DESIGN AND CONSTRUCTION OF A RELIABLE DRINKING WATER SYSTEM FOR AN ORPHANAGE IN CENTRAL AMERICA

Project Description

THE PROBLEM:

Upon student assessment of an orphanage located in the southern region of Central America the existing water distribution system was found to have numerous leaks, undersized pipes, pipes with mold growing inside, and underwhelming water pressure in addition to non-potable water. At that time, the water was primarily reserved for cooking and drinking. There was often little water available for lower priority usage like flushing toilets, showers, oral hygiene, laundry, or general cleaning. Furthermore, the approximately 12 ft tall concrete frame supporting the existing water storage tanks was severely cracked and spalled. These deficiencies resulted in a system that was not only inadequate, but also a health and safety hazard to the nearly 150 orphans who regularly drink the water and often play underneath the concrete frame. The students, with the help of professional engineers, worked to design, fund, and construct a new water distribution network and storage system to provide clean potable water for the orphanage, school, and clinic.

THE SOLUTION:

Answering the Call and Making a Difference

- Provided half mile of 1" distribution system piping
- Provided quarter mile of 2" water supply piping
- Provided 6000 gallons of water storage
- Provided a 20' x 20'x 3' concrete tank base
- Provided a water treatment system equipped with UV disinfection
- Provided a new 1.5 HP booster pump to pressurize system to 40 psi
- Provided three bladder tanks
- Trained end-users to operate/maintain water system
- Repaired 3,000 gallons per day of water leakage
- Countless meetings with professional engineers
- 1,500 (+/-) design labor hours
- 1,100 (+/-) construction labor hours
- 0 labor hours lost due to injuries

Mission: Improve the Health, Safety, and Welfare of the Children

Having access to clean water opens up a world of opportunities for community growth. Public sanitation and hygiene, combined with a source of clean drinking water, creates lasting community health and sustained human growth and development. As a child, disease from lack of clean water and sanitation carries over into education. A child's education is affected by an increase in truancy, decrease in intellectual potential, and increased attention deficits. With the benefits of clean water, adequate sanitation, and good hygiene, educated individuals grow up to be enterprising adults, who become the owners of businesses, as well as corporate, community and national leaders. From the early years of life, throughout childhood and into adulthood, water is a common beneficial factor determining the quality of life and the possibilities of the future.

Knowledge and Skills Learned

Technical Knowledge: In order to provide an effective solution, students applied a variety of engineering concepts to design, plan, and construct a new, sustainable water distribution system for the orphanage.

Listening and Problem-Solving Skills: Students communicated with the leaders and staff of the orphanage to better understand the existing problem so they could develop the most appropriate solution.

Interpersonal Skills: Since students were organized into design teams, good interpersonal skills were required to engineer the implemented system. During construction, students also had to work with one another to efficiently build the system, often alongside skilled and unskilled laborers to whom they needed to relay the design specifications.

Leadership: During the entire project, students were placed in leadership roles to manage the required tasks, thereby directly affecting the lives of the local community.

Applied Creativity: Students learned the ability to turn theoretical concepts into real-world applications that can help improve the lives of many local children as shown in the photo on the right.

Licensed Professional Engineers, Faculty, and Students Collaborate

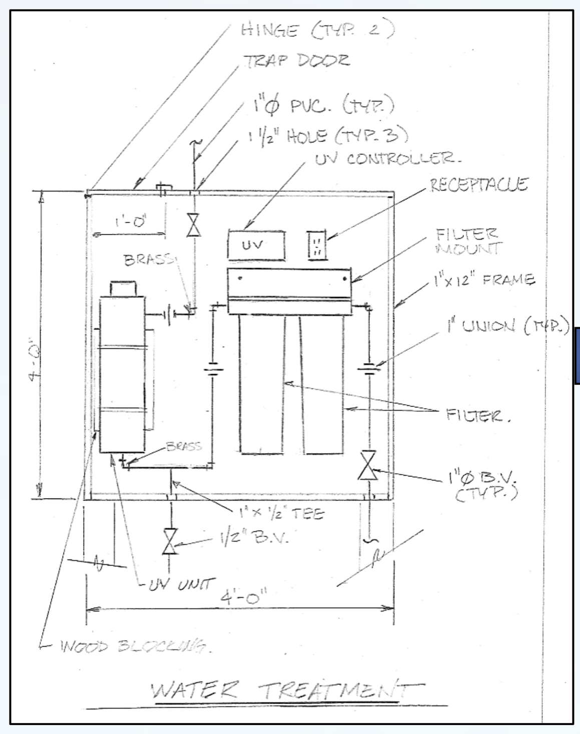
Since the start of this project in 2015, over sixty students worked alongside licensed professional engineers, engineers-in-training, and faculty to develop and construct the water distribution system at the orphanage. The student design team held bi-weekly project meetings over 18 months with licensed professional engineers and/or engineers in training (EITs) in attendance. During the assessment and implementation trips, the team always had two professional engineers accompanying the students.

