Creation of the Cartago Water Safety Plan:

Water Supply System Management and Risk Assessment in the Municipality of Cartago

By: Daniel Banco, Tom Graf, Nicholas Otero, Andrew Wood

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Water Supply System Management and Risk Assessment in the Municipality of Cartago

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Abstract

The goal of this project was to create and apply a comprehensive risk assessment process for small water supply systems in Cartago, Costa Rica. This process, known as a water safety plan, was developed for use by the municipality of Cartago and The Commission for the Planning and Management of the Reventazón River Basin. Our team accomplished this goal by following the World Health Organization's guide for creating water safety plans. The resulting water safety plan includes a step by step guide to consolidate data from different sources and use it to identify and assess risks. The plan also calls for a survey of consumers in order to gauge satisfaction with the system and prioritize improvements. Our team then assessed a Cartago water system using this plan. The project concluded with the delivery of the water safety plan and a set of recommendations for the assessed system to our sponsors.

Acknowledgements

Our team would like to thank the following organizations, institutions, and individuals for their help and involvement throughout our project:

- The Commission for the Planning and Management of the Reventazón River Basin (COMCURE) for sponsoring our project and providing us with accommodations.
- Don Guillermo Flores Marchena for welcoming us and providing us with support.
- Professor Paola Vidal Rivera and The University of Costa Rica for providing us with valuable information, feedback, space to work and internet access.
- Ana Patricia Guzmán and the Municipality of Cartago for providing system documentation, water quality test data, facility tours, transportation, guidance, feedback, work space, and help with conducting surveys.
- Professor Ault and Professor Ludwig for advising our team and reviewing our project.
- Worcester Polytechnic Institute for providing us with the opportunity to travel to Costa Rica and complete an Interactive Qualifying Project (IQP).

Authorship

Daniel Banco:

Daniel Banco served as the primary translator on our team. He is fluent in Spanish and performed the majority of the translating. Due to his Spanish speaking abilities, Mr. Banco conducted the majority of the residential surveys. He was also the primary contact to our sponsors, who spoke very little English. Mr. Banco authored the Data Collection section of our report, most of the appendices, the Ladrillera distribution network map, consumer perception scatterplot, and system diagram. In addition, he created several sections of the CWSP spreadsheet.

Thomas Graf:

Thomas Graf served as the primary creator of the CWSP spreadsheet. Mr. Graf spent most of his time working on the spreadsheet. For this reason, he authored the Development of the Tool section of our report, as well as the Conclusions section. He co-authored the Methodology section of the report with Mr. Wood.

Nicholas Otero:

Nicholas Otero wrote the Evaluation of the CWSP section of the report. He assisted in the collection of survey responses and prepared the graphical summary of the survey data. Mr. Otero was the best editor on our team. He also was the primary creator of our final presentation. Mr. Otero was proficient in Spanish and therefore translated many documents, including parts of the CWSP spreadsheet and Powerpoint presentations.

Andrew Wood:

Andrew Wood authored the Executive Summary section of the report. He also co-authored the Methodology section. Mr. Wood assisted in the creation and design of some sections of the CWSP spreadsheet. He was the primary creator of the Improvement Plan for the Ladrillera spring water supply system as well as the Recommendations section of the report.

All members of the team made equal contributions to the writing and editing of the Introduction and Background. Each member also equally contributed to the formatting and the editing of the entire report. In addition, each member authored the CWSP guide.

Contents

List of Figures

Executive Summary

Cartago is a municipality located in the Central Valley of Costa Rica. The organizations that manage water supply systems in Costa Rica are The Costa Rican Institute of Aqueducts and Sewers (AYA), municipalities, and Administrative Associations of Rural Water and Sanitation Systems (ASADAS). AYA manages all large water supply systems throughout Costa Rica, while the municipalities and ASADAS manage small spring systems for rural populations. The Commission for the Planning and Management of the Reventazón River Basin (COMCURE) assists both organizations in all environmental affairs.

The municipality of Cartago has existing water supply management systems, but does not have standardized system evaluation methods. It has taken the initiative to standardize its evaluation methods by implementing the Water Safety Plans (WSPs). The WSPs are a systematic approach for risk assessment and control of water supply systems. The plans, prepared by the World Health Organization (WHO), serve as a general framework for water suppliers to evaluate and improve their systems (Bartram et al., 2009). When the WSPs are implemented, they are intended to be modified to become specific to the area and systems being evaluated. COMCURE is seeking to provide other municipalities and ASADAS throughout the Central Valley with a water safety plan based on the WHO suggestions.

This goal of this project was to create and apply a Water Safety Plan for the Municipality of Cartago and COMCURE. This plan, known as the Cartago Water Safety Plan (CSWP), needed to provide a systematic and standardized procedure for evaluating and managing water supply systems. This plan also had to be specific to small Costa Rican water supply systems. The CWSP had to be easily adaptable for use by COMCURE, the municipality of Cartago, other municipalities, and ASADAS. Our team achieved these goals by completing the following specific objectives:

- Identify components of CWSP
- Create the CWSP
- Implement the CWSP on a small system

Our team created the CWSP by first reviewing the WSP manual and documentation from the municipality of Cartago. Tables and decision matrices from the WSP manual helped provide a framework for the system evaluation. The WSP manual also provided a table of possible risks for each section of a water supply system. The documentation from the municipality of Cartago included information specific to spring systems in Cartago. Annual reports provided examples of information to include in the system description section of the CWSP.

Our team organized the CWSP into four categories that best meet the requirements. The categories are water supply description, risk identification, risk assessment, and improvement plan. Each distinct group of data was given its own page in an organized spreadsheet tool. As the sections of the CWSP were created, they were simultaneously tested using data from the Ladrillera spring water supply system. The application of the sections ensured their effectiveness and helped identify new content and features.

As part of the spreadsheet, a general information page was designed to include administrative information and basic descriptive facts. Entering this information facilitates the identification of hazards. A set of system description questions was included in this section. These questions were taken from existing documentation provided by the municipality of Cartago. Consulting engineers in Cartago ensured that the questions sufficiently describe the Cartago water supply systems.

The Risk Identification section contains a system inspection checklist and space for storing water quality test results. The checklist was adopted directly from the municipality of Cartago where it has successfully been used to inspect water systems. It facilitates the risk identification process by enabling the user to analyze each stage of the water supply system. Examples of checks include system vulnerability, security, component integrity, presence of hazardous objects, and lack of documentation.

The risk assessment pages were composed of tables adapted from the WSP manual. The first columns of these tables suggest hazards that may impact any given water supply system. Checkboxes that hide irrelevant hazards were inserted to allow for flexibility. The relevant hazards are classified by type (physical, chemical, or biological) and are presented with their associated risks. The next two columns present a space for the user to identify control measures and validate their effectiveness. The WSP manual instructed users to assess risks and control measures separately. This process was deemed too complex and counter-intuitive for small systems. Our team consequently combined the two stages. Risks are assessed while considering the present state of the control measures. The remaining columns of the Risk Assessment tables focus on assigning a quantitative risk score to each hazard based on likelihood and severity.

The final section of the CWSP spreadsheet was designed to help the user create an improvement plan. The CWSP spreadsheet uses two steps to create an improvement plan: control measure selection and progress management. For control measure selection, the user is provided with tables to list possible control measures for each risk. The tables prompt the user to determine each potential control measure's cost, efficacy, time to implement, and probability of introducing new risks.

Our team created a scale to rank criteria for control measure selection. The sum of these criteria scores determines the overall score of the potential control measure. The potential control measure with the highest overall score is selected for implementation. Selected control measures are then assigned projected completion times and statuses on the improvement plan page. This page has to be updated as improvements are implemented.

The Ladrillera spring water supply system served as the first application of the CWSP. Both the municipality of Cartago and COMCURE seek to apply our water safety plan to spring systems comparable in size and complexity to the Ladrillera spring system.

We began to apply the CWSP to the Ladrillera spring water system by describing the system. Our team referred to the annual report created by Ana Patricia Guzmán for the water supply description. Notes and photographs during tours of the Ladrillera spring system aided in the system description.

Consumer feedback on the system is required for a full description. A residential survey was prepared in order to retrieve this information. From the responses, several important observations were made. One observation was that a majority of households used the water in every common practice, such as washing plates and brushing teeth. The only common practice most households did not use the water for was washing vehicles. The survey asked the consumers to rate their satisfaction with their service. The majority were not satisfied with their water supply. In particular, the survey results indicated large discontent with the quantity, continuity, and quality of their water service. Improved quantity of water was the most requested improvement.

System risks and control measures were identified during the description. System documentation and consulting Cartago engineers provided sources of additional risks. Using the same process, our team was able to find information regarding the control measures currently in place.

Once identified, risks and control measures were assessed. We validated control measure effectiveness by inspecting physical controls such as fences and enclosures. Our team validated chemical control measures by examining past chemical test results of the Ladrillera. Risks were assessed using the process laid out by the CWSP. Working with Cartago engineers helped to assign rankings for each risk based on likelihood and severity.

The final section in the CWSP calls for the creation of an improvement plan. We researched possible control measures for each risk. A table was created to assess each control measure's cost, efficacy, time to implement, and chance of introducing new risks. The potential control measure with the highest score was selected for recommendation.

After applying the CWSP to Ladrillera, our team concluded that the CWSP met the requirements of the project. The CWSP was capable of organizing important information about the spring from multiple documents. The surveys were particularly helpful because they called attention to problems, such as frequent water outages, that the engineers had not identified. By working with the engineers, we were able to easily identify the risks that were relevant to the system and validate the control measures in place. The CWSP process made ratings and prioritizations of the risks consistent and straightforward. This in turn made the creation of an improvement plan clear and easy as well.

Our team discovered multiple advantages gained from using the CWSP. Perhaps the most compelling is that the user of the CWSP requires little technical knowledge about water systems. Our team, with no previous experience of assessing water systems, was able to easily apply the CWSP to the Ladrillera system and create an improvement plan.

Furthermore, the CWSP has the advantage of being widely applicable. The tool was created with the goal of being able to assess multiple water systems. Even though there was not enough time to apply the CWSP to more than one system, the resources are directly applicable for other systems in Cartago.

A key advantage of the CWSP is that it is standardized. Along with the system assessment tool, the CWSP includes a step by step guide for carrying out the process. By following the guide, users can repeat the assessment on Ladrillera and achieve similar results.

Finally, the CWSP is easy to use and maintain. Our team often obtained new information from engineers after having previously completed a step in the CWSP process. Adding this information was easily accomplished due to the organization of the tool. The CWSP tool was easy to maintain as a result of being able to easily locate and add data. Ease of maintenance will help ensure the integrity of the document as it is updated.

The recommendations below are the most important for the Ladrillera spring system. Each recommendation includes information regarding the risks and the efficacy of mitigation. Many require further research such as determining the exact cost and time to implement.

<u>Clean tanks more frequently</u>

Risks mitigated - Unclean Tanks and Sediment Buildup

The tanks are currently being cleaned annually. This creates the potential for contamination to occur for an entire year before removal. Contaminants such as sediment build up in the tanks and then flow into the water system. A more frequent cleaning of the tanks will reduce the amount of contaminants. This is easily implemented since the cleaning cost will be low. In order to properly clean the tanks, the water should be shut off for a few hours. This will inconvenience the residents, but based on the survey responses, they will accept it in order to receive clean water.

<u>Replacing all leaky pipes</u>

Risk mitigated – Improperly sealed tanks

When the water level increases in the tanks, the pipes begin to leak. The overflow pipe does not have water flowing through it when the water level is highest. This is due to the fact that there are leaks below, preventing the water level from reaching the overflow pipe. Replacing the pipes will create less wasted water, and will ensure more supply to the consumer.

<u>Installation of a filter</u>

Risk mitigated – Sediment buildup

Frequently, consumers receive water containing excessive amounts of sediment. When surveyed, residents stated that their water often contained dirt and sand. In order to prevent more sediment from entering into the system a filter should be installed after catchment. However, filters will need regular maintenance.

Regular implementation of the CWSP will improve the water supply and management of the systems. We recommend annual or bi-annual implementation. This will ensure that high priority risks are properly controlled. Regularly implementing the CWSP gives engineers the opportunity to implement newly available control measures.

Another important reason to implement the CWSP is to standardize system evaluation and improvement. One systemic problem the municipality has encountered is incomplete documentation. Many chemical tests, such as residual chlorine, occur but are not documented. The CWSP will help with proper chemical test documentation. All important files should be kept in one folder to avoid errors.

If all recommendations are implemented, the Ladrillera spring system should provide high quality and quantity of water to the consumers. Consumers will already notice a significant change in their water if the higher priority recommendations are implemented. We hope that the CWSP will not only be implemented by the municipality of Cartago, but by ASADAS and other municipalities as well. The CWSP has the ability to improve all small water systems across Costa Rica and consequently improve the quality of life for many Costa Ricans.

1. Introduction

Water is a natural resource that is crucial to life. Its quality directly affects the health of those who drink it. For this reason, it is a priority to deliver clean water to communities and industries. Unfortunately this is not always an easy task. Only 2.5% of all the water on Earth is freshwater. Of that, about 30% is accessible for humans to drink (U.S. Geological Survey, 2013). As a result, large amounts of potable water often need to be transported across long distances. Water supply systems accomplish this task.

Costa Rica has expanded its coverage of water services over the last decade, but has yet to fulfill its population's need for safe water. Although approximately 99% of the urban population and 92% of the rural population receive service from water supply systems, problems remain (Black, 2012). Contamination of water sources is one of the main problems in Costa Rica. Primary sources of contamination originate from agricultural runoff, sewage, and wastewater. The contaminants produced from these sources foster waterborne illnesses that endanger the health of consumers. Additionally, flooding and landslides threaten to destroy exposed water transport pipes (Bower, 2014). To mitigate these dangers, water supply systems must undergo routine evaluations and improvements.

Cartago, a municipality located in the Central Valley of Costa Rica, is taking the initiative to evaluate their systems by implementing Water Safety Plans. These plans, created by the World Health Organization (WHO), call for an integrated approach to risk assessment and risk management of water supply systems (Bartram et al., 2009). The actions, outlined in 11 modules, cover all stages of the supply system from catchment to distribution to the consumer. COMCURE, a government organization, has taken a leading role in implementing the Water Safety Plans for water supply systems in Cartago.

The goal of this project was to create a Water Safety Plan specific to the municipality of Cartago and evaluate its effectiveness. This plan needed to include a set of evaluation tools that would allow COMCURE and Cartago engineers to carry out a systematic and standardized assessment of their systems. In addition, the plan needed to provide a framework to guide engineers through the process of improving their systems. Ladrillera, a small spring system in Cartago, was used as a case study to evaluate the effectiveness of the Cartago Water Safety Plans and its associated tools.

2. Background

Water supply systems collect, treat, and transport drinking water. Engineers employed by the local government must continuously maintain and improve the community water supply system. The Committee for Planning and Management of the Reventazón Upper Basin (COMCURE) is collaborating with other government organizations to maintain parts of Cartago's Aqueduct. COMCURE sponsored the WPI project to implement the Water Safety Plans in the Ladrillera spring water supply system. The framework for Water Safety Plans was created by the World Health Organization and the International Water Association (Bartram et al., 2009). This section will discuss water and water supply system concerns in Costa Rica, a case study of a small town water supply risk assessment, water supply management in Costa Rica, Cartago's Ladrillera spring water supply system, the Water Safety Plans, and water quality assessment in general.

2.1. Water in Costa Rica

In the 2014 Environmental Performance Index analysis of 178 countries, Costa Rica ranked third among Latin American countries and 54th overall (Hsu et al., 2014). Costa Rica ranked highly in most categories; however, in terms of access to drinking water it ranked poorly. The study predicts a 10% improvement in access to drinking water and sanitation in ten years. Costa Rica's humid tropical climate and high amount of precipitation position it among countries with the greatest freshwater resources (Phillips 2003). More than 4,000 wells, springs, and surface water resources provide water to Costa Ricans

Costa Rica's water resources vary by region. The two primary regions are on either side of the mountains that divide the country. The Atlantic slope is wet and windy with no water deficit. The Pacific slope is drier and experiences decreased flow during the dry season. There are seventeen major watersheds in the country. These watersheds are replenished by the country's abundant rainfall. Of the 167.2 km^3 of yearly rainfall, 37.3 km^3 is stored in groundwater reserves (Aquastat, 2000). These reserves are an important water source in Costa Rica. A total volume of 11 km^3 is available for use (D.A. Alvarado & García, 2007).

Costa Rica's water supply systems face various challenges to water quality and system infrastructure. Groundwater is susceptible to contamination through agrochemical leaching and sewage. This can originate from nearby farms, factories, or residential areas. The system infrastructure also faces hazards. Disasters such as earthquakes, landslides, and volcanoes can cause massive damage (Bower, 2014). COMCURE sponsored the WPI team to investigate the challenges faced by small water supply systems.

2.2. Water supply management in Costa Rica

Costa Rica's major water supply systems are managed by AyA (Instituto Costarricense de Acueductos y Alcantarillados), ASADAS (Administrative Associations of Rural Water and Sanitation Systems), and municipalities. AyA administers and operates 180 water systems directly. The centralized public institution serves 43% of the urban population and 3% of the rural population. ASADAS administer and operate 1,827 rural water systems serving 26% of Costa Rica. Municipalities administer and operate 240 water systems serving 17% of the population (Ezpinoza et al., 2003).

COMCURE is a government organization dedicated to the preservation of the environment. This organization has focused its efforts around the preservation of the Reventazón River Basin. This river basin is located in Cartago and in Limón. COMCURE's main objective is to plan, implement, and control of water conservation activities in this area. It hopes to improve the quality of life for Costa Ricans living near the Reventazón River Basinthrough the implementation of corrective programs (COMCURE, 2014). COMCURE exepects our project to provide a standardized way of implementing the Water Safety Plans in other municipalities and ASADAS along the Reventazón River Basin.

2.3. Water Safety Plans

The Water Safety Plans (WSPs) are a systematic approach for risk assessment and control for water supply systems. The plans, prepared by the World Health Organization (WHO), serve as a general framework for water suppliers to evaluate and improve their systems. The plans contain eleven modules. This section will group the modules based on their goals and discuss these goals.

2.3.1. Prepare to execute the Water Safety Plans

Modules 1 and 2 prepare teams to assess water supply systems. The first module of the WSP describes the need for a dedicated team. It also provides details and tools to assemble the team and secure financial resources. It tasks the leader to determine the team's size and the roles of each member. Once assembled, the team creates a timeline for development of the WSP (Bartram et al., 2008, pp. 8-17).

Module 2 tasks the team with creating a detailed description of the system. Any data collected cannot be extrapolated from past data or similar systems. The information collected will encompass the entire system from catchment to distribution. The description will also include stakeholder opinions. The collected data are then organized in tables, maps, and flowcharts. This allows the team to extract valuable data in an organized manner (Bartram et al., 2008, pp. 18-25).

2.3.2. Perform a risk assessment, identify existing and potential control measures

The modules in this group focus on risk assessment and control measure determination. This group is comprised of Modules 3 through 6. Module 3 requires the WSP team to identify possible hazards or hazardous events. Hazards are entities that impose risks on the system and could diminish the quality and/or quantity of the water supply. The three hazard categories are physical, biological, and chemical. The risks posed by each hazard are determined based on the likeliness and severity of the hazard. Risks should be rated on a well-defined, normalized scale. This allows team members to assign ratings to risks in a less subjective manner. The risks are assessed based on direct evidence from the system (Bartram et al., 2008, pp. 26-37).

Control measures are activities or processes applied to reduce or mitigate risks. Module 4 determines the current control measures. Afterwards, the team must evaluate control measure efficacy. Hazards that are addressed with the current control measures will be reassessed. The WSP recommends completing this step concurrently with Module 3. Once completed, the team will have a list of all control measures in place, an appraisal of how well they work, and a prioritized list of risks (Bartram et al., 2008, pp. 38-49).

It is likely that the WSP team will find risks without adequate control measures. In Module 5 the team must create an improvement plan that identifies control measures for these risks. The plan must include short, medium, and long term improvements. The team must also oversee the implementation of the plan and ensure that it is completed on time and within budget. When completed, the team will reassess the affected risks with consideration of the new or improved control measures (Bartram et al., 2008, pp. 50-57).

Module 6 requires that the team create a plan to monitor the state of the control measures. This step ensures that the control measures address the risks. The plan must be thorough in order to ensure consistent monitoring. The plan must also include responsive actions for a decrease in quality or quantity (Bartram et al., 2008, pp. 58-65).

2.3.3. Create long term procedures to support the water supply system

The remaining modules provide guidance on long term management of the system. Module 7 involves scheduling audits for plan execution. The audits ensure that the plans are being followed correctly and are effective. They are carried out in three stages: compliance monitoring, internal and external activity audits, and customer satisfaction surveys (Bartram et al., 2008, pp. 66-73).

In Module 8, the WSP team creates standard operating procedures and corrective actions for the water supply management. The procedures should be easy to understand and clearly delegate tasks to specific positions. The procedures should instruct managers how to monitor operations, create notifications, disseminate information, and take responsive actions to emergencies (Bartram et al., 2008, pp. 74-81).

The ninth module of the Water Safety Plans promotes the creation of supporting programs. Supporting programs reinforce the development of people's skills and knowledge. Examples of possible supporting programs are training, equipment calibration sessions, and research and development (Bartram et al., 2008, pp. 82-87).

Module 10 should be completed periodically. The purpose of this module is to revise the work done based on new experiences and procedures. Risks will be reassessed and control measures may need to be verified. When verifying control measures it is important to consider new technologies that provide better risk mitigation. In this case, a new improvement plan may need to be created (Bartram et al., 2008, pp. 88-91).

The final module of the Water Safety Plans explains that the system should be reevaluated after every incident. The incident must be analyzed and evaluated to prevent further incidents. The reevaluation of the system may result in a re-prioritization of risks. In this case, further action may be required to control the risks (Bartram et al., 2008, pp. 92-97).

