Implementation – Post-Trip Plan

Executive Summary	
Community:	Ait Bayoud
Country:	Morocco
Chapter:	Columbia University
Submittal Date:	10/26/2019
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Scope of Work for the project (50 words) [1]	Design and implement a water distribution system for two villages in rural Ait Bayoud, Morocco. The project includes a well, solar powered water pump, high density polyethylene (HDPE) pipeline, and water storage system.
Scope of Work for the trip (100 words) [2]	In this trip, we constructed a 38,000 L reinforced concrete storage tank, two water distribution sites, and a solar rack to hold 5.4 kW of solar panels. Additionally, we laid down 4 km of HDPE piping to connect the well site to the storage tank and the two distribution sites in Ilguilouda, and we installed a solar inverter to power the pump by the solar panels.
Proposed Next Step (100 words) [3]	We are currently designing for the next phase of implementation next summer in order to bring water to Izgouaren.
Describe Recent Contact with Community, NGO, and in country partners. (100 words) [4]	We are currently communicating with community members through WhatsApp. Additionally, the three translators we worked with this summer--Zineb, Zeynab, and Meriem--have also communicated with community members over phone calls and Whatsapp.

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Describe the Chapters current fundraising goals and milestones. (100 words) [5]	The program is currently seeking multiple sources of funding--including EWB's cost-share program, grants within our university, and the Rotary Global Grant--for the trip next summer. Our goal is to raise $32,100.
☒ [6]	**IS THE PROGRAM STILL ON TRACK TO MEET THE EWB PROJECT EXPECTATIONS?**

Privacy: EWB-USA may release this report in its entirety to other EWB-USA chapters or interested parties. Once the report is approved any member in Volunteer Village will be able to find and view the plan. Please do not include personal or sensitive information.

Project Timeline [1]

Major Milestone	Previous Date [3]	Current Date [3]	Description
Program Adoption Date	12/23/12		
Previous Project in Program Date Constructed [2]	06/26/13		Foot Bridge in Ait Bayoud
Program Adoption Date	01/06/14		
Completed Assessment Trip	1/19/14		Survey of project locations
Completed Assessment Trip	8/23/14		Survey of project locations, bridge maintenance
Completed Assessment Trip	1/18/15		Drilled well, map piping routes.

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Completed Implementation Trip	9/5/15		Began laying pipes and constructed chateau foundation
Completed Implementation Trip	1/16/16		Continued laying pipes, searched for leaks
Completed Implementation Trip	8/5/16		Laid pipe, installed well pump, televised inside of well, first time pumping water
Completed Implementation Trip	1/14/17		Piping pressure testing, bridge maintenance
Completed Implementation Trip	8/22/17		Bridge maintenance, installed temporary distribution site
Continued Implementation Trip	12/27/17		Trip to complete data collection and hydrogeologic assessment for onsite well.
Completed Implementation Trip	7/15/18		Checked for leaks in pipeline, discussed alternative power sources w/ community
Completed Implementation Trip	7/16/19		Installed solar pumping system, laid down pipeline well site to Ilguilouda), constructed concrete storage tank, constructed two taps at Ilguilouda, and installed a distribution tank near the well site.
Planned Continued Implementation Trip	8/1/20	7/18/20	Monitor and evaluate usage of Chateau site and condition of water distribution system. Lay down pipeline from Ilguilouda to Izgouaren, construct break pressure tank and second storage tank, construct two taps at Izgouaren, and install chlorinator at storage tanks.
Planned M&E Tip	8/1/21	8/1/21	Conduct further maintenance if necessary on any aspects of the system.

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1. Project Description

1.1. Project Background and History

1.1.1. Inception

The Morocco Program began in 2011 when the Columbia University Chapter was contacted by Nina Morency-Brassard, a Peace Corps Volunteer stationed in Ait Bayoud. This initial connection brought our program in touch with the ABDA and laid the foundation for our collaboration. In the summer of 2013, the program completed a bridge project in this community to connect the North and South areas of the community during the flood season. The water supply project began in July 2013, shortly after the bridge was completed. There have been two assessment trips for the water supply project. Initially, during January of 2014, the team gathered information about the demand for water in each douar, performed water quality tests, performed site reconnaissance, and recorded flow rates of a nearby spring and river. Next, during the August 2014 trip, more detailed assessment was done in regards to determining a well location, meeting with a groundwater hydrology professor, meeting with well drilling contractors, and sourcing materials for the project. CU-EWB has progressed on implementation of the Ait Bayoud water project over the past four years. In January 2015, with the permission of the official government representative of the community Rais el Madi, a 140-meter-deep well was drilled and cased approximately 2 miles northwest of the nearest douar (Figure 1). The well was constructed by the Moga Building Drilling Company and is located on the private property of a community collaborator.

1.1.1. 2015 Assessment

In 2015, a memorandum of understanding and a land easement were drafted and signed by the community collaborator (Mohamed) to ensure that the well remains a public resource.There have been no major contaminants of concern detected in the water. However, more rigorous tests will be needed to meet full compliance. In preparation for installing the temporary water tanks, the project team has laid a concrete foundation at the tank site. CU-EWB has also constructed approximately 4560 feet of 2” diameter galvanized steel pipe between the water tank location and the well site. The pipeline is not buried because trench excavation was deemed not feasible. In January 2016 , a gravity pressure test which required no additional pump pressurization was conducted which showed several leaks.

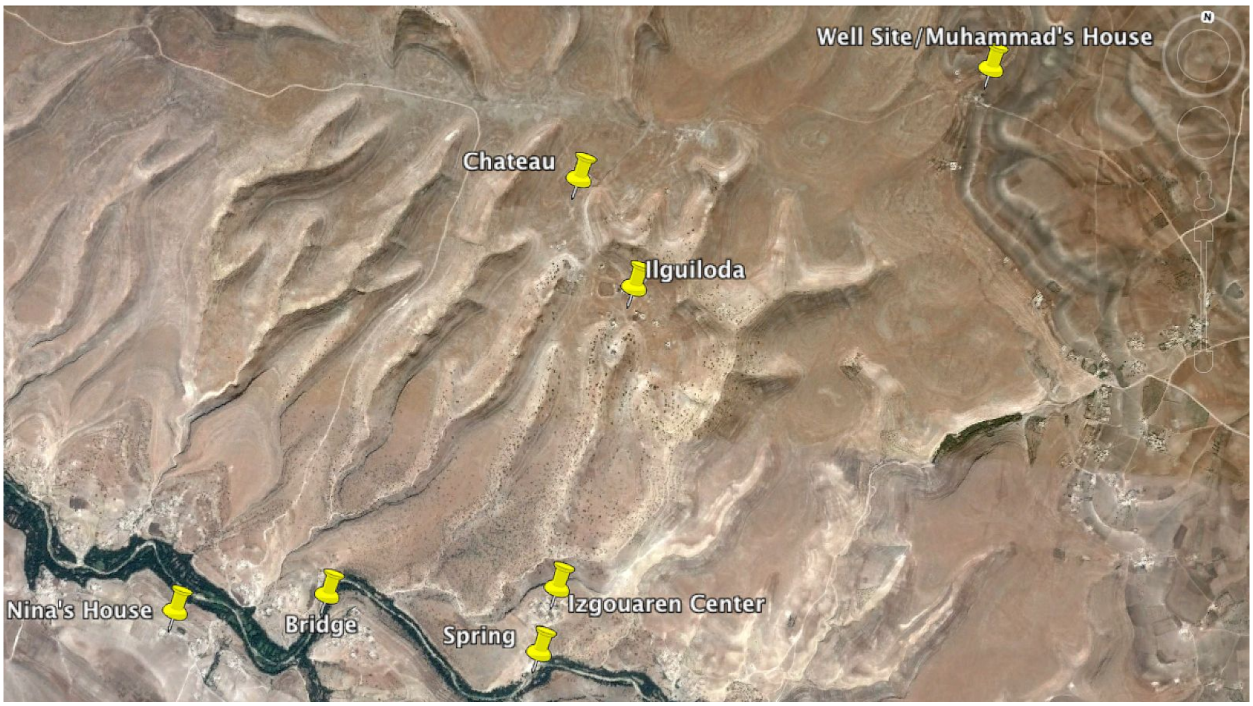

Figure 1. Map of key project locations.

1.1.2. 2016-2017 Implementation

The following trip in August 2016 was dedicated to the reconstruction of the pipeline tested in January 2016 and used a new piping procedure that utilized a combination of piping sealant (i.e. pipe dope) and Teflon tape in place of the previously used Teflon tape only procedure. To date, 2360 feet of piping has been laid from the well site towards the chateau and 2200 feet of piping has been laid from the chateau towards the well site. Much of this piping was done in partnership with the community, which has shown great initiative in leading and teaching new workers the correct pipe laying procedure. The August 2016 team also televised the inside of the well and installed the purchased well pump in hopes of performing a step-drawdown test on the well. However, issues around faulty flange gaskets purchased in Morocco delayed the testing schedule significantly. Water pumped from the well was more turbid than in the year prior. The August 2016 trip also saw the completion of an electrical building built at the well site by the community. The community president, the Rais, has promised electricity to the site upon completion of the electrical building. The next trip, in January 2017, included running the pump almost continuously for approximately five hours in an attempt to develop the well and assess the quality of the water. Local residents connected polyethylene pipe at the outlet of the well to their own pipe in order to get the pumped water into ponds lined with plastic tarps. This water was given to locals to use for washing and livestock, but not for human consumption. The turbidity of the water, measured using a turbidity tube with a Secchi disk, varied over time. Turbidity data and other water quality data were collected. Water samples collected from the well, the Tagawowt River, and a spring which arises from the same aquifer as the well were tested for nitrates, phosphates, turbidity, salinity, conductivity, dissolved oxygen content, and pH. The geological formations along the riverbed between the bridge and the spring were photographed and documented. The purpose of this is to compare the elevations and slopes of the formations to the location of the well and deduce what the formation at the well is like. Samples were also brought back to Columbia University for further information on particle size and density. No permanent components were installed during the January 2017 trip. In August of 2017, our program constructed a temporary water distribution site.

