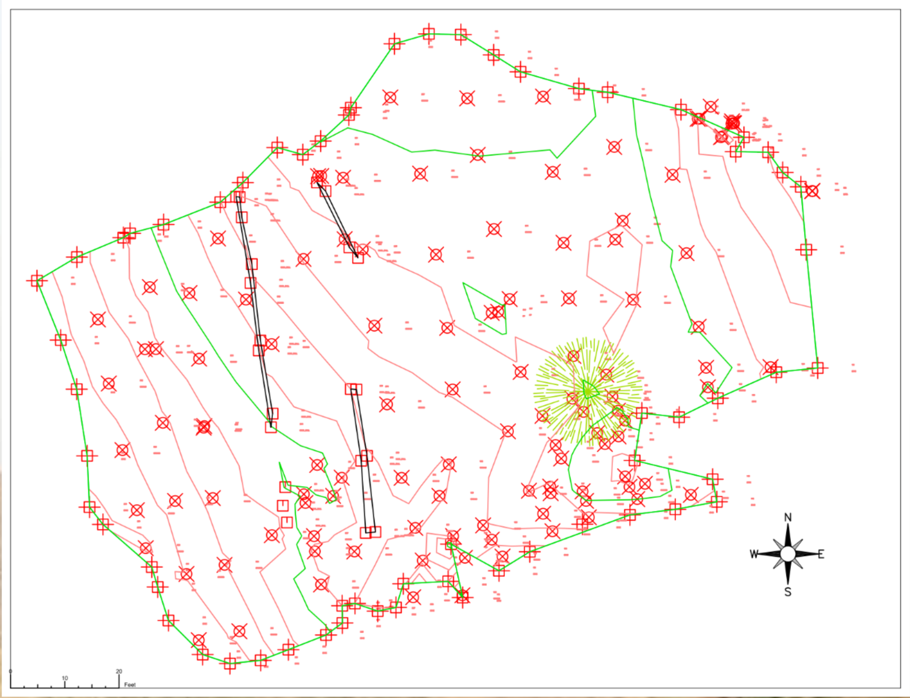
Multistage Drip Irrigation System in Ethiopia

Upper Field Survey Results: A grid of survey points (red) was taken to thoroughly map out Upper Field. The contour lines (green and red) indicate the change in elevation across the field.

