Abstract
The Green to Clean team has successfully worked with the community of Santiago de Quito in Ecuador to evaluate and design improvements to their water distribution system. This project came at the request of Bruce Rydbeck, the project client, who has experience working on other rural water distribution systems in South American countries and is the founder of Life Giving Water International. The team also worked in close collaboration with Codeinse Ecuador, a civil engineering consultant group with experienced engineers Martin Henrich and Efraín Morocho.

The Problem:
There are currently two independent water systems servicing the community of Santiago de Quito; the Rayo Loma system and the regional system. Both water distribution systems are unreliable for the community in terms of quality and quantity since community members reported that the Rayo Loma system turns their rice green and the regional system only supplies water a couple days a week. In addition, the piping for both of these systems is exposed above ground in some locations and has acquired damage from weather conditions. Some pipes have also had issues with sediment clogging. Overall, these two systems are inadequate for the needs of the community.

The Solution:
In the spring of 2015, Codeinse Ecuador and Life Giving Water team members oversaw the construction of a new well in the community. The quality and quantity of this well is much more reliable for the community. The team’s proposed water distribution system utilizes this new well in addition to multiple reservoirs, a new pipe network, and chemical dosing to provide much more reliable water to the community. Through engineering analysis this design has also been optimized based on EPANET modeling of pressures and flows as well as water quality tests for dosing concentrations. Disinfection for the project will include chlorination of the water at the source using a peristaltic pump. The chlorine solution will be produced on site by the use of an electrolysis system.

This Final Report contains specifics of the design chosen for Santiago de Quito and the engineering analysis done on the system to prove its success. The report also outlines design norms and project goals that the final design meets for the community. The final design presented in this report has been submitted to Codeinse Ecuador for consideration.
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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), Calvin College offers an engineering program with a variety of concentrations including chemical, civil & environmental, electrical & computer, and mechanical engineering. As a liberal arts school, Calvin offers an engineering curriculum combined with exposure to other course work. It also has a wide variety of international work and relationship opportunities. Combined, these aspects make Calvin College a uniquely challenging yet rewarding experience for students.

1.1.2. Senior Design Background

Calvin College’s accredited engineering program includes a capstone design course as the final step for students receiving an engineering degree. Regardless of their concentration, all engineering seniors students are required to propose, design, and present a design project of their choosing. In this 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 named themselves Green to Clean, is comprised of two senior civil and two senior chemical engineering students. Each member of the team brings a unique set of skills, interests, and background to the project that contributed 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 them find a sustainable clean drinking water solution.
MaKinnah Collins
MaKinnah Collins is an engineering major with a concentration in civil and environmental engineering from the Chicago area. She interned the last two summers at a civil engineering consulting firm, Engineering Resource Associates, Inc located in Warrenville, IL. At Calvin, she is involved in the Renewable Energy Organization and ASCE. Her role on the team is to be the head of team report design and writing as well an associate in hydraulic modeling. When she’s not busy with school, MaKinnah enjoys spending time outside with friends. After graduation she will move to Minneapolis and work at Ryan Companies.

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 the water distribution and modeling resource on the team, as well as the head of team stewardship. Ryan also has a passion for the outdoors and running. He will begin working full time at Prein & Newhof after graduation.

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 as well as chlorine and fluorine addition.
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 electrolysis production processes and chlorine addition.

1.2. Project Background

1.2.1. Project Summary

Team 04 worked with the rural Ecuadorian community of Santiago de Quito to evaluate their current water systems and propose improvements on design and quality of the system. The goal of the final distribution system is to provide reliable, potable water to the residents of the community that have requested to be a part of the water project. The project scope included designing a new well pumping station, reservoir storage tanks, and a new pipe network through survey work and modeling. Disinfection and filtration processes were also proposed in addition to recommendations for treating water quality components that exceeded the range specified by Ecuadorian governmental standards. Final plans, estimated costs, and recommendations for the final proposed system are included in this report.

During design, the team focused on maintaining minimum pressures at the homes and using available materials and labor to construct the final design. In addition, the team has assessed the best treatment options for the community including chlorination and fluorination methods. The final disinfection proposal provides dosing to the water without taste or odor concerns and complies with the Ecuadorian drinking water standards for chlorination. See Appendix D for a summary of the Ecuadorian Standards. In an effort to design a culturally appropriate system, the team valued minimizing operation and maintenance.

1.2.2. 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 (Lake of Colta) in the historic Cache region of Ecuador. The primary language in the community is Kichwa, however, most of the indigenous Quichua people are bilingual in Spanish. The territory covered by Santiago de Quito varies in elevation from to 3,300 to 3,600 meters (10,827 to 11,811ft).\(^2\) Annual average temperature is around 12 degrees Celsius (54 degrees Fahrenheit). Although the equator goes through Ecuador, the village is at a high altitude making the climate cold and wet. A rainy season extends from mid-September to mid-January. See Figure 2 below and Appendix A for a location map of Santiago de Quito.
Due to the community’s fertile soils, Santiago de Quito is primarily an agricultural region. In fact, most of the people in the community are employed in agriculture. The community is known for their production of quinoa, potatoes, barley, wheat, beans, cattle, sheep, pigs, poultry, and other vegetables and animals.

Santiago de Quito is the name of the larger region surrounding Laguna de Colta. The smaller parroquia (parish) where the project is located is called San Antonio which consists of six barrios (neighborhoods). The names of these barrios listed from north to south are Colta San Jose, Colta Santa Ines, Rayo Loma, Central (Consisting of sub-sector Verdepmba), and Capilla. These barrios make up the Junta de Agua de San Antonio (The Water Council of San Antonio). Each barrio has a neighborhood president, who is
responsible for representing the needs of their barrio to the Junta, or water council. The Junta leaders are an elected group of six individuals.

1.2.3. Current Water Situation

The official drinking water improvement project for the community of San Antonio de Quito currently involves 360 homes and 6 community centers (churches, schools, government buildings, etc.) located in the urban center of the city. 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>

See Appendix B 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 based out of the San Antonio barrio of Rayo Loma. This system’s water source is a well located near Laguna de Colta which is pumped to a higher elevation reservoir tank and then distributed through PVC pipes. This distribution system services about a fourth of the total number of homes in the community in addition to a few community centers located in the central barrio including the main community church, school, and restaurant. Overall, the pipe network is in good condition however the system lacks adequate water quality in regards to the Ecuadorian Governmental Standards. The second source of water for the community is a regional system fed from surface waters of a lake located in the neighboring community of Lirio (Lily). This system is extensive, servicing a total of 12 communities in the area including Santiago de Quito. As Santiago de Quito is located in the middle of this extensive distribution network, redesigning, removing, or interfering with this system is not allowed. A third source of water for the community are domestic wells residents have built themselves. Domestic wells are used in the abeyance of the other two water distribution systems, and community members often share these sources with their neighbors. Overall, the Rayo Loma well and regional system connection currently provide 40% of the community’s water while domestic wells provide the remaining 60%. See Appendix E for a schematic of the current distribution system locations.

1.2.4. The Client

Bruce Rydbeck, PE, D.WRE., presented this project to the team in April of 2015. Mr. Rydbeck, 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 Ripple’s pamphlet in Appendix C for a brief overview of the current projects Bruce and his team are currently working on.
Bruce has a strong connection with Calvin College and has coordinated multiple similar senior design projects in the past.

Codeinse is the name of the other local engineering organization partnering with Team 04 to develop solutions for Santiago de Quito. Codeinse Ecuador is headquartered in the nearby city of Riobamba, about a twenty minute drive northeast from Santiago de Quito. Engineers from Codeinse Ecuador working on this project include Martin Henrich and Efrain Morocho. Herr Henrich is a German missionary engineer who has lived in Ecuador for three years. In his past experience, he has worked on two other water development projects in Ecuadorian communities. Before coming to Ecuador he worked as an engineer in Germany. Herr Henrich is fluent in German, English, and Spanish. Efrain Morocho is an Ecuadorian technical consultant who is working with Mr. Heinrich, and has also provided the team with important information about the community and cultural contexts. He has extensive experience with water projects around Ecuador. He is fluent in Spanish as well as Kichwa, the language of the Quichua people in Santiago de Quito.

The team also worked closely with the Junta de Agua (the local Water Counsel) of Santiago de Quito. All constituents of the community are represented by the local Water Counsel, Luis Yuqenlema is the president of the Junta, and is joined by Luis Falconi, Jose Gomez, Manuel Chimbolema, and Manuel Toabanda.

1.3. Project Management

1.3.1. Team Organization

The team members were assigned designated roles to most efficiently pursue the project. Ryan DeGroot was in charge of scheduling and team management, and had a lead position in developing the hydraulic model for the water distribution system. Maria Steblay was in charge of task and timeline management to ensure the team stayed on track with their work. She was also the lead in website development, as well as research and development of chlorine disinfection processes. MaKinnah Collins was in charge of client communications and the team’s budget, and was an assistant to the computer modeling. Caleb Ingram was in charge of overseeing the business plan and was the lead researcher of filtration and fluoride treatment processes. Individually, all team members were responsible for tracking their progress and project completion. Many aspects of the project were collaborative and worked on by all team members.

1.3.2. Method of Approach

The team approached the project with humility while also being driven to design a solution that would significantly benefit the people of Santiago de Quito. As students, the team understood their lack of experience and their need to humbly seek and accept advice when necessary. As a result, the team has, throughout the project, sought the help of professionals with experience in similar design projects both in the United States and internationally. The team made an effort to continually show their gratitude whenever assistance was given to them during the duration of the project and they are especially grateful
for the experience this project will add to their education and knowledge of engineering design. The team would like to thank Bruce Rydbeck who has been a crucial part of this project as he was the team's mediator between both the engineers in Ecuador and the community. Gratitude must also be shown to professors and professional engineers that have graciously given time and guidance to the team during the duration of the project. The chance to work on this project was a blessing and the team strived to design the best possible solution.

This project followed 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 were finished, the team worked on modeling the proposed water distribution system in EPANET. They also looked more closely at water tests to determine the best treatment proposal. Throughout the design and treatment design process, the team continually consulted with their clients in Ecuador. The final design proposal serves as the team's final recommendation to the community for future improvements.

1.3.3. Schedule

As the senior design course is organized into two semesters, one focused primarily on research and the other focused on development and design, our project was 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 was primarily focused on gathering information to understand the project and chemical research. This preliminary phase was completed with the team’s trip to Ecuador in late January that included survey work, information gathering, and evaluation of previous water projects in the Santiago de Quito area. Spring semester was when the majority of the project development and design occurred. The project end date was May 9, 2016.

Throughout the project, the team met 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 covered what tasks are required for the next week, including course work, communication, research, and design goals. Although there was general group guidance for project due dates, the team usually broke down work on a week-to-week basis. This allowed the team to be as efficient as possible.

1.3.4. Budget

Throughout the project the team had to keep track of budgeting and expenses. The overall budget provided by the Calvin Engineering Department for each senior design group was $500 dollars. These funds went towards the disinfection and filtration testing supplies needed for water testing in Ecuador. These tests helped the team determine what the water quality issues were and how to best treat the water. In addition to these program funds, the team also spent approximately $4,000 in travel expenses for a site visit in January. These funds were supplied by the individuals on the team. The team budget can be found in Appendix G.
The team also created a final cost estimate and budget for their design recommendation for the community of Santiago de Quito. When considering the final design and creating this budget it was important for the team to factor in cultural appropriateness since the community would be offering their time and labor as payment for the overall project. Therefore the team had to decide which options financially meet the goals of the project to be included as their final recommendation. The final budget is discussed in section 5.7.

1.4. Design Norms

1.4.1. Cultural Appropriateness

The group approached this project with the mindset to understand and appreciate the community and their current situation. It was important throughout the project for the team to remember that the goal of the project was to make a positive impact without hurting or negatively impacting any aspect of the community. The team’s awareness of cultural appropriateness was developed during their trip to Ecuador in January. During this trip, the team received a better understanding of what systems will be appropriate for the community and they also got the opportunity to meet with community members to talk about what their desires are for this system as well. Cultural appropriateness is of the utmost importance since it will impact the future welfare and benefit of this system.

1.4.2. Transparency

Complete transparency was a key component of this project to appropriately aid the community of Santiago de Quito. Since the group is only participating in the engineering work and not the final building stages of the distribution system, all design recommendations are completely hinged on the ability of the team to communicate with the people in the community. There cannot be gaps or lack of information in the design report that confuse the reader. The community must have complete knowledge of their final drinking water system so that they can trust its safety and reliability.

1.4.3. 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 rather 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 shows the world wide importance to give people basic necessities like clean water.  

1.4.4. Humility  

In order for our team to successfully design this system we had to 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 our final system 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”.  

2. Trip to Ecuador  

2.1. Trip Agenda  

On January 26th the team began their travel to Quito Ecuador. Upon arriving the team stayed one night at the Rydebeck’s home before traveling about 4 hours to the community. The team was housed in a church located in the community of Santiago de Quito for three nights. During their time with the community, the team was able to develop relationships with the people involved with the project including the members of the water council. During the days the team had the opportunity to travel around the community with Bruce, Martin, Efrain, and community members to survey future reservoir locations, do various survey work, and take water quality tests. The final day in the community the team travelled to the surrounding communities of Achullay and Yanahcocha to evaluate their successful water distribution designs. The team then traveled to Riobamba to meet with Codeinse Ecuador engineers at their local office and discuss their collected data. During this time, the team stayed with the Henrich family. The last day of the trip the team was able to travel back the Quito for a day spent exploring the city. See Appendix H for a full trip agenda break down. Overall, this trip proved crucial to the team's understanding of the community and purpose of the project. The team is very grateful for the help and hospitality of Bruce and Cherith Rydebeck and Martin and Julia Henrich that made this trip possible.  

2.2. Design Decisions  

2.2.1. Distribution  

After touring the community and meeting with the community water council members, the team was able to make some critical design decisions about the project. One decision was the location of the four reservoirs used in the distribution design. Since these reservoirs needed to maintain certain elevations for pressure control, the elevation of the selected areas was taken using a GPS. As determined by the community members, the selected areas could be developed by the engineers without protest from residents. A second decision was the utilization of the privately owned Rayo Loma distribution pipes and
reservoir in the final design. This decision was made after water council members met with the owner who agreed to its use in the final design. (However, the owner later changed his decision, see Section 3.1.1.).

2.2.2. Disinfection and Treatment

During their time in the community, the team was able to conduct water quality tests on the different water sources within the community. However the data presented from these experiments are rough since the testing equipment only detected to a certain range. The final results did give the group an idea of which water quality components do not meet the Ecuadorian standards. Attached below are the water quality results for an array of components and chlorine. (Tables 2-3).

<table>
<thead>
<tr>
<th>Test Name</th>
<th>Detectable Range</th>
<th>Acceptable Range</th>
<th>Drinking Water</th>
<th>New Well</th>
<th>Achullay</th>
<th>Yanacocha</th>
<th>Regional</th>
<th>Error Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness</td>
<td>0-800+</td>
<td>300</td>
<td>75</td>
<td>150</td>
<td>200</td>
<td>250</td>
<td>100</td>
<td>+/- 100</td>
</tr>
<tr>
<td>Total Chlorine</td>
<td>0-10</td>
<td>-</td>
<td>0.1</td>
<td>0</td>
<td>1</td>
<td>0.7</td>
<td>0.3</td>
<td>+/- 1</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>0-240</td>
<td>-</td>
<td>30</td>
<td>200</td>
<td>200</td>
<td>220</td>
<td>80</td>
<td>+/- 50</td>
</tr>
<tr>
<td>pH</td>
<td>4-10</td>
<td>6.5 - 9.5</td>
<td>6.5</td>
<td>8.0</td>
<td>5.5</td>
<td>9.0</td>
<td>8.0</td>
<td>+/- 0.5</td>
</tr>
<tr>
<td>Nitrites</td>
<td>0-10</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
<td>+/- 1</td>
</tr>
<tr>
<td>Nitrates</td>
<td>0-50</td>
<td>-</td>
<td>0</td>
<td>7</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>+/- 10</td>
</tr>
<tr>
<td>Copper</td>
<td>0-3</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
<td>0.8</td>
<td>0</td>
<td>+/- 0.5</td>
</tr>
<tr>
<td>Iron</td>
<td>0-5</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
<td>0.1</td>
<td>0</td>
<td>0</td>
<td>+/- 0.5</td>
</tr>
</tbody>
</table>

Table 3: Test Data from a Hach Nine-Parameter Test Kit (1), Cole Parmer Chlorine Test Strips (2)

<table>
<thead>
<tr>
<th>Test</th>
<th>Achullay (1)</th>
<th>Yanacocha (1)</th>
<th>Clinic (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free Chlorine (ppm)</td>
<td>0.1</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Total Chlorine (ppm)</td>
<td>1</td>
<td>0.7</td>
<td>1500</td>
</tr>
</tbody>
</table>
3. Existing Distribution System Analysis

3.1. Distribution

3.1.1. Rayo Loma Distribution System

As discussed previously, the Rayo Loma system is a privately owned distribution system. This distribution system currently services only about a fourth of the community members as well as a few community centers. Since this system encompasses a large portion of the water project participants, it was important for the team to determine whether it could be used in the final project. After discussions with the owner during the team’s trip to Ecuador, community water council members advised the team that this system could be used in the final design. Upon returning to the states, the team moved forward assuming the Rayo Loma reservoir and distribution pipes could be used in the final design. However in mid-April after a discussion with their clients, Bruce and Martin, the team was notified that the owner had since altered his decision and the system could not be used. As a result, the team’s final design, is a completely independent system with pipes running along side the existing Raya Loma system. Moving forward, the team was able to optimize the new system without constraints from the existing system.

3.1.2. Regional System

The regional system encompasses a total of 12 communities including Santiago de Quito. Since this water system begins and ends outside of the community, the team was not allowed to interfere with this system. According to residents, this system lacks reliability since water is only delivered through the system about once every eight days. Availability, they say, is highly dependent on time of year (rainy versus dry season) and time of day (increased demand around meal times). According to water tests conducted by a local lab, this system was also not reliable in terms of quality. See Section 4.1.

3.1.3. New Well

In an effort to improve their current water systems, the community, in cooperation with Codeinse Ecuador and Life Giving Water, built a new groundwater well in the fall. See Figure 3 for the picture of the current well with a concrete casing cover to prevent surface runoff.
According to a well draw-down test done by Codeinse Ecuador and the community, the well can sustain a pumping rate of 51 GPM (3.2 LPS). According to Codeinse Ecuador, this test was done by drawing the water at 51 GPM for 2 hours and recording a water surface elevation drop of 50 cm which leveled out overtime. Although the team acknowledges this test could have had accuracy concerns, they assumed its results to be valid for their project design. See Table 4 below to see that 51 GPM (270,000 LPD) will be able to sustain this current system demands as well as future growth.

