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A STUDY OF WATER USE AND SUPPLY IN THE DISTRICT OF INDEPENDENCIA, PERU

By

Fletcher A. McKenzie

A REPORT

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

CIVIL ENGINEERING

MICHIGAN TECHNOLOGICAL UNIVERSITY

2011

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This report “A Study of Water Use and Supply in the District of Independencia, Peru,” is hereby approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE IN CIVIL ENGINEERING.

Civil and Environmental Engineering
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“By means of water we give life to everything”

- The Koran, Book of The Prophets 21:30

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Preface

The author's experience as a Peace Corps Volunteer working in water & sanitation in Peru was challenging in many ways: language being the first barrier, followed by cultural differences. The first project was with the local municipality for the construction of a sewer system and oxidation pond for a small community. After being given a lengthy technical report in Spanish, the author was to supervise the project without delay. This caused much confusion and frustration at not being given guidance or even a tour of the site with someone from the municipality. The engineers in the municipality were already overworked, so it was implied that things just had to be figured out alone, causing some anxiety and stress, but in the end the author decided to give it his best shot, and in the case of failure, it could always be chalked up to a learning experience. So, after diving in to the project and finding people in the community that did want to work on the project, things started to go more smoothly. The photo below is taken at the oxidation lagoon with the author and a colleague, Don José Espino Quispe, who was an inspiration to the author and a big reason that he made it through Peace Corps.



Figure 1: José Espino Quispe and the Author at the Construction Site of the Sewer Project

Toward the end of the author's service he started working on a project to continue construction on the newly added branch of the district's water distribution system. He applied for and was awarded a grant from USAID to construct 135 household water connections in the community of Toma León. This project inspired this master's report because the author was regularly exposed to the problems with insufficient

pressure that the community was having. So with much guidance from his advisors, he started to undertake the mapping of the entire distribution system with the goal to model it in EPANET 2.0 and make recommendations for improving the system. However, due to political change, it was difficult to get support for the project from the municipality. In the end, it boiled down to being patient, finding and working with motivated individuals, and being persistent in order to complete the various tasks for this and other projects during his two year service.

Acknowledgements

I would like to thank my graduate committee, without whom none of this would have been possible. My advisor Dr. David Watkins for all the guidance and direction he gave me throughout my two years in Peru. I would also like to thank Dr. Brian Barkdoll for his help working with the modeling component of the project, as well as Dr. Kathy Halvorsen for her help with the social aspect of my project, and for her input on the composition of this report.

My counterparts in Peru: Mr. Carlos Alvites Mayma and Mr. Jose Espino Quispe, whose motivation and hard work were instrumental in our projects. These men inspired me with their good nature and whose friendship, generosity, insight and patience got me through the toughest times in my community.

I would like to thank my host family in Independencia for their kindness and acceptance of a strange “gringo”. I couldn’t have asked for a better host family.

Finally, I would like to thank the current Peace Corps Volunteer in Independencia, Lucas Patton, for his help with follow-up questions and making clarifications about the water system operational procedures obtained from the municipality staff of the district of Independencia.

Abstract

Peru is a developing country with abundant fresh water resources, yet the lack of infrastructure leaves much of the population without access to safe water for domestic uses. The author of this report was a Peace Corps Volunteer in the sector of water & sanitation in the district of Independencia, Ica, Peru. Independencia is located in the arid coastal region of the country, receiving on average 15 mm of rain annually. The water source for this district comes from the Pisco River, originating in the Andean highlands and outflowing into the Pacific Ocean near the town of Pisco, Peru.

The objectives of this report are to assess the water supply and sanitation practices, model the existing water distribution system, and make recommendations for future expansion of the distribution system in the district of Independencia, Peru. The assessment of water supply will be based on the results from community surveys done in the district of Independencia, water quality testing done by a detachment of the U.S. Navy, as well as on the results of a hydraulic model built in EPANET 2.0 to represent the distribution system. Sanitation practice assessments will be based on the surveys as well as observations from the author while living in Peru.

Recommendations for system expansions will be made based on results from the EPANET model and the municipality's technical report for the existing distribution system.

Household water use and sanitation surveys were conducted with 84 families in the district revealing that upwards of 85% store their domestic water in regularly washed containers with lids. Over 80% of those surveyed are drinking water that is treated, mostly boiled. Of those surveyed, over 95% reported washing their hands and over 60% mentioned at least one critical time for hand washing when asked for specific instances. From the surveys, it was also discovered that over 80% of houses are properly disposing of excrement, in either latrines or septic tanks. There were 43 families interviewed with children five years of age or under, and just over 18% reported the child had a case of diarrhea within the last month at the time of the interview. Finally, from the surveys it was calculated that the average water use per person per day is about 22 liters.

Water quality testing carried out by a detachment of the U.S. Navy revealed that the water intended for consumption in the houses surveyed was not suitable for consumption, with a median *E. coli* most probable number of 47/100 ml for the 61 houses sampled. The median total coliforms was 3,000 colony forming units per 100 ml.

EPANET was used to simulate the water delivery system and evaluate its performance. EPANET is designed for continuous water delivery systems, assuming all pipes are always flowing full. To account for the intermittent nature of the system, multiple EPANET network models were created to simulate how water is routed to the different parts of the system throughout the day. The models were created from interviews with the water technicians and a map of the system created using handheld GPS units. The purpose is to analyze the performance of the water system that services approximately 13,276 people in the district of Independencia, Peru, as well as

provide recommendations for future growth and improvement of the service level. Performance evaluation of the existing system is based on meeting 25 liters per person per day while maintaining positive pressure at all nodes in the network. The future performance is based on meeting a minimum pressure of 20 psi in the main line, as proposed by Chase (2000).

The EPANET model results yield an average nodal pressure for all communities of 71 psi, with a range from 1.3 – 160 psi. Thus, if the current water delivery schedule obtained from the local municipality is followed, all communities should have sufficient pressure to deliver 25 l/p/d, with the exception of Los Rosales, which can only supply 3.25 l/p/d. However, if the line to Los Rosales were increased from one to four inches, the system could supply this community with 25 l/p/d.

The district of Independencia could greatly benefit from increasing the service level to 24-hour water delivery and a minimum of 50 l/p/d, so that communities without reliable access due to insufficient pressure would become equal beneficiaries of this invaluable resource. To evaluate the feasibility of this, EPANET was used to model the system with a range of population growth rates, system lifetimes, and demands. In order to meet a minimum pressure of 20 psi in the main line, the 6-inch diameter main line must be increased and approximately two miles of trench must be excavated up to 30 feet deep. The sections of the main line that must be excavated are mile 0-1 and 1.5-2.5, and the first 3.4 miles of the main line must be increased from 6 to 16 inches, contracting to 10 inches for the remaining 5.8 miles. Doing this would allow 24-hour water delivery and provide 50 l/p/d for a range of population growth rates and system lifetimes.

It is expected that improving the water delivery service would reduce the morbidity and mortality from diarrheal diseases by decreasing the recontamination of the water due to transport and household storage, as well as by maintaining continuous pressure in the system to prevent infiltration of contaminated groundwater. However, this expansion must be carefully planned so as not to affect aquatic ecosystems or other districts utilizing water from the Pisco River. It is recommended that stream gaging of the Pisco River and precipitation monitoring of the surrounding watershed is initiated in order to begin a hydrological study that would be integrated into the district's water resource planning. It is also recommended that the district begin routine water quality testing, with the results available to the public.

Introduction

Humankind is becoming more aware of the scarcity of our natural resources, as well as the need to address the unequal distribution of these resources and plan for responsible development for future generations. It is estimated that 1.1 billion people did not have access to improved water sources in the year 2002, representing 17% of the globe's population (WHO, 2004). Additionally, an estimated 2 million children die each year due to an insufficient supply of clean water. Latin America as a region has the largest disparity of income distribution and access to water is equally skewed (UNDP 2008). The daunting question becomes: How do we address and resolve this issue facing growing population, increased rainfall variability due to climate change, as well as increased pollutant loads on our natural ecosystems?

The first steps have been taken, manifested as the Millennium Development Goals. These goals address inalienable human rights, equality, and sustainable development, i.e., development that allows us to meet our needs while not impairing future generations from meeting theirs. At the base of human rights is the right to enjoy a healthy life, of which safe drinking water is paramount.

The right to safe water has been stated in a previous UN declaration, but was never officially inserted into the universal declaration of human rights. The original statement is:

“The human right to water entitles everyone to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses”
- General Comment No. 15 (2002): The Right to Water.

In July of 2010 the UN General Assembly integrated this statement into Article 25: the right to an adequate standard of living, declaring that safe and clean drinking water and sanitation is in fact a human right, and thus it is contained in existing human rights treaties and is therefore legally binding (WHO, 2011).

The seventh UN Millennium Development Goal (MDG) is to “ensure environmental sustainability,” with a specific target to “halve by 2015 the proportion of people without sustainable access to safe drinking water.” Sullivan et al. (2003) argue that the target to increase access to safe water is implicitly related to the first goal: “eradicate extreme poverty and hunger” because without safe water, a basic human requirement, one cannot be lifted from poverty. Access to safe water is related to many aspects of the MDGs. Sullivan et al. (2003) point out that neither variability in water delivery or collection time are accounted for; rather, the MDG target for monitoring is based on distance to source, which may not be the only factor related to time of collection.

Within the district of Independencia, several communities serviced by the water distribution system have ongoing problems with low pressure, or at times do not receive potable water for several days because of insufficient pressure in the system. The water quality of the piped water is also problematic, containing excessive

amounts of coliform bacteria. This report aims to improve the service level of the distribution system and help plan for water quality assurance and future growth in the district, using EPANET 2.0 as a decision support tool. This human right to safe water is of paramount importance for the livelihood and health of the local population, and is a big step towards accomplishing the MDGs while improving the quality of life for the inhabitants of the district of Independencia, Peru.

Objectives

The objectives of this report are to gain an understanding of the water use and sanitation practices as well as model the water distribution network in the district of Independencia, Peru. Specifically:

- Report the findings of water and sanitation surveys done in three communities within the district of Independencia, Peru.
- Report the results of water quality testing done in the district.
- Create a model representing the water distribution network for the district using software created by the United States Environmental Protection Agency, EPANET 2.0
- Make recommendations to the local municipality for:
 - Improving the service of the existing water distribution system to provide at least 25 l/p/d with adequate pressure;
 - Expanding the water distribution system to provide continuous delivery; accounting for future growth and meeting a minimum of 50 l/p/d of safe water; and planning for sustainable water resources management in the district.

It is expected that increasing the delivery time of the potable water supply in the district will have a positive impact on personal hygiene and reduce water-related diseases. However, increasing the service level of potable water could create an increase in demand, and therefore the water supply, namely stream flows in the Pisco River, must be closely monitored to ensure sustainability.

It has been estimated that the absolute minimum water requirements for replacing fluids lost in an average climate for the average person are around three liters per person per day (l/p/d) (Gleick, 1998). Other studies have broken this down into the water required for men and women, which yields 3.7 l/p/d for men and 2.7 l/p/d for women for the majority of cases (Sawka et al., 2005). However, because the majority of the population lives in tropical to sub-tropical climates, this minimum should be increased to about five l/p/d. In addition to human consumption, sanitation and hygienic needs must also be included, as they have demonstrated positive benefits to community health. Sanitation needs are estimated to be a minimum of 20 l/p/d to cover waste disposal and related hygiene. Bathing needs have been set at 15 l/p/d as a minimum, and food preparation is estimated to be 10 l/p/d to cover basic needs. Therefore, a minimum international standard for basic water requirements for domestic needs is 50 l/p/d (Gleick, 1998).

The improvement of the water system has already been promised by the new mayor in Independencia, and will be funded by the local municipality. The analysis and associated recommendations are aimed to aid the municipality in the design of a distribution system improvement and ensure that the system will operate satisfactorily, maintaining a minimum pressure and water quality standard.

Background

History

When the Spaniards arrived in Peru in the year 1531 it was part of the vast and highly developed Incan empire. The diseases brought by Europeans, namely smallpox, spread from the isthmus of Panama and hit the Incan empire in the 1520s, even before the Spaniards arrived, causing the death of a large portion of the population, most notably, several of their leaders. In the confusion of finding a successor for the Incan throne, civil war broke out severely debilitating the society, and thus Francisco Pizarro had little trouble in his conquest, (Crosby, 1967). Pizarro went on to take control of the largest amount of gold and silver the Spanish had yet seen from South America, shipping around 287,000 pounds of gold between 1550-1557 (Gabai, 1987).

In 1821 the movement for independence began, led by José de San Martín and Simón Bolívar from Argentina and Bolivia, respectively. In 1824, when General Antonio José de Sucre defeated the Spaniards in Ayacucho, Peru became independent. Spain made various attempts to regain colonies, in vain, and finally conceded in 1879 (Peace Corps, 2007).

Following independence Peru had several border disputes with its neighbors, including the war of the Pacific from 1879-1883, a border war won by Chile, in which Peru lost much of its southern territory and Bolivia lost its access to the sea. Several other brief military conflicts arose between Ecuador and Chile over border disputes, leading to peace treaties, the last of which was signed in 1998 demarcating the border between Peru and Ecuador (Peace Corps, 2007).

Peru, like many Latin American countries, has had its share of military coups. In 1968, General Juan Velasco Alvarado overthrew President Fernando Belaúnde Terry of the Popular Action Party and had control of the country until 1975. The Velasco regime focused on industrial growth and efficiency, and attempted to close the gap in wealth and power among social classes. Under this regime, there were several agrarian reforms in which land was divided and distributed to peasants. Velasco also nationalized the fish meal industry, the highly profitable cement-companies, some banks, as well as several petroleum and mining companies. The Velasco regime focused primarily in state-sector growth, and was accused of creating policy that made it impossible for private industrial enterprise (Bamat, 1983).

The year 1982 brought the already dismal economy to its knees with the onset of El Niño, decimating schools of fish and causing floods in the coast and drought in the

mountains. To make matters worse, the terrorist groups Shining Path and the Túpac Amaru Revolutionary Movement began and created alliances with the cultivation and trafficking of coca, which gave them financial resources, thus accelerating their activities (Peace Corps, 2007).

Alan García Pérez was elected in 1985, marking the first democratic transfer of power in Peru in over 40 years. García was considered the John F. Kennedy of Peru because of his youth and charisma, but his poor management of the economy led to hyperinflation, and he did little to check the rampant terrorism plaguing the country. He fled the country in disgrace with accusations of corruption (Peace Corps, 2007).

A relatively unknown mathematician turned politician Alberto Fujimori, of Japanese descent, succeeded García in 1990, defeating Nobel Prize winning author Mario Vargas Llosa (Peace Corps, 2007). Fujimori is a very controversial figure in Peruvian history because of human rights violations and corruption. Many of the rural poor are unwavering supporters because of the improvements to infrastructure in rural mountainous regions and virtually uprooting terrorism; however, he is currently serving a 25-year prison sentence for his role in kidnappings and death squads during his campaign against terrorism as well as bribery charges.

Alejandro Toledo won the presidency in 2001 becoming the first president of indigenous descent in Peru. He pledged to continue the reconstruction of democratic institutions, fight poverty, unemployment, and corruption. Although the gross domestic product (GDP) of the country was the fastest growing in South America from 2002-2005, the Toledo administration was perceived by the public to not be distributing the benefits of said growth, and his approval ratings went as low as 10 percent. Alejandro Toledo was taught English by a Peace Corps Volunteer as a child, and in 2001 he invited Peace Corps back to the country after their withdrawal due to political instability.

People and Culture

Peru has a population of about 28 million, with about 76 percent of the population living in urban areas (CIA, 2011). Eighty-five percent of the population is divided about equally between indigenous and mestizo descent (mix of indigenous and European), although this classification is blurred by socioeconomic and cultural factors, e.g. people of purely indigenous blood line who have adopted some Hispanic culture usually consider themselves mestizos. Roughly 12 percent of the population is white and the remaining 3 percent is made up of black, Chinese, Japanese and other groups (Peace Corps, 2007).

According to the CIA Fact-book (2011), over 80 percent of the population is Roman Catholic. However, from the author's experience, many people say they are Catholic but they do not regularly attend church or adhere to the strict scripture.

The two official languages are Spanish and Quechua with Spanish spoken in the vast majority of the country. Quechua is typically spoken in indigenous villages in the

highlands of the Andes, but most Quechua speakers also speak Spanish. There are a variety of other indigenous languages spoken east of the Andes and in the tropical lowlands of the Amazon basin.

There is a significant socioeconomic difference between the coastal mestizo culture and the traditional Andean culture. In the author's experience working in Peru, there is a lot of discrimination towards people of indigenous descent. East of the Andes, in the tropical lowlands, there are a variety of cultures, some very traditional and others nearly completely assimilated into the mestizo-Hispanic culture.

Geography

The land area of Peru is roughly 1.28 million km², slightly smaller than the state of Alaska (CIA, 2011). Peru has a very diverse geography, including arid coastal deserts, the Andean mountains and the Amazonian tropical forests.



Figure 2: Political Map of South America

Source: http://www.lib.utexas.edu/maps/americas/south_america_pol98.jpg

Courtesy of the University of Texas Libraries, The University of Texas at Austin



Figure 3: Shaded Relief Map of Peru

Source: http://www.lib.utexas.edu/maps/americas/peru_rel_06.jpg

Courtesy of the University of Texas Libraries, The University of Texas at Austin

Climate

The climate of Peru is very diverse due to the presence of the Andes Mountains and the Humboldt Current coming from Antarctica bringing cold waters up the Pacific coast. Peru has 34 of the world's 37 "life zones", which were defined by Leslie Holdridge in 1947 according to temperature, precipitation, and potential evapotranspiration (Parsons, 1962). However, there are three general climate regions - the coast, the mountains, and the jungle. Peru also contains the headwaters of the Amazon River and 16% of the Amazon Basin (Villar et al., 2009).

The coastal regions have hot, arid, and sunny summers, in general. The farther north the more humid it gets nearing the Equator. The winters are overcast, cool and damp. A few kilometers inland of the coast is a permanent fog, called *garua* in Spanish.

The Andean highlands have the most varied climate in the country. The rainy season starts in September continuing through May, peaking somewhere in January to March. In the southeast of the Peruvian Amazon Basin, a weather station recorded 9,000 mm (354 in) of rainfall in 1967 (Villar et al., 2009). In the Andes, May through August is marked by very dry conditions, with cold nights and mornings.

The eastern lowlands have an Equatorial climate which feeds the Amazon Rainforest. This climate is hot and rainy for most of the year, but in some southern areas there is a short dry season between June and August.

Development in Peru

The climate and soil in the district of Independencia are favorable for agriculture; however, multiple land reforms, natural disasters, and inequalities in natural resources distribution and have created poverty (Gómez, 2008).