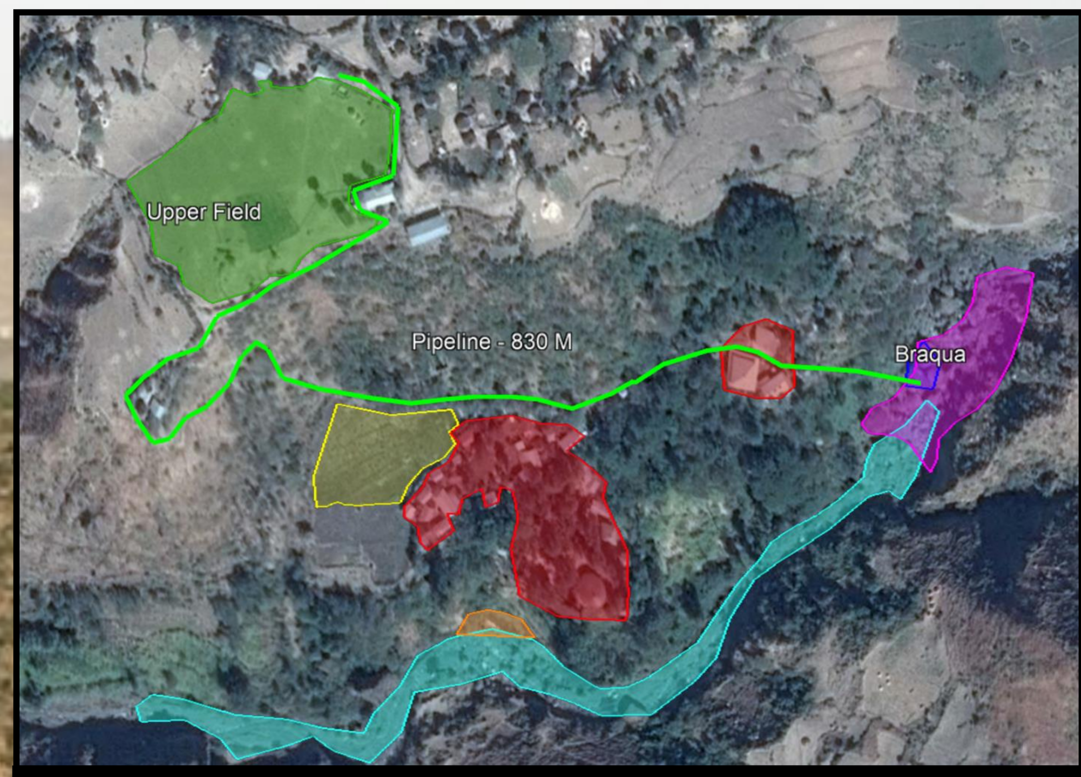


Project Summary

The purpose of this project is to design an improved irrigation method for the 500 person community of Filakit Geregera, Ethiopia. Multiple farm fields go uncultivated due to the inability to supply them with water during the dry season. The community leadership granted the student led project team access to a plot of land, Upper Field, which goes unused to come up with solution.

Upper Field is 250 feet up a rocky slope from the nearest water source, Braqua Spring. The field has an average grade of 9%. These significant topographical factors along with lack of power are the main challenges of this project. After considering multiple solutions, students chose to implement a drip irrigation system sourced from a series of water storage towers that can be refilled from a reservoir connected to a solar pump at Braqua Spring. This system design allows for the drip lines to be gravity fed while ensuring constant water pressure and uniform water of crops at different elevations.

The innovative multi-tower design addresses the issue of uneven water flow due to the field's significant slope. Valves are used to control the water level in the tanks preventing another possible issue, tank overflow. Water from the pump can then be redirected up into a reservoir to relieve pressure in the system. A valve would then shut off further flow into the tanks from the pump, and the drip line valves can be opened for watering.



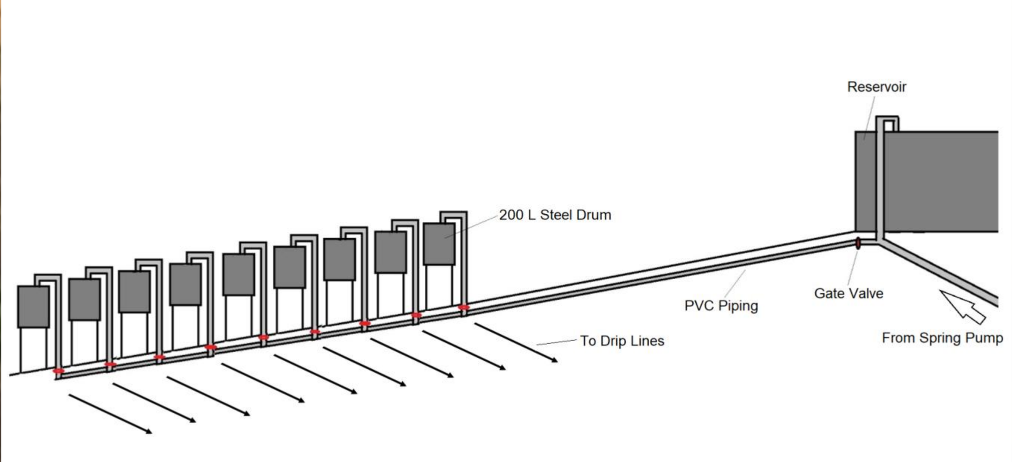
Color Coded Project Overview: Upper Field and pipeline to the drip irrigation system are highlighted in green. Purple and blue indicate Braqua Spring and a connected stream, respectively. The red areas are the residential portion of the community, while the yellow region is another community field.

