peru. Source: Cerilles, et al., 2004.

Water Treatment Option	Capital Cost	O&M Costs / year
Table Filter	$6.40[52]	$5
Table Filter + SODIS[53]	$6.40	$5
Table Filter + SWS	$16.20	$8
Safe Water System	$9.80	$3[54]
SWS + Cloth filtration[55]	$9.80	$3
Water Treatment Plant (w/ piped system, per family of 5)	$475	$36

A viable alternative to asking families to pay for their systems in one lump sum is to allow them to pay in monthly installments. Filter owners were asked if monthly payments would be better than having to pay all at once, and 72% answered positively. The average suggestion for monthly payments was S/ 8, with most people offering S/ 5 or S/ 10. As stated in Section 9.3.4.1, if families were asked to pay just S/ 2.5 per month for two years, this would cover the cost of a Table Filter plus O&M costs.

Alternatively, since it would be ideal to use the Table Filter in combination with chlorine disinfection, a monthly payment of just S/ 4.5, about $1.30, for two years would raise $31, more than enough to cover the $28.30 for a Table Filter, SWS *bidon*, disinfectant bottle, two extra ceramic candles, and 24 months' worth of disinfectant (assuming one 250-ml bottle of

[52] A Table Filter costs $11.40, which includes two ceramic candles. The capital cost is listed as $6 since the cost of the candles is included in the O&M costs, and they will not need to be replaced (on average) until the second year.
[53] This assumes that the SODIS containers are reused bottles that the family would purchase anyway, making the capital cost zero. If the family would not otherwise purchase plastic bottles, or if other containers are used, then the capital cost would be slightly higher. The same consideration applies to the O&M costs, since it is recommended that plastic bottles be replaced every six months due to degrading of the plastic.
[54] This assumes that one $1,400 chlorine generator serves 400 SWSs, as is true in Arequipa, even though one system could generate chlorine for many more or fewer SWSs.
[55] This assumes that the cloth used to pre-filter water for the SWS is already available in the home and does not need to be purchased.

disinfectant is used per month). This is the option that is recommended for households in Peru when possible.

Many of the target households should be able to afford this fee, however it is obvious that some will not. For these houses, either treatment alone could be used, and/or subsidized funding could be provided. Table 10-2 lays out the monthly payments required for each treatment and payment option. **It is important to create and follow a plan, involving business policy/planning and management researchers, that will enable and encourage families to meet their monthly payment, and procedures should be established for the times when families cannot make the payment.**

Table 10-2: Monthly Payment Levels for Each Treatment Option

	Monthly payment over 12 months	**Monthly payment over 24 months**	**Approx. monthly O&M after capital is paid off**
Table Filter (or TF+ SODIS)	S/ 3.5 ($1)	S/ 2.5 ($0.7)	S/ 1.5 ($0.4)
Safe Water System	S/ 4 ($1.1)	S/ 2.5 ($0.7)	S/ 0.9 ($0.25)
Table Filter + SWS	S/ 7 ($2)	S/ 4.5 ($1.3)	S/ 2.5 ($0.7)

Another concern that must be addressed is the problem of switching families to a household-funded system from the current system in which everyone has received their treatment systems for free. Additional recipients of the products presumably would be expected to cover at least some of the cost. This would probably meet with some resistance in the villages where treatment systems are already distributed because people know that their neighbors received them for free. Also, it may be difficult to get current system owners to start paying operation and maintenance costs (e.g. disinfectant production each month or the replacement of ceramic candles or spigots). These issues should not be of much concern when implementing the household treatment systems in *new* towns and villages.

Since this is mostly a technical report and not a business plan, the suggestions provided here in regards to funding the household water treatment systems are very brief. **It is recommended that a business model or cost recovery plan be created for the wide implementation of the low-cost treatment systems analyzed in this report. The business report regarding these household treatment systems in Peru, "H_2O-1B!: Bringing Safe Water to the World" (Cerilles, et al., 2004), should be consulted in conjunction with this engineering report.**

Finally, all of the information presented in this thesis should be helpful in the continuing search for appropriate and successful low-cost household drinking water treatment systems for countries around the world.

Appendix A: March 2004 Field Report: “Evaluation of Household Systems in La Joya”

A continuation of Coulbert’s and the H_2O-1B! team’s research in Peru by Longhi and del Carpio (Longhi, 2004).

SUMMARY

During one month were evaluated different households systems; in total 11 Filters and 33 Chlorination systems or *Bidones*; in the town of Cerrito Buena Vista in La Joya.

Also were evaluated twice two different treatment plants wich are:

- Cerrito Buena Vista Treatment Plant
- El Triunfo Treatment Plant

This evaluation consisted mainly in two evaluations:

1. Field Evaluation, that involves Chlorine free test (if the sample had *chloro*) and turbidity test, also only for Filters were evaluated the rate of filtration (Flow rate).
2. Laboratory Evaluation, that involves H_2S Test and coliform analysis.

For each system was sampling the input water or tap water and the output or treated water.

Also were made surveys with the owners of the purification systems, to know about the utility of this ttreatment water systems.

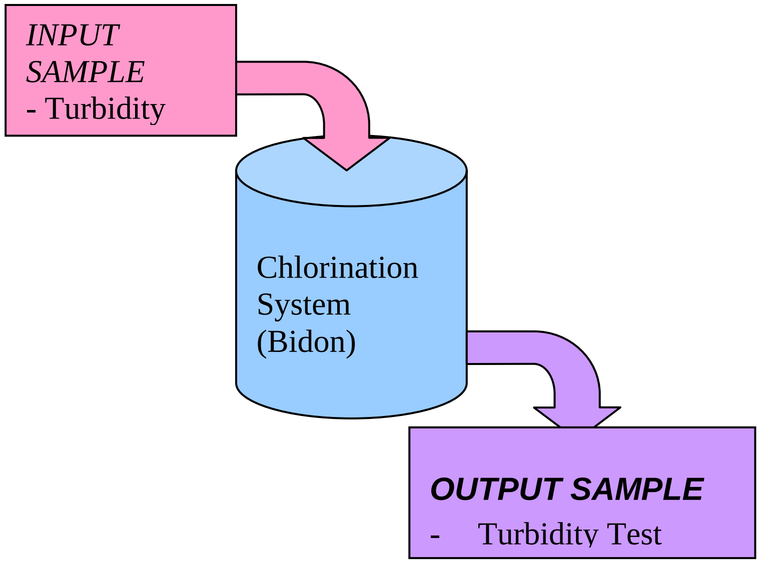
FIELD EVALUATION

1. Chlorinations Systems (*Bidones*)

For this case was made two sampling fo the input and output water, that involves two tests:

a) *Chloro* Free test for treat water.

b) Turbidity test for treated and not treated water.


INPUT SAMPLE
- Turbidity
Chlorination System (Bidon)
OUTPUT SAMPLE
- Turbidity Test

Results:

N°	Date	Sample	Chl. Free mg/L	Turbidity (UNT)	
				In	Out
1	March 10	C - 7	0.23	3.0	2.6
2	March 10	LL 18	0.10	14.2	4.2
3	March 10	LL - 27	0.13	3.9	3.5
4	March 11	M - 8	NP	16.1	3.4
5	March 11	LL - 2	0.03	14.2	6.1
6	March 11	I - 1	0.14	4.8	3.2
7	March 16	LL - 22	0.00	4.6	9.2
8	March 16	F - 7	0.20	4.1	5.3
9	March 16	E -2	0.23	15.2	5.3
10	March 17	LL - 11	0.23	7.4	11.1
11	March 17	M - 1	0.07	9.2	10.5
12	March 17	L - 16	1.09	7.9	7.9
13	March 18	N - 1	Too pink	10.2	9.5
14	March 18	M - 17	0.07	8.7	10.8
15	March 18	L - 1	NP	6.9	10.5
16	March 19	M - 17B	0.19	5.8	50.5
17	March 19	H - 10	0.54	18.9	16.1
18	March 19	LL - 4	0.18	9.6	7.0
19	March 23	L - 11	0.09	11.0	7.5
20	March 23	L - 10	0.15	7.2	3.8
21	March 23	M - 19	0.09	7.9	10.5
22	March 24	M - 19B	0.11	7.9	7.0
23	March 24	LL - 23	0.02	9.5	7.3
24	March 24	LL - 9	0.06	6.0	128.0
25	March 24	N - 3	0.07	11.8	9.2
29	March 25	CBV Post	0.10	9.8	13.1
30	March 25	CBV Kindergarden	0.32	9.5	2.1
31	March 26	B - 2	0.05	171.0	269.0
32	March 26	A' - 2	0.10	6.3	3.0
33	March 26	A' - 7	0.30	3.5	3.0
34	March 26	A' - 5	0.05	56.5	24.0
35	April 01	A' - 3	0.04	FFF	323.0
38	April 02	A' - 5B	0.29	173.0	267.0

NP: Occurs when the sample didn´t turn pink, so probably it hasn´t *chloro*.

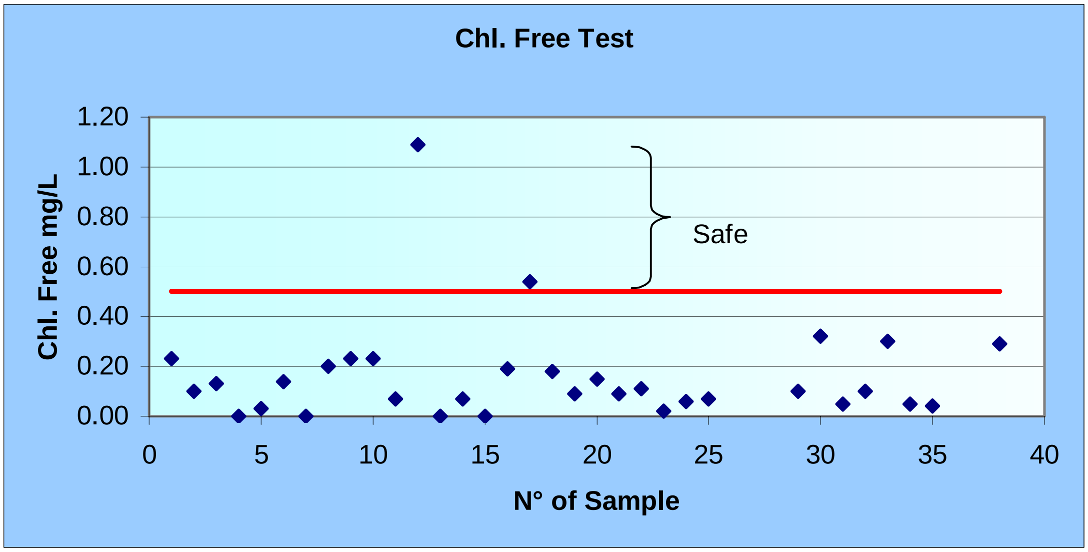
Too pink: Occurs when the sample turned too pink so was imposible to titrate until the sample turned transparent.

About the *Chloro* results, we can see that almost all of the samples are outside the safe range[56], only two of them are in the safe range. So this indicate that probably this system is not the best option to treat the Cerrito Buena Vista Water, because this water is too polluted.