1.2. Project Context

Ait Bayoud is a rural agrarian community in the Essaouira province of Morocco. Izgouaren and Ilguiloda are two of the poorest towns in this community. In the nearby Atlas Mountains, seasonal rain rapidly floods the Tagawowt river, the normally calm central water source for Ait Bayoud. Ait Bayoud is made up of twelve douars, or communities. Amongst these douars, there are two relatively isolated communities, Izgouaren and Ilguiloda, located 85m and 220m above the river level, respectively. A water supply, storage, and distribution system currently exists in the main douars in Ait Bayoud, but Izgouaren and Ilguiloda are excluded due to their remote location and lack of a nearby, year-round water source. Thus, to satisfy their water demands for daily needs, the communities we are trying to serve must gather water from a spring located in the riverbed. This requires slowly hiking up and down a plateau an hour each way multiple times a day in order to get the water they need. The time dedicated to gathering water is largely the responsibility of women and the elderly. Consequently, the growth and progress of these communities are stalled as other necessities, such as healthcare and education are not given the proper attention. Initial tests of the quality of the spring water indicated the presence of fecal coliform, likely since the community members's livestock also drink from the spring and defecate nearby. This finding is consistent with the fact that the main issue that the community hospital treats is gastrointestinal illness.

1.3. Project Goals and Objective

The goal of the project was to design and construct a distribution system to provide a source of drinking water for the residents of the douar of Ilguiloda in Ait Bayoud, Morocco. Currently, the members of Ilguiloda walk over 7 km each day— 2–4 hours per day—in order to get drinking water, and this distribution system will substantially reduce the time spent getting drinking water. The system consists of 20 solar panels, a solar rack to hold them made from steel and concrete, 6 km of high density polyethylene (HDPE) pipe, a 38,000 L water storage tank made from reinforced concrete, and two tap stands in each community.

1.4. Scope of Work

The purpose of this Columbia University EWB Morocco project is to provide a sustainable source of clean, easily accessible water that the communities of Izgouaren and Ilguiloda can use daily for all their water needs, including drinking, cleaning, bathing, domestic work, and providing for domestic livestock. This project was executed from 2014-2018 in collaboration with the United States Peace Corps, an organization that we have successfully used in the past on a prior project in Ait Bayoud. Since 2019, we have been working with local translators to facilitate project tasks.

By providing a clean and accessible water source in each community, our project hopes to give the women and elderly of Ilguiloda and Izgouaren more time for other priorities or opportunities instead of collecting water for hours each day. Potable water will greatly improve the communities' health by reducing their exposure to bacterial illnesses.

The water supply system we envision will distribute groundwater from an aquifer. The water will then be pumped through a piping system to a centrally located water storage tank and distributed by a gravity fed pipeline to the two communities.

1.5. Summary of Completed Facilities

1.5.1. Tap stands

Figure 2. Domestic tap stand (left) and livestock tap stand (right)

We constructed two tap stands at Ilguilouda—one domestic tap stand and one tap stand dedicated to livestock water. The domestic tap stand includes a slab with a minor slope on which two taps are fixed. The slab at the livestock tap stand was constructed by the community after we left, and as a result we believe, with reasonable certainty, that it was poured flat.

The piping in the spigots is 20mm galvanized steel, a more rigid material compared to the HDPE piping used for the distribution system. Since these pipes would be more susceptible to weathering, erosion, and possible damage from misuse, the team selected 20mm galvanized steel to protect system functionality. Each tap stand includes a check valve and a gate valve to manage the flow of water. Additionally, each valve will be accessible through a valve box, in order to ensure that they are protected from potential tampering that could interfere with the functioning of the system. To protect the upright pipes of the taps, each tap will be cast in concrete, using a 90mm PVC pipe of the same height as a mold.

A tap stand for domestic use was connected to the end of the main pipeline. In the future, the connection will be changed such that domestic tap stand branches off from the main pipeline through a tee. This way, the main pipeline can continue on to Izgouaren. A tap stand for livestock use was constructed next to the mosque in Ilguilouda and branches off from the main pipeline through a tee.

A series of compression and threaded fittings connect the 90mm HDPE main pipeline to each tapstand. First, the 90mm HDPE is reduced to 63mm with an HDPE reducer, Then, a compression-to-female-threaded fitting connects the 63mm HDPE pipe to 63mm galvanized steel pipe. Then another galvanized steel reducer connects 63mm galvanized steel pipe to the desired 20mm galvanized steel pipe. See Attachment A for a detailed diagram of the tap stand pipes and fittings.

1.5.2. Storage Tank

We constructed a reinforced concrete water storage tank on the reinforced concrete slab previously constructed by the EWB-CU Chapter. The tank has 38,000 liters of water storage capacity, consisting of two chambers: a settling chamber with a volume of 14,000 liters, and a storage chamber with a volume of 24,000 liters. The tank is in Ilguilouda at the highest elevation point between the pump and the tap stands. It stores enough water for two cloudy days and provides a minimum detention time of three hours for particle settling. See Attachment A for updated drawings

Figure 3: The finished storage tank with community members from Izgouaren.

1.5.3. Pipeline

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Four kilometers were implemented this summer, which corresponds to the length required to reach the first village of Ilguilouda from the well site. This pipeline portion is composed of 90mm PE100 pipeline, standard dimension ratio (SDR) hybrid of 11 and 17. The pipe is laid on-grade, parallel, and adjacent to a one meter wide dirt road, cleared of rocks and point loading, from the well to the Chateau site. Any bump greater than 0.3m in local extremity was flattened to reduce air entrapment within the pipeline. Community updates indicate the pipe is being covered with fine aggregate to protect from external damage and to insulate for cooler water. During installation, the pipe was allowed to snake to account for thermal expansion. There are three minor branches, one to feed into the community near the well site, and two branches for tap stands at Ilguiloda. Each branch contains a valve box with a check valve to prevent backflow and a gate valve, which acts as both an ON/OFF and a flow control valve. An additional check valve was installed after the location of the community near the well site to prevent backflow of water from the storage tank and main pipeline to flow downstream at night. This check valve prevents the well site community from draining the water supply. Air release valves and sediment drain valves have yet to be installed due to lack of time. A general overview of the pipeline is shown in Figure 3. Full updated hydraulics based on updated topography data can be found in Attachment J.

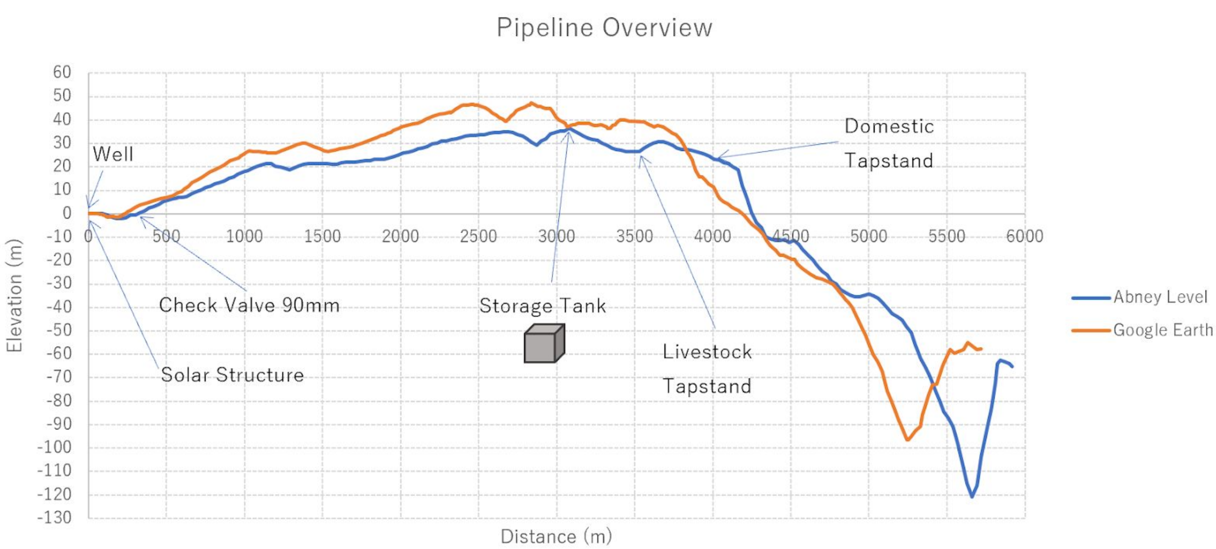

Figure 4: Overview of entire pipeline.

Approximately two kilometers of 50mm and 63mm pipe remain to be installed. Abney survey was completed for the entire six kilometers of the route, confirming topography will allow water to reach the second village of Izgouaren. Pipes and fusion machine remain with the community.

1.5.4. Solar Pumping System

After speaking in person with local solar pump suppliers, the team learned that Lorentz solar pumps are not commonly used in the region and must be special ordered. After testing the Lowara pump that was previously installed and determining that the pump was operating in good condition and the flow rate was sufficiently high to support the community's daily demand within the hours of sunlight available, the team decided not to replace the existing pump. Instead, a 4 kW INVT Goodrive 100-PV solar pump inverter (model GD100-004G-4-PV) was installed in the electrical room next to the pump control panel to power the pump using solar panels. One string of twenty 270 W Tesla solar panels (model TSP270-P156-60) was connected to the inverter input, while the inverter output was connected to the pump control panel (see Attachment A for wiring diagram). A circuit breaker (model Hager MV 225 B25) was wired between the solar panels and the inverter and installed in an electrical box attached to the underside of the solar panel structure, protected from rain. A grounding rod was buried near the solar panel structure to ground the circuit and the structure.

The solar panels were mounted on a large steel rack, cast into a reinforced concrete foundation. This structure was built to hold the solar panels at a tilt of 31 degrees from the horizontal. The dimensions of each solar panel are 1640 mm x 992 mm x 35 mm. The width of the structure is 4 meters, the length is 9 meters, and the height at the high end is 3 meters. The rack has four 9m long slots in which strings of 5 panels were inserted. Each panel was fastened to the steel rack by four screws at the corners.