Collaboration Between Students & Professionals

Student Design Team Majors:
- Mechanical Engineering
- Civil Engineering
- Chemical Engineering
- Mathematics

University Advisors:
- Associate Professor, Civil and Environmental Engineering Department
- Associate Professor, Environmental Health Sciences Department
- Department Financial Professionals
- College External Relations Officer

Professional Mentors:
- Construction Engineer (Licensed PE)
- Consulting Firm Senior Associate (Licensed PE)
- Principal Engineer in Medical Technology
- Project Manager at Architecture and Engineering Firm (Licensed Architect)
- Amharic Speaking Translator



System Schematic: Nine towers with storage tanks made of steel drums supply water to the drip irrigation lines. Overflow can be diverted to a pre-existing reservoir during the rainy season using a gate valve. All the water in this system comes from the solar pump which draws from Braqua Spring.

Skills & Knowledge Learned

Technical Skills:
- Assessment Phase- Completed topographical surveying, soil pH and nutrient testing, and water quality testing
- Post-assessment Phase- Developed working knowledge of photogrammetry, SWOT analysis, constructing Pugh Charts, and design research
- Pre-Implementation Phase- Gained experience in stress analysis, prototype building, materials sourcing and research, and creating itemized budget and bill of materials

Communication & Teamwork:
- Technical writing, interpersonal communication with community representatives, faculty, and professional mentors, and public speaking

Recognition of Societal, Cultural, and Global Issues

Health, Safety, & Public Welfare

Project sustainability and community welfare are ensured by involving the community members in project planning and decision making. This entails regular community calls and working with an in-country NGO partner, the local monastery. The monastery is an invaluable resource for determining the needs of the community.

While in-country, travel team members will educate the community on the system's function, work with the community to develop different plans for the system's maintenance, and help the community predict their costs. In the case of a system malfunction, a select group of trained community members will be able to pinpoint the failure and make the proper fixes.

System safety and proper construction practices will also be applied to this irrigation project. Tower stability is a crucial aspect of the design in order to allow for safe use; stress analysis was performed to ensure each tower can withstand the load of a full water tank. Pressure and flow checks along with emergency shut off valves also ensure safe operation.

The multi-towered drip irrigation system will ultimately increase community crop production. Utilizing this improved irrigation technique along with a double-cropping system that they already employ in their other fields, the community will be able to maximize the project's impact. These changes will lead to improved harvests that will directly benefit the community by giving them improved nutrition, more economic opportunity, and reducing the chance of government repossession of their farmland.

Multistage Drip Irrigation System for Inclined Fields in Ethiopia

Abstract

Ethiopia is facing an ongoing drought since 2015 that has led to 5.6 million people needing emergency food assistance.[1] During much of the year, the community of Filakit Geragera in the Amhara region of Ethiopia has insufficient irrigation capacity to utilize all of its fields. The community hopes to improve their economic standing and the nutrition of all residents, especially children. In addition, the local government is threatening to repossess these land if the situation remains unchanged. The student led project team has partnered with the people of Filakit Geragera to address these problems by designing an irrigation system that would make use of limited water supply during the dry season.

In order to make sure all of the village's needs are met, the team holds regular community calls and works with an NGO partner, a local monastery. The monastery is a foundational organization within the community and acts as both a funding partner and community-based partner. One of the biggest problems the village faces to this day is utilizing all of their tillable land and supplying enough food to meet the demands of the community's growing population. During the rainy season, water is plentiful, but a combination of wasteful irrigation practices, far-off water sources, and inefficient water distribution systems make the dry season difficult for the people who live there.