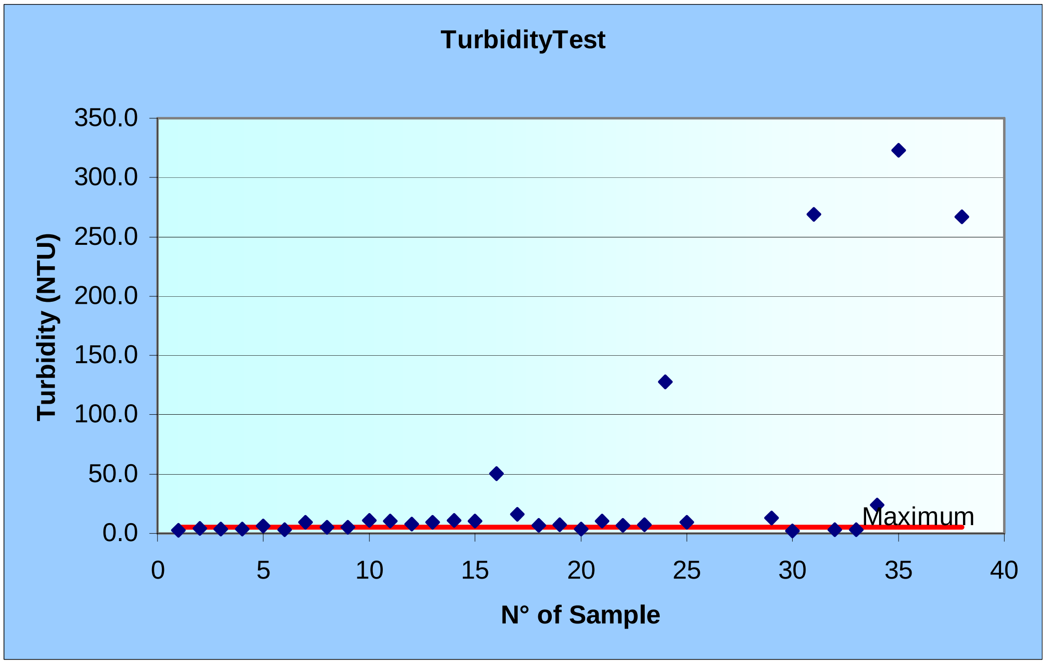
[56] Note by Coulbert: Longhi and the San Augustine research team were misinformed that free chlorine should be between 0.5 and 1.0 mg/L. In fact, it should be 0.2 – 1.0 mg/L. Therefore, a larger number of their findings were within the acceptable range.

Otherwise, some of the people didn´t know exactly how much *chloro* they have to add to the water or iin some cases they didn´t change this water often.

Also is important the day of sampling because there are some days that the water is more polluted than other days, maybe according to this, the people should have to add more *chloro* to their *bidones*.



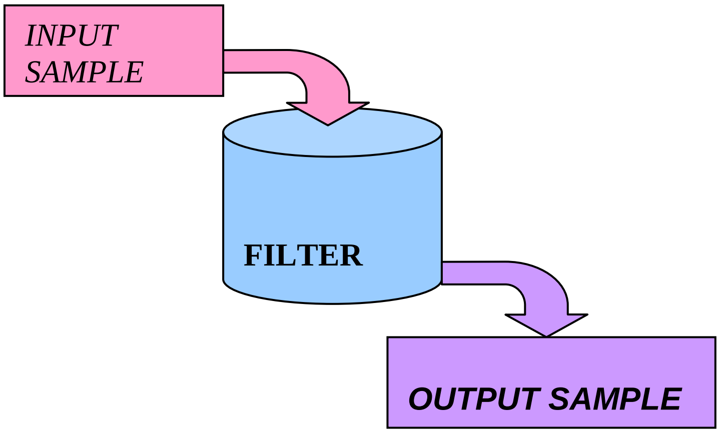
About turbidity results we can appreciate that there are less samples that are outside the safe range, but also there are samples that have too big turbidity results, this because the people put still dirty water into the *bidon* where settle and like the sample was taken from the spicket, this takes the settled part.



2. Filters

For filters the only analysis made was the turbidity test for input and output samples, besides the flow rate messure that involves the rate of the filtration.

There were some cases when "the filter wasn't working", this means that thus people use the filter but at the time when the samples was taken the top bucket was empty, so we couldn´t messured the flow rate, so this samples doesn't have this results.

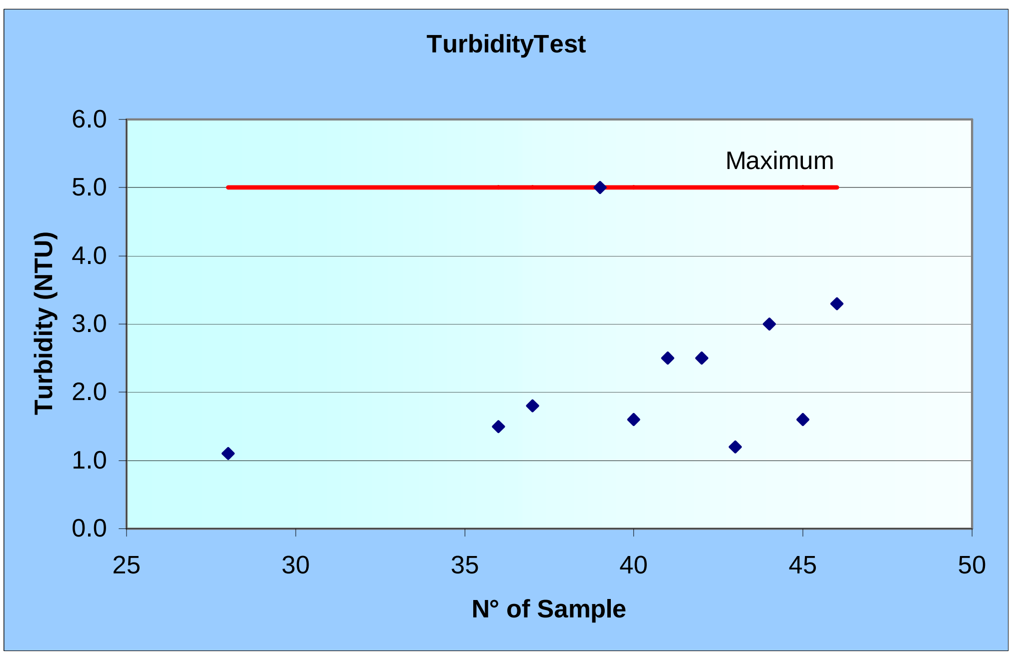


Results:

N°	Date	Sample	Turbidity (UNT)		Flow Rate (mL/sec)	
			In	Out	Left	Right
28	March 25	CBV Post	9.8	1.1		
36	April 01	H - 3	6.0	1.5	0.3913	0.3478
37	April 01	E - 9	5.2	1.8	0.0833	0.1
39	April 02	H - 2	5.7	5.0	-	-
40	April 02	O - 3	8.1	1.6	0.3	0.275
41	April 03	H - 1	9.3	2.5	0.1333	0.1511
42	April 03	B - 7	5.0	2.5	0.32	0.36
43	April 03	G - 8	5.5	1.2	0.0333	0.0333
44	April 04	H - 13	4.5	3.0	0.1111	0.0889
45	April 04	B - 5	3.7	1.6	-	-
46	April 04	N - 1	6.3	3.3	0.2222	0.2

We can apperciate that all of the samples are in the safe range, so the turbidity of the water decrease significally after been filtered, so we can say that the quality of water improve positively using the filter.

About the Flow rate results, we can see that they are not so similar,because some of the filters were cleaner than the others, because of the time they cleaned it or the quality of the waer of that day.



3. Treatment Plants:

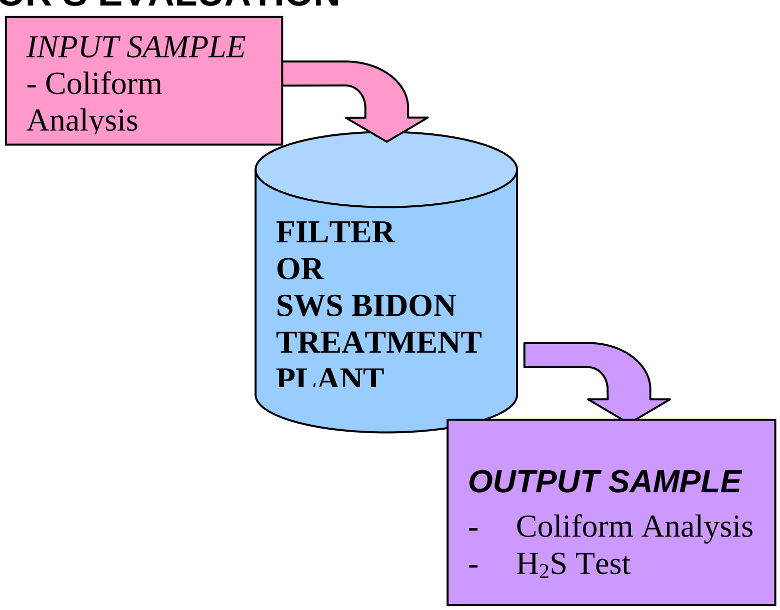
The treatment plants were evaluated only two days.
The first day was on March 25 when the canal water was too dirty that's why the turbidity values were so high that couldn't be measured by the turbidimeter (Results FFF), and for the Treatment plant of El Triunfo the sand filter wasn't working this day.
The second day on April 4 the values of turbidity are well but the *Chloro* results for El Triunfo are too high because the place of sampling is the same place where the *chloro* is added and there isn't other place where we could take the sample.

The evaluation system is the same as Chlorination system, we evaluate turbidity for input samples and turbidity and *Chloro* free for output samples.

Results:

N°	Date	Sample	Chl. Free mg/L	Turbidity (UNT)	
				In	Out
26	March 25	El Triunfo Treatment Plant	0.29	FFF	40.5
27		Cerrito Buena Vista Treatment Plant	0.46	FFF	FFF
47	April 04	Cerrito Buena Vista Treatment Plant	0.50	40.2	32.7
48		El Triunfo Treatment Plant	Too pink	37.2	52.7

LABORATOR'S EVALUATION



The Lab evaluation consisted in H_2S test and Coliform analysis.

Procedures: All the procedures were made following the instructions of the method.

Coliform Analysis

The only new procedure was the coliform analysis with Lauril Sulfate broth, which is the exactly the same method used for the e-coli blue broth, but this time the medium was prepared previously. (This is the only difference, besides the counting, we counts the well formed yellow colonies).

Preparation of Lauril Sulfate Medium:

- Pour 100 ml sterilized water.
- Add 7.6 gr. Of the medium.
- Bring to Autoclave on 120°C for 15 minutes.
- This medium was distributed on differents tubes containing 2 ml of medium each.
- So instead of the sachets we used the tubes to put the medium into the petri dishes.

The other part of the thecnic is exactly the same.

Other difference is in the counting, for Lauril Sulfate we count only well fromed yellow colonies.

Everyday were made one blank and one duplicate.

For Input samples were filtered 50 ml of the sample diluted (0.1, 0.001, 0.0001 or 0.00001).

For Output samples were filtered directly 10, 20, 30, 40 or 50 ml of the sample.

For Blank were always filtered 100 ml of clean water used for the dilutions.

For each samples, we tried at list with two dilutions.

For Example:

Date: March 23

Sample: M19

For Input: we filtered first 50 ml of 0.001 diluted sample then 50 ml of 0.01 diluted sample.

For Output: we filtered directly 20 ml of the samples and then 50 ml of the sample.

Counting Results:

After 24 hours of incubation we count the colonies formed in the plate.

INPUT SAMPLES

To expres the counting results for ***Diluted Samples*** in Coliform Counts/100 ml we used the following formula:

$$\boxed{\text{Coliform Counts/100 ml} = \frac{\text{Colonies counted per plate x 100}}{\text{Filtered volume x dilution}}}$$

For Example: For March 10; sample C-7 Dilution 2.

Counting results = 23 yellow colonies

$$\text{Coliform Counts/100 ml} = \frac{23 \text{ x } 100}{50 \text{ x } 0.01}$$

Coliform Counts/100 ml = 4600 = 46 x 10^2

For Example: For April 03; sample H-1 Dilution 2.

Counting results = 10 yellow colonies per plate

$$\text{Coliform Counts/100 ml} = \frac{10 \text{ x } 100}{50 \text{ x } 0.001}$$

Coliform Counts/100 ml = 20000 = 20 x 10^3

OUTPUT SAMPLES

To express the counting results for ***Samples*** directly filtered in Coliform Counts/100 ml we used the following formula:

$$\text{Coliform Counts/100 ml} = \frac{\text{Colonies counted per plate x 100}}{\text{Filtered volume}}$$

For Example: For March 23; sample L-10 Dilution 2.