The structure is composed of 50mm x 100mm x 9mm thick rectangular tubing, 75 mm x 75 mm x 6mm thick W members, and 75 mm x 35mm x 6mm thick C members. The W members formed 18m long slots for the panels and were bolted to the rectangular tubing, instead of welded as was originally planned. The rectangular tubing and C members were bolted together to form trusses. The legs of the tack were embedded in concrete.

Figure 5. Picture of the front of the completed solar panel structure. The formwork for the concrete had not yet been removed in this picture.

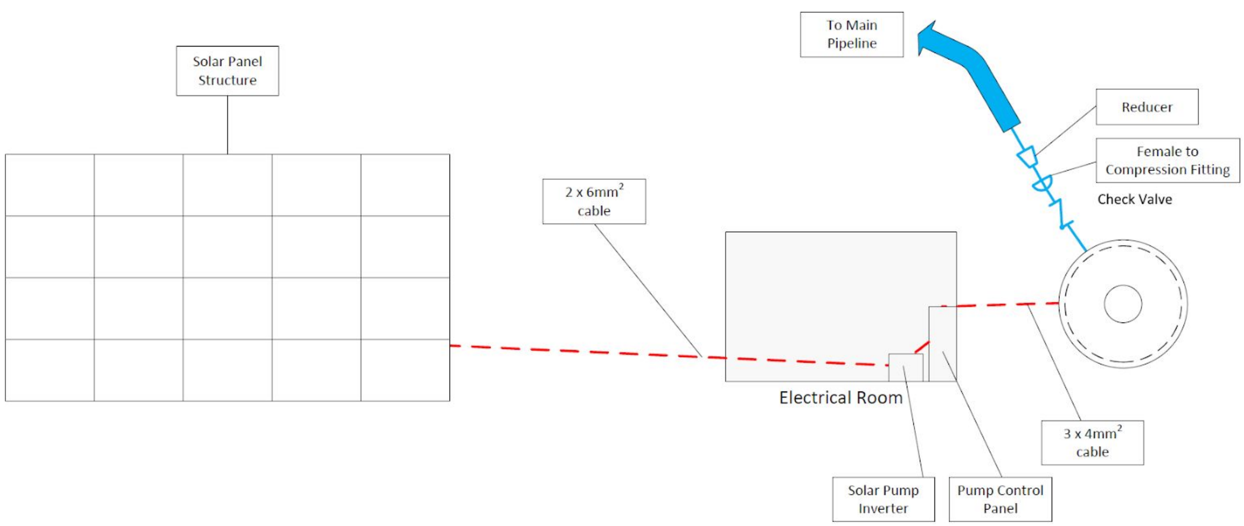

Figure 6. Aerial diagram of the well plan and solar pumping system.

1.6. Next Steps in Project

During our next implementation trip during the summer of 2020, we will lay 1.9 km of pipeline connecting Izgouaren to our water distribution system, construct four additional tap stands, increase the water storage capacity by installing a ferrocement tank and maintaining the existing storage tank, construct a ferrocement break pressure tank, install a water meter and pressure meter at the pump outlet, and implement a community water share system.

1.7. Project Team

REIC: Colin Barrett, a professional engineer at Mount Sinai, is our REIC. He specializes in water systems, and has previously traveled to Ait Bayoud with CU-EWB Morocco.

Internal Reviewer: Eric Lundborg is our main project contact at EWB-USA. Project leads speak regularly with Eric and REIC Colin Barrett when preparing to review travel plans, as well as when debriefing project trips.

Travel Team:
Sean Reischel is a Civil Engineer specializing in hydraulics. He traveled to provide input on the state of the well, pump, and water quality from the well site.

Robert Prager is an experienced Civil Engineer with specific piping experience. He worked with our travel team for several weeks in Morocco on laying and fusing the PE pipe.

Michael Conaboy is civil engineer, Senior Vice-President, and Executive Director at Michael Baker International. Michael oversaw the mixing and pouring of the first lift of the reinforced concrete tank.

Ethan Cotton is a structural engineer with LERA Consulting Structural Engineers. He advised the design process of the reinforced concrete tank and was present during the early part of tank construction.

Alice Wu is co-program manager of CU-EWB Morocco. She is a senior Electrical Engineering Student at Columbia University, and is also the design lead for the solar pumping system.

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John Yatsko is a recent graduate of Columbia University's School of General Studies and holds degrees in Civil Engineering, Math Education, and Philosophy. He has travelled on four EWB trips across West Africa, and served as the tank and solar rack design lead.

Donald Swen is a recent graduate in materials science in Columbia's School of Engineering and Applied Science. He served as piping design team lead along with Nicholas Vallin, a current senior in materials science, also at Columbia's School of Engineering and Applied Science. On the trip, Donald oversaw the implementation of piping.

Rachel Ballew is a student at Columbia University's School of General Studies

Leanne Pichay is a sophomore engineering student at Columbia's School of Engineering and Applied Science. She served as our program treasurer, and later as tap stand design lead.

Raayan Mohtashemi is co-program manager of CU-EWB Morocco. He is a junior in Industrial Engineering and Operations Research at Columbia University. Raayan started as a member of the piping design team. On the trip, he oversaw concrete mixing and acted as a logistics and team discussion facilitator.

Justin Paik is a sophomore engineering student at Columbia's School of Engineering and Applied Science. He leads water quality assessment and worked on construction implementation on the trip.

Gabriel Trinity McCormick is a sophomore engineering student at Columbia's School of Engineering and Applied Science. She helped with material sourcing/implementation on the trip.

Anwar, the nephew of Mo Sbai who is helping the team obtain funding from Rotary International for next summer, joined the team for the last two weeks of construction. Anwar is currently a second year engineering student, studying at a college in Tangiers, Morocco.

Translators:

Zineb Kouhel is a Moroccan translator who lives in a town about 30 minutes from the project site. She is fluent in English, French, Moroccan Arabic (Darija), and the local dialect. She helped provide cultural input in addition to translating. Zineb also helped with project implementation.

Zeynab (nickname “Z”) is also a Moroccan translator who is also from Hanchane and lives in Essaouira. She is fluent in English and Darija, amongst other languages, and helped communicate with the local community members. Zeynab has continued to serve as a point of contact between members of the community, helping us monitor the constructed infrastructure and check in with/instruct the community on infrastructure maintenance. Zeynab also helped with project implementation.

Meriem is also a Moroccan translator, and student in Essaouira. Meriem and Zeynab are sisters. Meriem is fluent in English and Darija, amongst other languages. Meriem helped translate, provide cultural understanding, and also helped with project implementation. All three translators were essential members of the team who not only helped us communicate, but also took pride and ownership in the project.

1.8. Community Partners

The previously established community water association expired in June of 2019. The community is now working on establishing a new water association to act as the decision-making authority over the project and collect water fees. At the end of this implementation trip, the team held a meeting with the men in the three communities--Izgouaren, Ilguilouda, and households around the well site--to instruct the community on maintenance, outstanding construction tasks, and hand over the keys to the valves boxes. During the meeting, the community members in attendance chose one representative from each of the three communities to be in charge of the keys and to lead the formation of the new water association. Most of the people who attended this meeting were also involved during the construction of the project.

Additionally, the team met with the governors of Bizdad, which is in charge of Izgouaren and Ilguilouda, and Meskala, which is in charge of the community around the well site, to inform them of the progress on the project and obtain their support. Specifically, the team asked the governor of Meskala for assistance in enforcing the land easement agreement with Mohamed regarding the well site. Additionally, the team met briefly with Rais Rachid, who is the elected authority over Ilguilouda and Izgouaren and controls government finances for the region. However, due to a perceived alliance between the team and the previous Rais Madi, who’s house we were living in, Rais Rachid did not wish to actively support the project. Next summer, the team plans to find alternative housing and obtain Rais Rachid’s support for the project, by clarifying our neutrality in local politics, since Rais Rachid is the only local authority capable of financially supporting the project.

2. Construction Activities

2.1. Description of Completed Construction Activities

2.1.1. Pipeline

In order of implementation schedule, first, a topographic survey of the entire route was done using an Abney hand level. After confirmation of working hydraulics, a backhoe operator was hired to clear a path for the pipe to lay on. The decision to use machines was made because of two primary factors. The initial team that arrived composed of two translators and two Columbia team members, Donald and Rachel. Possibly due to the fact that previous EWB members spent four years on the project with no results, there was possibly mistrust or suspicion that anything would happen this year. To re-build that trust, we decided that we needed to take action and show that we are serious about our commitments. The machines were the first observable sign of our investment and trust in them. Trust was thus the first consideration. The second was if they did not have our trust, there would be no reason for them to work alongside us for two to three weeks doing hard labor for eight hours a day without pay. Our options were to pay the locals for their labor or hire machines. As a result, it was decided that hiring machines would build trust and ensure our project would be on track for completion.

Before deciding on the use of machines, we considered using a Vermeer Rocksaw. However after a consultation visit, we received a quote of $20,000 for the four kilometers. Despite negotiations, the price was simply too high. We even met with Rais Rachid, the governing person in charge of Ait Bayoud, to ask for machines. In the end, we traveled to the town where our translators were from and hired an operator named Yssin.

Rachel oversaw the clearing of the path while Donald conducted the topographic survey. We discovered that the backhoe could dig trenches in the rocky terrain. We allowed the operator to continue digging the trench, however, there remained visible bumps in areas where large bedrock existed. We allowed this to continue telling the operator that any bump was not allowable. Unfortunately, the bumps continued to exist and the trench kept being dug. We decided to smooth over the dug trench despite ideal trenches in many areas. In this sense, we reverted back to the original plan of an on-grade pipeline.

Rachel, Donald, and community members cleaned the path of any remaining rocks after the backhoe's work.

Pipes were delivered in the first week of August. Initially, the drivers threw the pipes onto the ground. Pipes were unloaded from two large cargo trucks using ramps to prevent damage to the surfaces of the pipe. At least ten people were needed to unload each coil of pipe. Meriem, our translator, was instrumental in organizing the labor for this process while Donald directed and participated in the effort. Unloading took approximately four to five hours. The pipes were laid on a large surface approximately 50 square meters, which was cleared of rocks and point loading the night before. The location was right next to the Chateau site.