2.4. Ladrillera spring water supply system

The Ladrillera spring water supply system served as a test vehicle for the Cartago WSP. This system, shown in Figure 1, transports and treats water that passes from a spring to the town of Lourdes. The town is located in Aguacaliente, the 5th district of the municipality of Cartago as shown in Figure 2. Some of the residents receive water from the larger water supply system nearby. Most residents have a water meter that calculates their water bills. Water costs about two thousand colones (4 USD) for every 15m^3 of water. The price of water increases as residents use more water. Those who do not have a water meter installed pay a fixed price (Guzmán, 2013).

The spring is located near the brick factory in Lourdes, shown in Figure 3. The system consists of catchment, a chlorination system, pipelines, water tanks, and a distribution network as shown in Figure 3. The system provides water to 200 houses and passes bi-monthly water quality tests. These tests are conducted every ten weeks for Level 1 parameters and yearly for Level 2-3 parameters (See Appendix A). The spring produces water at a yearly average rate of 3.2 liters per second. The system includes two plastic storage tanks and one cement storage tank. The sodium hypochlorite disinfection system is housed in a small brick building. There are 5 meters of pipeline in the early stages of the system and 500 meters of pipeline in the distribution network. The system is surrounded by a fence for security.

Figure 1: Ladrillera spring water supply system grounds

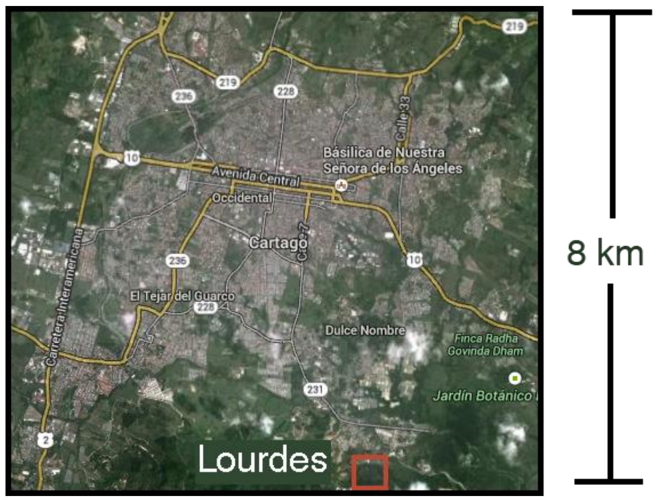


Figure 2: Map of Cartago courtesy of Google maps

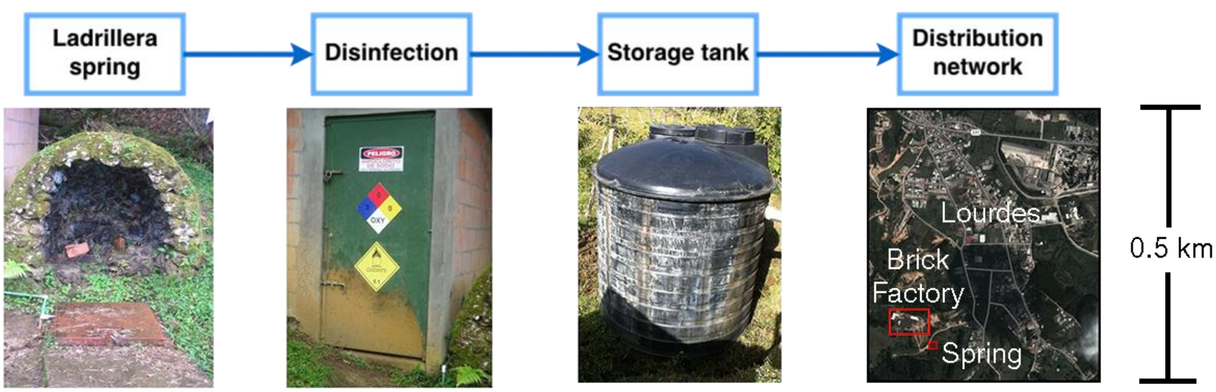


Figure 3: Ladrillera spring water supply system (Guzmán, 2013)

2.5. Case study: small scale water supply risk assessment

This section reviews an implementation of the Water Safety Plan on a small system. This section will also provide examples of possible hazards and solutions. The Romanian county of Cluj conducted a water supply risk assessment of the town of Luna (Gurazu et al., 2011). This risk assessment was carried out in accordance with the WHO Water Safety Plans. Luna has a higher population than the town served by the Ladrillera system with 4,450 people (Structura, 2002). This larger scale case study will provide an example of a successful application of the Water Safety Plans. The study discusses the water supply system of Luna, water quality tests, health risk assessment, and a compliance plan for mitigating effects caused by uncontrolled risks.

Luna collects groundwater from an aquifer by a drain from 6 shallow drillings. The proximity of the catchment to farmland treated with herbicides makes the water source vulnerable. Similarly to the Ladrillera water supply system, the water then undergoes chlorination. The vicinity above the Cluj aquifer is under sanitary protection (restricted access), but it is not enough to mitigate contamination from external factors. The aquifer's water quality depends heavily upon the soil structure above (Gurazu et al., 2011).

The water quality tests examined common parameters. These included color, odor, pH, conductivity, turbidity, free residual chlorine, E. coli, and others. Water quality tests found an increase in nitrate, enterococci, and coliforms present in the water from 2009 to 2010. Manure use during this time period was suspected to have caused these contaminants to exceed the legal limit. The chlorination process did not sufficiently treat the water (Structura, 2002).

The study identified two primary solutions and made suggestions. A denitrification filter brought the nitrate down to normal levels. An improved chlorination process mitigated the bacterial contamination. Additionally, the study noted the importance of public relations and risk communication (Gurazu et al., 2011).

2.6. Water supply systems

Both quality and quantity issues limit the availability of potable water in Costa Rica. Quality refers to the water in terms of its physical, chemical, and biological parameters. Quantity refers to the accessibility of water for consumption. In order to assess a water supply system, the quality and quantity need to be evaluated along the entire system. This includes source waters, catchment, treatment systems, storage tanks, and distribution to the consumer. All stages of the system have associated hazards that need to be identified.

Hazards in the system affect the quality of the water. Exposure to contaminated water can cause water-borne illnesses, birth defects, and cancer (de Albuquerque, 2009). Sewage, agrochemicals, medical waste, and wastewater are the main sources of contamination in Costa Rica. Sewage causes high nitrate levels as well as the spread of diarrheal diseases. This is a major problem in Costa Rica, as diarrhea is the second leading cause of death (Bower, 2014). Agrochemicals include fungicides, insecticides, and herbicides used in agriculture. These can leach into groundwater sources. These agrochemicals contain heavy metals like arsenic, lead, and mercury. Humans face both acute and chronic health problems when exposed to such chemicals (Ballestero & Reyes, 2006). Medical waste comes from the unsafe practice of dumping drugs into the water. The final primary hazard is wastewater, either from personal or industrial use. In Costa Rica all non-sewage wastewater is usually released directly into nearby streams without treatment (Bower, 2014). This untreated wastewater carries numerous diseases and dangerous chemicals that can be deadly when consumed. These hazards often make the water unsafe for consumption.

Hazards can also be physically threatening to the system. Volcanoes, flooding, earthquakes, and landslides, all of which are present in Costa Rica, can destroy delivery pipes and compromise the supply of clean water (Bower, 2014). Even if the supply is not totally disrupted, low pressure or flow rate variations can result. Such damage occurred during an earthquake in 2012 (Josephs, 2012). The earthquake caused landslides that destroyed water supply lines throughout Puntarenas. Residents lost water for over half a day (Vervaeck & Daniell, 2012). Had the supply system designers included landslide protection parameters, the citizens may not have lost water.

Engineers use a standardized set of quality and quantity tests to assess water supply systems. They test for over one hundred different chemicals. The tests are grouped into four different levels (Vidal, 2013). The level of testing is determined by potential hazards that could affect the safety of the water supply system. The results are compared to established recommended and maximum values. These values were assembled by COMCURE, and are outlined in Appendix A. Other factors such as odor and color can be used to determine water quality. Quantity testing can be done by checking water pressure and flow rate in the pipes. Tests are conducted at every stage of the water supply system to identify the locations of the hazards. Overall water quantity can also be assessed by determining the total water supply and the consumers' demand. Preventative measures can be put in place once the hazards and locations are determined.

The conventional water treatment process, depicted in Figure 4, consists of five steps. They are coagulation, flocculation, sedimentation, filtration, and disinfection. In the coagulation stage, a positively charged ion is added to neutralize negatively charged particles suspended in the water. The water along with the neutral particles moves to the flocculation stage, where large paddles mix the water and clump the particles into large groups. These large particle groups then fall out of suspension in the sedimentation chamber. Once leaving the sedimentation chamber the water passes through a mixture of sand and gravel to filter out any solids remaining. The filtered water is then disinfected by adding chlorine. After this process is completed, the water is ready to be distributed. This process is typically used by large-scale water supply systems to treat water from surface sources.

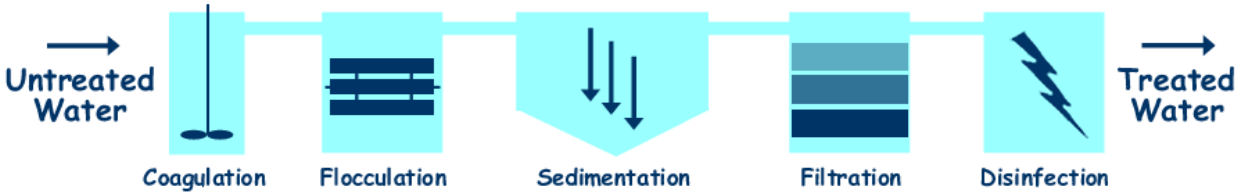


Figure 4: Conventional water treatment process, (Santa Clara Valley Water District, n.d.)

The municipality of Cartago and most ASADAS do not use complicated disinfection systems. The water that originates from the springs and wells is relatively clean (Bower, 2014). The water only requires the use of chlorine for disinfection. The main types of chlorine used for disinfection are chlorine gas and sodium hypochlorite. Chlorine gas is the best disinfectant, but requires the use of more complicated equipment. Since it is very toxic, any leak in pipes could be fatal. Chlorine gas also needs to have its pH regulated during the disinfection process. Sodium hypochlorite is a liquid, and therefore it is safer to store. It does degrade overtime, thus the storage time is much shorter than storage time for chlorine gas (Baar & Jewell, n.d.). When the hypochlorite degrades, it produces chlorate. Chlorate is very toxic when consumed (Grant-Trusdale, n.d.).

Chlorination removes most contaminants from the water. Contaminants such as E. coli, and cryptosporidium are resistant to chlorination, but are not always present. There are many treatment methods that can be utilized to remove specific hazards from the water. It is uneconomical to implement all of them in a water supply system, so they need to be applied as necessary. After they are applied, operational monitoring is used to determine the effectiveness of disinfection. Operational monitoring examines certain parameters during the treatment process (see Appendix A). By assessing the values of the parameters at a certain stage, workers know how each step is performing (Strategy, 2011).

3. Methodology

The goal of this project was to create and apply a Water Safety Plan (WSP) for the Technical Aqueducts Department of the municipality of Cartago and COMCURE. The application of this WSP would help identify potential improvements to the water supply systems in the area. Personalizing the WSP for use in Cartago would allow the process to be efficient and uniform for all systems. A specific plan was designed to help facilitate the methodology. This plan, known as the Cartago Water Safety Plan (CSWP), needed to provide a systematic and standardized procedure for evaluating and managing water supply systems. The CWSP had to be easily adaptable for use by COMCURE, the municipality of Cartago, other municipalities, and ASADAS. Our team achieved these goals by completing the following objectives:

- Identify components of CWSP
- Create the CWSP
- Implement the CWSP on a small system

3.1. Identify Components of the CWSP

The first step in the methodology required our team to identify the necessary components of the CWSP. This was accomplished by reviewing existing water system documents. These documents included the WSP manual and documentation from the Technical Aqueducts Department engineers. The CWSP needed to consolidate information from both of these sources. The WSP manual included tables and rubrics used to efficiently identify and assess risks for water supply systems. Engineers provided descriptions, system inspection forms, and water quality test results for its water supply systems. Our team selected specific content by reviewing information from the WSP manual and documentation from the municipality of Cartago. By consulting with engineers, our team was able to extract details specific to small water supply systems in the Costa Rican Central Valley. The application of the CWSP on the Ladrillera spring system helped identify any additional content or features.

3.2. Create the CWSP

The CWSP was structured using Modules 2-5 of the WSP. These modules contain all of the steps necessary to assess and improve a system. They are a system description, risk identification and assessment, control measure identification and risk prioritization, and the creation of an improvement plan.

To create the system description section of the CWSP, our team determined what information was necessary for a complete system description. An area to input this information was included in the CWSP. Existing documentation in Cartago and information from the WSP provided the outline for this section. This allowed the CWSP to be specific to Costa Rica while still reflecting the themes of the WHO.

Surveys were also created for a more complete description. The survey, shown in Appendix B, identifies points of dissatisfaction with regard to water service. They also help identify risks to the system.

The CWSP also required a section for risk identification and assessment. Since the CWSP had to be customized, our team conducted research to find what risks are relevant in the Central Valley. Engineers helped finalize the collection of risks. Once listed, the risks can be assessed and given risk scores as outlined in the WSP. The CWSP was further personalized by providing a method to prioritize each risk by including survey results.

The final section of the CWSP was an improvement plan. The WSP manual provided the method of creating this plan. This method includes control measures selection and the resulting improvement plan. Our team then tailored it for use in Cartago by creating a scale to rank each possible control measure to decide on the needed improvements.

A tool, consisting of a spreadsheet and instruction document, was created to expedite the CWSP application process. Its purpose was to regulate the utilization of the CWSP. It also provided a medium to store all of the data collected during a system evaluation.

We sought continued feedback from the project sponsor on all aspects of the CWSP. This feedback helped refine the CWSP. It furthermore helped make the CWSP more specific to the needs of Costa Rican water supply management.

3.3. Implement the CWSP on a Small System

The CWSP was applied to the Ladrillera spring system as a case study. This small spring system is similar to other water supply systems to which the sponsor intends to apply the CWSP. It allowed our team to test and revise the CWSP. The following section describes the methods used to apply the CWSP.

Our team began to apply the CWSP to the Ladrillera spring water system by describing the system. The description was based on the annual water supply description report. We took notes and photographs during tours of the Ladrillera spring system to aid in the system description. Furthermore, our team administered the survey created with the CWSP (see Appendix B). This survey requested information regarding consumer water use, payment for water service, and water service satisfaction. The survey was administered door-to-door with the assistance of Cartago engineers. The surveys were completed from each area served by a different line of distribution. These areas can be seen in the distribution map shown in Appendix F. Enough surveys were needed to discover new risks and the opinions of consumers who were discontent with the system. These objectives could be completed without having a good statistical approximation of the entire population.

Risks and control measures were identified while describing the water system. System documentation, such as water quality tests and maintenance records, provided sources of additional risks. We consolidated this information into the CWSP and created graphs to analyze the data. For undocumented risks, such as earthquakes and flooding, our team consulted the Cartago engineers to decide whether or not they were applicable to the system. Using the same process, information was also found regarding the control measures currently in place.

With the help of Cartago engineers, we used the rubric from the CWSP to assess each risk. Consumers' perceptions and risk ratings were incorporated to prioritize the risks. For each prioritized risk, our team researched potential control measures. For each control measure identified, our team gathered information about the cost, efficacy, time to implement, and potential for adding new risks. We used the ranking system provided by the CWSP to assign scores to the potential control measures. The control measures to be recommended for implementation were then selected based on the resulting score. These recommendations, along with recommendations on CWSP implementation, constitute the Ladrillera spring water supply system improvement plan.

3.4. Anticipated Obstacles

Before beginning the project, our team predicted potential problems which might impede its progress. It was important to understand what obstacles might arise so that plans could be made to circumvent them. Our team identified the language barrier, lack of technical background, and access to engineers as the main obstacles.

Of the members of the team, only one spoke Spanish competently. This was foreseen to be an issue because the sponsor and other contacts only spoke Spanish. Communication with these people would need to be handled by a single team member. This meant that any misunderstanding would not be able to be checked by the other members. Due to the technical language nature of the project, this language barrier was expected to cause more difficulty. Our team would need to work with technical vocabulary that may be unknown to many native speakers without a technical background. To solve this problem, we sought constant feedback from the sponsors to ensure our understanding was correct. It also proved useful to compare the Spanish and English versions of the WSP manual. This guaranteed the use of accurate terminology in Spanish.

Another anticipated problem was our lack of technical background in water systems. While conducting background research helped to alleviate this problem, the team still lacked knowledge in key areas. One task that needed to be accomplished for the system description was to create a distribution map. This is traditionally done through software such as AutoCAD Civil. Since we lacked experience using this software, creating the map had to be done by using less technically sophisticated tools. Lack of technical background was most detrimental when creating the improvement plan. To accomplish this, our team needed to research possible solutions for identified risks and select the best ones to recommend. Understanding the advantages and disadvantages of each solution was difficult without having an in-depth understanding of the area. This was solved by frequently consulting Cartago engineers. Also, our team planned to focus on honing the CWSP and to provide only a general improvement plan. Engineers with the appropriate knowledge could explore the details and make use of the CWSP for comparing options.

Consulting Cartago engineers helped provide explanations to technical problems, however it also exposed a new problem. Cartago engineers were often not available for questioning. During the project, there was a holiday week during which the engineers were not available at all. To overcome this problem, our team needed to plan its meetings with the engineers carefully to ensure all of its questions were answered.

4. Results and Findings

4.1. Data Collection

4.1.1 Water supply system management

The Technical Aqueducts Department of the municipality of Cartago manages thirteen spring water supply systems. Both fixed and measured water service fees collected from consumers allow the municipality to maintain these systems. A portion of water service fees pays for environmental education and reforestation programs such as the World Water Day celebration. The Technical Aqueducts Department consists of mostly engineers whose job it is to ensure the continuity of water service across the various systems. Engineers monitor tank levels in larger systems, such as the Río Loro spring system, in real-time with telemetry. Smaller systems, such as the Ladrillera spring system, only receive brief checks a few times per week. In addition to active maintenance, the Technical Aqueducts Department maintains documents for each system.

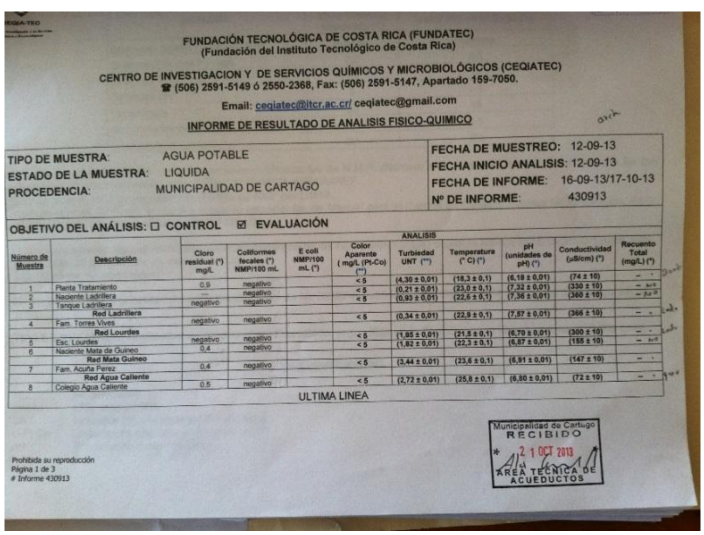
The Technical Aqueducts Department has a system description, risk assessment, and water quality test data forms for each system. Ana Patrica Guzmán updates the system description and risk assessment forms for each system annually. The system description for Ladrillera, included in Appendix G, provides the location, a simple diagram, some important descriptive facts, and photographs. The engineers were lacking a physical distribution network map for the Ladrillera spring system. The three risk assessment forms (included in Appendices H, I and J) guide engineers through a simple system inspection. The inspection entails a series of questions which prompt the inspector to check for faults in the system. These are faults that can be immediately noted and acted upon. The water quality data also serves to identify potential hazards.

The Technical Aqueducts Department oversees the execution of three water quality tests. The most frequent test is an uncertified residual chlorine test. The next most frequent test covers parameters of the first priority level. The least frequent test covers second and third level priority parameters. Tests for each priority are identified in Appendix A. A contractor, either Miguel Bertozzi or Cristian Pérez Ríos, conducts a residual chlorine test three times a week for the Ladrillera spring as a part of maintenance of the chlorination system. The contractor takes a sample of water before it reaches the second tank at the test location shown in Figure 5. He measures the residual chlorine with the chloroscope shown in Figure 6. The contractor prepares a brief report weekly, shown in Appendix K, of the last residual chlorine test conducted for each system after having regulated the chlorine dose. The reported residual chlorine test is conducted at the destination, the Urbanización Nazareth in the case of Ladrillera spring. Every year, the contractors and Ana Patricia Guzmán separately compile the weekly reports into two spreadsheets containing the same information.

Figure 5: Ladrillera spring system test location

Figure 6: Chloroscope used by Miguel Bertozzi to check residual chlorine during maintenance

The Microbiological and Chemical Research and Service Center (CEQIATEC) at the Fundación del Tecnológico de Costa Rica (FUNDATEC) conducts residual chlorine, fecal coliform, and "Level 1" tests every five weeks for the Ladrillera spring. The municipality of Cartago presents these certified test results to AYA to demonstrate sufficient drinking-water quality. The results, shown in Figure 7, are stored in physical form because they must be official. They are later scanned and uploaded. The municipality of Cartago tracks the occurrence of positive microbiological tests in a spreadsheet. The results of the residual chlorine and "Level 1" tests, however, are only available in physical or scanned form.