Counting results = 6 yellow colonies

$$\text{Coliform Counts/100 ml} = \frac{6 \times 100}{50}$$

Coliform Counts/100 ml = 12

For Example: For April 03; sample H-1 Dilution 1.

Counting results = 26 yellow colonies per plate

$$\text{Coliform Counts/100 ml} = \frac{26 \times 100}{20}$$

Coliform Counts/100ml = 130 = 13 x 10^1

In the following chart we can appreciate the counting results expressed in Coliform counts/100 ml of samples.

To make a better analysis of this results we take just one per sample as follow:

BIDON RESULTS

COLIFORM COUNTS / 100 mL						Rate of Reduction	% Reduction
INPUT			OUTPUT				
E. Coli (*)	C. Totales (*)	C. Fecales (**)	E. Coli (*)	C. Totales (*)	C. Fecales (**)		
20	4400	-	4	TNTC	-	16	80.00
100	1200	-	2	3	-	98	98.00
20	660	-	0	20	-	20	100.00
10000	50000	-	6	TNTC	-	9994	99.94
5000	15800	-	8	TNTC	-	4992	99.84
24000	13400	-	0	14	-	24000	100.00
-	-	13000	-	-	30	12970	0.23
-	-	14000	-	-	0	14000	0.00
-	-	5600	-	-	20	5580	0.36
7200	28000		5	665	-	7195	99.93
12800	19000		6	TNTC	-	12794	99.95
-	-	19000	-	-	40	18960	99.79
-	-	11800	-	-	50	11750	99.58
-	-	48000	-	-	350	47650	99.27
-	-	1000	-	-	1000	0	0.00
-	-	14000	-	-	66	13934	99.53
-	-	20000	-	-	500	19500	97.50
-	-	20800	-	-	30	20770	99.86
-	-	6000	-	-	235	5765	96.08
-	-	32000	-	-	12	31988	99.96
-	-	12000	-	-	10	11990	99.92
-	-	12000	-	-	95	11905	99.21
-	-	18000	-	-	5	17995	99.97
-	-	600	-	-	50	550	91.67
-	-	4000	-	-	60	3940	98.50
-	-	90000	-	-	130	89870	99.86
-	-	80000	-	-	50	79950	99.94
-	-	40000	-	-	TNTC		0.00
-	-	4000	-	-	66	3934	98.35
-	-	2000	-	-	70	1930	96.50
-	-	2000	-	-	235	1765	88.25
-	-	20000	-	-	TNTC		0.00
-	-	20000	-	-	65	19935	99.68

The rate of reduction of coliforms for the treated water by *chloro* is at least 80% in most of them, but there are cases where this rate is too little, so the good performance of the *bidon* depends on water's quality, depending how polluted is the water.

But this rate of reduction is not enough, this treated water by *chloro* is not completely clean, we can see that it has considerable coliform presence, so we couldn´t say that this is a good treatment system for this kind of water.

FILTER RESULTS

N°	Date	Sample	COLIFORM COUNTS / 100 mL		Rate of Reduction	% Reduction
			INPUT	OUTPUT		
			C. Fecales (**)	C. Fecales (**)		
47	March 25	CBV Post	90000	0	90000	100.00
59	April 01	H - 3	4000	86	3914	97.85
60	April 01	E - 9	4000	40	3960	99.00
64	April 02	H - 2	10000	32	9968	99.68
65	April 02	O - 3	16000	20	15980	99.88
67	April 03	H - 1	20000	130	19870	99.35
68	April 03	B - 7	26000	130	25870	99.50
69	April 03	G - 8	2000	2	1998	99.90
72	April 04	H - 13	1400	0	1400	100.00
73	April 04	B - 5	2000	0	2000	100.00
74	April 04	N - 1	12000	0	12000	100.00

We can appreciate that the rate of reduction is over 99%, so we can say that the filters are working very well. The treated water by filters is a clean water, the people can drink it, so this is a good treatment system for this kind of water.

TREATMENT PLANT RESULTS

N°	Date	Sample	COLIFORM COUNTS / 100 mL		Rate of Reduction	% Reduction
			INPUT	OUTPUT		
			C. Fecales (**)	C. Fecales (**)		
43	March 25	El Triunfo T. P.	200000	18400	181600	90.80
45	March 25	Cerrito Buena Vista T. P.	200000	70000	130000	65.00
75	April 04	El Triunfo T. P.	20000	0	20000	100.00
79	April 04	Cerrito Buena Vista T. P.	5000	50000	-45000	-900.00

We can see that treatment plants help a lot treating the water of the canal that is very polluted, maybe without this treatment we couldn´t get good results.

Specially we can see the good performance of El Triunfo Treatment Plant on April 04, but we can’t say this is a real result because of the place the sample was taken.

CONCLUSIONS:

Filter System is the best Household system for Cerrito Buena Vista Water.

Appendix B: Executive Summary of the Business Report: “H_2O-1B!: Bringing Safe Water to the World”

Report by the business team of H_2O-1B! (Cerilles, Lieu, & Obizhaeva, 2004)

One sixth of the world, or 1.1 billion people, currently lacks access to improved water sources and many more lack access to clean drinking water. There are 1.7 million deaths every year, mainly through infectious diarrhea and mostly among children under five years of age, related to unsafe water, sanitation and hygiene. Diarrheal diseases are the third highest cause of morbidity and sixth highest cause of mortality.[57]

The H_2O-1B! project attempts to answer the complex question of how to supply clean drinking water to greater than 1 billion people. Our approach is to take a multidisciplinary look at the technical, social and economic sustainability of innovative household-based (herein referred to as POU, Point of Use) drinking water treatment solutions. Each team consists of MIT Master of Engineering and Sloan Global Entrepreneurial Lab students. We hope to develop effective strategies for the evaluation, implementation and scale-up of POU water system deployments. The H_2O-1B! teams went to the Dominican Republic and Peru in January 2004 to examine existing projects in order to return to the U.S. with data for comparative analysis.

Project Context and Goals

Our main goal was to perform “social marketing” analysis and develop guidelines on the implementation of sustainable drinking water projects.

It is widely accepted by international community that in order to solve the drinking water problem we have to find a sustainable solution involving the local community in the process as much as possible. When choosing a solution, administrators should offer programs that would be well-matched technically with the needs of the community as well as socially, operationally and economically viable.

First and foremost, we must consider the correct technical solution, i.e. ones that protect public health, but we must also ensure that the solution is socially feasible. Many drinking water projects have failed in the past for political, financial and behavioral reasons. The World Development Report (World Bank, 2004)[58] identifies four failures:

1. Governments spend very little of their budgets on poor people;
2. Even spending earmarked for poor people does not always reach the frontline providers;
3. Even highly motivated service providers are caught up in a system where incentives to provide good quality services are weak, corruption is rife and political patronage is a way of life;

[57] *International Network to Promote Household Water Treatment and Safe Storage*, WHO brochure (Geneva, Switzerland, August, 2003), p. 2.

[58] World Bank. World Development Report, 2004: Making Services Work for Poor People 2004. World Bank and Oxford University Press, Washington DC

4. Demand for services is often weak because of poor quality, high cost in time and money and cultural factors. When services are poor quality or inaccessible, poor people don't use them, even when they are free.

We tried to understand the most crucial factors in implementation of different solutions, and tried to identify what multiple objectives that should be taken in account.

Second, there are many examples of projects that were initially successfully, but failed over time. Operational issues such as the lack of maintenance structure, which left broken systems unfixed and abandoned, often causes latent failures.

Third, we have to be sure that the solution is economically and financially feasible. One of the potential ways to achieve this is to privatize the system, i.e. to make clean water a marketable good that is bought and sold in the local market, either through the marketing and sale of household treatment systems or through sales of bottled or vended water To understand how plausible this is, we have to answer two questions: (a) How much will it cost to produce and implement the system? (b) How much are people willing to pay for it? Will this be a profitable business, and if not, then how much should international / local governments or NGO's subsidize the cost of clean water?

Dominican Republic
The Dominican Republic BioSand Filter (BSF) project is a successful effort, begun and directed by Dr. Jan Tollefson, to construct, market and disseminate a concrete version of a household scale intermittent slow sand filter, originally designed by Dr. David Manz of Calgary, Canada. .

The project follows a micro-entrepreneurial dissemination model. It has distributed over 3,600 filters to date, mainly in the northwest region of the Dominican Republic, through extensive subsidies of the filters and the local micro-entrepreneurial businesses supplying the filters. Except for some problems with too high flow rates causing less than optimal performance, the filters are of high quality, and almost all the filter users we met were happy with their filters. The most significant technical problem we observed was the recontamination of the filtered water from unsafe water storage. Safe water storage containers should be bundled with the filters to improve water safety.

The challenge for the project now is to find an effective method to spread the program to the rest of the Dominican Republic, and also to neighboring areas of Haiti where the water quality situation is even worse. The dilemma faced by the BSF project and the technicians is how to reconcile the challenges of building a viable BSF filter business with the complexities of satisfying the humanitarian water needs of the poor people.

We examined the following questions to analyze the sustainability of the BioSand filter project:
- How effective are the BioSand filters in delivering clean drinking water to consumers at the point of use??
- Is there a viable micro-entrepreneurial business model for the sale of BioSand filters?

- Is the current business model successful in the context of the Dominican Republic? If not, what is the most efficient and sustainable method for delivering clean drinking water to those without access to it?

We found that although there is a viable market for the BioSand filter, this is a one-time business opportunity due to the BSF filter's durability and low maintenance. The entrepreneurs must therefore find an appropriate exit strategy for when the market becomes saturated. Nonetheless, the entrepreneurs are motivated to produce high quality filters and offer superior support to filter users under the current model. The best market for the commercial sale of these filters is the bottled water market, which is about 42% of the population, since consumers in this segment are already interested in clean drinking water, have the ability to pay and can be enticed by the cost savings of filtering their own water. The entrepreneurs must now find distributors to partner with to expand their businesses beyond their local markets.

To spread the program further, we believe that the program needs to raise people's willingness to pay through education and by offering micro-financing. The program should also offer communities the option of producing filters themselves, under the supervision of the entrepreneurs, so that they may barter their own labor against the cost of the filters and the entrepreneurs are freed to focus on their commercial businesses. Lastly, we believe that it is necessary to establish a local NGO to manage the BioSand filter project locally so that the capacity of the local people and organizations is developed.

Peru

CEPIS, our host organization in Peru has implemented several household drinking water projects, one from 1995 – 1998 in 5 regions including the desert, the Andes and the jungle, reaching a population of 245,000; and a second project, a disaster relief project in the states of Arequipa and Tacna, initiated after an earthquake in 2001. Complicating matters, Peru is a fairly large country of great geographic variability, with medium-sized country – not a big one. A wide variety of initial "raw" water conditions that dictates a multitude of approaches. The dissemination model could be referred to as "agency-driven" by which we mean that it was supported by multi-lateral and bi-lateral funding, and administered through CEPIS, the technical branch of the Pan American Health Organization, which in turn is part of the World Health Organization. At the local level, the household water treatment interventions were administered by the regional and local Ministries of Health.

