Team 04
Project Proposal and Feasibility Study

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Executive Summary

The Green to Clean team is working with the community of Santiago de Quito in Ecuador to evaluate and design improvements to their water distribution system. This project comes at the request of Bruce Rydbeck, the project client, who has experience working with water distribution systems in South American countries. Based on information provided by Martin Henrich and Efraín Morocho, both onsite engineers, the current system is supplied by a well with poor quality water that turns the community’s rice green when cooked. Also the current distribution piping was installed in good condition but since some portions of the line are exposed above ground they have acquired damage from weather conditions and loose sediment. The current system only provides the community with water once every eight days. This is most likely caused by low system pressures (Morocho, Efrain). The team’s proposed water distribution system design will include a connection from a recently built well to the existing system, disinfection and filtration processes, storage tanks, and pressure reducing valves (PRVs). If projected community demands are determined to be more than the new well can sustain, treatment of the current well system and possible additional well construction will also be recommended. Disinfection and treatment for the project will include chlorination and fluorination of the water at the source using a non electric fluid-drive injector pump. The chlorine solution will also be produced on site by the use of an electrolysis system. Due to the high elevation range of the project (approximately 3300m to 3370m) pressure zones will be used to control the pressures for homes at different elevations.

In late January, the team will travel to Santiago de Quito to meet with the community, collect survey data, perform chemical and water quality tests, and visit neighboring distribution systems. Using the team’s survey data, the system will be modeled in EPANET, a water distribution software, to determine current issues and future improvements. The team will also use the water quality information to determine what water sources will be utilized in the final design as well what treatment processes will be necessary. This Project Proposal and Feasibility Study investigates design alternatives, design norms, and project goals to demonstrate the feasibility of this project and what the next steps of the project will be.
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1. Introduction

1.1. Senior Design Background

1.1.1. Calvin Engineering Program

As an accredited school for engineering by the Accreditation Board for Engineering and Technology (ABET), the Calvin College engineering program offers a variety of concentrations including chemical, civil & environmental, electrical & computer, and mechanical engineering degrees. A liberal arts curriculum combined with international work and relationship opportunities makes Calvin College a unique and challenging yet rewarding experience for students.

1.1.2. Senior Design Background

Calvin College offers an accredited engineering program which includes a capstone design course as the final step for students receiving an engineering degree. Regardless of the concentration, all engineering seniors are required to propose, design, and present a design project of their choosing. In the two semester course, the students work in teams to assure their projects are completed by the end of the year and presented at a senior design banquet to fellow students, professors, faculty, professionals, friends, and family.

1.1.3. Team Members

Team 04, which has named themselves Green to Clean, is comprised of two senior civil and two senior chemical engineers from Calvin College. Each member of the team brings a unique set of skills, interests, and background to the project that will contribute to design process success. All team members have a passion to help others with their education and to see global justice for all people including drinking water applications. As a result, they are committed to using their skills to work with the people of Santiago de Quito to help find a sustainable clean drinking water solution to the community members.
MaKinnah Collins
MaKinnah Collins is an engineering major in the civil and environmental concentration from the Chicago area. She interned the last two summers at a civil engineering consulting firm, Engineering Resource Associates, Inc. At Calvin, she is involved in the Renewable Energy Organization and ASCE. Her role on the team is to be a resource in Ecuadorian water pollutants as well as the extent of chlorination, and hydraulic modeling.

Ryan DeGroot
Ryan DeGroot is also a civil and environmental concentration engineering major from the Chicago area. He spent his last summer conducting research and developing hydraulic models with Plaster Creek Stewards at Calvin College. He is an avid runner and outdoorsman. He is the water distribution and modeling resource on the team, as well as the head of team stewardship.

Caleb Ingram
Caleb Ingram is a chemical concentration engineering major from Dublin, Ohio. For the last two summers, he has interned in both pharmaceutical and plastics companies. He enjoys being active both in his career and personal life and hopes to move to Houston, Texas after graduation. He is the team expert in water filtration alternatives.

1 Photo courtesy of Addotey Allotey
Maria Steblay

Maria Steblay, also an engineering major in the chemical concentration, is from Minneapolis, Minnesota. She worked for 3M in Greenville, South Carolina this past summer as an environmental engineer in the optical film business. At Calvin, she serves as leader of the track and field team, running sprints and hurdles. She is the team expert on the production processes for chlorine and fluoride.

2. Project Background

2.1. Project Summary

Team 04 is working with a rural community in Ecuador called Santiago de Quito to evaluate their current system and propose improvements that will include disinfection and filtration processes. Part of our project scope includes designing a new well pumping station, storage tanks, and distribution system improvements through survey work and modeling. The team will also assess the feasibility of on-site chlorine production and membrane filtration.

2.2. Location and Culture

Santiago de Quito is located in the Andes Mountains, approximately 100 miles south of Quito, the capital of Ecuador. The community is located on Laguna de Colta in the historic Cache region of Ecuador. The primary language in the community is Kichwa, however, most indigenous people are bilingual in Spanish. The territory covered by Santiago de Quito varies in elevation from 3,300 to 3,600 meters. Annual average temperature is around 12 degrees Celsius. Although Ecuador is on the equator, the village is at a high altitude, making the climate cold and dry. A rainy season extends from mid-September to mid-January. See Figure 2 below and Appendix A and B for location maps of Santiago de Quito.
Figure 2: Geographic location of Santiago de Quito

Google Maps: https://www.google.com/maps?q=laguna+colta+ecuador&ion=1&espv=2&bav=on.2,or.&bvm=bv.107467506,d.dmo&biw=1280&bih=924&dpr=1&um=1&ie=UTF-8&sa=X&ved=0CAYQ_AUoAWoVChMf6HaaxaVYQIVQrceCh3_2QFP

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\(^2\) Google Maps: https://www.google.com/maps?q=laguna+colta+ecuador&ion=1&espv=2&bav=on.2,or.&bvm=bv.107467506,d.dmo&biw=1280&bih=924&dpr=1&um=1&ie=UTF-8&sa=X&ved=0CAYQ_AUoAWoVChMf6HaaxaVYQIVQrceCh3_2QFP
Due to the location of the community and fertile soils, Santiago de Quito is primarily an agricultural region. In fact, most of the people in the community are employed by the agricultural and tourism sectors. The community is known for their production of quinoa, potatoes, barley, wheat, beans, cattle, sheep, pigs, poultry, and other vegetables and wild animals.

2.3. Current Water Situation

The community currently contains 400 urban homes, however only approximately 250 homes are occupied. The lack of occupants is likely due to rural flight trends caused by the low income from their primarily agricultural based economy and the higher wages offered in larger cities. With more development improvements and higher standards of living, Santiago de Quito hopes to increase back to its original size of 400 homes. Based on local survey information the estimated population of the village is shown in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>548</td>
<td>612</td>
<td>1160</td>
<td>20%</td>
</tr>
<tr>
<td>Rural</td>
<td>2029</td>
<td>2479</td>
<td>4508</td>
<td>80%</td>
</tr>
<tr>
<td>Total</td>
<td>2577</td>
<td>3091</td>
<td>5668</td>
<td>100%</td>
</tr>
</tbody>
</table>

3https://www.google.com/maps/place/Laguna+Colta,+Colta,+Ecuador/@-1.7380841,-78.8063051,496a,20y,90h,81.52t/data=!3m1!1e3!4m2!3m1!1s0x91d303e705cc419f:0x99755f8780fad8c4
See Appendix C for the population distribution within the urban area of Quito.

In Santiago de Quito there are currently two primary sources of water for the community members. The first is a distribution system that is supplied by water from a local well based out of Santiago de Quito and a regional system connection feeding surface water from the neighboring community of Lily. This system is extensive, servicing six other communities including RayoLoma, Central, Santa Ines, Colta San Jose, Alabado & Verde Pamba. The regional system also only supplies water to the community every eight days due to low pressure and high demand. A second source are hand-dug domestic wells residences have built themselves. The well and regional system connection currently provide 40% of the community member’s water while domestic wells provide the remaining 60%.  

Each of these sources have contamination and reliability issues. Specifically, community members have reported the current well water turns their rice green. This creates a significant aesthetic problem, as well as points to low and possibly unhealthy water quality. Determining the cause of this green hue will be important for design of appropriate filtration. It is likely there are organic contaminants in the water, such as peat, a partly decomposed vegetable matter, or organic acid. The domestic wells also have quality issues since they are not usually built to a standard to prevent surface runoff contamination. Since the community did not have a sanitary system in place until the recent years and has a lot of agricultural activity, contamination could be caused by animal and human waste runoff. Possible water contaminants are discussed later in this report, in section 6.4.

In an effort to improve the current water systems, the community has already built a new well in a groundwater system free of contamination. However, additional water quality tests will be performed to confirm this statement. This new well has a sustainable pumping rate of 25 gpm and will be designed to become the primary water source for the new water system. A 40 m³ reservoir tank has also been constructed in the high elevation region of the community (3371 m). These new improvements are discussed further in section 6.3. With these two improvements and future recommended additions by the team, Santiago de Quito hopes to have a more reliable water system that meets their community demands.

2.4. The Client

Bruce Rydbeck, PE, D.WRE., presented this project to the team. Mr. Rydbeck is a rural water supply consultant for Life Giving Water International and has spent 34 years living in Ecuador working on clean water projects in rural Peru and Ecuador. See the attached Rydbeck Ribble’s pamphlet in Appendix D for a brief overview of the current projects Bruce and his team are currently working on including the green rice problem in Santiago de Quito. Bruce has a strong connection with Calvin College and has coordinated multiple similar senior design projects in the past.

Alongside Mr. Rydbeck, Martin Henrich is also working on this project. Herr Henrich is a German missionary engineer living in Riobamba, Ecuador, a twenty minute drive from Santiago de Quito. He is
planning on living there for three years with his family. Herr Henrich is fluent in German, English, and Spanish.