FUNDACIÓN TECNOLÓGICA DE COSTA RICA (FUNDATEC)
(Fundación del Instituto Tecnológico de Costa Rica)

CENTRO DE INVESTIGACION Y DE SERVICIOS QUÍMICOS Y MICROBIOLÓGICOS (CEQIATEC)
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INFORME DE RESULTADO DE ANALISIS FISICO-QUIMICO

TIPO DE MUESTRA: AGUA POTABLE
ESTADO DE LA MUESTRA: LIQUIDA
PROCEDENCIA: MUNICIPALIDAD DE CARTAGO

FECHA DE MUESTREO: 12-09-13
FECHA INICIO ANALISIS: 12-09-13
FECHA DE INFORME: 16-09-13/17-10-13
Nº DE INFORME: 430913

OBJETIVO DEL ANÁLISIS: ☐ CONTROL ☑ EVALUACIÓN

Número de Muestra	Descripción	ANALISIS Cloro residual (*) mg/L	Coliformes fecales (*) NMP/100 mL	E coli NMP/100 mL (*)	Color Aparente (mg/L (Pt-Co) (**)	Turbiedad UNT (**)	Temperatura (° C) (*)	pH (unidades de pH) (*)	Conductividad (µS/cm) (*)	Recuento Total (mg/L) (*)
1	Planta Tratamiento	0,9	negativo		< 5	(4,30 ± 0,01)	(18,3 ± 0,1)	(6,18 ± 0,01)	(74 ± 10)	–
2	Naciente Ladrillera	—	negativo		< 5	(0,21 ± 0,01)	(23,0 ± 0,1)	(7,32 ± 0,01)	(330 ± 10)	–
3	Tanque Ladrillera	negativo	negativo		< 5	(0,93 ± 0,01)	(22,6 ± 0,1)	(7,36 ± 0,01)	(360 ± 10)	–
	Red Ladrillera									
4	Fam. Torres Vives	negativo	negativo		< 5	(0,34 ± 0,01)	(22,9 ± 0,1)	(7,57 ± 0,01)	(366 ± 10)	–
	Red Lourdes									
5	Esc. Lourdes	negativo	negativo		< 5	(1,85 ± 0,01)	(21,5 ± 0,1)	(6,70 ± 0,01)	(300 ± 10)	–
6	Naciente Mata de Guineo	0,4	negativo		< 5	(1,82 ± 0,01)	(22,3 ± 0,1)	(6,87 ± 0,01)	(155 ± 10)	–
	Red Mata Guineo									
7	Fam. Acuña Perez	0,4	negativo		< 5	(3,44 ± 0,01)	(23,6 ± 0,1)	(6,91 ± 0,01)	(147 ± 10)	–
	Red Agua Caliente									
8	Colegio Agua Caliente	0,5	negativo		< 5	(2,72 ± 0,01)	(25,8 ± 0,1)	(6,80 ± 0,01)	(72 ± 10)	–

ULTIMA LINEA

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Informe 430913

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Figure 7: Results of residual chlorine, fecal coli form, and "Level 1" tests conducted by CEQIATEC

CEQIATEC conducts “Level 2” and “Level 3” tests once per year for each system. These physical-chemical and pesticide tests are required by AYA. Pesticide tests are not required if there is no agricultural activity threatening the water source. Physical-chemical tests cost $383 and pesticide tests cost $249. These costs make frequent implementation difficult for the municipality. Engineers store this information in a spreadsheet for each water supply system.

4.1.2. Water supply systems

The thirteen spring water supply systems vary in source characteristics, technological sophistication, and population supplied. The springs produce water from 1 L/s to 115 L/s. Each system disinfects its water by means of chlorine gas, sodium hypochlorite, or calcium hypochlorite tablets. The larger systems disinfect the water using chlorine gas injection, such as the Regal system in place at the Rio Loro spring; it is shown in Figure 8 (Regal, 2007). Smaller systems, such as the Ladrillera spring, drip sodium hypochlorite directly into the spring catchment. Figure 9 shows the disinfectant dripping mechanism in place at the Ladrillera spring. Some large systems add calcium hypochlorite tablets to the catchment storage tanks in order to disinfect water for early distribution line connections. All systems transport water by means of gravity except for the Mata Guineo spring system which uses a pump.

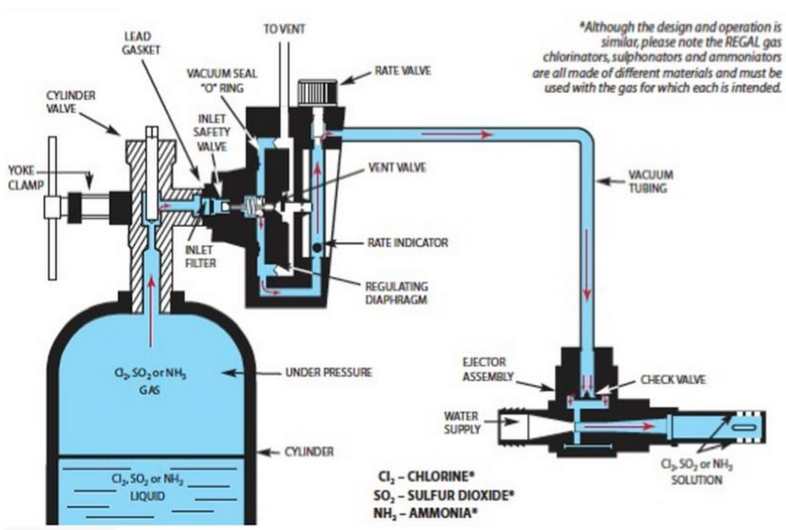

Figure 8: Regal chlorine gas injection system (Regal 2007)

Figure 9: Ladrillera spring sodium hypochlorite disinfection system

4.1.3. Consumer survey

Our team collected 38 survey responses from consumers of the Ladrillera spring. The surveys provided information about the consumers' perception of the water service and helped to identify point-of-use problems. Ana Patricia Guzmán accompanied two team members during response collection. The survey was conducted in three rounds.

During the first round, our team visited the brick factory located north of the Ladrillera spring as shown in Figure 10. The brick factory manager presented workers who receive water from the Ladrillera spring for surveying. The survey was administered using the following steps: reciting the oral consent form (Appendix E), orally administering the survey, and marking each response on individually printed copies of the survey. Since residents often provided additional commentary, one person took notes. We also visited the north end of "Zone 1" as indicated on the map. While conducting the survey in town, our team walked house to house calling the attention of residents. Four responses at the brick factory and two responses in the north end of "Zone 1" were collected. During the second round, the team visited "Zone 1" and "Zone 2". We conducted sixteen more surveys between both zones. During the third round, our team conducted ten surveys in "Zone 3" and five surveys in "Zone 4". We marked the locations of surveyed residents for the last round of surveys.

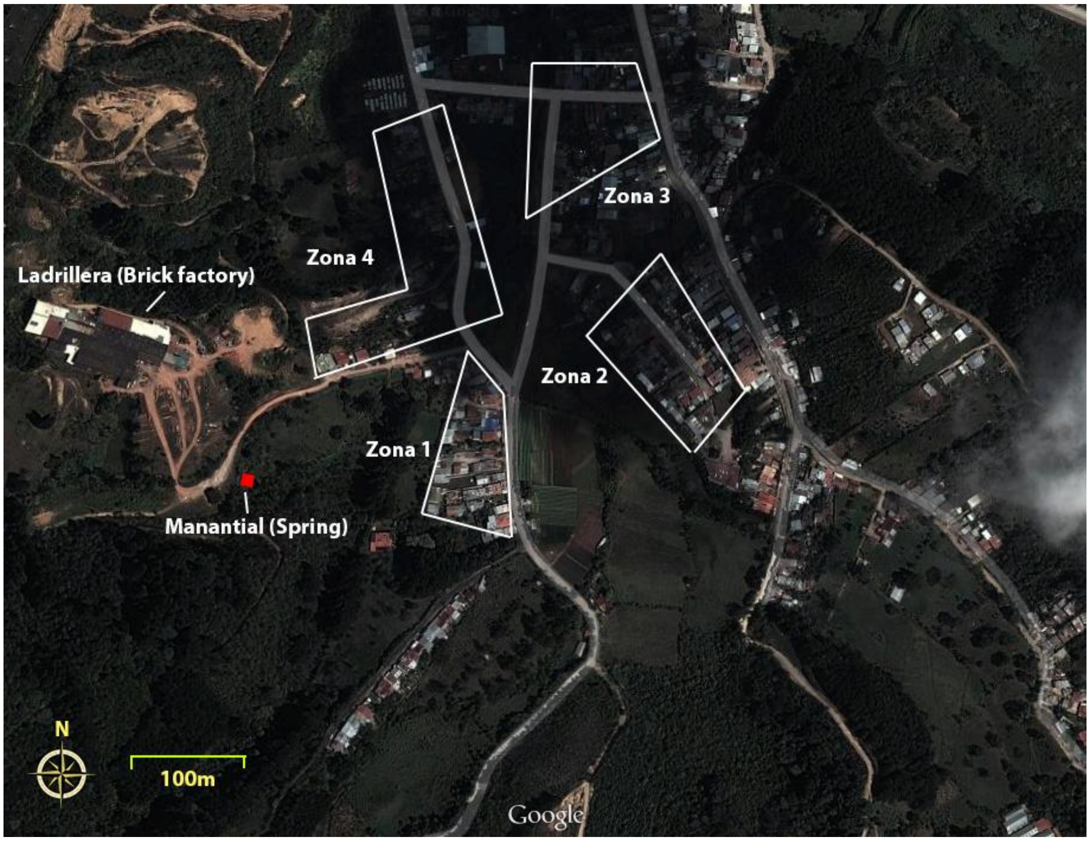

Figure 10: Map of region of Lourdes supplied water by the Ladrillera spring (courtesy of Google Maps, 2014)

In addition to the survey responses summarized in Figure 10, our team made observations about the interviewed residents and noted their commentary. The appearance of houses and number of residents per household of interviewed residents indicated that residents varied from low to middle class income levels. In addition, when asked about their water conserving habits, residents were able to give many examples such as fixing leaks, using dirty water to water plants, and taking advantage of rainwater cleaning. All residents indicated that they would be interested in learning more about water conservation. As indicated by the level of satisfaction and desired improvements graphs in Figure 11 and Figure 17, consumers did not hesitate to voice their complaints. They did so in a very civilized, level-headed manner. Residents complained about dirty water, yellow, brown or black water, water containing a virus, garbage, mud, or contamination, heavily chlorinated water, and water that smelled of like swamp water. These are issues that caused residents to doubt their water's potability (Figure 13, Figure 15), and some resorted to additional disinfection (Figure 12). Some residents also experience water service cuts and shortages as indicated by Figure 14. Most were willing to pay for improvements to their water supply, as seen in Figure 16. The full results of the survey can be found on the "Consumer Perception" page of the CWSP spreadsheet.

The 38 responses collected only represents nineteen percent of the households supplied by the Ladrillera spring. Although the results are not representative of the whole population, the nature of the data collected allowed for the identification of risks present in the system. The incidents reported were either isolated or representative of larger problems in the system. Problems may be local to a single household, local to one side of a particular pipeline, local to a single zone, or apply to the system as a whole. For instance, in the case of "Zone 4," all five residents complained about a lack of water and explained that all houses in the area were experiencing the same issues. Although five of the approximately twenty residencies would not be considered a full representation, one may reasonably conclude that there is problem local to the pipeline supplying water to "Zone 4."

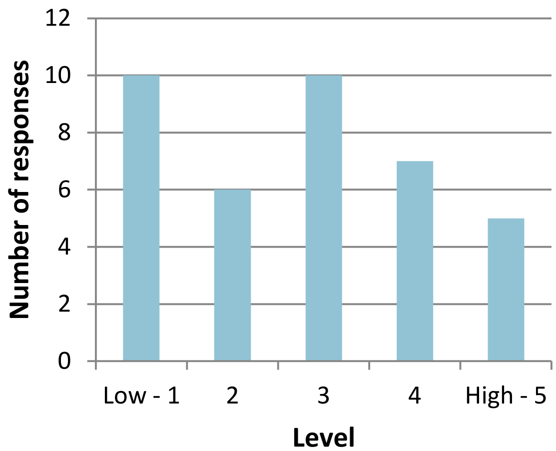

Figure 11 - Consumer satisfaction levels

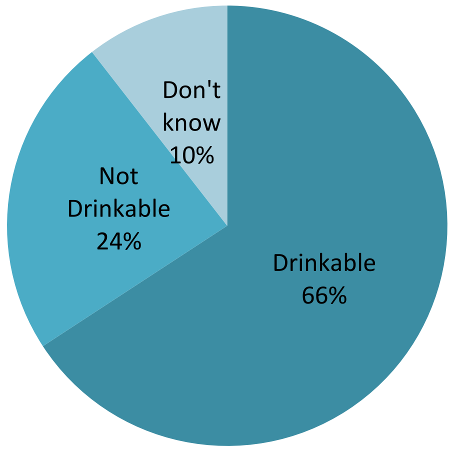

Figure 13 – Consumer perception of drinkability

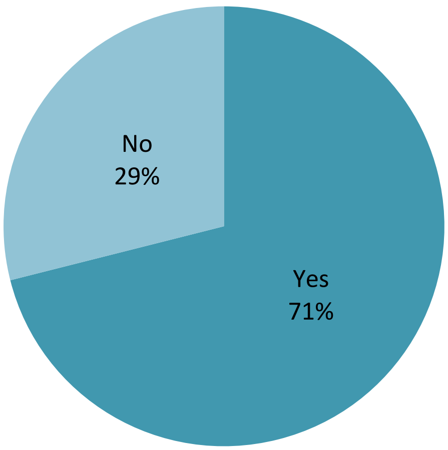

Figure 12 - Consumer responses to if they boil, filter, or clean water

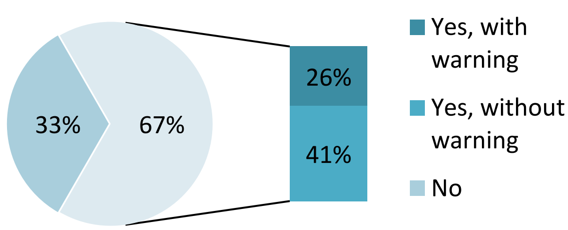

Figure 14 – Consumers that reported water outages

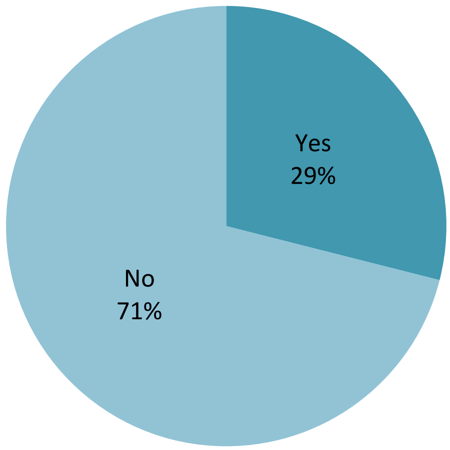

Figure 15 – Consumers that have ever fallen ill due to the water

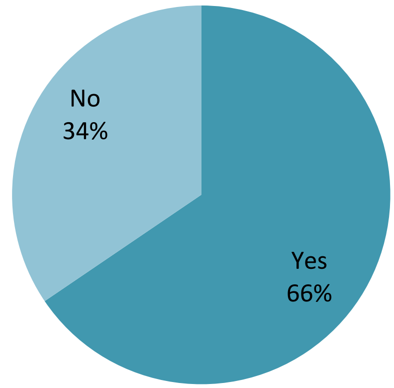

Figure 16 – Consumers' response to if they would pay more for improvements

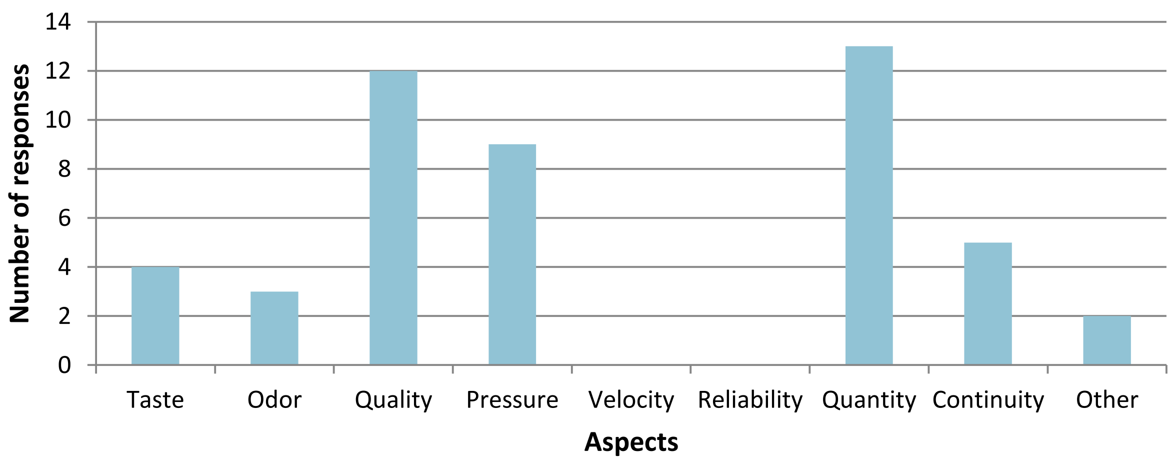

Figure 17 – Water supply features that consumers would like to see improved

4.2. Development of the CWSP tool

After consolidating all of the research, our team decided to create a new plan based on the Water Safety Plans for use in Cartago. Research suggested that a major issue in Cartago was a lack of a standardized way to manage and improve its systems. This new plan, called the Cartago Water Safety Plans (CWSP), would offer a solution by providing a personalized methodology for use in Cartago and surrounding areas. It included a tool which consisted of two components: a dynamic Excel spreadsheet (Appendix D) and an accompanying guide (Appendix E). Our team decided to create the spreadsheet in order to accommodate forms and risk assessment tools. Additionally, the spreadsheets allows for implementation of dynamic features such as formulas, data visualization, and macros. These dynamic features make the CWSP flexible so that it can be applied to multiple systems.

The first step in creating the CWSP was to determine all of the necessary requirements and limitations of the spreadsheet. The CWSP needed to be useful for documenting, managing, and conducting risk assessments for water supply systems. It had to reflect the steps in the Water Safety Plans while catering to the needs of Cartago. The limitations of the tool's scope also had to be determined from previous research. We designed the CWSP to be applicable to Cartago water supply systems that are fed by groundwater sources. Water supply systems in Cartago are similar in size and are located in virtually identical environments. This scope was designed to allow the CWSP to remain comprehensive while still being specialized. Groundwater was chosen as the only source because including surface water results in a large amount of additional factors that have to be accounted for. Only considering groundwater prevents the tool from being overloaded and disorganized with an excess of content. Once the spreadsheet was created, our team produced a step by step guide instructing the user how to use it in order to evaluate a water supply system. The guide standardizes the implementation of the spreadsheet.

The CWSP was organized into four categories that best met the determined requirements. As outlined in the WSP, they were a water supply description, risk identification, risk assessment, and an improvement plan. Each tool and distinct group of data was given its own page in the spreadsheet. Hyperlinks to each page of the spreadsheet allow the user to navigate between pages easily. Since the municipality of Cartago requested that the CWSP unify all parts of the water supply management system, this aesthetically appealing and organized interface is an important feature. As the sections were created, they were simultaneously tested on the Ladrillera spring system. The application of the sections ensured their effectiveness and helped identify additional content or features.

4.2.1. Description

The description section was created using the second module of the WSP as a guide. Our findings indicated that general information, system diagrams, a distribution map, and consumer perceptions of the system are required for a thorough description. The purpose of this section is to facilitate the identification of risks faced by the system.

The general information page includes administrative information and simple descriptive facts. This page also requests that the user provide a link to a geological study. The WSP manual notes that it may prove challenging to obtain detailed information about the water source, however it is an important resource. It is useful for identifying the water source's vulnerabilities as a part of the risk assessment. This information and the information pertaining to the use of the surrounding land allows for the easy identification of hazards.

A set of system description questions was included in this section. Questions were taken from existing documentation provided by the municipality of Cartago. These questions covered topics such as treatment practices and system components. Consulting engineers in Cartago allowed us to ensure that the questions sufficiently describe the Cartago water supply systems.

The system diagram page is used to store all diagrams of the system. The diagram, shown in Figure 18, allows for visualization of the system without actually viewing it in person. Our team decided to include this content because it allows any CWSP user to gain an understanding of how the system is put together. The WSP manual recommends creating a system flowchart, but a more detailed diagram is appropriate for the simple spring systems managed in Cartago. Smaller systems are generally simpler and can be completely mapped out with system diagrams similar to the one shown below.

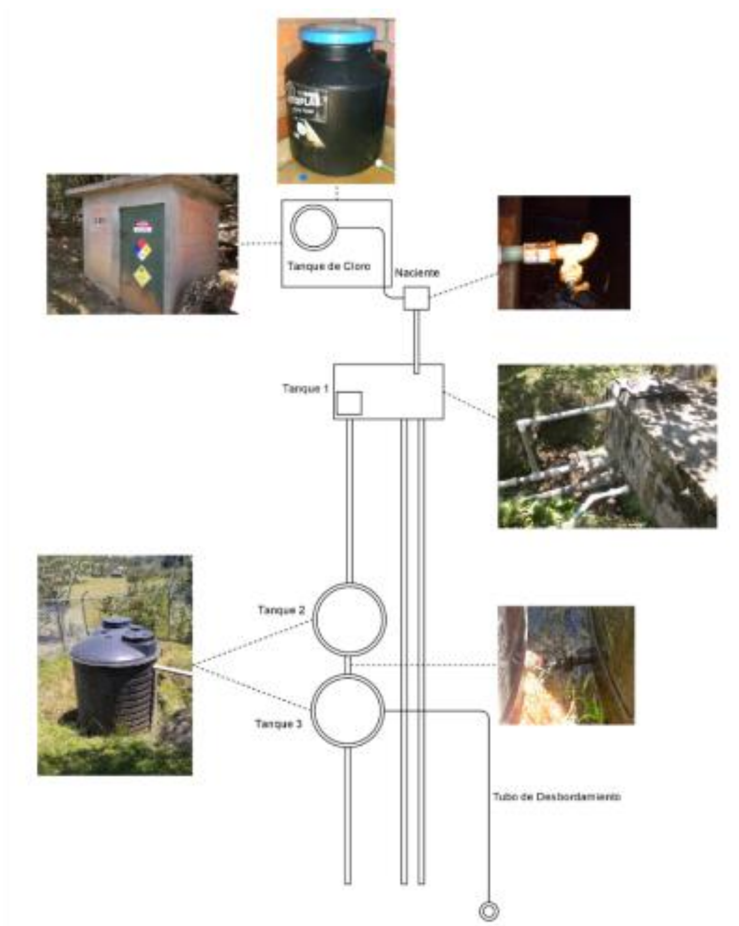

Figure 18: Example water supply system diagram

The distribution map page houses a record of the pipeline which delivers water to the consumer. Although not originally included in the CWSP, our team determined that a distribution map is an indispensable resource. This decision was made as we were attempting to apply the CWSP to the Ladrillera spring system. Engineers cannot effectively localize problems or maintain the system without an accurate distribution map. The example included in the CWSP guide is a satellite photograph of Lourdes taken from Google Maps overlaid with lines which represent different pipelines, shown also in Figure 19. Most systems in Cartago already have distribution maps. The CWP provides a location for them to be stored along with all other description data.