Licensed Professional Engineers and Faculty Partner with Students for a Multidiscipline Approach to Reach Solutions

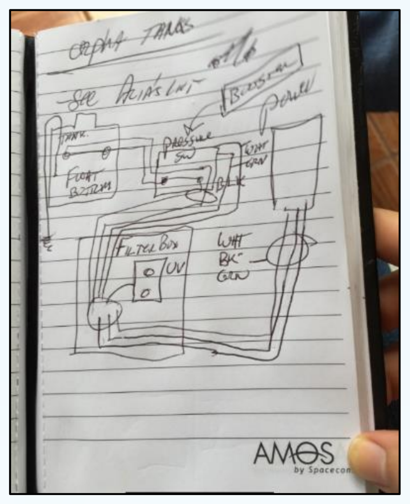
Structural Engineering:
Working alongside a professional civil engineer, students designed a 20'x20'x3' concrete base to support 6,000 gallons of water storage.

Principles and Practice of Surveying:
The surveyor's level was critical in determining how high to set the water storage tanks, as all the tanks in the system needed to be at the same level. Prior to the construction trip, students worked with a professional to set up the level and understand the basic principles. Students also drew a sketch of the existing site based on GPS coordinates obtained during the assessment trip.

Environmental Engineering:
Students collected and analyzed water samples onsite. Samples were taken for turbidity, bacteria, and pH. Students also worked with a professional engineer from the local Public Works Department to design a low maintenance, reliable filtration and ultraviolet disinfection water treatment system. The system is able to treat 30 gpm. Students also trained the orphanage staff how to perform O&M.

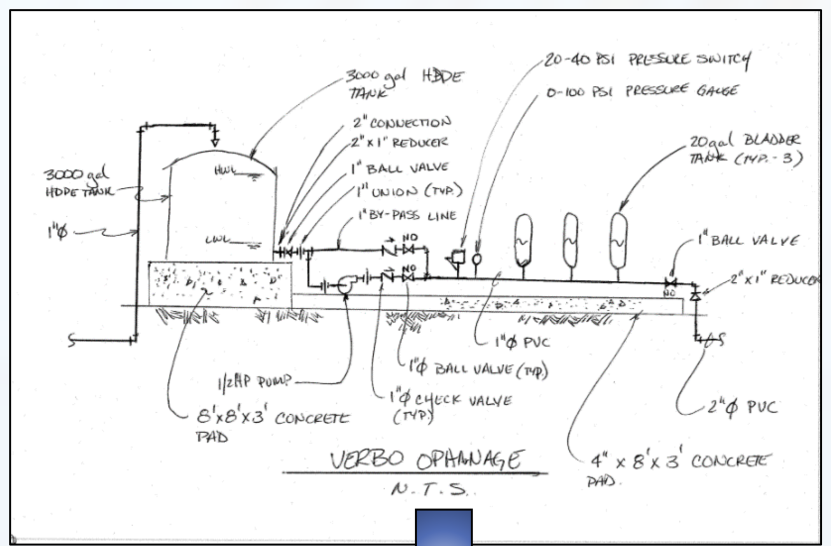


Construction:
Prior to traveling, students developed a Plan Of Action and Milestone (POAM). The POAM included, student assignments, materials management, procurement plan, and a detailed critical path project schedule. Every night during construction, the Project Manager (a student) would hold a meeting to review the critical path. Due to optimal construction management, the project finished on time and $900 under the original budget.



Electrical Engineering:
A professional electrical engineer was recruited to provide QA/QC on the electrical design and to help re-construct the power system. The electrical design included load analysis, filter controls, pump and pump controls, safety grounding and power supply for the UV disinfection system.