<table>
<thead>
<tr>
<th>Table 4. System Demands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily Supply and Demand</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Total (GPD)</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>Average Day</td>
</tr>
<tr>
<td>Projected Average Day</td>
</tr>
<tr>
<td>Max Day</td>
</tr>
<tr>
<td>Projected Max Day</td>
</tr>
<tr>
<td>Well Supply (51 GPM)</td>
</tr>
</tbody>
</table>

See Appendix K for complete supply/demand calculations. The new well was utilized as the primary and only water source for the new water system.
3.2. Pressure Zones

Based on the project location and an Ecuadorian standard pressure head of 10m to 70m (14 psi - 100 psi) the team had to decide how many pressure zones would be used for the project. See Appendix I for the topographic layout of the community. As the elevations of the homes are between 3311m and 3412m (a 101m difference), the community needed to be divided into two pressure zones, an upper zone and lower zone. Based on the community layout and meeting with community council members, the team decided to create an upper pressure zone between the elevations of 3423m and 3353m in the southern portion of the community and a lower pressure zone between the elevations of 3376m and 3306m servicing the remainder of the project participants. Both of these pressure zones allow homes to have a total head between 10 and 70m which is within the specified pressure range. See Appendix Q drawing A-3 for a plan drawing of the two pressure zones.

3.3. Design Alternatives

Considering the existing system components, the team had to decide how the final system would be configured. The biggest factors to this decision were the locations of the new well, reservoirs, and the two pressures zones. See Figure 4 for the layout of these different components.
After meeting with clients, consultants, and advisors the team decided on three different pumping configurations. The first configuration was to pump the water separately from the new well to reservoir B and reservoir E to provide water to both the lower and upper pressure zones. This option would require 4 pumps (2 for redundancy) at the pumping station and separate chlorine dosing systems for the two streams. The second option was to pump all the water from the new well to reservoir B and then use a booster pump to bring water to reservoir E. This option reduced the number of pumps at well A to two (one for redundancy) but required two more pumps at reservoir B to bring water to the upper elevation zone. The third option would be to pump all the water to reservoir E which would drain water to reservoir B. The pressure in reservoir B and the rest of the lower pressure zone would be controlled by a float valve in the tank. This option would require extra energy to bring all the water to a higher elevation but would not require additional pumps besides the two pumps at the new well and no additional chlorine dosing system.
4. Chemical Design

4.1. Water Quality

After the trip in January, the team decided that the new well has the capacity and water quality to be the primary source of water supply for the whole community of Santiago de Quito. The water quality, of course, was still in need of disinfection and potentially filtration. Table 5 and Table 6 show the water quality data of the new well received from a lab in Riobamba near the community. This lab is not government owned, which the team was not aware of until after their trip. As a result, additional tests should be done by a governmentally approved testing facility in the future. Also outlined in these two tables are the ecuadorian standard limits. The limits approved by the Ecuadorian governmental standards are in parenthesis ( ).
Table 5: Local Lab Data for the New Well in Santiago de Quito

<table>
<thead>
<tr>
<th>Determinate</th>
<th>Units</th>
<th>Lab Suggested Limits (Approved Ecuadorian Standards)</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Und co/Pt</td>
<td>&lt;15 (&lt;30)</td>
<td>9</td>
</tr>
<tr>
<td>pH</td>
<td>Unit</td>
<td>6.5-8.5 (6.5 - 9.5)</td>
<td>7.75</td>
</tr>
<tr>
<td>Conductivity</td>
<td>Ohms</td>
<td>&lt;1250</td>
<td>730</td>
</tr>
<tr>
<td>Turbidity</td>
<td>NTU</td>
<td>5</td>
<td>0.5</td>
</tr>
<tr>
<td>Chlorides</td>
<td>mg/L</td>
<td>250</td>
<td>14.2</td>
</tr>
<tr>
<td>Hardness</td>
<td>mg/L</td>
<td>(300)</td>
<td>328.0</td>
</tr>
<tr>
<td>Calcium</td>
<td>mg/L</td>
<td>70</td>
<td>41.6</td>
</tr>
<tr>
<td>Magnesium</td>
<td>mg/L</td>
<td>30-50</td>
<td>54.4</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>mg/L</td>
<td>250-300</td>
<td>460.0</td>
</tr>
<tr>
<td>Sulfates</td>
<td>mg/L</td>
<td>200 (&lt;400)</td>
<td>42.0</td>
</tr>
<tr>
<td>Ammonia</td>
<td>mg/L</td>
<td>&lt;0.50</td>
<td>0.160</td>
</tr>
<tr>
<td>Nitrites</td>
<td>mg/L</td>
<td>0.2</td>
<td>0.009</td>
</tr>
<tr>
<td>Nitrates</td>
<td>mg/L</td>
<td>50 (&lt;50)</td>
<td>3.20</td>
</tr>
<tr>
<td>Iron</td>
<td>mg/L</td>
<td>0.30 (&lt;0.5)</td>
<td>0.02</td>
</tr>
<tr>
<td>Phosphates</td>
<td>mg/L</td>
<td>&lt;0.3</td>
<td>2.130</td>
</tr>
<tr>
<td>Dissolved Solids</td>
<td>mg/L</td>
<td>500</td>
<td>390.0</td>
</tr>
</tbody>
</table>
Table 6: Further Lab Results from the New Well in Santiago de Quito

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Units</th>
<th>Method</th>
<th>Reference Value</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Coliforms</td>
<td>CFU (colony forming units)/100 mL</td>
<td>Membrane filtration</td>
<td>---</td>
<td>98</td>
</tr>
<tr>
<td>Fecal Coliforms</td>
<td>CFU (colony forming units)/100 mL</td>
<td>Membrane filtration</td>
<td>&lt;1</td>
<td>absence</td>
</tr>
</tbody>
</table>

Based on the laboratory results, the water has five main quality issues: hardness, magnesium, alkalinity, phosphates, and coliforms. The following sections seek to outline multiple ways of treating each of these five water quality issues.

*Water Quality Component 1: Hardness*

Water hardness is a term that describes the presences of dissolved ions, commonly calcium (Ca\(^{2+}\)) and magnesium (Ma\(^{2+}\)). Calcium and magnesium do not corrode piping, but reaction precipitation on the inner lining, known as scale, is common. This is not a desired effect due to its contribution to inner degradation. In addition, if levels are too high in drinking water, studies have shown that calcium and magnesium can show future potentials for cardiovascular risk, and thus there are approved hardness limits.

*Water Quality Component 2: Magnesium*

As mentioned in the section above, magnesium is a major part of hardness that contributes to potential negative side effects in cardiovascular health. Magnesium also is damaging to the distribution system by the formation of a precipitate along the inside of pipes.

*Water Quality Component 3: Alkalinity*

Alkalinity is the potential of water to resist change in pH and is measured in water's buffering capacity. Typically, carbonate compounds are derived from the contact of water with limestone, which is common in Ecuador. Some alkalinity levels are necessary in a water source to protect plant and animal growth. If a solution fluctuates in pH, it can be harmful to living organisms in the area. Both the Ecuadorian standards and the E.P.A. do not deem alkalinity as a health risk or an aesthetic/cosmetic factor and therefore they have no primary or secondary MCLs (maximum contaminant limits) in their standards.

*Water Quality Compound 4: Phosphates*

Phosphates, depending on levels and location, are not necessarily a bad component to have in water systems. For human health, extremely high levels in drinking water can lead to an imbalance in the phosphate calcium complex in the blood. Long periods of high exposure to organic phosphates can lead to
Phosphate toxicity is unknown for human consumption, and there are not set standards, however, it should be noted that some studies have shown levels for pigs to in the range of 35 mmol/kg of body weight. This value translates to 3324 mg/L, a value much higher than was discovered in the new well sample. (See Appendix K for conversions).

An environmental downside of high phosphate levels is the eutrophication, or chemical enrichment, of bodies of water. High levels of nitrogen and phosphates are the main contributors to unhealthy bodies of water. It causes dramatic algae and plant growth due to excessive nutrients for algae, plankton, and other biomass living materials. This toxic bloom consumes oxygen, decreasing ecosystem diversity, available food, and natural habitat.

Phosphates are helpful and important for the protection of metal piping. The city of Flint, Michigan, for example, used a phosphate corrosion inhibitor to coat the lining of lead and iron piping, preventing leaching. When the source was switched, upper management decided to not treat with phosphates. This resulted in their current issues of lead in the water. For the village of Santiago de Quito, the pipe material is PVC. For this type of plastic, the effects of corrosion due to phosphates or any other water mineral are minimal. In addition, leaching is not an issue in PVC piping. Ecuadorian standards do not dictate levels of phosphate in water and the United States E.P.A. does not have a set standard. As seen in Table 5, the allowable levels of phosphate were set by the testing lab facility which is independent of any government organization.

Water Quality Component 5: Total Coliform

The bacterial component coliform is not harmful to humans; however, it signifies the presence of other unknown pathogens in the water. Testing for specific pathogens can be expensive when total coliform is reason enough to treat the water. Luckily, fecal coliform is not present in the water, but further testing after implementation of the disinfection system is needed. Big potential parasitic components that are dangerous and hard to test for include Cryptosporidium parvum and Giardia lamblia. Once consumed, these parasites establish themselves in the intestinal tract and cause illness.

4.2. Filtration Alternatives

The goal of researching filtration options is to outline different models that can potentially be used to remove some of the water components that are mentioned above. Ideally, the goal is to have a cost effective method to decrease the amount of chlorine content in the water, but still provide safe drinkable water to the community. Furthermore, methods of filtration that were ruled out of the design include distillation, electrodialysis, and reverse osmosis due to the high amount of cost and constant monitoring.

The biggest factor of filtration in all of the cases is the ability to remove components in water making it deemed “safe” for consumption of long periods of time. With that in mind, the following filters were chosen for the best possible range of treatability.
**Filtration Option 1: Slow Sand Filter**

Slow sand filtration is a tried and true method for removing harmful pathogens and components from water with the use of a sand bed that collects and consumes bacteria. Figure 5 below shows the basic breakdown of a slow sand filter. The main components in this system include the tank, sand bed, ventilator, reservoir, and piping.

The positive side of using the slow sand filter lies in the less amount of maintenance required in the process; however, the cost of implementing this process is a big constraint. For the purpose of this project and due to the quality of the water, the team decided on not using a filter system and therefore the purification of the water will rely on the disinfection.

4.3. Disinfection Alternatives

In order to eliminate the total coliform count in the new well water, various disinfection techniques were researched. These include ultraviolet, ozone and chlorine disinfection.

**Disinfection Option 1: Ultraviolet**

Ultraviolet disinfection takes advantage of the high energy wavelengths UV-A, UV-B, and UV-C to kill bacteria and pathogens in water. Recommendations show that UV disinfection is best for water that has high levels of coliforms; however, that can also be the downfall of this option. It is required that before the water can be treated with UV, other components must be removed by filtration. Components such as suspended solids, color, iron, manganese, and pH need to be in a valid range before UV treatment. On the positive side, UV radiation is the least invasive method for treating water. It also does not affect the taste of the water. The basic idea of UV disinfection is shown in Figure 6.
Although this method of disinfection has many positive traits, the Ecuadorian standards dictate a level of chlorine that is required to be in the water. This requirement level supersedes the need for UV disinfection.

Disinfection Option 2: Ozone

Ozone \( (O_3) \) is formed when oxygen molecules are dissociated into oxygen atoms and collided to form the unstable gas of \( O_3 \). Due to the instability of this molecule, the ozone would have to be produced on the site of disinfection. Ozone is a strong disinfectant by its ability to kill most viruses and pathogens in water. With the high levels of total coliform, it is likely that high levels of viruses may be present in the water source. The basic principle behind ozone disinfection lies in the ability that \( O_3 \) has to decompose into free radicals in water. The reaction of water and ozone,

\[
H_2O + O_3 \rightarrow HO_2 + OH + O^-
\]

leads to the formation of hydroperoxyl and hydroxyl groups that play an active role in the disinfection of the drinking water source. A downside to using ozone lies heavily in the capital cost of implementing this processes and the safety of the operators. As one of the design norms for this project, it is the goal of this group to design a system that is culturally appropriate for the community being affected. Recommending a system that requires constant care and could be potentially dangerous to the people operating the machine, violates this design criteria. Furthermore, as mentioned above, chlorine is the preferred disinfection method by the Ecuadorian government and therefore is required to be in the system.

Disinfection Option 3: Chlorine

Chlorine was determined to be the most appropriate form of disinfection for the water system of the community of Santiago de Quito due to its ability to provide residual disinfection and its ease of application with local knowledge of the methods and technologies involved in the process. For these reasons, throughout the world, chlorine is the most common form of water disinfection. Issues with chlorination include the creation of byproducts with reaction to organics and metals, changes in water
taste, and chlorine decomposition over time in storage. These side effects were carefully considered and addressed during the design process.

4.3.1. Chlorination Chemistry

Reactions with Water

Chlorine in water dissociates to form hypochlorous acid (HClO), hydrogen (H\(^+\)), and and hypochlorite (ClO\(^-\)) (Figures 7 - 8).

![Figure 7. Equilibrium of Chlorine in Water](image)

Reactions with Bacteria and Pathogens

Chlorine’s usefulness as a disinfectant is due to the hypochlorous acid and hypochlorite that are biocides. The ions are able to enter bacterial cell walls and interfere with the enzyme systems, deactivating organisms and destroying their ability to reproduce. The specific mechanism for this is not yet known.\(^{18}\) The hypochlorite ion is an oxidative agent that reacts with other agents in water 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”.\(^{19}\) The available methods of filtration and their effectivenesses were discussed in section 5.2.

Reactions with Impurities in Water

Chlorine, as a potent oxidizing agent, reacts with a wide variety of substances found in water sources. These reactions often dissipate the chlorine, or weaken its disinfection capabilities. Reaction materials can be split into two categories: ones that make up the chlorine demand, and those that create combined chlorine. Chlorine demand is a level of chlorine that reacts with organic and inorganic materials present in the water, and consequently makes the chlorine ineffective for disinfection. The remaining chlorine
concentration after demand is accounted for is the total chlorine. This is made up of the free and combined chlorine of a system. Combined chlorine is the concentration of chlorine that has combined with organic and inorganic compounds in the water and decrease, but not fully destroy, the disinfection properties of chlorine. Any additional chlorine left behind after these two reactions is residual (or free) chlorine. Residual is important in a system to assure there is enough disinfection capability downstream of the source, in the case of additional contaminants. This chlorine breakdown is displayed in Figure 9.

![Chlorine Addition Flow Chart](image)

Figure 9. Chlorine Addition Flow Chart.

Demand levels of the system are very important to determine in disinfection to assure that residual chlorine remains after the initial reactions. Once the demand has been satisfied, the total chlorine can contribute to destroying bacteria in the system.

There are a variety of impurities in water that react with chlorine. Ammonia, metals such as Fe$^{2+}$, and Mn$^{2+}$, and naturally occurring humic materials such as H$_2$S and N$_{02}$-$ are all compounds that react with chlorine. Ammonia, or other nitrogen containing organics, react with chlorine to produce chloramines. These are called combined chlorine residuals because they are still disinfectants, but are less effective by concentration, especially at high pH. Thus, in practice, chlorine is added until the breakpoint chlorination is reached, an extent of chlorination where all the ammonia is converted to N$_2$ or a higher oxidation state. An example of the chlorination residual curve in given in Figure 10 below.
4.3.2. Chlorine System Design

Application

Chlorine dosing is determined by two system considerations: the chlorine demand and the desired chlorine residual. Dosing requirements are calculated by:

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

Chlorine demand can be determined two ways. The first way is to use a chlorine demand test. In this method, a known amount of chlorine is added to a set sample volume of water. After a long enough amount of time to allow for chlorine demand reactions, the chlorine level of the water is tested again. Chlorine demand of the sample is calculated by the difference in chlorine concentration at time zero and the end of the reaction period.

Demand

The second way to calculate chlorine demand is by using literature chlorine demand factors. Each reducing agent has an individual chlorine demand factor factor proportional to the quality concentration, in mg/L, as seen in Table 7.
### Table 7: Initial Chlorine Demand Factors for Reducing Agents.\textsuperscript{22}

<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>

### Table 8: Secondary Chlorine Demand Factors for Combining Agents.\textsuperscript{22}

<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>

Using information from the Ecuadorian lab water quality tests, it is possible to come up with a reasonable estimation of the source chlorine demand, as laid out in Table 9. A chlorine demand of 0.06 mg/L is calculated from these individual factors. This estimation could be more accurate with a more comprehensive water quality test, and additional correlations between coliforms and chlorine demand. For preliminary calculations, however, this is a plausible value. In addition, the desired chlorine residual value is much higher than the demand factor, and proper dosing should overshadow any small changes in demand.

### Table 9. Chlorine Demand Calculation.

<table>
<thead>
<tr>
<th>Primary Demand Factors</th>
<th>Water Quality (mg/L)</th>
<th>Demand Factor</th>
<th>Water Quality Results (mg/L)</th>
<th>Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td></td>
<td>0.64</td>
<td>0.02</td>
<td>0.0128</td>
</tr>
<tr>
<td>Manganese</td>
<td></td>
<td>1.3</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Sulfide</td>
<td></td>
<td>2.08</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Nitrite</td>
<td></td>
<td>5</td>
<td>0.009</td>
<td>0.045</td>
</tr>
<tr>
<td><strong>Total Demand</strong></td>
<td></td>
<td></td>
<td></td>
<td>0.06 mg/L</td>
</tr>
</tbody>
</table>

Secondary demand factors include ammonia and organics. These parameters were not included in the lab tests, and thus no correlation is currently able to be made for this system. The same is true for ammonia break point chlorination curves. Additional testing would allow these levels to be determined.
Consultation with Mr. Rydbeck revealed that many neighboring systems in the Santiago de Quito area have low chlorine demands, similar to the one calculated above. Thus, the team moved forward assuming the calculated demand is close to a measured demand.

*Residual*

Residual values for this design are determined by various standards and aesthetic chlorine properties. Standards from the Ecuadorian government specify that chlorine content must be between 0.3 and 1.5 mg/L, with a desired value of 0.5. Higher chlorine levels are more effective in killing pathogens and bacteria, but also increase the creation of disinfection by-products. In addition, as the chlorine concentration increases, it can be tasted in the water and the aesthetic quality of the water decreases. For areas where people are not accustomed to this taste, even a small amount of chlorine can be an adverse flavor. Thus, a tradeoff of chlorine residual exists. Important standards are outlined in Table 10.