On August 15, 2007 an earthquake of 8.0 on the Richter scale occurred just offshore of Pisco, about 20 km outside Independencia, which severely damaged the infrastructure of the department, and claimed the lives of thousands. Infrastructure repair has been slow, and there has been a huge influx of international development agencies such as: Oxfam, an Adventist agency (ADRA), Red Cross/Crescent Moon, A French NGO Terre des Homme, a.k.a. Action Against Hunger (ACF for its initials in French), as well as others.

A publication financed by Oxfam International for development of the district links the social and economic inequalities with lack of training and implementation of producers, scarce use of adequate and sustainable technologies for agriculture, lack of organization in the civil society, impractical education models, and a deficit of social and productive infrastructure for socioeconomic development, among other factors (Gómez, 2008).

With regard specifically to the water sector, in the 1980s when Peru was moving towards decentralization, water service providers were caught in this large-scale movement. This industry changed drastically, fragmenting it into 136 municipal bodies. The decentralization caused many problems, such as the loss of scale economies, no separation between the service providers and the regulatory body (the municipalities are both), and insufficient technical personnel to operate many small systems (Foster, 2005).

National Statistics

The Millennium Development Goals (MDGs) were designed to help create a global partnership for sustainable development. The MDGs are the following (Sachs and McArthur, 2005):

1. Reduce extreme poverty and hunger by half relative to 1990
2. Achieve universal primary education
3. Promote gender equality and empowerment of women
4. Reduce child mortality by two-thirds relative to 1990
5. Improve maternal health, including reducing maternal mortality by three-quarters relative to 1990
6. Prevent the spread of HIV/AIDS, malaria, and other diseases
7. Ensure environmental sustainability
8. Develop a global partnership for development

National production grew nearly 9% in 2010 (INEI, 2011), however the incidence of extreme poverty in Peru for the year 2008 was 3.6 million people, or 12.6% of the population, defined as people with income less than 1 U.S. dollar per day. There is a high incidence of extreme poverty in the rural mountainous regions, 37.4% of this demographic, followed by the rural jungle regions, with 20.7% of people in this area in extreme poverty (Espino, 2009).

Illiteracy in Peru is very much skewed, from as low as 5% in the wealthiest class, to 25% in the poorest. This trend is mirrored in school attendance of children from 6-12 years old, going from 99.6% attendance in the privileged class down to 75% in the poorest sector (UN, 2002).

A major problem in Peru is invasion settlements, i.e. displaced people who moved into an area without going through the proper channels. Nationally, there are 400,000 people who do not have titles to their land, and thus cannot legally build houses or even apply for programs that assist in building houses. There are also 500,000 families that live in *chozas*, which translates as a hut or shack (UN, 2002). These huts are usually made of small log posts with thatched walls.

The percentage of children completing primary school by the age of 11 has grown from 36.7% in 2001 to 63.8% in the year 2008, with no significant difference between boys and girls. However, once again the regions play an important role in this figure, with only 57.9% and 51.2% of children in the mountains and jungle, respectively, finishing primary school by this age in 2008 (Espino, 2009).

With respect to the goal of promoting gender equality, Peru is doing quite well. Indicators such as secondary school as well as superior education attendance were favoring women as of 2008. Another indicator is the presence of women in salaried positions in urban areas, which has grown from 34.2 to 37.5% of the female population in all sectors except agriculture from 2001 to 2008. In political participation, women holding seats in parliament has grown from 2.5% in the period of 1956-62 to 29.2% in the period of 2006-2011 (Espino, 2009).

Progress towards the goal to reduce child mortality can be seen in the reduction of infant mortality. In 1991-92, 64 of every 1,000 live births died, whereas in 2007-08 that figure dropped to 25. In children under five years old the number of mortalities decreased from 92 to 33 for every 1,000 live births for the same time frame (Espino, 2009).

Overall, the country has made much progress in improving sustainable access to safe water in urban areas, but the rural sector is in dire need of expanding this service. Sustainable access to safe water is defined as at least 20 l/p/d less than 1,000 meters from the home coming from either pipes, a public tap, a borehole/pumped, a protected well or spring, or rainwater (UN, 2003). Urban areas have increased sustainable access to safe water from 82.7% in 2001 to 87.1% in 2008, whereas rural areas have actually decreased, going from 42.5% to 33.9% over the same time period. This is especially dramatic considering socioeconomic factors: in the richest fifth of the population, 92.9% had access to safe water, while in the poorest fifth of the population, only 35.9% had this service in 2008 (Espino, 2009).

It should be noted that WHO/UNICEF estimates the proportion of Peruvians in urban areas with access to improved water supply at 90% in 2008 and rural areas at 61% in 2008, revealing a significant discrepancy in estimates of rural coverage despite both using household surveys as their data source (WHO/UNICEF, 2010).

Access to improved sanitation has increased both in urban and rural sectors. Improved sanitation is defined as anything that hygienically separates human feces from human, animal or insect contact (UN, 2003). Urban areas with access to improved sanitation increased from 77.5% in 2001 to 85.2% in 2008. Rural areas increased access from 15.9% to 39.1% over the same time period (Espino, 2009). The estimates reported by WHO/UNICEF are similar: 81% in the urban sector and 36% coverage in the rural sector for 2008 (WHO/UNICEF, 2010).

The Players

There are several NGOs working in Peru, namely, Oxfam, an Adventist agency (ADRA), Red Cross/ Red Crescent, a French NGO *Terre des Homme*, also called Action Against Hunger (ACF).

Oxfam International is a group of independent NGOs dedicated to fighting poverty and injustice. They aim to do the following:

- Address the structural causes of poverty and related injustice
- Work primarily through local accountable organizations, seeking to strengthen their empowerment
- Help people directly where local capacity is insufficient
- Assist the development of institutional structures which directly benefit people facing the realities of poverty and injustice and which are accountable to them.

Oxfam works in the areas of disaster relief and planning. In Peru, Oxfam is working to help locals understand climate change and manage their natural resources. Oxfam also works with indigenous groups to help them defend their right to land and resources (Oxfam, 2011). In the author's community, Oxfam built latrines for families that did not have adequate sanitation facilities.

ADRA forms part of one of the largest NGOs in the world, with an active presence in 120 countries. ADRA focuses on sustainable development to benefit people in poverty and socially high-risk demographics (ADRA, 2011). In the area that the author lived, ADRA worked with locals to improve health and hygiene through educational sessions with local agents. These agents are then responsible for the dissemination of the information to their respective communities.

The Red Cross/ Red Crescent is the largest humanitarian organization in the world, with 186 societies and growing. They focus on four areas, promoting humanitarian values, disaster response, disaster preparedness, and health and community care. Their vision is as follows: "To inspire, encourage, facilitate and promote at all times all forms of humanitarian activities by National Societies, with a view to preventing and alleviating human suffering, and thereby contributing to the maintenance and promotion of human dignity and peace in the world" (<http://www.ifrc.org/en/who-we-are/vision-and-mission/>).

The International Federation of Red Cross/Red Crescent societies is working in disaster relief and planning, and is currently building and donating houses to families affected by the earthquake of August, 2007. They have completed over 6,000 transitional houses in the areas affected by the earthquake (IRFC, 2011).

Terre des Homme (TDH), also called *Action Contra la Faim* (ACF), is an international aid organization working for the rights of children and for equitable development without biases. Mainly they work to improve the quality of life of children in vulnerable situations (TDH, 2011). In Independencia, their work was primarily with the schools dealing with issues of self-esteem, hygiene, as well as environmental education and awareness, to list a few. This organization was also involved in latrine construction and assisted in financing the water line for the community of Toma León, donating almost all of the materials required for the 7-kilometer main line.

Peace Corps Peru

The Peace Corps first arrived in Peru in 1962 and worked in the areas of health and nutrition, city planning, agriculture extension and cooperatives, savings and loan associations, elementary and secondary education, community development, as well as reconstruction in the areas affected by the 1970 earthquake and landslide. In 1975 Peace Corps Peru evacuated the country due to political and economic instability (Peace Corps, 2007).

In 2001, President Alejandro Toledo invited Peace Corps to return. In August of 2002 four volunteers arrived as third-year extensions from other Latin American countries, followed by the first group of new volunteers in November of the same year. Since then, two groups arrive each year, working in the following five sectors (Peace Corps, 2007):

- Small Business Development
- Community Health
- Youth Development
- Environmental Awareness
- Water and Sanitation

“All Peace Corps activities are directed towards providing people at the community level with knowledge, tools and capacities to improve their own lives” (Peace Corps, 2007). Specifically, the Water and Sanitation sector has three goals:

- Improve access to safe water for low-income families
- Improve personal hygiene in the community
- Improve the organizational capacity of individuals and institutions within the community

Description of the Study Area

Geography

The study area is the district of Independencia, located 250 kilometers south of the capital of Lima. Independencia is located in the heart of the Pisco Valley, in the department of Ica. The district is spread over 272.34 km², with a range of altitude from 125 to 950 meters above sea level. The capital of the district, Independencia, has an elevation of 203 m (Gómez, 2008).

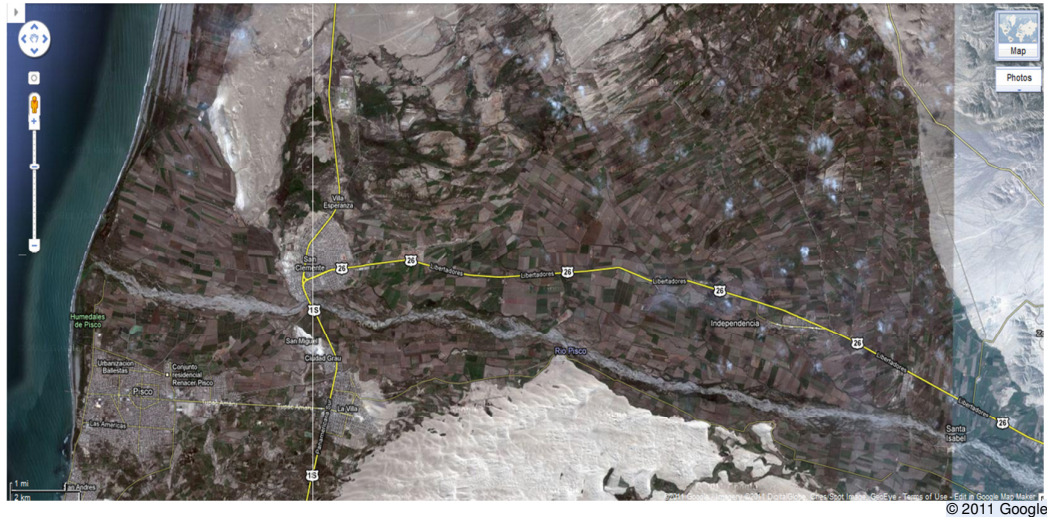


Figure 4: Google Aerial Image of Independencia, Peru.

The Pisco river originates in the mountainous region of Huancavelica in the Andes at an altitude of 5,000 meters and has a reach length of 170 Km (Gómez, 2008). There are four reservoirs that regulate the flow of the Pisco River. The flows are the lowest in August-September, where there may be no surface flow at the intake of the filtration gallery (see Figure 6). There are sufficient groundwater flows during the dry season, however, to supply the water demand for the district.

Climate

The climate of the department of Ica is temperate desert. There is a high humidity in the littoral zone of the ocean, decreasing sharply inland towards Independencia. Precipitation is practically nil, averaging 15 mm annually, with exceptional intense but short rains originating in the mountains to the east. However, during the two years the author was working in this region, he never witnessed intense rainfall. Temperature fluctuates little, between 55 and 82°F over the course of a year (Gómez, 2008).

Water Distribution System

The water line for the district is 9.2 miles long ending in the town of Independencia. From the source, the line is 6 inch diameter PVC along the highway ending in a 300 cubic meter storage tank in Independencia, shown in Figure 10. There is a well with a 50-horsepower pump to supplement the water for the town of Independencia. The water distribution system services ten communities within the district, approximately 13,276 people, with an expected growth rate of 2.61 percent. The system services each community intermittently, for 1.5 – 3 hours for each sector. The water is routed to each of the communities according to a water delivery schedule, (see Table 12), by manually opening and closing valves.

The photos below illustrate the study area and demonstrate some of the components of the water distribution system starting at the filtration gallery, where the water filters through alluvial sand and gravel before entering the intake structure to be distributed to the various communities within the district of Independencia.



Figure 5: Pisco River at the Filtration Gallery of Water Distribution System



Figure 6: Pisco River at the End of Dry Season (October)



Figure 7: Spring Just Upriver of Intake Structure to Water Distribution System



Figure 8: Intake Structure for Water Distribution System



Figure 9: Gas Chlorination Unit for the Water Distribution System



Figure 10: Water Storage Tank for Independencia

There is also a well with a pump in the town of Independencia, near the tank. This pump is turned on for half an hour at a time either to fill up the tank or to distribute water directly to the town of Independencia. After half an hour of pumping, the well infiltration chamber is empty, and so the pump is turned off for an hour to let the groundwater fill the chamber again and the cycle is repeated.

The elevation change from the intake structure to the last point in the line of Independencia is about 460 feet, as can be seen in Figure 11.

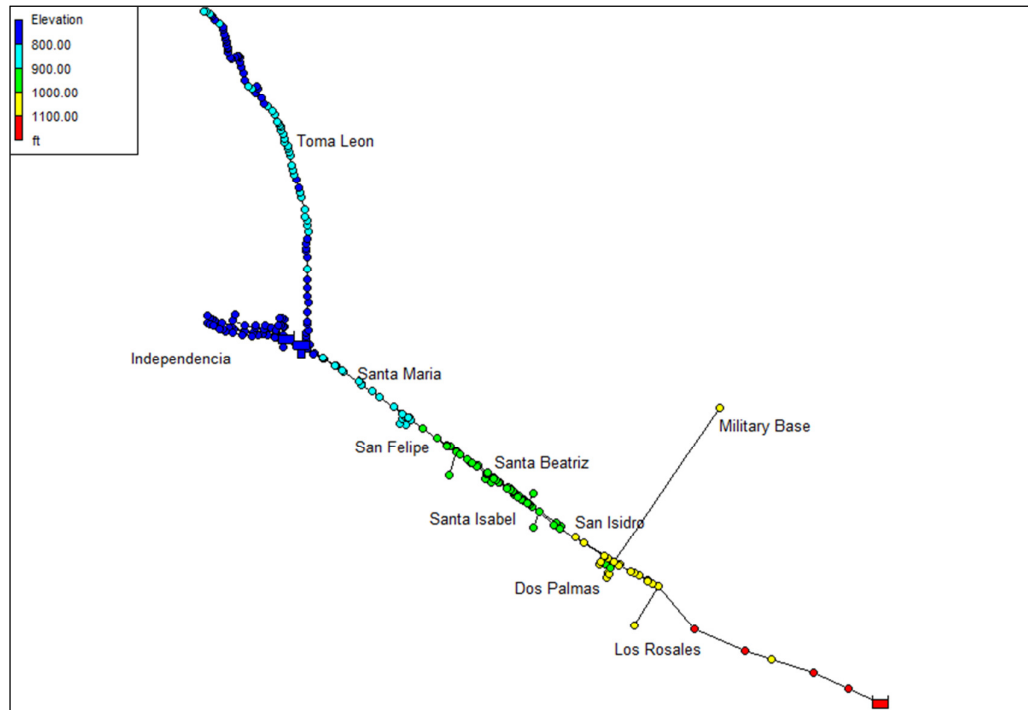


Figure 11: EPANET Schematic of Water Distribution System for Independencia with Elevation Legend

From the technical report prepared for the municipality, when the water distribution system was built in 2004, the mean household income was 350 Nuevo Soles, or about 120 US Dollars per month, and each household was expected to be able to pay about 10 Nuevo Soles per month, or about 3 US Dollars. From the technical report, it is assumed that there are 25% losses in the system; however, the technician reported that any leaks are immediately fixed.

Household Connections in Toma León

Peace Corps and the U.S. Agency for International Development (USAID) have an agreement that allows Peace Corps Volunteers (PCVs) to apply for small project assistance (SPA) grants for development in the community in which the PCV lives and works. The author wanted to do a project in the community of Toma León for several reasons, including the fact that they did not have a piped water distribution system, and several families did not have bathrooms. The first problem encountered was deciding which project should be chosen, because the community leaders had differing opinions as to what type of project would be best. The first project considered was an extension of sanitation coverage in the community, i.e., building 10-15 latrines for families who either did not have latrines or had latrines in a state of severe dilapidation. The second project was to complement a water distribution main

line that was recently installed in Toma León, connecting household lines from the main line to a valve box that could be easily continued to the household.

In order to ensure community participation in the project, the author met with the two community leaders and requested them to prepare a mini proposal for their respective projects. Each leader was given a printed out example of another PCV's SPA grant proposal, showing them how to formulate their proposals. It was thought that this would get them involved and promote sustainability: by going through the process of applying for these types of grants they could apply for funding in the future for other community development projects.

About two weeks later the author met with each of them to review their progress and plan what the next steps were. One of the leaders, the one wanting to build bathrooms, had done nothing in the way of advancing the proposal. Giving him the benefit of the doubt, he was given another week. The other leader had nine hand written pages describing the community, outlining the problem and the proposed solution. The author was very impressed with his initiative and dedication. At the end of the following week, the leader wanting to do bathrooms had still done nothing in the way of writing the mini proposal; therefore the choice was obvious to go ahead with the household water line connections so that there would be community participation and increase the sustainability of the project.

The project began with signing an agreement between the municipality, the community and Peace Corps. This was a contract stating what was expected out of each party, and was required for USAID funded projects. Materials were purchased, and to avoid problems with storing them, community members were responsible for picking up their own materials individually. Community members were also responsible for digging down to the main line and making a trench for the household line ending with a hole for the valve box before the author and the president of the potable water project came to do the installation.

Beforehand, forms were built out of wood to place the concrete for the valve boxes, as seen in Figure 15. Upon arriving to the households, concrete was placed for the valve box and then the main line was hand-drilled to connect the corporation valve, as shown in Figure 14. Next, the half-inch household line was connected from the main line to the valve box. This was done for each of the 135 households in Toma León, and water was then available on-plot to be collected between 5:00-8:00 AM by community members.



Figure 12: Main Water Line in Toma León



Figure 13: Air Valve for Main Water Line in Toma León



Figure 14: Household Water Line Connection in Toma León



Figure 15: Household Shut-off Valve in Toma León



Figure 16: Household Valve Box in Toma León



Figure 17: Household Tap in Toma León

Problems ensued soon after all the connections were installed. The water line for Toma León extends 7 km off the 6-inch main line for the district of Independencia. Community members at the end of the line were not getting water some days, and at times were without water for more than a week. Upon investigating the problem, it was found that several community members near the beginning of the line would fill up their storage vessels with water, and then use a hose to water their gardens or their livestock with the potable water, reducing the pressure in the Toma León main branch and affecting their downstream neighbors.