Pipes were loaded onto a tractor and dropped off every 100 meters at marked locations along the pipe route. This tractor belonged to a community member named Omar. Diesel was purchased for him for this effort. Approximately ten community members were involved in this process. After the coils were dropped, the strings holding the coils together was cut and the pipes were allowed to relax. After the initial day of figuring out how to uncoil the pipe, the locals found that rolling the pipe vertically was the easiest way to uncoil the pipe. The locals quickly took charge of this process. While Donald fused the uncoiled pipes, the locals set the pipes into position and uncoiled. Approximately three to four locals accompanied fusion while the other ten focused on staging the pipe.

Up to ten joints could be done per day with the McElroy PITBULL 14. Following ASTM F2620-13 procedures, 90mm DR 11 pipe was installed. Heat soak time was 1:26 while fuse/cool time was 3:32. Temperature of the heating plate was 425 F. After fuse/cool time, the pipe was let to sit in the machine for 15 minutes without disturbance as recommended by our mentor Rob Lawrence. Donald led the process for the first couple days, until thereafter, he switched to the role of directing and advising the installation. The locals quickly picked up the procedure and upwards of ten locals are knowledgeable in fusion procedures. Most days, only four to six joints were done due to other interruptions.

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Figure 7. Picture of the set-up for butt-fusing pipes.

Usually three to four locals would set the pipe into the holdings of the machine. Pulling 100 meters of 90mm DR 11 pipe can be strenuous. The pipe was installed such that each side of the pipe end came in to create an S shape, horizontal to the ground. An S-shape insured pipes would be square to each other. While waiting for the heating element or cool time, locals and Donald would clean the path free of rocks and point loading. We used shovels and pickaxes to do this work. After fusion, we would place the pipe into the pipe path created for the pipe.

Compression fittings (90mm tees) were installed for all branches of the main pipeline. See tap stand section for information of all construction that happened after the branches.

Compression fittings was installed after the GI swing check valve at the well to transition toward PE pipe. A reducer compression fitting was used to go from 63mm PE to 90mm PE. A polypropylene check valve rated to 16 bar was installed after the branch to the community near the well site. The check valve has been buried by the locals.

All GI material and compression fittings was sourced out of the Industrial District in Marrakech from Marrakech Fournitures Equipements and Sosates.

2.1.2. Tap stands

Two branches to both a livestock-focused tap stand and a domestic-focused tap stand were made for the village of Ilguilouda. Initially, changes had to be made to the locations we had selected from Google Earth. While they had seemed promising virtually, they proved to be too close to the houses of community members, which would have proved problematic in the long-run by bringing too much foot traffic constantly very close to their properties. We conducted a visual survey of the land surrounding the pipeline throughout Ilguilouda. We selected two locations, both with promising runoff potential.

We conducted abney level surveying to determine if there was sufficient head at the altitudes of the locations we had picked, and determined that, at both locations, there was about 14m of head — plenty for the water distribution we were planning on executing.

Excavation for the 2x1m slab at the Domestic Tap stand took place first, with a trench dug beneath the slab to allow for pipe burial. While the ground was difficult to work with, we managed to dig sufficiently at this tap stand to safely bury the pipe, preventing it from the wear-and-tear expected from the high-volume of use to be expected.

Then, formwork was made for a graded slab with trapezoidal sides, slanting horizontally toward one corner. The lowest corner was placed so as to be away from the incoming pipe, and towards the cliffside to optimize runoff. The concrete was poured at standard ratio, and left to cure.

The HDPE pipe was connected to galvanized steel pipe through a compression fitting, allowing for the tap stands to be entirely galvanized steel. These tap stands consisted of two upright taps, situated on a graded concrete slab. All necessary valves and fittings were installed withing the tap stands themselves to ensure that they are fully functional. We were able to finish construction of one of the two tap stands.

We completed the full assembly and testing of the pipes for the second tap stand, as well as excavating for the pipes to be laid. However, we did not have time to complete the concrete slab at this location. This was completed by the community. As a result, the community chose to move the second tap stand location to a higher altitude due to a more convenient location. At this location, the community members poured an ungraded slab. While the new location is not advisable due to a reduced pressure, to date there have been no issues with running water at this site, so we don't see a need for further action. Additionally, the pipes at this location were laid on grade, instead of buried, without any current measures to protect the pipe.

2.1.3. Tank

A 38,000 L reinforced concrete tank was constructed on the chateau, which consists of two chambers—21,000 L and 17,000 L.

Two manholes were constructed on the top of the tank—one for each chamber, each of which is approximately a square with side length 590 mm. The community has been tasked with securing the metal plates to cover the manholes with hinges, and devising a locking mechanism

The sourcing of the materials took approximately one week. The lower half of the tank was constructed in approximately one and a half weeks. The upper half was constructed in an additional one and a half weeks. Both instances of pouring concrete were each completed within the daylight hours of one day. The deconstruction of the forms and subsequent maintenance tasks took an additional four days. On average, the tanks were being worked on by 3-4 Columbia students, with 1-2 members of the community helping as well. Sometimes the Columbia students were working alone, while there were also times that more community members were helping. During the pours, an additional 8-10 community members would help.

The team decided to halve the size of the concrete tank after arriving in Morocco to have a more feasible implementation plan given the time and funding available. As a result, our structural engineering mentor Ethan and tank design lead John were instrumental in redesigning the tank before beginning construction. Civil engineering mentor Mike designed the concrete mix used for the tank and directed community members during the first pour.

All of the materials were sourced from within Morocco, except for the snap ties and snap tie wedges which were sourced in the United States and brought to Morocco through the team's collective checked luggage.

Next, the exact dimensions of the tank were marked on the concrete slab that sits underneath the tank using a marker, for the purpose of helping to ensure proper alignment of wooden formwork and iron rebar. Then, holes were drilled 22" apart, center to center, and vertical iron rebar placed into those holes. Horizontal iron rebar was also placed on the outside of the vertical rebar to create a grid-like pattern in a way that still allowed for entry in and out. In addition, a red water seal was glued to the concrete slab where the concrete would eventually be poured.

Figure 8. Left: Rebar cage. Right: Close-up of formwork being assembled around rebar.

After the rebar for the walls was secured in place, the wooden frames for the lower half of the walls of the tank were constructed. These frames included a large piece of plywood facing the area where the concrete would eventually be poured, as well as studs placed on their strong axis attached to the plywood for support. These studs were constructed from wooden pieces measuring 40 cm x 80 cm. After the frames secured and the corners attached, the snap ties were secured in place, with their precise locations measured out beforehand, and drilled to create a hole for them. Next the wales were constructed along the snap ties on their strong axis to provide additional support for the frames, and finally the snap tie wedges were drilled into place. During the process, the proper pipes—inflow, outflow, overflow, etc.—were also installed into the formwork.

Once the wooden formwork for the tank was constructed, the lower half of the concrete tank was poured, and vibrated throughout. The concrete was hydrated with water for the next four days, with blankets covering the concrete in an effort to minimize water loss from the wind. The same exact process—wooden frames, then snap ties, then wales, then snap tie wedges, with water seal—was repeated for the upper half of the walls. However, the formwork for the lid was also secured before the upper half of the walls were poured in an effort to make the upper walls and the lid one continuous pour. For the lid, first the rafters were secured in place. Then the plywood that sits on top of the rafters onto which the concrete would be poured was attached in such a way that the entire formwork could be disassembled entirely from the inside of the tank. In addition, the location and size of the two manholes were mapped out, and the wooden formwork for those manholes constructed. Next, the iron rebar cage for the lid was put into place.

Figure 9. Top left: Justin assembling formwork on the table we built, which was extremely useful. Top right: Mike and community members shoveling concrete from the

mixer during the first pour. Bottom left: Rachel vibrating concrete during the first pour. Bottom right: The completed formwork.

At this point, we were ready to pour the upper walls and the lid in one continuous pour. After the pour, the concrete was again watered and covered with blankets for four days. After the concrete had been given enough time to solidify, the wooden forms for the concrete were disassembled, both inside and outside, and the snap ties were snapped off. The inside of both chambers of the tank were swept with a broom and dust pan, and a water sealant was applied to the edges of where the walls met the concrete slab.

Figure 10. This picture shows the completed tank. The stairs in front of the tank were built to use during the construction.

2.1.4. Solar Pumping System

Construction on the solar panel structure began on August 20th. Justin led the construction of the formwork for the concrete base to hold down the solar rack and the rest of the team assisted as they were available. Meanwhile, John led the construction of the metal structure with assistance mainly from Anwar, Zineb, Meriem and Alice. On Thursday, August 22nd, John and Anwar made a trip to Marrakech to purchase a metal drill to drill holes in for the bolts, so construction paused for one day. The team worked through the weekend of August 24th to 25th. The concrete footing was poured on Wednesday, August 28th. From August 29th to 30th, the c channels for the metal structure were bolted down while simultaneously installing and bolting down the solar panels.

