Water Distribution System in El Tesoro, Guatemala


Highlands of El Tesoro, Guatemala

The community of El Tesoro, Guatemala has been trying to obtain access to clean water for over 30 years. Located in the rural highlands of Guatemala, El Tesoro community members currently get their water through rain capture systems without a formal tank, either by sending children to fetch water from up to 45 minutes away or purchasing water using a large percentage of their monthly income. The water they drink is usually contaminated, causing health issues across the community, and the time they spend collecting water keeps children out of school and adults from focusing on other ways of developing their families and community. Over the past three decades, homeowners in El Tesoro have attempted to address this problem by drilling wells and finding springs to serve their community. Unfortunately, the wells came up dry, and the previous springs were too far away for any nonprofit to connect them to their community. Finally, they were able to find and purchase a spring 4 kilometers away from their community. They then reached out to Engineers Without Borders, Guatemala (EWB-Guatemala) to begin a partnership, which is where this project began. In the standard EWB project process, El Tesoro was paired with this university's student EWB chapter, and the project to design a water distribution system that would bring clean water from the identified spring to community members' homes was adopted.

The student team worked on the project design for an entire academic year, and construction started the following summer in June 2022. The project design encompasses the following elements: spring box, conduction line, distribution tank, and distribution line. The spring box is a concrete box that is built around the water source to collect the water that comes out of the spring and sends it into the conduction line. The conduction line is a pipeline that takes the water from the source (spring box) to the distribution tank. The distribution tank is where the water is chlorinated and stored to provide an on-demand water supply to the community, and the distribution line is a branched pipeline that conveys water from the distribution tank to each home connection. As of April 2023, construction on the project is nearly complete. When it is, it will connect 120 households to the distribution line to receive clean water at their homes for the first time.

Completed spring box (left) and distribution tank (right)

There are several key stakeholders in this project who have all been instrumental in its success. The university students took responsibility for driving the design of the project, including forming a team of mentors and organizing the project from assessment through implementation. The community of El Tesoro provided the initiative to start the project, and they are the main beneficiary. EWB-Guatemala has worked with both the students and community throughout the process as well. They have acted as the in-country expert, with a licensed professional engineer to ensure the project complies with all Guatemalan laws and standards, local construction expertise, and personnel to train and communicate with the community. Other professional mentors, including licensed professional engineers in the United States and university faculty, were key in teaching the students the technical skills necessary to design a water distribution system of this magnitude. Finally, Rotary International funded a large portion of the project through their Global Grant. Without each of these groups, the project would not be where it is today.

Collaboration of Faculty, Students, and Licensed Professional Engineers

As mentioned previously, the project team included a number of important stakeholders, including students, faculty, and licensed professional engineers. The student team responsible for the project design was led by three project leads, and the remainder of the students were split between four design teams: hydraulics, water quality, structural, and construction. Each of these teams consisted of a team lead and 5-10 members who attended weekly design meetings throughout the academic year. Each design team was supported by professional mentors, and the entire project was supported by a licensed Responsible Engineer in Charge (REIC). These professional mentors were instrumental in guiding the students through the technical design of the project. The REIC had the unique experience of having a very successful civil engineer career before deciding to devote the rest of his career to development and disaster response engineering. He has had decades of experience with development projects in Guatemala, so his expertise in both the civil engineering aspects of the project and how to tailor the project's design to the area in which it would be implemented were invaluable. Other professional mentors included a structural engineer with experience in earthquake engineering who assisted with the design of structural components like the distribution tank and a civil engineer focusing on water and wastewater who assisted with the design of the conduction and distribution lines. A faculty member in the environmental engineering department specializing in water treatment supported the water quality team in determining the best way to ensure the water from the system would be clean and safe to drink.

The entire project was also reviewed and approved by a professional engineer on staff at EWB-Guatemala who was licensed in Guatemala to ensure compliance with local laws and standards. Without this essential relationship, the project would not have had the necessary input to move forward. With United States licensure not extending to Guatemala, the assistance given by the Guatemalan engineer was critical for the project to be implemented internationally.

Interactions with professional mentors occurred during both large-group student design-team meetings and separate meetings with just the project leads. The REIC met with the project leads weekly to provide guidance along every step of the design process. His contributions included teaching the leads how to use EPANET to complete the hydraulic analysis of the system, explaining calculations such as the demand for water the system would need to supply at the end of its 20-year design life, recommendations on how big of a tank to design, outlines of which drawings would be necessary to submit for each component of the system, and countless other explanations and suggestions. His guidance along each step of the process allowed the leads to then synthesize information, delegate tasks, and pass along learnings to the various student design teams. In this way, there was constant guidance and input from the REIC, but the students still had the freedom and responsibility to learn the information, ask questions, make mistakes, and complete the actual design work themselves.