<table>
<thead>
<tr>
<th></th>
<th>Ecuadorian Government</th>
<th>World Health Org. (WHO)</th>
<th>Mr. Rydbeck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desired (mg/L)</td>
<td>0.5</td>
<td>≥0.5</td>
<td>0.2-0.5</td>
</tr>
<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. He further recommended that the lower the chlorine levels, the more likely the community will accept and use the treated water. Without the community’s approval, the purpose of the entire chlorination design would be negated. Thus, the chosen level of residual chlorination for this project is 0.3 ppm (mg/L), high enough to meet all standards, but still as low as possible to avoid community rejection.

*Total Dose*

Adding the demand and residual values together yields a total chlorine dose of 0.36 milligrams per liter water (ppm). Frequency of chlorine dosing to obtain this concentration in the system is determined by the flow of water. The chemical feed equation is:

$$\text{Feed Chlorine Concentration} \times \text{Feed Chlorine Flow} = \text{System Chlorine Dose} \times \text{System Water Flow}.$$  

The feed chlorine concentration is determined by the source of chlorine. In this design, the feed is a 1.25% sodium hypochlorite solution, or 12,500 mg/L. For each mol of sodium hypochlorite in solution there is one mol of the chlorine ion, as the structure reveals in Figure 8. See the Electrolysis section for more specifications on the sodium hypochlorite solution production process. The system chlorine dose is the total desired dose, 0.36 mg/L. System water flow varies based on demands throughout a day between on and off for both the upper and lower pressure zones. In considering the dose, the team used a mass
balance around the mixing point to know an instantaneous dose rate. With this method, the current feed chlorine flow is calculated as 0.062 mL/s for the lower pressure zone and 0.009 mL/s for the lower pressure zone. Considering that the pump rate of 35 GPM and 5 GPM will not change, the dosing rate will also not change. Sample calculations for this can be found in Appendix K.

**Chlorine Demand**

Based on the 1,488 current residents of the San Antonio water system, the average daily water demand is 117,180 liters, or 30,956 gallons. Chlorine dosing demand for this system would need to be

\[
\text{daily chlorine dose} = \frac{117,180 \text{ L}}{\text{day}} \times \frac{(+0.36) \text{ mg}}{\text{L}} = 42.2 \text{ grams chlorine/day}.
\]

Based on the estimated 1,816 residents of the community twenty years out, in 2035, the average daily water demand would be 142,982 liters, or 37,772 gallons. Chlorine dosing demand for this system would need to be 50.0 grams chlorine per day.

**Chlorine Alternatives**

Chlorine to be used in disinfection can come from a variety of sources in liquid, gaseous, or solid form. Most common are liquid or solid sources. Gaseous chlorine is more difficult to come by, as well as has the potential to be dangerous if handled incorrectly. Worldwide, the most commonly used source of chlorine is liquid bleach, which is a dilute solution of sodium hypochlorite. In the Santiago de Quito area, this is available as a 5% hypochlorite solution. However, communities around Santiago de Quito that use chlorine complain that bleach is too expensive and more work to come by. In discussing this with the team, they expressed their wishes to have an electrolysis unit that would make dilute sodium hypochlorite solutions from salt, a product that is much less expensive than bleach. The RayoLoma system currently uses another source of chlorine, calcium hypochlorite tablets. All three of these chlorine sources were compared and analyzed for cost, effectiveness and ease of use.
Electrolysis was determined to be the highest in start-up costs, and had a payback period of 18 years, which is relatively high compared to design longevity of the system. However, there is the opportunity for the community to assist others in the area or make some entrepreneurial profit off this system. In addition, if start-up costs are covered in part by an outside benefactor, such as the Ecuadorian government, or a developmental organization, this could significantly decrease the payback time. With all these factors in mind, a decision matrix was created to determine the optimal option to pursue.

Table 11. Decision Matrix for Chlorine Source Options.

<table>
<thead>
<tr>
<th>Decision Factors</th>
<th>Max</th>
<th>Electrolysis</th>
<th>Bleach</th>
<th>Tablet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Maintenance</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Start-up Cost</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Annual Cost</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Simplicity of Use</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Accuracy</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Safety</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Entrepreneurial Profit</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>31</strong></td>
<td><strong>29</strong></td>
<td><strong>26</strong></td>
<td></td>
</tr>
</tbody>
</table>
Table 12. Factor Descriptions for Chlorine Source Decision Matrix.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>How much energy does it use?</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Experience and resources will be necessary to upkeep the</td>
</tr>
<tr>
<td>Start-up Cost</td>
<td>How expensive is the system?</td>
</tr>
<tr>
<td>Annual Cost</td>
<td>How much money is needed per year to use?</td>
</tr>
<tr>
<td>Simplicity of Use</td>
<td>Will community members understand the system enough to maintain the system in the future?</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Will the system supply reliable chlorine dosing?</td>
</tr>
<tr>
<td>Safety</td>
<td>Hazards and chemical hazards?</td>
</tr>
<tr>
<td>Entrepreneurial Profit</td>
<td>Can any extra money be made from this system?</td>
</tr>
</tbody>
</table>

**Solution Demand**

According to the specifications given by the electrolysis unit manual, the percent chlorine in solution is 1.25%, which is 12,500 ppm (mg/L). Thus, the current daily sodium hypochlorite solution would need to be

\[
\text{sodium hypochlorite solution demand} = \frac{42.2 \text{ g chlorine}}{\text{day}} \times \frac{1 \text{ L}}{12,500 \text{ mg}} = 3.4 \text{ liters solution/day.}
\]

For projected populations values, the demand would be 4.2 liters per day. It is recommended that the accuracy of the unit manual is verified, and a total chlorine test is conducted on a sample batch to assure it is 1.25% sodium hypochlorite. If the solution turns out to be a different concentration of chlorine, the above calculations should be re-evaluated with the accurate chlorine concentration.

**Dosing**

There are several ways in which to inject the chlorine solution to the distribution system. For non-electrical systems, fluid driven injector pumps can be used. The accuracy of these pumps were investigated by the ACE senior design team in 2015. While the client, Mr. Rydbeck, was satisfied with this design, there has yet to be implementation of this equipment. With the lack of field reliability data of the fluid driven pumps, coupled with the ease of access to electricity in the Santiago de Quito area, electronic dosing pumps were favored for this design.

Input from the client, Mr. Rydbeck, was used in picking the chlorine dosing system. Specifically, a peristaltic pump from Blue-White Industries was chosen, which has been used with much success in communities near Santiago de Quito. It is a metering pump, with the ability to adjust the control knob for varied output. The pump can also be programmed to respond to a range of input currents or voltages. An electrical line can be run from the reservoir float valves to the pump to be shut off in coordination with flow in the pipes. The technical data sheet can be seen in Appendix M.
Based on the modeling done of the distribution design, the water pump will run at 5 GPM for 8 hours a day for the upper pressure zone, and 20 hours for the 35 GPM lower pressure zone pump. A dosing rate for the upper thus becomes 0.009 mL/s, or a pump setting speed of 8.7%. The lower pressure zone has a rate of 0.062 mL/s, which is setting 61.3% on the peristaltic pump.

Contact Time
Contact time is the amount of time that chlorine and water interact in a system. Proper contact time assures the chlorine can deactivate all the microorganisms. It is affected by chlorine concentration, pathogens present, pH, and temperature. To calculate contact time the system’s highest estimated pH and lowest expected temperature are used. The equation to find necessary contact time based on 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. From local temperature information and pH values from water quality tests (Table 2), the highest possible K value is read from the table as 20.

Table 13. K Values of Chlorine Contact Time based on pH and Temperature.24 (Wagenet)

<table>
<thead>
<tr>
<th>pH</th>
<th>Highest Water Temperature (degrees F)</th>
<th>Lowest Water Temperature (degrees F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.5</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>7.0</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>7.5</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>8.0</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>8.5</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>9.0</td>
<td>24</td>
<td>30</td>
</tr>
</tbody>
</table>

With a K of 20, equation 1 yields a required contact time of at least 66 minutes. This parameter can be calculated and checked with known system variables.

\[
\text{Volume [gal]} = 23.5 \times (\text{radius of pipe}) \times (\text{[ft]}^2 \times \text{main length [ft]} + \text{reservoir volume [gal]})
\]

\[
\text{Contact time [min]} = \frac{\text{Volume [gal]}}{\text{Flow [GPM]}}
\]

For the designed system, contact times were calculated for the upper and lower reservoirs as 7,800 and 685 minutes, respectively. These are significantly more than the minimum time of 66 minutes.

CT/Virus Log Inactivation
Concentration Time (CT) is another system parameter that is used to estimate the effectiveness of chlorine in the inactivation of viruses. The 4 log inactivation uses CT value to determine the contact time and concentration in order to inactivate 99.99% of viruses. Detention time calculations prerequisite CT calculations:

\[
\text{Detention Time [min]} = \text{Contact Time [min]} \times \text{Baffling Factor},
\]

where detention time accounts the possibility of impure water being streamlined through the chlorination region. Baffling factors are determined as follows.

<table>
<thead>
<tr>
<th>Baffling Condition</th>
<th>Baffling Factor</th>
<th>Baffling Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unbaffled (mixed flow)</td>
<td>0.1</td>
<td>None, agitated basin, high inlet and outlet flow velocities</td>
</tr>
<tr>
<td>Poor</td>
<td>0.3</td>
<td>Single or multiple unbaffled inlets and outlets</td>
</tr>
<tr>
<td>Average</td>
<td>0.5</td>
<td>Baffled inlet or outlet with extra basin baffles</td>
</tr>
<tr>
<td>Superior</td>
<td>0.7</td>
<td>Perforated inlet or intra basin baffles, outlet weir</td>
</tr>
<tr>
<td>Perfect (plug flow)</td>
<td>1.0</td>
<td>High length to width pipeline ratio</td>
</tr>
</tbody>
</table>

Then CT is calculated by

\[
CT_{\text{calc}} [\text{min}*\text{mg/L}] = \text{Peak Flow Residual Concentration}[\text{mg/L}] \times \text{Detention Time [min]}.
\]

A calculated CT for the system is compared to a predetermined required CT\textsubscript{99.99} 3 or 4 log inactivation value, shown in Tables 15 and 16.

<table>
<thead>
<tr>
<th>Temperature\textdegree {C}</th>
<th>pH 6-9</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>25</td>
<td>2</td>
</tr>
</tbody>
</table>

With the Santiago de Quito system, the average yearly temperature is around 12 degrees Celsius and the water pH levels are 7.5. Thus, the 4 log CT\textsubscript{99.99} value is 6. The virus log inactivation is:
Virus Log Inactivation = 4 log \left( \frac{CT_{\text{CALC}}}{CT_{99.99}} \right).

For the designed system, the calculated CT values were 278 and 7.48 [min*mg/L], for the upper and lower reservoirs, respectively. These are higher than the \( CT_{99.99} \) value of 6 [min*mg/L], and thus the system is deemed sufficient for deactivating viruses. Sample calculations are displayed in Appendix K.

4.4. Fluoridation

Fluoride was considered for this system because it is known to aid in oral health and 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:\(^{26}\)

Tooth decay: \( \text{Ca}_5(\text{PO}_4)_3\text{OH} (s) + 4\text{H}_3\text{O}^+ (aq) \rightarrow 5\text{Ca}^{2+} (aq) + 3\text{HPO}_4^{2-} (aq) + 5\text{H}_2\text{O}(l) \)

Fluoridation: \( \text{Ca}_5(\text{PO}_4)_3\text{OH} (s) + \text{F}^- (aq) \rightarrow \text{Ca}_5(\text{PO}_4)_3\text{F} (s) + \text{OH}^- (aq) \).

However, this reaction can be overreaching at fluoride 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.\(^{27}\) The Ecuadorian government has created a standard for fluoride in drinking water, which can be seen in Appendix D Table 4.4. For Santiago de Quito, where the annual average temperature is 12 degrees Celsius, the maximum fluoride limit is 1.5 mg/L. The desirable limit, from the U.S. department of health is 0.7 mg/L.

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.\(^{28}\) 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. Sodium hexafluorosilicate is the most commonly used and least expensive solid fluoride source. Using this as a source of fluoride for the community of Santiago de Quito, the disodium hexafluorosilicate demand would be 136 grams/day, and the yearly cost of fluoride would be approximately $3,004, depending on the industrial source. While the team believes fluoride could improve oral health of the community and would be a worthwhile investment, there are many stigmas about fluoride in the United States and elsewhere. Before implementing this, it is recommended the community acceptance of spending money on fluoride be determined before continuing.
If fluoride were to be added to the system, it could be dissolved into the electrolysis salt solution by a double batch approach. Basically, the electrolysis unit would be used for the electrochemical reaction of producing chlorine, as well as the dissolving of fluoride in water. The first step would be a normal run of the electrolysis unit to produce 60 liters of a 12.5mg/l solution of chlorine. Once that solution is dumped into the 55 gallon drum dosing unit, the electrolysis unit is again filled up with 60 liters of water. Then 2.34 kilograms of disodium hexafluorosilicate are mixed into the water until all solids are dissolved. Again, this solution is drained into the dosing tank to be subsequently drawn by the peristaltic pumps.

With this further diluted solution of chlorine, the required dosing rate of the solution would double. Assuming the steps mentioned above are followed, the solution in the dosing tank would contain 6.25 mg/L of chlorine and 0.7 g/L of fluoride. This varies the peristaltic pump percent as 122.4% for the lower pressure zone and 17.4% for the upper pressure zone. If a different peristaltic pump, mentioned in appendix A14 is used, the lower pressure zone pump percent becomes 73.3% and the upper becomes 10.5%. This needs to be a decision of the community members to whether or not fluoridation is within their wants and needs.

4.5. Electrolysis
Electrolysis production of sodium hypochlorite was determined as the preferred low cost source of chlorine. This method uses table salt (NaCl), and electrolytically decomposes it to chlorine, sodium hydroxide, and hydrogen. Two electrically charged metal poles, an anode and cathode, allow for an electric current through the water and salt solution. The overall reaction is summarized as:

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

\[
\text{NaCl} + \text{H}_2\text{O} + e^- \rightarrow \frac{1}{2}\text{Cl}_2 + \text{NaOH} + \frac{1}{2}\text{H}_2
\]

\[
2\text{NaCl}(aq) + 2\text{H}_2\text{O} \rightarrow \text{Cl}_2(g) + \text{H}_2(g) + 2\text{NaOH}(aq).
\]

At the positively charged anode of the cell, negative ions are attracted. The major reaction here is:

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

Along with a sub reaction,

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

The most common form of electrolysis technology are membrane cell processes. This process, as summarized in Figure 12 below, keeps the products separate and pulls them off as chlorine and hydrogen gas. This technology is not ideal in a developing setting due to additional expensive technology needed to compress and store these gases. In addition, chlorine gas can be extremely dangerous, and a leak could potentially be toxic if not handled properly.29
A safer and simpler technology is a one cell, batch system electrolysis unit. In this system, a current is still run through an ionic solution. However, in one cell there is no membrane between the anode and cathode. The products recombine in the solution to form a dilute solution of sodium hypochlorite. This is comparable to a bleach solution, just usually at lower chlorine concentrations. In addition, this technology is easier to obtain and upkeep in a rural, developing setting.

An electrolysis machine for this design has been chosen from a local producer, Chlorid. A 60 liter unit needs 2 kg of salt input and 24 hours reaction to produce a 1.25% hypochlorite solution. Unit specs are displayed in Appendix N.

1http://www.essentialchemicalindustry.org/chemicals/chlorine.html
4.5.1. Chlorine Safety
Chlorine and its chemical compounds are potential health hazards. Inhalation of chlorine gas can highly irritate the respiratory system when in very low concentrations, and is categorized as a ‘choking agent.’ Liquid chlorine solutions, such as bleach, are corrosive and can cause chemical burns. These dangers are lessened with low concentrations, however caution is still advised.

As a part of the design implementation process, chlorine safety should be covered with system operators, and other involved members of the community. Participants should be informed of the situations in which they could come in contact with chlorine, the dangers it poses, and necessary first aid measures. In the designed process, the chlorine solution concentration should never be over 2.5%. This is half of a local bleach container concentration, and twice the concentration created from the electrolysis machine. If the solution should come in contact with skin, the victim should wash the affected area for at least 15 minutes with soap and water. Any contaminated clothing should be removed and washed and dried thoroughly before reuse. In the event of inhalation or ingestion, care should be administered by a qualified personnel.

5. Final Design Proposal

5.1. Distribution Design

5.1.1. Final Design Selection
The team’s final design for the pumping configuration was selected from the three alternatives discussed in section 3.3. See Appendix J for the team’s decision matrix for the three options. Based on this analysis the team originally chose option 3, to pump all the water to reservoir E and allow water to drain to reservoir B which would control the pressure in the lower elevation zone by a shut off head valve. This option was ideal for the design because it would only require one pumping station with 2 pumps (one for redundancy) and only one chlorine dosing system that would be provided enough mixing and contact time for treatment. The team believed this option would be more culturally appropriate for the community since it would require less maintenance.

However, after speaking with the clients in April, the team was advised that the project would utilize a design similar to option 1, to pump the water separately to the two reservoirs. The clients decided on this option since the two reservoirs are located closely in line from the well pumping station. This would allow them to dig only one trench that both pipes could be laid in and save them extra labor. This design would also help the project save in long run energy costs since the majority of homes are located in the lower pressure zone. Overall, although this option may be more work to maintain and add complexity to the pumping station for the community, the team moved ahead with this design.
5.1.2. Reservoir Design

The three lower reservoirs and one upper reservoir that needed to be designed were sized based by the number of homes each pressure zone would service. Demands were based on the average daily demand per person (75 liters or 20 gallons) and assumed 4 people per home, an excess storage of 50%, and a leakage of 5%. With a standard design as shown in Appendix Q Drawing A-10, each reservoir will be a circular reinforced masonry brick structure with a 4.7m diameter. All lower reservoirs were sized to have a water surface elevation of 3376m while the upper reservoir will have a water surface elevation of 3423m. See Appendix K for the demand calculations and sizing for each tank. Based on the calculations each of the lower reservoirs needed to hold 67.5m$^3$ (18,000 gallons) for a total of 202.5m$^3$ (54,000 gallons). While the upper reservoir needed to hold 12.1m$^3$ (3,200 gallons). According to these values and accounting for extra tank height for float valves, each tank was rounded to the nearest 10m$^3$ increment. This standard sizing was given to the team by their client Bruce Rydbeck. Table 16 shows the final tank size for each of the four reservoirs.

<table>
<thead>
<tr>
<th>Reservoir Sizing</th>
<th>Volume [m$^3$]</th>
<th>Volume (gallons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir B</td>
<td>80</td>
<td>21,100</td>
</tr>
<tr>
<td>Reservoir C</td>
<td>80</td>
<td>21,100</td>
</tr>
<tr>
<td>Reservoir D</td>
<td>80</td>
<td>21,100</td>
</tr>
<tr>
<td>Reservoir E</td>
<td>20</td>
<td>5,300</td>
</tr>
</tbody>
</table>

Overall these tanks will provide a total storage of 260m$^3$ (68,700 gallons) for the community and service 360 homes and 6 community centers. This storage also allows for a future growth in the community as discussed in section 5.1.3. A final schematic of each tank, 80m$^3$ and 20m$^3$, is shown in Appendix Q Drawing A-11.