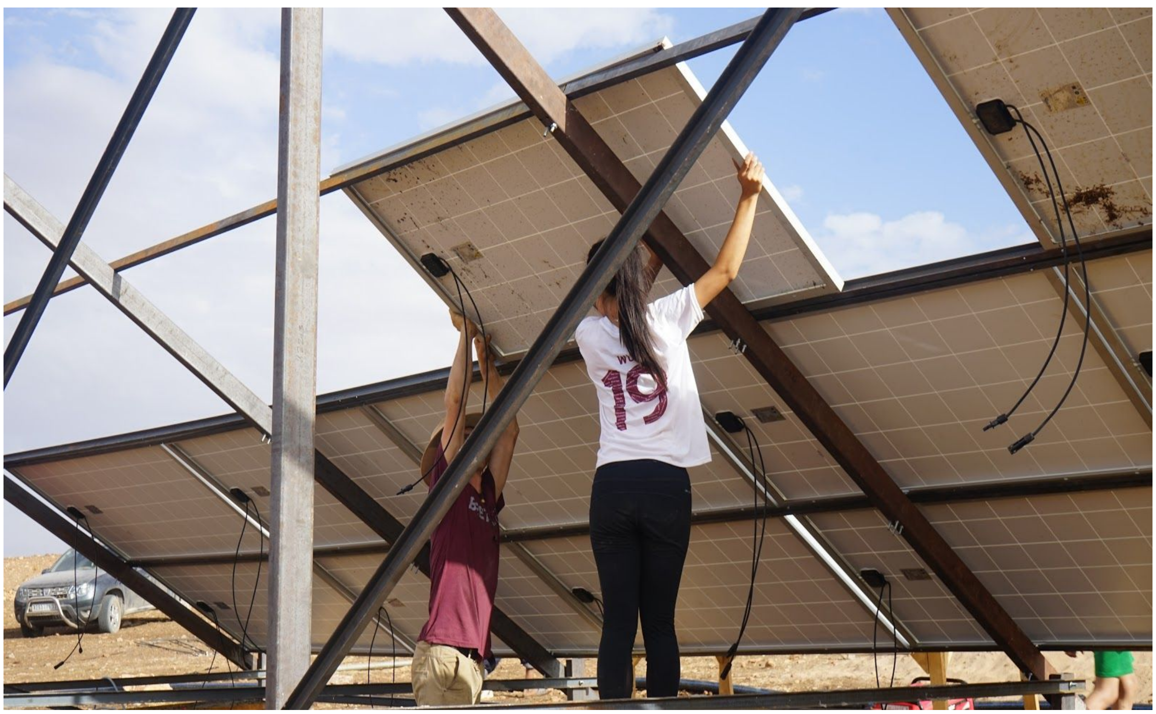

Figure 11. Picture of the process of installing solar panels. Solar panels and c channels were installed simultaneously from the bottom to the top of the solar rack. The top c channel had to be lifted in order for each solar panel to slot into place between the two c channels. Then, once the solar panels are in place, the top c channel would be bolted down and the solar panels would be bolted to the c channels at the four corners.

On August 29th, the grounding rod was buried and the electrical box for the circuit breaker was bolted to the solar panel structure. On the final day of construction, August 30th, John installed the inverter on the wall of the electrical room, and Alice wired the solar pumping system, set the settings for the inverter, and turned the system on for the first time. It took approximately three hours for the water to be pumped up to the storage tank. Additionally, on August 30th, steel plates were used to seal the holes in the well cap.

2.2. Outstanding Construction Tasks and Completion Schedule

2.2.1 Tap stands

Due to time and budget constraint, we decided to limit the scope of implementation to Ilguilouda, so the tap stands at Izgouaren were not constructed. These tap stands, along with all other construction to and in Izgouaren, will happen next summer. In the meantime, some construction regarding sanitation and ensuring a lack of standing water will occur through instructions for the community. This will occur gradually from now until our next implementation trip, and will be finalized in-country next summer. If possible, we want to have community members assemble drainage rocks around the slabs as was intended in our implementation, in order to have somewhere for standing water to flow without pooling onto the ground.

Additional construction tasks remaining are the installation of a flow-managing ball valve after the second Ilguilouda tap stand to allow for adequate water diversion from the storage tank and prevent water flow from favoring Izgouaren. We also plan to install a valve box around this next summer.

Finally, since the second tap stand was put in place by members of the community, the pipes at the tap stand were not buried. This is an issue since burial was to be our primary method of protecting these GI pipes. When we travel to the project site next summer, we will assess the situation surrounding this section of pipe and look into the potential of still burying parts of it, or other methods of protection.

2.2.2 Tanks

Due to leaks at the bottom of the storage tank caused by honeycombing, after the team left, the community poured a new layer of concrete on the floor of the tank to cover the leaks.

A second storage tank and a break pressure tank will be constructed to hold additional storage capacity for the residents of Izgouaren. The exact size, location, and structural design of the tank have not yet been determined.

2.2.3 Pipeline

Testing of the flow rate coming out of the tap stands was not achieved. On the last possible day of implementation, we saw the water successfully reach the village. However, the reinforced concrete tank leaked at the seam that connected to the ground. As a result, we were unable to test how the water would flow in the gravity portion of the pipeline. The locals have since then fixed the leaks in the tank and water is successfully gravity fed to both tap stands. Optimization of flow due to bumps in the pipeline path needs to be done. In other words, it is hard to say how much the locals have smoothed out the path. When we left, only 500 meters was made smooth. Bumps will cause lack of full flow to the tap stands. Air release valves and drain valves were also not installed in the main pipeline. The prior could possibly increase flow and the latter would prevent a decrease in flow over time. These will need to be installed in the next trip. The valves were not installed due to lack of compression tees which needed to be sourced out of Marrakech. Local compression fittings exist however the quality is dubious. Furthermore, there was not enough time to install these valves even if we had them. All minor components for these valves were purchased and are held by the community. The locals are now skilled in many aspects of leak-free pipe installation. After the team left, the locals installed a check valve for the main pipeline at a location specified after the branch to the distribution tank for the community around the well site.

A future expansion of the pipeline, approximately 1.9 kilometers, will be completed next summer, expanding a clean and sustainable water supply to the last village of Izgouaren. All the pipe coils are there, however, 100 meters of 63mm PE100 is being used by the well site community. Future team will need to replace that section with 20mm PE100 and repurpose the 63mm for the gravity fed pipeline. The 63mm PE100 was placed there to avoid conflict with the land owner of the well site, Mohamed. He saw the distribution of pipes unfair and wanted a larger pipe for his community around the well site. Physically, this makes no sense because his pipeline is part of the pumped section. However, due to limited time and a desire to avoid engaging with Mohamed’s aggressive behavior, we decided to install the pipe there.

The community around the well site plans to build a concrete tank to replace the temporary plastic tank that was installed. Once that is constructed, a float valve will be installed on a future trip. The implementation trip next summer will also need to ensure that Mohamed, the owner of the land in which the well is located, does not direct the pipeline toward his crops nor disconnect the rest of the pipeline towards Ilguilouda, causing unequal distribution of water. Keys to valve boxes were given to community leaders: Mohamed, Omar, and one held in place for a leader in Izgouaren. It is our hope that these keys serve as a source of checks and balances. The community agreed to form a new water association in order to govern the system.

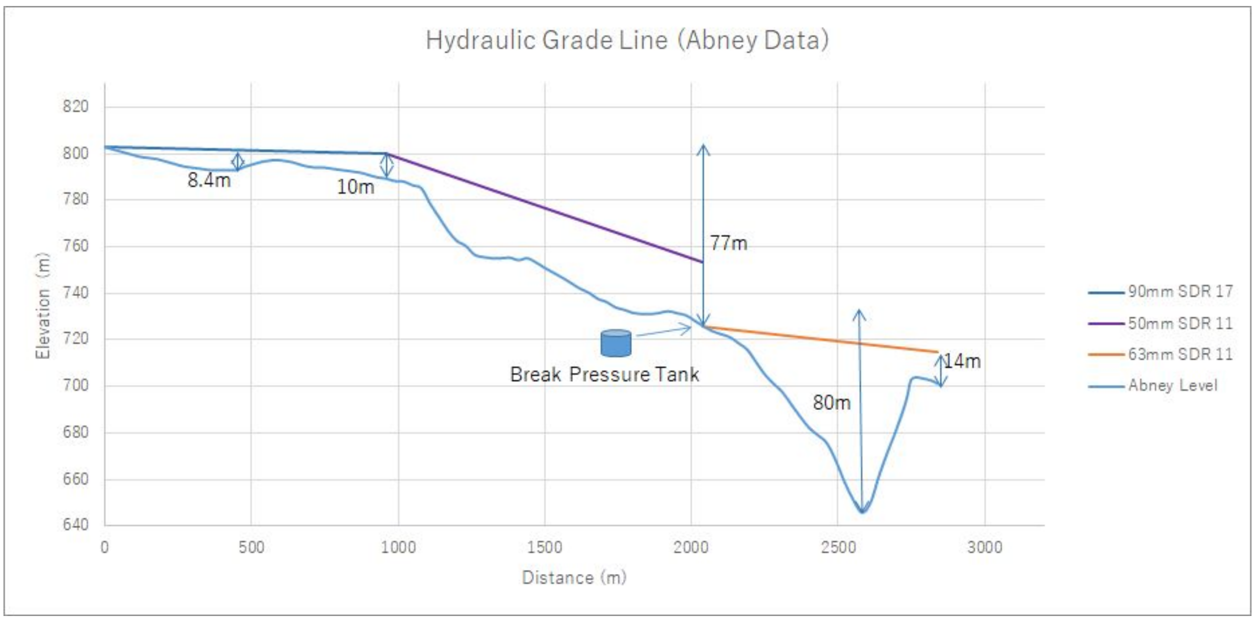

Figure 12. Updated hydraulic gradeline. See Attachment J for calculations.

2.2.4. Solar Pumping System

A water meter and a pressure meter will be installed at the pump outlet next summer. A land easement agreement for the solar panel structure also needs to be signed with Mohamed, who owns the land that the well site is on. Lastly, 36 total hours of pumping the well did not improve the turbidity of the well water, so the team plans to surge the well next summer, since there was insufficient time and funds to do so this summer.

2.3. Difference between Planned and Actual Construction

2.3.1 Scale of Trip

Due to limited funding and time--since sourcing took significantly longer than expected-- the team decided to focus on completing the system for Ilguilouda during this trip. As a result, the pipeline was only laid from the well site to the storage tank and Ilguilouda; distribution sites were only installed for Ilguilouda and the community around the well site; and the storage tank was downsized to 38,000 L.

2.3.2 Pipeline

Google Earth data was used to design the entire hydraulics of the pipeline. A comparison of the chosen route in Google Earth and the actual laid route is shown below.