Efrain Morocho is an Ecuadorian consultant who is working with Mr. Heinrich, and also provides the team with important information about the community. He has extensive experience with water projects in the area.

2.5. The Project

Joining with Mr. Rydbeck and Mr. Henrich, the team will assess and propose improvements to the water distribution system for the community of Santiago de Quito. The goal of the distribution system will be to provide reliable and potable water to as many community members as possible while using the available sources.

During design, the team will also look at maintaining pressures and using available materials and labor to construct the final design. In addition, the team will assess the best treatment options for the community including chlorination and fluorination methods. The disinfection system will produce water safe for human consumption without taste and odor concerns and will comply with the Ecuadorian drinking water standards for chlorination dosing. See Appendix E for a summary of the Ecuadorian Standards. Treatment will be designed to ensure future maintenance and operational needs are minimal so that the design is culturally appropriate for the community.

3. Project Management

3.1. Team Organization

The team members have been assigned designated roles to most efficiently pursue the project. Ryan DeGroot is in charge of scheduling and team management, and has a lead position in developing the hydraulic model for the water distribution system. Maria Steblay is in charge of task and timeline management to ensure the team stays on track and to inform the team manager what needs to be accounted for and completed in a timely manner. She is the lead in website development, as well as research and development of chlorine disinfection processes. MaKinnah Collins is in charge of client communications and the team budget, and is an assistant to computer modeling. Caleb Ingram is in charge of overseeing the business plan as well as the lead researcher of filtration processes and fluoride treatment. Individually, all team members are responsible for tracking their progress and project completion. Many aspects of the project are collaborative and will be worked on by all team members.
3.2. Schedule

As the senior design course is organized into two semesters, one focused primarily on research and the other focused on development, our project is organized in a similar fashion. See the attached Gantt chart included in Appendix F for a complete schedule of team tasks. For our team specifically, first semester will be primarily focused on client relationships, chemical research, and information gathering. This phase should be completed with the trip to Ecuador in late January that will include survey work, information gathering, and evaluation of previous projects in the Santiago de Quito area. Spring semester will be when the majority of the project development and design will occur. The project end date is May 7, 2016.

The team currently meets multiple times during the week to keep up to date with one another, talk about team progress, conduct research, do design work, and meet with clients, consultants, and advisors. At each meeting, the team covers what tasks are required for the next week, including course work, communication, research, and design goals. Although there is general group guidance for project due dates, the team usually breaks down work on a week-to-week basis. This breakdown will continue for the duration of the school year.

3.3. Budget

Throughout the project the team has to keep track of budgeting and expenses. The overall budget for each senior design group is $500 dollars for the project. This money is provided by the Calvin Engineering Department. These funds will also go towards the disinfection and filtration testing supplies needed for water testing and treatment in Ecuador. These tests will help the team determine what processes are best fit for the community based on their water quality. In addition to these program funds, the team has also budgeted approximately $4,000 in travel expenses for a site visit in January. These funds will be supplied by individuals on the team and possibly fundraising activities.

The team will also be creating a cost estimate and budget for the final design expenses for the community of Santiago de Quito. When creating this budget and considering the final design, the team will have to factor in cultural appropriateness. For instance, although there are many possible water distribution design options and processes, some may not be financially feasible in Ecuador as they are in the United States. Therefore the team will have to decide which options financially meet the goals of the project.

3.4. Method of Approach

The team is approaching the project with humility driven to design a solution that will significantly benefit the people of Santiago de Quito. As students, the team understands their lack of experience and their need to humbly seek and accept advice when necessary. As a result, the team has sought the help of professionals with experience in similar design projects both in the United States and internationally.
The team seeks to show their gratitude whenever assistance is given to them during the duration of the project and is especially grateful for the experience this project will add to their education and knowledge of engineering design.

Bruce Rydbeck has been a crucial factor for this project in being the mediator between the team and the client as well as assisting in the matching of the community with Team 04. Gratitude can also be shown to professors and professional engineers that have graciously given time and guidance to the team crucially impacting this project. The chance to work on this project a blessing and the team is striving to design the best possible solution.

This project will follow the format of research, preliminary design and modeling, water testing, redesign and modeling evaluation, and the final design proposal. After the initial research phase and the trip data collection is finish, the team will work on model creating in EPANET as well as water analysis and treatment proposal. The team will consult with the community of Santiago de Quito as well as their clients before any final design and treatment is recommended. The final proposal will likely include multiple options for the community to choose from and to implement in the future. It is important for each aspect of the final designs to be tested by the team as well as evaluated by the team and clients before any final recommendations are made.

4. Project Overview

4.1. Purpose and Objectives

First and foremost, the purpose of this project is to aid the village of Santiago de Quito in the rehabilitation and design recommendations for their existing water system. This includes analyzing their current water sources in addition to possible future sources of water. Both the existing and new well water will be tested to determine the water quality. Any necessary filtration and disinfection will be added to the system design. To improve the overall health of the community, fluoridation will be researched in consideration of its feasibility and culturally appropriateness. The main goal of this project is to evaluate and propose improvements to the water distribution system in order to provide as many community members as possible with clean, reliable water.

4.1.1. Distribution

The purpose of the water distribution and disinfection system is to supply a reliable source of drinking water. Currently, the urban community has 400 homes with 250 occupied. People in the community receive water either from a pumped well and regional system or from domestic wells. Generally, the domestic wells are used for drinking, cooking, and bathing water while the well system is used for laundry, toilet flushing, and washing dishes. Onsite engineers have noted both of the water sources are contaminated. The team predicts this is most likely due to human and animal waste as well as sediment
runoff. By evaluating, improving, and extending the current distribution system, community members will not have to depend on nonpotable water sources.

Based on the Ecuadorian standards seen in Appendix E the system will be designed to supply 100 liters/person/day at a pressure range of 7 to 30 meters. Based on request from the client, Bruce Rydbeck, the team will also design for a growth rate of 2.5% annually for 25 years. Servicing as many houses as possible with clean, reliable water, especially the occupied homes, is the main priority of the team. For homes unable to be provided with a water connection, a water faucet will be constructed nearby or in a community area. By the end of the project the team hopes to submit a full engineering design report to the community leaders for future development of the system.

4.1.2. Chlorine / Fluoride Deriving and Purification

Chlorine is the most effective, cost effective flexible method of disinfection, especially in undeveloped areas. However, “chlorine is difficult to store and transport economically and it is therefore generally produced near consumers”. With this in mind, the team also looked into the possibility of extracting the raw minerals needed for chlorine from local materials, or by production of chlorine from inexpensive and easily attainable raw materials. Additionally, fluoride will be considered in low doses, to aid in oral health. The feasibility and appropriateness of adding this to the water system will be analyzed by the team.

4.1.3. Chlorination / Filtration

The method of disinfection chosen by the team is chlorination. As stated in the Republic of Ecuador Ecuadorian Code of Practice, the government requires a certain level of disinfectant and residual chlorine to be present in the system, as outlined in the Appendix E Table E.1. The team has decided to lower the level of chlorine to close to the minimum amount and to reduce taste and odor concerns while still treating the water with a form of filtration that purifies the water in a range of acceptable consumption.

The team is researching the feasibility of different types of filtration, including simple screen filtration up to biofiltration, which involves membranes capable of consuming the undesired components in the water. Water testing at the end of January will shed more light on the potential contaminants in the water that will need to be removed. Coliforms, iron, nitrates, pH, and organic acids will be specifically tested both at the well and through the distribution system. Research and consultation is still required for further narrowing of the design constraints once the water quality tests reveal the current situation of both water well sources.

4.1.4. Future Funding and Improvements

In the future, the community plans to pursue more funding research and system improvement. As of recently, our client has conveyed to the team that the community is having issues finding full funding for construction. However, on site government officials are continuing to discuss funding options and with
engineering analysis and design complete, they are hopeful that future funding will be found. Although financing the whole project is the ideal situation, priority aspects of the project will be pursued first, and other parts of the project may have to be completed as funding is available.

4.2. Design Constraints

When designing this system multiple constraints will have to be considered. These include disinfection standards by the government of Ecuador, material availability, maintenance requirements, geographical features, and financial considerations. These constraints will guide the design of the team so that the final system will be successful in the future and culturally appropriate for the community.

The first constraint is a list of standards defined by the Republic of Ecuador government. These standards will guide the team’s water supply and treatment procedures. According to the Ecuadorian Standards, summarized in Appendix E, there are required disinfection levels as well as residuals for drinking water system.

The second constraint, material availability of the community, will determine what materials will be utilized for the project. Since this is a small rural community in the mountainous region of Ecuador, not all materials available in the United States will be readily obtainable there. Also, not all available materials may be adequate for the final design. Therefore, the team will have to weigh what materials are accessible and which of these will meet system pressures, sizes, and demands. The current distribution system is also made of PVC which may impact the team's decision for pipe network material.

The third constraint, maintenance, will determine how the system is designed and what upkeep and monitoring will be needed in the future. Since this is a rural community, many of the citizens may not have the technical background experience or time needed for the operation of certain drinking water systems. Therefore, it is pertinent that the team keep maintenance minimal so that the system can continue to be in use in the future and to insure that the community is able to handle system disturbances without having to shut it down.

Another constraint is the geographical topography of the community. As this community is located in a mountainous region, this will require multiple pressure zones in order for the system to function properly. From preliminary design three pressure zones will be needed to account for changes in elevation, as described later in section 7.2.3.

The last constraint is the financial restrictions of the community. This constraint will limit what design features the team will choose to implement and cause the team to focus on finding a balance between necessary system features and their associated costs.
All these factors will be given special consideration in the team's design process and final recommendations to the community. The team acknowledges that inability to follow these constraints may result in a faulty or inadequate system for the community.