Control Systems Engineering: The orphanage needed a system that was fully automatic. Students developed a process and control diagram (P&ID). This P&ID became the road map during construction. Shown above, is a professional engineer and one of the students calibrating a pressure switch during construction.



DESIGN AND CONSTRUCTION OF A RELIABLE DRINKING WATER SYSTEM FOR AN ORPHANAGE IN CENTRAL AMERICA

Abstract

In developing countries, children under five years of age are the most severely affected by the lack of access to safe drinking water. Without clean water, children may develop diarrheal diseases that can lead to fatal illnesses. An orphanage, in the southern region of Central America, had been using a water supply system that contained several deficiencies including open sources of water, undersized pipes, and leaking faucets and toilets. With little water and pressure in the system, the orphanage would experience many shortages, especially in the middle of the day when water was needed for cooking and cleaning purposes. The low flow rate was not only inconvenient, but had led to the development of mold in many of the water lines. Unfortunately, filtration and disinfection methods were unavailable, which further enabled bacteria growth. The onsite clinic at the orphanage provides help to the children affected by water-borne illnesses; however, the clinic supplies its water from the same source as the orphanage, exacerbating the problem of unsafe water. In response to the problem, the student organization dedicated their engineering skills and time to help improve the safety and quality of life for the community.

Working alongside professional engineers, the student organization implemented an Ultra Violet (UV) Disinfection System capable of processing the water demand for approximately 150 orphaned children. In addition to the UV system, a new, pressurized, looped water distribution network was installed, which encompassed the existing facilities and replaced the broken, cracked, and moldy infrastructure.

The replacement and expansion of the distribution, disinfection, and storage systems were planned and designed over two academic years, totaling thousands of man-hours by the student group. Several multi-disciplinary aspects of engineering were involved in the design and implementation such as hydraulics, electrical engineering, mechanical engineering, and structural analysis, with an emphasis on sustainable design that requires minimal maintenance. The contribution of 60 engineering students of various degree concentrations, as well as 10 technical advisors and practicing professional engineers, made a large improvement in the protection of public health, safety, and welfare through this project. In addition, the project created a collaborative experience for students and industry leaders, who experienced a rewarding finish in January 2017.

The following report discusses the details of the findings, collaboration, lessons learned, and results of the planning and construction of a reliable drinking water system for the orphanage. The report highlights the collaboration between the team of engineering students, practicing professional engineers, and university faculty to improve the standard of living of the current and future orphaned children in this community.

DESIGN AND CONSTRUCTION OF A RELIABLE DRINKING WATER SYSTEM FOR AN ORPHANAGE IN CENTRAL AMERICA

From January 2015 through January 2017, engineering students participated in an international development project with the goal of improving the water storage, disinfection, and distribution system that serves not only an orphanage, home to nearly 150 children, but also an onsite school and medical clinic in the southern Central American region. Upon assessment, the water distribution system was found to have numerous leaks, undersized pipes, pipes with mold growing inside, and underwhelming water pressure in addition to non-potable water. Furthermore, the approximately 12 ft tall concrete frame supporting the existing water storage tanks was severely cracked and spalled. These deficiencies resulted in a system that was not only inadequate, but also a health and safety hazard to the orphans who regularly drink the water and often play underneath the concrete frame. The students, with the help of professional engineers, worked to design, fund, and construct a new water distribution network and storage system to provide clean potable water for the orphanage, school, and clinic.

Phase One: Distribution Network

Based upon an initial assessment conducted in January 2015, students began designing a new water storage, disinfection, and distribution network to improve existing conditions for the orphanage. The students divided the project into two main phases: the distribution network and the supply network. While many students actively participated in the design portion of the project, due to limited resources, a team of seven students and two professional engineers were selected to implement the first phase in May 2016. The primary objective was to improve the distribution network and storage system servicing the orphanage, school, and clinic facilities. The students worked with professional engineers to develop a reliable and efficient water distribution system that would eventually provide potable water for the orphans. In addition, students took the opportunity to design a foundation for future storage tanks.

Three teams were organized to expedite the completion of required tasks and were labeled as the pump station team, the distribution team, and the electrical team. To assist with the short duration of the implementation, the students partnered with the local community and were able to have all the digging required for hydraulic pipe and electrical conduit placement completed before arrival. Additionally, the concrete structure designed for the storage tanks was placed a week prior to arrival to allow for a longer curing time.