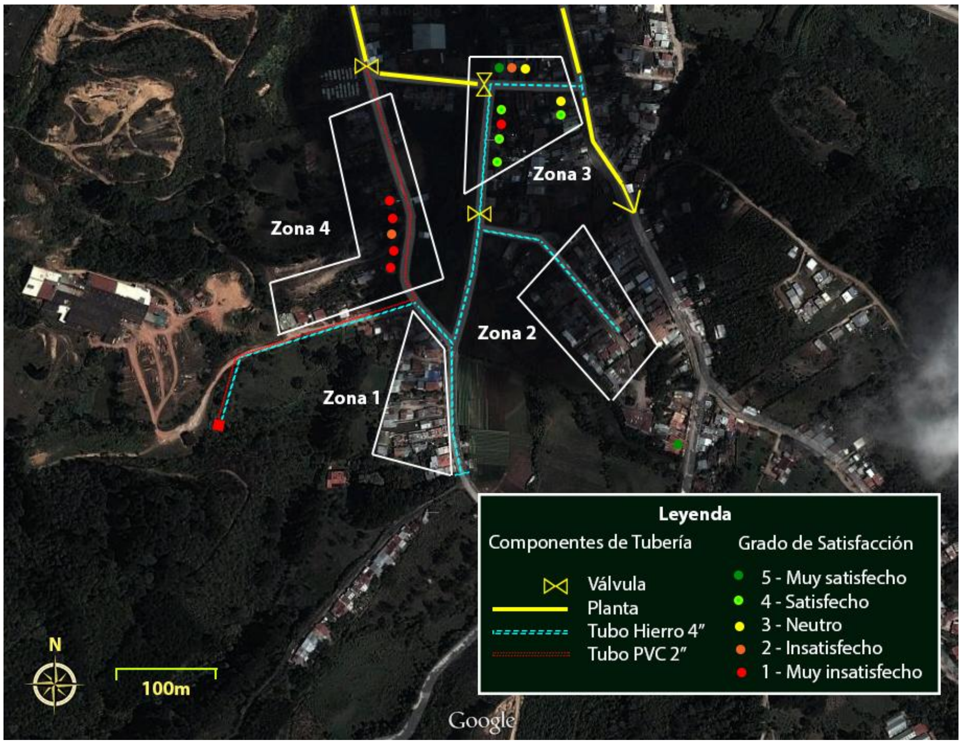

Figure 19: Distribution and consumer satisfaction map for the town of Lourdes

The consumer perception page presents the results of our consumer survey. The CWSP survey is needed in order to identify and localize risks in the system as a whole. Plotting the locations of surveyed residents on a map with satisfaction level indicators, shown in the map above, can help engineers find trends when trying to isolate problems in the distribution network. With a complete description of the water supply system, the next step in the CWSP is risk identification.

4.2.2. Risk Identification

The Risk Identification section contains a system inspection checklist and three pages addressing water quality tests. The system inspection checklist was adopted from the municipality of Cartago's system inspection documentation. This checklist facilitates the risk identification process by walking the user through each stage of the water supply system. Examples of checks include system vulnerability, security, component integrity, presence of hazardous objects, and lack of documentation.

The first water quality test page lists tests relevant for water supply systems as well as information on testing locations, parameter levels, and test priority. The tests can also be organized to further accommodate a specific system by having irrelevant tests at the bottom. Values for the recommended parameter levels, level limits, and test priority levels were taken directly from COMCURE.

The next two water quality test pages focus on water quality data recorded by the municipality of Cartago. The first sheet provides a location to record the annual tests administered in Cartago. This sheet is personalized for use in Cartago because the only tests listed reflect the parameters that apply to Cartago water supply systems. Our team found that a specific test, residual chlorine, was tested much more often than the others at the Ladrillera spring system. To accommodate this, a second sheet was created for the weekly results.

Research indicated that engineers in Cartago desired the ability to visualize water quality trends over time. The next page in the spreadsheet has a graphical display of data along with lines indicating parameter limits. The test results can be compared via two graph areas that allow for a side-by-side comparison. The user can toggle which tests are displayed using drop down menus above the graph areas.

4.2.3. Risk Assessment

The Risk Assessment section contains six pages used to conduct a risk assessment. Each of the first five pages corresponds to a different stage of the water supply. These stages are source, treatment, storage, distribution, and destination. These stages apply to every groundwater supply system in Cartago. The last page is used for prioritizing the risks assessed in the previous five pages.

The risk assessment tables were adapted from the WSP manual. The first three columns of these tables suggest hazards that may impact any given water supply system. This hazard list was determined originally through a combination of referencing the WSP and by brainstorming. The hazard list was then further refined by consulting engineers from the municipality of Cartago. To allow the tables flexibility, we inserted checkboxes that hide irrelevant hazards. The remaining hazards are classified by type (physical, chemical, or biological) and are presented alongside their associated risks. The next two columns present a space for the user to take into account existing control measures during the risk assessment. Any control measures already in place should be listed so that the user can its effectiveness. One column provides space to identify the control measure and the other provides space to validate the control or elaborate on the status of the control measure.

The WSP manual instructed users to assess risks and control measures separately. This process was complex and counter-intuitive for small systems. Our team combined the two stages. Risks are assessed while considering the present state of the control measures. The five remaining columns of the Risk Assessment tables focus on assigning a quantitative risk score to each hazard, as outlined in the WSP. The columns provide space for a likelihood score, severity score, risk score, risk rating, and basis. Likelihood is the frequency or probability of a hazardous event. Severity is the impact of the hazardous event on the public health. Our team ranked these two attributes using a table provided by the WSP manual, shown in Figure 20. The ranks of these two attributes are multiplied together to yield the risk score. Risks with scores from "1" to "5" receive a "Low", from "6" to "9" receive a "Medium", from "10" to "15" receive a "High", and above "15 receive a "Very high" risk rating. In the basis column, the user briefly explains the assigned scores. This process is carried out for every stage of the system.

		Severity or consequence				
		Insignificant or no impact - Rating: 1	Minor compliance impact - Rating: 2	Moderate aesthetic impact - Rating: 3	Major regulatory impact - Rating: 4	Catastrophic public health impact - Rating: 5
Likelihood or frequency	Almost certain / Once a day - Rating: 5	5	10	15	20	25
	Likely / Once a week - Rating: 4	4	8	12	16	20
	Moderate / Once a month - Rating: 3	3	6	9	12	15
	Unlikely / Once a year - Rating: 2	2	4	6	8	10
	Rare / Once every 5 years - Rating: 1	1	2	3	4	5

Risk score	<6	6-9	10-15	>15
Risk rating	Low	Medium	High	Very high

Figure 20: Risk assessment guideline (Bartram et al., 2009)

Any risk rated medium or higher appears on the risk prioritization page. This page compiles these highly rated risks into a single table. A combination of risk score and consumer value is used to prioritize each risk. The survey data is analyzed to determine what characteristics consumers find important. Some example characteristics are quality, quantity, pressure, and taste. The ranked characteristics are compared to the risk score to determine the final risk prioritization order. Each risk is then given a relative priority score where "1" corresponds to the risk of the highest priority.

4.2.4. Improvement Plan

The final section of the CWSP spreadsheet helps the user create an improvement plan. The CWSP spreadsheet uses two steps to create an improvement plan: control measure selection and progress management. For control measure selection, the user is provided with tables to list possible control measures for each risk. These tables were designed with the influence of information found in the WSP. The tables prompt users to determine each potential control measure's cost, efficacy, time to implement, and probability of introducing new risks. Our team created a scale to rank each criterion, shown in Figure 21. The sum of these criteria scores determines the overall score of the potential control measure. This entire process was designed as a general and standardized way to rank potential control measures in any system.

The potential control measure with the highest overall score is selected for implementation. Selected control measures are then assigned projected completion times and statuses on the improvement plan page. This page should be updated as the improvements are implemented. It is the responsibility of the engineers to develop and implement a specific solution which fulfills the general suggestions provided by the improvement plan.

		Worst	Scale		Best
		1	2	3	4
Criteria	Cost	Too expensive to implement	Large capital investment	Fair capital investment	No capital investment
	Time to implement	Too long to implement	Significant amount of time to implement	Fair amount of time to implement	Little or no time to implement
	Efficacy	Will not reduce the severity of the problem	Will slightly reduce the severity of the problem	Will significantly reduce the severity of the problem	Will completely solve the problem
	Chance of introducing new risk	Will undoubtedly introduce new risks	Will introduce new risks with high certainty	May introduce new risks	Will not introduce new risks

Figure 21 - Control measure criteria rating scale

4.2.5. Summary

The CWSP tool provides the ability to carry out the Water Safety Plans for any system in Cartago. It was designed to specifically cater to the needs of systems in Cartago. It is able to describe and identify risks to the system. In addition, it includes a rubric that presents a standardized method to evaluate the risk of each hazard. It also incorporates a method for selecting control measures for high priority risks, which culminates in an improvement plan for the respective system. The finalized CWSP addresses the needs of both the municipality of Cartago and COMCURE. It allows for the unification of water supply system documentation and for the execution of systematic risk assessment.

4.3. Evaluation of the CWSP

An additional goal of our team was to evaluate the CWSP tool. To accomplish this, we applied our tool to the Ladrillera spring water supply system. Its application allowed us to test key attributes and gain insight into its advantages and limitations. This section will describe what we learned from this evaluation.

4.3.1. Testing Key Attributes

We were interested in testing three attributes of the CWSP: usefulness, completeness, and usability. The CWSP would be useful if it helped the municipality of Cartago and COMCURE identify and assess risks in small water systems. Additional usefulness would be gained if the CWSP could help develop an improvement plan. Testing the CWSP was also vital to determining its completeness. By assessing Ladrillera, our team was able to determine if more or less information was needed to be included in the tool. Finally, the CWSP was tested in order to gauge its usability. The CWSP provided value to COMCURE and the municipality of Cartago by being convenient and easy to use. Any difficult to use features or counterintuitive processes needed to be identified and fixed.

After applying the CWSP to Ladrillera, our team concluded that the CWSP was useful. Firstly, the CWSP was able to organize important information about the spring from multiple documents. The surveys were particularly useful because they called attention to problems, such as frequent water outages, that engineers working on the system had not previously identified. Secondly, by working with these engineers, our team was also able to easily identify which risks were relevant to the system and validate the control measures in place. In addition, the CWSP process made ratings and prioritizations of the risks consistent and straightforward. This in turn made the creation of an improvement plan clear and easy as well.

In the process of applying the CWSP, our team was able to identify multiple forms of content to be added to the tool. For instance, the description documents provided by the municipality of Cartago did not include a distribution map showing which of the pipes delivered water to which parts of the town. While preparing to interview residents, our team realized that having a distribution map would be useful for deciding on locations to conduct surveys. With the map, our team was able to choose locations and analyze data based on which distribution line served the area. The consumer satisfaction scatterplot, shown in Appendix F, allowed for the localization of problems in the distribution network. Additional risks were also added to the collection of previously identified potential risks. While conducting surveys, we noticed areas where the water distribution pipes were exposed. This resulted in the introduction of a new set of risks we had not previously considered. All of these risks were added to the CWSP.

Application of the CWSP helped determine which parts could improve in terms of usability. The risk and control measure identification and assessment tools taken from the WSP manual required risks and control measures to be considered separately. Our team found the process could be streamlined and made more user-friendly by combining the tools. Considering both the risks and the control measures at the same time also made the risk assessment step easier and more intuitive. Usability was also negatively affected by having too many macros. While the addition of macros helped automate the risk assessment process, it unfortunately introduced lag into the tool. Switching between certain sections of the CWSP became slow due to processing time of the macros. In addition, the macros inhibited the flexibility of the tool. Adding additional content, such as new risks or new types of water quality data, became difficult. In order for the tool to work correctly, the user would need to copy the macros for the already existing content and edit them for the additional content.

4.3.2. Advantages and Limitations of the CWSP

In addition to learning about the key attributes of the CWSP, our team was interested in exploring its advantages and limitations. Once the application of the CWSP to the Ladrillera system was complete, our team reflected on the process and determined its overall suitability. This section will describe those findings.

Our team discovered multiple advantages to using the CWSP. The first is that the user requires very little technical knowledge about water systems. Our team, with no previous experience of assessing water systems, was able to easily apply the CWSP to the Ladrillera system and create an improvement plan. Other users with little experience would need only to consult existing documentation and ask the engineers for the required information. Additional research would be needed to create an improvement plan; however, the user would have a clear idea of where improvements are needed.

The CWSP also has the advantage of being widely applicable. Our tool was created with the goal of being able to assess multiple water systems. While we did not have sufficient time to apply the CWSP to more than one system, the resources used are consistent with other systems in Cartago. Additional tests are necessary to prove that the CWSP is applicable outside of Cartago. We believe that the flexibility designed into the CWSP would allow it to be easily adjusted for any discrepancies found during those tests.

Another advantage of the CWSP is that it is standardized. Along with the system assessment tool, the CWSP includes a step by step guide for carrying out the process. By following the guide, users can repeat the assessment on Ladrillera and achieve similar results. Alternatively, they can apply the tool to another water system and achieve results that can then be easily compared to other systems assessed with the CWSP.

Finally, the CWSP is easy to use, navigate, and maintain. New information was obtained from engineers after having previously completed a step in the CWSP process. Adding this information was trivial due to the organizational structure. It was readily apparent where each distinct piece of information should be placed, or can be retrieved if needed. The cover page, shown in Figure 22, was especially helpful in this regard. As a result of its flexibility to locate and add data, we found the CWSP tool very easy to maintain. This is an important aspect because if a user decides to use it as his/her central document, the CWSP has the potential to be updated many times and by a variety of different users. Ease of maintenance will help ensure the integrity of the document as it is updated.

Figure 22 : Cover page showing the graphical user interface for the CWSP

Unfortunately, our team also discovered limitations of the CWSP while testing it. For instance, our team provided a list of possible risks based on review of the WSP manual. During testing, however, new risks were discovered. Despite the addition of those new risks, the CWSP still does not contain a comprehensive list of risks. For example, the risks in the source section are limited to groundwater, making it ineffective for surface water systems. While the user may add new risks if they find them, having different collections of risks for different instances of the CWSP compromises the standardization of the tool. In addition, users of the CWSP may miss important risks if they are not identified within the CWSP, leading to an incomplete assessment.

Another limitation was in the system description process. While the CWSP description stage encompasses all of the materials used by the municipality of Cartago, it may not include all of the materials used by other municipalities. If these missing materials involve only the general description of the system, they can be easily added. If they are new figures or schematics, however, the user would need to add new pages to the CWSP. Unfortunately, this requires significant additional work and formatting because there is no automated process to creating new pages.

Additional features that might improve usability were identified, but due to time constraints could not be implemented. One such feature involves a more streamlined process for adding risks. Macros currently carry information about risks from one page to another. If the user adds a new risk, a new macro will need to be written to carry the information forward. The alternative to adding a macro is manual entry. Our team found that having versions of the distribution map or schematic with different levels of detail could be helpful. Moreover, it would be desirable to add a feature that makes viewing different versions of the map or schematic user-friendly. Such a feature could resemble the water quality graph selector.

The final identified limitation was the water quality data entry. The CWSP currently requires the user to enter all such data by hand. This introduces the risk of transcription errors. Transcription errors could affect the analysis of the water quality trends and lead to incorrect risk identification. Solving this limitation while maintaining generality and flexibility is difficult, but it is not impossible. A script could be created to interpret different organizations of data and automatically move the data to the CWSP. Implementation of such a script, however, was beyond scope of our research.

5. Conclusion and Recommendations

5.1. Conclusion

The CWSP provided a standardized way to carry out a water supply system evaluation in Cartago. The Water Safety Plans served as the initial inspiration for the plans. They were then refined to suit the needs of COMCURE and the municipality of Cartago. Background research allowed our team to recognize the specific requirements that had to be met. The municipality of Cartago lacked a uniform method of creating improvement plans for systems. Moreover, there was not a centralized system to store certain information, such as water quality test results. In addition, survey data indicated that, of a small sample, consumers were generally unhappy with their water supply. They doubted the potability of the water and complained about water shortages. The CWSP was created to address these issues.

Our team created a tool to facilitate CWSP implementation, which consisted of a spreadsheet and an instruction document. The spreadsheet allows users to carry out a system evaluation as outlined in the WSP. The procedure includes a description, risk identification, risk assessment, and a resulting improvement plan. The instruction document provided a method to standardize this process. The spreadsheet was further enhanced with macros that expedited the CWSP. These macros allow users to focus on describing and assessing the system.

Applying the CWSP to the Ladrillera system allowed our team to test its capabilities and limitations. Through this case study we found that it fulfills the goals of our project. It successfully guides the users through the Water Safety Plans and generates a list of suggested improvements. It also provides a systematic method for carrying out the evaluation. However, the application also revealed the limitations of the plan: the presence of macros makes the spreadsheet difficult to adjust. Any additional information that is added during a CWSP application has to be entered manually during each stage. Although the CWSP provides a system for maintaining documentation and conducting risk assessment, it is up to the user to further customize it.

5.2. Recommendations for the Ladrillera Spring Water Supply System

Applying the CWSP to the Ladrillera water supply system allowed our team to draft an improvement plan based on identified risks. The improvement plan addressed risks based on the physical system, consumers, and managerial practices. The highest priority risks to the physical system appeared in the water storage, where water is highly susceptible to either being wasted or contaminated. New piping, filters, and more frequent cleaning were found to be the most appropriate control measures that would mitigate these risks. Our team suggested additional control measures, including water pumps and more frequent chlorine monitoring. We identified a lack of communication between consumers and the municipality of Cartago. Many issues in the system were known in the town but were not reported and thus not fixed. This suggests the need for a streamlined method of communicating and documenting complaints. Finally, our team found that improving managerial practices would help minimize risks to the system. More thorough recordkeeping of water quality tests will help engineers monitor the state of the system. Furthermore, creating a centralized location for documentation will help improve efficiency and minimize error for the municipality of Cartago. Our team provided the sponsors with a full improvement plan (see Appendix F)

5.3. Recommendations for CWSP Implementation

Our team recommends implementation of the CWSP on a regular basis. It will improve the water supply systems as well as enable effective management. Annual or bi-annual implementation is recommended. This regularity will ensure that high priority risks are properly controlled. Regularly implementing the CWSP allows for examination of newly available or discovered control measures. The CWSP will also unify all miscellaneous documentation. Unifying documentation under the CWSP will promote efficiency, make work on water systems easier, and make errors less likely. Another important reason to implement the CWSP is to standardize system evaluation and improvement. One issue the municipality has encountered is incomplete documentation. Many chemical tests, such as residual chlorine, occur but are not documented. The CWSP will help with proper chemical test documentation.

When implementing the CWSP on other water systems, our team recommends that the user first review the provided documentation. This documentation includes the CWSP guide (Appendix E) and a set of accompanying videos. It is recommended that the user consults the completed CWSP for Ladrillera as an example.

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Appendix A: Water Quality Assessment Tools

This appendix shows all chemicals tested (Figure A1 and Figure A1) for water systems along the Reventazón River Basin. It is taken from Paola Vidal Rivera's publication (Vidal, 2013). Tests are grouped by chemical type.