The author and community leader went from house to house one day, explaining the problem and pointing out that this water was for human consumption only, and then a couple of days later the same people were observed misusing the water again. Pictures were taken of the unacceptable water uses with the threat of reporting them to the municipality (see Figure 18), but no actual penalty could be enforced. When the author left Peru, the problem of low or no flow at the end of the Toma León branch was still persisting. If there was no water for various days, the water technician would leave the valve for Toma León open for a longer period of time to ensure that water made it to the end of the line, but this strategy was causing much conflict in the community.



Figure 18: Photo Taken of Unapproved Water Uses in Toma León

Community Surveys

Methodology

The surveys focused on the small agrarian communities of Dos Palmas, José Olaya, and Toma León. All three communities belong to the district of Independencia; however José Olaya has a separate water distribution system. While all three communities are rural, Toma León is more dispersed, with 135 houses along a dirt road stretching 7 kilometers off the main highway.

Upon arriving to site, the author administered the first round of surveys in José Olaya and Dos Palmas in January of 2009, surveying 28 and 3.5 percent of the houses within these communities, respectively. The survey was created by the Associate Peace Corps Director for the Water & Sanitation Program of Peace Corps Peru, and was given to all PCVs in the program to be completed as part of a community diagnostic. Survey participants were chosen by availability; the author went from house to house administering the survey if the family consented to participate.

The second round of surveys were in Toma León, and would begin with casual conversation about the weather, crops, and/or the water line. This was followed by the reciting of the oral consent form from memory and then proceeding into the actual survey questions (Appendix C). The surveys were started at the farthest houses from the highway, the end of the water distribution branch of the Toma León line. If community members were observed outside their household, they were approached and asked if they wanted to participate. If there were loose dogs that looked dangerous outside the house, the house would be skipped. If the author did not see people outside the house, he would approach and shout out for someone. If nobody answered after a minute or so, he would move upstream along the waterline and try another household. Once the author had advanced past a region that he thought was sufficiently represented, he would not return to that part of the water line.

Thus, Toma León was surveyed from the end of the line toward the highway by availability of participants until the author believed it was sufficiently represented. In total, about 25% of the houses were surveyed in Toma León.

Table 1 reports the total number of interviewees in each community. Due to the distance to Dos Palmas from the author's community, and the work schedule of the community members, only 13 surveys were conducted there.

Table 1: Number of People Interviewed by Community

Community	Number of interviewees	Percentage
José Olaya	38	45.2%
Dos Palmas	13	15.5%
Toma León	33	39.3%
Total	84	100.0%

Results

From the surveys it has been discovered that the average water use per household is about 21.9 liters per person per day, based on responses from all households surveyed, regardless of types of water use. If we consider estimates by families who reported their consumption uses only, the average goes down to around 14 liters per person per day. Eighty-eight percent of families surveyed have only one tap on their lot, and the most common storage container is a large plastic trash can with a lid.

From the surveys, it was found that the majority of the people boil their water, and some add chlorine tablets or bleach. Twenty-six percent of people interviewed say they wash their hands “all the time”, and 58% mention washing before preparing food/eating. None of the communities surveyed have a sewer system; most people have simple pit latrines with concrete slabs covering the hole and a privacy structure made of adobe bricks or corrugated metal. Some people do not have any type of bathroom and just go to the fields to do their necessities.

Trash is normally stored just outside of the home in the patio in large plastic bags or buckets. Supposedly there is trash collection once per week, but in an effort to avoid attracting flies and rats a lot of people burn their trash or throw it in the canal because it piles up after a few days. Also, sometimes the trash collectors do not come, so people are forced to deal with their trash themselves. It has been noticed that there is a stark difference between the American taboo of littering and the culture of Independencia of discarding trash wherever. In the communities that have been visited, it is very common to see waterways, gutters, and streets littered with all kinds of trash.

In the communities surveyed, many people own fowl; e.g., in Toma León, 30 out of 33 families surveyed have either chickens, turkeys, or ducks, with the majority reporting that they are either corralled or tied up, although it is common to see them wandering around freely. Most families in the community cook with gas, and some use both gas and firewood, with only about 13% of households surveyed using firewood as their only cooking fuel. Finally, from the surveys people are reporting very low incidences of diarrhea, conjunctivitis, mange, typhoid fever, and hepatitis within the subpopulation of children under the age of 5 years old.



Figure 19: A Typical Kitchen with a Wood-Burning Cook-Stove

The tables below provide a summary of the primary findings of the household water use and sanitation surveys.

Table 2: Average Reported Water Use for All Domestic Uses by Community

Community	Average water use (L/p/d)
José Olaya	23.4
Dos Palmas	20.0
Toma León	22.3
Average	21.9

With an intermittent supply, the water must be stored for domestic uses throughout the day. Most families surveyed cover and wash their storage vessels, as seen in Tables 3 and 4 below, respectively.

Table 3: Number of Interviewees That Use Lids on Storage Vessels for Water for Human Consumption

Lids on storage vessels	Number of interviewees	Percentage
Yes	75	89.3%
No	9	10.7%
Total	84	100.0%

Lids could be anything from plastic sheeting to plywood. This was visually checked by the author whenever possible, unless the participant did not invite the author into the premises and the storage container was not in view.

Table 4 shows the number of people who reported that they wash their storage containers. This survey question was a simple yes or no, with no open ended follow up question about with what or how often.

Table 4: Number of Interviewees That Wash Storage Vessels

Wash storage vessels	Number of interviewees	Percentage
Yes	72	85.7%
No	1	1.2%
No response	11	13.1%
Total	84	100.0%

The number of participants not responding in Table 4 was mainly due to the author accidentally skipping over the question during the interview. Ten of the 11 cases happened during the first round of surveying, thus it was due to the author not being very familiar with the survey and trying to hurry through it so as not to inconvenience families who were pressed for time.

In Table 5, three participants mentioned multiple household water treatment methods, which is why the total is over 100 percent. Boiling was the most common treatment method, however the length of time water was held at a boil was not asked.

Table 5: Household Water Treatment Method Used by Interviewee

Water treatment	Number of interviewees	Percentage
Boil	58	69.0%
Bleach	4	4.8%
Chlorine	5	6.0%
Buy water	5	6.0%
No treatment	14	16.7%
No response	1	1.2%
Total	87	103.6%

Respondents in Table 6 were double counted in the category “two or more key times” if they mentioned both “before cooking/eating” and “after using the bathroom” for the key times.

Table 6: Moments When Hand Washing was Reported by Interviewee

Hand Wash	Number of interviewees	Percentage
All the time	22	26.2%
Before cooking/eating	49	58.3%
After using the bathroom	16	19.0%
Two or more key times	13	15.5%
Other time	6	7.1%
Doesn't wash hands	1	1.2%
No response	3	3.6%
Total	110	131.0%

Simple pit latrines are the most common bathroom type within the communities surveyed, as shown in Table 7. However, the town of Independencia is connected to a sewer system and most residents have flushing toilets.

Table 7: Type of Bathroom Used by Family

Bathroom Type	Number of interviewees	Percentage
Pit Latrine	58	69.0%
Open air	16	19.0%
Pour flush	6	7.1%
Composting latrine	4	4.8%
Total	84	100.0%

Table 8 has the results of childhood diarrheal cases within the subpopulation of families surveyed with children under five years old living in the house. It is suspected that people do not want to report sicknesses such as diarrhea to a stranger due to embarrassment, so this should be taken into consideration when analyzing the survey results.

Table 8: Interviewees Reporting Children Under 5 Years Old in Household Had Diarrhea Within Last Month

Children under 5 with diarrhea in last month	Number of interviewees	Percentage
Yes	8	18.6%
No	35	81.4%
Total	43	100.0%

Discussion

The three communities surveyed are very similar with respect to water and sanitation coverage; however, José Olaya is not on the same water distribution system because they have a different source of water, which is a small spring located to the southwest of Independencia. Nonetheless, the water use is expected to be roughly equal because of the similarities in sanitation, water delivery, storage, and taps per household, as well as socioeconomic structure.

During the first round of surveys, the author was virtually unknown and people were not very receptive. The author would ride his bike to the community and walk from house to house administering the surveys, and almost every family was very suspicious of a foreigner wanting to know about their water use and sanitation practices. Some families would not participate because they suspected the author was from the government and wanted to take away their land, so the door was shut in his face a few times. During the first round of surveys the oral consent form (Appendix B) was read out loud to the family members, which was not very effective. Once the author started reading from a sheet of paper, people were automatically put off, and it was very apparent that they were uncomfortable and suspicious. At this point the author was not fluent in Spanish and had not practiced the oral consent form much which made the whole survey very awkward.

The second round of surveys in Toma León went much better as the author had become much more proficient in Spanish, and was well known in the community from his work on the water line. Additionally, the author was more familiar with the idiosyncrasies of Peruvian culture.

In Toma León water is supplied anywhere from zero to three hours per day, depending on the day and distance from the main line. The lack of supply for the downstream users should be taken into account when analyzing the water use data taken from the surveys because it is believed that many people do not want to say how much water they actually use because they fear that further restrictions will be imposed if they report more than their neighbors.

In the district of Independencia, Peru, the water use is lower than what Gleick (1998) proposes because the majority of the population (93% of those surveyed) has a latrine which does not require water to dispose of human waste. Another reason for the disparity between survey data and Gleick's basic water requirement is that many people wash their laundry and bathe in the river or canal rather than using piped water.

Water Quality

Methodology

Water quality testing in the district of Independencia was performed by a division of the U.S. Navy, the Naval Medical Research Center Detachment (NMRCD) based in Lima, Peru. During the time the author was in Independencia, two rounds of water sampling and laboratory testing were conducted at houses where there were children five years of age or under. The NMRCD study aims to provide a baseline assessment of the water quality in the district, as well as to prioritize intervention strategies.

The water sampling was carried out by laboratory technicians sub-contracted by NMRCD in the communities of José Olaya, Toma León, and Independencia. Two 100 ml water samples were collected aseptically from the primary source where water is consumed in the home, in a Whirl-Pak bag or Colilert vessel with sodium thiosulfate to eliminate residual chlorine in the sample. At the time of sampling, the pH, chlorine, and turbidity were measured, and the samples were stored between 2 and 8 C until arrival at the laboratory in Lima within eight hours of collection.

The commercial Colilert system was used to test the samples for presence/absence and quantify coliform forming bacteria. Positive samples were transferred to a filter media for isolation and identification of the bacteria.

Results

The first round of tests had an average pH of 7.92, average residual chlorine of 0.32 mg/L, and an average turbidity of 4.97 NTU. Results for the Colilert and filter tests for coliforms and E. coli were above permissible limits in all of the 31 samples tested. The second round had an average pH of 7.95, average residual chlorine of 0.41 mg/L, and an average turbidity of 8.82 NTU. In this round, 29 out of 30 samples by Colilert and filter tests were again above the limit for coliforms and E. coli.

The median results for the two rounds of tests are shown in Table 9 below. See Appendix D for all results.

Table 9: Median Results of Water Quality Parameters from NMRC Testing

Water Quality Parameters		
Median Results	Round 1	Round 2
pH	7.80	7.80
Chlorine (mg/l)	0.30	0.20
Turbidity (NTU)	2.31	0.75
Total Coliforms (MPN/100ml)*	2,420	2,076
E. Coli (MPN/100ml)	52.80	14.60
Total Coliforms (CFU/100ml)	3,900	3,000
Non-Coliforms (CFU/100ml)	30,000	17,000

Cases of sicknesses at the health post in Independencia are recorded by the staff, and any cases considered by the author to be water-related were noted. The results are presented below in Table 10.

Table 10: Cases of Sicknesses Reported to the Health Post in Independencia by Community for the Year 2008

Illness	Community				
	José Olaya	Dos Palmas	Toma León	Cabeza de Toro 4	Cabeza de Toro 5
Diarrhea	0	0	11	0	32
Enterobiasis	31	68	7	15	0
Giardiasis	16	62	0	10	0
Parasitosis	0	0	0	9	0
Total Population	1,608	2,214	810	763	531

Discussion

In addressing the MDGs, it is important to relate cultural views on what is considered “safe” water. Safe from a microbiological standpoint may not coincide with what the local population considers safe. Studies done in Latino populations in the developing world show that many people from this demographic view water-related diseases as something that is a normal part of life, and thus not a serious health risk (Robles et al., 2011). However, from the author’s experience conducting several educational sessions for children in the district about hand-washing and water-treatment, it was apparent that most children did understand the germ-theory of disease.

In the district capital of Independencia, water quality assurance comes from the local health post, which carries out daily checks of residual chlorine from different households within the community. The residual chlorine checks are performed by a technician from the health post using a Hach color-wheel test kit. However, this was not a consistent endeavor from the author’s personal experience. Moreover, there were frequent cases when the author would assist in the chlorine checks where there

was no residual chlorine in the distribution system. The acceptable value of chlorine residual in a distribution system should be above 0.2 mg/l (CDC, 2008).

While residual chlorine testing is a good check that the water is being treated, it is not necessarily indicative of suitable water quality. The WHO recommends a microbial guideline of zero *E. coli* for a 100 ml sample, which was met in only one water sample analyzed. In addition, this fecal indicator alone could be misleading, as there are certain viruses and protozoal cysts that are more resistant to treatments such as chlorine (WHO, 2006).

Intermittent water distribution systems can also introduce contamination because they are more prone to stagnant water in the lines which promotes microbial growth. Also, intermittent systems are much more likely to have negative pressure when water is being re-routed to parts of the system with empty pipes, which can be caused by rapid opening or closing of valves. This negative pressure is thought to be a common way to introduce contaminants by creating reverse-flow, i.e. siphoning bacteria from the surrounding groundwater through leaks or bad connections (Lee et al., 2005). Additionally, biofilm accumulated on the pipe walls can be introduced into the drinking water due to higher velocity and pressure caused by intermittent operations, resulting in a 'first-flush' phenomenon and diminishing the water quality in the system (Rahimi, 2008). Thus, coliform forming bacteria could be introduced by these phenomena and have insufficient contact time with the residual chlorine in the system to disinfect the water (See Appendix E).

Water contamination could also happen during collection and/or storage in the household. A study done on water quality between point of use (POU) and source done by Levy et al. (2008) has shown that the type of water vessel used for storage in the home can be a big factor in water quality, with narrow mouthed containers and covered vessels having superior water quality. The results from this study also reinforce the notion that source water quality and sanitation improvements are a prominent factor in reducing water-related diseases (Levy et al., 2008). Thus, integrated water quality interventions are likely to be the most effective, rather than focusing on individual interventions.

Hydraulic Model

Introduction to EPANET

EPANET 2.0, a software program developed by the Environmental Protection Agency (EPA, 2000) was used to model the water distribution system in Independencia. This program is used to model piped water distribution systems. The hydraulic modeling is based on conservation of mass and energy. Rossman (2000) explains that to characterize the hydraulic state, EPANET uses what is termed a hybrid node loop approach to solve the flow continuity and headloss equations. The flow headloss relationship, i.e. conservation of energy, between nodes i and j is as follows:

$$H_i - H_j = h_{ij} = rQ_{ij}^n + mQ_{ij}^2$$

where: H = Nodal head

h = Headloss

r = Resistance coefficient

Q = Flow rate,

n = Flow exponent

m = Minor loss coefficient.

The resistance coefficient depends on which headloss equation is used. The Hazen-Williams formula for headloss is the most common in the U.S. (Rossman, 2000). Also the Hazen-Williams is empirical, giving accurate results while not being overly complex, which can cause problems with solution convergence (Rahimi, 2008).

The continuity of flow equation used in EPANET is as follows, and by convention, flow into a node is positive.

$$\sum_j Q_{ij} - D_i = 0 \quad \text{for } i = 1, \dots, N.$$

where: Q_{ij} = Flow from node i to j

D_i = Flow demand at node i

N = Number of junction nodes in the model

The hydraulic modeling capabilities include unlimited system size (number of pipe segments), friction and minor head losses, pumping energy and cost, and dynamic pressure of any node in the system (Rossman, 2000). The flow rate in EPANET 2.0 is based purely on nodal demands input into the model; thus pressure was evaluated to determine whether or not the model could meet demands.

Methodology

The communities serviced by the water distribution system within the district of Independencia are shown in Table 11. The demand is based on the community surveys done in the district, rounded up to 25 liters per person per day to be conservative.

Table 11: Communities within the District of Independencia Fed by the Water Distribution System

<i>Community</i>	<i>Population</i>	<i>Lots</i>	<i>EPANET Junctions</i>	<i>Demand (GPM)</i>
Los Rosales	180	30	1	39.63
Dos Palmas	2,214	369	24	2.80
Military Base	400	67	1	22.01
San Isidro	306	51	18	1.25
Santa Isabel	990	165	19	2.87
Santa Beatriz	486	81	18	1.49
San Felipe	240	40	18	1.47
Santa María	156	26	17	0.67
Toma León	810	135	80	0.37
Independencia alto	2,910	485	23	16.00
Independencia medio	2,322	387	12	17.00
Independencia bajo	2,262	377	14	17.78
Total	13,276	2,213	245	N/A

The EPANET model of the system does not represent each household in the system; rather nodes were created to match changes in elevation or direction, or corners of a subsystem. Therefore, in order to create the demand at each node that corresponds with the surveys (25 liters per person per day), the population of that community was multiplied by 25 l/p/d and then divided by the number of nodes representing that community in EPANET. However, because each community only gets water for a few hours each day, this product was then divided by the corresponding number of hours that water is delivered to yield the nodal demand in liters/hour. This demand was then converted to gallons per minute (GPM) and input into EPANET (column 5 in Table 11).

The water distribution system in Independencia operates intermittently, which violates the assumption in EPANET that pipes are flowing full at all times. To account for this, various scenarios were created for each time period in which water is routed to different sectors or the pump was turned on or off. The scenarios are represented below in Table 12. For each scenario, all pipes in the model were closed except for those in the communities being delivered water at that time and any upstream main (6-inch pipe) or other transmission line (in the cases of Independencia Medio and

Bajo). See the Microsoft Excel file titled “EPANET_IWS” included in the CD for details on which pipes are open and closed in each scenario.