The pump station team began by placing the necessary components of the storage system on the newly constructed concrete base. The components included two 1500 gallon storage tanks, three bladder tanks, a 1.5 HP booster pump, and two check valves, which were all connected by one inch diameter polyvinyl chloride (PVC) piping. The booster pump pressurized the system; a brand new experience for the orphans. The check valves were utilized to prevent backwash from the distribution system into the storage tanks. The design included a second check valve before the pump to ensure there would be no backwash into the storage tanks during one of the frequent power outages that occur.

Under the guidance of a professional engineer to ensure the design specifications were met, the water distribution team began installation of the system. The design was created to provide water to the kitchen area, public health clinic, staff residence facility, and the three dormitories for the orphans with a priority on the infant and toddler dormitory. The buildings were connected by engineering a looped distribution system, approximately one-half mile long and constructed from one-inch PVC with multiple in-line valves to allow for maintenance and repairs as necessary. This system allowed the facility to be supplied from a single aggregated source, rather than from multiple interconnected sources without an engineered direction of flow.

The electrical team worked with a professional electrical engineer to run power to and properly install the 1.0 HP booster pump. A float switch was installed and placed inside the tank to automatically shut off the pump when the water level drops below the intake pipe. Based on engineering judgment and knowledge of the inefficiencies of the existing supply system, it was decided the pump would be manually switched on and off until the completion of Phase Two. A pressure switch was also installed allowing for expansion and future improvements of the automatic system.

In addition to the three major tasks performed by these teams, students also used a GPS tracking device to locate key connections and intersections identified on the water supply line to assist in the design and construction of Phase Two. The locations were plotted on a map of the property, also created by the students, which has the orphanage buildings previously sighted during the January 2015 assessment trip.

The implementation took five days to complete with over 550 man-hours and zero time lost due to injury. The partnership between the community members, the students, and the professional engineers resulted in a significant improvement in the quality of life of the community. Throughout this period, the students were instructed and guided by two licensed professional engineers, serving as their mentors about the installation of the system as well as safe practices associated with the work.

Phase Two: Supply Network

Upon return from the May 2016 implementation trip, students began working on a plan to improve the water supply to the newly completed distribution network, including the installation of a water disinfection system. In January 2017, ten students and three technical advisors travelled on behalf of the entire student group to install approximately 1000 ft of new one inch and two inch diameter PVC pipe from the existing pumps to the storage system, two additional 1,500 liter storage tanks, and an Ultraviolet (UV) Disinfection system. With these three components, the orphanage now has enough pressure and clean water to create a healthier living-learning environment. To expedite work, the team was split into three subgroups: the disinfection team, electrical team, and supply team.

The disinfection components are housed in a wooden control panel and were installed in-line into the water system after the storage tanks and booster pump, but before the bladder tanks, which were all installed during Phase One. The original connection at the pump station included a 1.5 HP booster pump and a gravity fed bypass connection in preparation for power outages. A backup generator was generously donated by another organization allowing water to be continuously pumped through the treatment system into the bladder tanks and then discharged into the distribution network in the event of a power outage.

The main focus for the electrical team was to connect power to the disinfection control panels and to a pressure switch at the well pump. With a professional electrical engineer advising, the students learned various practices in working with electricity, such as electrical safety techniques, the importance of grounding, how to estimate the length of wire needed, planning the number of colored wires to be used, and methods to physically string the wire from the power source to the destination.

In Phase One, a float switch was installed inside the newly placed water storage tanks to turn the well pump on/off depending on the water level of the tank. To simplify the documentation of the location of constructed utilities, the electrical wires for the float switch were placed in the same trench as the water supply leading from the well to the water storage tanks, but in a separate, grey, ¾ inch PVC pipe to differentiate it from the water lines. The forward thinking initiated in Phase One to install the electrical lines prevented unnecessary re-digging of the trench in Phase Two. The second phase did require the connection of a power control box, located nearby the storage tanks, to the UV disinfection unit and to the pressure switch that controls the booster pump. The connection box and outlet to plug in the UV and controller were installed inside the sealed wooden control panel box on the opposite side of the trapdoor, which allows removal of the relatively long UV light bulb, to minimize the possibility of water in the outlet. From the connection box, electrical wires were run to the pressure switch, which turns the booster pump on/off according to the measured pressure. The pressure switch was set to turn on at 20 psi and turn off at 40 psi. Lastly, students connected the previously installed float switch inside the storage tanks to the power source.