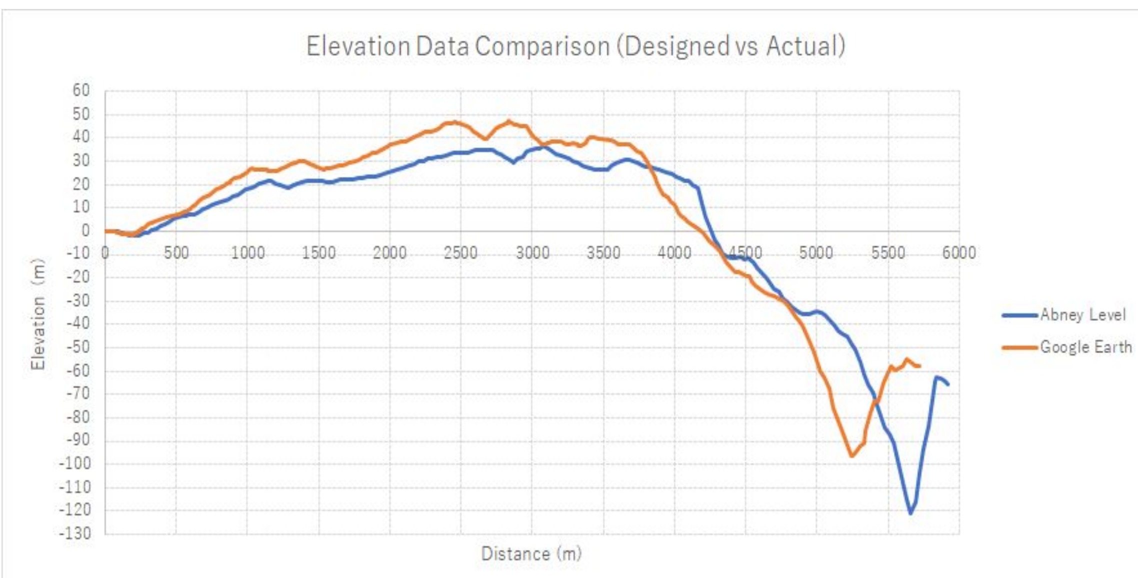

Figure 12. Comparison of elevation data from Google Earth and collected in-country.

The primary difference is the route surveyed by the Abney level was longer by 200 meters. The discrepancy is because routes selected on Google Earth crossed fields of hard rock. It was decided that it would be more effective to focus efforts on expanding the existing road, albeit a longer route. The existing road was created by backfilling over the rocks in the area with sand, creating a smooth surface. We had the backhoe simply expand the shoulder to accommodate the pipeline. By following the shoulder for the entire length, our pipeline increased by 200 meters. Raw data can be found in Attachment I.

Another interesting note is that upon reaching the Chateau, the elevation is ten meters lower than what we predicted in Google Earth. To be conservative, we can take the Google Earth as a designing parameter.

The gravity fed portion begins at the Chateau site. Therefore, to see if the gravity system differed from Google Earth, we align the starting points, accounting for a 200 meter difference and elevation). The discrepancy between Google Earth and as measured topographic survey done by an Abney hand level was negligible. An overlay of Google Earth with Abney data for the gravity portion is shown here:

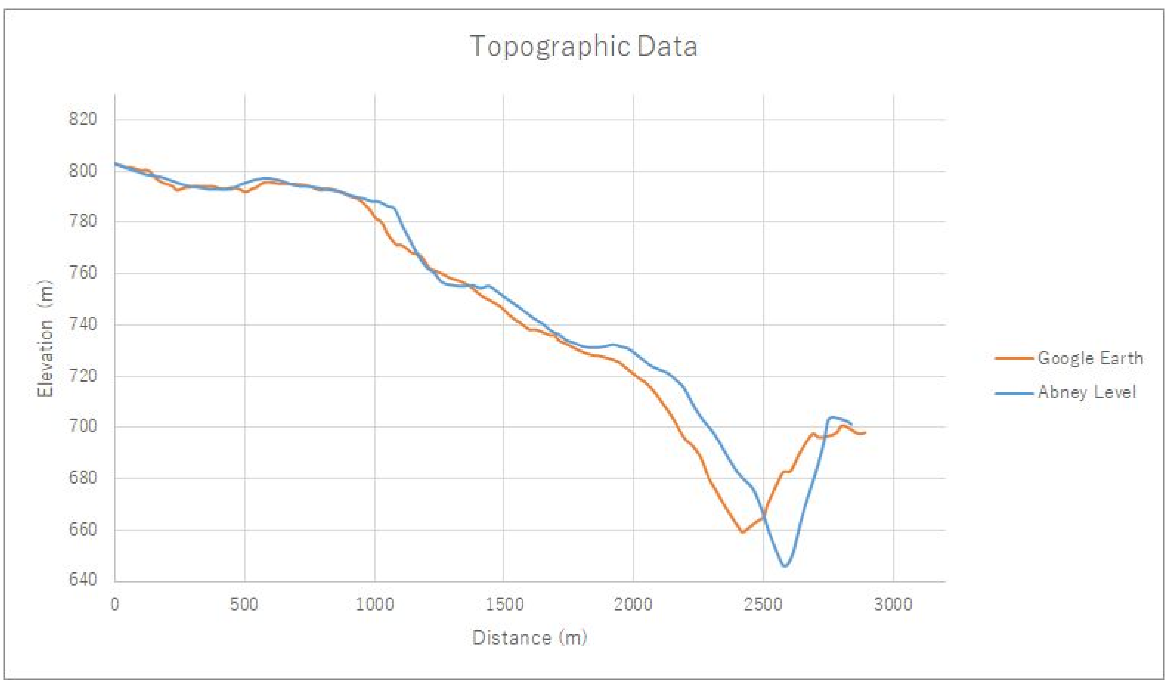

Figure 13. Zooming in on elevation data from chateau to Izgouaren.

The difference lies in about a 13 meter difference. Because the break pressure tank is located exactly where it needs to be after a pipe derating of 0.5, burial of the pipe at the bottom of the valley is essential; anywhere above 13 meters from lowest elevation point. The slight difference in the distance is because the exact route walked did not align with the planned route.

The plan was to create an on-grade pipeline. An unexpected feature was that a backhoe could dig in this region, breaking up large amounts of rock. A JCB backhoe can break through rock albeit slowly. A larger, more powerful unit backhoe could be used to adequately dig a trench. The alternatives are a hoe ram, which is expensive, and a rocksaw, which is even more expensive. In country, a hoe ram costs upwards of $360/day while a rocksaw costs $5 per meter. We tried digging but lack of supervision resulted in bumps in the pipeline route. The backhoe simply could not dig through certain rocks, possibly shale rock, and at one point even broke down. Our attempt to dig a trench was not successful. However for about 400 meters of the pipeline path between the well and Chateau, there are two sections that feature a clean trench of 0.7 meters depth and 0.4 meters wide. Those trenches were kept, and the rest of the pipeline was filled in and kept above grade on a smooth surface. We also tried building rock walls but in the end, the best solution was simply creating earthen berms which the locals will work on while the team is gone.

2.3.3 Storage Tank

The tank was shortened to include only two chambers instead of three. However, all structural elements remained the same, so no revisions were necessary in the design calculations of the tank.

2.3.4 Tap stands

The overall design of the tap stands remained similar to that described in the Implementation Pre-Trip Report, however, a few changes were made in-country.

First, the original design had more elbows and overall pipe. While there was nothing wrong with this design in terms of head, it would have required significantly more excavation. As we resolved to bury the pipe at the tap stand sites, this excess excavation would have been a heavy drain on time. As a result, the overall pipe structure was altered to have fewer tees and elbows. Additionally, our in-country piping mentor made suggestions to reduce the number of valves used in our design. Instead of having a ball valve for each individual tap, we are simply having a gate valve at each tap, coupled with a check valve to prevent backflow. Detailed diagrams are in Attachment A.

Also, the locations we selected on Google Earth ended up proving ineffective for the community, so they were altered. New locations are shown in Attachment A. Since we ran out of time to physically pour the second slab in-country, the community ultimately moved the location of the second tap stand to a different location than discussed at a higher elevation. This location has less head, and the pressure is at most 1 bar. While it is not something we would have advised and may result in reduced water pressure at the taps, there have been no issues with water collection as of October 2019. Additionally, since the concrete slab has been poured there is little we can do, other than informing the community.

The ball valves were also moved from the branch to the tap stands, to directly after the tee was made, as our conceptualization of their purchase was incorrect and rectified by our in-country mentor. Instead of our belief that we needed to limit flow going to the branches, we realized that hydraulic head favors lower elevations with more potential energy, and so we needed to place the ball valves directly after the tee to prevent water from skipping over the Ilguilouda tap stands that existed at higher elevations.

Other minor changes that were made include the fact that, in-country, not all supplies ended up being GI due to limited stores being open due to Eid on some of our sourcing days. We have certain fittings and fixtures that were cast iron or brass. Cast iron components were primarily elbows and reducers, and brass components included the GI Union, some reducers, and faucets. There is little difference that this change in materials makes.

2.3.5 Solar Pumping System

Instead of replacing the existing pump with a Lorentz solar pump, the team decided to work with the existing pump and only install a solar inverter. Unlike the solar pump we chose, which can operate at up to 9 kW of power, the existing pump only uses 3 kW of power, so the solar panel array was downsized to 5.4 kW, or twenty 270 W panels. With the smaller solar array, a smaller solar panel structure needed to be built, so the width of the structure was decreased from the original design, though the other dimensions remained the same. Additionally, due to experiences during the trip with unreliable hired skilled workers, the team decided not to weld the c channels to the rectangular beams and instead bolted them through the rectangular beams. The team determined that the bolting system was complex enough that an additional locking mechanism would not be necessary, since there is no way for the solar panels to slide out without disassembling the entire rack.

2.4. Issues Encountered During Construction and Mitigation

2.4.1 Pipeline

We encountered many different types of fusion failures while doing 40 fusion joints. Improper heat contact of the heating plate with the squared pipe walls will lead to improper fusion. This error was spotted by a local. Dust was an issue during the fusion process, especially in the mornings when there were strong winds. We created a makeshift tent from a tarp, however, the wind ended up rushing from underneath the pipe where there was no air-tight seal of the tarp and pipe to the ground. Our solution was just cleaning the pipe walls extremely well, making sure there was no lint or dust during fusion.