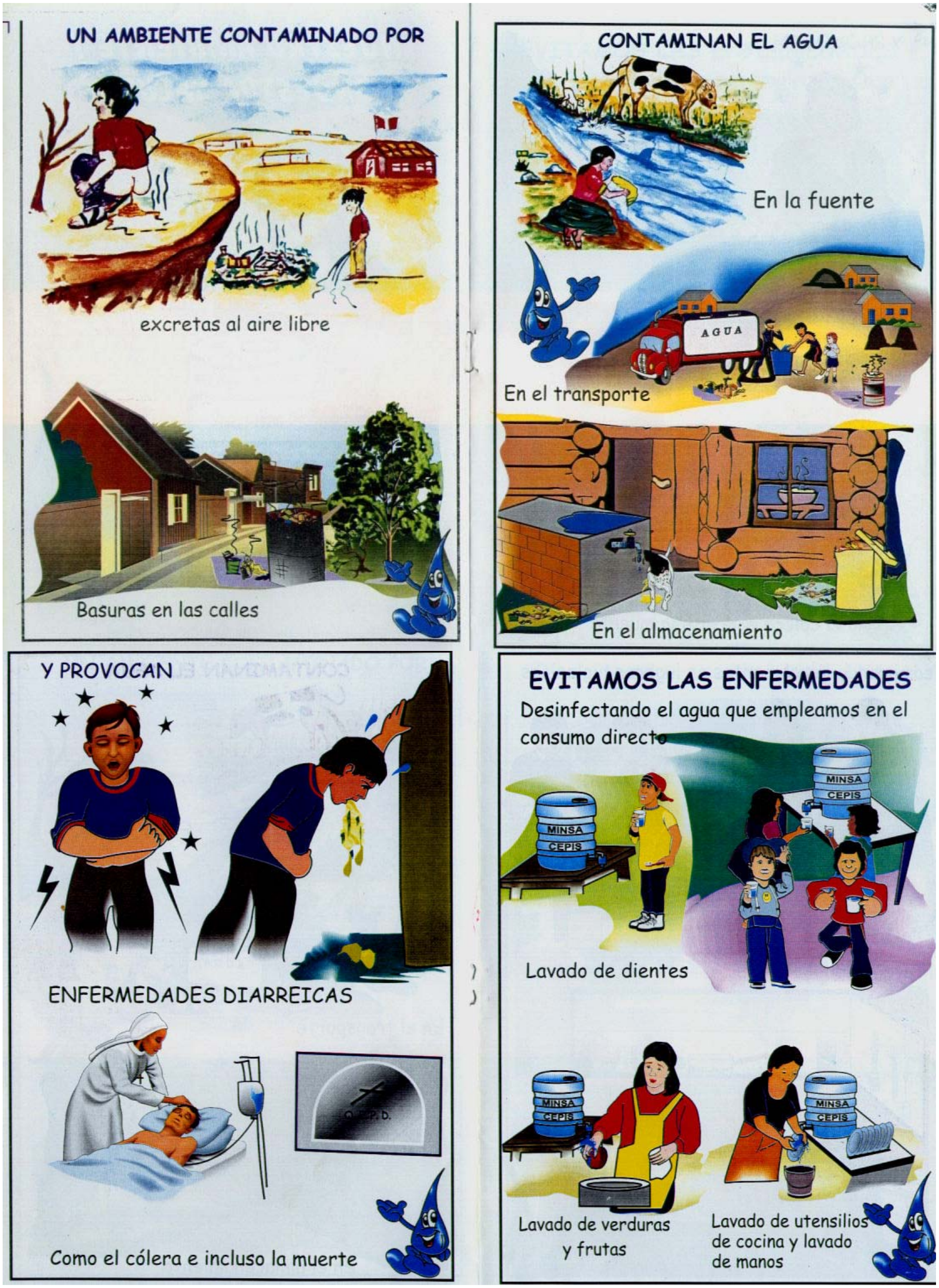
The challenge for the H_2O-1B team was to grasp a large diversity of programs and geographical settings in a short time and to identify a patterns of success and/or failure, which we could then use to create guidelines for going forward.

We worked in two areas in southern Peru: the La Joya District of Arequipa and the Tarata and Micula Districts and coastal area of Tacna. These areas were chosen for their geographic and social similarity. Yet, we found projects in these two neighboring states to have very different results: quite successful in Tacna and less successful in Arequipa. This gave us a good chance to identify the some crucial elements for successful implementation of household drinking water systems.

Our main conclusion is that the principal factors that influence success have to do with commitment and leadership of the personnel in the Health Ministries charged with project implementation. In other words, the people who implement the program and their attitude and sense of responsibility towards the problem correlated directly with the success or failure of the program. The education of medical personnel, the operational dynamics and the time and efforts spent on interacting with local people are likely proportional to the rate of success.

Appendix C: "Our Environment and Our Health" Pamphlet Distributed by the Ministry of Health in Peru

(English translation in Table 5-4 in Section 5.3.3.)


UN AMBIENTE CONTAMINADO POR
excretas al aire libre
Basuras en las calles
CONTAMINAN EL AGUA
En la fuente
AGUA
En el transporte
En el almacenamiento
Y PROVOCAN
ENFERMEDADES DIARREICAS
Como el cólera e incluso la muerte
EVITAMOS LAS ENFERMEDADES
Desinfectando el agua que empleamos en el consumo directo
MINSA
CEPIS
Lavado de dientes
Lavado de verduras y frutas
Lavado de utensilios de cocina y lavado de manos


comprando los alimentos en lugares higienicos
Protegiendo los alimentos


Construyendo y usando nuestras letrinas
Limpiando las calles de la comunidad
Manteniendo limpia nuestra casa


¿CÓMO DESINFECTAR EL AGUA?
1.- Mida media tapita de desinfectante.
2.- Agregue la media tapita de desinfectante al bidón vacío.
3.- Agregue 20 litros de agua.
4.- Espere 30 minutos.
MINSA
CEPIS
MINSA
CEPIS

Appendix D: Methods Use for Creating Dilutions for Membrane Filtration in this Study

To test 0.1 ml of water (10^{-1}):

- Mix 90 ml blank water with 10 ml sample water. This creates a 1:10 solution.
- Pipette 1 ml of 1:10 solution onto 20-30 ml of blank water in the MF funnel.

…or…

- Pipette 10 ml of 1:100 solution onto 20-30 ml of blank water in the MF funnel.

To test 0.01 ml of water (10^{-2}):

- Mix 99 ml blank water with 1 ml sample water. This creates a 1:100 solution.
- Pipette 1 ml of 1:100 solution onto 20-30 ml of blank water in the MF funnel.

To test 0.001 ml of water (10^{-3}):

- Mix 90 ml of blank water with 10 ml of 1:100 solution. This creates a 1:1000 solution.

…or…

- Mix 99 ml of blank water with 1 ml of 1:10 solution. This creates a 1:1000 solution.
- Pipette 1 ml of 1:1000 solution onto 20-30 ml of blank water in the MF funnel.

To test 0.0001 ml of water (10^{-4}):

- Mix 99 ml of blank water with 1 ml of 1:100 solution. This creates a 1:1000 solution.
- Pipette 1 ml of 1:1000 solution onto 20-30 ml of blank water in the MF funnel.

Appendix E: Spanish Interview Questions and their English Translations

E.1 General Questions for all Households

E.1.1 English Version

<u>Family Composition and Wealth Information</u>

1. Number of inhabitants? How many children under 5?
2. Number of rooms in house?
3. Who in the house works outside the home and what does s/he do?
4. Do you have electricity? If so, how much do you normally pay each month for electricity?
5. In general, how much money do you spend each month for everything for the family (including food, tools, supplies, transportation)?

Do not ask the following, just write down observations:

6. House type:
7. Floor type:
8. Wealth indicators and estimate of relative affluence:

<u>Outside the home</u>

1. How many hours are you normally outside the home per day? Your spouse? The children?
2. What do you drink when you are not at home?
3. Do you ever buy water? If yes, from where?
4. Where do you go to buy necessities?

<u>Water source</u>

1. Where do you get your water?
2. Was the water dirty before you started using the filter? If yes, how did you know and what did you do to make it clean?

E.1.2 Spanish Version

Encuesta: Preguntas Generales para las Familias

Departamento: Localidad:____________________.
Casa de:____.
Dirección:____.
Fecha de Entrevista:____.

PREGUNTA
<u>Composición de la Familia e Información sobre sus Ingresos</u>

1. Número de miembros conforman la familia? ¿Cuántos niños menores de 5 años?
2. Número de habitaciones que hay en la casa?
3. ¿Quién trabaja fuera del hogar y que es lo que él/ella hace?
4. ¿Tiene luz eléctrica?. Si es así, ¿cuánto normalmente paga por mes?
5. En general, ¿Cuánto dinero gasta mensual para las cosas de la familia (incluyendo comida, herramientas transporte y provisiones?
6. Tipo de vivienda
7. Tipo de piso
8. Indicadores económicos y estimar la riqueza relativa:
1. ¿Cuántas horas normalmente está fuera de casa por dia?¿Su esposo?¿Sus hijos?
2. ¿Qué bebe cuando no esta en casa?
3. ¿Compra agua? Si es así ¿Dónde la compra?
5. ¿Dónde compra todo lo que necesita?
1. ¿Dónde consigue el agua que necesita?
2. ¿Era el agua sucia antes de que empezara a usar el filtro? Si es así, ¿cómo lo supo y que hacía para limpiarlo?

E.2 Questions for Households with Table Filter

E.2.1 English Version

Filter use, operation and maintenance

1. Is the taste of the water better, worse, or the same with the filter than from before?
2. Since you've begun using the filter, do you use more water, the same amount, or less?
3. Do you filter all the water you and the rest of the family use?
4. Do you ever drink unfiltered water? If so, when?
5. Since you started using the filter, do you feel better?
6. Does the filter produce enough clean water for the whole family?
7. Who usually use the filter?
8. Do the children know how to use the filter?
9. How do you clean the filter? How often do you do this?
10. How often do you replace the filter?
11. If the filters or candles were sold in this area, where and in what kind of shop would you expect to find them?
12. If the filter were broken, could you fix it yourself (assuming spare parts were available) or would you need a technician to come and fix it?

Perception

1. Do you think using the filter is beneficial for your family?
2. Is it easy to use the filter?
3. Do you like the filter? Why or why not?
4. Would you recommend the filters to others?
5. Have you had any problems with the filter?

6. Do you have any complaints about the filter?

Willingness to pay

1. Imagine that your filter system is broken and they are no longer distributed for free. Would you buy the new one and if yes how much you are willing to pay for it?

   For surveyor: we will try to obtain more accurate "willingness to pay information by using a split-case method. Each time you do an interview, start with different initial prices (5$, 10$, 15$) then try to find the maximum price they are willing to pay.
   For example in one case you might ask: "Will you pay $10?" Yes. "Will you pay $12?" Yes. "Will you pay $14?" No." Stop here.
   The actual price is something in between, in this case, $13. So you will write down the last price $13 in the answer section.

2. Do you think that your neighbors will buy filters for this price?
3. Would it be better if the filters were sold by making monthly payments? If so, how much should the monthly payment be?
4. How much do you think it costs to produce this filter?

E.2.2 Spanish Version

Encuesta: Casas con el Sistema de Filtro

Departamento: Localidad:____________________.
Casa de:____.
Dirección:____.
Fecha de Entrevista:____.

PREGUNTA
Uso del Filtro, operación y mantenimiento
1. Es el sabor del agua mejor, peor o el mismo con el filtro que antes de él?
2. Desde que Ud. empezó a usar el filtro. ¿Usa más agua, la misma cantidad o menos?
3. ¿Filtra toda el agua que Ud. y el resto de la familia usa?
4. ¿Alguna vez ha bebido agua no filtrada? Si es así, ¿cuándo?
5. Desde que Ud. empezó a tratar su agua, ¿se siente mejor?
6. ¿Produce el filtro suficiente agua limpia para toda la familia?
7. ¿Quién generalmente usa el filtro?
8. ¿Los niños saben como usar el filtro?
9. ¿Cómo limpia el filtro?¿Cuán a menudo hace esto?
10. ¿Cuán a menudo reemplaza el filtro?
11. Si los filtros o las velas fueran vendidos en esta área, ¿Dónde y en que clase de tienda esperaría encontrarlos?
12. Si el filtro se rompiera ¿podría arreglarlo Ud. mismo (asumiendo que las partes estuvieran disponibles) o necesitaría un técnico que venga a arreglarlo?