The four-student design team determined that a drip irrigation system would minimize water loss from evapotranspiration while still meeting the field's water demands. However, the terrain of the area is very mountainous. The upper field has a slope of about 5°, while the lower field has a slope of about 8°. This makes traditional irrigation methods and a normal gravity fed drip irrigation system impractical. Another major challenge is the lack of power in the region and the community's distance from major markets. A sustainable solution that does not rely on modern power and piping infrastructure is required. To overcome these challenges, students designed and are implementing a gravity drip irrigation system that utilizes a set of towers each feeding a set of drip lines that run perpendicular to the slope of the field. This multi-tower system allowed for effective use in an inclined situation without relying on a pressurized water pipe system. Human oriented design and sustainability were major focuses of this innovative engineering and construction project.

Reference [1] https://reliefweb.int/disaster/dr-2015-000109-eth Accessed April 25, 2018.

Multistage Drip Irrigation System for Inclined Fields in Ethiopia
Project Description

The broader goal of this project is to improve the quality of life for the community of Filakit Geregera, Ethiopia. The multi tower drip irrigation project is a major portion of a more extensive water distribution system involving household and drinking water components as well. The project began in 2016 when the project team, about 30 current members, and the community first got in contact. In summer of 2017, students traveled the community on an assessment trip. Students will travel to the community in May 2018 to complete the first stage of implementation in which the irrigation system will be installed.


Figure 1: Students, mentors, and community leaders inspect the natural spring on 2017 assessment trip

One of the biggest problems the community faces to this day is utilizing their land and supplying enough food to meet the demands of the community's growing population of 500 during the dry season. The community granted the project team access to one of their agricultural fields to help improve irrigation methods. This field is 80 ft wide and 140 ft long and is sloping downwards along the length of the field. It is currently not utilized due to the fact that the nearest water supply, a natural spring shown in Figure 1, is roughly 2000 feet away and 250 lower in elevation than the fields. Thus, watering the field is a challenge to the members of the community. Using a quantitative evaluation criteria, the design team determined that adapting the drip irrigation system would be the optimal solution given its efficiency, its low cost, the local availability of materials, and the operational time commitment.

Introduction

Drip irrigation is a method of watering crops by outputting low volumes of water over a long period of time at precise locations. The system minimizes water loss from evapotranspiration due to the slow rate of water discharge. Traditional drip irrigation designs involve a large water tower with a main water line running down the center of the field and many smaller drip lines branching off, perpendicular to the main line. Each drip line has emitters, devices that control and restrict the flow rate of water, attached at regular intervals. These systems recommend 10 to 30 psig of water pressure to maintain a consistent level of water drainage across all of the emitters. In developing countries, the system has been modified to work on flat fields with as low as 1.5 psig using gravity as the only source of pressure in the system.

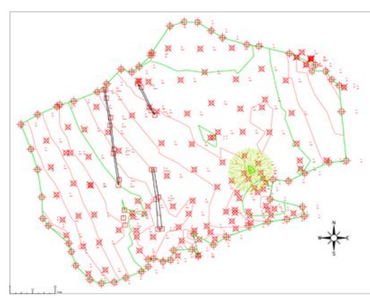


Figure 2: Survey Results of Upper Field displaying contour lines, survey points, and field border.

From the initial assessment trip, Upper Field was determined to have an average grade of 9% (approximately 5°). Figure 2 displays surveying data of Upper Field; the contour lines exhibit the field's significant slope. A traditional drip irrigation system could utilize a main line along the slope of the field with drip lines running parallel to the slope. To compensate for the increased water pressure in the tubing at the bottom of the hill, a pressurized system could simply increase the pressure in the system and use pressure-compensating emitters to maintain a steady flow rate throughout the system.

However, for a gravity powered system, this would result in significantly more water being supplied by the emitters along the bottom drip lines and uneven watering of the crops. A multi-tower system avoids this issue.