Another beneficial interaction between students and faculty/licensed engineers came when it was time for the student team to travel to Guatemala. This happened twice throughout the project. The first was to complete a plan-in-hand final assessment of the design right at the end of the academic school year. This trip included the three project leads, one student in charge of monitoring previous projects, the environmental engineering faculty member, and the REIC. During this trip, the students learned valuable lessons from both the faculty member traveling with them and the REIC. With the assistance of these professionals, the students updated some aspects of their design, mainly along the conduction line, based on the rocky terrain and steep elevation changes that they found when on-site for the first time. The second trip included 14 students, the REIC, and the faculty advisor for the university EWB chapter. This trip coincided with the construction of the distribution tank, so during the two weeks spent on-site in Guatemala, the students learned all about the differences between construction in Guatemala and the United States and continued to absorb some of the wisdom and experience passed down by the professional engineers traveling with them.

REIC explaining engineering concepts to the student team at the distribution tank site

After a year and a half working with professional mentors and faculty on the project, it is clear that the project would not have been possible without them. Their contribution to the students' technical knowledge was invaluable. However, perhaps more important was their demonstrated commitment to using their engineering skills to further a humanitarian cause. Especially in the case of the project REIC, who had been doing similar work for decades, his example of dedicated service through engineering provided an example to every student on the project team of what they too might be able to do with their careers. This example combined with patient lessons during the academic year and hands-on instruction during the two trips to Guatemala gave the students a unique opportunity to learn from experienced professionals while greatly developing their own skillsets.

Protection of Public Health, Safety, and Welfare of the Public

A significant outcome of this project will be the connection of 120 families to clean water taps for the first time. The impacts on the community of El Tesoro in areas including public health, education, social welfare, and economic development once construction of this project is completed and the basic need of safe water is addressed are enormous. In addition to the system infrastructure itself, part of the implementation of the project includes trainings conducted by EWB-Guatemala personnel on health and hygiene, as well as how to manage the water distribution system. The health and hygiene training emphasizes safe use of water, washing hands, sanitary cooking practices, and other ways to maximize the impact of clean water on the public health of the community. The training on management of the system is key to ensuring that it can be sustained throughout its entire 20-year design life. Determining what fees users will be charged, how to collect them, how to maintain the system, and what to do if issues arise are all beyond the scope of the strict technical design of the system but essential components of making sure the system continues to provide water as it is designed to. Including these educational aspects of the project reinforces the sustainability of the project and therefore enables the protection of public health, safety, and welfare.

From a student perspective, there were many examples of the real-world impact of engineering decisions. One of these was the adjustments made to the project design for easier constructability in Guatemala. For example, the foundation of the distribution tank was formed with CMU blocks rather than wooden formwork because wood was expensive and hard to source in the area around the community, whereas blocks were available at any hardware store. Similarly, rocks found near the tank site were used in the foundation rather than pouring an extra layer of concrete, and the height of the tank was kept low enough that scaffolding was not necessary to work on the roof of the tank. Another engineering decision that was made with the greater project context in mind was calculating the demand that the system should be designed for to ensure it would last its full 20 years. Typically, this demand is obtained by finding the demand based on the current population of the community and multiplying it by a growth factor to take into account community growth over the project's life. In this case, though, the community had requested an initial total of 55 home connections and 58 lots to be connected to the water distribution system. In this way, they had already estimated and planned the growth they expected their community to have through their wish to connect empty lots to the system for family members or future users. Rather than just applying the growth factor to the current homes that would be connected, which would leave a demand much smaller than that the community had predicted for themselves, or adding a growth factor to the total home and lot connections, which would result in an overly large and expensive system, the students sized the system demand to reflect the demand if all homes and lots were connected and in use at the end of the system's life. In this way, the community's input was respected, but the system was not designed to be prohibitively large.

Rocks collected near the tank site were used for the tank foundation

In addition to the impact of certain engineering decisions on the outcome of the project itself, this project was also a lesson in how engineering in general can help address a multitude of problems faced by communities across the globe. This project took place in Guatemala, but the same premise of combining technical expertise with an understanding of the greater social context of a project can be applied to any location or issue. Furthermore, through involvement in this project students gained real experience in how to go about this process that they will now be able to implement throughout the rest of their careers. Students took responsibility for funding over $17,000 of the project through a student-led silent auction, gathering a team of professional mentors, leading all project design meetings with other students, faculty, and professional mentors, communicating with all project stakeholders, and coordinating all travel arrangements when visiting the community in Guatemala. They therefore gained real-world experience where they were responsible for a large portion of this humanitarian engineering project's success.