1. ¿Piensa que usar el filtro es beneficioso para su familia?
2. ¿Es fácil usar el filtro?
3. ¿Le gusta como el filtro? ¿Por qué?
4. ¿Recomendaría el filtro a otros?
5. ¿Ha tenido problemas con el filtro?
6. ¿Tiene quejas acerca del filtro?
1. Imagine que su sistema de filtro esta roto y ya no se distribuyen más gratis. ¿Compraría uno? Y si es así ¿Cuánto estaría dispuesto a pagar por él ?
2. ¿Piensa que sus vecinos comprarían el filtro por este precio?
3. ¿Sería mejor si los filtros fueran vendidos en pagos mensuales? Si es así, ¿Cuánto sería el pago mensual?
4. ¿Cuánto piensa Ud. que cuesta producir este filtro?

E.3 Questions for Households with *Bidon* (Chlorination System)

E.3.1 English Version

<u>Filter use, operation and maintenance</u>

1. Is the taste of the water better, worse or the same after treatment (adding chlorine) than before?
2. Since you've begun treating your water, do you use more water, the same amount, or less?
3. Do you treat all the water you and the rest of the family use?
4. Do you ever drink untreated water? If so, when?
5. Since you started treating your water, do you feel better?
6. Who is responsible for treating the water?
7. Do the children know how to treat the water?
8. How often do you treat (add chlorine) to the water?
9. When was the last time you added chlorine to the water?
10. When was the last time you consulted the distributor of the system for maintenance?
11. Where do you store your chlorine?

<u>Perception</u>

1. Do you think treating water is beneficial to your family?
2. Is it easy to treat the water?
3. Do you like the treated water and the treatment system? Why or why not?
4. Would you recommend treating water to others?
5. Have you had any problems with the treatment?
6. Do you have any complaints about the treatment?

<u>Willingness to pay</u>

1. Imagine that the post is shut down but you still have at home your 20-liter can which was distributed to you for free. But you can buy the bottle of disinfection solution which will be

enough for you to use for 4 weeks. What is the maximum price you are willing to pay for it if any?

2. Do you think that your neighbours will do the same?
3. Imagine that you lost the can and it is not distributed now for free. Will you still buy it?
4. If yes then how much you are willing to pay for it?
5. Do you think that your neighbours will do the same?

E.3.2 Spanish Version

Encuesta: Hogares que cuentan con Sistema de Clorinación

Departamento: Localidad:____________________.
Casa de:____.
Dirección:____.
Fecha de Entrevista:____.

PREGUNTA
Uso del Filtro, operación y mantenimiento
1. Es el sabor del agua mejor, peor o el mismo despues del tratamiento (agregando cloro) que antes?
2. Desde que Ud. empezó a tratar su agua. ¿Usa más agua, la misma cantidad o menos?
3. ¿Trata toda el agua que Ud. y el resto de la familia usa?
4. ¿Alguna vez ha bebido agua no tratada? Si es así, ¿cuándo?
5. Desde que Ud. empezó a tratar su agua, ¿se siente mejor?
6. ¿Quién es el responsable del tratamiento del agua?
7. ¿Los niños saben como tratar el agua?
8. ¿Cuán a menudo trata (agrega cloro) al agua?
9. ¿Cuándo fue la última vez que agregó cloro al agua?
10. ¿Cuándo fue la última vez que consulto al distribuidor del sistema por su mantenimiento?
11. ¿ Dónde compra el cloro?
Percepción
1. ¿Piensa que tratar el agua es beneficioso para su familia?
2. ¿Es fácil tratar el agua?
3. ¿Le gusta como trató el agua y el sistema de tratamiento?
4. ¿Piensa que tratar el agua es beneficioso para su familia?
5. ¿Es fácil tratar el agua?
6. ¿Le gusta como trató el agua y el sistema de tratamiento?
1. Imagine que la posta esta cerrada pero Ud. aún tiene en casa su envase de 20 litros el cual fue distribuido gratis. Pero Ud. quiere comprar la botella con la solución de desinfección la cual sera suficiente para su uso por 4 semanas. ¿Cuál es el máximo precio que Ud. estaría dispuesto a pagar por el o cualquiera?
2. ¿Piensa que sus vecinos harán lo mismo?
3. Imagine que Ud. perdió su envase y no se distribuye gratis ahora. ¿Aún lo compraría?
4. Si es así ¿cuánto estaría dispuesto a pagar por él?

5. ¿Piensa que sus vecinos harán lo mismo?

E.4 Questions for Households with None of the Above

E.4.1 English Version

1. How many peope among your neighbors do you know own filter systems or use disinfection for their household water?

2. Why do you not use a filter systerm or disinfection for your water?

If the answer is that the household do not feel it´s necesary, then the surveyer needs to explain the hazards of poor water quality.

3. Would you like to have a water purification system that gives you safe drinking water? If yes, what is the maximum price you are willing to pay for a water purification system?

Here you can actually try to sell the system and write down the reaction of people. Are they willing to pay the price you get from the question? What is the actual price they paid for the system?

4. Do you think your neighbors will want to buy a water purification system?

E.4.2 Spanish Version

ENCUESTA: FAMILIAS SIN SISTEMA DE PURIFICACIÓN DE AGUA

Departamento: Localidad:____________________.
Casa de:____.
Dirección:____.
Fecha de Entrevista:____.

1. ¿Cuántos de sus vecinos, conoce usted utilizan un sistema del filtro o desinfección para el agua de uso familiar?

2. ¿Por qué usted no usa un sistema del filtro o desinfección para su agua?
Si la respuesta es que la familia no siente la necesidad de estos, entonces el encuestador necesita explicar los riesgos de calidad de agua pobre.

3. ¿Le gustaría tener un sistema de la purificación de agua, que le dé agua potable segura? Si respuesta es SÍ, ¿ Qué precio máximo usted pagaría por este sistema de la purificación de agua?
Aquí usted puede intentar vender el sistema y apuntar la reacción de las personas. ¿Ellos están dispuestos apagar ese precio? (De la pregunta anterior) ¿Cuál es el precio real que ellos pagaron por el sistema?

4. ¿Usted piensa que sus vecinos querrán comprar un sistema de la purificación de agua?

Appendix F: Peru Microbial Test Data: Table Filters

F.1 Average E.Coli & TC Concentrations of Valid Tests Before and After Treatment by Table Filters in Peru (All values used in calculations in this study)

Date	Sample	Raw Water		Treated Water		% Removal		LRV	
		AVG E.Coli	AVG TC	AVG E.Coli	AVG TC	E. Coli	TC	E. Coli	TC
Jan 16	H-3	1200	8400	4	153	99.7%	98.2%	2.5	1.7
Jan 17	F-7	200	1300	2	40	99.0%	96.9%	2.0	1.5
Jan 18	H-3 (2)	200	900	0	23	100.0%	97.4%	2.3	1.6
March 25	CBV Post		90000		0		100.0%		5.0
April 01	H - 3		2800		86		96.9%		1.5
April 01	E - 9		5000		30		99.4%		2.2
April 02	H - 2		4600		32		99.3%		2.2
April 02	O - 3		6000		63		98.9%		2.0
April 03	H - 1		20000		415		97.9%		1.7
April 03	B - 7		26000		130		99.5%		2.3
April 03	G - 8		1300		2		99.8%		2.8
April 04	H - 13		1400		0		100.0%		3.1
April 04	B - 5		1200		0		100.0%		3.1
April 04	N - 1		6500		0		100.0%		3.8
Average		**533**	**3533**	**2**	**72**	**99.4%**	**97.6%**	**2.3**	**2.5**
Std. Dev.		577	23516	2	111	0.5%	1.2%	0.3	1.0
N		3	14	3	14	3	14	3	14

F.2 H_2S P/A Test Results on Water Treated by Table Filters in Peru

Date	Sample	H_2S
March 25	CBV Post	P
April 01	H - 3	P
April 01	E - 9	P
April 02	H - 2	P
April 02	O - 3	P
April 03	H - 1	P
April 03	B - 7	P
April 03	G - 8	P

F.3 Set of all MF Data for Table Filters in which the Number of Colonies is Between 20-200 *Only*

(Lower limits are ignored with 100-ml Samples)

(For purposes of comparison with the data set used in this thesis (F.1 above), which includes tests with fewer than 20 colonies per plate, as explained in Section 7.1.3.1)

Date	Sample	Raw Water	Treated Water	% Removal	LRV
		AVG TC	AVG TC	TC	TC
March 25	CBV Post	90000	0	100.0%	5.0
April 01	H - 3	2800	86	96.9%	1.5
April 01	E - 9	5000			
April 02	H - 2	4600			
April 02	O - 3	6000			
April 03	H - 1	20000	415	97.9%	1.7
April 03	B - 7	26000	130	99.5%	2.3
Average		**22057**	**158**	**98.6%**	**2.6**
Std. Dev.		31253	180	1.4%	1.6
N		7	4	4	4

Appendix G: Peru Microbial Test Data: Safe Water Systems

G.1 Average E.Coli & TC Concentrations of Valid Tests Before and After Treatment by Safe Water Systems in Peru (All values used in calculations in this study)

Date	Sample	Raw Water [CFU/100ml]		Treated Water [CFU/100ml]		% Removal		LRV	
		AVG E.Coli	AVG TC	AVG E.Coli	AVG TC	E. Coli	TC	E. Coli	TC
Jan 19	B-11			0	95				
Jan 20	E-3	8000	37000	3	203	100.0%	99.5%	1.0	2.3
Jan 20	H-12	4000	146000	0	10	100.0%	100.0%	3.6	4.2
March 10	C - 7	7	2540						
March 10	LL - 18	100	1300	2	5	98.0%	99.6%	1.7	2.4
March 10	LL - 27	20	680	0	20	100.0%	97.1%	1.3	1.5
March 11	M - 8	6700	33700						
March 11	I - 1	12400	24800	0	14	100.0%	99.9%	4.1	3.2
March 16	LL - 22		13000		30		99.8%		2.6
March 16	F - 7		14000						
March 16	E -2		4815		20		99.6%		2.4
March 17	LL - 11			5	670				
March 17	L - 16		16500		35		99.8%		2.7
March 18	N - 1		11800		50		99.6%		2.4
March 18	M - 17		27000		340		98.7%		1.9
March 18	L - 1		1200		1050		12.5%		0.1
March 19	M - 17B		5800		66		98.9%		1.9
March 19	H - 10		12300		485		96.1%		1.4
March 19	LL - 4				30				
March 23	L - 11		2000		235		88.3%		0.9
March 23	L - 10		32000		12		100.0%		3.4
March 23	M - 19		2700		10		99.6%		2.4
March 24	M - 19B		7300		95		98.7%		1.9
March 24	LL - 23		11300		5		100.0%		3.4
March 24	LL - 9		600		50		91.7%		1.1
March 24	N - 3		2600		55		97.9%		1.7
March 25	CBV Post		90000		130		99.9%		2.8
March 25	CBV Kinder.		80000		50		99.9%		3.2
March 26	B - 2		24000						
March 26	A' - 2		4000		66		98.4%		1.8
March 26	A' - 7		1100		70		93.6%		1.2
March 26	A' - 5		5700		258		95.5%		1.3
April 01	A' - 3		15700						
April 02	A' - 5B		10867		128		98.8%		1.9
Average		**4461**	**20719**	**1**	**148**	**99.6%**	**94.7%**	**2.8**	**32.0**
Std. Dev.		4819	31393	2	232	0.9%	17.0%	1.3	0.9
N		9	33	7	29	5	26	5	26