Table 12: Different Scenarios to Account for Water Routing Changes and Satisfy EPANET 2.0 Assumption of Pipes Flowing Full at All Times

<i>Scenario</i>	<i>Time</i>	<i>Communities</i>	<i>Demand (GPM)</i>
1	4-4:30AM	Independencia alto w/ pump	16
2	4:30-5AM	Independencia alto w/o pump	16
3	5-5:30AM	Toma León, Independencia medio w/o pump	.37; 17
4	5:30-6AM	Toma León, Independencia medio w/ pump	.37; 17
5	6-7AM	Toma León Independencia bajo w/o pump	.37; 8.9
6	7-7:30AM	Dos Palmas, Toma León, l bajo w/ pump	3.4; .37; 8.9
7	7:30-8AM	Dos Palmas, Toma León, l bajo w/o pump	3.4; .37; 8.9
8	8-8:30AM	Dos Palmas w/o pump	3.4
9	8:30-9AM	Dos Palmas w/ pump	3.4
8	9-10AM	Dos Palmas w/o pump	3.4
10	10-10:30AM	Military Base w/pump	22
11	10:30-11:30AM	Military Base w/o pump	22
10	11:30-12PM	Military Base w/pump	22
12	12-12:30 PM	Los Rosales	39.6
13	12:30-2PM	San Isidro	1.2
14	2-4PM	Santa Isabel	2.9
15	4-6PM	Santa Beatriz	1.5
16	6-7PM	San Felipe	1.5
17	7-8:30PM	Santa María	0.67

The model was set up using the Hazen-Williams formula for head loss, and a roughness coefficient, C , of 145. Rossman (2000) gives Hazen-Williams C values for new plastic pipe ranging from 140-150. The Hazen-Williams formula is:

$$h_L = q^{1.852} * (4.727 * C^{-1.852} * d^{-4.871} * L)$$

where: h_L = headloss (ft)
 q = Flow rate (cfs)
 C = Hazen-Williams roughness coefficient
 d = Pipe diameter (ft)
 L = Pipe length (ft)

The tank in Independencia was initially set to the maximum water level for the first scenario in EPANET. Next the tank water level was graphed using EPANET, and the water level at the end of the scenario was input as the initial tank water level for the subsequent scenario.

Two uncertainties in the model were the water level in the well and the pump horsepower. However, it was known that during the half-hour that the pump is turned on, it fills the tank in Independencia, keeping it at a maximum level to deliver higher pressure to the town of Independencia. The well water level was set at about 10 feet below the ground surface, an estimate based on the author's experience working in a nearby community where the water table was known. Once the well water level elevation was input into the model, the pump horsepower was adjusted until it could fill the tank after each off-cycle.

In order to make recommendations for future growth scenarios and a 24-hour delivery system, EPANET was used to predict what diameter main line would be required to satisfy various conditions. The variables for these future scenarios were population growth, demand per capita, and system design life. Each of these three variables was modified across a range of values to present a robust recommendation that would satisfy the majority of different scenarios modeled.

The base-case scenario was a population growth rate of 2.61%, which was taken from the technical report of the existing water distribution system, a per capita demand of 50 l/p/d, which is a published minimum (Gleick, 1998), and a 20-year system lifetime, which was also taken from the technical report. For each scenario, the diameter of pipe chosen was the smallest size that satisfied a minimum pressure of 20 psi in the main line from the first demand node to the end of the main line (Dos Palmas to Independencia). A pressure value of 20 psi is a published minimum for piped water distribution networks (Chase, 2000).

To simulate continuous service, a daily demand pattern was estimated based on the author's observations while living in the district, and was used for all future scenarios analysis. Shown in Table 14, the pattern mostly reflects the eating habits of the community, with lunch being the primary meal of the day. Bathing and clothes washing were not considered in the demand pattern as they are highly variable from family to family; however, bathing generally takes place around the lunch hour because the majority of people do not have heated water and take advantage of the warmest time of the day.

Table 13: Hourly Demand Pattern for the District of Independencia

<i>Time</i>	<i>Demand Multiplier</i>
6-8AM	1
8-10AM	0.5
10AM-12PM	1.5
12-2PM	1.5
2-4PM	0.5
4-6PM	1

Elevation and Pipe Length Data

The topographical study of the water distribution system was performed using two handheld Garmin E-trex Global Positioning System (GPS) units. The GPS units were set up using the World Geodetic System (WGS) 84, Zone 12 South, corresponding to the district of Independencia, Peru and UTM coordinates. The handheld GPS units have a barometric altimeter accurate within 10 feet (<http://www8.garmin.com/products/etrexVista/spec.html>). One GPS unit was used in order to make corrections for variations in atmospheric pressure, remaining at a stationary location and recording elevation readings every 15 minutes to capture these pressure fluctuations. The other GPS unit was used to mark waypoints along the water line at points of interest, e.g. major bends, elevation changes, valves, offshoots, and storage tanks. The elevation measurements were taken at the ground surface, directly above the water line with the assumption that the actual pipeline was a uniform depth below ground.

Elevation was corrected by adjusting the GPS output values with the stationary fluctuations. Specifically, the moving GPS elevation data are adjusted by the interpolated elevation change of the stationary GPS. For example, say the mapping began at 7:00, with both GPS units recording elevations at the same point. The moving GPS unit then follows the water line, recording 11 waypoints from 7:00 to 7:15. If the stationary GPS unit recorded 235 m at 7:00 and 240 m at 7:15, then the first waypoint would not be adjusted, the second waypoint would be adjusted by -0.5 m, the third waypoint would be adjusted by -1 m, etc., up to the 11th waypoint which would be adjusted by -5 meters.

The water system was divided into three sectors and mapped in three different days. The first sector was the main line from the intake at the river to the water tank in the town of Independencia. The second sector was Toma León, and the third sector was the town of Independencia. To account for different climatic conditions on each day, i.e. different reference elevation values, waypoints from the second and third day were adjusted to match a reference point elevation recorded on the first day. The reference point chosen was the water tank in Independencia, and was marked on all three different days to adjust the second and third day's elevation values to the first day's values.

Pipe lengths were entered in EPANET 2.0 using the Auto-length function to connect waypoints from the GPS unit. These lengths are not exact due to instrumentation error of the GPS unit, which has a locational accuracy of less than 50 feet (<http://www8.garmin.com/products/etrexVista/spec.html>), plus error introduced from not accounting for slope, as the length calculations made in EPANET are the planar distances between waypoints. However, if slope were accounted for it would make a negligible difference; for example, the average percent difference of main line pipe segments is 0.03%.

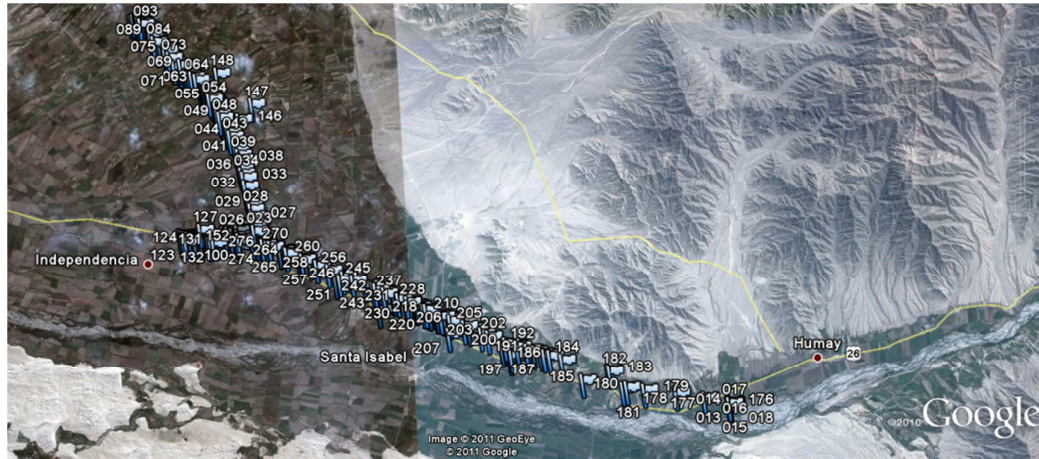


Figure 20: Google Earth Image with GPS Waypoints of Water System

Results

Modeling results reveal that, according to the current water delivery schedule obtained from the municipality, all the communities in the district of Independencia except Los Rosales can get 25 liters per person per day. According to the EPANET model, Los Rosales can be supplied a maximum of only 3.25 l/p/d while maintaining a positive pressure in the node. In order to supply Los Rosales with 25 l/p/d, the 3,284 feet of 1-inch line to the community would need to be replaced with a 4-inch line. Doing this would increase the pressure in Los Rosales from 3.32 to 31.36 psi.

Figure 21 below shows the nodal pressures for Toma León in scenario 7, demonstrating that the pressure is quite high throughout the line; however, on some occasions low or no pressure was observed in the field at taps toward the end of the line.

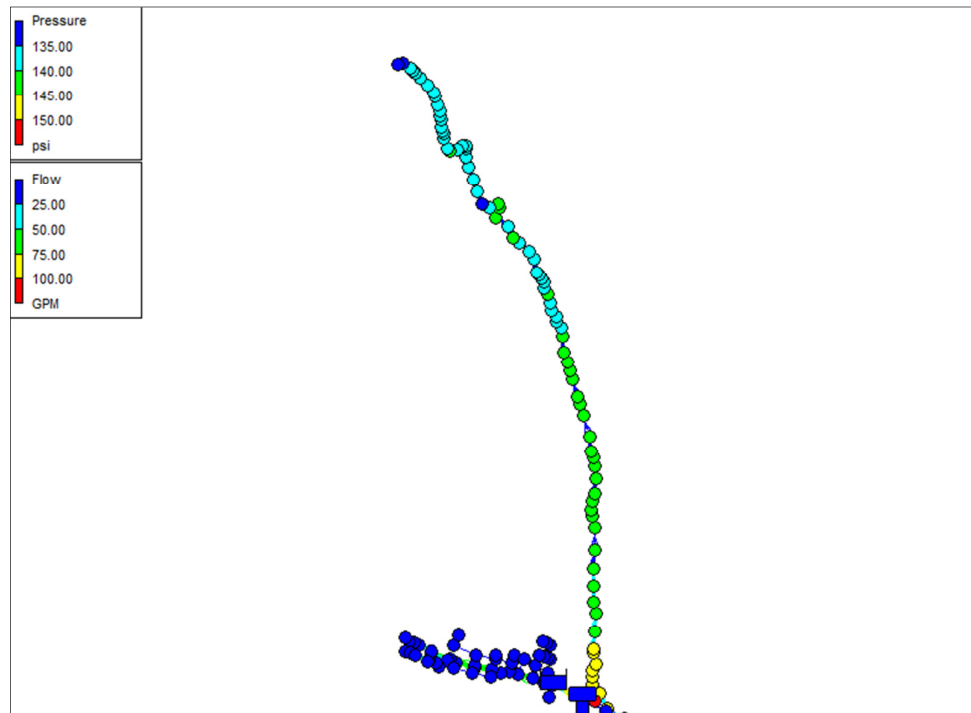


Figure 21: EPANET Screen Capture for Scenario 7 -Toma León Without Pump

In Figure 22 below, the pressure in Independencia Bajo (to the left of the screen) is shown along with the entire matrix of Independencia. Independencia is fed purely from the tank. The pipe segment upstream of the tank must be closed for all times that any sector of Independencia is being supplied; otherwise the model has negative nodal pressures upstream in the main line. This operational procedure was confirmed with the water technician.

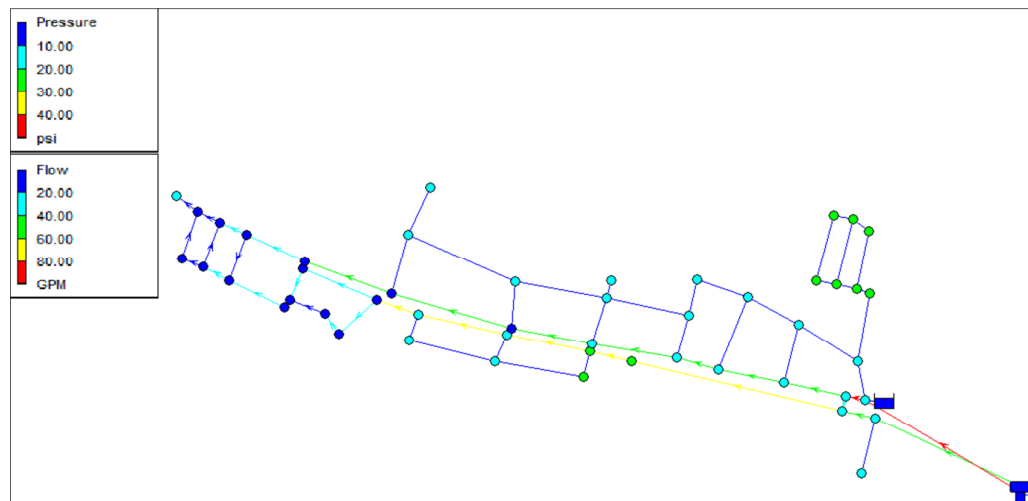


Figure 22: EPANET Screen Capture for Scenario 7 -Independencia Bajo Without Pump

The summary of nodal pressure for each community is shown in Table 13 below. Independencia Bajo had the lowest minimum pressure of any node in the network, as well as the lowest average nodal pressure. This is due to the distance from the tank and the smaller size piping that water must be routed through to arrive in this sector.

Table 14: Minimum, Maximum and Average Pressure for each Community in the District of Independencia

Community	Minimum Pressure (psi)	Maximum Pressure (psi)	Average Pressure (psi)
Los Rosales	3.32	3.32	3.32
Dos Palmas	6.55	65.85	42.95
Military Base	61.23	61.23	61.23
San Isidro	74.67	91.34	86.31
Santa Isabel	82.61	88.89	85.34
Santa Beatriz	89.89	107.14	95.65
San Felipe	109.86	138.05	124.24
Santa María	146.23	160.44	152.21
Toma León	131.41	157.43	145.66
Independencia Alto	12.37	22.56	18.06
Independencia Medio	13.68	27.55	20.39
Independencia Bajo	1.31	39.95	16.44

In addition to evaluating the current infrastructure system and operating plan, the EPANET model can be of real value to the district by aiding in decision making on how to increase the capacity of the system to provide continuous water delivery and account for population growth. This was done by increasing the main line pipe diameter until demands for a specific scenario were met. The scenarios are comprised of system lifetimes from 10 to 30 years, population growth rates from 1.5 to 3.5%, and demands from 20 to 100 l/p/d. Three values were chosen for each variable, totaling 27 scenarios.

First, a set of simulations were run for 10, 20, and 30 year system lifetimes, in which the demand was held constant at 20 l/p/d, with a population growth rate of 1.5%, computing the future population as follows:

$$P_f = P_0 * e^{r*t}$$

where: P_f is future population
 P_0 is current population
 r is the population growth rate
 t is time in years

Next, the population growth rate was set at 2.61%, with the demand at 20 l/p/d and the same system lifetime values. This process was repeated until all 27 combinations of variables were tested to determine the required pipe diameters for the main line in order to meet the specified demand, population growth rate, and system lifetime.

Due to the topography of the beginning of the main line, from the headwaters to Dos Palmas, maintaining 20 psi was not possible, and a minimum pipe diameter for this section needed to be 4 inches larger than the line reported in the analysis below just to maintain a positive pressure. This was deemed acceptable for this analysis since there is no demand in this section. It should be noted that community pipe diameters in the system may also need to be changed, as discussed below.

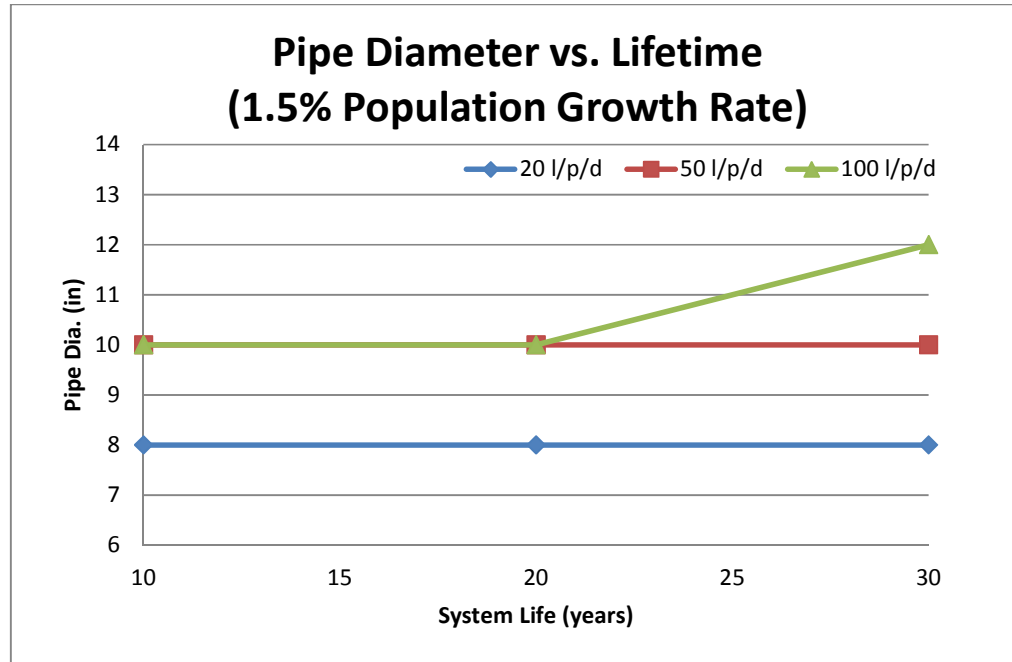


Figure 23: Required Pipe Diameter Versus Estimated System Lifetime for Population Growth Rate of 1.5%

From Figure 23 it is seen that a 10-inch diameter pipe would meet the minimum 20 psi pressure requirements along the main line from Dos Palmas to Independencia for up to 20 years with a demand of 100 l/p/d at 1.5% population growth.

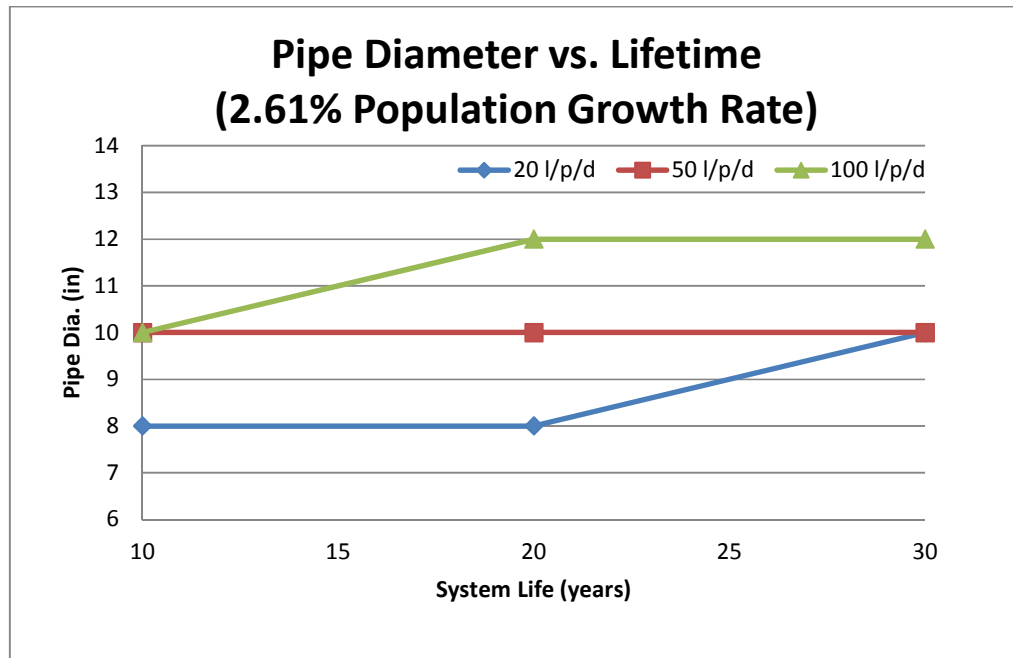


Figure 24: Required Pipe Diameter Versus Estimated System Lifetime for Population Growth Rate of 2.61%

Figure 24 shows that a 10-inch diameter main line would supply 50 l/p/d for an estimated system life of 30 years at 2.61% population growth, which is the value given in the municipality's technical report on the existing distribution system.