4.3. Design Criteria

In order to determine the best options for the design, a decision matrix will be utilized for the final design. This matrix will help the team decide what are the best disinfection and treatment processes will meet the community’s needs. All design criteria considerations are based on the team’s design norms to seek justice, cultural appropriateness, transparency, and humility.

4.3.1. Chlorine and Fluoride Derivation Method

The following design criteria was considered for the chlorine and fluoride production method:
1. Safety
2. Availability
3. Cost
4. Byproducts
5. Final product quality
6. Process difficulty

4.3.2. Disinfection Process

The following design criteria was considered for the disinfection process:
1. Safety
2. Cost
3. Byproducts
4. Residuals
5. Level of disinfection
6. Water quality
7. Process difficulty/procedure

4.3.3. Filtration Process

The following design criteria was considered for the filtration process:
1. Safety
2. Cost
3. Level of filtration/water quality
4. Process difficulty/procedure
The World Health Organization (WHO) has identified 5 key parameters of water supply services. These criteria are quality, coverage, quantity, continuity, and cost. All of these parameters will be considered in the design of the overall water system for Santiago de Quito.

5. Design Norms

5.1. Cultural Appropriateness

The group is approaching this project with a heart full of understanding and appreciation for the community and their current situation. It is important to remember that the goal of the project is to make a positive impact without hurting or changing any aspect of the community.

5.2. Transparency

Complete transparency is a key component of this project to appropriately aid the community of Santiago de Quito. The group is not building the distribution system, therefore, all design recommendations are completely hinged on the ability of the team to communicate with the people in the community. Furthermore, for this design to be trusted, an explicit and thorough report is necessary. There cannot be gaps or unintelligible sections in the design report that confuse the reader. The community must have complete knowledge of their drinking water system so that they may trust its safety and reliability.

5.3. Justice

Clean water is something citizens of first-world countries take for granted. For those living in developing countries, getting drinking water is not always so easy. We believe that everyone has the right to clean water and we seek to act on this belief through this project. The World Health Organization (WHO) has said a better indicator of health is not the number of hospital beds, but the number of water taps. In addition, "disinfection is unquestionably the most important step in the treatment of water for public supply". By designing a system that can safely and reliably provide clean water to the community of Santiago de Quito we hope to relieve a very small part of the injustice experienced in the developing world.

Safe drinking water is also acknowledged in the Target 7.C of the United Nations Millennium Goals. This goal is to “halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation.” Although this goal was already met a few years ago and the final date has passed, it does not take away from the world wide importance to give people basic necessities like clean water.
5.4. Humility

In order for our team to successfully design this system we must have an attitude of humility. We are only students that have been blessed with this opportunity to apply the knowledge we have acquired from our education. As students we have limited design experience and rely on professors and practicing engineers for guidance. Lastly, although we hope for a final system that will significantly benefit this community and demonstrate Christ’s love, we must understand that we are just a small part of a much larger plan that began long before us. “We are not bringing Christ to poor communities. He has been active in these communities since the creation of the world, sustaining them, Hebrews 1:3 says, by His powerful Word. Hence, a significant part of working in poor communities involves discovering and appreciating what God has been doing there for a LONG time”.

6. Initial Research

6.1. Previous Group Analysis

6.1.1. ACE

During analysis, the team utilized the design of the Ecuadorian Water Distribution Team in 2014. Study of this report was important for the team’s chlorine dosing system since the team's design last year has been largely successful. The team also referenced this report for general project guidance since both designs involve a water distribution system in Ecuador.

6.2. Existing Distribution System

As discussed above, the existing distribution system services the 400 community homes community, there are currently 400 homes, 250 of which are occupied. Of these occupied homes, 40% are supplied by a current distribution system and the other 60% use domestic wells they have built for private use. The distribution system is supplied both by surface water from the regional system based out of the nearby community of Lily as well as the contaminated well of Santiago de Quito. The driving line of the distribution system is a 8 km long PVC pipe with a diameter of 90 mm. The pipe was installed in good condition, but since installation the exposed parts of the line have been damaged by the elements and clogged by sediment.

Another problem of the system is it was built with a lack of pressure due to low supply and high demand. As a result, the community only has water at their homes every eight days. Many members of the community have resorted to building their own wells which were not built to any technical standard and are subject to surface contamination and runoff. An existing distribution model and layout will be prepared after additional survey is collected by the team in January.
6.3. New Developments

From documentation, the team has some information on the newly built well dimensions and flow rates. The new well which provides cleaner water compared to the existing well. It has a depth of 10 m and a diameter of 1.2 m. This well, built to replace the existing non-potable well, maximizes groundwater infiltration filtration and is protected at the surface to prevent runoff into the source. The well, named by the community “The Water of Life San Antonio of Quito”, provides a maximum pumping rate of 3.2 L/s [51 gpm]. However, only 25 gpm will be pumped to prevent overdrawing. It is the hope that this new well will be able to serve as the main source of water for the community system. Additional assessment of the well’s conditions will be done on the trip in January.

Another new development is the 40 m\(^3\) (10,600 gallons) reservoir tank built at an elevation of 3371 meters. This tank will be utilized in the final distribution design as a way to control pressures and maintain continuous supply to the community members. Although Bruce has indicated this new reservoir is usable in the new design, further assessment of it’s current conditions will be conducted during the trip in January.

6.4. Sources of Pollutants

Since this community is primarily rural with a large agricultural focus, a possible source of water contamination is human and animal waste as well as loose sediment and possible fertilizer and pesticide runoff from the farm fields. Since the agricultural lands are located in the higher elevation mountainous region of the community, runoff most likely flows from there, through the urban community to the low lying lake where it has caused excess organic matter and algae. Bruce has also expressed to the team that there are high levels of peat in the lake which may also be a result of this runoff. However, further water tests will be conducted during the trip in January to determine the exact pollutants and their sources.

6.5. Methods of Disinfection

Disinfection of water is an important aspect of designing water systems. Worldwide, contaminated drinking water is estimated to be the cause of at least 502,000 diarrhoeal deaths per year, and this only accounts for one type of illness contracted through infected water.\(^{21}\) At least 1.8 billion people use a water source contaminated with human and animal waste in the form of coliform, which has a high probability of carrying infectious diseases. The WHO has identified at least 16 types of orally transmitted pathogens that can be carried in drinking water and that have a high health significance.\(^{12}\) In a water distribution system, it ideal to include a disinfection aspect to correct these possible contaminants, as well as include a residual disinfection to prevent any additional contagions downstream of the original disinfection. Various types of water disinfection used in small and large scale settings include ultraviolet, ozone, and chlorine disinfection.
6.5.1. Ultraviolet Disinfection

Ultraviolet light (UV) uses the short UV wavelengths to disrupt DNA in microorganisms and inactivate them. In order for the UV to come in contact with all the water it is disinfecting, multiple banks of UV tubes are usually needed, with small spaces between tubes and large light to water surface areas. The advantages of UV are safety, low cost, and labor. The largest disadvantage of UV treatment is that there is no residual disinfectant in the water. In addition, for developing location applications, it has a continuous and large energy demand, which is not always reliable in these areas.

6.5.2. Ozone Disinfection

Ozone is an unstable molecule of three oxygen atoms, which makes it a strong oxidizing agent able to kill most waterborne organisms and pathogens. It leaves fewer byproducts than the chlorine disinfection methods, and has no odor or taste problems. Ozone is created by passing oxygen through a high voltage current. Due to its instability and quick decomposition time, ozone must be created on site of disinfection. Like UV treatment, this method also lacks residual disinfection.

6.5.3. Chlorine Disinfection

Chlorine is the most common form of water disinfection. Its value as a bacterial disinfectant has been known and exploited for nearly a century. One of its advantages is the possibility for residual disinfection in addition to point-of-use disinfection. It also has no energy constraints for continual use. Chlorine can be used in various forms, and can be easily stored. Constraints include length of storage due to decomposition, and type of storage container, as chlorine can react with metal. With too high levels of chlorine, changes to water taste and odor can become an issue. Byproducts created by reactions with organics in water are another issue with chlorination, although the WHO has stated those risks are far smaller than the risks associated with inadequate disinfection.

6.6. Water Chlorination

6.6.1. Chemistry of Chlorination

All sources of chlorine used in disinfection dissociate in water to form hypochlorous acid (HClO), hydrogen (H⁺), and and hypochlorite (ClO⁻) (Figure 4). The gaseous form of chlorine acidifies the water and reduces, while the liquid and solid forms increase the pH and alkalinity of water.
Hypochlorous acid is a biocidal that is able to enter bacterial cell walls and interfere with the enzyme systems, deactivating organisms and their ability to reproduce. Hypochlorous acid is neutrally charged, unlike many other components of water, and thus, instead of being repelled, can pass through the negatively charged membranes of bacteria and disrupt the cell components. The specific mechanism for this is not yet known. The hypochlorite ion is an oxidative agent that reacts with other reducing agents in the water, many times inorganics, and improves overall water quality.

Despite the success of chlorine disinfection, there are a few parasitic protozoans recently determined to be highly resistant waterborne pathogens. *Cryptosporidium parvum* and *Giardia lamblia* are the two most troublesome, and have posed a large challenge for the water disinfection industry. Currently, “filtration is the most effective process for removing these protozoa from drinking water”. The available methods of filtration and their effectivenesses are covered further in section 6.8.