A smooth flat surface to lay the pipe on was another challenge. Originally we dug a three kilometer trench from the well site to the Chateau. Despite areas where the trench was consistently flat for 200 meters, there would be localized areas where massive bedrock made it impossible to excavate or dig. These localized bumps would cause air entrapment within the pipeline and reduce flow significantly. Following the advice of our mentor, Rob Lawrence, we hired the same backhoe operator to smooth out the trench. The result was a smooth, one meter wide surface, perfect for the pipe to lay on.

One issue that may be causing the lack of full designed flow is the pipeline route from the Chateau to the tap stands within the village. There were visible bumps that would cause air entrapment in the gravity pipeline. Approximately 500 meters was smoothed out before leaving, however there remains areas with bumps. A completely smooth path is needed for full flow. This issue falls into the on-going work that the community needs to do. This issue of possible lack of full flow may be exacerbated by the lack of air release valves or drain valves along the main pipeline. We will need to check in with the community and have them conduct a flow rate test at the tap stands to assess the extent of the possible problem.

Another small issue was leaking of compression fittings. Proper installation of compression joints can be quite difficult. It is suggested that implementers are cognizant of proper joint installation prior to traveling. It is not recommended to rely on local knowledge here. Implementers need to be the expert here. Tightening can also be difficult without the right tools.

A large enough chain wrench is needed. Unfortunately, we had to make do with the power of four hands to tighten or large pipe wrenches that had trouble gripping the fittings.

Supervision of any machine excavators is needed to ensure quality. The pipeline installation was carried out by one team member the entire time. Because all labor had to be shifted to the concrete tank construction, the solution was to be accompanied by one translator and work extensively with locals. This result was effective at knowledge transfer, however, it also means the team member cannot be in two places at once. One example of this is the difficulty of multi-tasking. Topographic surveying cannot be done at the same time that excavators are operating. This led to bumps existing in the dug trench.

2.4.2 Storage Tank

First, it was hard to find the materials for the project, because not every store sold everything we were looking for. Additionally, sometimes they sold the materials in different dimensions than we had designed for. Furthermore, transporting the materials to the site was difficult because of the volume/weight of the materials we were ordering. The companies were reluctant to deliver the materials onsite because it would require driving down an extremely rocky road that would likely damage a vehicle that drives down it. The wood that was bought was not cut well—lots of the pieces were warped, which made constructing the wooden formwork more difficult. Another limitation for the wood formwork was that we did not have access to a miter saw during construction. Other challenges encountered were that the slab on which the tank was constructed was not level and also did not have a smooth surface. Furthermore, maintaining the correct geometries of the formwork and keeping the forms perfectly vertical and rectilinear was difficult because of the strong winds that blew throughout the day.

2.4.3 Solar Pumping System

In constructing the metal solar rack, the team realized during the early part of its construction that the drill and drill bits that we had were not strong enough to drill through the steel we had, and thus could not drill the holes we needed in order to fasten the structure with nuts and bolts. As a result, we returned to Marrakech to purchase a new drill and drill bits designed for drilling through steel; these new tools proved much more effective in accomplishing the task required.

2.4.4 Tap stands

The tap stands portion of implementation fell victim to a lot of delays due to limited labor, with most labor going towards the reinforced concrete tank. Additionally, Leanne, the tap stands lead had to leave due to a family medical emergency taking place during the trip. The combination of these things meant that there wasn't time to finish the second tap stand. However, recognizing that this would likely take place through the course of construction, we made extensive measures to make sure the community had been included enough so as to be able to tie up our loose ends by finishing pouring the slabs and setting up the second tap stand. This proved successful, as the community was able to pour the second slab and place the pipes in place.

However, issues did arise as a result of relying on the community to complete labor on their own. On of these issues is the moving of the second tap stand to a location with less head, resulting in a reduction of pressure. Given that water is still running to this location, the negative results of this are not too profound, however when in country next we can do more extensive testing of this to see if more intervention is necessary.

Another issue that came about due to us not being able to adequately finish the tap stands was that we were not there to ensure that the slab poured at the second site is graded, and as a result we may need to take extensive measures at our next trip to ensure that there's no issues with standing water. This leads into an additionally overarching issue in that we didn't have enough time to create uniform sanitation standards, and ensure that runoff is going through correct drainage. To mitigate this, we are remaining in close contact with the community to ensure that we begin laying measures even while we are not in country, before finally creating a uniform code in country. These measures include keeping r a radius around the tap stand free of animal waste, as well as ensuring standing water isn't left to sit there. We are also currently in talks with the community about adding drainage rocks around the slab, and entering a more formal discussion with them about the risks raised by standing water. The second location is also not as good for runoff as the location we had intended, so we are entertaining alternatives such as planting a tree to soak up runoff.

2.5. Materials Used Description

2.5.1 Pipeline

The pipeline remained almost identical to our initial design. Prior to implementation, we accounted for all types of connections that we could possibly encounter: threaded, flanged, fusion, and compression. One notable difference is using compression fittings rather than fusion fittings. Fusion fittings were purchased, however the stems did not fit into our butt fusion machine. We used 90 degree compression tees for all branches. Compression was used anytime we needed to transition to a valve or GI. For example, the donated 90mm check valve we used on the main line required compression fitting. Additionally, the check valve required the use of PVC and PVC glue. There was no effect on the functionality of the pipeline. All valve manuals and specifications can be found in Attachment D.

2.5.2 Storage Tank

The storage tank was constructed with concrete, iron rebar, and wood. The wood was used to build the formwork into which the concrete was poured. The iron rebar was secured inside the concrete for reinforcement. The forms were constructed using a variety of different drills (DeWalt and Milwaukee), a reciprocating saw (Ryobi), a circular saw (Ryobi), and occasionally an angle grinder with a wooden blade (Bosch). The materials used for the tank were the same materials that we anticipated using for the construction of the tank.

2.5.3 Solar Pumping System

The solar rack was constructed with concrete, steel, and wood. The wood was used to build the formwork for the concrete. The concrete was used to cast a foundation into the bottom of the steel part of the structure, serving as a weight to counteract the heavy winds that could topple the solar rack over.

Instead of installing a new solar pump and pump controller, the team decided to keep the existing Lowara pump and instead purchase a 4 kW INVT solar pump inverter to power the pump with the solar panels. This decision was made because the team found from talking to local suppliers that Lorentz solar pumps are not commonly in the region and need to be special ordered by suppliers in Essaouira, which is over an hour away. This would make it more difficult for the community to find someone to maintain and eventually replace the pump when it breaks down in about twenty-five years. Thus, we decided that using the standard system of an AC pump with a solar inverter would be easier to replace and more sustainable for the community. This change means that if the community ever wants to increase their water supply, they will need to purchase a higher power pump and inverter and additional solar panels; whereas with the Lorentz solar pump that could operate at up to

9 kW, the community could simply install additional solar panels to increase the output flow rate.

2.5.4 Tap stands

For the most part, the materials used and construction methods put in place were representative of those outlined in the Implementation Pre-Trip Report. The tap stands used 20mm Galvanized steel pipe, with various valves and fittings. The pipes were threaded, and joined with the use of pipe wrenches. In country, we made the addition of using hemp thread to better the water seal on these threaded joints.

One change made with materials was that some fittings ended up being cast iron instead of galvanized iron, due to construction timeline requiring we buy some fittings during the week of Eid, when many stores were closed. The changes made were cast iron elbows and tees, and brass unions and faucets. This has little effect, as the cast iron fittings are very small and were in good condition when purchased, which suggests it will not cause any large issues regarding rust etc. until normal wear occurs on the tap stands as a whole.

Concrete pours were done as expected, with no changes proving necessary in country.

3. Testing Results

3.1. Materials Testing

A hydrostatic pump borrowed from a shop in Marrakech was used to test the performance of hemp thread versus PTFE tape. We performed this test on one of the tap stands we constructed. We discovered that hemp thread provides a consistently leak-proof seal that swells upon expansion of water. Our test ended at six bars of hydrostatic pressure which was the point in which PTFE leaked extensively. For all threaded steel connection, hemp thread should be utilized. Hemp can be purchased in all local hardware stores.

3.2. System Performance Data

The flow rate directly at the pump outlet without the main pipeline connected was on average 1.48 L/s. The flow rate was measured at 1.41 L/s coming out of the pipeline end at Ilguilouda. A simple stopwatch and bucket was used for these measurements, with an uncertainty of about 0.3 L/s. The flow rate matched our predicted and designed flow of 1.4 L/s.

3.3. Additional Technical Data Gathered.

A topographic survey of the entire pipeline route was conducted using an abney level. Raw data for this survey is included in Attachment I. This data includes routes to the various possible tap stand locations we considered.

The water level in the well was measured to be 168 ft or 51 m below ground level, which is consistent with previous measurements of 50-60 m. Well development was conducted by pumping continuously at a slightly faster rate than normal operation. The turbidity of the well water was measured throughout well development. Well development did not seem to improve the turbidity, which never went below 300 NTU, except at the very beginning of development. The raw data is included in attachment C. The team observed a brown sediment in the water, which smelled metallic, settled quickly, and was likely rust from the drop pipe. An oily sheen was noticed on top of 5 L samples of well water, suggesting the presence of iron bacteria. When the rust cleared up, the sediment was predominantly white with a yellow tinge. The team believes that the sediment contains calcium carbonate, which is common in Moroccan soil profiles; calcisol, a fine white soil native to Morocco; and perhaps some sulfur compound to explain the light yellow sediment and the light smell of sulfur. The yellow sediment was noted to settle faster than the white sediment.