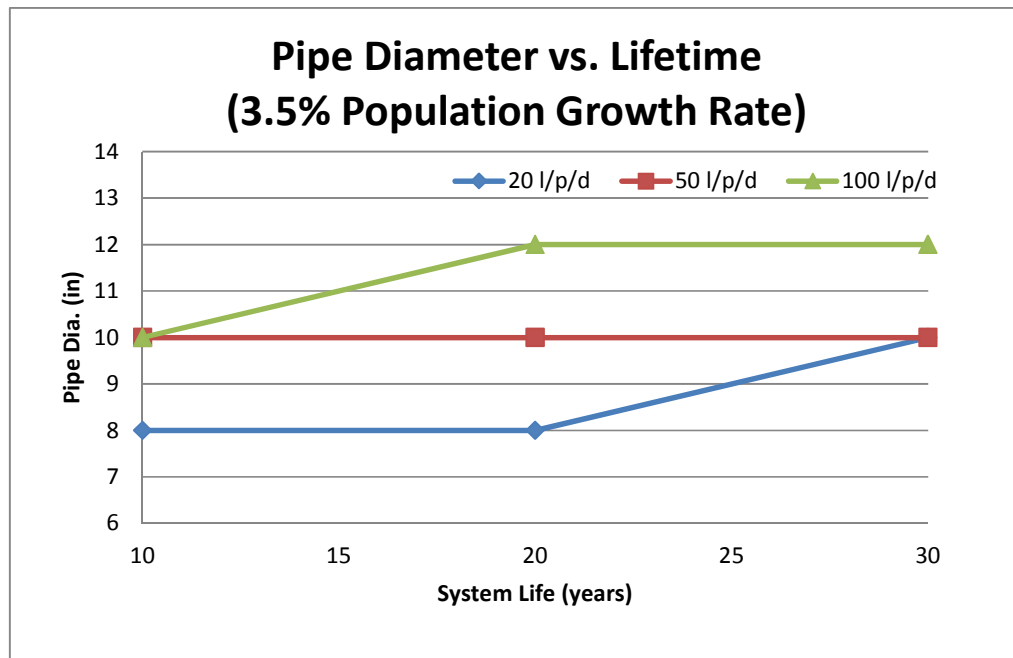


Figure 25: Required Pipe Diameter Versus Estimated System Lifetime for Population Growth Rate of 3.5%

Figure 25 shows that a 10-inch main line pipe diameter would also cover a demand of 50 l/p/d for up to 30 years or a demand of 100 l/p/d for up to 10 years at a population growth rate of 3.5%.

The model had negative pressure in the community of Los Rosales for nearly every future scenario, therefore the 1-inch pipe was replaced with 2-inch for all future analyses except the scenario of a 100 l/p/d demand with a 30-year system life and 3.5% growth rate, which required a 4-inch pipe. Several other community nodes had negative pressure with a demand of 100 l/p/d, thus, network pipes in the following communities would also need to be augmented to be able to supply these specific scenarios, as shown below in Table 15.

Table 15: Community Pipes to be Replaced in Specific Scenarios

Community	Scenario	Pipe Diameter (in)		Length of Pipe (ft)
		Original	New	
Dos Palmas	30yr100L3.5%	1	2	1,826
	20yr100L3.5%	1	2	829
	30yr100L2.61%	1	2	829
Toma León	30yr100L3.5%	3	4	4,164
	30yr100L3.5%	2	3	6,981
	20yr100L3.5%	2	3	539
	30yr100L2.61%	2	3	539
Independencia Medio	30yr100L3.5%	2.5	4	3,381
	20yr100L3.5%	2.5	4	1,706
	30yr100L2.61%	2.5	4	1,706
	20yr100L2.61%	2.5	4	1,706
	30yr100L1.5%	2.5	4	1,706
Independencia Bajo	30yr100L3.5%	2.5	4	3,282
	20yr100L3.5%	2.5	4	966
	30yr100L2.61%	2.5	4	966
	20yr100L2.61%	2.5	4	966
	30yr100L1.5%	2.5	4	966
Los Rosales	30yr100L3.5%	2	4	3,284

In summary, a 10-inch diameter pipe would cover a range of system characteristics, including up to a 3.5% population growth rate, a 30-year system design life, and a demand of 50 l/p/d for domestic uses.

Using the base case scenario of 20-year design life, 2.61% population growth rate, and a demand of 50 l/p/d, with a 14-inch line contracting to a 10-inch main line, the hydraulic grade line (HGL) was plotted with ground elevation during the highest demand period. The results are visually represented in Figure 25, showing that the pressure is minimal along the first section of the main line due to topography, but meets the minimum pressure requirement of 20 psi in the 10-inch section of the main line (Dos Palmas to Independencia).

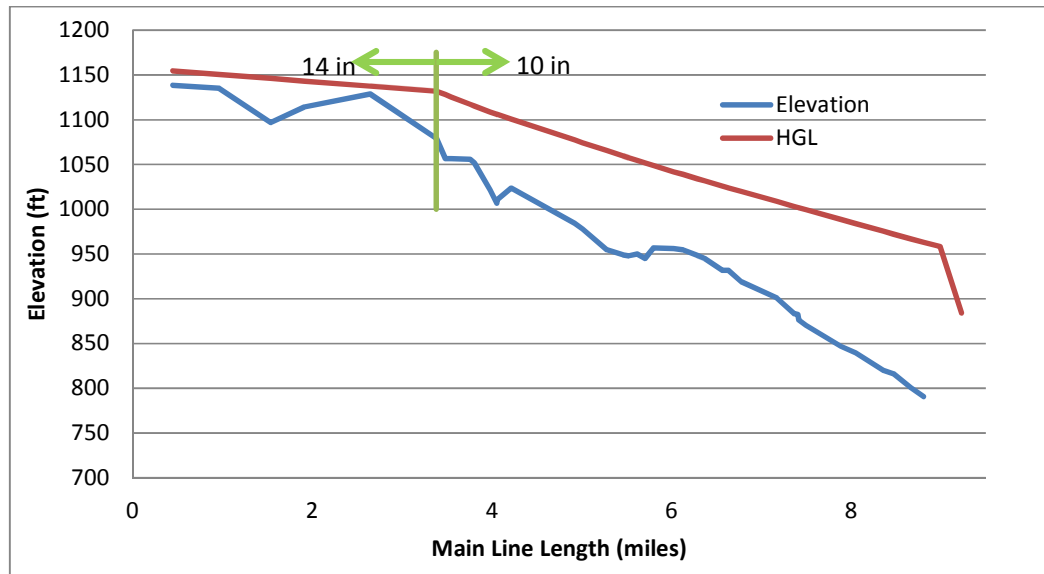


Figure 26: Hydraulic Grade Line Plotted with Elevation Profile for the Main Line under the Base Case Scenario

Next, the base case scenario was used again, but the trench elevation was dropped by 30 feet for four high points in the beginning of the main line (roughly mile 0.5, 1, 2, 2.5), and a 16-inch pipe diameter was used for the first 3.4 miles, again contracting to a 10-inch diameter for the remainder of the main line. This scenario was created to satisfy the minimum pressure requirements of 20 psi along all nodes of the main line. However, this may not be feasible, and thus alternatives such as routing around the high points should be considered by the local municipality, as this data is not available for this analysis. The elevation versus HGL can be seen in Figure 26 below.

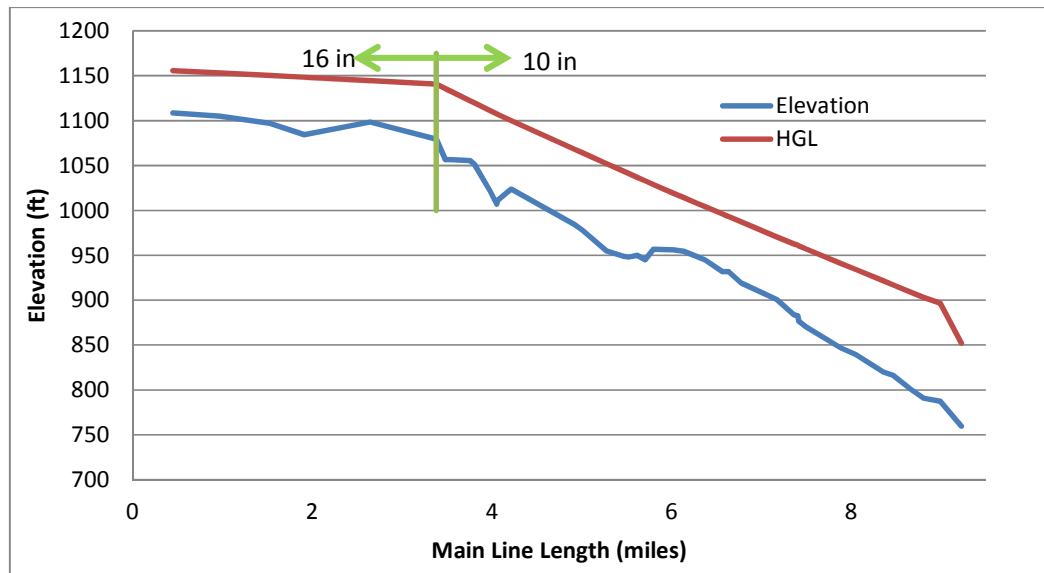


Figure 27: Elevation Profile Plotted with HGL for Main Line of Base Case Scenario and Modified Pipe Elevation to Satisfy 20 psi Requirements

Discussion

Hydraulic model results indicate that the only communities that should experience problems with low pressure are Los Rosales and Independencia Bajo; however, in reality other parts of the system also have problems with low pressure, such as Toma León. Therefore, the problems of low pressure in the district of Independencia arise due to phenomenon that were not represented in the model, such as the nature of the operations (i.e., manually closing and opening valves to route water), as well as people in the upstream reaches leaving their taps on to water gardens or livestock. Another factor that could cause insufficient pressure in the system is illegal taps that are not regulated and cannot be shut off. These illegal taps can severely diminish pressure in the main line and can also lead to excessive water losses in the system that were not accounted for in the model.

It is thought that the biggest uncertainty that was not accounted for in the hydraulic modeling of the existing system was the effect that intermittent water supply (IWS) operation has on EPANET. The way the model was set up is only valid once the system reaches a steady-state condition and pipes are flowing full. In IWS systems, it has been observed that the Hazen-Williams C value can vary up to 25% in a matter of hours (Rahimi, 2008). This is thought to be due to the presence of air introduced into the system when pipes are filling (Sashikumar et al., 2003).

Another characteristic of the system that was not modeled in EPANET was the effect of minor losses caused by valves and bends in the system. Because of the inaccuracies due to modeling an IWS rather than continuous system, elevation error, and due to the fact that all the individual household connections were not included in the model, it was decided that minor losses would not have an appreciable effect on the results and thus were not accounted for.

It was discovered that the EPANET model is very sensitive to pipe diameter in the first 3.4 miles of the main line due to the topography. This section has abrupt changes in slope compared to the rest of the line, and therefore it was required to put pipe diameter 6 inches larger than the rest of the main line and excavate up to an additional 30 feet deep along two sections of the pipeline. The additional excavations would be from the beginning of the main line to mile one, as well as from mile 1.5 to 2.5. Doing this maintains the 20 psi minimum pressure along the entire main line of the distribution network, according to EPANET.

Leaks in the system were not accounted for after analyzing the effect that they would have on the nodal pressure. Using the scenario 17 for Santa María, 40% of the total demand was input as a 'leaky demand' in EPANET and distributed to all upstream nodes along the main line. Comparing this scenario to the same scenario but without leaks, it was determined that there was only an average of 0.1% difference in pressure at the nodes in Santa María. This was thought to be a negligible difference, and thus leaks were not accounted for in the EPANET modeling.

Conclusions

Summary

This report was written with the end goal to improve public health and water resource management in the district of Independencia. Improving public health will reduce the disease burden and improve the quality of life in the district. This will be accomplished by making recommendations to improve the water distribution system in reliability, water quality, and water quantity, taking into account population growth.

There is much debate about how global warming will affect water stress globally. However, a study done using large-scale hydrology models reveals that the effects of growing population and increasing water demand far outweigh those due to climate change on water stress for the year 2025 (Vörösmarty et al., 2000). Thus, population growth is a key factor that should be accounted for in a district's water management plan to avoid water stress in the near future.

The biggest problems right now with the water system in Independencia are the unequal distribution and poor water quality. These problems occur because of intermittent operations, illegal taps in the system, non-sanctioned uses such as watering gardens and livestock, the municipality's deviation from the set delivery schedule, and inadequate and/or inconsistent disinfection. These problems lead to insufficient pressure to deliver water to certain sectors, along with delivered water that is not safe for human consumption. The water users at the downstream end often do not have water for several consecutive days, while many users upstream abuse the system because it is more convenient to water gardens from their tap than from the canal.

Esrey et al. (1985) reviewed studies done on diarrhea disease reduction and compiled the results of different intervention techniques. The results of improving water quality and availability produced a mean reduction in diarrhea morbidity of 37%, with a range from 0-82% of the 8 studies reviewed. Diarrhea morbidity is influenced by many factors, including living conditions, etiology of the diarrhea, and age of the individual. Also, it is interesting to note that improvements in water quality did not have as much of an impact in reducing diarrhea incidences as did improvements in water availability (Esrey et al., 1985).

Therefore, in the case of Independencia, water availability should be given priority, ensuring consistent delivery to all users. A report reviewing data of operating several water distribution systems in India continuously versus intermittently found that there were less cases of coliform contamination when operated continuously (Lee et al., 2005). Based on this data, the system would greatly benefit from switching to continuous operation to improve availability and reduce chances of contamination from transport and storage of water. Improving availability would also promote

personal hygiene and hand-washing, which has been shown to greatly reduce water-washed diseases (Esrey et al., 1991).

Secondly, water quality assurance needs to be more regulated, with results recorded and made accessible to the public. However, this must be done in combination with community education and training. To use the concept of Levy et al. (2008), integrated interventions could bring about the best results by improving the service, educating the public, documenting results, and making information easily accessible.

Many Latin American countries are known to have good community-based water and sanitation organizations at the grass-roots level, but often times there are too many stakeholders, such as third party institutions and NGOs, which can complicate local governance and create conflicts. In the community of Independencia, the influx of aid agencies and NGOs has created a culture of dependency and paternalism because people began to expect things to be done for them.

The district of Independencia currently does not have community water boards. Communities often neglect maintenance because they believe that if the system is not working properly, someone from the municipality will come fix it, and if there is conflict, the municipality will resolve it. However, this mentality also creates dependency; additionally, when the municipality changes staff with the election of a new mayor, many problems from the previous administration are left unresolved.

Recommendations

The seventh MDG's target is to reduce the proportion of the population without access to safe water; however some communities with water system infrastructure may be counted as having access, even if the delivery is not daily, the time it takes to gather the water is burdensome, or the water quality is not monitored. Therefore, this specific target should be modified to account for reliability of water delivery, as well as logistics of water collection and quality control. For example, in the case of Toma León within the district of Independencia, they would now be counted as having improved access to safe water although often times community members resort to obtaining water from the canal because the system has insufficient pressure to deliver water to certain sectors.

To improve the service of the existing water supply system in Independencia, it is recommended that the water delivery schedule is strictly followed and the community line to Los Rosales is augmented from one to four inches to ensure a minimum of 25 l/p/d. This must be accompanied with a campaign to reduce misuse of the water such as watering gardens, for dust control, or for livestock. Implementing these changes could drastically improve the satisfaction of the community members in the district.

Future population growth will create demands that cannot be met by the existing system; therefore, it is recommended to install a 16-inch pipe for the first 3.4 miles, and 10 inch pipe for the remaining 5.8 miles of main line in the system. In addition, it is recommended to excavate up to an additional 30 feet at the high point from mile 0-

1 and mile 1.5-2.5 along the main line, totaling two miles of additional trench excavation. This new main line would allow Independencia to have continuous water supply, satisfy the basic water requirement proposed by Gleick (1998) of 50 l/p/d for domestic uses, as well as accommodate future growth in the district. This recommendation is based on several analyses done with EPANET varying demand values, population growth rate values, and system lifetime estimates while satisfying a minimum pressure in the main line of 20 psi.

However, increasing the service to 24-hour delivery also means that people will be more likely to use water for watering home gardens, livestock, and watering the area surrounding their houses for dust control, a common practice in the area. To deal with these types of non-essential uses, it is highly recommended to incorporate flow meters at each household and implement the policy of paying for quantity. Flow meters are inaccurate with intermittent systems because when valves are opened water pushes large air bubbles through the empty pipes, creating false flow readings.

These meters will help the municipality regulate flow and find leaks, as well as maintain an economically viable system. Flow meters will also help create sustainability of the water resources in the district by reducing the demand and improving efficiency. Flow meters that register both rate and total volume for half-inch pipes were found for around 20 U.S. dollars (http://www.futurlec.com/Flow_Sensor.shtml), which might be unaffordable for many households, but could perhaps be included in infrastructure grants. The need for more affordable water meters is recognized.

To ensure environmental sustainability, water resource planning must take into account aquatic ecosystems. Most water planning today is done by estimating population growth and corresponding future demand, then looking at augmenting the supply to meet this demand. However, this model does not take into account sustainability, and thus Gleick (1998) proposes quantifying the amount of water that can be withdrawn while still maintaining aquatic ecosystems, and then back-calculating the demand to meet this sustainable use.