5.1.3. Pump House Specifications

The pumping station was designed using submersible Franklin Electric pumps and motors. These pumps were selected since the client had experience working with them in other Ecuadorian water projects. See Appendix K for pumping station calculations. The final pumps were designed based on a design head and demand. See Table 17 for pump selection criteria.
Table 17. Pump Design Points

<table>
<thead>
<tr>
<th>Pressure Zone</th>
<th>Design Head (m)</th>
<th>Projected Max Day Demand (GPM)</th>
<th>Design Flow (GPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher</td>
<td>103.5</td>
<td>1.851</td>
<td>5</td>
</tr>
<tr>
<td>Lower</td>
<td>56.5</td>
<td>30.9</td>
<td>35</td>
</tr>
</tbody>
</table>

Based on this criteria, final pumps were selected for the design. The pump specifications are shown in Table 18.

Table 18. Pump Specifications

<table>
<thead>
<tr>
<th>Pressure Zone</th>
<th>Flow (GPM)</th>
<th>Motor Power (hp)</th>
<th>Volts (V)</th>
<th>Model Number</th>
<th>Motor Number</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher</td>
<td>5</td>
<td>0.75</td>
<td>230</td>
<td>5JV07S4-2W230</td>
<td>2445079004S</td>
<td>300 series Stainless Steel</td>
</tr>
<tr>
<td>Lower</td>
<td>35</td>
<td>3</td>
<td>230</td>
<td>35JS11S4-2W230</td>
<td>2445079004S</td>
<td>Stainless Steel</td>
</tr>
</tbody>
</table>

Both of these models were selected based on their flow rates and corresponding flow rates. See Appendix L for full pump specification from the manufacturer. 300 series stainless steel is ideal for this site since “stainless steel alloys resist corrosion, maintain their strength at high temperatures and are easy to maintain”.

5.2. Proposed EPANET Model

The team’s final distribution layout was optimized for pressure, flow capacity, and head level in the reservoirs using EPANET modeling. EPANET models were made for average day demand per house (0.282L/min or 0.074 GPM) and maximum day demand per house (0.353L/min or 0.093 GPM). Both models also used the diurnal pattern shown in Figure 14 from the American Water Works Association (AWWA).
The water levels in the two reservoirs directly connected to the pumps, reservoirs B and E, are controlled by code entered into EPANET. This code tells the pumps to shut off and turn on at different water surface elevations within these tanks. Water levels in the other reservoirs, C and D, are a byproduct of head losses and demand flows between the reservoirs. Refer to Appendix P to see this syntax. In the actual system, a float valve in both reservoirs will close the inlet pipe from the pumps once the water surface reaches levels of 3423m for the upper zone and 3376m for the lower. The pumps will still be running at this point and the pressure in the pipes from the pump to the reservoirs will surge. In this scenario the water system operator can notice this pressure increase with a pressure gauge and choose to turn off the pumps until the tank level decreases. This setup allows a simple design without complicated electrical controls or wiring that runs from the reservoirs down to the pumping station at the well. Also, the pump can remain on during this time since it will reach its shut-off head level with no flow.

5.2.1. EPANET Assumptions

The EPANET model was done using topographic survey information in Civil 3D given to the team by Codense Ecuador. Additional assumptions for modeling based on this information include the following:

1. Average daily water demand of the community members: 75L/person/day based on the Ecuadorian Standards for a 2b community designation (1 spicot for the whole family/home).
2. Houses at common elevations grouped together (1-26 homes) with the most extreme elevation in each grouping selected.
3. Community centers include churches and schools.
4. Grouped homes were modeled as a single node with a demand along the main segment of distribution pipe.
5. The 360 homes and 6 community centers on the map will be apart of the water project.
7. One community center uses as much water daily as two to four households (depending on its location).
8. Maximum day is 1.25 times that of the average daily demand.
9. The new system will be independent of the Regional system and Rayo Loma system.
10. Roughness for PVC is 150 using Hazen Williams’ Equation.
11. Daily fluctuations modeled with a diurnal pattern from the AWWA.

5.2.2. EPANET Procedure

The modeling processes proceeded as follows:
1. Import all homes from Civil 3d with elevations and [x,y] locations for scaling the map appropriately.
2. Created groups of 1-26 total houses.
3. Took the extreme elevation of these homes, based on their location and create a point along the distribution network.
4. Created the pipe network links between chosen nodes (material: PVC, length: program determined, default diameter: 12mm).
5. Assign tank sizes based on average day demand calculations.
6. Create pumping station based on selected pumps.
7. Add demands at each node based on the number of homes within their group.
8. Add the diurnal demand pattern to each node.
9. Optimize pipe diameters based on pressures and tank head levels.

5.3. Distribution Results

5.3.1. Optimization

The distribution layout was optimized for pressure by running both average day and maximum day simulations and ensuring all node pressures were between 10-70m of head. The system was also tested to ensure the three lower reservoirs fill to adequate levels during maximum day demands. See Figure 15 for head levels in each of lower tanks on max day (Tank B being the closest and Tank D being the farthest).
As seen in the picture above, the lower 35 GPM pump runs for about 20hrs and is off for 3hrs for a total cycle time of 23hrs during maximum day. This is ideal since the first tank is filling at at least once a day during this “worst case” model. Also seen in the figure, the water surface elevation of each tank decreases with distance from the first tank by about 3.25m. This result is likely due to head losses and water being quickly pulled out of the system by the homes. However, all home pressures within the system remain within the 14 to 100 psi pressure range during max day. The team also found that this decrease is not as significant during lower demand days. Such as for the average daily demand model the lower tank head levels decrease only by 2.3 meters are seen in Figure 16.
And when there are no demands in the system the water surface elevation in all tanks converges to 3375.1m, where the pump is off, as seen in Figure 17.

Overall the distribution models show that the head levels in the tanks can converge with day to day fluctuations in demand. However, even without convergence, each of these simulations maintained the required 10 to 70 meters (14-100psi) of pressures at each demand node.
The chosen pipe diameters were also optimized based on head losses and cost. Specifically larger diameter pipes have less friction and head loss but are more expensive compared to smaller diameter pipes. In addition, longer, main-line pipes were slightly upsized to allow for population growth in the community.

Overall, these results indicate that the final design is adequate for the community demands and clients requests. See Appendix P for full distribution modeling results.

5.3.2. Pump Cycle Times

Based on average day and maximum day models, pump cycle times could be determined from tank head levels. The cycle time is the total “peak to peak” time on the head vs. time plots. The time the pump is on is when the slope is greater than zero while the time the pump is off is when the slope is less than zero. The overall results for the lower pressure zone and upper pressure zone cycle times are shown in Figures 19 and 20 respectively.

Figure 18. Lower Pressure Pump Zone Cycle Times
The longer run times for maximum day in the lower and upper pressure zones reflects the larger quantity of water being drawn from the reservoirs (or demand) throughout the day. While the shorter run times during average day in the lower and upper pressure zones reflects the smaller quantity of water being drawn out. Overall, both the upper and lower pumps run longer during maximum day when compared to average day run times.

5.3.3. System Map

See Appendix Q for the full plan set. The final plan set includes the final layout of the proposed home locations, reservoir sites, pressure zones, the proposed system, valve locations, and more specifications within the design.

5.4. Future Growth

Both the reservoirs and pumps were designed to allow for some future growth. Based on the flow rate of the pumps (35 GPM and 5 GPM) and the size of the reservoirs maximum capacities could be determined for each of these components. See Table 19 for the current and 20-year projected population capacity of the system as well as the maximum number of people that the system can handle.
### Table 19. Population Capacity

<table>
<thead>
<tr>
<th></th>
<th>Upper Pressure Zone</th>
<th>Lower Pressure Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pumps</td>
<td>Reservoirs</td>
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<tr>
<td>Current</td>
<td>84</td>
<td>84</td>
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<tr>
<td>Projected</td>
<td>103</td>
<td>103</td>
</tr>
<tr>
<td>Max</td>
<td>273</td>
<td>165</td>
</tr>
</tbody>
</table>

Based on the current system design, the upper pressure zone will be able to supply a maximum of 165 people (96% population increase) and the lower system will be able to supply a maximum of 1937 people (38% population increase). The upper pressure zone allows for more growth since the team has been notified by their client that this portion of the water project has more potential for growth in participants.

### 5.5. Disinfection and Treatment

For the treatment of the water mentioned in section 5, chlorine at a dosage level of 0.55 mg/L is desired to appropriately disinfect the drinking water. The weight between taste and appropriate safety is balanced in this decision. Fluorine is to be added to the water at a level of 0.7 mg/L as recommended by the World Health Organization. Filtration methods were decided to be cut out of the project due to the scope restraints like maintenance, accessibility, and costs. The water quality levels of the new well are also within a comfortable range to outweigh the cost of various filtration methods.

### 5.6. Pump House Design

See Appendix Q Drawing A-6 for the new well drawing/schematic. The pump house is to be built on top of this well structure. The recommended pump house structure is shown in Drawing A-7. The final pumphouse will include the four pumps (two for redundancy), on electrolysis machine, two peristaltic pumps for dosing, two 55 gallon drums for chlorine housing, and two main driving lines leading to the reservoirs. Control units from manufacturers will also be provided for the peristaltic and water pumps.

### 5.7. Final Costs

Based on design specifications and material costs given to the team by their client final costs for the project were estimated. See Table 20 for these results.
Table 20. Final Costs

<table>
<thead>
<tr>
<th>Total Costs</th>
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<tbody>
<tr>
<td>Distribution Network</td>
</tr>
<tr>
<td>Reservoirs</td>
</tr>
<tr>
<td>Pump House</td>
</tr>
<tr>
<td>Disinfection System</td>
</tr>
<tr>
<td><strong>Total</strong></td>
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<td>$36,500.00</td>
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<td>$35,500.00</td>
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<td>$19,700.00</td>
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<tr>
<td>$3,100.00</td>
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<tr>
<td><strong>$94,800.00</strong></td>
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These costs do not include labor costs since the community members participating in the project will provide their own labor. This is known as “minga hours” which each family offers as a form of payment for the water service. These costs are also subject to change as the project progresses.

5.8. Future Funding and Improvements
In order for the system to remain functional through its design life of 20 years, occasional improvements and repairs are to be expected. Typically, a water distribution system is thoroughly assessed every 5 years to ensure that the system is continually meeting demand and quality standards. If updates are necessary the local Junta de Agua (water council) is responsible for finding them, figuring out a solution or notifying an engineering service, and providing (or collecting) the funds to carry out the improvements. Allowing the community’s water council to take ownership of the system is a key component of designing a sustainable project.

5.9. Conclusion
Team Green to Clean is proud to present this report as a possible solution to the community of Santiago de Quito’s desire for more reliable, clean water. The team believes that the design outlined in this report will provide all participating homes in the community, current and projected, with disinfected water for the next 20 years, with only minimal system checks and improvements. There is sufficient room in the system to allow for additional homes added to the system in the future. With sufficient funding, the project could be implemented in the community within the next few months. The system and project were designed such that the community can have complete ownership of the final system. It is the team’s hope that Codeinse Ecuador and Life Giving Water can continue to be in contact with the community to offer any assistance the community may desire.

Throughout this project, design, and course process, the team learned a variety of important lessons and gained an expanded knowledge of engineering principles. Learning good communication was a key component for this project when talking to clients, advisors, and consultants. This project, like many others and especially those that are international, had many underlying politics, expectations, and changing scopes that were hard to understand and navigate at times. However the team has walked away with a better understanding of how to communicate well cross culturally in a professional setting.

If this project were to be expanded, the team would recommend that more filtration options should be explored, as well as additional water sources for future community/project growth. Options for water
sources include natural springs higher in the hills of the community, or another well in a clean groundwater source.

6. Acknowledgements

There were many individuals and groups who contributed to this project to assure its completion and success. Team Green to Clean would like to thank the following people for offering their time and knowledge to the project:

Calvin College Engineering Professors Jeremy VanAntwerp and Robert Masselink for offering expert advice and anticipating design decisions to be addressed; Professor Robert Hoeksema for providing in depth information on EPANET modeling; David Wunder for connecting the team with the project and offering advice; Bob DeKraker of the Calvin Engineering Department for his assistance in obtaining water testing materials; David Baar of Fishbeck, Thompson, Carr, & Huber for his significant assistance in distribution analysis and for meeting with and advising the team as an industrial consultant; Benjamin Whitehead of Black and Veatch for his insight on development in Ecuador and culturally appropriate design decisions; Bruce Rydbeck of Life Giving Water International for providing the project, coordinating the trip to Ecuador, and continuously communicating with the team; Cherith Rydbeck for her hospitality and cultural insight while in Ecuador; Martin Heinrich of Codeinse Ecuador for working in tandem with the team on this project, as well as being a gracious host; Julia Heinrich for her hosting, touring, and translating; Efrain Morocho of Codeinse Ecuador for his local knowledge and translation and project experience; the San Antonio Junta de Agua for their collaboration and time spent with the team; the citizens of Santiago de Quito for generously hosting and welcoming the team; DeGroot family for hosting and providing sustenance for the team.
7. Sources

1. Photo courtesy of Addottey Allotey.
3. Picture from Google Maps.
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Appendix A. Location Map A

Location Map
Santiago De Quito

Project Location
Appendix B. Population Distribution

<table>
<thead>
<tr>
<th>Sector</th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
<th>Percentage</th>
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<td>185</td>
<td>186</td>
<td>371</td>
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<td>Sector 2</td>
<td>106</td>
<td>130</td>
<td>236</td>
<td>20%</td>
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<td>Sector 3</td>
<td>26</td>
<td>25</td>
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<tr>
<td>Sector 4</td>
<td>77</td>
<td>97</td>
<td>174</td>
<td>15%</td>
</tr>
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<td>Sector 5</td>
<td>154</td>
<td>174</td>
<td>328</td>
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</tr>
<tr>
<td>Total</td>
<td>548</td>
<td>612</td>
<td>1160</td>
<td>100%</td>
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Appendix C. Fall 2015 Rydbeck Ripples Report

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 tank 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 tank truck to distribute water.

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

CODEINSE/Kawsaypak Yaku, the Quichua 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.
Appendix D. Ecuadorian Standards

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

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<th>Parameter</th>
<th>Desired Limit</th>
<th>Maximum Acceptable Limit</th>
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<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>
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### Table E.2. Parameters

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<th>Parameter</th>
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<tr>
<td>total Coliforms (NMP/100 cm(^3))</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>
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<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>
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<tr>
<td>21.5-26.2</td>
<td>0.86-0.76</td>
<td>0.8</td>
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<td>26.3-32.6</td>
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### Table E.4 Parameters III

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<td>Hardness (mg / l CaCO3)</td>
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<td>TDS (mg / l)</td>
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<td>1000</td>
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<tr>
<td>Iron (mg / l) 500</td>
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</tr>
<tr>
<td>Manganese (mg / l)</td>
<td>0.05</td>
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<tr>
<td>Nitrates (mg / l NO3-)</td>
<td>10</td>
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</tr>
<tr>
<td>Sulfate (mg / l)</td>
<td>50</td>
<td>400</td>
</tr>
<tr>
<td>Fluorides</td>
<td>Table 4.4</td>
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### Table E.5 Water Allocations for different levels of service

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<th>Level of services</th>
<th>Cold Weather (l/person*day)</th>
<th>Warm Weather (l/person*day)</th>
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<tr>
<td>Ia</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>Ib</td>
<td>5</td>
<td>65</td>
</tr>
<tr>
<td>Ila</td>
<td>60</td>
<td>85</td>
</tr>
<tr>
<td>IIb</td>
<td>75</td>
<td>100</td>
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Table E.6 Percentage of leaks to be considered in system design potable water

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<th>SERVICE LEVEL</th>
<th>LEAK PERCENTAGE</th>
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<tr>
<td>la and lb</td>
<td>10%</td>
</tr>
<tr>
<td>lla and llb</td>
<td>20%</td>
</tr>
</tbody>
</table>

4.5.2 Maximum Daily Flow

4.5.2.1 The maximum daily flow rate is calculated using the equation:

\[ Q_{MD} = K_{MD} \times Q_m \]

Where:
- \( Q_{MD} \) = maximum daily flow (l/s)
- \( K_{MD} \) = Max Factor majorization daily

4.5.2.2 The maximum factor majorization daily (KMD) has a value of 1.25 for all levels of service.

4.5.3.1 The maximum hourly flow is calculated using the equation:

\[ Q_{MH} = K_{MH} \times Q_m \]

Where:
- \( Q_{MH} \) = maximum hourly flow (l/s)
- \( K_{MH} \) = Max Factor majorization schedule

4.5.3.2 The maximum majorization time factor (KMD) has a value of 3 for all levels of service.
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<td>Pump House Design</td>
<td>9</td>
<td>20-Apr-16</td>
<td>29-Apr-16</td>
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<tr>
<td>50</td>
<td>Project Night Poster</td>
<td>5</td>
<td>24-Apr-16</td>
<td>29-Apr-16</td>
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<td>51</td>
<td>Chlorine Calcs</td>
<td>9</td>
<td>25-Apr-16</td>
<td>4-May-16</td>
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<td>52</td>
<td>Verbal presentation II</td>
<td>5</td>
<td>1-May-16</td>
<td>6-May-16</td>
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<td>53</td>
<td>Final Presentation</td>
<td>6</td>
<td>1-May-16</td>
<td>7-May-16</td>
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<td>54</td>
<td>Website Upgrade</td>
<td>3</td>
<td>6-May-16</td>
<td>9-May-16</td>
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<td>55</td>
<td>Report Due</td>
<td>13</td>
<td>26-Apr-16</td>
<td>9-May-16</td>
</tr>
</tbody>
</table>
## Appendix G. Budget

### Team 04 - Budget

<table>
<thead>
<tr>
<th>Date</th>
<th>Team member</th>
<th>Description</th>
<th>Description</th>
<th>Estimated Price</th>
<th>Debit</th>
<th>Credit</th>
<th>Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/30/10</td>
<td></td>
<td>Beginning Balance</td>
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<td>$500.00</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1/14/16</td>
<td>Maria Steblay</td>
<td>Cole Parmer Chlorine Test Strips</td>
<td>Order placed with Bob DK</td>
<td>41.25</td>
<td>37.13</td>
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<td>$462.87</td>
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<tr>
<td>1/14/16</td>
<td>Maria Steblay</td>
<td>Amazon Fluroide Test Strips</td>
<td>Order placed with Bob DK</td>
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<tr>
<td>1/15/16</td>
<td>MaKinnah Collins</td>
<td>Drinking Water Test Kits and Test Tubes Amazon</td>
<td>Order placed with Bob DK</td>
<td>52.3</td>
<td>50.64</td>
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<tr>
<td>12/15/10</td>
<td>Maria Steblay</td>
<td>Water Testing Kits (9) From Lowe's</td>
<td>Pick up order</td>
<td>95.21</td>
<td>95.21</td>
<td></td>
<td>$303.89</td>
</tr>
</tbody>
</table>
Appendix H. Trip Agenda