The system, shown in Figure 3, consists of nine towers running parallel to the slope of the hill each with a 200 L steel water storage drum on top. A valve at each tank can be closed when the water level in the tanks reaches the desired height. The lower tanks fill up first. When the top tank is filled to the necessary water level, a valve further up on the hill would be closed, diverting the water into a large reservoir for later use by the village. Four drip lines will extend from each tower, perpendicular to the field's slope, so that there the tubing runs at constant elevation. Emitters run along each of the drip lines every eighteen inches to supply water to the crops.

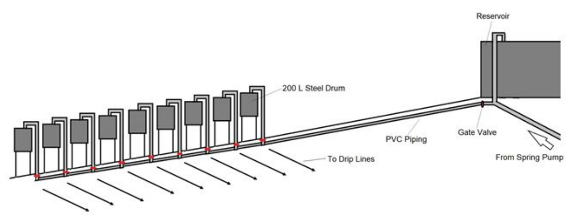


Figure 3: Schematic of irrigation towers and overall system setup

The towers are fed by a piping system with water running up from the Braqua spring. A solar pump will also pump water from that spring, which will be dammed, through a pipeline to the drip irrigation towers at a higher elevation. The entire system is designed to withstand the significant rainfall that the north central region of Ethiopia experiences during the wet season. The previous solutions the community have used in the past have been simply washed away by natural flooding in past years.

The primary challenge this unique design addressed is filling each tank without the preceding tank overflowing. The pipeline from the Braqua spring primarily leads to the reservoir but it also branches off to the tank series. The designed solution is to run the pipe across the entire system, branching off to each of the nine towers in parallel, which allows the system to fill each tank equally utilizing the solar-powered pump downstream. Without this, filling the towers would be a time-intensive step for the community. Valves are installed into the pipes that fed into the tanks, which the operator would close once the water reached a desired level. This way, once all of the tanks were filled, the water from the pump is redirected up into a reservoir to relieve pressure in the system. A valve can then shut off further flow into the tanks from the pump, and the drip line valves could be opened for watering.

Collaboration of faculty, students, and licensed professionals

The Ethiopia project involved multiple mentors with professional engineering experience. While the student group is completely student led,

Figure 4: Team member assembling early tower prototype at a build day

these mentors assisted the various sub-groups within the project, including with the drip irrigation sub-group. One of the professional engineers, whose background is in construction and public works, provided design advice and also held a "build day" to teach team members vital construction skills, such as laying pipes, using concrete, and constructing the tower bases as shown in Figure 4. Another mentor recommended coating the below-ground parts of the tower in used motor oil to prevent against corrosion in the wood. The build day was also used to create a prototype of one of the water storage towers. A project manager of an architecture and engineering firm is the design team's primary mentor. One principal engineer who works for a medical device company also mentors the drip irrigation group, giving input on creating a budget, setting deadlines, and design decisions. A group of students, who will implement the project in May 2018, will also be accompanied by two professional engineers. Mentors make sure construction goes smoothly and help solve any problems that may arise in-country. One of the mentors acts as a translator, as he can speak Amharic. Finally, the professional engineers who volunteer as project mentors help students make connections in with local companies and set up presentations at their workplaces to inform associates about the impact of student's work.

Besides the professional engineers and architects who work with the project team, students also have direct support from staff within the college and department. Two professors meet with the student group leaders in regular meetings every two weeks to discuss administrative decisions, long-term goals, and provide technical support. They also are advocates for the student group when it comes to reaching out to local companies and supporters within the university. The staff from the university department and college help maintain continuity with financial accounting and benefactor relations. Each advisor helps students learn soft skills, such as communication and group decision making, while helping the students retain knowledge and connections as new members take over leadership roles in the group and outgoing members transition out of school and into the industry.

The student project team members are also pursuing many different degrees and career paths, which makes the project process truly a multidisciplinary endeavor. Members of the design team are currently pursuing degrees in civil engineering, mechanical engineering, chemical engineering, and mathematics. This synthesis of ideas and backgrounds allows for a variety of approaches from across disciplines that further provides development as engineers and student leader.