G.2 H_2S P/A Test Results on Water Treated by the Safe Water System in Peru

Date	Sample	H_2S
Jan 19	B - 11	A
Jan 20	E - 3	A
Jan 20	H - 12	A
March 10	C - 7	P
March 10	LL - 18	P
March 10	LL - 27	P
March 11	M - 8	P
March 11	LL - 2	P
March 11	I - 1	P
March 16	LL - 22	P
March 16	F - 7	P
March 16	E -2	P
March 17	LL - 11	P
March 17	M - 1	P
March 17	L - 16	P
March 18	N - 1	P
March 18	M - 17	P
March 18	L - 1	P
March 19	M - 17B	P
March 19	H - 10	P
March 19	LL - 4	P
March 23	L - 11	P
March 23	L - 10	P
March 23	M - 19	P
March 24	M - 19B	P
March 24	LL - 23	P
March 24	LL - 9	P
March 24	N - 3	P
March 25	CBV Post	P
March 25	CBV Kinder.	P
March 26	B - 2	P
March 26	A' - 2	P
March 26	A' - 7	P
March 26	A' - 5	P
April 01	A' - 3	P
April 02	A' - 5B	P

G.3 Set of all MF Data for Safe Water Systems in which the Number of Colonies is Between 20-200 *Only*

(Lower limits are ignored with 100-ml Samples)

(For purposes of comparison with the data set used in this thesis (G.1 above), which includes tests with fewer than 20 colonies per plate, as explained in Section 7.1.3.1)

Date	Sample	Raw Water [CFU/100ml]		Treated Water [CFU/100ml]		% Removal		LRV	
		AVG E.Coli	AVG TC	AVG E.Coli	AVG TC	E. Coli	TC	E. Coli	TC
Jan 20	E-3	8000	37000						
Jan 20	H-12	4000	146000						
March 10	C - 7	7	2540						
March 10	LL - 18	100	1300	2	5	98.0%	99.6%	1.7	2.4
March 10	LL - 27	20	680	0	20	100.0%	97.1%	1.3	1.5
March 11	M - 8	6700	33700						
March 11	I - 1	12400	24800	0	14	100.0%	99.9%	4.1	3.2
March 16	LL - 22		13000						
March 16	F - 7		14000						
March 16	E -2		4815						
March 17	LL - 11			5	670				
March 17	L - 16		16500						
March 18	N - 1		11800		50		99.6%		2.4
March 18	M - 17		27000		340		98.7%		1.9
March 18	L - 1				1050		12.5%		0.1
March 19	M - 17B		5800		66		98.9%		1.9
March 19	H - 10		12300		485		96.1%		1.4
March 23	L - 11		2000		235		88.3%		0.9
March 23	L - 10		32000						
March 23	M - 19		2700						
March 24	M - 19B		7300						
March 24	LL - 23		11300						
March 25	CBV Post		90000		130		99.9%		2.8
March 25	CBV Kinder.		80000		50		99.9%		3.2
March 26	B - 2		24000						
March 26	A' - 2				66		98.4%		1.8
March 26	A' - 7				70		93.6%		1.2
March 26	A' - 5		5700		257.5		95.5%		1.3
April 01	A' - 3		15700						
April 02	A' - 5B		10867		160		98.8%		1.9
Average		**4461**	**24339**	**2**	**229**	**99.3%**	**91.8%**	**2.4**	**1.9**
Std. Dev.		4819	33134	2	288	1.2%	22.2%	1.5	0.9
N		7	33	4	16	3	15	3	15

Appendix H: Peru Microbial Test Data: Other Sources

H.1 Average E.Coli & TC Concentrations of Valid Tests Before and After Treatment by Water Treatment Plants in El Triunfo & Cerrito Buena Vista, Peru
(All values used in calculations in this study)

El Triunfo WTP

Date	Raw Water		Treated Water		% Removal		LRV	
	Avg. E.coli CFU/100ml	Avg TC CFU/100ml	Avg. E.coli CFU/100ml	Avg TC CFU/100ml	E.coli	TC	E.coli	TC
Jan 17	104000	182500	300	1500	99.7%	99.2%	2.5	2.1
March 25		350000		69200		80.2%		0.7
April 04		18000		0		100.0%		4.3
Average	**104000**	**183500**	**300**	**23567**	**99.7%**	**93.1%**	**2.5**	**2.3**
Std. Dev.		166002		39527		11.2%		1.8
N	1	3	1	3	1	3	1	3

Cerrito Buena Vista WTP

Date	Raw Water		Treated Water		% Removal		LRV	
	Avg. E.coli CFU/100ml	Avg TC CFU/100ml	Avg. E.coli CFU/100ml	Avg TC CFU/100ml	E.coli	TC	E.coli	TC
Jan 17	190000	300000	15000	23000	92.1%	92.3%	1.1	1.1
March 25		290000		61000		79.0%		0.7
April 04		4500		47000		-944.4%		-1.0
Average	**190000**	**147250**	**15000**	**43667**	**92.1%**	**-257.7%**	**1.1**	**0.3**
Std. Dev.		201879		30875		894.8%		4.1
N	1	3	1	3	1	3	1	3
t-test (TC % removal at El Triunfo vs. CBV)						41%		

H.2 Set of all MF Data for Water Treatment Plants in which the Number of Colonies is Between 20-200 *Only*

(Lower limits are ignored with 100-ml Samples)

(For purposes of comparison with the data set used in this thesis (H.1 above), which includes tests with fewer than 20 colonies per plate, as explained in Section 7.1.3.1)

El Triunfo WTP

Date	Raw Water		Treated Water		% Removal		LRV	
	Avg. E.coli CFU/100ml	Avg TC CFU/100ml	Avg. E.coli CFU/100ml	Avg TC CFU/100ml	E.coli	TC	E.coli	TC
Jan 17	104000	182500						
March 25		350000		120000		65.7%		0.5
April 04		18000		0		100.0%		4.3
Average	**104000**	**183500**		**60000**		**67.3%**		**0.5**
Std. Dev.		166002		84853		24.2%		
N	1	3		2		2		2

Cerrito Buena Vista WTP

Date	Raw Water		Treated Water		% Removal		LRV	
	Avg. E.coli CFU/100ml	Avg TC CFU/100ml	Avg. E.coli CFU/100ml	Avg TC CFU/100ml	E.coli	TC	E.coli	TC
Jan 17	190000	300000	15000	23000	92.1%	92.3%	1.1	1.1
March 25		400000		61000		84.8%		0.8
April 04		4500		47000		-944.4%		-1.0
Average	**190000**	**234833**	**15000**	**43667**	**92.1%**	**-255.8%**	**1.1**	**0.3**
Std. Dev.		205646		19218		596.4%		1.2
N	1	3	1	3	1	3	1	3
t-test (TC removal of ET vs. CBV)						41%		

H.3 H_2S P/A Test Results on Water Samples from Water Treatment Plants and Other Sources in Peru

Date	Sample	Type	H_2S
Jan 14	La Joya Health Clinic	Household Tap	A
Jan 14	CBV #8	Household Storage Tank	P
Jan 14	La Joya Canal	Canal	P
Jan 20	CBV E-3	Household Tap	P
Jan 21	Villa Hermosa	Table Filter Raw Water	P
March 25	El Triunfo Treated	WTP	P
March 25	Cerrito Buena Vista Treated	WTP	P
April 04	Cerrito Buena Vista Treated	WTP	P

Appendix I: Peru Performance Test Data: Table Filters

I.1 Turbidity Data of Raw and Treated Water from Table Filters in Peru

Date	Sample	Turbidity		
		Raw Water	**Treated Water**	**% Removal**
Jan 18	H - 3	6.5	0.2	97%
Jan 17	F - 7	50	5.5	89%
Jan 21	Villa Hermosa house	21	2.8	87%
March 25	CBV Post*	9.8	1.1	89%
April 01	H - 3	6.0	1.5	75%
April 01	E - 9	5.2	1.8	65%
April 02	H - 2*	5.7	5.0	12%
April 02	O - 3	8.1	1.6	80%
April 03	H - 1	9.3	2.5	73%
April 03	B - 7	5.0	2.5	50%
April 03	G - 8	5.5	1.2	78%
April 04	H - 13	4.5	3.0	33%
April 04	B - 5*	3.7	1.6	57%
April 04	N - 1	6.3	3.3	48%
Average		**10**	**2.4**	**67%**
Std. Dev.		12	1.5	24%
N		14	14	14
Average (of “working” filters)		12	2.4	70%
N		11	11	11

* These Table Filters were reported as “not working” at the time of sampling.

I.2 Flow Rate Data of Raw and Treated Water from Table Filters in Arequipa, Peru

Date	Sample ID (Arequipa)	Flow Rate [L/hr]
Jan 7	CBV (Ramirez)	3.88
Jan 7	La Cano Post	0.86
Jan 7	Cruz de Mayo (Belisario)	1.88
Jan 7	Villa Hermosa C - 16	2.66
April 01	CBV H - 3	2.66
April 01	CBV E - 9	0.66
April 02	CBV O - 3	2.07
April 03	CBV H - 1	1.02
April 03	CBV B - 7	2.45
April 03	CBV G - 8	0.24
April 04	CBV H - 13	0.72
April 04	CBV N - 1	1.52
Average		**1.72**
Std. Dev.		1.1
N		12

I.3 Turbidity Data of Raw and Treated Water from Table Filters in Tacna, Peru

Date	Sample ID (Tacna)	Flow Rate [L/hr]
Jan 9	Chucatamani (Chavez)	3.30
Jan 9	Chucatamani "E"	3.51
Jan 9	Chucatamani "F"	4.03
Jan 9	Pistala (Toma)	4.37
Average		**3.80**
Std. Dev.		0.5
N		4

Appendix J: Peru Performance Test Data: Safe Water Systems

Date	Sample ID	Free Chl. mg/L	Turbidity (NTU)	
			Raw Water (Tap)	Treated Water
Jan 7	CBV (Valdivia)	0.28		
Jan 7	I-1	0.10		
Jan 16	CBV School	0.80		6.3
Jan 19	B-11	0.04		7.4
Jan 19	A-8	0.05		34
Jan 20	H-12	0.15	24	3.2
Jan 20	E-3	0.05	21	12
March 10	C - 7	0.23	3.0	2.6
March 10	LL - 18	0.10	14	4.2
March 10	LL - 27	0.13	3.9	3.5
March 11	M - 8		16	3.4
March 11	LL - 2	0.03	14	6.1
March 11	I - 1	0.14	4.8	3.2
March 16	LL - 22	0.00	4.6	9.2
March 16	F - 7	0.20	4.1	5.3
March 16	E -2	0.23	15	5.3
March 17	LL - 11	0.23	7.4	11
March 17	M - 1	0.07	9.2	11
March 17	L - 16	1.09	7.9	7.9
March 18	N - 1		10	9.5
March 18	M - 17	0.07	8.7	11
March 18	L - 1		6.9	11
March 19	M - 17B	0.19	5.8	50
March 19	H - 10	0.54	19	16
March 19	LL - 4	0.18	9.6	7.0
March 23	L - 11	0.09	11	7.5
March 23	L - 10	0.15	7.2	3.8
March 23	M - 19	0.09	7.9	11
March 24	M - 19B	0.11	7.9	7.0
March 24	LL - 23	0.02	9.5	7.3
March 24	LL - 9	0.06	6.0	130
March 24	N - 3	0.07	12	9.2
March 25	CBV Post	0.10	9.8	13
March 25	CBV Kinder.	0.32	9.5	2.1
March 26	B - 2	0.05	170	270
March 26	A' - 2	0.10	6.3	3.0
March 26	A' - 7	0.30	3.5	3.0
March 26	A' - 5	0.05	55	24
April 01	A' - 3	0.04		320
April 02	A' - 5B	0.29	170	270
Average		**0.18**	**20**	**38**
Std. Dev.		0.2	39	78
N		37	34	38

Appendix K: Peru Performance Test Data: Other Sources

K.1 Turbidity Data from Water Treatment Plants Input and Output Samples

CBV WTP

Date	Turbidity [NTU]		% Removal
	Input	Output	
Jan 17	95	70	26%
April 04	40	33	18%
Average	**68**	**52**	**22%**
Std. Dev.	40	26	6%
N	2	2	2