Finally, it is recommended to develop local, grass-roots water boards in order to create continuity between political administrations and foster public participation. These water boards could act as a regulatory body, overseeing the municipality. The water boards should incorporate the criteria proposed by Gleick (1998) into their management policy in order to improve the equal distribution and sustainability of their freshwater resources. These criteria are as follows:

1. Define a minimum basic human water requirement (BWR).
2. Establish the basic environmental requirements.
3. Establish water quality standards, based on the intended use, including a monitoring and contingency/mitigation plan.
4. Ensure renewability of the water resources.
5. Data collection and availability.
6. Create management institutions.

The second criteria can be difficult to define, as environmental requirements are dependent on geology, hydrology, and climate, to name a few. The fourth criterion aims to protect against mismanagement of the watershed, e.g. contaminating the groundwater and over-pumping any wells. The fifth criterion aims to ensure information is not restricted including surface water flow data and groundwater basin characterization, including extraction/recharge rates. The sixth criterion sets goals for water policy, like establishing a democracy and creating public participation. The final criterion aims to protect future interests, prevent and resolve conflicts, and ensure equity.

Beneficiaries of the distribution system within the district currently do not pay for water; and when the author was living there the mayor at the time was trying to implement a pay schedule. However, this might be better suited for the community water boards, along with deciding upon sanctions for not paying dues as grass-roots social pressure would likely be the most effective way to enforce payment of an improved delivery system.

If the district implements these recommendations, the public health could drastically improve. It is believed that if these criteria are followed, the district of Independencia not only will have a leg up on all other communities in the department, but could possibly serve as a model for water resource planning for the entire country.

Future Work

Studies of hand-washing have proven to reduce incidences of diarrhea by about one-third (Ejemot, 2008). Therefore, although most community members surveyed reported washing their hands, a better evaluation of this would be to observe the hand-washing method to verify if the correct technique was employed. This is also the case with household water treatment; it was not determined if it was treated correctly or consistently. Survey respondents treating water by boiling were not asked for how long, therefore further investigation should be done to determine the length of time water should be boiled to kill all bacteria, parasites and viruses in the water.

Another way the survey could be improved would be to do a more extensive analysis of domestic water use. A separate survey could focus on quantifying water use for each category: consumption/cooking, hygiene/bathing, washing laundry, washing dishes/cleaning, and other uses. This survey could also attempt to study the water demand pattern that could be expected if a continuous water delivery system were implemented. This study would be useful to integrate into the EPANET model and for water management/planning purposes.

From the surveys it was learned how important, in fact paramount, it is to put people at ease when administering a household survey, and thus the following should be taken into account for further surveying in the district. For the second round of surveys the oral consent form was memorized, which made the surveys much smoother and more effective. The oral consent form is the first official step in a survey, but even before this there are important steps to be an effective surveyor. In

Peruvian culture, small talk is extremely important. Many Americans are used to being very direct and to the point, wasting no time in asking for what they want, whereas this can be considered down-right rude in Peru.

It is unclear how the communities within the district of Independencia perceive the risk of consuming unsafe water or failing to properly wash their hands at critical moments. Thus it is recommended that open-ended questions are incorporated into the survey to assess this risk perception within the district, which could help improve intervention strategies as well as convince people of the value of safe water, which may be the most effective way to get them to pay for services.

In order to improve the EPANET model, a detailed topographical study of the water line should be performed with a theodolite or Abney level. This would increase the accuracy of the elevation readings and could have a significant effect on the modeling results as this is one of the most sensitive variables in a gravity-fed system. Additionally, since it was the ground elevation that was measured in this study, the trench elevation of the future pipeline should be determined to get the most accurate results in EPANET.

Another way to improve the accuracy of the EPANET model would be to take a series of simultaneous pressure and flow measurements throughout the system in order to validate and calibrate the model. To do this, pressure transducers must be attached to various nodes in the system while measuring flow rates in other nodes in the system with all other taps shut off. This type of testing was beyond the scope of the author while living in Peru, mostly because the equipment and personnel were not available.

The water quality testing that is being carried out in the district should test the water quality in three specific locations: (1) the water of the river entering the filtration gallery, (2) the water directly out of the distribution line, and (3) the water directly out of the storage containers used by a sample of families in the district. This comparison could help pinpoint where contamination is introduced into the system and plan for the most effective treatment intervention.

Finally, it is the intention of the author to translate into Spanish a summarized version of this report, along with supporting spreadsheets and data files and submit them to the municipality of Independencia, Peru. This will be accomplished in coordination with Lucas Patton, the Peace Corps Volunteer living in the district, acting as an intermediary between the author and the municipality. Improvements to the water distribution system have already been promised by the current mayor of Independencia; therefore this report should be well accepted by the municipality and integrated into the water resource management plan of the district.

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Appendices

Appendix A: Survey Description

Community Water Use and Sanitation Practices in Ica, Peru

Principal Investigator: David Watkins

Co-Investigator: Fletcher McKenzie

A. Description of Project: This study is meant to aid in the assessment of intervention techniques for improving community health via improved water quality and sanitation practices in the rural community of Toma León, located in the department of Ica, Peru. In addition, this survey is meant to assess the incidences of specific sicknesses among children under 6 years old, namely diarrhea, conjunctivitis, scabies, typhoid or hepatitis.

B. Procedures to be Followed: The survey will be carried out with the co-investigator and a local community leader, hereafter called “investigators”. First, after consent is acquired, the investigators will ask to see the kitchen and bathroom to visually inspect water storage vessels and sanitation facilities. Next the survey will be given orally. The survey will be repeated after interventions have been implemented. The survey is attached as the document entitled “Hygiene_Survey.doc”.

Family names will be recorded because this is the most efficient way to locate families to assess improvements at a household level, which will be kept confidential unless permission is granted to give a copy of the survey to the local health post for their records.

C. Potential Risks: Exposing the hygiene and sanitation practices of a family, as well as their children’s health can be embarrassing for some people. These issues are indicators of the financial situation of the family; therefore this may be a barrier to getting truthful answers. However, since the results will not be shared with anyone unless permission is granted to give to the local health post, as mentioned above, they can avoid the risk of embarrassment. In addition, the community leaders will be involved from the beginning and will also provide us consent to work in their villages.

D. Informed Consent Forms: A small portion of the residents in the study area are semi-literate and most do not speak English, therefore the informed consent form (attached) and translated into Spanish (attached) will be read to participants and oral consent will be obtained by the subjects before proceeding.

Appendix B: Oral Consent Form

Community Water Use and Sanitation Practices in Ica, Peru

November 10, 2010 – December 20, 2010

In addition to my duties as a Peace Corps Volunteer, I am writing a report as part of my education at Michigan Tech University. I would like to talk to you about your water use and sanitation practices. I may use what you tell me in my written report to my professors at my university. I will have some particular things that I would like to talk about, but you may ask me questions and talk about things you think I should know about, even if I don't ask. You are not required to talk to me or answer my questions. Even if you decide now to talk to me about water and sanitation practices, you may later ask me to stop asking you about it. When you ask me to stop, I will stop asking you about water and sanitation practices. You decide if you want to talk to me about water and sanitation practices. I will do my work as a Peace Corps Volunteer with you no matter what you decide. Nothing bad will happen to you or to me if you decide not to answer my questions about water and sanitation practices.

Appendix C: Human Subject Research Approval

Original Protocol: M0403

Continuation Approval: M0658



Michigan Technological University

Office of Research Integrity
and Compliance

302 Lakeshore Center
1400 Townsend Drive
Houghton, MI 49931
906.487.2902

MEMO

TO: Dr. David Watkins, Jr., CEE

CC: Fletcher McKenzie, CEE

FROM: Joanne Polzien, Director Research Integrity and Compliance

A handwritten signature in blue ink that reads "Joanne Polzien".

DATE: October 21, 2010

SUBJECT: Approval M0658

Your application to use human subjects in research or classroom situations has been reviewed with the following determination:

Protocol #: M0658

Protocol Title: "Community Water Use and Sanitation Practices in Ica, Peru (Additional Surveys)"

Approved Dates: October 21, 2010 through October 20, 2011

Approvals are granted for up to a one year period. You will need to request a continuation for each year of the project six weeks prior to the end date indicated above for each year of the project. The Office of Research Integrity and Compliance will make every effort to send the Principal Investigator annual reminders. However, the Principal Investigator is responsible for submitting annual Continuation Forms in advance of the expiration date for the project. It is very important that these expiration dates are not missed. Failure to submit annual review materials on time will result in the termination of this protocol.

This approval applies only for this project, and only under the conditions and procedures described in the application; if any changes are made in the protocol or conditions set forth in the application, the principal investigator must obtain a separate approval before these changes take place. The approved project will be subject to surveillance procedures requiring periodic review. This review will consist of consulting with the principal investigator and examining the appropriate project records.

Individual identification of human subjects in any publication is an invasion of privacy. Before beginning a project involving human subjects, and only if required, the principal investigator must obtain a properly executed informed consent from each subject and/or the person legally responsible for the subject. **If a consent form has been reviewed and approved it has been attached with an official date stamp on it. Only copies of the official date stamped informed consent is to be distributed to participants relating to this project. If any changes or modifications are needed regarding this form, you must first submit the revised document for review and approval prior to use.** The principal investigator must retain informed consent forms on file for at least three years after the end of the project. If a project involves a high level of risk, copies of the signed informed consent forms must be filed with the Human Subjects Committee; if this is the case, you will be notified.

This document is on file in the Office of Research Integrity and Compliance. If you have any questions, please contact me at 487-2902 or jpolzien@mtu.edu.

Appendix D: Water Use and Sanitation Survey

1 GENERAL

- 1.1 Address
- 1.2 Observation
- 1.3 Number of houses in the community
- 1.4 Number of people living in the household
- 1.5 Number of children under 6 living in the household

2 WATER SUPPLY

2.1 PUBLIC MATRIX

- 2.2 Water connection inside home
- 2.3 Public tap stand

--

☐ Distance from home ☐

SOURCES OF WATER SUPPLY

- 2.4 Well
- 2.5 Spring
- 2.6 River
- 2.7 Canal
- 2.8 Other

☐ Distance from home ☐

3 WATER USE PRACTICES

- 3.1 Water stored in containers inside the home?
- 3.2 How often is water stored?
- 3.3 Where is water stored?
- 3.3.1 (What type of container, covered or not, clean or dirty, close or far from latrine)
- 3.4 How often are containers cleaned?
- 3.5 How is water transported to the home?

--

4 WATER PRACTICES INSIDE THE HOME

- 4.1 How much water is consumed daily?
- 4.2 Water containers for drinking and cooking are:
(Clean or dirty, covered or not, safely located or not)
- 4.3 How is drinking water treated inside the home?
(Boiled, bleach added, SODIS, nothing)
- 4.4 During the day, when are hands washed?

--

5 USES OF WATER

- 5.1 Uses
- 5.1.1 Personal Hygiene
- 5.1.2 Washing clothes
- 5.1.3 Washing pots
- 5.1.4 Cleaning the house
- 5.1.5 Drinking
- 5.1.6 Cooking
- 5.1.7 Watering plants
- 5.1.8 Construction
- 5.2 Where does grey water go?

- | | | |
|-------|-------------------|--------------------------|
| 5.2.1 | In the street | <input type="checkbox"/> |
| 5.2.2 | In a septic tank | <input type="checkbox"/> |
| 5.2.3 | In the patio | <input type="checkbox"/> |
| 5.2.4 | To water plants | <input type="checkbox"/> |
| 5.2.5 | In a sewer system | <input type="checkbox"/> |

6 SANITARY INSTALATIONS INSIDE THE HOME

- | | | |
|-------|--|--------------------------|
| 6.1 | Water connection inside home? | <input type="checkbox"/> |
| 6.2 | When was it constructed? | |
| 6.3 | Is there connections for: | |
| 6.3.1 | Shower | <input type="checkbox"/> |
| 6.3.2 | Sink | <input type="checkbox"/> |
| 6.3.3 | Washer | <input type="checkbox"/> |
| 6.4 | Is there a sewer connection inside the home? | <input type="checkbox"/> |
| 6.5 | When was it constructed? | |
| 6.6 | Where does black water go? | |
| 6.6.1 | In the street | <input type="checkbox"/> |
| 6.6.2 | Septic tank | <input type="checkbox"/> |
| 6.6.3 | Sewer system | <input type="checkbox"/> |

7 EXCRETA DISPOSAL

- | | | |
|-------|--|--------------------------|
| 7.1.1 | Septic tank | <input type="checkbox"/> |
| 7.1.2 | Family latrine | <input type="checkbox"/> |
| 7.1.3 | Open field | <input type="checkbox"/> |
| 7.2 | Bathroom has: | |
| 7.2.1 | Toilet | <input type="checkbox"/> |
| 7.2.2 | Turkish toilet | <input type="checkbox"/> |
| 7.3 | Does the toilet have an automatic flush? | <input type="checkbox"/> |
| 7.3.1 | Is it always utilized? | <input type="checkbox"/> |
| 7.4 | How is the bathroom cleaned? | |
| 7.4.1 | Lime | <input type="checkbox"/> |
| 7.4.2 | Bleach | <input type="checkbox"/> |
| 7.4.3 | Detergent | <input type="checkbox"/> |
| 7.4.4 | Water | <input type="checkbox"/> |
| 7.4.5 | Kerosene | <input type="checkbox"/> |
| 7.5 | How often is the bathroom cleaned? | |

8 SOLID WASTE

- | | | |
|-------|--|--------------------------|
| 8.1 | Is there trash inside the house? | <input type="checkbox"/> |
| 8.2 | How is waste stored?
(Bags, trashcan, open or closed, stored adequately or not) | |
| 8.3 | How is trash disposed of? | |
| 8.3.1 | Burned | <input type="checkbox"/> |
| 8.3.2 | Buried | <input type="checkbox"/> |
| 8.3.3 | Outside the house | <input type="checkbox"/> |

8.3.4	In common area	<input type="checkbox"/>
8.3.5	Collected by the Municipality	<input type="checkbox"/>
8.4	How often is trash disposed of/collected?	
8.5	Where does organic waste go?	
8.5.1	In the street	<input type="checkbox"/>
8.5.2	With the trash	<input type="checkbox"/>
8.5.3	Fed to animals	<input type="checkbox"/>
8.5.4	Utilized as fertilizer	<input type="checkbox"/>

9 SICKNESSES AMONG CHILDREN UNDER SIX YEARS OLD

- 9.1 In the last month, have children under six been sick with diarrhea?
- 9.2 In the last month, have children under six been sick with Conjunctivitis?
- In the last month, have children under six been sick with Scabies or other skin disease?
- 9.3
- 9.4 In the last month, have children under six been sick with Typhoid or Hepatitis?

10 VOLUNTEER'S COMMENTS:

Appendix E: Water Quality Results

Naval Medical Research Center Detachment (NMRCD), Lima, Perú

Departamento de Bacteriología

"Evaluación del Efecto de la Intervención para Mejoramiento de la Calidad del Agua Realizada por Voluntarios del Cuerpo de Paz"

RESULTADOS PRELIMINARES DE AGUAS PROVENIENTES DE INDEPENDENCIA - PISCO									
Muestras ⁽⁵⁾					PRUEBAS DE LABORATORIO				CALIDAD
					COLILERT		FILTRO		
Número	Fecha del muestreo	pH	Cloro (Cl ⁻)	Turbidez UTN ⁽³⁾	Coliformes totales/100ml NMP/100 ml ⁽¹⁾	E. Coli/100 ml NMP/100 ml	Coliformes totales/100 ml UFC/100 ml ⁽²⁾	Non-coliformes/100 ml UFC/100 ml	Límite Maximo Permissible (LMP) ⁽⁶⁾
1	8/31/2010	7.6	0.3	1.46	>2419.6	13.5	4.50E+04	DNPC ⁽⁴⁾	No Apto
2	8/31/2010	7.6	0.2	0.6	1203.3	12	1000	38X10 ³	No Apto
3	8/31/2010	8	0.1	3.54	>2419.6	56.5	DNPC ⁽⁴⁾	DNPC ⁽⁴⁾	No Apto
4	8/31/2010	7.4	0.3	1.83	1119.9	5.2	1000	DNPC ⁽⁴⁾	No Apto
5	8/31/2010	7.7	0.2	0.84	>2419.6	235.9	2.00E+03	21x10 ³	No Apto
6	8/31/2010	7.6	0.4	0.74	>2419.6	99	2.00E+03	11x10 ³	No Apto
7	8/31/2010	8	0.3	0.24	>2419.6	1	8.00E+03	DNPC ⁽⁴⁾	No Apto
8	8/31/2010	8	0.2	2.02	>2419.6	218.7	2.00E+03	DNPC ⁽⁴⁾	No Apto

9	8/31/2010	7.8	0.4	5.15	>2419.6	290.9	3.00E+03	20x1000	No Apto
10	8/31/2010	7.8	0.3	5.82	>2419.6	261.3	DNPC ⁽⁴⁾	DNPC ⁽⁴⁾	No Apto
11	8/31/2010	8	0.1	1.56	>2419.6	178.9	2.00E+03	13x10 ³	No Apto
12	8/31/2010	7.8	0.3	4.26	>2419.6	261.3	1.40E+04	70x10 ³	No Apto
13	8/31/2010	7.9	0.4	2.81	>2419.6	261.3	2.20E+04	38x10 ³	No Apto
14	8/31/2010	7.8	0	2.31	1986.3	49.5	2.00E+03	29x10 ³	No Apto
15	8/31/2010	7.4	0.2	0.49	>2419.6	10.9	2.90E+03	80x10 ²	No Apto
16	8/31/2010	7.5	0.2	0.48	816.4	4.1	9.00E+02	11x10 ²	No Apto
17	9/1/2010	9.1	0.8	19.5	>2419.6	36.9	9.00E+03	36x10 ³	No Apto
18	9/1/2010	8.7	0.4	2	>2419.6	5.2	4.00E+02	80x10 ³	No Apto
19	9/1/2010	8	0.3	12.6	>2419.6	52.8	DNPC ⁽⁴⁾	DNPC ⁽⁴⁾	No Apto
20	9/1/2010	7.3	0.1	1.73	>2419.6	47.4	DNPC ⁽⁴⁾	DNPC ⁽⁴⁾	No Apto
21	9/1/2010	8.5	0.5	1.15	>2419.6	648.8	1.90E+04	31x10 ³	No Apto
22	9/1/2010	9.3	0.5	5.45	>2419.6	68.3	1.10E+04	DNPC ⁽⁴⁾	No Apto
23	9/2/2010	7.6	0.1	2.31	2419	1299.7	2.40E+03	25x10 ³	No Apto
24	9/2/2010	7.4	0.1	2.86	>2419.6	770.1	6.00E+04	DNPC ⁽⁴⁾	No Apto
25	9/2/2010	7.6	0.3	3.32	>2419.6	3.1	7.20E+04	50x10 ³	No Apto
26	9/2/2010	7.6	0.2	1.71	>2419.6	127.4	4.80E+03	11x10 ³	No Apto
27	9/2/2010	8	0.6	13.3	>2419.6	4.1	DNPC ⁽⁴⁾	DNPC ⁽⁴⁾	No Apto
28	9/2/2010	8.1	0.2	2.65	>2419.6	21.8	3.20E+04	25x10 ³	No Apto
29	9/2/2010	9.3	0.9	36.8	>2419.6	41.1	6.00E+04	50x10 ³	No Apto
30	9/2/2010	7	0.4	5.92	307.6	19.7	2.00E+02	65x10 ³	No Apto
31	9/2/2010	8	0.6	8.62	>2419.6	488.4	3.20E+04	34x10 ³	No Apto