Multidiscipline and Allied Profession Participation

The project team included students across all disciplines of engineering. The student EWB chapter emphasizes that there is not one type of engineer that belongs on the project team; rather, all engineering disciplines are needed and welcomed on any project. The project team learns most of the technical knowledge needed for design in club meetings and through working with mentors. Thus, the goal is not to have a team of any one discipline of engineers, but rather engineers of any discipline who are excited about learning how to design the project. The engineers that are from disciplines other than civil, construction, and environmental engineering, such as mechanical, electrical, and biomedical engineering, learned extra skills that they would not normally learn in the classroom. This helped create well rounded engineers with extra knowledge.

Other professions that were involved throughout the project were marketing, event planning, fundraising, and government officials; the involvement with all of these professions was to fund the project. The chapter holds multiple smaller fundraisers and a large silent auction every year to support the projects. These fundraisers involve marketing to get the word out and event planning to hold successful events that will bring in enough money to support the project. Due to this project's large scope, it also included working on a grant with the Rotary Club to receive part of the funding. Additionally, managing the project throughout the implementation process while also scoping and planning other projects requires accounting to ensure that there are enough funds to complete each project in a timely manner and avoid stalls in construction due to insufficient funding. Students on the project team also worked with the municipal government in Guatemala to receive approval of the plans from the mayor and his team of municipal engineers. This was an important aspect of the project to secure the government funding that a portion of the project was reliant on.

In addition to those related to funding the project, other professions that directly contributed to the project's design and implementation were surveying, CAD drafting, and contractors. Surveys completed by a professional Guatemalan surveyor were critical to the pipeline's design in confirming the feasibility of the proposed pipeline route and sizing it to handle the required flow rates, demands, and elevation changes. CAD drafting was used to put together the plan set that indicated the design of the pipeline and all associated elements, details for every component of the pipeline and supporting infrastructure, and all the structural drawings for the tank and elevated crossings. Finally, the contractors that work for EWB-Guatemala were essential for constructability reviews of the design and providing crucial feedback about the design. They were also the ones to spearhead the construction and implementation of the project, using their expertise to ensure all system components were constructed as designed.

The project involved many branches of civil engineering to complete the design and implementation of the water system. The structural team designed the tank and the elevated crossings. The hydraulics team sized the system, looking at demands, pressures, and elevations to choose the right material and size for each pipe segment. The water quality team looked at the required treatment for the water based on test results of the spring. The construction team performed material quantity and price estimates, developed a schedule for the project's implementation, and developed a safety plan to be followed throughout implementation. Each of these branches depended on the other teams to complete their design as each team relied on information from other teams to complete their portions of the design. For example, the material quantity estimates needed a complete structural and hydraulic design to accurately estimate the quantities of rebar, pipes, fittings, and other materials needed.

Knowledge and Skills Gained

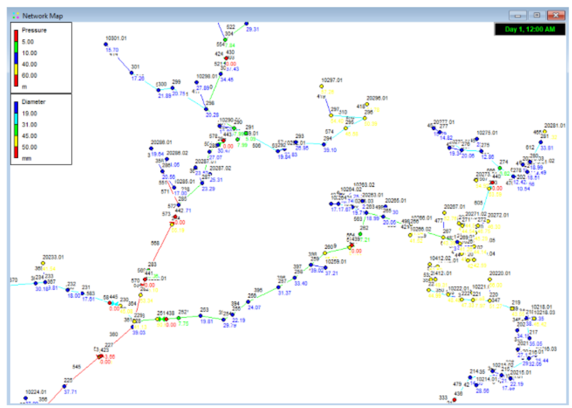
Involvement in the project was a major learning opportunity for every student involved. The students gained a large amount of technical knowledge as well as an array of non-technical skills. Each student team had a unique set of technical skills learned.

Structural Team – Technical Skills

The students on the structural team learned how to design a tank based on the size of the community and the required volume of water. The students used multiple methods to calculate the amount of water needed. This was an important lesson in designing with uncertainty, as having multiple calculations and using the more conservative volume for the final design is important. Based on the required tank volume, the structural team worked on selecting the material and dimensions for the tank. The structural team had to consider many types of loads including shear, water weight, self-weight, and earthquake loads. Additionally, the structural team used United Nations Commission on Human Rights guidelines to design the rebar that would be used in the tank foundation and walls. The structural team also designed elevated pipe crossings for areas at which the pipes would have to cross ravines. To design these crossings, the structural team learned how to design a bridge with the proper anchor size, column height, and cable spacing based on the span of the pipe and the weight of the full pipe that the crossing would support.