CUADRO 1. PARÁMETROS DE CALIDAD DEL AGUA
- PRIMER NIVEL DE CONTROL - N1

Parámetro	Unidad	Valor Recomendado	Valor Máximo Admisible
Coliforme fecal	NMP/100 mL o UFC/100 mL	Ausente	Ausente
Escherichia coli[a]	NMP/100 mL o UFC/100 mL	Ausente	Ausente
Color aparente	mg/L (U - Pt-Co)	5	15 [b]
Turbiedad	UNT	<1	5 [b]
Olor	--	Debe ser aceptable	Debe ser aceptable
Sabor	--	Debe ser aceptable	Debe ser aceptable
Temperatura	°C	18	30
pH[c]	Valor pH	6,5	8,5
Conductividad	µS/cm	400	
Cloro Residual Libre	mg/L	0,3	0,6
Cloro Residual Combinado	mg/L	1,0	1,8

CUADRO 2. PARÁMETROS DE CALIDAD DEL AGUA
- SEGUNDO NIVEL DE CONTROL - N2

Parámetro	Unidad	Valor Recomendado	Valor Máximo Admisible
Dureza Total	mg/L $CaCO_3$	400	500
Cloruro	mg/L Cl^-	25	250
Fluoruro	mg/L F^-		0,7 a 1,5 *
Nitrato	mg/L NO_3^-	25	50
Sulfato	mg/L SO_4^{-2}	25	250
Aluminio	mg/L Al^{+3}	0,2	
Calcio	mg/L Ca^{+2}	100	
Magnesio	mg/L Mg^{+2}	30	50
Sodio	mg/L Na^+	25	200
Potasio	mg/L K^+		10
Hierro	mg/L Fe		0,3
Manganeso	mg/L Mn	0,1	0,5
Zinc	mg/L Zn		3,0
Cobre	mg/L Cu	1,0	2,0
Plomo	mg/L Pb		0,01

CUADRO 3. PARÁMETROS DE CALIDAD DEL AGUA
-TERCER NIVEL DE CONTROL- N3

Parámetro	Unidad	Valor Recomendado	Valor Máximo Admisible
Nitrito	mg/L NO_2^-		0,1 o 3,0 *
Amonio	mg/L NH_4^+	0,05	0,5
Arsénico	mg/L As		0,01
Cadmio	mg/L Cd		0,003
Cromo	mg/L Cr		0,05
Mercurio	mg/L Hg		0,001
Niquel	mg/L Ni		0,02
Antimonio	mg/L Sb		0,005
Selenio	mg/L Se		0,01

CUADRO 4. PARÁMETROS DE CALIDAD PARA RESIDUOS DE PLAGUICIDAS
-TERCER NIVEL DE CONTROL- N3

Parámetro Ingrediente activo ISO, BSI, ANSI	Nombre Químico IUPAC	Valor Máximo Admisible µg/L
Alachlor	2–cloro-2,6-dietil–N-(metoximetil)acetanilida	20
Aldicarb	2–metil–2–(metiltio)propionaldehído-O-(metilcarbamoil) oxima.	10
Aldrin/dieldrin	(1R,4S,4aS,5S,8R,8aR)–1,2,3,4,10,10–hexacloro–1,4,4a,5,8,8a–hexahidro–1,4:5,8–dimetanonaftaleno.	0,03
Atrazine	6-cloro-N²-etil-N4-isopropil-1,3,5-triazina-2,4-diamina.	2
Bentazone	3-isopropil-1H-2,1,3-benzotiadiazin-4(3H)-ona-2,2-dióxido.	300
Carbofuran	2,3–dihidro-2,2–dimetil–7–benzofuranil-metil-carbamato.	7
Chlordane	1,2,4,5,6,7,8,8-octacloro-2,3,3*,4,7,7a-hexahidro-4,7-metanoindeno.	0,2
2,4-D	Ácido–2,4–diclorofenoxiacético.	30
2,4-DB	Ácido–4–(2,4–diclorofenoxi)butírico.	90
DDTs	Dicloro–difenil–tricloroetano.	2
Dibromocloropropano	1,2–dibromo–3–cloropropano.	1
Dichloropropene	1,3–dicloropropeno.	20
Dichlorprop	Ácido (RS)–2–(2,4–diclorofenoxi)propiónico.	100
Heptachlor + epoxide	1,4,5,6,7,8,8–heptacloro-3a,4,7,7a-tetrahidro-4,7-metanoindeno.	0,03
Isoproturon	3–(4–isopropilfenil)–N',N'-dimetilurea	9
Lindane	Isómero gama de 1,2,3,4,5,6-hexacloro–ciclohexano	2
MCPA	Ácido (4–cloro–2–metilfenoxi)acético.	2
Mecroprop	Ácido (RS)–2–(4–cloro–2–metilfenoxi)propiónico.	10
Methoxychlor	2,2–bis(p–metoxifenil)-1,1,1–tricloroetano.	20
Metolachlor	2–cloro–N–(2–etil–6–metilfenil)–N–(2–metoxi–1–metiletil) acetamida.	10
Molinate	S–etil hexahidro–1H–azepina–1–carbiotiota	6
PCP	Pentaclorofenol	9
Pendiméthaline	N–(1–etilpropil)–3,4-dimetil–2,6–dinitobenzamina.	20
Permethrin	3–fenoxibenzil (1RS)–cis, trans–3–(2,2–diclorovinil)– 2,2 dimetilciclopropanocarboxilato.	20
Propanil	N–(3,4–diclorofenil)propionamida.	20
Pyridate	O–(6–cloro–3–fenil–4–piridazin) S–octil carbone tiota.	100
Simazine	2–cloro–4,6–bis(etilamino)–s–triazina.	2
2,4,5-T	Ácido–2,4,5–triclorofenoxi–acético.	9
Trifluraline	α,α,α–Trifluoro–2,6–dinitro–N,N–dipropil–p–toluidina.	20

* Corresponde a la suma de todos los isómeros.

Figure A1: Recommended values and limits for Level 1, 2, 3 water quality parameters

CUADRO 5 PARÁMETROS DE CALIDAD PARA SUSTANCIAS ORGÁNICAS DE SIGNIFICADO PARA LA SALUD, EXCEPTO PLAGUICIDAS PARA EL CUARTO NIVEL: N4

Parámetro		Valor Máximo Admisible, µg/L
Alcanos Clorados		
	Tetracloruro de carbono	2
	Diclorometano	20
	1,2-dicloroetano	30
	1,1,1-tricloroetano	2000
Etenos Clorados		
	Cloruro de Vinilo	5
	1,1-dicloroeteno	30
	1,2-dicloroeteno	50
	Tricloroeteno	70
	Tetracloroeteno	40
Hidrocarburos Aromáticos		
	Tolueno	700
	Xilenos	500
	Etilbenceno	300
	Estireno	20
	Benzo-alfa-pireno	0,7
Bencenos Clorados		
	Monoclorobenceno	300
	1,2-diclorobenceno	1000
	1,4-diclorobenceno	300
	Triclorobencenos	20
Otros Compuestos Orgánicos		
	di (2-etilhexil) adipato	80
	di (2-etilhexil) ftalato	8
	Acrilamida	0,5
	Epiclorohidrino	0,4
	Hexaclorobutadieno	0,5
	EDTA	200
	Acido nitriloacético	200
	Oxido de tributilestaño	2
	Hidrocarburos policíclicos aromáticos totales	0,2
	Bifenilos policlorados totales	0,5

CUADRO 6. PARÁMETROS DE CALIDAD DEL AGUA - CUARTO NIVEL - N4

Parámetro	Unidad	Valor Recomendado	Valor Máximo Admisible
Sólidos totales disueltos	mg/L		1000
Amonio	mg/L $NH4^+$	0,05	0,5
Sulfuro de Hidrógeno	mg/L H_2S		0,05

CUADRO 7. PARÁMETROS PARA DESINFECTANTES Y SUBPRODUCTOS DE LA DESINFECCIÓN PARA EL CUARTO NIVEL: N4

Parámetro		Valor Máxim Admisible, µg
Desinfectantes		
	Monocloramina	4000
Subproductos de la desinfección		
	Bromato	25
	Clorito	200
a- Clorofenoles		
	2,4,6-triclorofenol	200
	Formaldehido	900
b- Trihalometanos		
	Bromoformo	100
	Dibromoclorometano	100
	Bromodiclorometano	60
	Cloroformo	200
c- Ácidos Acético Clorados		
	Ác. Dicloroacético	50
	ác. Tricloroacético	100
	tricloracetaldehido/cloralhidrato	100
d- Haloacetonitrilos		
	Dicloroacetonitrilo	90
	Dibromoacetonitrilo	100
	Tricloroacetonitrilo	11
e- Cloruro de cianógeno (como CN-)		70

Figure A2: Recommended values and limits for Level 4 parameters

Appendix B: Residential Survey

This appendix contains the residential survey originally created and administered by our team. Questions pertain to overall quality of the service, conservation habits, and water uses.

21/4/2014 Servicio de Agua en Lourdes - Google Forms

Servicio de Agua en Lourdes

Descargo de responsabilidad: No publicaciones o informes de este proyecto incluirán información identificación sobre cualquier participante sin el consentimiento firmado, y la revisión de los participantes de los materiales. Esta encuesta es totalmente voluntaria.

Información General

1. **¿Cual es el número que corresponde con la casa de la persona encuestada?**

____

2. **¿Cuantas personas habitan la casa?**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10
⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭

3. **¿Cuántos grifos tiene?**
Mark only one oval.

0	1	2	3	4	5
⬭	⬭	⬭	⬭	⬭	⬭

4. **¿Cuántos baños tiene?**
Mark only one oval.

0	1	2	3	4	5
⬭	⬭	⬭	⬭	⬭	⬭

5. **¿Cuántos duchas tiene?**
Mark only one oval.

0	1	2	3	4	5
⬭	⬭	⬭	⬭	⬭	⬭

https://docs.google.com/forms/d/16ZW4olljPqt4MD1hpW1Pr3TqZ8ARfh5-M3knDTZP_hA/edit 1/6

6. **¿Tiene medidor de agua?**
Mark only one oval.
   - Sí
   - No

7. **¿Paga una tarifa fija?**
Mark only one oval.
   - Sí
   - No

8. **¿Está interesado en instalar un medidor de agua?**
Mark only one oval.
   - Sí
   - No

Uso de Agua

9. **¿Para qué usa el agua de tubo?**
Check all that apply.
   - Beber
   - Lavar la comida
   - Bañar
   - Lavar la ropa
   - Lavar los platos
   - Fregar
   - Regar las plantas
   - Dar agua a la mascota
   - Other: ____________________

10. **¿Utiliza alguna fuente de agua alterna?**
Mark only one oval.
   - Sí
   - No

11. **Si respondió "Sí"... ¿Cuáles son los usos?**

12. **Si respondió "Sí"... ¿Por qué no usa agua del grifo?**

Servicio de Agua

13. **¿Cuál es su grado de satisfacción con su servicio de agua potable?**
Mark only one oval.

	1	2	3	4	5	
Más bajo	◯	◯	◯	◯	◯	Más alto

14. **¿Cree usted que el agua del grifo es potable?**
Mark only one oval.

- ◯ Sí
- ◯ No
- ◯ No se

15. **¿Por qué?**

16. **¿Siente la necesidad de hervir, filtrar o limpiar el agua de alguna forma?**
Mark only one oval.

- ◯ Sí
- ◯ No

17. **¿Por qué?**

____

____

____

____

____

18. **¿Alguna vez se ha enfermado debido al agua del tubo?**
Mark only one oval.

- ◯ Sí
- ◯ No

19. **¿Hay cortes de suministro de agua?**
Mark only one oval.

- ◯ Sí
- ◯ No

20. **¿Hay alguna advertencia antes de que ocurran?**
Mark only one oval.

- ◯ Sí
- ◯ No

21. **¿Por cuanto tiempo duran los cortes de suministro de agua?**
Check all that apply.

- ☐ Media hora
- ☐ Una hora
- ☐ Dos horas
- ☐ Cuatro horas
- ☐ Mitad del día
- ☐ Todo el día
- ☐ Unos cuantos días
- ☐ Una semana

22. **¿Alguna vez ha almacenado agua del grifo por cualquier motivo?**
Mark only one oval.

- ⬭ Sí
- ⬭ No

23. **¿Toma precauciones para almacenar el agua?**
Mark only one oval.

- ⬭ Sí
- ⬭ No

24. **¿Cuales son?**

____

____

____

____

____

25. **¿Que hábitos tiene usted que le ayuda ahorrar el agua habitan la casa?**
Check all that apply.

- ☐ Cerrar el tubo mientras jabonar los manos
- ☐ Cerrar el tubo mientras cepillar los dientes
- ☐ Cerrar el tubo mientras lavar los platos
- ☐ No dejar que gotean los tubos
- ☐ Regar plantas con lluvia
- ☐ Other: ____

26. **¿Está interesado en aprender a conservar el agua?**
Mark only one oval.

- ⬭ Sí
- ⬭ No

27. **¿Mejoraría su servicio de agua?**

Check all that apply.

- [ ] Sabor
- [ ] Olor
- [ ] Calidad
- [ ] Presión
- [ ] Velocidad
- [ ] Fiabilidad
- [ ] Cantidad
- [ ] Continuidad
- [ ] Other: ____________________

28. **¿Pagaría más para hacer estas mejoras?**

Mark only one oval.

- ( ) Sí
- ( ) No

Appendix C: Oral Consent Form

This is the oral consent form administered before each residential survey.

"Good morning. We want to invite you to participate in a survey. We are students working with the municipality of Cartago to improve the water supplied to Lourdes. We are interested in learning about how people use their water and about people's opinions of the water. We are doing this voluntary survey to gather this information. Participation is voluntary. The survey will take approximately 15 minutes to complete. We will not publish individual responses. We will not reveal your name or address. The survey is completely voluntary, and you are free to skip any questions. Would you like to help us?"

Appendix D: Excel Spreadsheet

This is the English version of the Excel spreadsheet portion of the Cartago Water Safety Plan (CWSP). The only pages omitted are treatment, storage, distribution, and destination. This is due to the fact that they are very similar to the source page. The only differences in those pages are the hazards and rankings, the format does not change.

Cover Page

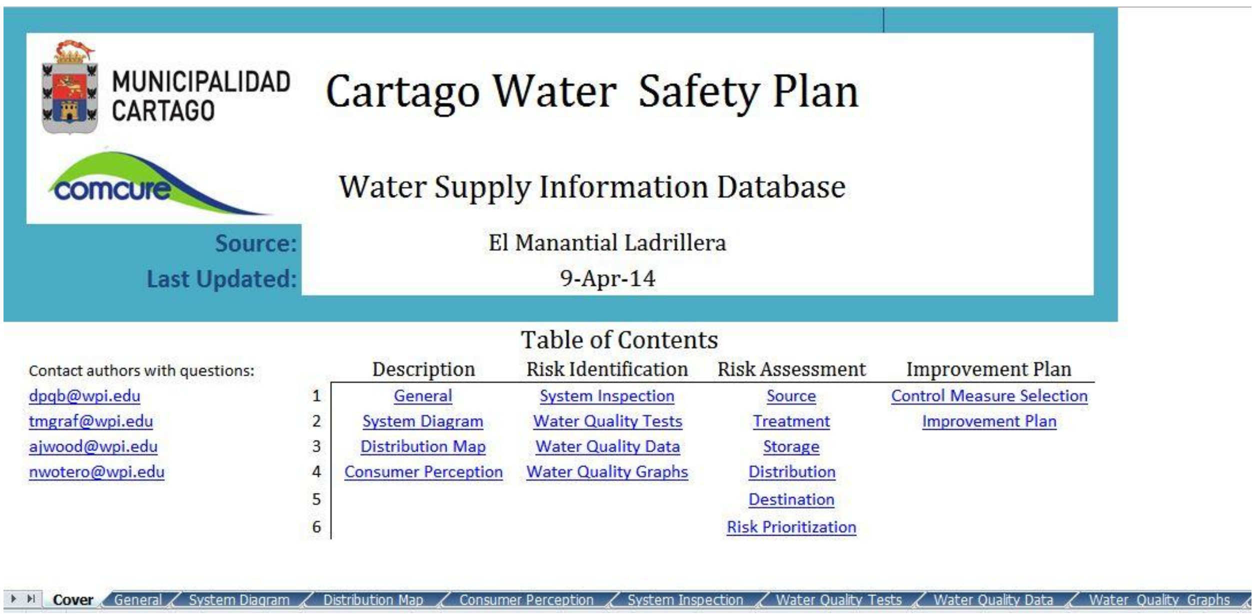


Figure D1: The CWSP cover page

The cover page displays information on the water system as well as the organization of the CWSP. Each section under the table of contents contains a set of links that can be used to navigate throughout the document.

General

Water Supply Description:		General	
Cover		Prev	Next
	General Information		
		Last updated:	4/21/2014
Name of Aqueduct:	Municipalidad de Cartago		
Name of Source:	Naciente Ladrillera		
Location:	Hoja Topográfica Tapantí		
City:	Lourdes		
District:	Aguacaliente		
Province:	Cartago		
Coordinates:	200.852/546.093		
Elevation:		m	
Years in Operation:			
Administrator:	Municipalidad de Cartago	2550-4612	
Manager:	Ing. Julio Urbina Rojas	2550-4612	
Property Owner:	La Ladrillera		
Property Area:		m^2	
	Water Source		
Source Type:	Spring		
Catchment Type:	Drainage		
Flow Rate:	3	l/s	
Location:			
Elevation:			
Accessibility:	Bueno		
Caja de Reunión:	Sí		
Uses of surrounding land:	Agriculture ☑	Roads and Railways ☐	
	Industry ☑	Wildlife ☐	Development ☐
Geological Study:	Caracterización y modelo hidrogeológico		
	Treatment		
Treatment Chemical:	NaClO		
Chemical State:	Liquid		
Concentration:	1	percent	
Treatment Dose:	1	mg	
Treatment Rate:	18	ml/min	
Average Contact Time:		min	
Chemical Storage:	Tank	400 l	
Delivery Method:	2" Pipe		
	Storage		
Number of Tanks:	3		
Materials:	Concrete, plastic		
Elevations:		m	
Total Tank Volume:	10	m^3	

Figure D2: The CWSP general description page

System Inspection

Risk Identification: System Inspection

Cover

General

Regularity:	Annually	
Responsible Party:	Ana Guzmán apguzmanm@yahoo.com	

Water Source

#	Question	Yes / No	Comments:
1	Is the catchment perimeter unsecure?	N	
2	Is the source unprotected against contamination?	N	
3	Is the catchment damaged?	N	
4	Is the catchment exposed?	N	
5	Is the catchment lid corroded?	S	
6	Is the catchment locked?	S	
7	Can water accumulate on top of the catchment	N	
8	Does the catchment have a flood drain system	N	
9	Are there plants, roots, sediment, leaves, or algae inside the catchment?	N	
10	Are the drain and cleaning pipelines lacking a grating?		
11	Is there a nearby contamination source within 20 meters?	N	

Figure D3: The CWSP system inspection page

Water Quality Tests

Water Quality Tests

Cover

Parameter	Location	Recommended Level	Limit	Priority	Testing Frequency
Color		5 mg/L	15 mg/L	1	Annually
Combined				1	Never
Conductivity		400 µs/cm		1	Annually
E. Coli		None	None	1	Never
Fecal Coliform		None	None	1	Never
Flavor		Must be acceptable	Must be acceptable	1	Annually
Free Residual Chlorine		0.3 mg/L	0.6 mg/L	1	Never
pH		6.5	8.5	1	Annually
Residual Chlorine		1.0 mg/L	1.8 mg/L	1	Never
Smell		Must be acceptable	Must be acceptable	1	Never
Temperature		18 °C	30 °C	1	Annually
Turbidity		<1	5	1	Annually
Aluminum		0.2 mg/L		2	Annually
Calcium		100 mg/L		2	Annually
Chlorides		25 mg/L	250 mg/L	2	Annually
Copper		1 mg/L	2 mg/L	2	Never
Flouride			0.7-1.5 mg/L	2	Annually
Hardness		400 mg/L ($CaCO_3$)	500 mg/L (CaCO3)	2	Annually
Iron			0.3 mg/L	2	Annually
Lead			0.01 mg/L	2	Annually
Magnesium		30 mg/L	50 mg/L	2	Annually
Manganese		0.1 mg/L	0.5 mg/L	2	Annually
Nitrates		25 mg/L	50 mg/L	2	Annually
Potassium			10 mg/L	2	Never
Sodium		25 mg/L	200 mg/L	2	Annually
Sulfates		25 mg/L	250 mg/L	2	Annually
Zinc			3 mg/L	2	Annually
1,2-dibromo-3,3-chloropropane			1 µg/L	3	Never
1,2-dichloropropane			20 µg/L	3	Never
1,3-dichloropropane			20 µg/L	3	Never
2,4,5-T			9 µg/L	3	Never
2,4-D			30 µg/L	3	Never
2,4-DB			90 µg/L	3	Never
Alachlor			20 µg/L	3	Never
Aldicarb			10 µg/L	3	Never

Figure D4: The CWSP water quality test page

Water Quality Data

Year	Conductividad- 400	pH- 6.5-8.5	Turbiedad- 5	Color aparente- 15	Temperatura- 18-30	Sulfatos- 250	Fluoruros- 0.7-1.5	Sólidos totales disueltos -1000	Dureza total- 400
11/30/1998	319	7.3	0.1	0	19	8.8	0.14	245	158.4
8/21/2000	329	6.84	0.1	0	20.7	7.8	0.63	229	179.4
9/3/2001	306	7.57	0.3	0	23.8	12.3	0.17	237	175
5/5/2003	361	7.18	0.1	0	23	10	0.98	220	153
5/3/2004	355	6.99	0.45	0	23	7.2	0.099	243	176
10/4/2005	198	7.11	0.03	0	20	7	0.18	375	170.7
11/20/2006	282	7.15	0.27	0	21.2	6	0.12	239	11.12
4/23/2007	320	7.19	0	0	22.4	5	0.06	295	63.7
8/18/2008	330	6.76	0.22	0	22.7	3.09	0.01		168.23
4/20/2009	320	6.75	0	0	22.4	8.64	0.045		130.69
3/8/2010	330	6.97	0.05	0	24.3	3.1	0.045		162.9
3/14/2011	340	7.65	0.18	5	21	16.9	0.093		38.8
3/12/2012	317	7.19	0.99	5	21.5	34.6	0.06		98.13
6/24/2013	100	6.9	0.6	5	22.7	11.5	0.05		170.08

Figure D5: The CWSP water quality data page

The cell turns red if the value falls outside of the acceptable range.