The task of mapping the existing water supply network in the orphanage was quite difficult. Since there was no record of the existing water supply lines, the students could not be sure whether or not pipes branched off to adjacent buildings or properties. Therefore, the students had to unearth most of the supply line to verify that there were no cross feeds. The most challenging problem

encountered was verifying where the existing water supply line crossed a local street. Moreover, following Phase One, a neighboring church had been extended, building directly over the existing supply line. Not to be deterred, students eventually found the location of the existing water supply line crossing the street and unearthed, replaced, and rerouted the existing supply line around the church, directly to the water storage tanks. By doing so, they ensured that the water storage tanks were only fed by the main water supply line and would have sufficient inflow at any given time. Students mapped the changes that were made and kept the locals informed to improve future projects on the orphanage grounds. Installation, troubleshooting, testing, and delivery of the system was accomplished in six days with over 550 man-hours and zero time lost due to injury. After leaving, communication with the community verified that, after fixing leaking faucets and toilets, the orphanage now has a sufficient water supply to be able to provide water to the children throughout the day.

Licensed Professional Engineers, Faculty, and Students Collaborate

Student leaders determined the scope of work and partnered professional engineers with student teams based on the necessary skills needed to complete the tasks. During the design, students from different engineering degree programs met bi-weekly throughout the academic year for progress meetings and were able to discuss any concerns with available technical advisors. Throughout both phases, more than 60 students gained first-hand planning and design experience from direct contact and interaction with professional engineers, engineers-in-training, and faculty advisors.

As aforementioned in the project description, students selected for the implementation trips were matched with professional engineers and faculty advisors in teams to accomplish the required tasks, including the installation of the water supply and distribution system, the water disinfection system, and the various electrical systems. The traveling students had nightly meetings to review the day's progress, to record a daily log documenting that all safety measures were followed, to describe any challenges encountered, to report the achievement of daily goals, and to outline the work yet to be completed. With the data collected, students were able to design and implement a readily accepted and sustainable system to nurture future development and water demand growth. With the experienced planning methods utilized and shared by the licensed engineers, the orphanage project was completed over a combination of two trips to Central America, totaling eleven working days.

Mission: Improve the Health, Safety, and Welfare of the Children

Due to the presence of water-borne bacteria and mold in existing pipelines, water consumption directly from faucets posed serious safety and health risks to those living in the orphanage. The installation of new distribution piping and a UV disinfection system made the tap water potable. Moreover, a significant portion of the previous existing supply system had been located below wastewater pipes. Many of these wastewater pipes had lost structural integrity, resulting in wastewater flowing directly onto the previous supply system, some of which showed evidence of cracking. The problem was most acute along the building that housed the kitchen and a female dormitory. The immediate solution was to bring the new supply piping above ground and affix it to the exterior of the building, but this did not solve the entire problem. The connections to supply water to the interior fixtures were still in the area of the wastewater pipe. All care was taken to sanitize the areas involved at the time that the new distribution system was tied into the existing fixtures. Finally, the existing concrete frame supporting the original water storage tanks was severely cracked and spalled. The 12 ft tall frame was located in the middle of the play area, meaning children would frequently be running underneath the unsafe structure. Working with the local community, a new base was constructed away from the playground, and the existing structure was demolished. Logistics, planning, and quick thinking were necessitated to implement all of these solutions to improve the health, safety and welfare of the children at the orphanage.

Licensed Professional Engineers and Faculty Partner with Students for a Multidiscipline Approach to Reach Solutions

There were interactions among all disciplines of engineering to design and install a system that was reliable, sustainable, and easily maintained. The team practiced a multidisciplinary approach when resolving potential conflicts in the planning stages. By communicating between teams during design, members practiced forward thinking in order to take advantage of the brief time of implementation in Central America and to avoid spatial conflicts during construction. Documentation and logistics planning were of peak importance to facilitate the construction and installation of the water distribution, storage and disinfection systems. By incorporating all system components to create an effective water system, students learned not only technical knowledge from the licensed engineers, but also developed skills related to the client-partner relationship and project planning. The following paragraphs highlight the multidisciplinary aspects involved in the project.