### 6.6.2. Chlorine Extraction

Initially, the team set out to design a water treatment system that could extract the chlorine from a source in the earth and purify it for chlorine disinfection. The primary raw material for chlorine is rock salt. This is available worldwide in underground deposits that are pumped to the surface as a concentrated solution with high pressure water. The team looked into the possibility of extracting the raw minerals needed for chlorine from local materials from the mountain areas of Ecuador. This option was quickly ruled out by 1) the extravagant expenses needed to start up a mining structure, 2) complicated governmental regulations

\[ \text{Cl}_2 + \text{H}_2\text{O} \rightleftharpoons \text{HClO} + \text{HCl} \]

**Figure 4. Equilibrium of Chlorine in Water**

Hypochlorous acid is a biocidal that is able to enter bacterial cell walls and interfere with the enzyme systems, deactivating organisms and their ability to reproduce. Hypochlorous acid is neutrally charged, unlike many other components of water, and thus, instead of being repelled, can pass through the negatively charged membranes of bacteria and disrupt the cell components. The specific mechanism for this is not yet known. The hypochlorite ion is an oxidative agent that reacts with other reducing agents in the water, many times inorganics, and improves overall water quality.

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**Figure 5: a. Structure of Sodium Hypochlorite (NaClO-)** b. Structure of Hypochlorous Acid (HClO)

---


regarding mining and extraction and 3) little to no recent exploration of nonfuel mineral production, and difficulties in obtaining any new information. With these constraints in mind, as well as the cultural appropriateness and long startup time of the project, this project option was ruled out as a feasible option for Santiago de Quito.

6.6.3. Chlorine Production

Chlorine is available to be purchased as compressed elemental gas, aqueous sodium hypochlorite solution (NaOCl), or solid calcium hypochlorite (Ca(ClO)₂). Over 95% of chlorine production is based on the electrolysis of brine, an aqueous salt solution. The salt, such as sodium chloride (NaCl), commonly known as table salt, is electrolytically decomposed to chlorine, sodium hydroxide, and hydrogen between the two poles of an electric current, the anode and cathode. The chemistry of chlorine electrolysis follows the overall reaction:

\[
\text{Salt} + \text{Water} + \text{Electricity} \rightarrow \text{Chlorine} + \text{Custic} + \text{Hydrogen}
\]

\[
\begin{align*}
\text{NaCl} + \text{H}_2\text{O} + e^- & \rightarrow \frac{1}{2} \text{Cl}_2 + \text{NaOH} + \frac{1}{2} \text{H}_2 \\
2\text{NaCl}(aq) + 2\text{H}_2\text{O} & \rightarrow \text{Cl}_2(g) + \text{H}_2(g) + 2\text{NaOH}(aq)
\end{align*}
\]

(Chlorine Basics) (Caustic Soda). At the positively charged anode of the cell, negative ions are attracted. The major reaction here,

\[
\text{Cl}_2(aq) - 2e^- \rightarrow \text{Cl}_2(g)
\]

Along with a sub reaction,

\[
4\text{OH}^- (aq) - 4e^- \rightarrow 2\text{H}_2\text{O}(l) + \text{O}_2(g)
\]

In the gaseous phase, the chlorine must be purified to remove the oxygen. At the negative cathode, positive sodium and hydrogen ions are attracted. Here the reaction

\[
2\text{H}^+(aq) + 2e^- \rightarrow \text{H}_2(g)
\]

is completed. As the concentration of H₂(g) increases in the aqueous solution, the water equilibrium shifts to replace them as the H⁺ ions are removed during electrolysis:

\[
\text{H}_2\text{O}(l) \leftrightarrow \text{H}^+(aq) + \text{OH}^-(aq)
\]

All three of the co-products are highly reactive, and must be kept separate as produced to be independently useful.
Chlorine is manufactured using electrolysis technology, most commonly mercury, diaphragm, or membrane cell processes. Mercury cells use a mercury metal anode. Most diaphragm cells use asbestos as the chamber separator. Due to research proving the harm of both mercury and asbestos, there have been widespread policy changes to no longer implement these methods. A diaphragm membrane can be made with various other types of permeable materials separating the anode from the cathode. Both sodium and chloride ions can travel across the diaphragm resulting in cell solutions containing approximately 12% sodium hydroxide and 16% sodium chloride. The most common material used for the diaphragm is asbestos parchment. This technology is also outdated due to the carcinogenic effects of asbestos dust.

Thus, membrane technology is the method currently used for electrolysis. Perfluorinated polymer cation exchange membranes are used to separate the anodes and cathodes. Positive sodium ions and water can selectively travel across the membrane to the cathode side of the cell. Solid salt is usually used to re-saturate the brine. This method produces more concentrated solutions of sodium hydroxide, up to 35%. This process is the one most used today in large scale production settings. A diagram of how this cell is set up is shown below, in Figure 6.

![Figure 6. Typical Membrane Reactor Setup](http://www.essentialchemicalindustry.org/chemicals/chlorine.html)

Another option, which is much more simple, is electrolysis with no separation attempt between the cathodes. The advantage to this is that the brine then contains a solution of NaOCl, which can be immediately added to the water to disinfect it. This eliminates the need to store the chlorine. It also exists in a dilute solution, which is safer to handle.

Of the other two outputs to the membrane electrolytic process, caustic soda can be useful. It can be used to control pH, and is also used as a neutralizer for the fluoridation chemical, fluorosilicic acid (FSA) to
result in sodium fluoride. The other product, hydrogen, is a combustible gas that is used in various processes. However, it has little to no use in this context, due to the difficulties storing and transporting.

6.6.4. Chlorine Safety

Chlorine as a chemical has the potential to be hazardous to health, and safety when using chlorine compounds must be considered. Inhalation of chlorine gas can highly irritate the respiratory system and is categorized as a ‘choking agent’. A leak in a chlorine gas tank could also react explosively. Liquid chlorine, also known as bleach, can cause chemical burns and is a potential hazard. However, it is normally available as a 3-6% dilute solution, which does not have as significant effects. Physical contact with the solution however is not recommended, and must be properly cared for by washing with soap and water. Education about chlorine safety will need to be a part of the team’s recommendation to Santiago de Quito.

6.6.5. Chlorine Water Treatment

Various aspects affect how much chlorine is required to be added to water to achieve the desired level of disinfection. As chlorine reacts with dissolved chemicals in the water, such as microorganisms and plants, its disinfection properties are inactivated. The chlorine needed to overcome these impurities is termed the chlorine demand of a system. The point at which enough chlorine is added to a system to meet the chlorine demand is called the breakpoint. Additional chlorine must be added over the breakpoint to provide residual disinfection. Chlorine that does not combine with the other components is called free, or residual chlorine. This provides the disinfection that stays with the water as it travels through pipes.

6.6.6. Determining Chlorine Demand

Calculating the chlorine demand is a function of many aspects of water quality. On site, a chlorination test with the source water can be utilized to determine the chlorine demand. However, this can also be estimated using other parameters of the water quality. The initial demand is equal to the amount of reducing agents, in mg/L. These agents donate electrons to the chlorine ions, consuming the oxidative and disinfecting power of the chlorine. These agents include iron, manganese, sulfides, and nitrates (Fe^{2+}, Mn^{2+}, H_2S, NO_3^-). Each agent has an individual free chlorine demand factor in proportion to the chlorine demand, as seen in Table 2.
Table 2: Initial Chlorine Demand Factors for Reducing Agents.

<table>
<thead>
<tr>
<th>Water Quality (mg/L)</th>
<th>Free Chlorine Demand Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>X 0.64</td>
</tr>
<tr>
<td>Manganese</td>
<td>X 1.3</td>
</tr>
<tr>
<td>Sulfide</td>
<td>X 2.08</td>
</tr>
<tr>
<td>Nitrite</td>
<td>X 5.0</td>
</tr>
</tbody>
</table>

Other impurities in water act as combining agents, also contributing to the chlorine demand. These secondary demand agents are ammonias, NOM, and decayed plants/animals. Demand factors for these aspects are as follows.

Table 3: Secondary Chlorine Demand Factors for Combining Agents.

<table>
<thead>
<tr>
<th>Water Quality (mg/L)</th>
<th>Free Chlorine Demand Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia</td>
<td>X 10-12</td>
</tr>
<tr>
<td>Organic</td>
<td>X 1.0</td>
</tr>
<tr>
<td>Total Organic Carbon</td>
<td>X 0.1</td>
</tr>
</tbody>
</table>

Total demand is the addition of initial and secondary chlorine demand. Values for chlorine demand factors given from “Breakpoint Chlorination” by Spon Water Consulting.33

6.6.7. Chlorine Contact Time

Effective disinfection with chlorine also requires a long interaction between chlorine and the microorganisms. Proper contact time varies with water chlorine concentration, pathogens present, pH, and temperature. To calculate contact time, the system’s highest expected pH and lower water temperature should be used. The equation to find necessary residual is

\[
t \text{ (minutes required)} = \frac{K}{\text{chlorine residual (mg/L)}}.
\]

The K values used in this equation are based on pH and temperature parameters.
Table 4. K Values of Chlorine Contact Time based on pH and Temperature (Wagenet)

<table>
<thead>
<tr>
<th>pH</th>
<th>Lowest Water Temperature (degrees F)</th>
<th>&gt;50</th>
<th>45</th>
<th>&lt;40</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.5</td>
<td></td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.0</td>
<td></td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.5</td>
<td></td>
<td>12</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>8.0</td>
<td></td>
<td>16</td>
<td>20</td>
<td>24</td>
</tr>
<tr>
<td>8.5</td>
<td></td>
<td>20</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>9.0</td>
<td></td>
<td>24</td>
<td>30</td>
<td>36</td>
</tr>
</tbody>
</table>

From the time chlorine is added to the time a user can first use the water should be greater than the contact time in insure proper disinfection.

6.6.8. Residual Disinfection
Residual levels of chlorine are required by the Ecuadorian government in a water system to protect against further contaminants that may be introduced into the system downstream of disinfection. However, required chlorine doses that are also low enough to not be tasted are not sufficient to guard against pathogens that can result from the contamination due to sewage. Thus, it is extremely important that an area with water disinfection first have an effective wastewater system that can competently keep the two water systems completely isolated.