RESULTADOS PRELIMINARES DE AGUAS PROVENIENTES DE INDEPENDENCIA - PISCO

Muestras ⁽⁵⁾					PRUEBAS DE LABORATORIO				CALIDAD
					COLILERT		FILTRO		
Número	Fecha del muestreo	pH	Cloro (CL-)	Turbidez UTN(3)	Coliformes totales/100ml NMP/100 ml(1)	E. coli/100 ml NMP/100 ml	Coliformes totales/100 ml UFC/100 ml(2)	Non-coliformes/100 ml UFC/100 ml	Límite Maximo Permisible (LMP)(6)
1	12/14/2010	7.8	0.3	2.19	>2,419.6	>2,419.6	3X103	30X103	No apto
2	12/14/2010	7.6	2.3	4.55	0	0	0	0	Apto
3	12/14/2010	7.8	0.1	0.75	648.8	14.6	2X102	2X102	No apto
4	12/14/2010	7.9	0.3	0.53	1011.2	2	2X103	4X103	No apto
5	12/14/2010	7.6	0.3	0.35	1553	46.5	1X103	60X103	No apto
6	12/14/2010	7.7	0.2	0.33	866.4	1	3X103	DNPC(4)	No apto
7	12/14/2010	7.6	0.1	1.26	>2,419.6	2	30X103	30X103	No apto
8	12/14/2010	7.5	0.2	0.3	1732.9	1	1X103	20X103	No apto
9	12/14/2010	7.5	0.2	0.53	2419.6	0	30X102	30X102	No apto
10	12/14/2010	7.8	0.2	0.5	1732.9	5.2	1X103	7X103	No apto
11	12/14/2010	7.7	0.1	0.35	1203.3	98.8	15X103	10X103	No apto
12	12/14/2010	7.7	0.2	0.25	123.6	0	1X102	1X102	No apto
13	12/14/2010	7.5	0.1	0.75	>2,419.6	13.1	30X103	30X103	No apto
14	12/14/2010	7.7	0.3	1.89	>2,419.6	185	30X103	30X103	No apto

15	12/14/2010	7.8	0.1	0.6	488.4	5.2	4X102	10X102	No apto
16	12/14/2010	7.9	0.2	0.51	>2,419.6	1986.3	11X103	8X103	No apto
17	12/15/2010	9.3	1.3	66.6	>2,419.6	>2,419.6	3X103	64X103	No apto
18	12/15/2010	7.8	0.1	1.66	>2,419.6	>2,419.6	19X103	24X103	No apto
19	12/15/2010	9.3	0.3	4.67	50.4	0	3X10	9X102	No apto
20	12/15/2010	7.8	0.2	0.49	1299.7	547.5	3X103	17X103	No apto
21	12/15/2010	7.8	0.5	5.19	>2,419.6	93.3	DNPC(4)	60X103	No apto
22	12/15/2010	8	0.4	7.29	>2,419.6	920.8	DNPC(4)	DNPC(4)	No apto
23	12/15/2010	8.2	0.1	0.43	>2,419.6	12.2	12X103	20X103	No apto
24	12/15/2010	8	0.7	47.2	1553	46.5	1X103	60X103	No apto
25	12/15/2010	7.7	0.1	0.27	33.2	2	5X10	4X10	No apto
26	12/15/2010	7.7	0.1	0.4	307.6	123.4	1X102	30X102	No apto
27	12/15/2010	7.9	0.2	1.78	>2,419.6	250.4	80X103	DNPC(4)	No apto
28	12/15/2010	9.1	2.1	92.8	>2,419.6	1046.2	DNPC(4)	DNPC(4)	No apto
29	12/15/2010	8.1	0.2	1.79	>2,419.6	25.6	3X103	10X103	No apto
30	12/15/2010	8.7	0.7	18.5	>2,419.6	115.3	31X103	74X103	No apto

- 1 NMP: Numero mas probable (MPN: Most Probable Number)
- 2 UFC : Unidades formadoras de colonia (CFU: Colony Forming Units)
- 3 UTN : Unidades de turbidez nefelometricas (NTU: Nephelometric Turbidity Units)
- 4 DNPC : Demasiado numerosas para contar (TNTC: Too Numerous To Count)
- 5 All samples have been obtained from recipients of water for domestic use in the house where there are children under 5 years old in the community mentioned
- 6 The guide from the OMS recommends Maximum Permissible Limit for total coliforms = 0 in the water, therefore values ≥ 1 means water is not apt for human consumption

Appendix F: EPANET Intermittent Water Supply Results

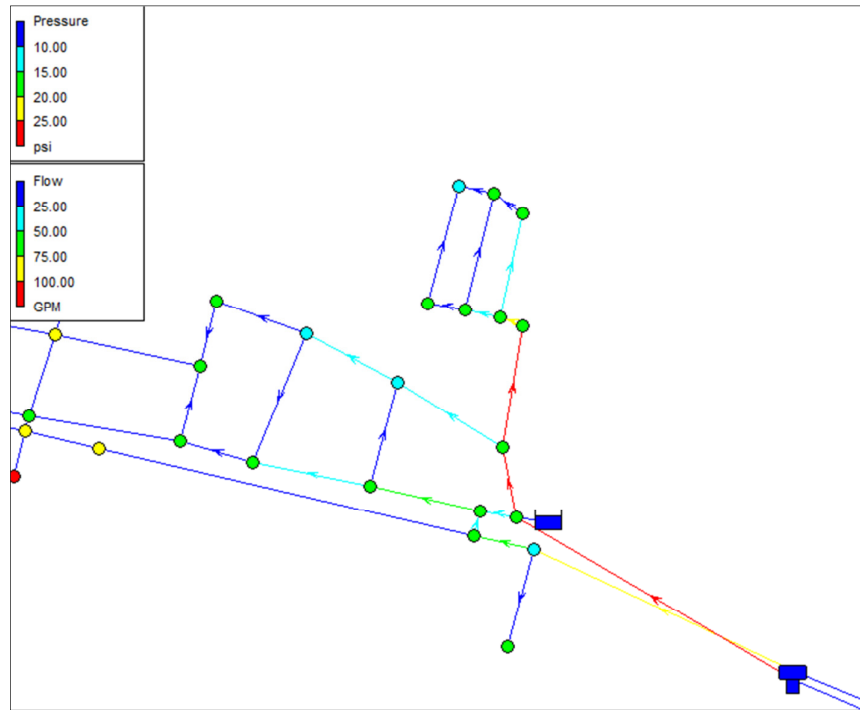


Figure 28: EPANET Screen Capture for Scenario 2 – Independencia Alto Without Pump

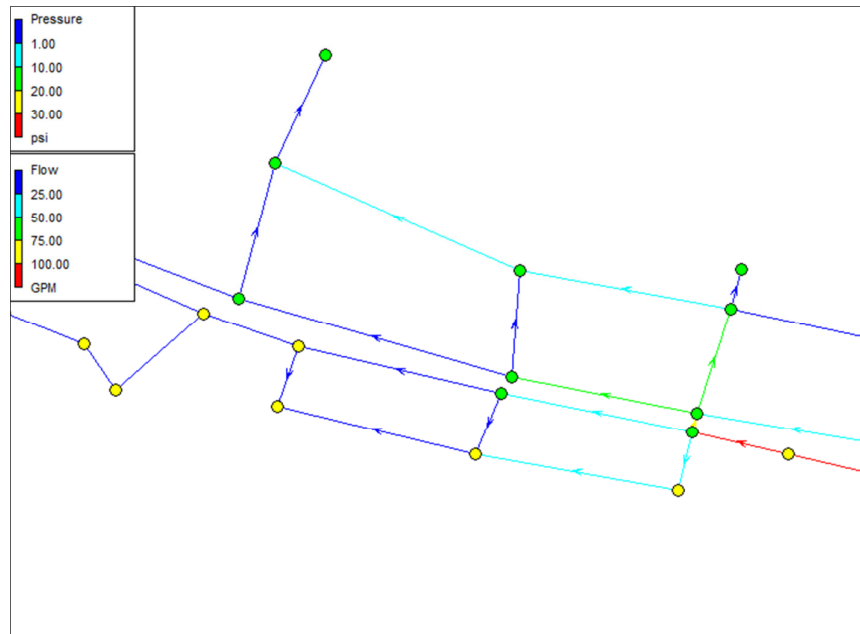


Figure 29: EPANET Screen Capture for Scenario 3 – Independencia Medio Without Pump

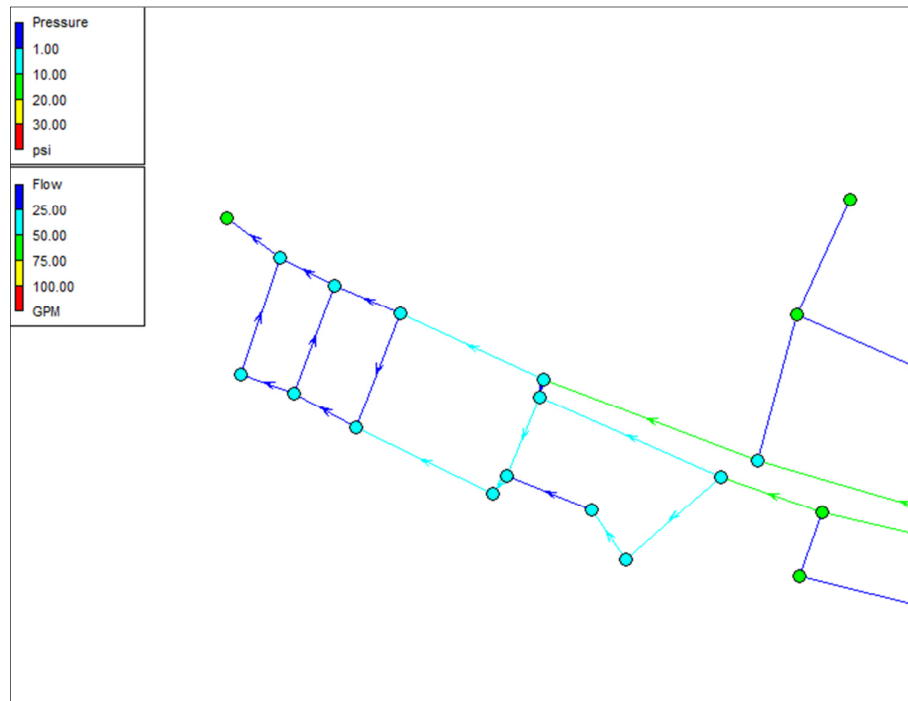


Figure 30: EPANET Screen Capture for Scenario 7 - Independencia Bajo Without Pump