Health, Safety, and Sustainability

One way to ensure project sustainability and community welfare is to involve the community members in many aspects of the project planning and decision making process. This entails regular community calls and working with the monastery NGO partner. As the monastery is led by two main priests who live within and lead the community, they are the clear points of communication from which the project team can receive reliable information about the community and ask for input on the project design. They are invaluable resources for determining the needs of the community. Furthermore, they are leaders in the community and know how to introduce new ideas or spread information to the residents. This helps ensure that project plans are understood and well received by community

Figure 5: Travel team members meeting with Filakit Geregera resident and NGO representatives

members and local officials. Beyond the NGO partner and the community leaders, project leads communicate with the local government council, the Woreda, to ensure the project best meets the community's needs. The Assistant Director of the Woreda has also introduced the project team to local engineers who will be valuable resources with knowledge on aspects of engineering specific to the area. Another important person in ensuring successful communication between the community members and the project team is an Ethiopian university student who will help translate. She also has a background in public health. These collaborators, along with the project team, all have an important role in the project's success, which will ultimately improve the lives and health of community members.

It is imperative for project sustainability that community members understand and are engaged in the system's implementation. Informative discussions along operation and maintenance manuals will supplement community members hands on understanding. That way, they will be able to operate the system properly and to its full potential. In the case of a system malfunction, a select group of trained community members will be able to pinpoint where a failure is and make the proper fixes. To foster this understanding, students will give a detailed and thorough explanation of how the system works and the reasoning behind the design choices made. This will make repairs easier and also build trust and further communication between the community and our team. Beyond emergency repairs, establishing a regular maintenance program will make problems less frequent and easier to address. The student group has calculated the financial cost estimates for maintaining the system, which assures community members the system will be financially feasible for them in the future. One important point students emphasize with the community leadership is that the irrigation system water is not intended to be used for drinking. Other portions of the larger project (described above) with the community of Filakit Geragera are simultaneously being implemented in the community and are intended to provide access to treated water for household use.

System safety and proper construction practices will also be applied to this irrigation project. Tower stability is a crucial aspect of the design in order to allow for safe use. While operating the system, it is imperative that each tower can withstand the load of a full tank as well as unexpected horizontal loads. In order to prevent failure, a stress analysis was performed on the tower design to make sure that it can support the weight of the water. Each tower also has outer dimensions of 2.5 by 2.5 feet and each of the leg will be dug and anchored into the ground to improve stability. The pipeline feeding into the system took into consideration other safety effects to prevent pressure buildup and backflow in the system. The tanks themselves are open to atmosphere to prevent pressure buildup and subsequent damage to the drip lines. Since this system uses gravity to feed water to the field, there is no risk of pressure building up in the system after it leaves the tower. The total hydrostatic pressure in the drip line is only about 5 feet of head or 2.2 psi. The flag emitters used in the system have a low flow rate of 1 gph. Drip systems inherently avoid erosion of the communities fields and overwatering of the crops. Emergency shutoff valves will also be installed in case of malfunction.

The multi-towered drip irrigation system will ultimately increase community crop production. Utilizing this improved irrigation technique along with a double-cropping system that they employ in their other fields, the community will be able to maximize the project's impact. These changes will lead to improved harvests that will directly benefit the community by giving them improved nutrition, more economic opportunity, and reducing the chance of regional government repossession of their farmland.

Knowledge or skills gained

Technical Skills:

The research, design, and implementation of this project fostered the development of numerous technical skills. Each project phase offers students the ability to gain proficiency in a different set of skills.