Agenda - Calvin Team
January 26 - February 2, 2016

26 Jan
11:16 PM DL flight arrives at UIO
spend night at Rydebeck's home
27 Jan
breakfast and prayer at Rydebeck's
10:00 AM leave for Riobamba
1:00 PM lunch with Martin Henrich and Efrain Morocho at restaurant
meet with Martin & Efrain at CODEINSE office
6:00 PM arrive in Santiago de Quito
evening Bible study and de-brief time

28 Jan
7:00 AM breakfast in community
walk the extents of community
view possible reservoir sites & select options
locate/define existing pipes
observe existing wells and existing reservoir
noon
lunch in community
continue information gathering
6:00 PM dinner in Santiago de Quito
evening Bible study and de-brief time

29 Jan
7:00 AM breakfast in community
continue information gathering & design work
visit clinic to observe CI production unit
noon
lunch in community
continue information gathering & design work
6:00 PM dinner in Santiago de Quito
evening Bible study and de-brief time

30 Jan
7:00 AM breakfast in community
pack up truck and leave Santiago de Quito
visit Yanacocha water system
visit Achullay water system
1:00 PM lunch in Cajabamba
3:00 PM arrive at Martin & Julia's home in Riobamba
5:30 PM University student event at William's church
7:00 PM Dinner

31 Jan
10:00 AM church service at Henrich's church
observe market day in Cajabamba
1:00 PM lunch at restaurant
tour some of Riobamba
6:00 PM evening meal with Henrich's
evening Bible study and de-brief time

1 Feb
7:00 AM leave for Rydebeck's
10:00 AM unpack at Rydebeck's/snack/ and leave for sightseeing
noon lunch at restaurant or packed sandwich
6:00 PM leave for dinner at Briciolias
8:30 PM return to Rydebeck's for prayer and to pack up
9:30 PM leave for Quito airport

2 Feb
12:30 AM Flight DL 680 Departs Quito
Appendix I. Topographic Map¹

¹ http://www.lib.utexas.edu/maps/topo/ecuador/txu-pclmaps-oclc-869565072-riobamba-3888-i.jpg
I. Two pumps at the well bringing water separately Reservoirs B and E
II. One pump that lifts water to Reservoir B and then a booster pump to Reservoir E
III. One Pump that lifts water to Reservoir E and allows water to drain to Reservoir B which acts as a pressure breaking tank

<table>
<thead>
<tr>
<th>Decision Matrix</th>
<th>Scores</th>
</tr>
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<tbody>
<tr>
<td>Decision Factors</td>
<td>Max</td>
</tr>
<tr>
<td>Energy</td>
<td>5</td>
</tr>
<tr>
<td>Maintenance</td>
<td>5</td>
</tr>
<tr>
<td>Pipe Costs</td>
<td>5</td>
</tr>
<tr>
<td>Chlorine Contact Time</td>
<td>5</td>
</tr>
<tr>
<td>Simplicity of Design/Construction</td>
<td>5</td>
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<tr>
<td>Dependability</td>
<td>5</td>
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<tr>
<td>Safety</td>
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<tr>
<td>Legality</td>
<td>5</td>
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<tr>
<td>Total</td>
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<table>
<thead>
<tr>
<th>Decision Factor Definitions</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>What is the overall energy efficiency of the system?</td>
</tr>
<tr>
<td>Maintenance</td>
<td>What will the future maintenance look like? What educational experience and resources will be necessary to upkeep the system?</td>
</tr>
<tr>
<td>Pipe Costs</td>
<td>How much will additional pipes cost for the system? Also consider redundant pipe costs for design.</td>
</tr>
<tr>
<td>Chlorine Contact Time</td>
<td>What will chlorine dosing look like? Will there be adequate time for chlorine dosing?</td>
</tr>
<tr>
<td>Simplicity of Design/Construction</td>
<td>Will community members understand the system enough to build and maintain the system in the future</td>
</tr>
<tr>
<td>Dependability</td>
<td>Will the system supply reliable water that meets water quality standards consistently?</td>
</tr>
<tr>
<td>Safety</td>
<td>Will users and maintenance works be protected from design hazards and chemical treatment hazards</td>
</tr>
<tr>
<td>Legality</td>
<td>Will this system meet Ecuadorian Standards?</td>
</tr>
</tbody>
</table>
Appendix . Calculations

Calculations - Lower Pressure Zone

I. Supply and Demand Lower Pressure Zone

i. Demand

\[ \text{homes} := 339 \]
\[ \text{cc} := 6 \]
\[ \text{daily\_demand\_person} := 75 \frac{L}{\text{day}} \]
\[ \text{population\_home} := 4 \]
\[ \text{population\_cc} := 8 \]
\[ \text{design\_period} := 20\text{yr} \]
\[ \text{growth\_rate} := 1\% \]
\[ \text{max\_day\_factor} := 1.25 \]
\[ \text{max\_hour\_factor} := 1.75 \]
\[ \text{leakage} := 5\% \]

\[ \text{current\_population} := \text{cc} \cdot \text{population\_cc} + \text{homes} \cdot \text{population\_home} = 1404 \]
\[ \text{design\_period} := \frac{1}{\text{yr}} = 1.22 \]
\[ \text{projected\_population} := \text{projected\_population\_factor} \cdot \text{current\_population} = 1713.147 \]
\[ \text{current\_avg\_daily\_demand} := \text{current\_population} \cdot \text{daily\_demand\_person} \cdot (1 + \text{leakage}) = 110565 \frac{L}{\text{day}} \]
\[ \text{projected\_avg\_daily\_demand} := \text{projected\_population} \cdot \text{daily\_demand\_person} \cdot (1 + \text{leakage}) = 134910.312 \frac{L}{\text{day}} \]
\[ \text{current\_max\_daily\_demand} := \text{max\_day\_factor} \cdot \text{current\_avg\_daily\_demand} = 138206.25 \frac{L}{\text{day}} \]
\[ \text{projected\_max\_daily\_demand} := \text{max\_day\_factor} \cdot \text{projected\_avg\_daily\_demand} = 168637.89 \frac{L}{\text{day}} \]
\[ \text{current\_max\_hour\_demand} := \text{max\_hour\_factor} \cdot \text{current\_avg\_daily\_demand} = 8062.031 \frac{L}{\text{hr}} \]
\[ \text{projected\_max\_hour\_demand} := \text{max\_hour\_factor} \cdot \text{projected\_avg\_daily\_demand} = 9837.21 \frac{L}{\text{hr}} \]

ii. Supply

\[ \text{well\_pumping\_rate} := 35 \frac{\text{gal}}{\text{min}} (35\text{gpm}) \]
\[ \text{daily\_supply} := (\text{well\_pumping\_rate}) = 190784.763 \frac{L}{\text{day}} \]

iii. Excess

\[ \text{current\_avg} := \text{daily\_supply} - \text{current\_avg\_daily\_demand} = 80219.763 \frac{L}{\text{day}} \]
\[ \text{current\_max} := \text{daily\_supply} - \text{current\_max\_daily\_demand} = 52578.513 \frac{L}{\text{day}} \]
\[ \text{projected\_avg} := \text{daily\_supply} - \text{projected\_avg\_daily\_demand} = 55874.451 \frac{L}{\text{day}} \]
\[ \text{projected\_max} := \text{daily\_supply} - \text{projected\_max\_daily\_demand} = 22146.873 \frac{L}{\text{day}} \]
II. Reservoir Sizing Lower Pressure Zone

excess_storage := 50%  \( \text{Ecuadorian Standard} \)

current_population = 1404

projected_population = 1713.147

ii. Reservoir D, C, and B  \( \text{Lower Pressure Zone} \)

elev\_high\_lpz := 3376m

elev\_low\_lpz := 3306m

head\_d := elev\_high\_lpz – elev\_low\_lpz = 70 m

tank\_min\_size\_lpz := \text{projected}\_\text{avg}\_\text{daily}\_\text{demand} \cdot (1 + \text{excess}\_\text{storage}) \cdot \frac{\text{day}}{3} = 67.455\text{m}^3

tank\_size\_lpz := 80m^3  \( \text{Extra height for storage and equipment (See Detail)} \)

v. Sizing

total\_homes := \frac{\text{projected}\_\text{population}}{\text{population}\_\text{home}} = 428.287

total\_storage := \text{tank}\_\text{size}\_\text{lpz} \cdot 3 = 240\text{m}^3

d\_tank := 4.7m

height\_tank := 4 \cdot \frac{\text{tank}\_\text{size}\_\text{lpz}}{3.14 \cdot d\_tank^2} = 4.613 m
III. Pump Selection Lower Pressure Zone

well_elevation := 3319.5m

elev_high_lpz = 3376 m

shut_off_head := elev_high_lpz – well_elevation = 56.5·m

gallon_min := projected_max_daily_demand = 30.937 gal/min

design_pont_flow := 35gpm
Calculations Upper Pressure Zone

I. Supply and Demand Upper Pressure Zone

i. Demand

- **homes** := 21  
  \( \text{number of homes in water project} \)

- cc := 0  
  \( \text{number of community centers in water project} \)

- daily_demand_person := 75 \( \frac{L}{\text{day}} \)  
  \( \text{Ecuadorian Standard} \)

- population_home := 4  
  \( \text{assumed number of people per home} \)

- population_cc := 8  
  \( \text{assumed number of people per community center} \)

- design_period := 20 yr  
  \( \text{assumed project design period} \)

- growth_rate := 1%  
  \( \text{Ecuadorian Standard} \)

- max_day_factor := 1.25  
  \( \text{Ecuadorian Standard} \)

- max_hour_factor := 3  
  \( \text{Ecuadorian Standard} \)

- leakage := 5%  
  \( \text{Ecuadorian Standard} \)

- current_population := cc \cdot population_cc + homes \cdot population_home = 84

- projected_population_factor := \( (1 + \text{growth rate}) \cdot \frac{1}{\text{design period (yr)}} \) = 1.22

- projected_population := projected_population_factor \cdot current_population = 102.496

- current_avg_daily_demand := current_population \cdot \text{daily_demand_person} \cdot (1 + \text{leakage}) = 6615 \cdot \frac{L}{\text{day}}

- projected_avg_daily_demand := projected_population \cdot \text{daily_demand_person} \cdot (1 + \text{leakage}) = 8071.557 \cdot \frac{L}{\text{day}}

- current_max_daily_demand := max_day_factor \cdot current_avg_daily_demand = 8268.75 \cdot \frac{L}{\text{day}}

- projected_max_daily_demand := max_day_factor \cdot projected_avg_daily_demand = 10089.446 \cdot \frac{L}{\text{day}}

- current_max_hour_demand := max_hour_factor \cdot current_avg_daily_demand = 826.875 \cdot \frac{L}{\text{hr}}

- projected_max_hour_demand := max_hour_factor \cdot projected_avg_daily_demand = 1008.945 \cdot \frac{L}{\text{hr}}

ii. Supply

- well_pumping_rate := 5 \( \frac{\text{gal}}{\text{min}} \) \( (5 \text{gpm}) \)

- daily_supply := (well_pumping_rate) = 27254.966 \( \frac{L}{\text{day}} \)

iii. Excess

- current_avg := daily_supply − current_avg_daily_demand = 20639.966 \( \frac{L}{\text{day}} \)

- current_max := daily_supply − current_max_daily_demand = 18986.216 \( \frac{L}{\text{day}} \)

- projected_avg := daily_supply − projected_avg_daily_demand = 19183.409 \( \frac{L}{\text{day}} \)

- projected_max := daily_supply − projected_max_daily_demand = 17165.52 \( \frac{L}{\text{day}} \)
II. Reservoir Sizing Upper Pressure Zone

excess_storage := 50%   Ecuadorian Standard

current_population = 84

projected_population = 102.496

i. Reservoir E   High Pressure Zone Tank

elev_high_e := 3423m

elev_low_e := 3353m

head_e := elev_high_e - elev_low_e = 70 m

tank_min_size_e := projected_avg_daily_demand·(1 + excess_storage)·day = 12.107·m³

tank_size_e := 20m³   Extra Room for Storage and Equipment (See Detail)

v. Sizing

total_storage := tank_size_e = 20·m³

total_storage = 20·m³

d_tank := 4.7m

height_tank := \frac{\text{tank_size}_e}{3.14 \cdot d_tank^2} = 1.153 m
III. Pump Selection Upper Pressure Zone

\[ \text{well_elevation} := 3319.5 \text{m} \]

\[ \text{elev_high_e} = 3423 \text{ m} \]

\[ \text{shut_off_head} := \text{elev_high_e} - \text{well_elevation} = 103.5 \text{ m} \]

\[ \text{gallon_min} := \text{projected_max_daily_demand} = 1.851 \frac{\text{gal}}{\text{min}} \]

\[ \text{design_pont_flow} := 5 \text{gpm} \]
Calculations-Disinfection System

I. Chlorine Dosing

i. Water Demand

\[
\text{lower\_pump\_rate} := 35 \frac{\text{gal}}{\text{min}} \quad \text{Taken from Lower Pressure Zone}
\]

\[
\text{upper\_pump\_rate} := 5 \frac{\text{gal}}{\text{min}} \quad \text{Taken from Upper Pressure Zone}
\]

\[
\text{current\_lower\_ave\_daily\_demand} := 110565 \frac{\text{L}}{\text{day}}
\]

\[
\text{current\_upper\_ave\_daily\_demand} := 6615 \frac{\text{L}}{\text{day}}
\]

\[
\text{proj\_lower\_ave\_daily\_demand} := 134910.312 \frac{\text{L}}{\text{day}}
\]

\[
\text{proj\_upper\_ave\_daily\_demand} := 8071.557 \frac{\text{L}}{\text{day}}
\]

\[
\text{current\_lower\_max\_daily\_demand} := 138206.25 \frac{\text{L}}{\text{day}}
\]

\[
\text{current\_upper\_max\_daily\_demand} := 8268.75 \frac{\text{L}}{\text{day}}
\]

\[
\text{proj\_lower\_max\_day\_demand} := 168637.89 \frac{\text{L}}{\text{day}}
\]

\[
\text{proj\_upper\_max\_daily\_demand} := 10089.44 \frac{\text{L}}{\text{day}}
\]

\[
\text{peak\_lower\_hourly\_flow} := 8062.031 \frac{\text{L}}{\text{hr}}
\]

\[
\text{peak\_upper\_hourly\_flow} := 482.344 \frac{\text{L}}{\text{hr}}
\]

\[
\text{current\_peak\_hourly\_flow} := \text{peak\_upper\_hourly\_flow} + \text{peak\_lower\_hourly\_flow} = 8.544 \times 10^3 \frac{\text{L}}{\text{hr}}
\]

\[
\text{current\_ave\_daily\_demand} := \text{current\_lower\_ave\_daily\_demand} + \text{current\_upper\_ave\_daily\_demand}
\]

\[
\text{current\_ave\_daily\_demand} = 117180 \frac{\text{L}}{\text{day}}
\]

\[
\text{proj\_ave\_daily\_demand} := \text{proj\_lower\_ave\_daily\_demand} + \text{proj\_upper\_ave\_daily\_demand}
\]

\[
\text{proj\_ave\_daily\_demand} = 142981.869 \frac{\text{L}}{\text{day}}
\]
ii. System Chlorine Dosing
a. Water Chlorine Demand

\[
\text{water_chlorine_demand} := 0.06 \frac{\text{mg}}{\text{L}} \quad \text{Calculated from chlorine demand factors}
\]

\[
\text{desired_residual} := 0.3 \frac{\text{mg}}{\text{L}} \quad \text{Ecuadorian Standard and international standard}
\]

\[
\text{solution_chlorine_concentration} := 12.5 \frac{\text{gm}}{\text{L}} \quad \text{From Chlorid unit manual}
\]

\[
\text{desired_chlorine_dose} := \text{water_chlorine_demand} + \text{desired_residual} = 0.36 \frac{\text{mg}}{\text{L}}
\]

\[
\text{daily_chlorine_demand} := \text{current_ave_daily_demand} \cdot \text{desired_chlorine_dose} = 42.185 \frac{\text{gm}}{\text{day}}
\]

\[
\text{current_daily_chlorine_solution_demand} := \frac{\text{daily_chlorine_demand}}{\text{solution_chlorine_concentration}} = 3.375 \frac{\text{L}}{\text{day}}
\]

\[
\text{current_daily_chlorine_solution_demand_dosing} := \frac{\text{daily_chlorine_demand}}{\text{solution_chlorine_concentration}} = 0.039 \frac{\text{mL}}{\text{s}}
\]

\[
\text{proj_daily_chlorine_demand} := \text{desired_chlorine_dose} \cdot \text{proj_ave_daily_demand} = 51.473 \frac{\text{gm}}{\text{day}}
\]

\[
\text{projected_daily_chlorine_solution_demand} := \frac{\text{proj_daily_chlorine_demand}}{\text{solution_chlorine_concentration}} = 4.118 \frac{\text{L}}{\text{day}}
\]

\[
\text{current_upper_daily_chlorine_demand} := \text{current_upper_ave_daily_demand} \cdot \text{desired_chlorine_dose}
\]

\[
\text{current_upper_daily_chlorine_demand} = 2.381 \frac{\text{gm}}{\text{day}}
\]

\[
\text{proj_upper_daily_chlorine_demand} := \text{proj_upper_ave_daily_demand} \cdot \text{desired_chlorine_dose}
\]

\[
\text{proj_upper_daily_chlorine_demand} = 2.906 \frac{\text{gm}}{\text{day}}
\]

\[
\text{current_lower_daily_chlorine_demand} := \text{current_lower_ave_daily_demand} \cdot \text{desired_chlorine_dose}
\]

\[
\text{current_lower_daily_chlorine_demand} = 39.803 \frac{\text{gm}}{\text{day}}
\]

\[
\text{proj_lower_daily_chlorine_demand} := \text{proj_lower_ave_daily_demand} \cdot \text{desired_chlorine_dose}
\]

\[
\text{proj_lower_daily_chlorine_demand} = 48.568 \frac{\text{gm}}{\text{day}}
\]

\[
\text{current_days_per_batch} := 60 \frac{\text{L}}{\text{current_daily_chlorine_solution_demand}} = 17.779 \frac{\text{day}}{\text{}}
\]
Dosing via the demand on the system

\[
current_{upper\ daily\ solution} := \frac{current_{upper\ daily\ chlorine\ demand}}{solution_{chlorine\ concentration}} = 0.002 \ \text{mL/s}
\]

\[
proj_{upper\ daily\ solution} := \frac{proj_{upper\ daily\ chlorine\ demand}}{solution_{chlorine\ concentration}} = 0.003 \ \text{mL/s}
\]

\[
current_{lower\ daily\ solution} := \frac{current_{lower\ daily\ chlorine\ demand}}{solution_{chlorine\ concentration}} = 0.037 \ \text{mL/s}
\]

\[
proj_{lower\ daily\ solution} := \frac{proj_{lower\ daily\ chlorine\ demand}}{solution_{chlorine\ concentration}} = 0.045 \ \text{mL/s}
\]