Hydraulics Team – Technical Skills

Students on the hydraulics team learned about designing a pipe system to ensure there is a serviceable pressure at each house. This involved sizing the pipes and selecting pipe material to ensure that there is sufficient pressure throughout the line without having a pressure that is too high that would potentially burst a pipe. This analysis was done using EPANET to model the system. The system is gravity fed, so it was important to keep enough pressure that water would reach every connection on the system. To achieve this, the team learned about break pressure tanks, where the pressure in the system can be reduced before it regains pressure from another drop in elevation. The hydraulics team also learned about the importance of designing a water system with considerations for future operations and maintenance in mind. The team had to select the types of valves and meters to be used and learned the importance of looking at longevity and performance of these elements. The team also had to design the system with a cleanout valve at any low points that could potentially be blocked with excess sediment and an air valve at any high points so air can be released, and optimal flow can be achieved.



Portion of distribution line network in EPANet

Water Quality Team – Technical Skills

Students on the water quality team learned about testing a water source for any health concerns that would need to be treated. They learned about the proper way to test the spring to get a good sample that is representative of the water source's quality. They also learned how to evaluate the test results and determine what treatment measures are necessary. Additionally, the students on this team learned about different types of water treatment measures and researched the pros and cons of different types of water treatment. The team decided on chlorine but then further explored options for how to distribute the chlorine. A chlorine tablet distributor was selected as it has less maintenance needs than other chlorine distribution types. This was an important lesson for the water quality team to understand that a design should consider future operations and how accessible the consumable materials are in the location of the system, as well as the amount of maintenance work that is required for the system.

Construction Team – Technical Skills

Students on the construction team learned about construction scheduling and managing multiple work teams to maximize the efficiency of the implementation process. They also learned about estimating the required material quantities and project budget by quantifying the design that each of the other groups had put together. An important lesson for the construction team related to estimating was the value of making sure all areas and materials on the project are captured in the estimate. The team also learned that even though the estimate was very detailed, carrying a contingency is important to have a budget for any unknown changes and construction waste that occurs.

Non-Technical Skills

The entire project team learned many non-technical skills through this project process. Overall, the team learned how to work on an engineering/construction projection from start to finish and all the coordination that needs to occur between different parts of the process. The student team also learned that there are multiple ways to design a project, and that non-technical aspects should be considered such as material availability and familiarity, operations and maintenance, operating cost, and most importantly, the interests of the end user. The student team also learned about risk management through presentations from a professional organization that trains companies in risk management. The team identified risks for the project and developed plans to mitigate risks on the project's design and implementation. Another non-technical skill that the project team developed was leadership and teamwork. The student team was split into smaller subgroups to handle each component of the project, which required coordination between each subgroup that was facilitated by the project leads.

Students learned about ethics through the project adoption process as they had to ensure that the project was a good fit for both the chapter and the community, that it could be completed within a reasonable amount of time, and that the entire community would be served effectively by this project. Some considerations that went into this analysis were evaluating the chapter's budget and ability to complete design as well as evaluating the communities existing infrastructure, like bathrooms or latrines, that would impact overall public health and prevent the water system from becoming compromised. Students also learned about working with other engineers, surveyors, contractors, and suppliers. This was a lesson in project management and how to communicate between the multiple parties involved to ensure everyone had all relevant information about the project. Another important lesson in project management that the students learned was the importance of receiving multiple quotes for materials and work that is subcontracted for the project.

Another non-technical skill that students learned was about international relationships in engineering. It was important for students to draw on the experience of local professional engineers and construction professionals to sustainably accomplish the design of the water system. Students learned the importance of designing based on available materials and construction methods. Students also learned about priorities of construction in Guatemala, where labor is maximized to minimize material waste, and how that differs from construction practices in the United States. In addition to the infrastructure itself, the importance of providing training on the new infrastructure being implemented was also emphasized. Because many of the community members have never had access to running water, they needed training in sanitation and other practices to keep the water system clean and safe for all users.

Through this experience, students gained a plethora of technical knowledge in addition to vital non-technical skills. These skills, combined with the mentorship and experience received through this project, are invaluable in the development of the team members into stronger engineers who are ready to take on real-world challenges.