Figure 6: Students and mentors surveying Upper Field

The assessment portion of this project, in Summer 2017, involved traveling to the Filakit Geregera for the first time. The team surveyed the community and the surrounding farmland using traditional surveying tools as shown if Figure 6. Students also learned to use nutrient and pH test kits to test the fields' soil. Most importantly, the students learned to apply design principles to some of the complex problems the community faces to address the most pressing needs before designing a solution for those problems. Through this process, the team identified malnutrition as one of the most pressing issues the community is facing, and decided that an effective irrigation system was necessary to address this issue.

The post-assessment phase (August 2017-December 2017), the data collected on the assessment trip was analyzed survey data and converted it into a topographic map. In addition, project members experimented with the use of photogrammetry to construct 3D models in CAD. These models gave the design team members who were unable to travel a realistic 3D view of the systems based off their actual appearance. This phase included alternatives analysis in which the student team researched the positive and negatives aspects of different potential solutions to address the irrigation problem. To compare ideas, a SWOT analysis and Pugh Chart were created after the problem statement was fully defined. This alternatives analysis covered various irrigation methods, including drip irrigation, spray irrigation, and deep pipe irrigation. Ultimately, sprinkler irrigation was rejected for its inefficient water usage and deep pipe irrigation was considered labor-intensive and difficult to maintain if problems arose.

Throughout the pre-implementation phase of the project (January 2018-April 2018), team members gained design and planning experience. A thorough stress analysis of the towers was performed by students during the school year with the help of a professional mentor as one way to check the safety of the water storage tower design. Building a full scale water tower prototype offered the students to have hands-on experience in building the tower, something that undergraduate classes rarely offer. Student members also created an itemized materials budget and worked to source the materials needed for implementation. Much of this phase involved students improving their technical writing skills through the composition of a formal pre-trip plan involving a comprehensive description of the stage one implementation trip.

As the project team proceeds onto the project's implementation phase (April 2018-May 2018), are finalizing the system's design, budget, and construction plans. On the implementation trip

(May 19-June 4, 2018), student members will gain field experience surveying more land, connecting pipelines, mixing and pouring concrete, constructing stable structures, and laying out an irrigation system.

Communication and Teamwork:
The residents of Filakit Geregera are considered partners in the entire project process; this is to ensure the system meets their needs and desires while also fostering a sense of responsibility in each community member. Regular community calls are held between the project team, community leaders, and representatives from the monastery throughout every aspect of the project process. An Amharic-speaking project mentor helps with each call by translating to ensure agreement from both parties on how to move on with the project process. This not only ensures project sustainability, but also teaches students the importance of international responsibility as well as considering the problem in the point of view of the beneficiary before attempting to implement a solution. To create a successful system within multiple design constraints, critical thinking and problem solving skills were also applied by the design team with mentors' guidance. Students regularly email and talk with professionals, potential financial supporters, and other project members, similar to that of a collaborative workplace environment. By working with other students and professionals of different backgrounds, members learn how to leverage the skill sets of their collaborators while also gaining technical knowledge and interpersonal proficiency.

Cultural Understanding:
Project team members focus primarily on designing an effective solution to the technical problem of field irrigation, but they also gain a sense of international responsibility and an appreciation for other cultures. The community partnership agreement, a document outlining the obligations of both partner groups, exposed the students to the process of creating a contract. Part of this contract highlights the community's project outlook and the investment made by the community's residents toward the success of the project.

One cultural staple students came across while in-country was a sourdough-risen flatbread and national dish of Ethiopia called injera. A leader of the partner NGO mentioned there is interest within the community and in the surrounding towns for the development of a sustainable way to cook injera. The project team is working on a long-term research project that involves an investigation in the feasibility and cultural appropriateness of a solar injera cooker to reduce smoke inhalation and deforestation in the region. Respect for religious practices by team members while in-country is also emphasized before each trip to Ethiopia.

Each person with whom the students interact and every aspect of the project process offer members unique opportunities to gain an understanding of specific technical and interpersonal skills which they can apply to future endeavors such as continued education, careers in industry, and making a positive impact on people's lives.