Dosing via the flow rate of each pump

\[
dosing_{lower} := \frac{lower_{pump\ rate}}{solution_{chlorine\ concentration}} \cdot \frac{desired\ chlorine\ dose}{solution_{chlorine\ concentration}} = 0.064 \ \text{mL/s}
\]

\[
dosing_{upper} := \frac{upper_{pump\ rate}}{solution_{chlorine\ concentration}} \cdot \frac{desired\ chlorine\ dose}{solution_{chlorine\ concentration}} = 0.009 \ \text{mL/s}
\]

b. Dosing Correlation

\[
max_{feed} := 2.3 \ \text{gal/day}
\]

\[
lower_{percent\ estimation} := \frac{dosing_{lower}}{max_{feed}} = 63.11\%
\]

\[
upper_{percent\ estimation} := \frac{dosing_{upper}}{max_{feed}} = 9.016\%
\]

c. Dosing Allocation

\[
proj_{upper\ cl\ demand} := proj_{upper\ ave\ daily\ demand} \cdot desired\ chlorine\ dose = 2.906 \ \text{gm/day}
\]

\[
proj_{upper\ cl\ soln\ demand} := \frac{proj_{upper\ cl\ demand}}{solution_{chlorine\ concentration}} = 0.232 \ \text{L/day}
\]

\[
proj_{lower\ cl\ demand} := proj_{lower\ ave\ daily\ demand} \cdot desired\ chlorine\ dose = 48.568 \ \text{gm/day}
\]

\[
proj_{lower\ cl\ soln\ demand} := \frac{proj_{lower\ cl\ demand}}{solution_{chlorine\ concentration}} = 3.885 \ \text{L/day}
\]

\[
proj_{tot\ cl\ soln\ demand} := proj_{upper\ cl\ soln\ demand} + proj_{lower\ cl\ soln\ demand} = 4.118 \ \text{L/day}
\]
II. Contact Calcs

i. Contact Time  

*Ecuadorian Standard says this must be greater than or equal to 30 minutes*

a. required

\[
K_{value} := 20min \frac{mg}{L}
\]

\[
\text{desired_contact_time} := \frac{K_{value}}{\text{desired_residual}} = 66.667 \text{ min}
\]

b. calculated

\[
\text{lower_pipe_radius} := 0.09m
\]

\[
\text{lower_pipe_length} := 475.8m
\]

\[
\text{upper_pipe_radius} := 0.09m
\]

\[
\text{upper_pipe_length} := 1202.45m + \text{lower_pipe_length} = 1.678 \times 10^3 \text{ m}
\]

\[
\text{lower_pipes_volume} := \text{lower_pipe_radius}^2 \cdot 3.1415 \cdot \text{lower_pipe_length} = 12.107 \text{ m}^3
\]

*total volume of pipes from well to lower reservoir*

\[
\text{lower_reservoir_volume} := 80 \text{ m}^3
\]

*volume of lower reservoir*

\[
\text{total_lower_volume} := \text{lower_pipes_volume} + \text{lower_reservoir_volume} = 92.107 \text{ m}^3
\]

\[
\text{current_lower_contact_time} := \frac{\text{total_lower_volume}}{\text{peak_lower_hourly_flow}} = 685.489 \text{ min}
\]

\[
\text{upper_pipes_volume} := \text{upper_pipe_radius}^2 \cdot 3.1415 \cdot \text{upper_pipe_length} = 42.705 \text{ m}^3
\]

*total volume of pipes from well to upper reservoir*

\[
\text{upper_reservoir_volume} := 20 \text{ m}^3
\]

*volume of reservoir*

\[
\text{total_upper_volume} := \text{upper_pipes_volume} + \text{upper_reservoir_volume} = 62.705 \text{ m}^3
\]

\[
\text{current_upper_contact_time} := \frac{\text{total_upper_volume}}{\text{peak_upper_hourly_flow}} = 7.8 \times 10^3 \text{ min}
\]
ii. CT (Concentration Time) and Log Inactivation

\[
\text{baffle}_\text{fctr}_{\text{reservoir}} := 0.1  \quad \text{unbaffled reservoir factor}
\]
\[
\text{baffling}_\text{fctr}_{\text{pipes}} := 1  
\]
\[
\text{residual}_\text{chlorine}_\text{concentration} := 0.05 \frac{\text{mg}}{\text{L}}  \quad \text{assuming same as designed value}
\]
\[
\text{water}_\text{temp} := 13 \, ^{\circ}\text{C}  \quad \text{from field quality data}
\]
\[
\text{pH} := 8.0  \quad \text{from field quality data}
\]
\[
\text{inactive}_\text{4log}_\text{concentration}_\text{time} := 6\text{min} \frac{\text{mg}}{\text{L}}  \quad \text{value comes from CT Values table, based on temperature and pH, Appendix XX}
\]
\[
\text{giardia}_3\text{log}_\text{CT}_{99.99} := 102\text{min} \frac{\text{mg}}{\text{L}}  \quad \text{value comes from CT Values table, based on temperature and pH, Appendix XX}
\]

\[
\text{upper}_\text{theoretical}_\text{detention}_\text{time} := \frac{\text{total}_\text{upper}_\text{volume}}{\text{peak}_\text{upper}_\text{hourly}_\text{flow}} = 7.8 \times 10^3 \cdot \text{min}
\]

\[
\text{upper}_\text{detent}_\text{time} := \frac{\text{upper}_\text{reservoir}_\text{volume}}{\text{peak}_\text{upper}_\text{hourly}_\text{flow}} \cdot \text{baffle}_\text{fctr}_{\text{reservoir}} + \frac{\text{upper}_\text{pipes}_\text{volume}}{\text{peak}_\text{upper}_\text{hourly}_\text{flow}} = 5.561 \times 10^3 \cdot \text{min}
\]

\[
\text{upper}_\text{calc}_\text{CT} := \text{residual}_\text{chlorine}_\text{concentration} \cdot \text{upper}_\text{detent}_\text{time} = 278.048 \frac{\text{mg}}{\text{min}} \frac{\text{L}}{}
\]

\[
\text{lower}_\text{theoretical}_\text{detention}_\text{time} := \frac{\text{total}_\text{lower}_\text{volume}}{\text{peak}_\text{lower}_\text{hourly}_\text{flow}} = 685.489 \cdot \text{min}
\]

\[
\text{lower}_\text{detention}_\text{time} := \frac{\text{lower}_\text{reservoir}_\text{volume}}{\text{peak}_\text{lower}_\text{hourly}_\text{flow}} \cdot \text{baffle}_\text{fctr}_{\text{reservoir}} + \frac{\text{lower}_\text{pipes}_\text{volume}}{\text{peak}_\text{lower}_\text{hourly}_\text{flow}} = 149.644 \cdot \text{min}
\]

\[
\text{lower}_\text{calc}_\text{CT} := \text{residual}_\text{chlorine}_\text{concentration} \cdot \text{lower}_\text{detention}_\text{time} = 7.482 \frac{\text{mg}}{\text{min}} \frac{\text{L}}{}
\]

\[
\text{giardia}_3\text{log}_\text{upper}_\text{inactivation} := 3 \left( \frac{\text{upper}_\text{calc}_\text{CT}}{\text{giardia}_3\text{log}_\text{CT}_{99.99}} \right) = 8.178
\]

\[
\text{giardia}_3\text{log}_\text{lower}_\text{inactivation} := 3 \left( \frac{\text{lower}_\text{calc}_\text{CT}}{\text{giardia}_3\text{log}_\text{CT}_{99.99}} \right) = 0.22
\]

\[
\text{virus}_\text{log}_\text{upper}_\text{inactivation} := 4 \left( \frac{\text{upper}_\text{calc}_\text{CT}}{\text{inactive}_4\text{log}_\text{concentration}_\text{time}} \right) = 185.366
\]

\[
\text{virus}_\text{log}_\text{lower}_\text{inactivation} := 4 \left( \frac{\text{lower}_\text{calc}_\text{CT}}{\text{inactive}_4\text{log}_\text{concentration}_\text{time}} \right) = 4.988
\]
III. Chlorine Cost Comparisons

a. Electrolysis

\[
\text{batch\_size} := 60\text{L}.
\]
\[
\text{salt\_cost} := 0.80 \frac{\text\{\textparagraph\}}{\text{kg}}.
\]

Values given from Martin Heinrich and Efrain Morocho

\[
\text{days\_per\_batch} := \frac{\text{batch\_size}}{\text{projected\_daily\_chlorine\_solution\_demand}} = 14.571\text{-day}
\]
\[
\text{batches\_per\_year} := \frac{365}{\text{days\_per\_batch}} = 25.05 \frac{1}{\text{yr}}
\]
\[
\text{amount\_salt\_per\_year} := \text{batches\_per\_year}\cdot2\text{kg} = 50.101 \frac{\text{kg}}{\text{yr}}
\]
\[
\text{yearly\_salt\_cost} := \text{amount\_salt\_per\_year}\cdot\text{salt\_cost} = 40.081 \frac{\text{\textparagraph}}{\text{yr}}
\]

b. Bleach

\[
\text{bleach\_solution\_concentration} := 50000 \frac{\text{mg}}{\text{L}}.
\]
\[
\text{volume\_bleach\_container} := 5\text{gal}
\]
\[
\text{cost\_bleach\_gallon} := 5.00\text{\textparagraph}
\]

Values given from Bruce Rydbeck

\[
\text{chlorine\_per\_container} := \text{bleach\_solution\_concentration}\cdot\text{volume\_bleach\_container} = 946.353\text{\textparagraph}
\]
\[
\text{containers\_per\_year} := \frac{\text{proj\_daily\_chlorine\_demand}}{\text{chlorine\_per\_container}} = 19.866 \frac{1}{\text{yr}}
\]
\[
\text{yearly\_bleach\_cost} := \text{containers\_per\_year}\cdot\text{cost\_bleach\_gallon} = 99.33 \frac{\text{\textparagraph}}{\text{yr}}
\]

c. Tablets- Calcium Hypochlorite (65% effective chlorine)

\[
\text{cost\_tablet\_per\_pound} := 6 \frac{\pi}{\text{lb}}
\]
\[
\text{tablet\_chlorine\_concentration} := .65
\]
\[
\text{lbs\_tablet\_per\_year} := \frac{\text{proj\_daily\_chlorine\_demand}}{\text{tablet\_chlorine\_concentration}} = 28.924 \frac{\text{kg}}{\text{yr}}
\]
\[
\text{yearly\_tablet\_cost} := \text{lbs\_tablet\_per\_year}\cdot\text{cost\_tablet\_per\_pound} = 382.593 \frac{\pi}{\text{yr}}
\]
IV. Fluoride Dosing
i. Single Batch Operation

\[
\text{disodium_hexafluorosilicate\_cost} := 121.50 \frac{\text{¥}}{2\text{kg}} = 60.75 \frac{\text{¥}}{\text{kg}}
\]

\[
\text{disodium_hexafluorosilicate\_density} := 2.68 \frac{\text{g}}{\text{mL}}
\]

\[
\text{disodium_hexafluorosilicate\_molecular\_weight} := 188.06 \frac{\text{gm}}{\text{mol}}
\]

\[
\text{fluoride\_molecular\_weight} := 18.99 \frac{\text{gm}}{\text{mol}}
\]

\[
\text{desired\_fluoride\_level} := 0.7 \frac{\text{mg}}{\text{L}}
\]

\[
\text{fraction\_fluoride\_per\_gramDHFS} := \frac{6\text{-fluoride\_molecular\_weight}}{\text{disodium\_hexafluorosilicate\_molecular\_weight}} = 0.606
\]

\[
\text{fluoride\_demand} := \text{current\_ave\_daily\_demand} \cdot \text{desired\_fluoride\_level} = 82.026 \frac{\text{gm}}{\text{day}}
\]

\[
\text{hexafluorosilicate\_demand} := \frac{\text{fluoride\_demand}}{\text{fraction\_fluoride\_per\_gramDHFS}} = 135.385 \frac{\text{gm}}{\text{day}}
\]

\[
\text{yearly\_cost} := \text{hexafluorosilicate\_demand} \cdot \text{disodium\_hexafluorosilicate\_cost} = 3003.993 \frac{\text{¥}}{\text{yr}}
\]

\[
\text{DHFS\_per\_L\_batch} := \frac{\text{desired\_fluoride\_level} \cdot \text{current\_ave\_daily\_demand}}{\text{current\_daily\_chlorine\_solution\_demand} \cdot \text{fraction\_fluoride\_per\_gramDHFS}} = 40.117 \frac{\text{gm}}{\text{L}}
\]

\[
\text{DHFS\_per\_batch} := \text{DHFS\_per\_L\_batch} \cdot 60 = 2.407 \text{kg}
\]

ii. Double Batch Operation

\[
\text{new\_solution\_chlorine\_concentration} := \frac{\text{solution\_chlorine\_concentration}}{2} = 6.25 \frac{\text{gm}}{\text{L}}
\]

\[
\text{new\_dosing\_lower} := \text{lower\_pump\_rate} \left( \frac{\text{desired\_chlorine\_dose}}{\text{desired\_chlorine\_dose} + \text{new\_solution\_chlorine\_concentration}} \right)
\]

\[
\text{new\_dosing\_lower} = 0.127 \frac{\text{mL}}{\text{s}}
\]

\[
\text{new\_dosing\_upper} := \text{upper\_pump\_rate} \left( \frac{\text{desired\_chlorine\_dose}}{\text{desired\_chlorine\_dose} + \text{new\_solution\_chlorine\_concentration}} \right)
\]

\[
\text{new\_dosing\_upper} = 0.018 \frac{\text{mL}}{\text{s}}
\]

\[
\text{new\_fluoride\_dosing\_conc} := \text{desired\_fluoride\_level} \left[ \frac{(\text{new\_dosing\_lower} + \text{lower\_pump\_rate})}{\text{new\_dosing\_lower}} \right] = 12.154 \frac{\text{gm}}{\text{L}}
\]

\[
\text{required\_DHFS\_mass} := (1 + \text{fraction\_fluoride\_per\_gramDHFS}) \cdot \text{new\_fluoride\_dosing\_conc} \cdot 120 = 2.342 \text{kg}
\]

\[
\text{total\_batch\_conc\_F} := \frac{\text{required\_DHFS\_mass}}{60 \text{L}} = 39.036 \frac{\text{gm}}{\text{L}}
\]
b. Dosing Correlation

\[
\text{max_feed} = 2.3 \text{ gal/day} \quad \text{Value from peristaltic pump specification}
\]

\[
\text{new_fluor_lower_percent_estimation} := \frac{\text{new_dosing_lower}}{\text{max_feed}} = 126.212\% 
\]

\[
\text{new_fluor_upper_percent_estimation} := \frac{\text{new_dosing_upper}}{\text{max_feed}} = 18.03\% 
\]

\[
\text{new_max_feed} := 15 \frac{\text{L}}{\text{day}} \quad \text{Value from different peristaltic pump specification}
\]

\[
\text{new_lower_percent_estimation} := \frac{\text{new_dosing_lower}}{\text{new_max_feed}} = 73.257\% 
\]

\[
\text{new_upper_percent_estimation} := \frac{\text{new_dosing_upper}}{\text{new_max_feed}} = 10.465\% 
\]

V. Phosphate Levels Check

\[
\text{molecular_weight_phosphate} := 94.97 \frac{\text{gm}}{\text{mol}}
\]

\[
\text{density_water} := 1 \frac{\text{L}}{\text{kg}}
\]

\[
\text{lab_phosphate_levels} := 2.130 \frac{\text{mg}}{\text{L}}
\]

\[
\text{new_well_phosphate_levels} := \frac{\text{lab_phosphate_levels} \cdot \text{density_water}}{\text{molecular_weight_phosphate}} = 2.243 \times 10^{-5} \frac{\text{mol}}{\text{kg}}
\]

\[
\text{pig_toxicity_levels} := 35 \times 10^{-3} \frac{\text{mol}}{\text{kg}}
\]

\[
\text{toxicity_level} := \frac{\text{pig_toxicity_levels} \cdot \text{molecular_weight_phosphate}}{\text{density_water}} = 3.324 \times 10^{3} \frac{\text{mg}}{\text{L}}
\]
Series V

4" Submersible Series V

The standard J-Class Series Five submersible pump features unique hydraulics that improve efficiency and minimize wear even when pumping abrasives. Discharge and motor brackets are available in thermoplastic or stainless steel with a removable check valve system. Available in 5, 7, 10, 15, 20, and 25 gpm, 1/2 - 5 horsepower. For details on how to become a registered dealer and receive a 5-year warranty, contact your local distributor.

Features:

- 6 performance ranges: 5, 7, 10, 15, 20, and 25 gpm.
- Horsepower ranges: 1/2 - 5.
- Discharge head and motor bracket produced with industry proven, engineered materials. Available in 300 series stainless steel or high quality thermoplastic resins.
- Large wrench flat area on the discharge head for ease of installation.
- Dry run designed top bearing positively supports the 300 series stainless steel 7/16" hex shaft.
- Removable internal check valve.
- Powered by Franklin Electric corrosion-resistant super stainless 4" submersible motors with lightning protection.
- Maximum water temperature with proper flow is 120 °F/49 °C. Consult factory for details.
# Submersible Pumps

## 4" Series V Pumps - 5 GPM

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<thead>
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<th>Stainless Steel - PMA Model</th>
<th>Order No.</th>
<th>Motor</th>
<th>2-Wire</th>
<th>3-Wire</th>
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## Capacities in U.S. Gallons per Minute

### Depth to Pumping Water Level (Lift) in Feet

<table>
<thead>
<tr>
<th>HP</th>
<th>PS</th>
<th>Depth to Pumping Water Level (Lift) in Feet.</th>
<th>Shaded Areas Indicate Most Efficient Performance</th>
</tr>
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<tr>
<td></td>
<td>20</td>
<td>40</td>
<td>60</td>
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<td>1/2</td>
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<td></td>
</tr>
<tr>
<td>3/4</td>
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</tr>
<tr>
<td>1.5</td>
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</tbody>
</table>

### Notes:
- Discharge is 1-1/4" NPT. Maximum diameter across cable guard is 3.90" on all models.
4" Series V Pumps - 5 GPM

Capacities in U.S. Gallons per Minute

<table>
<thead>
<tr>
<th>HP</th>
<th>PS</th>
<th>Depth to Pumping Water Level (Lift) in Feet</th>
<th>Shaded Areas Indicate Most Efficient Performance</th>
</tr>
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</tr>
<tr>
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</tr>
<tr>
<td></td>
<td>80</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>

Notes: 1. Performance shown does not include friction loss in the drop pipe. 2. All performance data is based on rated motor nameplate voltage.
4" High Capacity Pump - Features

4" SandHandler

Features:

- 4 performance ranges - 35, 45, 60, and 90 gpm.
- Stainless steel discharge head and motor bracket.
- High flow impellers and stages are glass-filled Noryl® for maximum efficiency.
- Ceramic shaft sleeve and rubber discharge bearing eliminates sand wear.
- Intermediate bearing for increased shaft stability.
- Floating eye and hub seals for improved performance and efficiency.
- Stainless steel hex pump shaft, shell, and shaft coupling.
- High capacity upthrust assembly for protection during start-up and operation (45, 60, and 90 gpm models).
- Powered by Franklin's corrosion-resistant 4" submersible motors.
- 2" NPT discharge.
- Check valve must be ordered separately. See page 76.