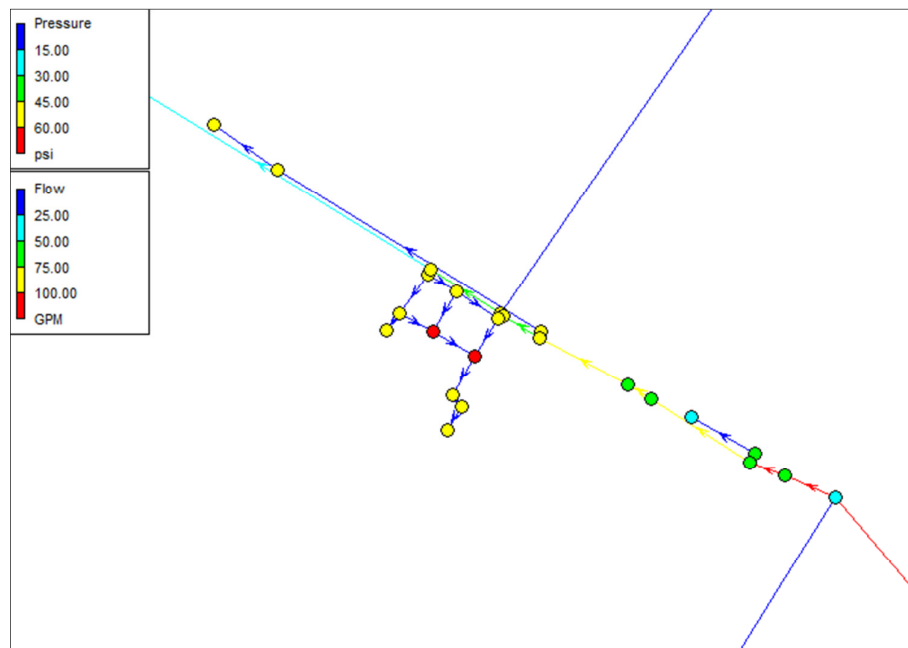


Figure 31: EPANET Screen Capture for Scenario 7 - Dos Palmas Without Pump

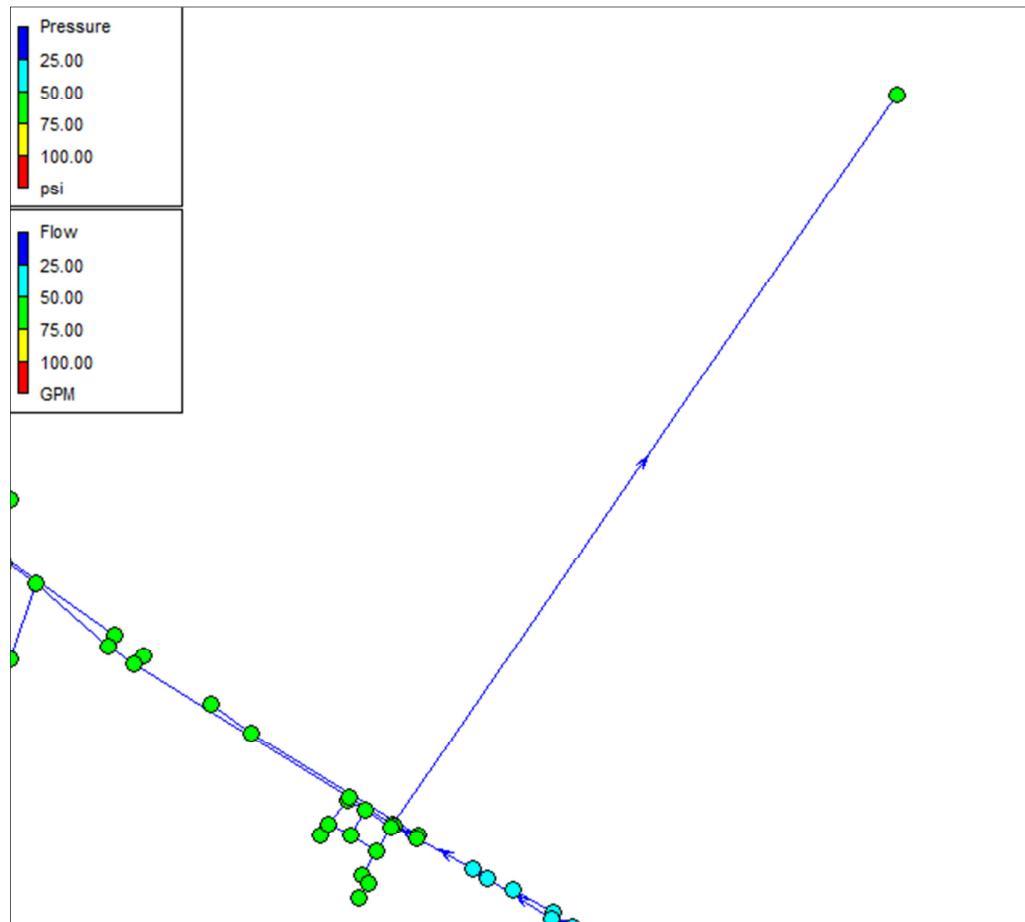


Figure 32: EPANET Screen Capture for Scenario 11 - Military Base Without Pump

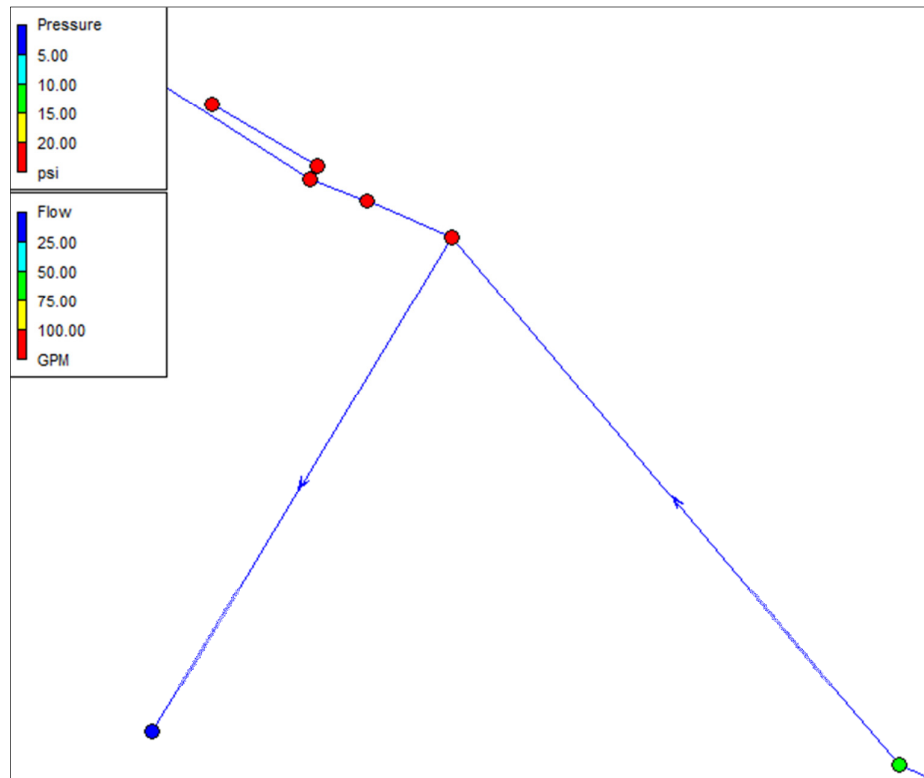


Figure 33: EPANET Screen Capture for Scenario 12 – Los Rosales Without Pump

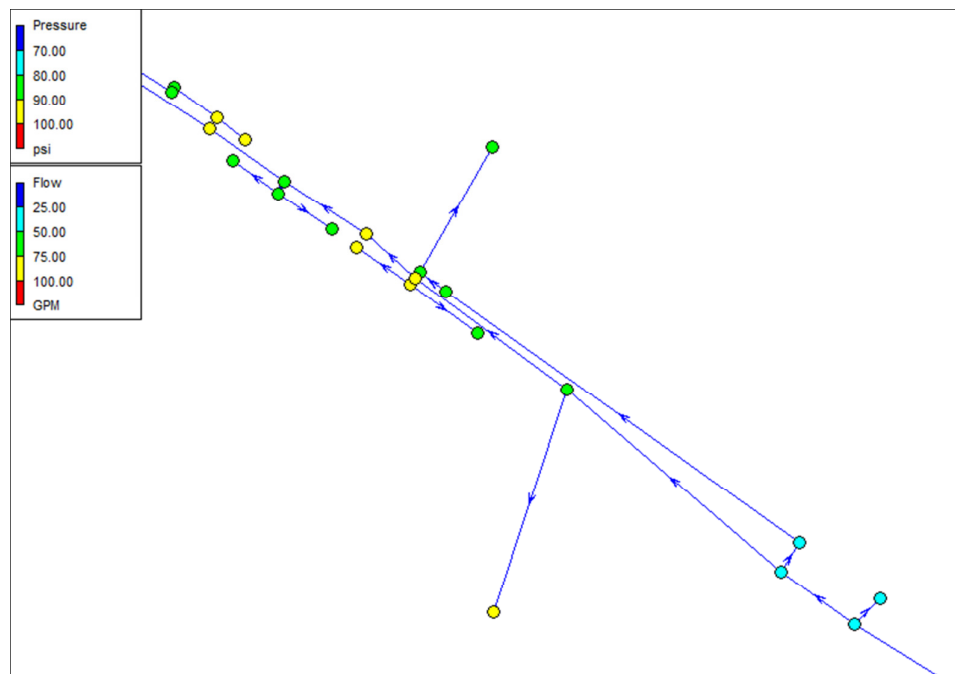


Figure 34: EPANET Screen Capture for Scenario 13 – San Isidro Without Pump

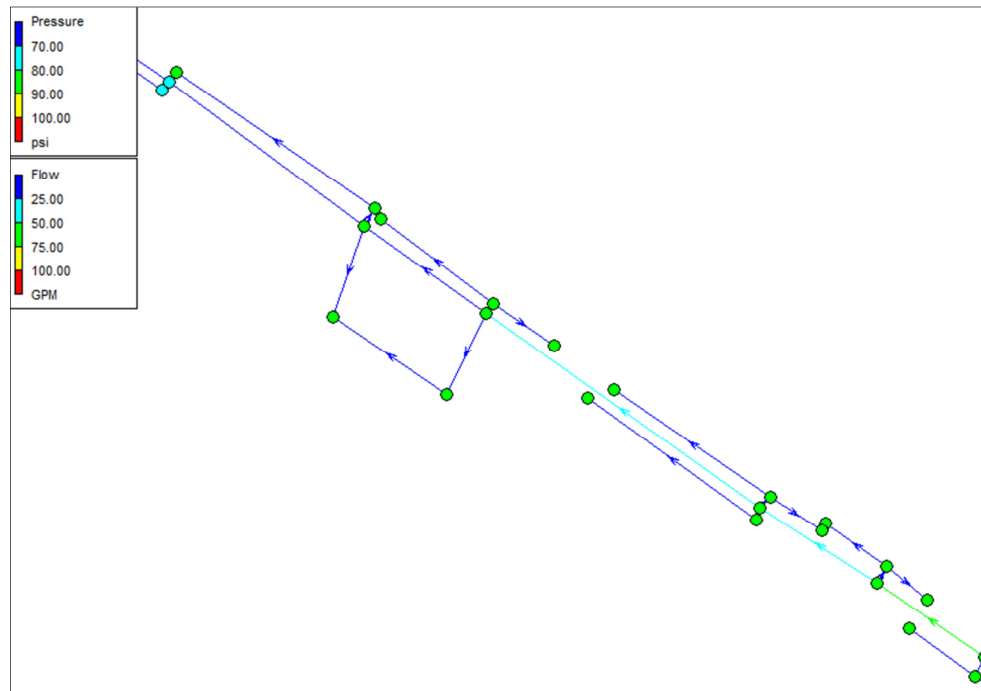


Figure 35: EPANET Screen Capture for Scenario 14 – Santa Isabel Without Pump

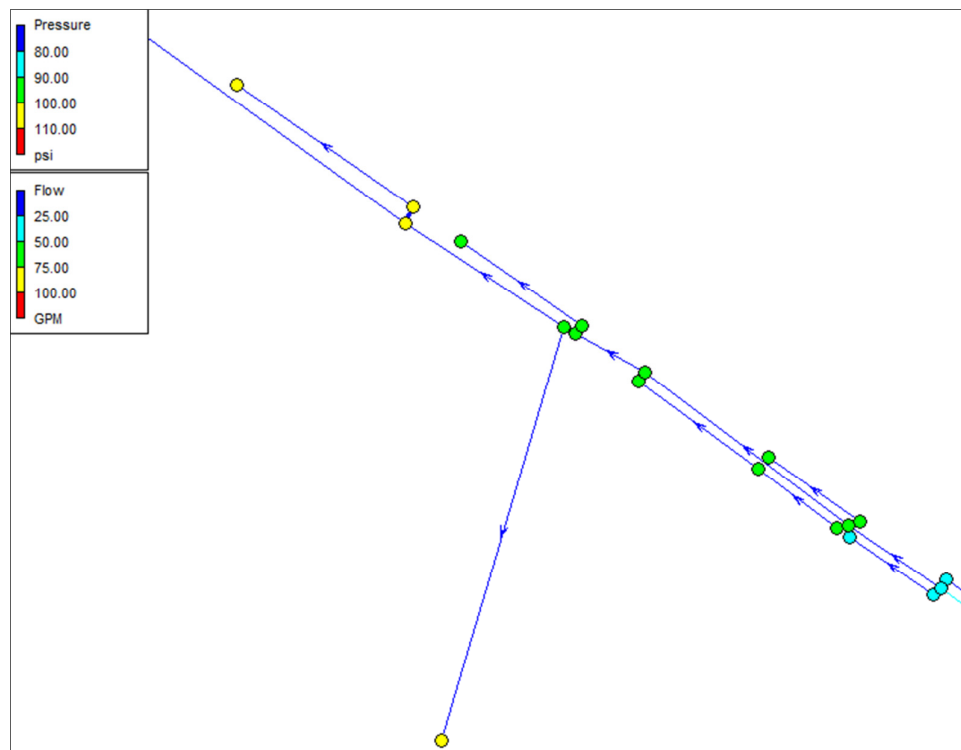


Figure 36: EPANET Screen Capture for Scenario 15 – Santa Beatriz Without Pump

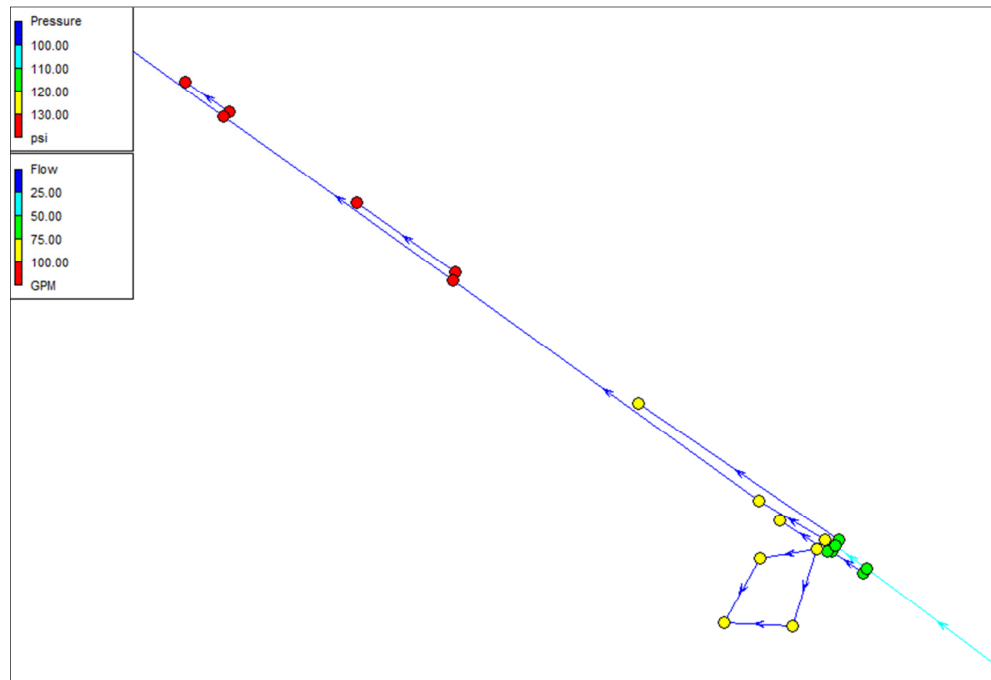


Figure 37: EPANET Screen Capture for Scenario 16 - San Felipe Without Pump

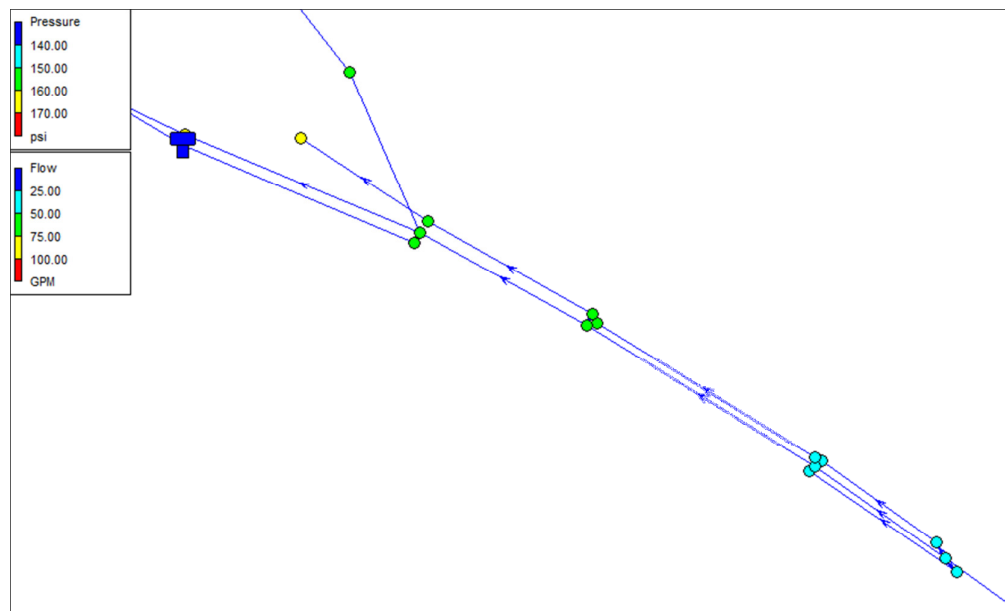


Figure 38: EPANET Screen Capture for Scenario 17 - Santa María Without Pump

Appendix G: EPANET Future Nodal Demand Scenarios

Table 16: Future Demand of 20 l/p/d at 1.5% Growth Rate

Community	EPANET Junctions	10YR (GPM)	20YR (GPM)	30YR (GPM)
Los Rosales	1	1.53	1.78	2.07
Dos Palmas	24	0.79	0.91	1.06
Military Base	1	3.41	3.96	4.60
San Isidro	18	0.14	0.17	0.20
Santa Isabel	19	0.44	0.52	0.60
Santa Beatriz	18	0.23	0.27	0.31
San Felipe	18	0.11	0.13	0.15
Santa Maria	17	0.08	0.09	0.11
Toma Leon	80	0.09	0.10	0.12
Independencia alto	23	1.08	1.25	1.46
Independencia medio	12	1.65	1.92	2.23
Independencia bajo	14	1.38	1.60	1.86

Table 17: Future Demand of 20 l/p/d at 2.61% Growth Rate

Community	EPANET Junctions	10YR (GPM)	20YR (GPM)	30YR (GPM)
Los Rosales	1	1.71	2.23	2.89
Dos Palmas	24	0.88	1.14	1.48
Military Base	1	3.81	4.95	6.42
San Isidro	18	0.16	0.21	0.27
Santa Isabel	19	0.50	0.64	0.84
Santa Beatriz	18	0.26	0.33	0.43
San Felipe	18	0.13	0.16	0.21
Santa Maria	17	0.09	0.11	0.15
Toma Leon	80	0.10	0.13	0.16
Independencia alto	23	1.21	1.56	2.03
Independencia medio	12	1.84	2.39	3.11
Independencia bajo	14	1.54	2.00	2.59

Table 18: Future Demand of 20 l/p/d at 3.5% Growth Rate

<i>Community</i>	<i>EPANET Junctions</i>	<i>10YR (GPM)</i>	<i>20YR (GPM)</i>	<i>30YR (GPM)</i>
Los Rosales	1	1.87	2.66	3.77
Dos Palmas	24	0.96	1.36	1.93
Military Base	1	4.17	5.91	8.39
San Isidro	18	0.18	0.25	0.36
Santa Isabel	19	0.54	0.77	1.09
Santa Beatriz	18	0.28	0.40	0.57
San Felipe	18	0.14	0.20	0.28
Santa Maria	17	0.10	0.14	0.19
Toma Leon	80	0.11	0.15	0.21
Independencia alto	23	1.32	1.87	2.65
Independencia medio	12	2.01	2.86	4.06
Independencia bajo	14	1.68	2.39	3.39

Table 19: Future Demand of 50 l/p/d at 1.5% Growth Rate

<i>Community</i>	<i>EPANET Junctions</i>	<i>10YR (GPM)</i>	<i>20YR (GPM)</i>	<i>30YR (GPM)</i>
Los Rosales	1	3.84	4.46	5.18
Dos Palmas	24	1.97	2.28	2.65
Military Base	1	8.53	9.91	11.51
San Isidro	18	0.36	0.42	0.49
Santa Isabel	19	1.11	1.29	1.50
Santa Beatriz	18	0.58	0.67	0.78
San Felipe	18	0.28	0.33	0.38
Santa Maria	17	0.20	0.23	0.26
Toma Leon	80	0.22	0.25	0.29
Independencia alto	23	2.70	3.13	3.64
Independencia medio	12	4.12	4.79	5.57
Independencia bajo	14	3.44	4.00	4.65

Table 20: Future Demand of 50 l/p/d at 2.61% Growth Rate

<i>Community</i>	<i>EPANET Junctions</i>	<i>10YR (GPM)</i>	<i>20YR (GPM)</i>	<i>30YR (GPM)</i>
Los Rosales	1	4.29	5.57	7.23
Dos Palmas	24	2.20	2.85	3.70
Military Base	1	9.53	12.37	16.06
San Isidro	18	0.40	0.53	0.68
Santa Isabel	19	1.24	1.61	2.09
Santa Beatriz	18	0.64	0.83	1.08
San Felipe	18	0.32	0.41	0.54
Santa Maria	17	0.22	0.28	0.37
Toma Leon	80	0.24	0.31	0.41
Independencia alto	23	3.01	3.91	5.08
Independencia medio	12	4.61	5.98	7.77
Independencia bajo	14	3.85	5.00	6.49

Table 21: Future Demand of 50 l/p/d at 3.5% Growth Rate

<i>Community</i>	<i>EPANET Junctions</i>	<i>10YR (GPM)</i>	<i>20YR (GPM)</i>	<i>30YR (GPM)</i>
Los Rosales	1	4.69	6.65	9.44
Dos Palmas	24	2.40	3.41	4.84
Military Base	1	10.41	14.78	20.97
San Isidro	18	0.44	0.63	0.89
Santa Isabel	19	1.36	1.92	2.73
Santa Beatriz	18	0.70	1.00	1.42
San Felipe	18	0.35	0.49	0.70
Santa Maria	17	0.24	0.34	0.48
Toma Leon	80	0.26	0.37	0.53
Independencia alto	23	3.29	4.67	6.63
Independencia medio	12	5.04	7.15	10.14
Independencia bajo	14	4.21	5.97	8.47

Table 22: Future Demand of 100 l/p/d at 1.5% Growth Rate

<i>Community</i>	<i>EPANET Junctions</i>	<i>10YR (GPM)</i>	<i>20YR (GPM)</i>	<i>30YR (GPM)</i>
Los Rosales	1	7.67	8.91	10.36
Dos Palmas	24	3.93	4.57	5.31
Military Base	1	17.05	19.81	23.02
San Isidro	18	0.72	0.84	0.98
Santa Isabel	19	2.22	2.58	3.00
Santa Beatriz	18	1.15	1.34	1.55
San Felipe	18	0.57	0.66	0.77
Santa Maria	17	0.39	0.45	0.53
Toma Leon	80	0.43	0.50	0.58
Independencia alto	23	5.39	6.27	7.28
Independencia medio	12	8.25	9.58	11.13
Independencia bajo	14	6.89	8.00	9.30

Table 23: Future Demand of 100 l/p/d at 2.61% Growth Rate

<i>Community</i>	<i>EPANET Junctions</i>	<i>10YR (GPM)</i>	<i>20YR (GPM)</i>	<i>30YR (GPM)</i>
Los Rosales	1	8.57	11.13	14.45
Dos Palmas	24	4.39	5.70	7.41
Military Base	1	19.05	24.74	32.11
San Isidro	18	0.81	1.05	1.36
Santa Isabel	19	2.48	3.22	4.18
Santa Beatriz	18	1.29	1.67	2.17
San Felipe	18	0.64	0.82	1.07
Santa Maria	17	0.44	0.57	0.74
Toma Leon	80	0.48	0.63	0.81
Independencia alto	23	6.03	7.82	10.16
Independencia medio	12	9.22	11.97	15.53
Independencia bajo	14	7.70	9.99	12.97

Table 24: Future Demand of 100 l/p/d at 3.5% Growth Rate

<i>Community</i>	<i>EPANET Junctions</i>	<i>10YR (GPM)</i>	<i>20YR (GPM)</i>	<i>30YR (GPM)</i>
Los Rosales	1	9.37	13.30	18.87
Dos Palmas	24	4.80	6.82	9.67
Military Base	1	20.83	29.55	41.94
San Isidro	18	0.89	1.26	1.78
Santa Isabel	19	2.71	3.85	5.46
Santa Beatriz	18	1.41	1.99	2.83
San Felipe	18	0.69	0.99	1.40
Santa Maria	17	0.48	0.68	0.96
Toma Leon	80	0.53	0.75	1.06
Independencia alto	23	6.59	9.35	13.27
Independencia medio	12	10.07	14.30	20.29
Independencia bajo	14	8.41	11.94	16.94