El Triunfo WTP

Date	Turbidity [NTU]		% Removal
	Input	Output	
Jan 17	70	58	17%
April 04	37	55	-49%
Average	**54**	**57**	**-16%**
Std. Dev.	23	2.1	47%
N	2	2	2

K.2 Free Chlorine Residual Data from Water Treatment Plants Input and Output Samples

CBV WTP

Date	Free Chlorine [mg/L]	
	Input	Output
Jan 17	0.09	0.28
March 25		0.46
April 04		0.50
Average	**0.09**	**0.41**
Std. Dev.		0.12
N	1	3

El Triunfo WTP

Date	Free Chlorine [mg/L]	
	Input	Output
Jan 17		0.77
March 25		0.29
Average		**0.53**
Std. Dev.		0.34
N		2

Appendix L: MIT Microbial Test Data: Table Filters

L.1 Average TTC Concentrations of Valid Tests Before and After Treatment by Safe Water Systems in Peru (All values used in calculations in this study)

Date	Raw Water	MSTF			FSTF		
	Avg TTC CFU/100ml	Avg TTC CFU/100ml	% Removal	LRV	Avg TTC CFU/100ml	% Removal	LRV
20-Feb	1390	198	85.8%	0.8	75	94.6%	1.3
23-Feb		205			231		
27-Feb	20000	10	100.0%	3.3	22	99.9%	3.0
1-Mar	12000	6	100.0%	3.3	45	99.6%	2.4
5-Mar	4600	83	98.2%	1.7			
8-Mar	67333	61	99.9%	3.0	1340	98.0%	1.7
12-Mar	7500	9	99.9%	2.9	500	93.3%	1.2
15-Mar	34700				1040	97.0%	1.5
19-Mar	4067	5	99.9%	2.9	220	94.6%	1.3
1-Jun		3			4		
15-Jun		1			1		
16-Jun	200	1	99.8%	2.6	3	98.8%	1.9
18-Jun		0			1		
21-Jun	1575				0	100.0%	3.2
22-Jun	3400				93	97.3%	1.6
23-Jun	1050	0	100.0%	3.0	0	100.0%	3.0
24-Jun	400	0	100.0%	2.6	10	97.5%	1.6
Average	**12170**	**41**	**98.3%**	**2.6**	**224**	**97.5%**	**2.0**
Std. Dev.	19295	72	4.4%	0.8	404	2.3%	0.7
N	15	17	10	10	16	12	12
t-test comparing MSTF & FSTF						62%	
Ceramic Candles Alone (w/o Sand)							
30-Jun	1500						
1-Jul	3000	150	95.0%	1.3	59	98.1%	1.7
2-Jul	1100	4	99.6%	2.4	8	99.3%	2.1
Average	**1867**	**77**	**97.3%**	**1.9**	**33**	**98.7%**	**1.9**
Std. Dev.	1002	103	3.3%	0.8	36	0.9%	0.3
N	3	2	2	2.0	2	2	2.0
t-test comparing MSTF & FSTF						67%	
t-test comparing WITH & WITHOUT Sand			75%			28%	

L.2 Average E.coli & TC Concentrations of Valid Tests Before and After Treatment by Safe Water Systems in Peru (All values used in calculations in this study)

Date	Raw Water	MSTF			FSTF		
	Avg E.coli CFU/100ml	Avg E.coli CFU/100ml	% Removal	LRV	Avg E.coli CFU/100ml	% Removal	LRV
24-Jun	1817	0	100.00%	3.3	10	99.5%	2.3
Ceramic Candles Alone (w/o Sand)							
28-Jun	1000				3	99.7%	2.5
30-Jun	47	0	100.0%	1.7			
1-Jul	500	0	100.0%	2.7	0	100.0%	2.7
2-Jul	2000	0	100.0%	3.3	5	99.8%	2.6
Average	**887**	**0**	**100.0%**	**2.6**	**3**	**99.8%**	**2.6**
Std Dev	838	0	0.0%	0.8	3	0.2%	0.1
N	4	3	3	3	3	3	3
t-test comparing MSTF & FSTF						0.19171	

Date	Raw Water	MSTF			FSTF		
	Avg TC CFU/100ml	Avg TC CFU/100ml	% Removal	LRV	Avg TC CFU/100ml	% Removal	LRV
24-Jun	6467	3	99.95%	3.3	64	99.0%	2.0
Ceramic Candles Alone (w/o Sand)							
28-Jun	15700				7	100.0%	3.4
30-Jun	2333	5400	-131.4%	-0.4			
1-Jul	36700	79	99.8%	2.7	85	99.8%	2.6
2-Jul	146000	420	99.7%	2.5	272	99.8%	2.7
Average	**50183**	**1966**	**22.7%**	**1.6**	**121**	**99.8%**	**2.9**
Std Dev	65425	2979	133.5%	2.6	136	0.1%	0.4
N	4	3	3	3	3	3	3
t-test comparing MSTF & FSTF							42%

L.3 Average HPC Concentrations of Valid Tests Before and After Treatment by Safe Water Systems in Peru (All values used in calculations in this study)
(All colony counts were between 20-200)

Date	Raw Water	MSTF			FSTF			Blank Water
	Avg HPC CFU/100ml	Avg HPC CFU/100ml	% Removal	LRV	Avg HPC CFU/100ml	% Removal	LRV	Avg HPC CFU/100ml
1-Jun	239000	900	99.6%	2.4				66
15-Jun	1290000							0
23-Jun	7685000	105000	98.6%	1.9	1280000	83.3%	0.8	
Average	**3071333**	**52950**	**99.1%**	**2.1**	**1280000**	**83.3%**	**0.8**	**33**
Std. Dev.	4029962	73610	0.7%	0.4				47
N	3	2	2	2	1	1	1	2

L.4 Set of all TTC Data for Table Filters in which the Number of Colonies is Between 20-200 *Only*
(Lower limits are ignored with 100-ml Samples)
(For purposes of comparison with the data set used in this thesis (L.1 above), which includes tests with fewer than 20 colonies per plate, as explained in Section 7.1.3.1)

Date	Raw Water	MSTF			FSTF		
	Avg TTC CFU/100ml	Avg TTC CFU/100ml	% Removal	LRV	Avg TTC CFU/100ml	% Removal	LRV
20-Feb	1380	198	85.8%	0.8			
23-Feb		205			231		
1-Mar		8			70		
5-Mar	4600	83	98.2%	1.7			
8-Mar	67333	61	99.9%	3.0	1340	98.0%	1.7
12-Mar		12					
15-Mar	34700				1040	97.0%	1.5
19-Mar	4067	5	99.9%	2.9	220	94.6%	1.3
1-Jun		1					
15-Jun		1			0		
16-Jun		1			3		
18-Jun		0			0		
21-Jun	2150				0	100.0%	3.3
22-Jun	5900				93	98.4%	1.8
23-Jun	1050						
24-Jun	400	0	100.0%	2.6	10		
Average	**13509**	**48**	**96.8%**	**2.2**	**273**	**97.6%**	**1.9**
Std. Dev.	22847	77	6.2%	0.9	466	2.0%	0.8
N	9	12	5	5	11	5	5
t-test comparing MSTF & FSTF						78%	
Ceramic Candles Alone (w/o Sand)							
1-Jul					59		
2-Jul		4			12		
Average		**4**			**35**		
Std. Dev.					33		
N		1			2		

L.5 Set of all E.coli & TC Data for Table Filters in which the Number of Colonies is Between 20-200 *Only*
(Lower limits are ignored with 100-ml Samples)
(For purposes of comparison with the data set used in this thesis (L.2 above), which includes tests with fewer than 20 colonies per plate, as explained in Section 7.1.3.1)

Date	Raw Water	MSTF			FSTF		
	Avg E.coli CFU/100ml	Avg E.coli CFU/100ml	% Removal	LRV	Avg E.coli CFU/100ml	% Removal	LRV
24-Jun	1817	0	100.0%	3.3	9.5	99.5%	2.3
Ceramic Candles Alone (w/o Sand)							
28-Jun	1000				0	100.0%	3.0
30-Jun	47	0	100.0%	1.7			
1-Jul	500	0	100.0%	2.7	0	100.0%	2.7
2-Jul	2000	0	100.0%	3.3	0	100.0%	3.3
Average	**887**	**0**	**100.0%**	**2.6**	**0**	**100.0%**	**3.0**
Std. Dev.	838	0	0.0%	0.8	0	0.0%	0.3
N	4	3	3	3	3	3	3

Date	Raw Water	MSTF			FSTF		
	Avg TC CFU/100ml	Avg TC CFU/100ml	% Removal	LRV	Avg TC CFU/100ml	% Removal	LRV
24-Jun	6467	0	100.0%		63.5	99.0%	2.0
Ceramic Candles Alone (w/o Sand)							
28-Jun	15700				0	100.0%	4.2
30-Jun	2333	5400	-131.4%	-0.4			
1-Jul	36700	79	99.8%	2.7	85	99.8%	2.6
2-Jul	146000	420	99.7%	2.5	374	99.7%	2.6
Average	**50183**	**1966**	**22.7%**	**1.6**	**153**	**99.8%**	**3.1**
Std. Dev.	65425	2979	133.5%	1.7	196	0.1%	0.9
N	4	3	3	3	3	3	3
t-test comparing MSTF & FSTF						42%	

Appendix M: MIT Performance Test Data: Table Filters

M.1 Average Turbidity Data of Raw and Treated Water from Table Filters With and Without Sand at MIT

Date	Source	MSTF			FSTF			Blank	Tap[59]
	Avg. Turbidity [NTU]	Avg. Turbidity [NTU]	% Removal	LRV	Avg. Turbidity [NTU]	% Removal	LRV	Avg. Turbidity [NTU]	Avg. Turbidity [NTU]
Feb 17	4.6	0.3	93%	1.2	0	100%			
Feb 20	4.3	0.9	79%	0.7	0.55	87%	0.9	0.35	0.2
Feb 23	5.1	0.95	81%	0.7	0.85	83%	0.8		
Feb 27	16	0.78	95%	1.3	0.93	94%	1.2		
March 1	4.4	0.65	85%	0.8	0.75	83%	0.8		
March 5	8.3	0.45	95%	1.3	0.6	93%	1.1		
March 8		0.3			0.58			0.1	
March 12	15	0.2	99%	1.9	0.58	96%	1.4		
March 15	6.6	0.3	95%	1.3	0.5	92%	1.1		
March 19	8.6								
June 22	77	0.93	99%	1.9	2.0	97%	1.6		
Average	**15**	**0.58**	**91%**	**1.2**	**0.73**	**92%**	**1.1**	**0.23**	**0.2**
Std Dev	22	0.30	8%	0.5	0.50	6%	0.3	0.18	
N	10	10	9	9	10	9	9	2	1
t-test comparing MSTF to FSTF % Removal						87%			
(Sand Removed)									
June 28	22	0.8	96%	1.4	0.75	97%	1.5		
June 30	4.5	1.55	65%	0.5	1.5	66%	0.5		
July 1	28	0.93	97%	1.5	1.1	96%	1.4		
July 2	23	0.87	96%	1.4	1.1	95%	1.3		
Average	**19**	**1.0**	**89%**	**1.2**	**1.1**	**88%**	**1.2**		
Std Dev	10	0.35	16%	0.5	0.31	15%	0.5		
N	4	4	4	4	4	4	4		
t-test comparing MSTF to FSTF % Removal						99%			
t-test comparing % Removal of TFs *With* & *Without* Sand			76%			69%			

[59] From the MIT laboratory sink.

M.2 Flow Rate Measured in Table Filters With and Without Sand at MIT

Date	Flow Rate [L/hr]	
	MSTF	**FSTF**
June 22	1.0	0.8
Sand removed		
June 30	7.1	6.7
July 2	0.8	1.5
Avg. (no sand)	**4.0**	**4.1**

Works Consulted

American Water Works Association (AWWA). 1999. Raymond D. Letterman, Tech. Ed. *Water Quality and Treatment: A Handbook of Community Water Supplies*. 5th Ed. New York: McGraw-Hill.