Water Quality Graphs

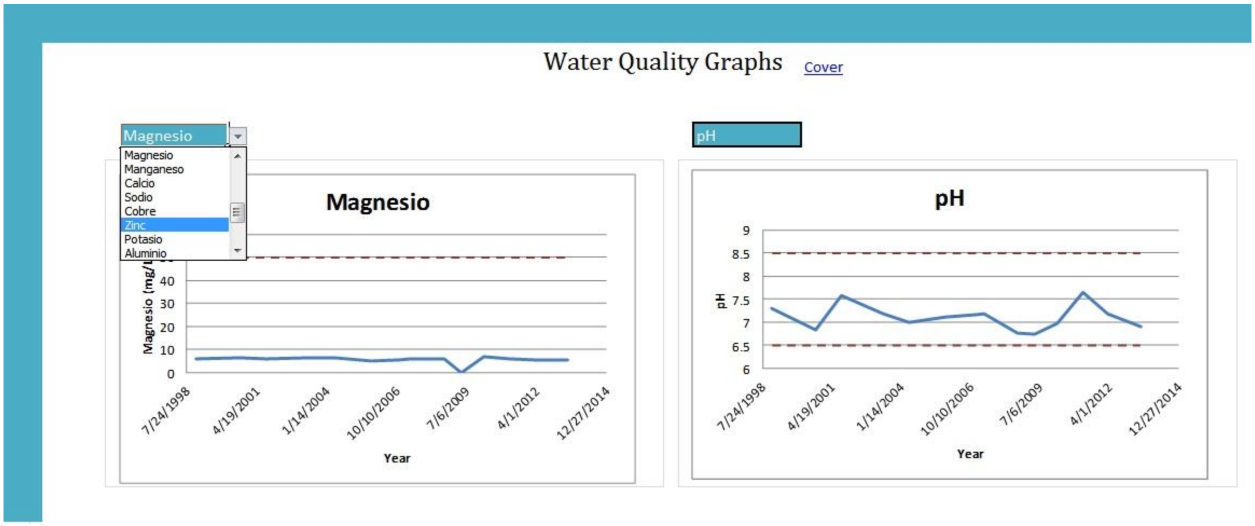


Figure D6: The CWSP water quality graphs

The graphs display the water quality data along with acceptable parameter values. Different graphs can be selected from the drop down menu.

Risk Assessment

Risk Assessment: Source — Prev | Cover | Next

Source of Hazard	Associated hazards (and issues to consider)	Type of Hazard	Current Control Measures	Validation of Control Measures	Likelihood or Frequency	Severity or Consequence	Risk Score	Risk Rating	Basis
Heavy Rain	Flooding, rapid changes in source water quality	Physical	None		2	1	2	LOW	There is no chance of flooding. Heavy rain is not likely to cause issues. Source is not exposed.
Earthquakes	Objects inhibits water source System structure damaged	Physical	None		1	5	5	LOW	A severe earthquake has not affected Cartago in many years.
Agriculture	Agrochemicals Animal waste Dead animal disposal	Biological Chemical	**Find out if land is protected**		2	2	4	LOW	There is minimal cow waste in the area above the spring from passing cows.
Industry	Waste produced during production	Chemical	None		1	3	3	LOW	Brick factory is nearby, but any solid/liquid waste produced is unlikely to reach source.
Public Access/Crime	Chemicals / waste from recreational water use	Biological Chemical Physical	Fences and locked enclosures	Fences are only effective against wildlife, easy for humans to circumvent. Locks can be cut	1	3	3	LOW	Only someone with malicious intenet could contaminate the water system. Nothing to rob.
Unconfined Aquifer	Water quality subject to unexpected change	Chemical	None		1	3	3	LOW	Semi-confined aquifer/groundwater level does not surpass 8 meters of depth
Fires	Pollution resulting from combustion	Chemical	None		2	2	4	LOW	Fires can occur. They would not cause much contamination
Illegal Dumping	Contamination from runoff	Biological Chemical Physical	Fences	Fences are easy to circumvent.	1	3	3	LOW	People walk the trail.
Sediment	Natural blockage of source Sediment in system	Physical	None		5	1	5	LOW	Not enough to cause problems and does not accumulate

Figure D7: The CWSP source risk assessment page

Risk Prioritization

Risk Assessment: Prioritization Prev Cover Next

Source of Hazard	Hazard	Location	Risk Score	Risk Rating	Corresponding Characteristics	Priority
Unclean tanks	Contamination of water	Storage	15	HIGH	Quality, Taste, Odor	1
Improperly insulated tanks	Water leakage	Storage	10	HIGH	Quantity, Pressure	2
Sediment	Contamination of water Blockage of pipes	Storage	10	HIGH	Quality, Taste, Odor	3
Uncontrolled time spent in storage	Inadequate mixing time for treatment chemicals	Storage	9	MEDIUM	Quality, Taste, Odor	7
Disinfection process	Disinfection byproducts Inadequate disinfection Too much added chemicals	Treatment	9	MEDIUM	Quality, Taste, Odor	6
Pressure Fluctuations	Ingress of contamination	Distribution	6	MEDIUM	Quantity, Pressure	5
Intermittant Supply	Ingress of contamination	Distribution	6	MEDIUM	Quantity, Continuity	4
Exposed Pipes	Damaged pipes allow leaks or ingress of contaminants	Distribution	6	MEDIUM	Quantity, Pressure	8

Characteristic	Responses	%
Quantity	13	27.08%
Quality	12	25.00%
Pressure	9	18.75%
Continuity	5	10.42%
Taste	4	8.33%
Odor	3	6.25%
Other	2	4.17%
Velocity	0	0.00%
Reliability	0	0.00%

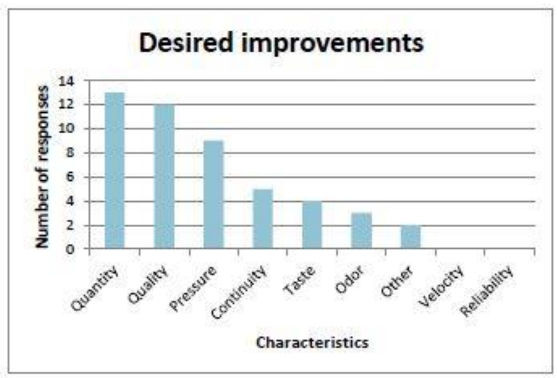


Figure D8: The CWSP risk prioritization page

Control Measure Selection

Improvement Plan: Control Measure Selection Prev Cover Next

Inadequate disinfection, Too much added chemicals

Options	Cost	Cost Score	Efficacy	Efficacy Score	Time to Implement	Time Score	Chance of introducing new risk	Risk Score	Final Score
Commercial automated chlorine injectin system	$7,300	2	Ensures proper amount of added chlorine for the flow rate of water	4	Maybe a month	3	Power failure will cause the system to stop proportioning chlorine correctly	1	10
Build an automated chlorine injection system	Flow rate sensor - $10 Electronic Valve - $9 Microcontroller - $20 Development - $?	3	A simple automated chlorine injector will improve the proportion of chlorine to water but may not be able to maintian the proportion exactly	3	An appreciable amount of time will need to be invested in designing the system, choosing parts, programming the controller, and installing the system	2	Power failure will cause the system to stop proportioning chlorine correctly(these arent likely risks so would it be higher?)	1	9
Require daily monitoring of chlorine levels	Additional man-hours - $?	3	Daily monitoring will help keep daily fluctuations under control but will not guarantee appropriate proportions of chlorine to water for the whole day	2	Can begin immediately	4	None (wouldn't if hes not there monitoring it and there are major flooding or something be a risk)(3?or 2)	4	13
									0
									0
							Chosen Option: Monitoring		

Improperly insulated tanks = water leakage

Options	Cost	Cost Score	Efficacy	Efficacy Score	Time to Implement	Time Score	Chance of introducing new risk	Risk Score	Final Score
Replace pipes	$20-40	3	Will fix the problem if done properly	4	Maybe will take half a day	4	None	4	15
Sealant	$5 for one tube	3	If pipes are not cracked/corroded, this is all that is needed. But most likely option 1 is needed	3	Maybe will take half a day	4	This method is more of a temporary fix. Problem will come back	2	12
									0
									0
									0
							Chosen Option: pipe replacement		

Figure D9: The CWSP control measure selection page

Improvement Plan

Improvement Plan: Prev Cover

Source of Hazard	Hazard	Location	Risk Score	Risk Rating	Priority	Action	Projected Time of Implementation	Status	Notes
Unclean tanks	Contamination of water	Storage	15	HIGH	1	Clean tanks more often			
Improperly insulated tanks	Water leakage	Storage	10	HIGH	2	Pipe replacement			
Sediment	Contamination of water Blockage of pipes	Storage	10	HIGH	3	Clean tanks more often and install filters			
Intermittant Supply	Ingress of contamination	Distribution	6	MEDIUM	4	Average pump			
Pressure Fluctuations	Ingress of contamination	Distribution	6	MEDIUM	5	Average pump			
Disinfection process	Disinfection byproducts Inadequate disinfection Too much added chemicals	Treatment	9	MEDIUM	6	Require daily monitoring of chlorine levels until injection system is purchased			
Uncontrolled time spent in storage	Inadequate mixing time for treatment chemicals	Storage	9	MEDIUM	7	Investigate contact time and solutions			
Exposed Pipes	Damaged pipes allow leaks or ingress of contaminants	Distribution	6	MEDIUM	8	Bury pipes underground			

Figure D10: The CWSP improvement plan page

Appendix E: Cartago Water Safety Plan Guide

This appendix contains the guide on how to use the CWSP spreadsheet. This is a comprehensive, step-by-step guide. Every section of the spreadsheet is covered and provides steps on how to implement each section.

E1. INTRODUCTION

The Cartago Water Safety Plan (CWSP) provides a standardized method for assessing, managing, and identifying improvements for water supply systems. The CWSP is based on the Water Safety Plans Manual distributed by the World Health Organization (WHO). The Water Safety Plans Manual uses the third edition of WHO's Guidelines for Drinking-water Quality to establish system requirements. The publication provides information regarding water quality, health, and approaches for water safety management. It also recommends a framework for applying the water safety plans to drinking water systems. The WSP manual serves as a guide for developing custom water safety plans.

The CWSP is intended for use by engineers to assess and monitor spring or well water supply systems. This document allows for the systematic consolidation of all information related to a water supply system. This document accompanies a comprehensive spreadsheet for storing all of this information. One copy of the spreadsheet will be maintained for each water supply system. This document will direct the user in populating the spreadsheet.

Each page of the CWSP spreadsheet contains information relating to the description, risk identification, risk assessment, or improvement plan for the system. The user can access each page from the spreadsheet's cover page. Alternatively, the user can navigate using hyperlinks found on each page. For the spreadsheet to be fully functional macros need to be enabled.

E2. DESCRIPTION OF THE SYSTEM

In order to complete the water supply description, the user will need collect both administrative and technical information. The user may need to conduct field tests in order to provide recent technical information. The user can begin by navigating to the "General" information page.

E2.1 General

This section contains general information pertaining to each component of the water supply system. The user should populate the fields requested. Under the "Uses of surrounding land" section the user should check all options that are relevant to the system.

The "General" section should contain a link to a geological survey of the water source and surrounding area. The purpose of this survey is to establish clear protection zones for the water source. These zones are determined through a combination of geological parameters, hydraulic parameters, and the land use around the water. A hyperlink to this document can be inserted using the following steps:

1. Store the geological study in the same folder as the CWSP*
2. In Excel, select Insert → Hyperlink
3. In the hyperlink menu select "Existing File or Web Page"
4. Navigate to the location of the survey and select it

*Note: The CWSP must be distributed with the full folder.

E2.2 System Diagram

The user should create some kind of system diagram that at least provides a qualitative description of the system. Ideally this diagram will lay out every component in its relative position in the system. This includes all piping and any additional connections. An example diagram is shown in Figure E1. This system diagram was completed using the online application draw.io which can be accessed and used for free at https://www.draw.io. The following are steps for creating system diagrams:

1. Navigate to https://www.draw.io.
2. Click "Device" to save diagrams to your local storage device.
3. Click "Create new diagram…"
4. Under "Filename:" enter a name for the diagram (Ex: "Ladrillera_diagrama.xml").
5. Click "Blank diagram" and click "Create".
6. One can click and hold on shapes from the shapes list on the left to drag them onto the page.

7. Shapes representing parts of the system can be connecting by lines
    a. Hovering over a shape with the cursor will reveal connection points which are each denoted by an “x”.
    b. Clicking and holding on an “x” and moving the cursor to another “x” on the same or another shape will connect the two shapes with lines.

8. The line properties can be changed by clicking  .
9. Pictures can be added by clicking Arrange -> Insert -> Insert Image.
10. A box will appear; images can be inserted via Google search, Google+, or your computer.
11. For images from your computer, hit Google+ -> Upload photos.

E2.3 Distribution Map

In this section the user should insert a map of the area that is serviced by the supply system. This map should clearly diagram the entire distribution network of the system, including all pipelines and supplied areas. Any additional important information should also be included in the map, such as scatter plots of survey data and elevation. An example of a simple distribution map and opinion scatter plot is shown below in Figure E2.

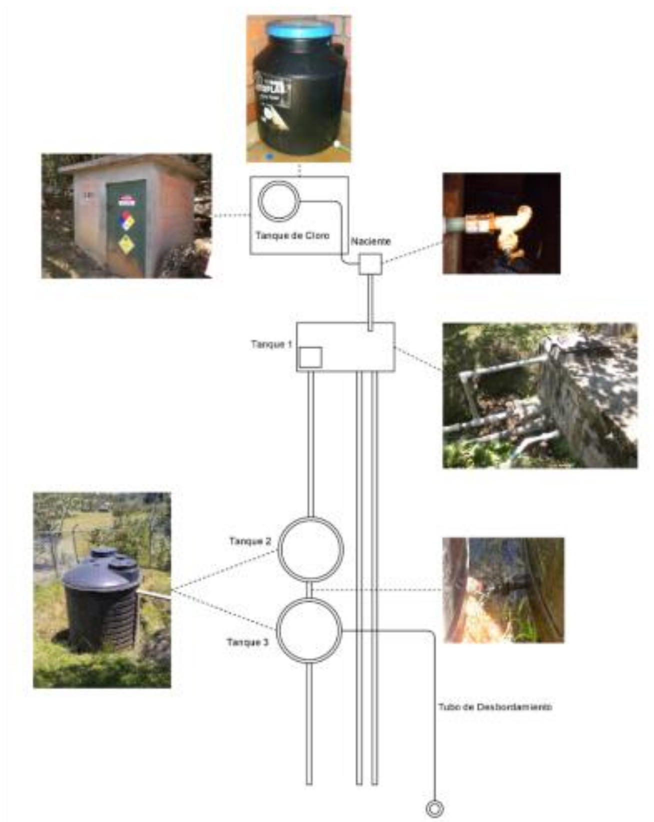


Figure E1: Ladrillera system diagram

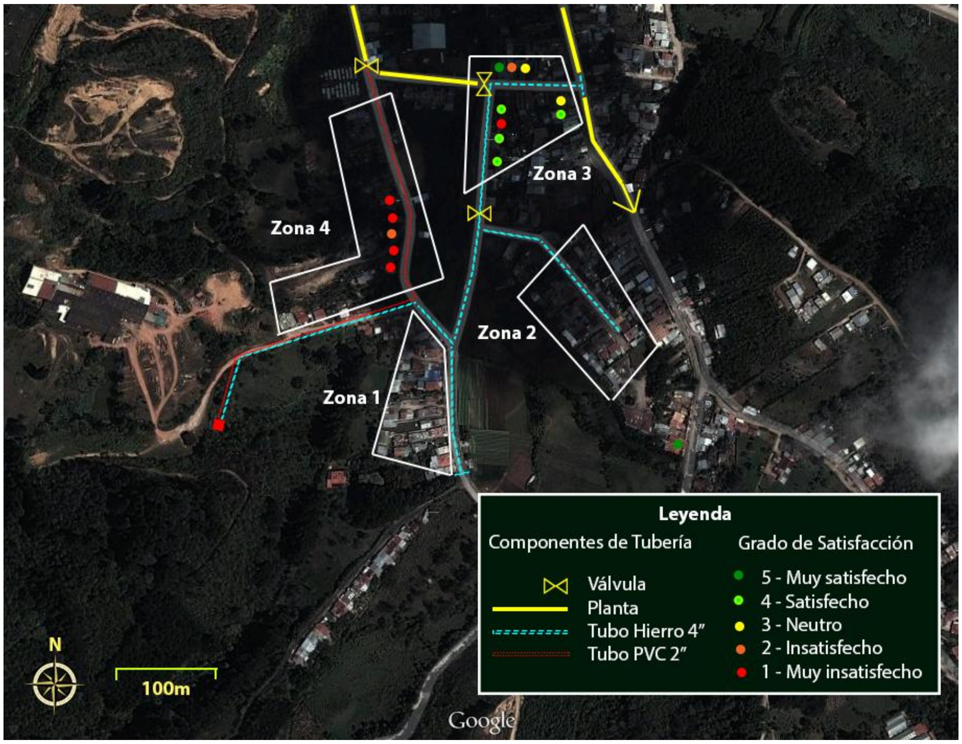


Figure E2: System distribution and satisfaction map

E2.4 Consumer Perception

The consumer can provide invaluable information about the performance of the water supply system. As a result, their perception of the water service is an important part of the system description. The user should conduct surveys, interviews, or focus groups with consumers. A sample survey is included in the CWSP. It is suggested that the user mark on a map the location of each household at which a survey was conducted in order to localize persistent problems in the distribution system. Each survey can be labeled with a number which corresponds to a location on the map.

The user can create a survey with Google Forms. An example survey can be found at the link below.

https://docs.google.com/forms/d/1cNzKgySdFpbOtiS_YdHXOnvPfSIIa5GDz22pt2spriE/viewform?usp=send_form

The user can enter survey data into the Google Form by viewing the live form and entering each response. Once the results have been entered, the data can be visualized on Google Forms.

Additionally, the user should enter the data into the CWSP spreadsheet under the Consumer Perception section. The surveyor should also take note of any additional information residents provide that is not addressed by the survey questions.

E3. RISK IDENTIFICATION

Risk identification requires physically inspecting the system, reading system documentation, and reviewing water quality data. The consumer survey conducted during the previous section will aid in identifying specific problems. Each of these methods for identifying risks have separate sections within the CWSP. This chapter will discuss each of those sections in detail.

E3.1 System Inspection

This section is a printable form used for identifying risks caused by physical faults in the system. The inspection covers each stage of the system with a series of simple questions. The inspection should be carried out at least annually to sufficiently monitor the system. Certain parameters have a drop down list of acceptable answers.

E3.2 Water Quality Tests

This section contains a complete list of water quality parameters. The table serves as a reference and as a tool for tracking tests for the water supply system. The user can keep track of the test location and frequency for each parameter. The recommended parameter levels and limit values provided are the international standard values established by the WHO. The priority level of each parameter as given by the WHO is indicated on a scale of "1" to "4" where "1" is the highest priority level.

E3.3 Water Quality Data

This section stores results of water quality tests. The user is encouraged to update the table upon receiving results of level "2" and "3" tests. New results added to the bottom of the table will extend the table and be added to the water quality graphs automatically. Any test value that falls outside of the acceptable range will turn red.

E3.4 Water Quality Graphs

This section plots the data from "Water Quality Data" and parameter level limits. The user can select to view other tests by clicking on the arrow next to the parameter name and selecting a parameter from the drop-down menu.

E4. RISK ASSESSMENT

E4.1 Risk Assessment (Source – Destination)

Under the column “Risk Assessment” on the cover page, there are risk assessment tools for each part of the water supply system. The tables present possible hazards that may threaten any water supply system and allow the user to rate the risk that hazard poses to the system. The user can uncheck the boxes on the right side of the page to hide hazards that do not apply to the system. Additionally, the user can add additional hazards to the table.

Under the column “Current Control Measures” provide the current control measures, if any, in place to mitigate the risks. If no control measures exist, simply enter "None". In the next column, explain why they are or are not working properly.

Once control measures are determined, the user should assess the risks. Ratings are based on the likelihood and severity of the risks after application of control measures. The user should attempt to ensure that the likelihood and severity ratings accurately reflect the nature of each hazard. The table shown in Figure E3 can be used to determine the ranking. A risk score and risk rating will appear once ratings for likelihood and severity are provided. Depending on the magnitude of the risk score, the risk rating can be "LOW", "MEDIUM", "HIGH", or "VERY HIGH". If the risks are higher than “LOW”, they will be sent to the “Risk Prioritization” page. The user should justify the risk scores under the “Basis” column.

		Severity or consequence				
		Insignificant or no impact - Rating: 1	Minor compliance impact - Rating: 2	Moderate aesthetic impact - Rating: 3	Major regulatory impact - Rating: 4	Catastrophic public health impact - Rating: 5
Likelihood or frequency	Almost certain / Once a day - Rating: 5	5	10	15	20	25
	Likely / Once a week - Rating: 4	4	8	12	16	20
	Moderate / Once a month - Rating: 3	3	6	9	12	15
	Unlikely / Once a year - Rating: 2	2	4	6	8	10
	Rare / Once every 5 years - Rating: 1	1	2	3	4	5

Risk score	<6	6-9	10-15	>15
Risk rating	Low	Medium	High	Very high

Figure E3: Risk assessment tool (Bartram et al., 2009)

E4.2 Risk Prioritization

Any risk that appears on this page should be addressed. If the user identifies a risk that should be addressed but does not appear on this page, he may add it. In addition, characteristics that consumers are unhappy with will be shown in a table and graph below the risks. A higher number of responses to a certain characteristic indicates that the characteristic is perceived as a larger issue among the consumers. Any characteristics relevant to each hazard should be listed under the "Corresponding Characteristics" column. Finally the risks should be prioritized by factoring in risk score, the associated corresponding characteristics, and the importance of each characteristic.

E5. IMPROVEMENT PLAN

This section will facilitate the process of making an improvement plan. This plan will be used to address any risks found to be a high priority. Any risks given a low score still need to be considered while making an improvement plan, but they are not urgent enough to warrant immediate attention. In contrast, higher ranked risks usually necessitate immediate action. Potential solutions to these risks, also known as control measures, must be carefully assessed to determine the best choice for implementation.

E5.1 Control Measure Selection

This section is used to list, rank, and decide on a new control measure that will mitigate risks appearing on the risk prioritization page. The user should name each risk's associated hazard at the top of its respective chart and list 1-5 new control options. Next the user should make note of the cost, efficacy, time to implement, and chance of introducing new risk for each option. These categories will be scored based on the table shown in Figure E4. The most appealing option can be recorded in the "Chosen Option" section. Additional tables can be created by coping and pasting the existing tables.