Surveying: The students improved their understanding of surveying while working alongside professional engineers and faculty advisors who taught them how to survey beyond the classroom curriculum. Prior to traveling to the site, the location of the existing distribution system and the establishment of which tanks served which buildings was unknown until students collected conventional, topographical information of the salient features of the property. The elevation change was measured between the newly located water storage base in comparison to the elevation of the kitchen sink to verify the water would still be able to flow to the faucet in case of a power outage. Working with multiple civil engineers to strategize the placement of the water system, GPS equipment was used to create an as-built plan of the facility and the data was reduced and plotted to document the constructed water distribution system components so that it is easily understood by the local orphanage workers, should they need to repair or expand the system.

Geotechnical Engineering: Observing the existing land features, the highest usable point on the property was selected to construct the tank base. Surveying measurements were taken to calculate the difference in head from the kitchen faucet to this high point. There was a 1 ½ ft height difference, but for constructability, the tank pad was built at 2 ft. Before construction, gravel was collected into a mound to act as fill where the tank pad was to be built. As done in engineering practice, the earth was surcharged by applying weight where the intended structure would be built to encourage settlement.

Water Resources Engineering: Professionals taught concepts of hydraulics and strategies to design an efficient system that increased flow and maintained pressurized water. Students learned common practices to understand how components of a water system work together to create an easily maintained, sustainable system. With guidance from a professional engineer, students used the software EPANET to design and model the new water system.

Environmental Engineering: Using preliminary research on US water quality standards and the characteristics to measure to assure potable water, students followed standard lab procedures in quantifying the safety of the water. Water quality tests were completed on site using membrane filters so that the results were available for counting within 24 hours of obtaining the sample. Three samples per testing source were acquired, and the amount of bacteria within each sample was recorded. Performing these tests on-site allowed the students to make quick judgments to explore local availability of water disinfection methods, such as chlorine dosing, as a temporary resolution until a permanent method of disinfection could be designed and implemented.

Structural Engineering: Students were guided in the design of several potential tank pads and the construction techniques of elevated structures. Ultimately built out of CMU blocks with a concrete overlay, calculations ensured that the structure could safely hold 50,000 pounds from the water weight of the 6000 gallons of total storage. To ensure that the wooden 4 ft x 4 ft control panel was designed to allow general maintenance and to be durable enough to withstand severe weather, loading scenarios were calculated. Because of the importance of the control cabinet in protecting the UV disinfection equipment and filters, the location of the unit was strategically placed behind the tank pad. The students designed the control panel to be of a user-friendly height and to take up as little space as possible to function. To limit the required space of the panel, a trap door was included to allow the UV light to be replaced annually, as recommended by the manufacturer to ensure performance. To prevent water seepage into the unit, silicon caulking was used around this trap door and all seams of the cabinet.

Electrical Engineering: The students worked with a professional electrical engineer to design and install the control panel that powers the distribution and switch components. A pressure switch was installed and set to turn on the booster pump when water pressure is below 20 psi and to turn it off when the pressure exceeds 40 psi. A float switch was installed in the interconnected tanks so that when the tanks are filled, the switch turns the well pump off. Once the water elevation goes below a certain point, the float switch turns on the well pump to begin filling the tanks once more. All of the electrical components were installed underground or a minimum of 12 ft above ground in a manner to prevent the children from accidental contact with any wiring, both ensuring their personal safety and preventing system tampering.

Mechanical Engineering: Under the guidance of licensed engineers, an appropriate booster pump size of 1.5 HP was selected and the pressure switch was calibrated to a range between 20-40 psi.

Knowledge and Skills Learned

In addition to the plethora of technical skills required to complete the extensive water distribution system installed at the orphanage, students identified communication as the key component to developing an acceptable solution to any problem. During the design phase, students had to communicate their engineering ideas to one another, often requiring the use of sketching, an important graphical means of communication. While planning, students worked with international partners to coordinate travel arrangements and delivery of construction materials. In the construction phase, students had to communicate with one another to share tools and to help one another when necessary. Lastly, along with communication among the student teams and professional engineers, it is important to communicate with the community to ensure the product meets expectations. The significance of a client-partner relationship with the community positively impacted the students and facilitated the understanding that although a perfect design may be constructed, if it does not meet the intended needs, it is not a successful project. There was no better feeling than when members of the community thanked the team for their hard work in taking the time to improve their quality of life.

The lessons the students learned from this project and the community is something they will carry with them and appreciate for a long time to come; in doing so, they will continue to realize that, as engineers, they have a responsibility to society to never overlook a community's declining public welfare. The knowledge gained through this incredible experience ranges from field experience in engineering to cultural learning for everyone involved.