Borda, Luis Carlos Arxe. 2004. Director, Ministry of Health, Arequipa, Peru. Personal communication. January 7.

Brin, Genieve. 2003. "Evaluation of the Safe Water System in Jolivert, Haiti by Bacteriological Testing and Public Health Survey." Master of Engineering Thesis, Massachusetts Institute of Technology, Dept. of Civil and Environmental Engineering. Cambridge, MA.

Brown, Joe. 2003. "Evaluation of Point-of-Use Microfiltration for Drinking Water Treatment in Rural Bolivia." Master of Philosophy Disseration, University of Cambridge, Dept. of Geography. Cambridge, UK.

Centers for Disease Control and Prevention (CDC). 2001. *Safe Water Systems for the Developing World: A Handbook for Implementing Household-Based Water Treatment and Safe Storage Projects*. Atlanta: CDC.

-----. 2004. *Safe Water Systems for the Developing World: A Handbook for Implementing Household-Based Water Treatment and Safe Storage Projects*. Atlanta: CDC. <www.cdc.gov/safewater/manual> Accessed: December.

-----. 1991. "International Notes Cholera – Peru, 1991." *Morbidity and Mortality Weekly Report*. 40(6); 108-110. February 15.

CEPIS. 2000. "Estudio de Desinfeccion de Agua y Alimentos al Nivel Domicilario: Resultados del Monitoreo y Evaluacion, Periodo Julio/Setiembre 2000." CEPIS/PAHO: Lima.

CEPIS. 2004. Website. <www.cepis.ops-oms.org> Accessed: October.

CEPIS, DGCI, and the Peruvian Ministry of Health. 2001. "Medidas para el Mejoramiento de la Calidad del Agua y Saneamiento de las poblaciones Afectadas por el Terremoto de junio 2001 en el Sur del Peru." CEPIS/PAHO.

CEPIS, DGCI, and the Peruvian Ministry of Health. 2003. "Rehabilitación de Sector Agua y Saneamiento en Poblaciones Afectadas por el Sismo Junio 2001: Proyecto No. 4: Desinfección de Agua al Nivel Domiciliario." Powerpoint presentation.

Cerilles, Jeffrey; Charlie Lieu; and Anya Obizhaeva. 2004. "H_2O-1B!: Bringing Safe Water to the World." Global Entrepreneurial Lab Group Report, Massachusetts Institute of Technology, Sloan School of Management. Cambridge, MA.

Cervantes, Déborah Xanat Flores. 2003. "Feasibility of Semi-Continuous Solar Disinfection System for Developing Countries at a Household Level." Master of Engineering Thesis, Massachusetts Institute of Technology, Dept. of Civil and Environmental Engineering. Cambridge, MA.

CIA. 2004. "Peru." *The World Factbook*. <www.cia.gov/cia/publications/factbook/geos/pe.html> Last updated: Novemeber 30. (Accessed: December 6.)

Clasen, Thomas. 2003. "Safe Household Water Treatment and Storage using Ceramic Filtration." Presentation, London School of Hygiene and Tropical Medicine. London, UK. December 3.

Clesceri, L.S.; A. E. Greenberg; and A. D. Eaton; Editors. 1998. *Standard Methods for the Examination of Water and Wastewater*. 20th Ed.

Coulbert, Brittany and Kori Donison. 2004. "Laboratory Comparison of the Peruvian Table Filter and the BioSand Filter." Master of Engineering Group Report, Massachusetts Institute of Technology, Dept. of Civil and Environmental Engineering. Cambridge, MA.

DCGI, OPS/CEPIS, Ministerio de Salud. 2003. "Guia de Construccion, Operacion y Mantenimiento de Filtros de Mesa con Velas Ceramicas y Prefiltro de Arena." ["A Guide to the Construction, Operation, and Maintenance of Table Filters with Ceramic Candles and Sand Prefiltration."] Unpublished document. Lima.

Dies, Rob. 2003. "Development of a Ceramic Water Filter for Nepal." Master of Engineering Thesis, Massachusetts Institute of Technology, Dept. of Civil and Environmental Engineering. Cambridge, MA.

Donison, Kori. 2004. "Household Scale Slow Sand Filtration in the Dominican Republic." Master of Engineering Thesis, Massachusetts Institute of Technology, Dept. of Civil and Environmental Engineering. Cambridge, MA.

Galvis, Gerardo. 1999. "Development and Evaluation of Multistage Filtration Plants: An Innovative, Robust, and Efficient Water Treatment Technology." Doctor of Philosophy Thesis, University of Surrey, Centre for Environmental Health Engineering. Guildford, Surrey, UK.

Gao, Yong Xuan; Soon Kyu Hwang; Chian Siong Low; et al. 2002. "Nepal Water Project: 2001-2002." Master of Engineering Group Report, Massachusetts Institute of Technology, Dept. of Civil and Environmental Engineering. Cambridge, MA.

Hach. 2004. Company website. <www.hach.com> (Accessed: December 8, 2004.)

House, Sarah; Margaret Ince; and Rod Shaw. 2004. Water, Engineering, and Development Centre, Loughborough University. "Technical Brief No. 52: Water: Quality or Quantity?" *WaterLines*. Vol. 22, No. 4. UK, April.

Howard, Guy and Jamie Bartram. 2003. "Domestic Water Quality, Service Level, and Health." WHO: Geneva.

Joint Monitoring Programme for Water Supply and Sanitation (JMP). 2004. "Meeting the Millennium Development Goals Drinking Water and Sanitation Target: A Mid-Term Assessment of Progress." WHO/UNICEF.

Khayyat, 'Amer Mohamad 'Adnan. 2000. "Study of Point of Use Treatment Methods for the Disinfection of Drinking Water in Nepal." Master of Engineering Thesis, Massachusetts Institute of Technology, Dept. of Civil and Environmental Engineering. Cambridge, MA.

LeChevallier, Mark W.; T. M. Evans; and Ramon J. Seidler. 1981. "Effect of Turbidity on Chlorination Efficiency and Bacterial Persistence in Drinking Water." *Applied and Environmental Microbiology*. Vol. 42, No. 1; July. Pp. 159-167.

Lieu, Charlene. 2004. "Notes: Charlie 1-16-04." Personal notes from Lieu on a conversation with CEPIS engineers. January 16.

Longhi, Viviana Ruiz. 2004. "Evaluation of Household Systems in La Joya." Report of March 2004 Research in Arequipa, Funded by the Master of Environmental Engineering Program at the Massachusetts Institute of Technology. Arequipa, Peru. May 24.

Malies, Robert; Jennifer Lappin; and Amber Jaycocks. 2004. "Investigating the Effectiveness of a Variety of Household Water Systems on Microbially Contaminated Water in Arequipa, Peru 2004." Undergraduate Research Opportunity Program Report, Massachusetts Institute of Technology, Dept. of Civil and Environmental Engineering. Cambridge, MA.

Massachusetts Institute of Technology (MIT). 2004. "Ceramic Water Filter Technologies." MIT Civil and Environmental Engineering Water and Sanitation Website. <web.mit.edu/watsan/ceramic_tech.htm> Last updated: December 16. (Accessed: December 29.)

Measure DHS. 2004. "Country Statistics: Peru." *Demographic and Health Surveys*. <www.measuredhs.com/countries/country.cfm?ctry_id=33> (Accessed: December 6.)

Millipore. 1992. "Water Microbiology: Laboratory and Field Procedures." Catologue No. AD323. Bedford, MA: Millipore Corporation, Revised March 1992.

Ministry of Health – Arequipa, Peru. 2003. "Análisis Microbiologico de Aguas." Unpublished reports of water quality tests performed by Claudia Mena at Cerrito Buena Vista, Los Médanos, and Leche Gloria. October 28.

Mintz, Eric D.; Fred M. Reiff; and Robert V. Tauxe. 1995. “Safe Water Treatment and Storage in the Home: A Practical New Strategy to Prevent Waterborne Diseases.” *Journal of the American Medical Association*. 273: pp. 948-953.

Murcott, Susan. 2004. “Household Water Treatment and Safe Storage Field Projects in Nepal, Haiti, Dominican Republic, Nicaragua, and Peru.” Special Session on Household Drinking Water Treatment. International Water Association – World Water Congress. Marrakech, Morocco. September 23.

Murcott, Susan and Heather Lukacs. 2002. “Household Water Treatment in Nepal.” Bangalore: ThinkCycle.

Ngai, Tommy Ka Kit. 2002. “Arsenic Speciation and Evaluation of an Adsorption Media in Rupandehi and Nawalparasi Districts of Nepal.” Master of Engineering Thesis, Massachusetts Institute of Technology, Dept. of Civil and Environmental Engineering. Cambridge, MA.

Oates, Peter. 2001. “Solar Disinfection for Point of Use Water Treatment In Haiti.” Master of Engineering Thesis, Massachusetts Institute of Technology, Dept. of Civil and Environmental Engineering. Cambridge, MA.

Pardón, Mauricio. 2003. Powerpoint presentation on the CEPIS HWTS program to The International Network to Promote Household Water Treatment and Safe Storage. PAHO. June 4-5.

Pecchia, David. 2004. Microbiological Customer Support at Millipore. Telephone coversation between Pecchia and Susan Murcott. December 3.

Pozzani Water Filters. 2004. Company website. <www.pozzani.co.uk> (Accessed: December 7.)

Rojas, Ricardo. 2002. *Guidelines for the Surveillance and Control of Drinking Water Quality*. Lima, Peru: PAHO/CEPIS.

Rojas, Ricardo and Sixto Guevara. 2000. “Filtros de Mesa.” Lima, Peru: PAHO/CEPIS.

Rojas, Ricardo; Luis Valencia Sifuentes; Mauricio Pardón; and Jose Luis Huaman. 2004. Senior Engineers, CEPIS. Personal communication. January 5.

Rose, Lisa. 2004. Microbiological Customer Support at Millipore. Telephone coversation between Rose and Coulbert. December 15.

Rust, Mary and Katie McArthur. 1996. “Slow Sand Filtration.” *Water Treatment Primer*. Course: CE 4124: “Environmental Information Management,” Virginia Technical Institute, Civil Engineering Department. VA.

Schmitt, Dottie and Christie Shinault. 1996. "Rapid Sand Filtration." *Water Treatment Primer*. Course: CE 4124: "Environmental Information Management," Virginia Technical Institute, Civil Engineering Department. VA.

Sobsey, Mark D. and Frederic K. Pfaender. 2002. "Evaluation of the H_2S Method for Detection of Fecal Contamination of Drinking Water." University of North Carolina, School of Public Health. Chapel Hill, NC: WHO.

Spellman, Frank R. and Joanne Drinan. 2000. *The Drinking Water Handbook*. Lancaster, PA: Technomic Publishing Co.

United Nations (UN). 2003. "Indicators for Monitoring the Millenium Development Goals: Definitions, Rationale, Concepts and Sources." New York: UN.

-----. 2000. "United Nations Millenium Declaration." 8th Plenary Session: UN, Sept. 8.

World Health Organization (WHO). 1993. *Guidelines for Drinking-Water Quality*. 2nd Ed. Vol. 1: "Recommendations." Geneva: WHO.

-----. 1996. *Guidelines for Drinking-Water Quality*. 2nd Ed. Vol. 2: "Health Criteria and Other Supporting Information." Geneva: WHO.

-----. 1997. *Guidelines for Drinking-Water Quality*. 2nd Ed. Vol. 3: "Survellience and Control of Community Supplies." Geneva: WHO.

-----. 2004. *Guidelines for Drinking-Water Quality*. 3rd Ed. Vol. 1: "Recommendations." Geneva: WHO.

-----. 2004. Organization website. <www.who.int> (Accessed: December 7.)