One aspect of chlorination that may potentially be harmful, especially when there are excess levels of chlorine in a system, is the creation of disinfection byproducts (DBP). The chlorine in water reacts with suspended solids and can produce undesirable components in the water that cause harmful side effects. Overall, these byproducts are significantly less harmful than anything that can be caused by inadequate disinfection, however it is a possibility that cannot be overlooked. More is written on this topic in section 6.6. Methods of Filtration.

6.7. Fluoride Addition
The possibility of fluoridation of the water system in Santiago de Quito is also a possibility for the team to continue researching. Fluoride is being considered because in low concentrations it is known to help reduce the incidence of tooth decay. It aids by binding to tooth enamel and making the tooth more resistant to bacteria, resulting in decreased rates of tooth decay. This is achieved by replacing
hydroxyapatite \((\text{Ca}_5(\text{PO}_4)_3\text{OH})\) with fluorapatite \((\text{Ca}_5(\text{PO}_4)_3\text{F})\), which is more resistant to acid attack. The reactions associated with this are:

\[
\begin{align*}
\text{Tooth decay:} & \quad \text{Ca}_5(\text{PO}_4)_3\text{OH}(s) + 4\text{H}_2\text{O}^+ (aq) \rightarrow 5\text{Ca}^{2+}(aq) + 3\text{HPO}_4^{2-} (aq) + 5\text{H}_2\text{O}(l) \\
\text{Fluoridation:} & \quad \text{Ca}_5(\text{PO}_4)_3\text{OH}(s) + \text{F}^-(aq) \rightarrow \text{Ca}_5(\text{PO}_4)_3\text{F}(s) + \text{OH}^- (aq)
\end{align*}
\]

However, at concentrations above 1.5 mg/L, there may be browning of teeth or even skeletal fluorosis at very high concentrations. The U.S. Department of Health and Human Services has recommended that 0.7 milligrams of fluoride per liter of water is the optimal fluoride consumption in water to prevent tooth decay.\(^{16}\)

This recommendation is based on many factors, one of which is the average American consumption of fluoride in daily food and other beverage sources. For a different country, such as Ecuador, these averages may be different. The Ecuadorian government has created a standard for fluoride in drinking water, which can be seen in Appendix Table 4.4.

It is likely that the decision whether or not to continue pursuing this additive will be entirely based on the community’s wants and attitudes towards fluoride. There are valid concerns that anyone who drinks more water than the average person, such as a laborer, could consume more than the recommended dose of fluoride, leading to the previously stated negative side effects. There is also a personal rights aspect of fluoridation, that once a system has fluoride, an individual cannot chose to be excluded.

Fluoride is a naturally occurring mineral that is present in many groundwaters. The level of fluoride in the water will need to be tested before addition parameters can be more specifically outlined. The three additive options for fluoridation are fluorosilicic acid, a water based solution, sodium fluorosilicate, and sodium fluoride, two dry additives that are typically dissolved into a solution before being added to water.\(^{30}\)

The general concept of fluoridation is usually completed with the use of a tabetized form of disodium hexafluorosilicate \((\text{Na}_2\text{SiF}_6)\). The reaction for this tablet or powder in water is as follows,

\[
\text{Na}_2\text{SiF}_6 + 4\text{H}_2\text{O} \leftrightarrow 6\text{F}^-\text{Si(OH)} + 2\text{Na}^+ + 4\text{H}^+
\]

Where the extent of fluoridation lies in the extent of dissociation of disodium hexafluorosilicate. This artificial addition of fluoride is treated the same chemically as natural fluoridation when it comes to the user. Natural fluoridation happens when the water travels over rocks containing the mineral fluorspar or calcium fluoride \((\text{CaF}_2)\). This reaction:

\[
\text{CaF}_2 \rightarrow \text{Ca}^{2+} + 2\text{F}^-
\]

allows the concentration of fluoride ions to be higher in water which consequently gives the health effects as mentioned above.\(^{31}\) Sodium hexafluorosilicate is the most commonly used and least expensive solid fluoride source. Availability in Ecuador will be assessed during the trip to Santiago de Quito.
6.8. Methods of Filtration

The biggest problem in water systems, especially drinking water systems, lies in the methods of removing undesired contaminants. With the chosen method of disinfection being chlorination, possible byproducts of chlorination becomes a significant issue to address. Disinfection byproducts (DBP) are created when natural organic matter (NOM), in the form of suspended solids, interacts with the disinfectants. Evidence suggests the current water source may have excess NOM since NOM is a major component in the formation of peat and organic acid. From research of various contaminants, organic acid is believed to be a possible source of the green color when cooking rice. Water quality testing will confirm these assumptions at the end of January. Common DPB when disinfecting with chlorine involve Trihalomethane (THM), Haloacetic acid (HAA), and Mucochloric acid (MCA). Research has shown that a nanofiltration membrane is one of the best methods for removing THM in drinking water.8 Reactions take place on the filtration membrane that specifically interact with THM to consume it and essentially remove it from the water. Once the water quality tests are conducted, the necessity of the nanofilter will be reevaluated.

The biggest downside to membrane filters is that it can be easily destroyed by chlorine and requires a large amount of daily backwashing, quarterly cleans, and troubleshooting. The pressure drop through the membrane is the biggest factor in operation. As the membrane works more and more to remove the contaminants, the pressure across the filter builds requiring daily backwashing and more extensive monthly and quarterly washes. Forms of membrane filtration includes microfiltration, ultrafiltration, nanofiltration, and reverse osmosis. All of these filtration systems have varying pore sizes and pressure requirements. Table 5 outlines the different aspects of each membrane filter.

<table>
<thead>
<tr>
<th>Filtration method</th>
<th>Pore Size (microns)</th>
<th>Pressure (kPa)</th>
<th>Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microfiltration</td>
<td>0.03 – 10</td>
<td>100 – 400</td>
<td>Sand, silt, clays, cryptosporidium cysts, algae, and some bacterial species</td>
</tr>
<tr>
<td>Ultrafiltration</td>
<td>0.002 – 0.1</td>
<td>200 – 700</td>
<td>Microbiological species, viruses, and humic material</td>
</tr>
<tr>
<td>Nanofiltration</td>
<td>0.001</td>
<td>600 – 1,000</td>
<td>Cysts, bacteria, viruses, and humic materials</td>
</tr>
<tr>
<td>Reverse Osmosis</td>
<td>&lt; 0.001</td>
<td>N/A</td>
<td>NOM, cysts, bacteria, and viruses</td>
</tr>
</tbody>
</table>

Another method of filtering the DBP with less involvement is to prevent the production of these products at source of NOM. The biggest component to filtering out NOM involves the size of the material, the electrostatic repulsion, and aromaticity. Sand filtration could be a potential method in removing the
organics from the water before the chlorine is dosed. Cysts of protozoa such as Giardia and Cryptosporidium are also efficiently removed by means of slow sand filters. Similarly, enteric viruses are inactivated by the maintenance of a disinfectant residual of at least 0.5 mg/litre free chlorine for a minimum of 30 minutes in waters with a turbidity of less than 1 NTU and a pH of less than 8.0. The biggest downside to this method, and may be the reason it could be ruled out, is the size and cost of the filter. Depending on the water quality tests, however, sand filtration could be a necessary addition if iron is present.

Acidity of the water indicates the presence of organic acids as well as potential iron contamination. The green color to the water could be potentially due to the presence of organic acids. Nitrate contamination is another common contaminant in groundwater wells and may be in need of filtration to prevent and harmful side effects. At this point in the project, membrane filtration has been ruled out for the newest well, however it along with other methods of filtration including sand filtration, greensand filtration, coagulation, and flocculation may still be a part of the equation to remove these contaminants if necessary.

7. Design Alternatives

7.1. Disinfection

7.1.1. Feasible Alternative

Current practices for water disinfection include ozone, UV and chlorine treatment. Worldwide, the most commonly used material for water disinfection is chlorine. As a cost effective and efficient bactericide, chlorine is relatively easy to obtain and store, as well as being relatively harmless in its customary concentrations. It was also the most obvious choice since chlorine is already required by the Ecuadorian government for purposes of residual disinfection. In addition, the other methods of ozone and UV require constant electricity and technology that would be difficult to replace or repair in rural Ecuador due to lack of materials and specific technical education. Therefore, chlorine was chosen as the best method of disinfection.

7.1.2. Chlorine and Fluoride Derivation Methods

For a remote location, such as Santiago de Quito, the hardest part about using chlorine in a water system would be acquiring the chlorine, and maintaining the appropriate supply needed to treat water. Both liquid and powder bleach can degrade when stored for long periods of time. In addition, chlorine is difficult to transport economically. Thus, the production of chlorine on site would be a useful aspect of an isolated water system.
Due to regulatory restrictions the mining of rock salt for the purposes of chlorine extraction was ruled out early in the research process and the team continued to research other alternatives for acquiring and producing chlorine and fluoride. After analysis, electrolysis was determined to be the best method of chlorine production. Mercury and asbestos diaphragm cells were determined to be unhealthy alternatives and research on those options were discontinued. The remaining considerations for chlorine production were either membrane cell electrolysis, or electrolysis without a membrane. Each option would produce chlorine as a form that would be sufficient for disinfection purposes.

However, there are differences in the form of chlorine produced from the membrane electrolysis versus one cell electrolysis. Membrane reactors produce hydrogen and chlorine that bubble from the cathode and anode as gaseous products. From there, the gaseous chlorine would need to be immediately converted to liquid phase, due to the elevated risks of gaseous chlorine. Compression and liquefaction of chlorine gas would require additional equipment including a compressor and chillers or refrigerants.