Noryl® is a registered trademark of G.E.
# Submersible Pumps

## 4" High Capacity Pumps - 35 GPM

### Capacities in U.S. Gallons per Minute

<table>
<thead>
<tr>
<th>HP</th>
<th>PSI</th>
<th>Depth to Pumping Water Level (Lift) in Feet. Shaded Areas Indicate Most Efficient Performance</th>
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<tr>
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<td>40</td>
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</tr>
<tr>
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<td>50</td>
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</tr>
<tr>
<td></td>
<td>60</td>
<td>0  44  40  34  31  27  27  21  11</td>
</tr>
<tr>
<td></td>
<td>70</td>
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<td></td>
<td>80</td>
<td>0  44  40  34  31  27  27  21  11</td>
</tr>
<tr>
<td></td>
<td>Shut-off PSI</td>
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</tr>
<tr>
<td>1.5</td>
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</tr>
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<td>30</td>
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</tr>
<tr>
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<td>60</td>
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<tr>
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<td>70</td>
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<td>80</td>
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<tr>
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<td>Shut-off PSI</td>
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</tr>
<tr>
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<tr>
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<td>Shut-off PSI</td>
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</tr>
<tr>
<td></td>
<td>60</td>
<td>0  44  40  34  31  27  27  21  11</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>0  44  40  34  31  27  27  21  11</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>0  44  40  34  31  27  27  21  11</td>
</tr>
<tr>
<td></td>
<td>Shut-off PSI</td>
<td>258 239 235 224 216 216 216 216 216</td>
</tr>
<tr>
<td>7.5</td>
<td>20</td>
<td>0  44  40  34  31  27  27  21  11</td>
</tr>
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<td></td>
<td>30</td>
<td>0  44  40  34  31  27  27  21  11</td>
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<td></td>
<td>40</td>
<td>0  44  40  34  31  27  27  21  11</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>0  44  40  34  31  27  27  21  11</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>0  44  40  34  31  27  27  21  11</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>0  44  40  34  31  27  27  21  11</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>0  44  40  34  31  27  27  21  11</td>
</tr>
<tr>
<td></td>
<td>Shut-off PSI</td>
<td>593 584 575 567 559 551 543 535</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>0  44  40  34  31  27  27  21  11</td>
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<td>0  44  40  34  31  27  27  21  11</td>
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<td>0  44  40  34  31  27  27  21  11</td>
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<td>50</td>
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<td>0  44  40  34  31  27  27  21  11</td>
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<td></td>
<td>80</td>
<td>0  44  40  34  31  27  27  21  11</td>
</tr>
<tr>
<td></td>
<td>Shut-off PSI</td>
<td>539 538 537 536 535 534 533 532</td>
</tr>
</tbody>
</table>

**Notes:**
1. Performance shown does not include friction loss in the drop pipe.
2. All performance data is based on rated motor nameplate voltage.
Submersible Pumps

4" High Capacity Pumps - 35 GPM

GPM
0 5 10 15 20 25 30 35 40 45 50 55

M³PH
0 1 2 3 4 5 6 7 8 9 10 11 12

FEET
0 100 200 300 400 500 600 700 800 900 1000 1100 1200

METERS
0 50 100 150 200 250 300 350 400 450 500 550 600 650

PUMP OPERATING RANGE

BEST EFFICIENCY RANGE

10 hp
7.5 hp
5 hp
3 hp
2 hp
1.5 hp
1 hp

35gpm
56.5m

2.5 GPM
50 FT
**Appendix M. Peristaltic Pump from Blue-White**

**FLEXFLO® Peristaltic Metering Pumps**

**Engineering and Technical Data**

---

**A-100NC**

*Fixed Speed*

*Dial Knob Control*

*5 second cycle timer*

---

**Features:**
- Peristaltic pump design does not have valves that can clog requiring maintenance.
- Self priming - even against maximum line pressure. By-pass valves are not required. Cannot vapor lock or lose prime.
- Outputs to 5.17 GPH (19.56 LPH).
- Output pressures to 100 PSI (6.9 bar).
- Output volume is not effected by changes in back pressure.
- Patented pump tube design installs easily and stays centered on the rollers without manual adjustment.
- Two pump tubes supplied with each pump. No extra tubing required.
- Easy to use dial knob output control.
- 20:1 turndown ratio.
- Adjustable 5 second repeating interval timer. 0.25 - 5.0 second adjustable on time per 5 second cycle.
- Built-in Tube Failure Detection system (TFD). Senses chemical in the pump head, shuts off the pump and activates an NPN open collector output.
- Compatible with Blue-White’s output flow verification sensor system.
- Durable housing of chemical resistant Valox (PBT) thermoplastic.

---

**Specifications:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. working pressure</td>
<td>100 psig (6.9 bar)</td>
</tr>
<tr>
<td>Max. fluid temperature</td>
<td>130° F (54° C)</td>
</tr>
<tr>
<td>Max. ambient temperature</td>
<td>14° to 110° F/-10° to 43° C</td>
</tr>
<tr>
<td>Output adjustment range</td>
<td>5-100%</td>
</tr>
<tr>
<td>Duty cycle</td>
<td>Continuous</td>
</tr>
<tr>
<td>Maximum viscosity</td>
<td>5,000 Centipoise</td>
</tr>
<tr>
<td>Maximum suction lift</td>
<td>30 ft. Water 0 psig</td>
</tr>
<tr>
<td>Maximum Solids</td>
<td>50% by volume</td>
</tr>
<tr>
<td>Enclosure</td>
<td>NEMA 3R, (IP23)</td>
</tr>
<tr>
<td>Approximate shipping wt</td>
<td>10 lb. (4.5 kg)</td>
</tr>
</tbody>
</table>

| Voltage (max amp)                  | 115VAC/60Hz, 14 & 30 rpm = 1.37 amp |
|                                    | 45 & 60 rpm = 1.87 amp              |
|                                    | 230VAC/60Hz, 14 & 30 rpm = 0.64 amp |
|                                    | 45 & 60 rpm = 0.74 amp              |
|                                    | 220VAC/50Hz, 14 & 30 rpm = 0.68 amp |
|                                    | 45 & 60 rpm = 1.14 amp              |
|                                    | 240VAC/50Hz, 14 & 30 rpm = 0.66 amp |
|                                    | 45 & 60 rpm = 1.04 amp              |

| Power Cord Plug Type               | 115V/60Hz = NEMA 5/15 (USA) |
|                                    | 230V/60Hz = NEMA 6/15 (USA)   |
|                                    | 220V/50Hz = CEE 7/11 (EUROPE) |
|                                    | 240V/50Hz = CEE 7/11 (EUROPE)  |

---

**Materials of Construction:**

**Wetted components:**
- Pump Tube Assembly: Norprene®, Tygothane® or FKM tubing
- PVDF tube assembly connection fittings
- Suction Tubing: Clear PVC
- Suction Strainer: Natural Polypropylene
- Discharge Tubing: Natural Polyethylene (LLDPE)
- Injection/Check valve:
  - Body & insert: Polypropylene (optional PVDF)
  - Check Ball: Ceramic
  - Spring: Hastelloy C-276
  - Ball Seat O-ring: TFE/P (optional EP)
  - Static Seal O-ring: FKM (optional EP)

**Non-Wetted components:**
- Pump Head & Enclosure: Valox® (PBT) thermoplastic
- Pump Head Cover: Clear Acrylic
- Cover Screws: 300 Stainless, Polypropylene cap
- Roller Assembly:
  - Rotor: Valox® (PBT)
  - Rollers: Nylon
- Roller Bearings: Bronze
- Motor Shaft: Nickel plated steel
- TFD System Sensor pins: Hastelloy C-276
- Power Cord: 3 conductor, SJTW-A Water-resistant
Blue-White® Peristaltic Metering Pumps

Dimensions:

**Base Mounting**
- .200" Dia. 5mm 4 places
- 7.625" 194mm
- 3.500" 89mm
- 7.375" 187mm

**Rear Panel Mounting**
- .200" Dia. 5mm 4 places
- 8.187" 208mm

---

**Model Number Matrix:**

<table>
<thead>
<tr>
<th>Maximum Motor RPM</th>
<th>MODEL A1N</th>
<th>C</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 = 14 RPM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 = 30 RPM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 = 45 RPM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 = 60 RPM</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Power Supply**
- 0 = 115V/60Hz
- 1 = 220V/50Hz
- 2 = 230V/60Hz
- 3 = 240V/50Hz

**Output Control**
- V = Digital speed control with external input
- E = Analog speed control
- A = Analog timer, 60 sec. Cycle - 100% duty
- C = Analog timer, 5 sec. Cycle - 100% duty
- S = Analog timer, 60 sec. Cycle - 10% duty
- X = No output control - fixed feed rate

**Miscellaneous Options (not required)**
- 0 = 3x40-6V injector replaces A-014N-6A
- 1 = C-340V foot valve replaces C-342-6 strainer
- 5 = A-014NK-6A injector PVD
- 6 = Jumper set for digital square wave input
- 7T = 7 gallon chemical tank system
- 15T = 15 gallon chemical tank system
- 30T = 30 gallon chemical tank system
- X = NSF61 certified (ships without accessories)

**Tubing Connection Type**
- T = Compression type nuts

**Pump Tube Size and Material**
- 1 = 1/4" OD Tygothane
- 2 = 3/8" OD Tygothane
- 3 = 7/16" OD Tygothane
- 4 = 1/4" OD Norprene
- 5 = 5/16" OD FKM
- 6 = 3/8" OD Norprene
- 7 = 7/16" OD Norprene
- 8 = 7/16" OD Norprene Chemical

---

**Maximum Flow rate and pressure capacities:**

<table>
<thead>
<tr>
<th>Tube no.</th>
<th>Tubing Material</th>
<th>14 RPM MODELS</th>
<th>30 RPM MODELS</th>
<th>45 RPM MODELS</th>
<th>60 RPM MODELS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ml/m oz/m lph gph PSI(bar)</td>
<td>ml/m oz/m lph gph PSI(bar)</td>
<td>ml/m oz/m lph gph PSI(bar)</td>
<td>ml/m oz/m lph gph PSI(bar)</td>
<td></td>
</tr>
<tr>
<td>1 Tygothane</td>
<td>15 0.51 0.90 0.24 65(4.5)</td>
<td>35 1.18 2.10 0.55 65(4.5)</td>
<td>54 1.83 2.34 0.68 65(4.5)</td>
<td>67 2.26 4.02 1.06 65(4.5)</td>
<td></td>
</tr>
<tr>
<td>2 Tygothane</td>
<td>32 1.08 1.92 0.51 65(4.5)</td>
<td>75 2.54 4.50 1.19 65(4.5)</td>
<td>115 3.89 6.90 1.82 65(4.5)</td>
<td>140 4.73 8.40 2.22 65(4.5)</td>
<td></td>
</tr>
<tr>
<td>3 Tygothane</td>
<td>73 2.47 4.37 1.16 50(3.5)</td>
<td>173 5.85 10.38 2.74 50(3.5)</td>
<td>261 8.82 15.68 4.14 50(3.5)</td>
<td>328 11.01 19.56 5.17 50(3.5)</td>
<td></td>
</tr>
<tr>
<td>4 Norprene</td>
<td>6 0.20 0.36 0.10 100(6.9)</td>
<td>13 0.74 1.44 0.21 100(6.9)</td>
<td>20 1.07 1.72 0.33 100(6.9)</td>
<td>25 0.85 1.50 0.40 105(5.2)</td>
<td></td>
</tr>
<tr>
<td>5 FKM</td>
<td>11 0.37 0.66 0.17 25(1.7)</td>
<td>26 0.88 1.56 0.41 25(1.7)</td>
<td>39 1.31 2.34 0.60 25(1.7)</td>
<td>48 1.62 2.88 0.76 25(1.7)</td>
<td></td>
</tr>
<tr>
<td>6 Norprene</td>
<td>18 0.61 1.08 0.29 150(6.9)</td>
<td>42 1.42 2.52 0.67 150(6.9)</td>
<td>63 2.13 3.78 1.00 150(6.9)</td>
<td>79 2.67 4.74 1.25 155(5.2)</td>
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</tr>
<tr>
<td>7 Norprene</td>
<td>57 1.92 3.42 0.90 50(3.5)</td>
<td>138 4.66 8.28 2.19 50(3.5)</td>
<td>200 6.78 12.00 3.17 50(3.5)</td>
<td>250 8.45 15.00 3.96 50(3.5)</td>
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<tr>
<td>8 Norprene</td>
<td>40 1.35 2.40 0.63 50(3.5)</td>
<td>84 2.80 5.04 1.31 50(3.5)</td>
<td>140 4.73 8.40 2.22 50(3.5)</td>
<td>180 6.10 10.80 2.85 50(3.5)</td>
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</table>

**Replacement Pump Tubes:**

<table>
<thead>
<tr>
<th>Pump Tube Part Number</th>
<th>Pump Tube Material</th>
<th>Nominal Pump Tube OD</th>
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<tbody>
<tr>
<td>A1-1T</td>
<td>Tygothane</td>
<td>1/4&quot; (6.4mm)</td>
</tr>
<tr>
<td>A1-2T</td>
<td>Tygothane</td>
<td>3/8&quot; (9.5mm)</td>
</tr>
<tr>
<td>A1-3T</td>
<td>Tygothane</td>
<td>7/16&quot; (11.1mm)</td>
</tr>
<tr>
<td>A1-4T</td>
<td>Norprene</td>
<td>1/4&quot; (6.4mm)</td>
</tr>
<tr>
<td>A1-5T</td>
<td>FKM</td>
<td>5/16&quot; (7.9mm)</td>
</tr>
<tr>
<td>A1-6T</td>
<td>Norprene</td>
<td>3/8&quot; (9.5mm)</td>
</tr>
<tr>
<td>A1-7T</td>
<td>Norprene</td>
<td>7/16&quot; (11.1mm)</td>
</tr>
<tr>
<td>A1-8T</td>
<td>Norprene Chemical</td>
<td>7/16&quot; (11.1mm)</td>
</tr>
</tbody>
</table>

Gallons shown are U.S. Gallons.

---

Blue-White Industries, Ltd.
5300 Business Drive, Huntington Beach, CA 92649
Tel: 714-893-8529  Fax: 714-894-9492
www.blue-white.com  Email: sales@blue-white.com

Technical data sheet #85000-039 rev.03022016
Equipos productores de cloro en situ
Para zonas Urbanas Marginales y Rurales

Clorid
Cuenca – Ecuador
Web www.clorid.com
Mail ventas@clorid.com
### Clorid S.A.

<table>
<thead>
<tr>
<th>Cliente:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nª Serie:</td>
<td></td>
</tr>
<tr>
<td>Año de Fabricación:</td>
<td></td>
</tr>
<tr>
<td>Producto:</td>
<td></td>
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<tr>
<td>AF.Nº:</td>
<td></td>
</tr>
<tr>
<td>F.D.N. Nª:</td>
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</tr>
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<td>D.W.G. Ref:</td>
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<td>TAG Nª:</td>
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<tr>
<td>TAG Cliente:</td>
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</tr>
<tr>
<td>Servicio:</td>
<td>Generador de hipoclorito de sodio en situ</td>
</tr>
<tr>
<td>Modelo:</td>
<td>Modelo Clorid L-60</td>
</tr>
</tbody>
</table>

| Capacidad: | 0.750kg/día cloro |
| Cantidad: | 1 |
| Concentración: | 12,5 g/ litro |
| Paso: | 60 L |
| Temperatura Operación: | 25 º C |
| Presión Máxima de operación: | Bacheo |
| Tem. Máx.: | 45 º C |
| Presión Proyecto: |  |
| Temperatura Proyecto: | 50 º C |
| Peso Vació: |  |
| Peso Lleno: |  |

### FUENTE DE ALIMENTACION

<table>
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<th>Entrada</th>
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<tr>
<td>110 V A C (monofasica)</td>
<td>5.2 V C V</td>
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<tr>
<td>60 Amperios</td>
<td>0 A 30 Amperios CC</td>
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<tr>
<td>60 HZ</td>
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<tr>
<td>Clorid</td>
<td>Fotos</td>
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<td>--------</td>
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</table>

![Image of L-60 device](image-url)

L - 60
## Distribution Network

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit</th>
<th>Quantity</th>
<th>Unit Cost</th>
<th>Cost</th>
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</thead>
<tbody>
<tr>
<td>90mm PVC</td>
<td>per 6 meter</td>
<td>491</td>
<td>$21.75</td>
<td>$10,700.00</td>
</tr>
<tr>
<td>63mm PVC</td>
<td>per 6 meter</td>
<td>447</td>
<td>$9.81</td>
<td>$4,400.00</td>
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<tr>
<td>50mm PVC</td>
<td>per 6 meter</td>
<td>0</td>
<td>$6.26</td>
<td>$0.00</td>
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<tr>
<td>40mm PVC</td>
<td>per 6 meter</td>
<td>149</td>
<td>$5.40</td>
<td>$800.00</td>
</tr>
<tr>
<td>32mm PVC</td>
<td>per 6 meter</td>
<td>490</td>
<td>$3.36</td>
<td>$1,600.00</td>
</tr>
<tr>
<td>25mm PVC</td>
<td>per 6 meter</td>
<td>574</td>
<td>$2.35</td>
<td>$1,300.00</td>
</tr>
<tr>
<td>Water Meters 20mm</td>
<td>Each</td>
<td>388</td>
<td>$20.50</td>
<td>$8,000.00</td>
</tr>
<tr>
<td>63mm DECA Ball Valve with Lever</td>
<td>Each</td>
<td>24</td>
<td>$30.92</td>
<td>$700.00</td>
</tr>
<tr>
<td>32mm DECA Ball Valve with Lever</td>
<td>Each</td>
<td>21</td>
<td>$14.53</td>
<td>$300.00</td>
</tr>
<tr>
<td>25mm DECA Ball Valve with Lever</td>
<td>Each</td>
<td>21</td>
<td>$10.10</td>
<td>$200.00</td>
</tr>
<tr>
<td>25mm DECA Ball Valve with Lever - Homes</td>
<td>Each</td>
<td>366</td>
<td>$10.10</td>
<td>$3,700.00</td>
</tr>
<tr>
<td>Floating Valve 3/4&quot;</td>
<td>Each</td>
<td>4</td>
<td>$12.00</td>
<td>$48.00</td>
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</tbody>
</table>