Criteria	Scale: 1 (Worst)	2	3	4 (Best)
Cost	Too expensive to implement	Large capital investment	Fair capital investment	No capital investment
Time to implement	Too long to implement	Significant amount of time to implement	Fair amount of time to implement	Little or no time to implement
Efficacy	Will not reduce the severity of the problem	Will slightly reduce the severity of the problem	Will significantly reduce the severity of the problem	Will completely solve the problem
Chance of introducing new risk	Will undoubtedly introduce new risks	Will introduce new risks with high certainty	May introduce new risks	Will not introduce new risks

Figure E4: Control measure ranking tool

E5.2 Improvement Plan

Any risks ranked "MEDIUM" or higher will be displayed on this page. The user may choose to add additional risks if desired. Risk priority values should be given based on findings from the "Risk Prioritization" sheet. Control measure selections from the previous page should be noted in the "Action' column. The user should also note the projected time of implementation (short-term, 5 months, 5 years, etc.) and the status of the action (Ongoing, not started, etc.). The last column provides a space for any additional notes.

Additional Information

Any questions, comments, or concerns regarding the integrated methodology or the Excel spreadsheet can be directed toward:

Daniel Banco...................................dpb@frontiernet.net
Tom Graf.......................................tmgraf@wpi.edu
Nick Otero.................................nwotero@wpi.edu
Drew Wood.................................ajwood@wpi.edu

Appendix F: Improvement Plan

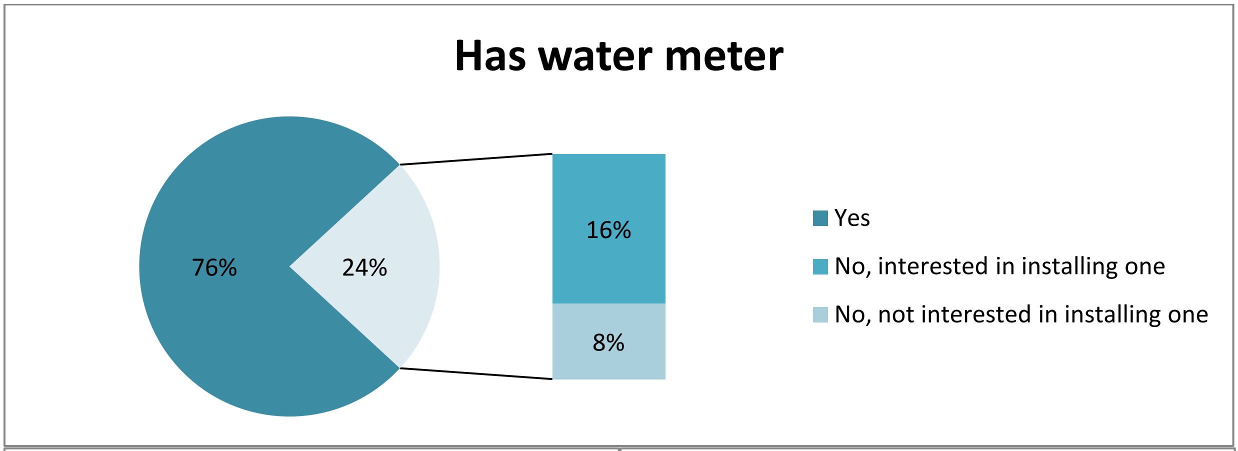
This appendix contains the improvement plan created for the Ladrillera spring water supply system. Information included in this document are consumer perceptions, high priority risks, possible solutions for the risks, and recommendations.

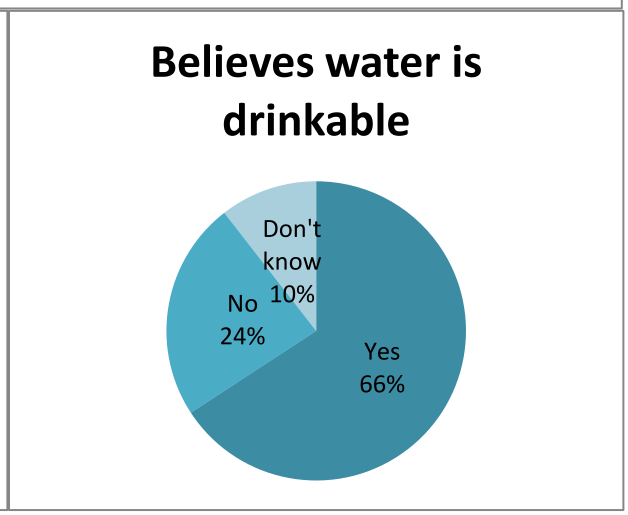
Introduction

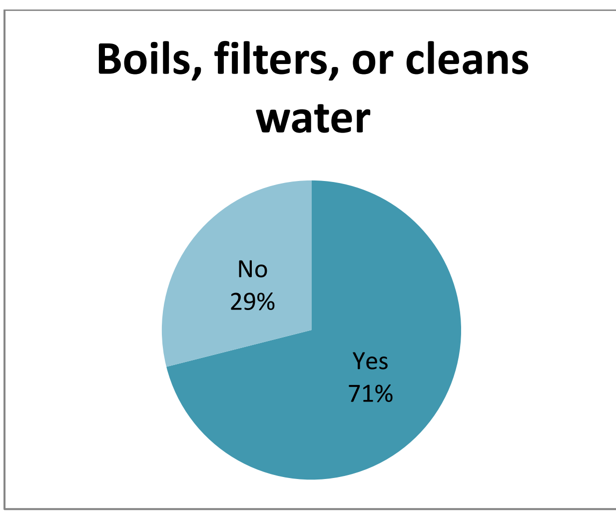
The purpose of this document is to propose suggestions to mitigate risks identified by the WPI team. The first section presents the results of the consumer survey. The municipality of Cartago should seek to address issues specifically identified by residents in addition to those identified by the WPI team. Next, the plan presents the results of risk assessment and suggests control measures. The risks are presented by category: physical risk, consumer risk, and management risks. Physical risks are risks associated with the physical state of the Ladrillera spring system. Consumer risks are risks introduced by the consumer population. Management risks are risks associated with the upkeep and documentation of the system. The list of possible solutions given for each risk is not exhaustive.

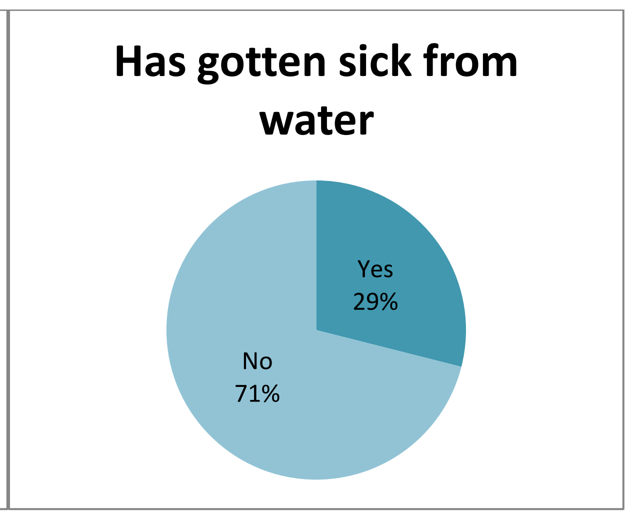
F1. Consumer Perceptions

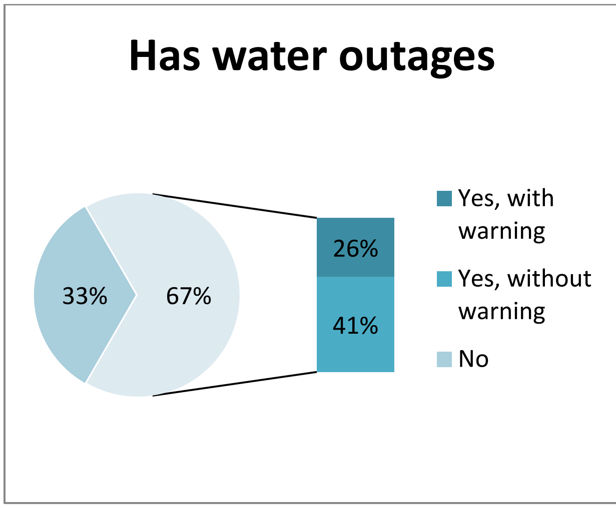
The following section summarizes the consumer responses to the survey, additional comments, and highlights key observations.

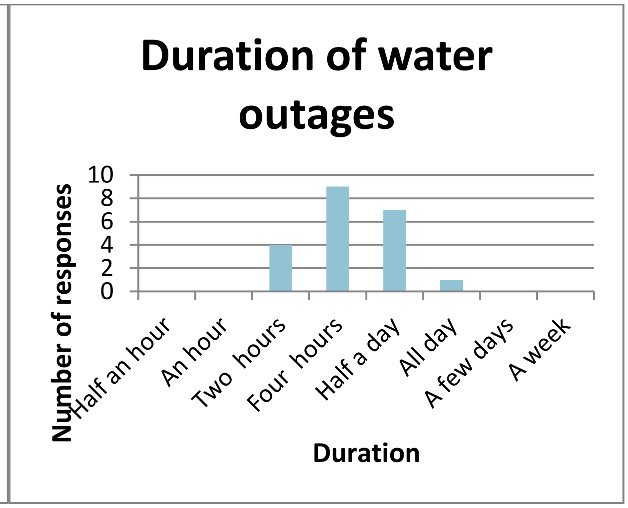


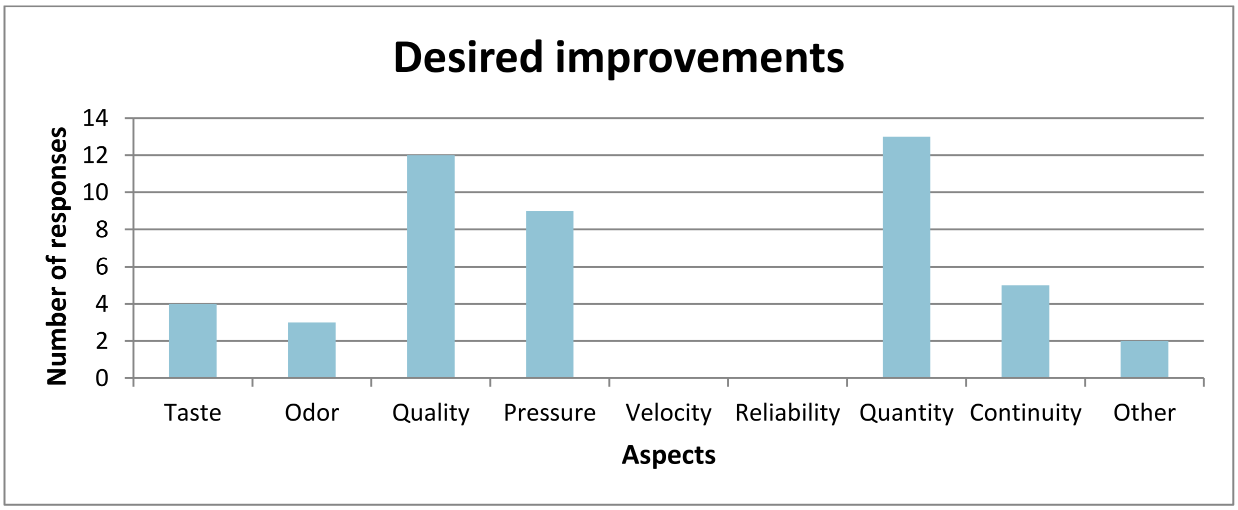


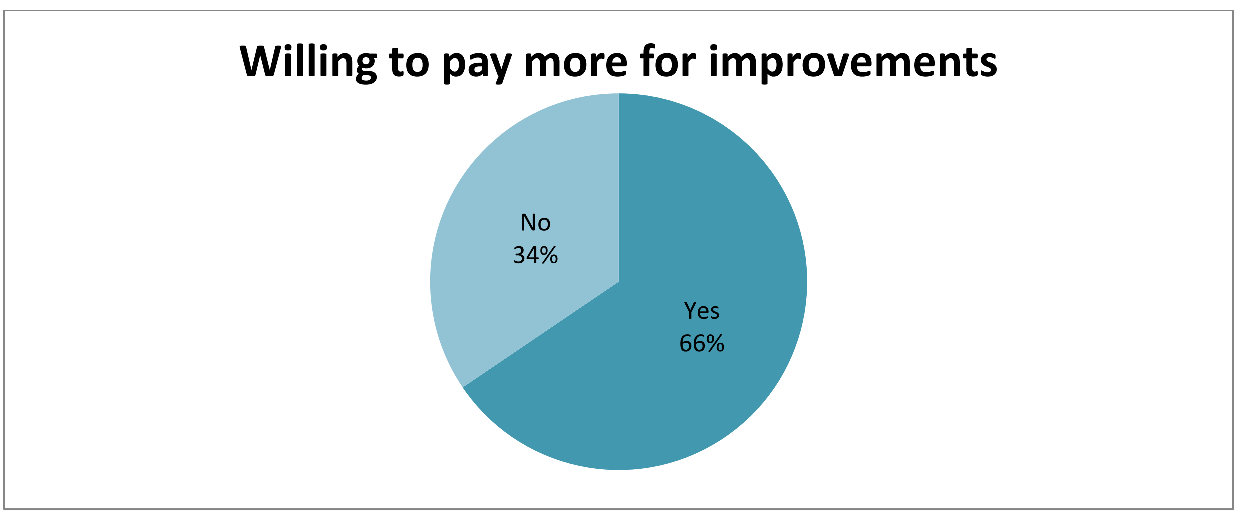





Has water outages
33%
67%
26%
41%
Yes, with warning
Yes, without warning
No


Duration of water outages
Number of responses
10
8
6
4
2
0
Half an hour
An hour
Two hours
Four hours
Half a day
All day
A few days
A week
Duration


Desired improvements
Number of responses
14
12
10
8
6
4
2
0
Taste
Odor
Quality
Pressure
Velocity
Reliability
Quantity
Continuity
Other
Aspects


Willing to pay more for improvements
No
34%
Yes
66%

Summary of additional consumer comments:

- Interviewed residents varied from low to middle class income levels.
- Most residents had a fairly strong knowledge of water conservation and safety.
- Residents of Urbanización Nazareth experience some confusion as to the source of their water because of the adjacent population which receives water from the treatment plant.
- A worker drives around town to alert residents that their water service will be suspended on the last Friday of each month. The storage tanks at the AYA treatment plant are cleaned during this time. This only applies to residents who receive water from the treatment plant, but residents who receive water from the spring also respond to this warning. During this time, residents who receive water from the Ladrillera spring will experience reduced water pressure and quantity.
- Some residents lose water service for large portions of the day.
- Some residents experience few or no problems
- Many people understand that Costa Rica's climate has been very dry recently and the spring has less water as a result.
- The team informed some people about the source of their drinking-water and its treatment.
- Many people boil water to ensure its potability (especially for children).
- All those surveyed expressed interest in water conservation, but none reported a leaky fire hydrant that the team observed.
- Multiple residents mentioned that a virus spread through the town. Many believe that the virus came from the drinking-water.
- Some residents complained about an excessively strong chlorine smell and taste.
- Reasons residents doubt the potability of the water (Number of times mentioned):
    - It is sometimes dirty (6)
    - It is sometimes yellow or brown or black(3)
    - Tastes heavily chlorinated (1)
    - It contains a virus (1)
    - It contains garbage(1)
    - It sometimes contains mud (2)
    - It contains sediment(2)
    - It smells like swamp water(1)
    - It seems contaminated(1)

The map shown below marks the locations of households of surveyed residents. The color of the marks indicate level of satisfaction. The satisfaction levels accurately represent the problems being experienced by residents in Zone 4. Those residents complained about water service cuts lasting more than twelve hours. They have been having such issues for more than six months. The municipality of Cartago should investigate these issues that seem to correspond to the 2” PVC pipeline. In general, other instances of water supply problems do not correspond to particular zones. In such cases it is possible that problems are local to individual households. It would prove worthwhile for the municipality of Cartago to investigate hazards in the distribution system. It will certainly prove worthwhile to investigate the problems occurring in “Zone 4.” Other isolated incidents with unknown causes, however, may not warrant investigation. Endeavours to address identified hazards will prove to be the most lucrative option.

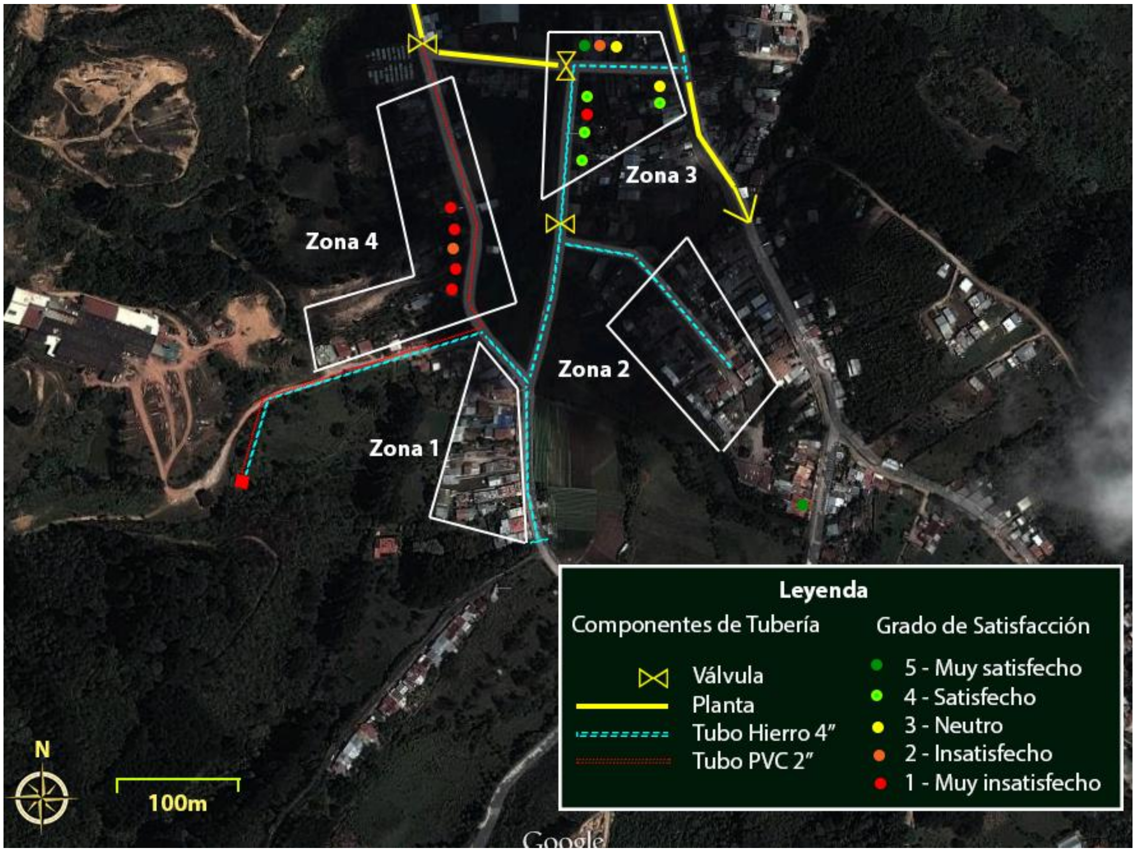


Figure F1: Water distribution map and resident satisfaction scatterplot

F2. Suggestions for Consumer Communication

Many Lourdes residents had complaints which they were willing to communicate directly to the municipality of Cartago. Also, the team observed small leaks and exposed pipes in the town of Lourdes. These are all risks that can be reported directly to the municipality by residents. When the team asked the engineer, he said that no one in town had reported the leaks. In order to increase communication between the municipality and residents, the municipality should distribute problem specific contact information. The municipality can use the Google Form shown below to document complaints. A link to access the form is included below. The municipality can distribute contact information or simply collect complaints while conducting surveys using printed forms. The municipality can take this opportunity to distribute educational material regarding problem reporting, water safety, and water conservation. The form is accessible at:

https://docs.google.com/forms/d/1VecafkyoaZvMumzfID4IsMARAJnXBr-PayL0c5ShSDE/viewform?usp=send_form

Formulario de Denuncia de Servicio de Agua

1. Nombre:

2. Dirección:

3. Teléfono:

4. Correo electrónico:

5. Queja:
   Check all that apply.
   - ☐ Color
   - ☐ Olor
   - ☐ Sabor
   - ☐ Turbiedad
   - ☐ Sedimento
   - ☐ Suciedad
   - ☐ Contaminación
   - ☐ Enfermedad
   - ☐ Fugas
   - ☐ Rupturas
   - ☐ Presión
   - ☐ Suspension de servicio
   - ☐ Other: ____________

6. Detalles:

7. Fecha:

8. Recipiente de la queja:

Powered by Google Drive

Figure F2: Water service complaint form

F3. Physical Risks

This section presents risks associated with the physical state of the Ladrillera spring system. Figure F shows a list of physical risks with risk ratings of medium or higher. The risks were identified by means of the consumer survey, a system inspection, and considering the surrounding environment of the water supply system. The team prioritized the risks by integrating consumer perceptions and risk score. The following will present improvement options for each source of hazard.