One cell electrolysis would produce the chlorine as part of the original brine solution, in the form of sodium hypochlorite (NaOCl). This chemical form is very dilute and is safer to handle. This solution could be added directly to water to disinfect it without any other treatments. Since the solution will contain all the components of the salt, the type of salt used for this process should be an common table salt, with acceptable amounts of metals. If other rock salts are used, which contain higher levels of metals, individuals have the potential to intake more than the daily recommended dose.

In addition, the team has been made aware that there already exists a one cell electrolysis system that exists in Santiago de Quito (information from Bruce Rydbeck). The location of this electrolysis system is in a local medical clinic. A picture of the equipment in use, as of last January, 2015, is pictured below.
In talking further with Mr. Rydbeck about this machine, it was discovered this is a 60 liter hydraulic unit. 60 liters of water is combined with 2 kg of salt for each batch. This produces a chlorine solution given by the equipment manual as 2% chlorine. However, Bruce Rydbeck commented that in practice, this solution is closer to 1.25% chlorine.

7.1.3. Chlorine Dosing Specifications

There are various parameter specifications from which to base the design, including specs given by Mr. Rydbeck, the Ecuadorian government, and worldwide development organizations. A table summarizing these options are shown below.
Table 6: Residual Chlorine Standards for Addition to Drinking Water.

<table>
<thead>
<tr>
<th>Desired (mg/L)</th>
<th>Ecuadorian Government</th>
<th>World Health Org. (WHO)</th>
<th>Mr. Rydbeck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptable Limit</td>
<td>0.3-1.5</td>
<td>0.2-x</td>
<td>0.5</td>
</tr>
</tbody>
</table>

It is required that the design level of chlorine be within the government standards, however it is preferred that it meets all requirements. Mr. Rydbeck has commented that, in his experience, communities in Ecuador tend to reject water with more than 0.5 ppm (mg/L) chlorine due to adverse taste. If this were to happen, it would defeat the purpose of the entire chlorination design. Thus, the chosen level of residual chlorination for this project is 0.5 ppm (mg/L).

7.1.4. Preliminary Chlorine Dosing Calculations

Determining the overall chlorine dose needed for proper residual disinfection is based on chlorine demand and residual past the breakpoint.

\[
\text{Dose (mg/L) = Demand (mg/L) + Residual (mg/L)}. 
\]

The demand can be determined by chlorine dosing tests using the water samples, or through the method outlined in section 6.5.6. Both methods require values taken by testing of the water in Santiago de Quito. Without those values currently, the chlorine demand is going to be modeled as 0 mg/L. Once this test has been completed in January, the system demand will be updated.

Based on the estimated 2,300 residents of the Santiago de Quito area twenty years out, in 2035, the water demand would be 227124 liters, or 60,000 gallons. Chlorine residual demand for this system would need to be

\[
\text{free chlorine} = \frac{227124 \text{ L}}{\text{day}} \times \frac{0.5 \text{ mg}}{\text{L}} = 113.5 \text{ grams chlorine/day}. 
\]

Assuming the electrolysis equipment was similar to the one that already exists in the Santiago de Quito medical clinic (Figure 6), the percent chlorine in solution would be 2%, which is 20,000 ppm (mg/L). Thus, the daily sodium hypochlorite solution would need to be

\[
\text{sodium hypochlorite solution demand} = \frac{113.5 \text{ grams chlorine/day}}{20,000 \text{ mg/L}} = 5.68 \text{ liters solution/day}. 
\]

Alternatively, if the percent chlorine is only the 1.5%, as suggested by Mr. Rydbeck, the solution demand would be
sodium hypochlorite solution demand = \frac{113.5 \text{g chlorine}}{\text{day}} \times \frac{1 \text{L}}{15,000 \text{mg}} = 7.57 \text{ liters solution/day}.

Contact time is also determinate on water quality tests. However, estimates for contact time can be made based on water quality information from nearby areas. Using the city of Apatug from the ACE team’s report last year, it can be assumed water temperatures and pH’s are between 53 and 60 degrees Fahrenheit (11.7 and 15.6 degrees Celsius) and 7.5 and 8 pH, respectively. As the K value calculation method requires, the lowest temperature and highest pH are used for calculation. From Table 4, the K value is 16. Using equation below, the contact time is

\[ t \ (\text{minutes required}) = \frac{K}{\text{chlorine residual (mg/L)}} = \frac{16}{0.5 \text{ mg/L}} = 32 \text{ minutes contact time}. \]

This time will be updated with specific information gathered in Santiago de Quito at the end of January.

7.2. Fluoride Addition

While the recommendation for the addition of fluoride is going to be highly dependent on community attitude towards additional chemicals, there are a few design decisions that can be made in advance. Appendix Table 4.4 gives standards from the Ecuadorian government on fluoride concentrations. These are based on average annual temperatures. For the community of Santiago de Quito, where the average annual temperature is 12 degrees Celsius, the desired range of fluoride is 1.27-1.17 mg/L. The maximum acceptable limit is 1.7 mg/L. If fluoride was added to the Santiago de Quito system, the optimal level would be 1.17 mg/L. The corresponding fluoride dosing based on projected demand is as follows:

\[ \frac{272124 \text{L}}{\text{day}} \times 1.17 \text{mg fluoride} = 265.7 \text{ grams chlorine/day} \]

7.3. Chlorine / Fluoride Dosing System

In the past, chlorine and fluoride dosing have been largely rejected by local people due to taste and maintenance concerns. However, in order to comply with government regulations, the team will be designing a system with treatment capabilities. As a result, the team has chosen to utilize the non-electric fluid driven injector pump design by the Ecuadorian Water Distribution Team in 2014 to consistently and reliably dose the water with chlorine.

Nonelectric fluid driven pumps are ideal for developing regions because they do not require electricity and provide a liquid chemical feed proportional to flow.\(^3\) Maintenance is also minimal since a full-time operator is not necessary but rather only an occasional O-ring’s will need to be replaced. Based on this ACE team’s results, the final injector pump will be the Dosmatic® SuperDos 20 2.5%.\(^3\) See Appendix H for Pump Specifications. This pump was chosen by the team because it allows for a greater flow range at a higher dosing ratio than comparable pumps. It also does not have to complete as many cycles to achieve a higher dosing ratio which will reduce wear and tear to extend the future life of the pump.\(^3\)
7.4. Filtration Method / System

The biggest constraint in choosing the correct method of filtration lies in the level of troubleshooting and replacement required. This system needs to be reliable and not easily broken. Ideally, the best system would include little to no involvement of the indigenous people while still delivering optimal filtration since they do not have the technical experience necessary for reliable operation. For a third world community and at this point in the research, membrane filtration will most likely not be necessary for the newest well. However, this does depend on the quality of the water in the new well which will be tested during the team’s trip at the end of January. The old well, which is assumed to contain peat and organic acid, will need to be analyzed for the potential implementation and consequent filtration. Figure 8 shows a design matrix for the implementation of a membrane filter on the old well.

![Figure 8: Design Matrix for the filtration method potential with membrane filter.](image)

The weight for each decision will be placed on each method once the water quality data is taken at the end of January.

7.5. Distribution System Approach

Complete distribution system analysis will include existing system model creation and proposed system model creation. For modeling purposes, community homes will be placed as nodes so that demands can be represented. Modeling will be done using EPANET a water distribution modeling software often used for designing drinking water systems.

The existing model will help the team identify problem areas as well as portions of the system that can be used in the new design. Inspection of existing system pipes will be critical to determine which, if any,
current pipes are usable in the new design. Accounting for unusable pipes may require their replacement or damage repair depending on onsite analyses.

The proposed model will incorporate desired improvements to the community’s system including home connections, a pump house connecting the newly built well, and connection to the 40m³ reservoir tank. Since existing plans of the site are currently unavailable, most of the distribution modeling will be done after survey information is collected from both the team’s trip in January as well as an Engineering Missions International survey trip done in November which primarily focused on topographical survey information. Final survey information will include additional necessary topographical information as well as dimensions and locations of the existing distribution lines and water sources. A draft trip agenda is presented in section 8.1. This information will then be put on engineering plans and used for modeling the distribution system. It is also important to note that during modeling pressure zones should be implemented to maintain reasonable pressures in this mountainous regions. Pressure reducing valves (PRVs) will be used to create these zones.²

For treatment of the distribution system, the team will look at water samples from the final sources and determine the optimal dosing approach for chlorine and fluoride procedures. Maintenance, cost, and demand considerations will be used to determine what sources should be kept in the final design. The primary focus of treatment is to meet The Ecuadorian Standards of contaminant levels outlined in Appendix E.

7.5.1. Distribution Design Analysis

Current distribution analysis includes projected population and demand estimates. See Table 7 for complete population estimates based on an annual growth rate specified by Ecuadorian Standards.

<table>
<thead>
<tr>
<th>Table 7. Santiago De Quito Population.²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of homes</td>
</tr>
<tr>
<td>People per home</td>
</tr>
<tr>
<td>Estimated Population</td>
</tr>
<tr>
<td>Annual Growth Rate</td>
</tr>
<tr>
<td>Projected Population (2035)</td>
</tr>
</tbody>
</table>

As specified in the Ecuadorian Standards, the daily demand requirement per person for the community is 100 liters [26.4 gal/person/day]. According to population estimates, the community’s current demand is approximately 33,000gpd while projected demand in 2035 is approximately 60,000 gpd. Compared to the supply rate of the new well pumping 36,000gpd (25gpm), an additional water source will need to be considered to meet the projected demand of the community. Additional source options that will be considered are outlined in section 7.5.1 Well Analysis. It is also noted that the newly built reservoir only
has a capacity of 10,600 gallons so additional reservoirs may need to be constructed. Overall the team's analysis will focus on designing a reliable system that supplies potable water to the community.