Total: $31,748.00

Accessories 15%: $4,762.20

Total: $36,500.00

## Reservoirs

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit</th>
<th>Quantity</th>
<th>Unit Cost</th>
<th>Cost</th>
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</thead>
<tbody>
<tr>
<td>Reservoir 80m³</td>
<td>Each</td>
<td>3</td>
<td>$8,910.65</td>
<td>$26,700.00</td>
</tr>
<tr>
<td>Reservoir 20m³</td>
<td>Each</td>
<td>1</td>
<td>$4,176.65</td>
<td>$4,200.00</td>
</tr>
</tbody>
</table>

Total: $30,900

Accessories 15%: $4,635

Total: $35,500

## Pump House

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit</th>
<th>Quantity</th>
<th>Unit Cost</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Franklin 4&quot; Submersible Well Pump 3</td>
<td>Each</td>
<td>2</td>
<td>$1,576.20</td>
<td>$3,200.00</td>
</tr>
<tr>
<td>Franklin Submersible Motor Control 5</td>
<td>Each</td>
<td>1</td>
<td>$200.48</td>
<td>$200.00</td>
</tr>
<tr>
<td>Franklin 4&quot; Submersible Well Pump 4</td>
<td>Each</td>
<td>2</td>
<td>$798.55</td>
<td>$1,600.00</td>
</tr>
<tr>
<td>Pump House Design From Bruce</td>
<td>Each</td>
<td>1</td>
<td>$14,703.22</td>
<td>$14,700.00</td>
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</table>

Total: $19,700.00
### Disinfection System

<table>
<thead>
<tr>
<th>Description</th>
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<th>Quantity</th>
<th>Unit Cost</th>
<th>Cost</th>
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</thead>
<tbody>
<tr>
<td>Clorid Chlorination Equipment L-60</td>
<td>Each</td>
<td>1</td>
<td>$1,675.52</td>
<td>$1,700.00</td>
</tr>
<tr>
<td>Blue White Peristaltic Pump Model A</td>
<td>Each</td>
<td>2</td>
<td>$347.40</td>
<td>$700.00</td>
</tr>
<tr>
<td>Eva Tubing 500Ft 1/4in X 1/8in GVD</td>
<td>Each</td>
<td>1</td>
<td>$112.50</td>
<td>$100.00</td>
</tr>
<tr>
<td>Eva Tube 100Ft 3/8in GDV100</td>
<td>Each</td>
<td>1</td>
<td>$44.00</td>
<td>$44.00</td>
</tr>
<tr>
<td>Nat Ploy tube 500Ft 3/8in LMPE12N</td>
<td>Each</td>
<td>1</td>
<td>$110.30</td>
<td>$100.00</td>
</tr>
<tr>
<td>Hose Cutter 1-1/4in OD EVSL100</td>
<td>Each</td>
<td>1</td>
<td>$15.00</td>
<td>$15.00</td>
</tr>
<tr>
<td>Nat Nylon Tube 100Ft 1/4in FCUN20</td>
<td>Each</td>
<td>1</td>
<td>$35.00</td>
<td>$35.00</td>
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<tr>
<td>Handling Costs</td>
<td>Each</td>
<td>1</td>
<td>$17.00</td>
<td>$17.00</td>
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<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>$2,711.00</strong></td>
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<tr>
<td><strong>Accessories 15%</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>$406.65</strong></td>
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<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>$3,100.00</strong></td>
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</tbody>
</table>

### Total Costs

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
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</thead>
<tbody>
<tr>
<td>Distribution Network</td>
<td>$36,500.00</td>
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<tr>
<td>Reservoirs</td>
<td>$35,500.00</td>
</tr>
<tr>
<td>Pump House</td>
<td>$19,700.00</td>
</tr>
<tr>
<td>Disinfection System</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>$94,800.00</strong></td>
</tr>
</tbody>
</table>

**Sources**
- Lower Pump+Motor+Control
- Higher Pump with Motor and Control built in
- Pipe and Valve Costs from TIGRE
- Reservoir costs from Client Bruce
- Peristaltic Pumps costs from Client's preferred supplier
  - [https://www.dultmeier.com/products/0.851.875/1257](https://www.dultmeier.com/products/0.851.875/1257)
- Electrolysis costs from Client Bruce's previous receipts
# Reservoir Costs

From Bruce Rydbeck  
Date: 4/15/2016

## Accessory Unit Quantity Unit Price Cost

<table>
<thead>
<tr>
<th>Accessory</th>
<th>Unit</th>
<th>Quantity</th>
<th>Unit Price</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>Each</td>
<td>95</td>
<td>$7.00</td>
<td>$665.00</td>
</tr>
<tr>
<td>Boards</td>
<td>meters</td>
<td>80</td>
<td>$2.60</td>
<td>$208.00</td>
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<tr>
<td>Rails</td>
<td>meters</td>
<td>40</td>
<td>$2.25</td>
<td>$90.00</td>
</tr>
<tr>
<td>Iron</td>
<td>Each</td>
<td>16</td>
<td>$52.00</td>
<td>$832.00</td>
</tr>
<tr>
<td>Nails</td>
<td>Lbs</td>
<td>50</td>
<td>$1.50</td>
<td>$75.00</td>
</tr>
<tr>
<td>Wire</td>
<td>Lbs</td>
<td>25</td>
<td>$1.50</td>
<td>$37.50</td>
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<tr>
<td>Rags (3m)</td>
<td>C/U</td>
<td>50</td>
<td>$1.50</td>
<td>$75.00</td>
</tr>
<tr>
<td>Sanitary Lid</td>
<td>C/U</td>
<td>1</td>
<td>$160.00</td>
<td>$160.00</td>
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<tr>
<td>Stairs</td>
<td>Teir</td>
<td>10</td>
<td>$20.00</td>
<td>$200.00</td>
</tr>
<tr>
<td>Concrete block (15x40x20)</td>
<td>C/U</td>
<td>400</td>
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<td>$800.00</td>
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<tr>
<td>Control</td>
<td>Kg</td>
<td>30</td>
<td>$1.50</td>
<td>$45.00</td>
</tr>
<tr>
<td>DM Impersam</td>
<td>Kg</td>
<td>30</td>
<td>$1.50</td>
<td>$45.00</td>
</tr>
<tr>
<td>Betoncryl</td>
<td>Kg</td>
<td>30</td>
<td>$10.00</td>
<td>$300.00</td>
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<tr>
<td>Triplex 1/4&quot; 4'x8'</td>
<td>C/U</td>
<td>2</td>
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<td>$20.00</td>
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<tr>
<td>Monitoring &amp; abanil</td>
<td></td>
<td>1</td>
<td>$1,200.00</td>
<td>$1,200.00</td>
</tr>
<tr>
<td>6% of plumbing</td>
<td></td>
<td></td>
<td></td>
<td>$213.15</td>
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</table>

**Total Cost** $4,965.65  
**Cost Differential per 10m^3** $789

## Reservoir Tank Costs

<table>
<thead>
<tr>
<th>m^3</th>
<th>Unit Cost</th>
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<tbody>
<tr>
<td>10</td>
<td>$3,387.65</td>
</tr>
<tr>
<td>15</td>
<td>$3,782.15</td>
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<td>20</td>
<td>$4,176.65</td>
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<tr>
<td>30</td>
<td>$4,965.65</td>
</tr>
<tr>
<td>40</td>
<td>$5,754.65</td>
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<tr>
<td>50</td>
<td>$6,543.65</td>
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<tr>
<td>60</td>
<td>$7,332.65</td>
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<tr>
<td>70</td>
<td>$8,121.65</td>
</tr>
<tr>
<td>80</td>
<td>$8,910.65</td>
</tr>
<tr>
<td>90</td>
<td>$9,699.65</td>
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</table>
## Pumping Station Costs

From Bruce Rydbeck  
Date: 5/6/2016

<table>
<thead>
<tr>
<th>No.</th>
<th>Details</th>
<th>Quantity</th>
<th>Unit</th>
<th>Cost U.</th>
<th>Cost T.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pumping station Structure</td>
<td>1</td>
<td>Each</td>
<td>$2,600.00</td>
<td>$2,600.00</td>
</tr>
<tr>
<td>2</td>
<td>Concrete pole *</td>
<td>1</td>
<td>Each</td>
<td>$2,600.00</td>
<td>$2,600.00</td>
</tr>
<tr>
<td>3</td>
<td>8 posts</td>
<td>1</td>
<td>Each</td>
<td>$45.00</td>
<td>$45.00</td>
</tr>
<tr>
<td>4</td>
<td>Square D Breaker 2 pole 230v 30 amp</td>
<td>1</td>
<td>Each</td>
<td>$20.00</td>
<td>$20.00</td>
</tr>
<tr>
<td>5</td>
<td>Square D Breaker 1 pole 115v 15 amp</td>
<td>7</td>
<td>Each</td>
<td>$6.00</td>
<td>$42.00</td>
</tr>
<tr>
<td>6</td>
<td>Lamp tubes fluorescent 2 x 40 W</td>
<td>1</td>
<td>Each</td>
<td>$35.00</td>
<td>$35.00</td>
</tr>
<tr>
<td>7</td>
<td>Electrical wire 2x14AWG</td>
<td>10</td>
<td>Meters</td>
<td>$1.50</td>
<td>$15.00</td>
</tr>
<tr>
<td>8</td>
<td>plate</td>
<td>1</td>
<td>Each</td>
<td>$5.00</td>
<td>$5.00</td>
</tr>
<tr>
<td>9</td>
<td>Plastic ties electrical 25cm</td>
<td>100</td>
<td>Each</td>
<td>$0.08</td>
<td>$8.00</td>
</tr>
<tr>
<td>10</td>
<td>Gompa</td>
<td>1</td>
<td>Each</td>
<td>$1,800.00</td>
<td>$1,800.00</td>
</tr>
<tr>
<td>11</td>
<td>Bare wire to ground. 8</td>
<td>8</td>
<td>Meters</td>
<td>$2.25</td>
<td>$18.00</td>
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<tr>
<td>12</td>
<td>Elbow EMT 1 1/2&quot; NAC.</td>
<td>2</td>
<td>Each</td>
<td>$6.00</td>
<td>$12.00</td>
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<tr>
<td>13</td>
<td>Reversible 1 1/2&quot;</td>
<td>1</td>
<td>Each</td>
<td>$8.00</td>
<td>$8.00</td>
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<tr>
<td>14</td>
<td>28mm20mm</td>
<td>1</td>
<td>Roll</td>
<td>$4.00</td>
<td>$4.00</td>
</tr>
<tr>
<td>15</td>
<td>19mmx2.5m</td>
<td>5</td>
<td>Meters</td>
<td>$3.25</td>
<td>$16.00</td>
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<tr>
<td>16</td>
<td>500mm x 2.5m</td>
<td>2</td>
<td>Roll</td>
<td>$1,800.00</td>
<td>$3,600.00</td>
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<td>17</td>
<td>Voltmeter, ammeter for each pump,</td>
<td>1</td>
<td>Each</td>
<td>$1,500.00</td>
<td>$1,500.00</td>
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<tr>
<td>18</td>
<td>Sucre flexible cable 3x12AwG</td>
<td>30</td>
<td>M</td>
<td>$3.50</td>
<td>$105.00</td>
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</table>

### Electrical - Pumping Station

<table>
<thead>
<tr>
<th>No.</th>
<th>Details</th>
<th>Quantity</th>
<th>Unit</th>
<th>Cost U.</th>
<th>Cost T.</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>Franklin 4&quot; Submersible Well Pump 35gpm 5HP 230V 3W</td>
<td>2</td>
<td>Each</td>
<td>$1,576.20</td>
<td>$3,152.40</td>
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<tr>
<td>24</td>
<td>Franklin Submersible Motor Control Box 3.0 HP 230V 3W</td>
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<td>Each</td>
<td>$200.48</td>
<td>$200.48</td>
</tr>
<tr>
<td>25</td>
<td>Franklin 4&quot; Submersible Well Pump 5GPM 3/4HP 230V 2W</td>
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<td>Each</td>
<td>$798.55</td>
<td>$1,597.10</td>
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<tr>
<td>26</td>
<td>PVC drain pipe 110mm x 3m</td>
<td>1</td>
<td>Each</td>
<td>$10.00</td>
<td>$10.00</td>
</tr>
<tr>
<td>27</td>
<td>PVC drain pipe 1 1/2&quot; 4&quot; x 4&quot;</td>
<td>1</td>
<td>Each</td>
<td>$15.00</td>
<td>$90.00</td>
</tr>
<tr>
<td>28</td>
<td>Health Mark 6&quot; x 1 1/4&quot;</td>
<td>4</td>
<td>Each</td>
<td>$40.00</td>
<td>$160.00</td>
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<tr>
<td>29</td>
<td>Tee HG 1-1/4&quot;</td>
<td>8</td>
<td>Each</td>
<td>$2.00</td>
<td>$16.00</td>
</tr>
<tr>
<td>30</td>
<td>Universal HG 1-1/4&quot;</td>
<td>8</td>
<td>Each</td>
<td>$2.50</td>
<td>$20.00</td>
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<tr>
<td>31</td>
<td>Corridor Neplo HG 1-1/4&quot;</td>
<td>16</td>
<td>Each</td>
<td>$1.50</td>
<td>$24.00</td>
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<td>32</td>
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<td>4</td>
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<td>$280.00</td>
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<td>33</td>
<td>DECA Valve 1-1/2&quot;</td>
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<td>Each</td>
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<td>$140.00</td>
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<tr>
<td>34</td>
<td>Elbow HG 1-1/4&quot; x90deor</td>
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<td>Each</td>
<td>$2.00</td>
<td>$8.00</td>
</tr>
<tr>
<td>35</td>
<td>Bushing HG 1/2&quot; 1&quot;</td>
<td>6</td>
<td>Each</td>
<td>$2.20</td>
<td>$13.20</td>
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<tr>
<td>36</td>
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<td>4</td>
<td>Each</td>
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<td>$4.80</td>
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<tr>
<td>37</td>
<td>D-380 PSI Gauge</td>
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<td>Each</td>
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<td>$128.00</td>
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<td>38</td>
<td>PVC Adapter (M) 1-1/4&quot; x40mm</td>
<td>2</td>
<td>Each</td>
<td>$3.00</td>
<td>$6.00</td>
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<tr>
<td>39</td>
<td>PVC Reducer 40mm x 30mm</td>
<td>2</td>
<td>Each</td>
<td>$2.60</td>
<td>$5.20</td>
</tr>
<tr>
<td>40</td>
<td>Permatex large</td>
<td>2</td>
<td>Each</td>
<td>$5.00</td>
<td>$10.00</td>
</tr>
<tr>
<td>41</td>
<td>HG Union 1-1/4&quot;</td>
<td>4</td>
<td>Each</td>
<td>$3.00</td>
<td>$12.00</td>
</tr>
</tbody>
</table>
This structure will be 2.6x2.6x2.1m constructed of structural reinforced masonry block. The inside and outside of the structure will be done with plastering. The roof of the house will be constructed of tiles made of reinforced concrete with 10 mm rods and a 2% decline from the middle of the roof. Changed from their original design, the team has included two submersible 35GPM 3HP pumps and two submersible 5GPM 3/4HP pumps along with control panels (BOLDED). The team has included automatic chlorination equipment in a separate cost table, but this equipment will also be used in the design.

Information from Improvement of Potable Water System, Santiago de Quito Report by Efrain Morocho, July 2015
Appendix P. EPANET Results

Model Overview

Figure 1. EPANET Model
Pressure

Results shown below verify that all node pressures stayed between 10-70m during maximum day demands in both the upper and lower pressure zones.

Figure 2. Lowest Elevation Nodes in each Pressure Zone
Figure 3. Pressure head at the highest node in both pressure zones for maximum daily demand

Note: The green and red lines represent the minimum/maximum pressures in the lower pressure zone and the blue and magenta lines show the minimum/maximum pressures in the higher pressure zone. For both pressure zones the pressure remains between the 10 to 70 meter design range.
Figure 4. Water surface elevation in Tank E (the higher pressure zone reservoir)

Note: design target was for the water surface level to remain between 3422m and 3423m which is shown in this diagram.
Figure 5. Water surface elevation in the lower pressure zone reservoirs

Note: the design target was for the water surface level to remain between 3374m and 3378.5m which is shown in this diagram.
Figure 6. Control syntax for the pumps (Link 84 and 81) to control the level in the tanks (node 6 and 7).
Note: The first line means: Open the pump (for the lower pressure zone) if the water level in reservoir B is less than 2.5 meters above the bottom of the tank.
Figure 7. Proposed Pipe diameters, in millimeters (northern section)
Figure 8. Proposed pipe diameters, in millimeters (southern section)
<table>
<thead>
<tr>
<th>Page</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-15</td>
<td>Home Connection Ditch</td>
</tr>
<tr>
<td>1-11</td>
<td>Reservoir and Road Valves Details (2)</td>
</tr>
<tr>
<td>1-10</td>
<td>Reservoir Section (1)</td>
</tr>
<tr>
<td>6-9</td>
<td>Ball Valve with Lever Dam</td>
</tr>
<tr>
<td>4-8</td>
<td>French Drain</td>
</tr>
<tr>
<td>4-7</td>
<td>Pump House Location</td>
</tr>
<tr>
<td>4-6</td>
<td>New Well Specification</td>
</tr>
<tr>
<td>4-5</td>
<td>Valve Locations</td>
</tr>
<tr>
<td>4-4</td>
<td>Proposed System Layout</td>
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<tr>
<td>4-3</td>
<td>Pressure Area</td>
</tr>
<tr>
<td>4-2</td>
<td>Reservoir Locations</td>
</tr>
<tr>
<td>4-1</td>
<td>Home Locations</td>
</tr>
</tbody>
</table>

---

**Team 04 Green to Clean**

**Project 2016**

Calvin College Senior Design

**SANTIAGO DE QUITO, ECUADOR**

**PORTABLE WATER DISTRIBUTION SYSTEM**
New Well Dimensions
All measurements in units of meters
Chlorine Tank

Electrolysis Unit

All measurements in units of meters