Source of Hazard	Hazard	Location	Risk Score	Risk Rating	Corresponding Characteristics
Agriculture	Agrochemicals Animal waste Dead animal disposal	Source	6	MEDIUM	Quality
Unclean tanks	Contamination of water	Storage	15	HIGH	Quality, Taste, Odor
Improperly insulated tanks	Water leakage	Storage	10	HIGH	Quantity, Pressure
Sediment	Contamination of water Blockage of pipes	Storage	10	HIGH	Quality, Taste, Odor
Uncontrolled time spent in storage	Inadequate mixing time for treatment chemicals	Storage	9	MEDIUM	Quality, Taste, Odor
Disinfection process	Disinfection byproducts Inadequate disinfection Too much added chemicals	Treatment	9	MEDIUM	Quality, Taste, Odor
Pressure Fluctuations	Ingress of contamination	Distribution	12	HIGH	Quantity, Pressure
Intermittent Supply	Ingress of contamination	Distribution	12	HIGH	Quantity, Continuity
Exposed Pipes	Damaged pipes allow leaks or ingress of contaminants	Distribution	6	MEDIUM	Quantity, Pressure

Figure F3: Highest priority risks for the Ladrillera spring water supply system

1. Disinfection Process

The current disinfection has poor dosage control and is vulnerable to changes in the flow rate of the spring. When the flow rate of the spring increases the chlorination amount should also increase. Also, when the level of the sodium hypochlorite in the tank lowers the input of chlorine into the system proportionately decreases/decreases as well. To address these problems, we recommend considering the following options.

1. Automatic injection system
   - Cost: High
   - Efficacy: High
   - Implementation time: Fair
   - Risk created: The system will become vulnerable to power outages and more vulnerable to robbery.
2. Build an injection system
   - Cost: Low
   - Efficacy: Fair
   - Implementation time: Fairly long
   - Risk created: The system will become vulnerable to power outages, more vulnerable to robbery, and is more subject to human error in creating the system.
3. Daily monitoring
   - Cost: Somewhat Low
   - Efficacy: Fairly low
   - Implementation time: Very low
   - Risk created: The system will become slightly more vulnerable to human error.

2. Leaky Tanks

Currently, there is a significant amount of water leakage in the system. This reduces the quantity of water available for consumers. To fix this problem, we recommend the following options:

1. Replace pipes
   - Cost: Low
   - Efficacy: High
   - Implementation time: Fair
   - Risk created: None
2. Sealant
   - Cost: Low

- Efficacy: Fair
- Implementation time: Very low
- Risk created: This is a temporary fix and the problem will likely reoccur.

3. Uncontrolled Time Spent in Storage

The amount of time the water spends in the system before reaching the first consumer must be increased in order to avoid health risks. The minimum contact time of sodium hypochlorite is 20 minutes. The minimum time taken by the water to reach consumers is less than this. More research is needed before implementing any of the below options.

1. Install an agitator in the tanks
    - Cost: Fairly high
    - Efficacy: Fairly low
    - Implementation time: Fairly long
    - Risk created: The agitator will require electricity to run, making it vulnerable to power outages
2. Build a baffling system
    - Cost: Fairly high
    - Efficacy: Fairly high
    - Implementation time: Fairly long
    - Risk created: None

4. Unclean Tanks

The storage tanks are not cleaned regularly enough. This promotes contamination. To reduce contamination, the tanks must be cleaned more regularly.

1. Clean tanks more regularly
    - Cost: Very low
    - Efficacy: Very high
    - Implementation time: Fairly low
    - Risk created: Water service will need to be suspended while tanks are being cleaned.

5. Sediment Buildup

Sediment build up occurs throughout the system. To eliminate sediment, filters must be installed. More research will be needed on proper filter placement.

1. Various filter options: More research is needed
    - Cost: Fairly high
    - Efficacy: High
    - Implementation time: Fairly long
    - Risk created: If the filters are not cleaned regularly, water flow will become inhibited.
2. Clean tanks more regularly (in previous risk)

6. Pressure Fluctuations

Pressure fluctuations occur in the distribution system. These may cause an ingress of contamination and is a primary concern for residents. To eliminate pressure fluctuations, pumps should be installed. More research on specific pumps and locations is needed.

1. Various pump options – More research is needed
    - Cost: Fairly high
    - Efficacy: High
    - Implementation time: Fairly long
    - Risk created: Pumps will be vulnerable to power failure and theft.

7. Intermittent Supply

Consumers often experience cuts in their water service. To provide a constant supply of water to the residents, the team provides these recommendation options, as well as any previously stated that apply.

1. Water saving programs
    - Cost: Fairly low
    - Efficacy: Fairly low
    - Implementation time: Fairly long
    - Risk created: None
2. Install another tank
    - Cost: Fair

- Efficacy: Fairly high
- Implementation time: Fairly long
- Risk created: No new risks will be introduced if the work is done properly.

8. Exposed Pipes

Exposed pipes in the town create to possibility for damage and vandalism. If the pipes break, residents will lose water for a fairly long time, and pipe replacement will be costly. A person with malicious intent can break pipes, or introduce contaminants to the system.

1. Bury pipes underground
    - Cost: High
    - Efficacy: High
    - Implementation time: Long
    - Risk created: None
2. Bury pipes in concrete
    - Cost: Fair
    - Efficacy: High
    - Implementation time: Long
    - Risk created: Impossible to repair.

F4. Managerial Suggestions

Water supply system documentation can be improved by completing documentation of water quality tests. When given the annual water quality test results for the Ladrillera spring system, the team noted that many test parameters had no data. Residual chlorine, a high priority level parameter, did not have any results. The results of official tests for all tested parameters should be recorded consistently in the CWSP spreadsheet every year.

F5. Conclusion

The results from the consumer surveys indicate that the most desired improvements are quality and quantity. For this reason, we suggest that improvements which address these concerns should be implemented first. We have prioritized the improvements in the following order, with the first being the most urgent:

1. Clean tanks more regularly
2. Replace leaking pipes
3. Install filters
4. Install a pump
5. Improvement of disinfection process
6. Investigate contact time and its solutions
7. Bury exposed pipes underground

The primary recommendation is that the tanks be cleaned more regularly. This will reduce a large amount of sediment that consumers report as an issue as well as remove chemical and biological contaminants. Next, we suggest the leaky pipes be re-installed with new pipes. This will create less wasted water, and more to the consumer. Installing filters into the system will also reduce the amount of sediment delivered to the consumer. To ensure more consistent water delivery and pressure to houses of all elevations, we recommend that a pump be installed. This is expensive but is much more effective than using gravity to reach the consumer, especially when residents live on tops of hills. Another recommendation is to improve the disinfection. The team suggests that daily monitoring will be effective until an automatic chlorine injection system can be installed. Consumer complaints of water smelling and tasting strongly of chlorine are likely brought about by decreases in the water flow rate without an adjustment in the chlorine dose. Our next recommendation, investigate contact time and its solutions, also seeks to solve this problem. With a longer contact time, the chlorine will be more uniformly distributed throughout the water. This will make the disinfection more effective and the smell and odor less apparent. Our final recommendation is to bury the exposed pipes underground. This process will be time consuming and costly, but will eliminate risks such as vandalism and accidental pipe breaks.

Appendix G: Water Supply System Description

This appendix contains the water supply system description maintained by the municipality of Cartago. It includes a full description of the system, the area around the system, and a system diagram. This is taken directly from section 3.1 of the Informe Annual 2013 prepared by Ana Patricia Guzmán.

3.1. MANANTIAL LA LADRILLERA

3.1.1. Ubicación geográfica

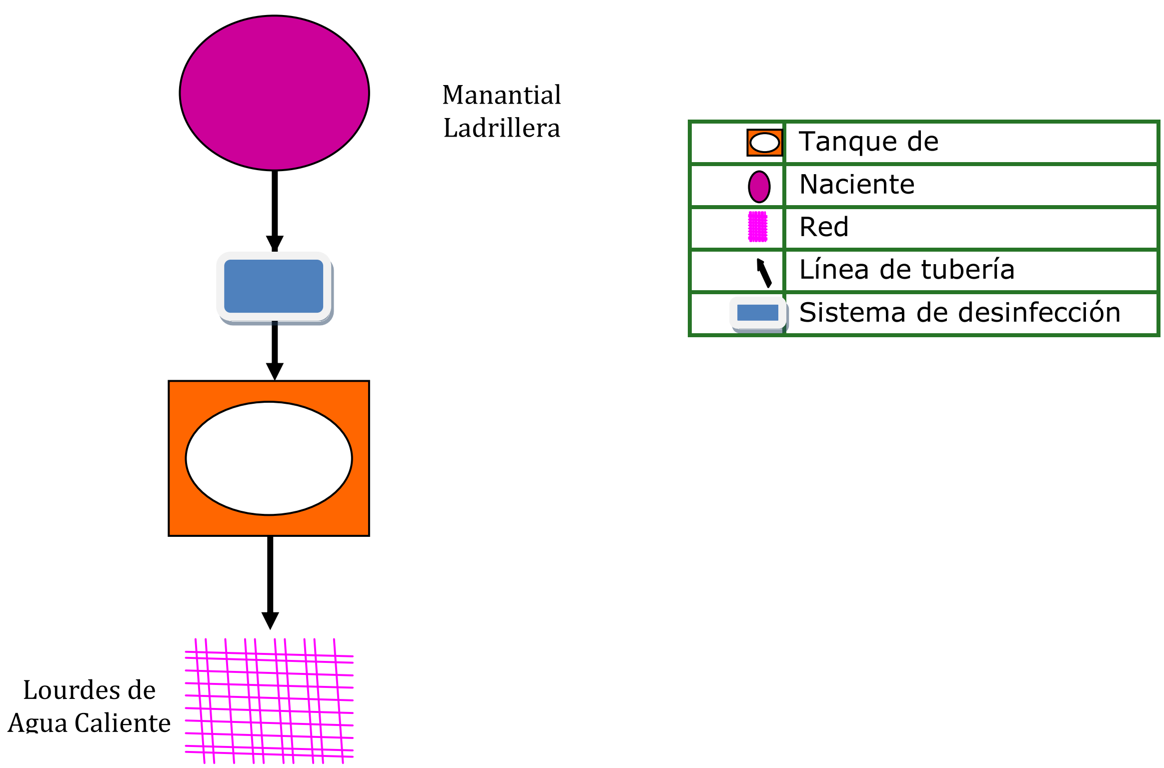
Esta naciente se ubica en Lourdes, en el Cantón Central de Cartago, en la Hoja Topográfica Tapantí, coordenadas 200.852/546.093. Se encuentra cercana a la Ladrillera Industrial Agua Caliente.

3.1.2. Descripción del sistema

Avances obtenidos en el área operativa y administrativa: Se cuenta con el estudio de identificación de las zonas de protección para esta naciente, además se eliminó la antigua caseta de cloración en malla ciclón por una de concreto y ladrillo.

La comunidad abastecida es Lourdes de Agua Caliente, es su mayoría son servicios domiciliares.

3.1.3. Croquis del sistema



3.1.4. Características del sistema

El tipo de fuente de este sistema es una naciente, cuya producción es 3,2 l/s. Se encuentra en una propiedad privada cuyo acceso es fácil en cualquier época del año. Alrededor de la naciente hay una cerca de alambre de púas que la delimita, para este 2013 una parte de la cerca fue reemplazada con malla ciclón, según se muestra en las fotografías.

Tanto la naciente como los tanques se encuentran ubicados frente a la Ladrillera Industrial Agua Caliente.

Tiene dos tanques de almacenamiento de plástico, y uno de cemento, todos muy cercanos entre sí, entre los tres tienen una capacidad de $10m^3$. El acceso a este tanque es fácil, tienen electricidad. La frecuencia de la limpieza interna es anual.

La tubería es de PVC, la tubería de conducción es de 5 m y la de distribución es de aproximadamente 500 m. Los diámetros de la tubería van desde las 4 pulgadas.

En cuanto a los sistemas de desinfección es de tipo hipoclorito de sodio, el sistema se tiene dentro de una caseta construida de ladrillo lo que le da mayor seguridad.

3.1.5. Programa de protección para fuentes de agua

- **Protección de fuentes**

Esta fuente de agua está debidamente cercada, con una buena estructura que protege la fuente de agua.

- **Mantenimiento de la estructura de captación**

Para llevar a cabo las actividades de mantenimiento de la estructura de captación se trabaja con el manual de Mantenimiento Preventivo BID

- **Mantenimiento del canal de escorrentía**

Para llevar a cabo las actividades de mantenimiento del canal de escorrentía se trabaja con el manual de Mantenimiento Preventivo BID.

- **Mantenimiento de tapas y sistema de cierre**

Para llevar a cabo las actividades de mantenimiento del sistema de cierre se trabaja con el manual de Mantenimiento Preventivo BID. En cuanto a las tapas estás son de concreto.

3.1.6. Programa de mantenimiento y limpieza de tanques, redes y otras estructuras

Para llevar a cabo las actividades de mantenimiento de la estructura de captación se trabaja con el manual de Mantenimiento Preventivo BID.

3.1.7. Rotulación y pintura de las estructuras

Estructura	Estado de la pintura	Estado de la rotulación
Naciente	Sin pintura	Sin rótulo
Caseta de cloración	No requiere pintura, es de ladrillo. Puerta pintada	Con rotulación
Tanques de almacenamiento	No requiere pintura, son plásticos	Sin rótulo

3.1.8. Fotografías

Captación

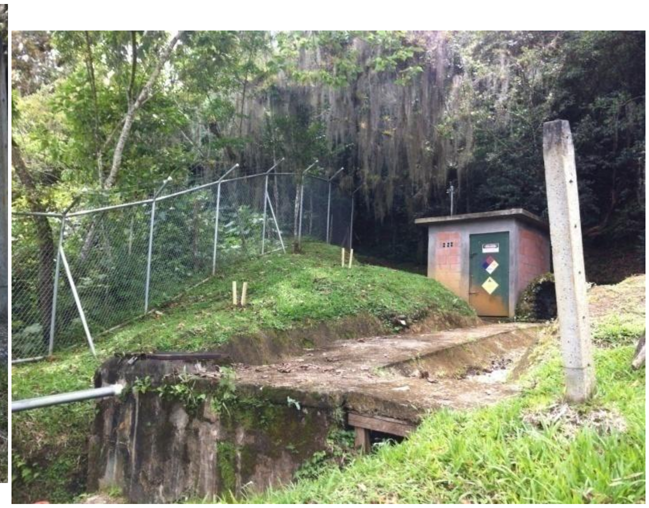
Caseta cloración

Tanques

Colocación de malla perimetral

2012

2013



Appendix H: Tank Risk Evaluation Form

This appendix contains a form created and filled out by the municipality of Cartago for risk evaluation of tanks. This form is filled out for the Ladrillera spring water supply system.

Tanque de almacenamiento

Nombre del acueducto:	Municipalidad de Cartago	Nombre del tanque:	
Dirección:		Ladrillera 1 y 2	
El agua viene de:	Nac. Ladrillera	El agua va para:	
Tipo de tanque:		Lourdes de Agua Caliente	
Elevado:		Enterrado:	
A nivel:	x	Semienterrado:	
Está pintado:		Estado de la pintura	

Acceso: B=Bueno R=Regular M=Malo — **B**

B=Bueno R=Regular M=Malo

Frecuencia de limpieza:

Mensual		Bimensual		Trimestral	
Semestral		Anual	x	Otro	

Volumen del Tanque:

1. (*) ¿Están las paredes agrietadas (concreto o mampostería) o herrumbradas (metálicas)?	SI	NO
2. (*) ¿La tapa de inspección está construida en forma inadecuada y/o sin sistema seguro de cierre?	SI	NO
3. (*) ¿La acera alrededor del tanque es de menos de 0.80 m. de ancho o inexistente?	SI	NO
4. ¿La losa superior o techo está en malas condiciones de impermeabilidad?	SI	NO
5. ¿El nivel del agua en el tanque es menos de ¼ del volumen total o las escaleras están herrumbradas?	SI	NO
6. (*) ¿Existe sedimento, raíces, algas y/o hongos dentro del tanque?	SI	NO
7. (*) ¿Está ausente o defectuosa la cerca de protección alrededor del tanque?	SI	NO
8. (*) ¿Está el lote donde se ubica el tanque, sucio o enmontado?	SI	NO
9. (*) ¿Existen focos de contaminación a menos de 20 m del tanque, tales como: letrinas, animales, viviendas, basura, actividad agrícola o industrial?	SI	NO
10. (*) ¿Carece el tanque de rejilla de protección en respiraderos y tubería de rebose?	SI	NO
Total de fallas sanitarias	1	

(*) De existir dos o más opciones de respuesta a la misma pregunta, encerrar en un círculo la que corresponda.

Appendix I: Spring Risk Evaluation Form

Included in this appendix is a risk evaluation form. This form is filled out for the Ladrillera spring water supply system.

NACIENTE

Nombre del acueducto:	Municipalidad de Cartago	Nombre de la naciente:	Ladrillera
Dirección:	Cerrillos, Cartago		
El agua va para:	Lourdes De Aguacaliente	Se clora en la naciente??	Sí

Tipo de captación:

Drenaje:	X	Caja:		Mixta:		Visible:	

Hay caja de reunión:	si

Características de la naciente:

Caudal (l/s):	3,2	Acceso:	B	Se clora en la naciente:	Si

B= Bueno R= Regular M= Malo

1. ¿Carece la naciente de cerca que la proteja del acceso de personas y animales o ésta está defectuosa?	SI	NO
2. ¿Carece la naciente de caja de captación que la proteja de la contaminación ambiental?	SI	NO
3. **(*)** ¿La tapa de inspección está construida en forma inadecuada y sin sistema seguro de cierre?	SI	NO
4. ¿Presentan grietas las paredes o la losa superior de la captación?	SI	NO
5. ¿Carece la losa superior o techo de pendiente para que no se empoce el agua?	SI	NO
6. ¿Carece la captación de un sistema para desviar el agua de escorrentía?	SI	NO
7. **(*)** ¿Se encuentran plantas, raíces, sedimentos, hojas, algas, etc. dentro de la captación?	SI	NO
8. **(*)** ¿Carece de rejilla en las tuberías de rebalse y limpieza?	SI	NO
9. **(*)** ¿Existe alguna fuente de contaminación alrededor de la captación, tales como letrinas, animales, viviendas, basura, calles públicas, etc. a menos de 20 metros?	SI	NO
10. **(*)** ¿Se encuentra la naciente ubicada aguas abajo de zonas de actividad agrícola, industrial o está el sitio deforestado?	SI	NO
Total de fallas sanitarias	0	

(*) De existir dos o más opciones de respuesta a la misma pregunta, encerrar en un círculo la que corresponda.

Appendix J: Pipeline and Distribution Risk Evaluation Form

Included in this appendix is the form used by the municipality of Cartago to evaluate risks in the pipeline and distribution network. This form is completed for the Ladrillera spring water supply system.

LÍNEA DE TUBERÍA CONDUCCIÓN Y DISTRIBUCIÓN

Nombre del acueducto: Municipalidad de Cartago

Dirección: Cerrillos, Cartago

Población Abastecida: Lourdes de Aguacaliente — Número de servicios: 50

¿Se clora en la Línea? No

Fecha de instalación de las líneas:

Número de fugas reparadas por mes:

Material de la tubería:

PVC: X — Otro: — Detalle:

Diámetro menor (mm): 1" — Diámetro mayor (mm): 4"

1. ¿Existen fugas visibles en la línea de conducción o distribución?	SI	NO
2. **(*)** ¿Existen tanques quiebra gradientes con tapas inadecuadamente construidas y sin sistema seguro de cierre ocon grietas en las paredes?	SI	NO
3. **(*)** ¿Se observa tubería expuesta de PVC o con huecos en lugar de válvulas?	SI	NO
4. ¿Es vulnerable la línea a los desastres o accidentes?	SI	NO
5. **(*)** ¿Existen pasos elevados en mal estado o en tubería de PVC sin protección?	SI	NO
6. ¿Carece de cloro residual en algún tramo de la línea de distribución?	SI	NO
7. ¿Existen interrupciones constantes en el servicio de distribución de agua?	SI	NO
8. **(*)** ¿No cuentan con un sistema para purgar la tubería de distribución y no desinfectan la tubería cuando reparan las fugas?	SI	NO
9. ¿Carecen de fontanero o encargado del mantenimiento de las líneas de tubería?	SI	NO
10. ¿Carece laAdministración un plano del sistema de tuberías?	SI	NO
Total de fallas sanitarias	1	

(*) De existir dos o más opciones de respuesta a la misma pregunta, encerrar en un círculo la que corresponda.

Appendix K: Weekly Residual Chlorine Test Report

This appendix contains the weekly residual chlorine test report for all systems managed by the municipality of Cartago. It includes values collected and recommended improvements.

Control de los sistemas de cloración de la MUNICIPALIDAD de CARTAGO

Realizado por Cristian Pérez Ríos y Miguel Bertozzi

Año 2013

Mata de guineo por el telefono-- 0.3

Ladrillera Urb Nazareth---0.3

San Blas Hip de sodio Fabrica de papas--------------------------------------0.4

Padre Mendez en la cuarta etapa de la Urb El Atardecer se corrige----------------------------------0.7

Paso Ancho   Restaurante Mi Tierra--0.3

Celedonio---0.05

Navarro   Familia Coto Boza casa de las matas donde Doña Olga --------------------------- --0.4

La MISION – Banderilla casa de Miguel Marin---0.4

La Alumbre Casa de WALTER---0.7

Ortiga   primeras casa del sistema---.0.4

Ortiga   San Juan Norte en la puiperia diagonal a la escuela------------------- --0.4

Arriaz   Costado norte de la escuela de la Lima en la carniceria la Lima-------0.3

Rio Loro   calle Jimenez Loyola---0.9

Turbina   100 sur escuela de El Carmen---0.9

San Blas gas por VIMUSA ---1.3

08/11/2013

Se les recuerda los trabajos pendientes.

(1) Paso Ancho la caseta y el cambio del sistema de cloración.

(2) Ortiga toda la losa.

(3) Navarro la segunda etapa, que es la estructura de metal sobre el tanque ,

y cambio de sistema de cloración.

(4) La compra de bombas dosificadoras para cambiar el sistema en cloración

en Aumbre y Ladrillera.

(5) Recordar trabajo de seguridad en el tanque de la Mision Tierra Blanca.

(6) Comprar bombas de ½ caballo ya que las que estan en los puestos de

San Blas y Turbina se ven muy deterioradas por el cloro gas, y las que tenemos

en bodega no son nuevas no se garantisa el buen funcionamiento.

Todos los trabajos urgen gracias por su atencion.