7.5.2. Well Analysis

The team will be conducting multiple well analysis’ for the community. The purpose of these analysis’ will be to evaluate what wells should be utilized in the final design. Well analysis will include water samples of the existing well, the new well, the regional system, and the domestic wells. Additional water samples will be taken from Laguna Colta for contaminant comparison. The types of water tests conducted are discussed in the trip agenda in section 8.1 and a draft sample data collection sheet is provided in Appendix K. These analysis’ will help to determine what treatment processes should be utilized for a water source and whether a source should be avoided due to quality issues.

During analysis the team will also consider the new well’s lack of capacity to provide for projected growth demands. The team will need to assess what additional sources could be treated and utilized to better meet this demand or whether adding an additional well near to the newly built well could better account for the lack of capacity. It is important to the team’s goal to provide as much community members as possible with clean reliable water.

During analyses the team will have to consider the communities current financial situation. If an additional source is necessary to meet demand, both constructing an additional well or treating an existing source will put additional cost burdens on the community. Therefore, although analysis may suggested a second source be utilized, this may not be financially possible for the community and will serve mainly as a proposed improvement for the community to implement in the future.

7.5.3. Pump House Design Approach

A preliminary pump house design for the new well has been developed by Efraín Morocho according to his report Improvement of the Potable Water System which was given to the team. His design utilizes two submersible 25FA2s4 pumps (one for redundancy), each with a pumping rate of 25 gpm and 2 hp motors. The pump specifications are shown in Appendix X. The plan also utilizes a 2.6x 2.6x 2.1m masonry brick pump house surrounding the well and pumps. As well as a 400m, 63mm pvc pipe surge line connection between the pumping station and reservoir tank (Morocho, Efraín).

The team will evaluate this preliminary design after further survey information is collected during the trip in January. The final pumphouse design will be based on the topography and layout of the system. The goal of the pumphouse is to deliver water to the community homes at reasonable pressures. Since the pump house will bring water to the elevated storage tank, the team will use elevations of the well and the reservoir to determine the shutoff head and discharge needed for pump design. A masonry brick building will be provided around the well and submersible pumps to ensure both are protected from debris and surface runoff.
7.5.4. Source Alternatives

During design the team will be looking at different source alternatives to provide for the population demand. Various sources that will need evaluation include an existing contaminated well, a newly built well, and the existing regional connection. Analysis of these sources will include water samples, advised treatment procedures, and cost estimates. If treatment is determined to be unrealistic either by the necessary dosing levels, potential costs, or maintenance, the team may decide to disconnect the source from the system. The team will also be considering the option of designing a second well next to the newly built well. The hope is a second well could provide extra capacity, if need be, for the community from a reliable source.

7.5.5. Pressure Control / Pressure Zones

Water distributions systems are designed to keep each node (such as a house connection) within a certain pressure range. For Ecuador, this range is between 7 and 30 meters (10 and 43 psi).¹ The pressure at a node is determined by the equation:

\[ H = P + Z \]  

(1)

where:

- \( H \) = hydraulic (piezometric) head
- \( P \) = pressure head at the node
- \( Z \) = node elevation

Each variable has units of length, such as meters. The pressure head can be converted to pressure units by multiplying by the specific weight of water.

A pressure zone is a section of the distribution system that has a single hydraulic head value. The hydraulic head is set by the water surface elevation (WSE) in a storage tank or reservoir or by the pressure setting of a pressure reducing valve. According to (1), minimum pressures will occur at the node with the highest elevation and the lowest node will experience maximum pressures. If the pressures at a node fall outside of the 7 - 30 meter range, another pressure zone must be designed. Due to the community’s mountainous geography, multiple pressure zones will be required to keep pressures within the range. See Appendix I for the preliminary designed pressure zones for the community. These pressure zones are based on the topographic map shown in Appendix C and will need to be verified with survey data.

8. Future Work

At this point in the project, the team is transitioning from initial research to design alternatives and optimization. More work will be conducted in the areas of filtration methods, chlorination dosing, purification, and distribution system analysis after the team's trip in January.
8.1. Trip to Ecuador

The team will take a trip down to Ecuador for a week in late January to visit the community of Santiago de Quito. This trip will give the team a chance to collect information about the existing system and see firsthand the people that this design will benefit. While in Ecuador, the team will be taking samples of the water quality, measuring and analyzing parameters of the current water system, and learning more of the physical constraints of the project. Mr. Rydbeck has plans to show the team other communities that have had similar projects done so that the team can better understand design and cultural concepts that make water distribution projects successful in this region.

8.2. Trip Agenda

A preliminary trip agenda has been prepared for testing, survey, and other work to be done on the trip:

- Additional topographical survey work as necessary to add information to the plans.
- Assessment of the existing house water connections and meters.
- Measure existing drilled well dimensions and flow rates.
- Measure and assess existing well pumping facilities (flow rates, pump specs, pump house dimensions).
- Measure reservoir tank current condition as well as its dimensions, use, and materials.
- Measure/verify newly drilled well dimensioning and flow rates.
- Conduct newly drilled well drawdown test if necessary.
- Conduct water test sampling of the new well, old well, regional system, domestic wells, and surrounding lake.
  - Testing will include: copper, peat, pH, coliforms, hardness, TDS, iron, manganese, nitrates, sulfate, fluorides, and organic matter/acid.
- Chlorine demand test.
- Review the wastewater situation of the communities.
  - Inquire about the sewer system plan.
  - Brief survey work if necessary.
  - Where does it discharge?
- Visits to other nearby communities with successful pumped water systems - observations and discussions with their leaders and water system operators.
- Review/assessment of chlorination disinfection in several communities to help guide chlorination design for Santiago de Quito.
- Visit the local government water laboratory to understand their role in this project and obtain additional testing if needed.
- Visit local hospitals to inquire about water related disease outbreaks.
- Plan out design work with the community to insure project end result is useful to the community.
A final list of tests to be conducted will be finalized in January before the team leaves for Ecuador. Possible water tests include but are not limited to a Hatch Nine-Parameter Test Kits, Ion Chromatography at Calvin if samples can be brought back properly, or local tests at a local governmental testing facility the client has mentioned. Necessary equipment and kits will be obtained before the departure date. Tests will also be researched and practiced to insure efficient and accurate use on site. Sample data collection sheets can be seen in the Appendix.K.

8.3. Spring Semester

By spring, the team will finalize research and transition into designing the plans of the distribution and disinfection system. This work will be a part of the second half of the senior design course (Engineering 340) and will be completed by graduation in May.

9. Acknowledgements

The team would like to take this opportunity to formally thank the following for generously giving their valuable time and expertise to the benefit of the team and the project:

Martin Henrich, a German missionary engineer, the team’s main contact, who was very generous with his time and helping us with design work and information; Bruce Rydbeck, the founder of Life Giving Water and the team’s main local contact for his help and guidance during the duration of the project; Efrain Morocho, a local engineer for his engineering efforts on the project; Jeremy VanAntwerp, a Chemical Engineering Professor at Calvin College and the team’s advisor for his insight into chemical processes and project oversight; Robert Masselink, a Civil Engineering Professor at Calvin College and the team’s second advisor for his time and oversight of the project; David Baar from FTCH, the team’s official industrial consultant for meeting with the team throughout the year to discuss the team’s progress; Benjamin Whitehead from Black & Veatch, a second industrial consultant and member of AWWA who shared his experience with Ecuadorian water distribution projects; David Wunder an Environmental Engineering Professor at Calvin College for his insight into water treatment systems both locally and internationally; Robert Hoeksema a Civil Engineering Professor at Calvin College for his insight into water distribution design; And the EMI team for their time and efforts to survey the area surrounding Quito and the distribution system.

10. Sources


36


   "NITRATE POLLUTION OF GROUNDWATER." NITRATE POLLUTION OF GROUNDWATER. Web. 4 Dec. 2015.
Appendix A. Location Map A
Appendix C. Population Distribution

<table>
<thead>
<tr>
<th>Sector</th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sector 1</td>
<td>185</td>
<td>186</td>
<td>371</td>
<td>32%</td>
</tr>
<tr>
<td>Sector 2</td>
<td>106</td>
<td>130</td>
<td>236</td>
<td>20%</td>
</tr>
<tr>
<td>Sector 3</td>
<td>26</td>
<td>25</td>
<td>51</td>
<td>4%</td>
</tr>
<tr>
<td>Sector 4</td>
<td>77</td>
<td>97</td>
<td>174</td>
<td>15%</td>
</tr>
<tr>
<td>Sector 5</td>
<td>154</td>
<td>174</td>
<td>328</td>
<td>28%</td>
</tr>
<tr>
<td>Total</td>
<td>548</td>
<td>612</td>
<td>1160</td>
<td>100%</td>
</tr>
</tbody>
</table>
Fall 2015
Bruce & Cherith Rydbeck

RYDBECK RIPPLES
Sharing the living water.

Enabling Communities to model spiritual and physical health through Life-Giving Water

If anyone is thirsty, let him come to me and drink. Jesus - John 7:37

Help, the Water Turns Our Rice Green!

People in Santiago de Quito realized the vile quality of their water when cooked rice turned green! CODEINSE/Kawsaypak Yaku, our Ecuadorian ministry partner, took on the challenge to assist the community - providing the technical assistance needed. They completed a hand-dug well producing 50 gallons per minute of clean water. But the process has just begun. A topographic survey, design of the piping and reservoirs for the distribution system, an estimate and financing must be completed to facilitate the remaining construction for their water system. The community contributes materials and labor.

Bruce watched a fire department tanker truck hauling water to homes. “Thank you! Clean water makes a huge difference for our 500 students,” exclaimed the school principal.

Even before the well completion the community began using a fire department tanker truck to distribute water.

Martin & Julia Henrich and their children; Finn Yanik, Joel, and Phil Joos, from Germany recently moved to Riobamba, Ecuador to serve with the Kawsaypak Yaku water ministry. Martin, an engineer, worked previously with us on projects.

CODEINSE/Kawsaypak Yaku, the Quicha mission organization with whom we work is boldly growing their ministry to rural communities. They signed working agreements with Life Giving Water International and two other missions.
The Ecuadorian Standards\(^1\) specifies certain design constraints for drinking water as well as sanitation systems in Ecuador. Some highlights are shown below and are used for the design process in the Santiago de Quito distribution system. According to government literature, Santiago de Quito is categorized as a 2b community with greater than 2,500 inhabitants, household water connections, and more than 1 faucet located in the homes.

### Table E.1. Chlorine Standards

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Desired Limit</th>
<th>Maximum Acceptable Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbidity (NTU)</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Residual chlorine (mg / l)</td>
<td>0.5</td>
<td>0.3-1.5</td>
</tr>
<tr>
<td>PH</td>
<td>7.0-8.5</td>
<td>6.5-9.5</td>
</tr>
</tbody>
</table>

### Table E.2. Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Desired Limit</th>
<th>Maximum Acceptable Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>total Coliforms (NMP/100 cm3)</td>
<td>absence</td>
<td>absence</td>
</tr>
<tr>
<td>Color (UC Pt-Co)</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>Odor</td>
<td>absence</td>
<td>absence</td>
</tr>
<tr>
<td>Flavor</td>
<td>objectionable</td>
<td>objectionable</td>
</tr>
</tbody>
</table>

Table E.3 Concentration of Fluoride

<table>
<thead>
<tr>
<th>Annual Average Temperature (degrees Celsius)</th>
<th>Desirable Limit (mg/L)</th>
<th>Maximum Acceptable (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0-12.0</td>
<td>1.27-1.17</td>
<td>1.7</td>
</tr>
<tr>
<td>12.1-14.6</td>
<td>1.17-1.06</td>
<td>1.5</td>
</tr>
<tr>
<td>14.7-17.6</td>
<td>1.06-0.96</td>
<td>1.3</td>
</tr>
<tr>
<td>17.7-21.4</td>
<td>0.96-0.86</td>
<td>1.2</td>
</tr>
<tr>
<td>21.5-26.2</td>
<td>0.86-0.76</td>
<td>0.8</td>
</tr>
<tr>
<td>26.3-32.6</td>
<td>0.76-0.65</td>
<td>0.8</td>
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</tbody>
</table>

Table E.4 Parameters III

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Desired Limit</th>
<th>Maximum Acceptable Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness (mg / l CaCO3)</td>
<td>120</td>
<td>300</td>
</tr>
<tr>
<td>TDS (mg / l)</td>
<td>500</td>
<td>1000</td>
</tr>
<tr>
<td>Iron (mg / l) 500</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Manganese (mg / l)</td>
<td>0.05</td>
<td>0.3</td>
</tr>
<tr>
<td>Nitrates (mg / lNO3-)</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>Sulfate (mg / l)</td>
<td>50</td>
<td>400</td>
</tr>
<tr>
<td>Fluorides</td>
<td>Table 4.4</td>
<td>Table 4.4</td>
</tr>
</tbody>
</table>

Table E.5 Water Allocations for different levels of service

<table>
<thead>
<tr>
<th>Level of services</th>
<th>Cold Weather (l/person*day)</th>
<th>Warm Weather (l/person*day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>lla</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>lb</td>
<td>5</td>
<td>65</td>
</tr>
<tr>
<td>lla</td>
<td>60</td>
<td>85</td>
</tr>
<tr>
<td>llb</td>
<td>75</td>
<td>100</td>
</tr>
</tbody>
</table>
Appendix F. Gantt Chart
Accurate and Reliable

Installed directly in the fluid supply line, the injector operates without electricity, using fluid (water) pressure as the power source. The fluid drives the injector, which pulls the required percentage of concentrate directly from the chemical solution container. Inside the Hydro patented mixing chamber, the concentrate is mixed with the fluid, and the fluid pressure forces the mixed solution downstream. The amount of concentrate will be directly proportional to the volume of fluid entering the injector, regardless of variations in flow or pressure.

Chemical does not come in contact with the motor.

Chemical is mixed in the patented mixing chamber.

Fluid flow drives motor piston.

Blended solution

"MiniDos model shown, example only. SuperDos 20 is not equipped with on/off lever."
**Package Contents**

The injector is packaged with the following items:

- Injector (not shown)
- Dosage Piston
- O-ring
- Manual (not shown)
- Lower End Wrench (0.03" only)
- Mounting Bracket
- Mounting Nuts and Bolts
- Filter
- Suction Tube

<table>
<thead>
<tr>
<th>Model</th>
<th>NPT</th>
<th>BSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3%</td>
<td>113228R</td>
<td>113728R</td>
</tr>
<tr>
<td>0.3% HAC</td>
<td>113228HAC</td>
<td>113728HAC</td>
</tr>
<tr>
<td>2.5%</td>
<td>113205</td>
<td>113705</td>
</tr>
<tr>
<td>2.5% WSP</td>
<td>113205WSP</td>
<td>113705WSP</td>
</tr>
<tr>
<td>5%</td>
<td>113206</td>
<td>113706</td>
</tr>
<tr>
<td>10%</td>
<td>113207</td>
<td>113707</td>
</tr>
<tr>
<td>10% Remote Injection</td>
<td>113232</td>
<td>113233</td>
</tr>
<tr>
<td>2.5% HAC</td>
<td>113205HAC</td>
<td>113706HAC</td>
</tr>
<tr>
<td>5% HAC</td>
<td>113206HAC</td>
<td>113706HAC</td>
</tr>
</tbody>
</table>

**Specifications**

**SuperDos 20 gpm (100 max. psi)**

- **Model 0.3%**: 0.005% - 0.03%, 0.6000 - 1.933
- **Model 2.5%**: 0.005% - 0.03%, 0.6000 - 1.933
- **Model 5%**: 0.005% - 0.03%, 0.6000 - 1.933
- **Model 10%**: 0.005% - 0.03%, 0.6000 - 1.933

- **Flow Rate**: 0.05 - 30 gpm (11 - 4,500 l/hr)
- **Operating Pressure**: 5 - 100 psi (0.34 - 6.9 bar)
- **Pipe Coupling**: 1" NPT/BSP
  - *10% model maximum operating pressure to 65 psi (4.5 bar).
  - ** 5% with remote injection kit maximum operating pressure to 60 psi (4 bar).

**Housing**: Proprietary Engineered Composite Material

- **Avg. Dosing Accuracy**: ±± 5% of ratio
- **Repeatability**: ±± 3% of ratio
- **Maximum Temp.**: 109°F (40°C)
- **Minimum Temp.**: 34°F (-1°C)
- **Maximum vertical suction of concentrate**: 13 Feet (3.6 Meter)
- **Maximum horizontal suction of concentrate**: 49 Feet (15 Meter)
- **Self-Priming**: Yes

**Seal Material Available:**

- *Contact your distributor for specific chemical information*
- **Alkaline concentrates**
- **Viton - Acids, oils & pesticides**
- **EPDM - Alkaline concentrates**
- **Kalrez**
Franklin Electric 4400 Tri-Seal 25FA2S4-PE Submersible Well Pump End Only 25 GPM 2.0 HP

Franklin Electric 4400 Tri-Seal

The Standard FPS 4400 4-inch submersible pump features the new TRI-SEAL floating stage system. This new stage system improves efficiency and protects against wear when pumping abrasives (sand). All FPS 4400 pumps are unconditionally guaranteed against sand locking in abrasive conditions for one full year.

Franklin Electric 4400 Tri-Seal Features

- 300 series stainless steel hub floats with the impeller maintaining a positive seal
- Phenolic washer provides down-thrust protection
- Celcon®* impeller provides high efficiency performance and abrasion resistance
- Noryl®* diffuser and disc - proven abrasion resistant material
- Floating stage design allows impeller to float independently
- Removable, spring-loaded check valve
- Maximum water temperature: 120 °F / 49 °C
- Ceramic shaft sleeve and rubber discharge bearing protect shaft and eliminate sand wear
- Powered by Franklin Electric corrosion resistant 4" submersible motor

Patented impeller hub seal system seals radially and axially to prevent fluid recirculation. Providing high performance in the harshest conditions.
Shipping Weight:
11.0 LBS
Shipping Dimensions
Length: 5 In
Width: 5 In
Height: 19.22 In
Appendix I. Pressure Zones

Pressure Zone 1:
3364m - 3341m
Heads = 3371m

Pressure Zone 2:
3321m - 3318m
Heads = 3328m

Pressure Zone 3:
3318m - 3302m
Heads = 3325m
## Appendix K. Testing Sheets

<table>
<thead>
<tr>
<th></th>
<th>Apatug Water Sample</th>
<th>Purified Water Sample*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time 1</td>
<td>Time 2</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonia (mg/L)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrite (mg/L)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Hardness (mg/L)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloride (mg/L)</td>
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<td></td>
</tr>
<tr>
<td>Copper (mg/L)</td>
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<td></td>
</tr>
<tr>
<td>TDS (mg/L)</td>
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<tr>
<td>Iron (mg/L)</td>
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</tr>
<tr>
<td>Manganese (mg/L)</td>
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</tr>
<tr>
<td>Sulfates (mg/L)</td>
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<td></td>
</tr>
<tr>
<td>Fluorides (mg/L)</td>
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<td></td>
</tr>
<tr>
<td>Organic Matter/Acid</td>
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<td></td>
</tr>
<tr>
<td>(mg/L)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Filtered Drinking Water from Quito, Ecuador