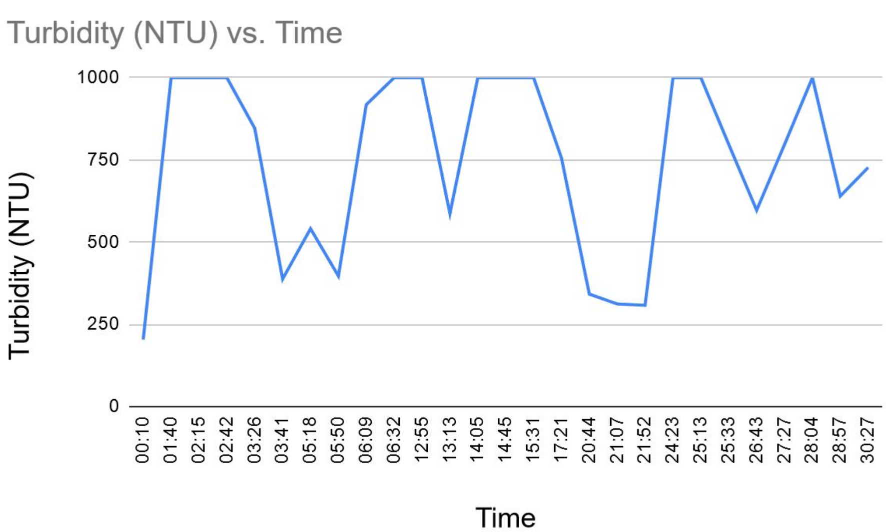

Figure 14. Plot of the turbidity measurements over the span of well development time. The turbidity meter was able to measure a maximum of 1000 NTU.

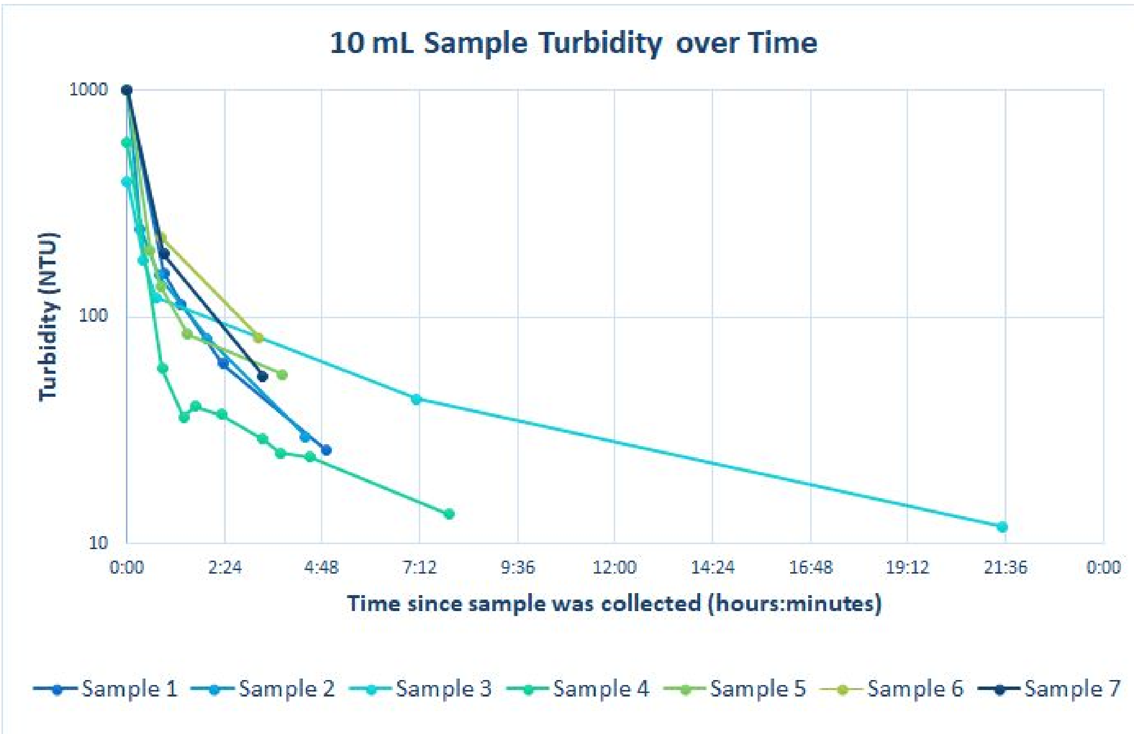

Figure 15. Plot of turbidity measurements of samples as they settled. The maximum turbidity measurable was 1000 NTU, which is why a lot of the samples start at 1000 NTU.

Turbidity measurements over the course of settling for many samples are recorded in attachment C and shown in Figure 15. It took three days of settling for the turbidity to reach 5 NTU, which is the World Health Organization's limit on acceptable turbidity of drinking water.

A water sample was brought back by the team for further analysis. The pHof the water was measured to be 7.79, and the dissolved air was measured to be 72% of the value at standard temperature and pressure, which translates to approximately 6.22 mg/L. Ion chromatography tests are currently being conducted and the team will also test for lead, arsenic, iron, nickel, and zinc in the water.

4. Construction Budget

4.1. Final Material Quantity

Tank		
Name	Dimensions	Quantity
Hilti Epoxy for anchors	.5 L Cartridges	20
20mm rebar for vertical dowels in walls	2650mm	75
16mm rebar for roof	4100mm	15
16mm rebar for roof	4900mm	11
12mm rebar for horizontal reinforcement in walls	5500mm	40
12mm L-bars for splicing wall and roof rebar	1000mm	75
M20 Concrete	1 cubic meter	11.1
6mm thick steel plates for lids	600mm x 600mm	2
15mm thick OSB Sheeting	12500mm x 2500mm	30
4-meter long boards	175mm x 40mm	25
4-meter long boards	87mm x 40mm	125
Steel angle ties	80mm x 10mm	1000
Long LAMO screws	60mm	600
Screws	30mm	3000
Short Screws	15mm	1000
Snapties	6 inch with long ends	100
Snaptie wedges	-	200
Rack		
Name	Dimensions	Quantity
6mm thick rectangular tubing	100mm x 50mm x 6000mm	9

6mm thick C shaped tubing	50mm x 25mm x 6000mm	24
12mm thick threaded rod	1000mm	5
10mm thick threaded rod	1000mm	5
8mm thick threaded rod	1000mm	5
hex nuts	12mm	50
hex nuts	10mm	50
hex nuts	8mm	50
hex nuts	5mm	80
5mm thick bolts	10mm	80
Concrete	Cubic meter	2
20 mm rebar reinforcing back base wall	5.5 m pieces	4
16mm rebar reinforcing base legs	3800mm pieces	8

The electronic components of the solar pumping system consisted of twenty 270 W solar panels, a solar inverter, a circuit breaker, and 40 m of 6 mm^2 two-wire cables.The solar inverter was used for solar power instead of replacing the existing pump with a new solar pump and pump controller.

TAP STANDS			
Item	**Length (mm)**	**Diameter (mm)**	**Quantity**
GI Pipe	100	20	4
	400	20	1
	500	63	2
	500	20	1
	1000	20	1

	1100	20	4
	1500	20	2
PVC	1100	90	4
Tees		20-20-20	3
Elbows		20-20	10
Union		20	5
Faucet		20	5
Gate Valves		20	4
Check Valves		20	3
Valve Box			3

PIPELINE		
Pipe	**Diameter (mm)**	**Length (m)**
SDR 11 HDPE	90	3051
	63	70
	20	30
SDR 17 HDPE	90	933
Fittings	**Diameter (mm)**	**Quantity**
Tee	90	3
Reducer	90 to 63	4

Reducer	63 to 20	1
Check Valve	90	1
Compression to male threaded	63	1
Compression to male threaded	20	2
Compression to female threaded	63	2

4.2. Final Cost Estimate Summary

Total project costs, excluding travel expenses, totaled to $27,000, which is approximately half the estimated cost of $50,000, since the community volunteered most of the labor and the scale of implementation was limited to Ilguilouda for this trip.

$12,000 were spent on the concrete storage tank, which is $2,000 less than the $14,000 predicted for the tank. The size of the tank constructed was half the size of the original design. The cost of renting the concrete mixer and purchasing wood and concrete components was more expensive than expected though.

$4,000 was spent on the pipeline, which is $1,000 more than estimated. Pipe transportation and pipe fitting were cheaper than expected, but $2,000 was spent on having a hoe ram clear the pipeline path of rocks.

$1,000 was spent on well testing and development, which is $2,500 cheaper than estimated because the team chose not to hire a contractor to surge the well. The well sounder and turbidity meter were rented instead of purchased. The money saved was spent on renting a generator, which was more expensive than estimated.

$6,000 was spent on the solar pumping system, which is $8,500 cheaper than the original estimate because the team decided not to purchase a new solar pump and pump controller. As a result, only twenty panels were purchased instead of forty. Additionally, the team installed everything themselves, so no installation fee was paid.

$400 was spent on the tap stands. The GI pipes and valves were significantly cheaper than expected and only two tap stands were built instead of four.

Lastly, $3,000 was spent on miscellaneous costs, which included translator salaries and gas for the generators used in the construction of the tank, the solar panel rack, and the pipeline. Translator salaries were cheaper than originally estimated because the team found translators through our own contacts instead of going through the High Atlas Foundation.

5. Changes to Operations and Maintenance Plan

5.1. Description of Revisions to O&M Plan

For the chlorination of the storage tank, the use of household bleach (5-8% chlorine) was recommended instead of chlorine tablets because it is more easily available in stores near the community. 38 L of household bleach total should be added to a full tank and allowed to sit for 12 hours before draining the water through the tap stands.

5.2. Trainings Completed

Fusion training was done for most of the men of Ilguilouda Hydrostatic test procedure was demonstrated to four elders within the community, one of which is the representative for Ilguilouda. Proper installation of compression fittings and GI threaded connections was demonstrated and practiced by ten men within the community including the representative for Ilguilouda and young men.

Hamid, one of the residents closest to the well site, and several other men from Ilguilouda were instructed on how to turn the solar pumping system on and off. Hamid will be in charge of turning the system on and off as needed for maintenance or other reasons.

6. Changes in the Community Based Organization CBO

6.1. Description of Revisions to CBO Structure

The name of the partnering community-based organization was the Ait Bayoud Water Association. This association was formed several years ago after initial implementation of the original galvanized steel pipeline and well drilling to be the local entity with legal jurisdiction over the operation and maintenance of the entire water distribution system. When the association was formed, it was seeded with $4,000 in local funding. However, due to lack of completion of the water distribution, the water association expired in the past year, and we are currently speaking with the community to discuss restarting it now that the water distribution system is almost partially ready for normal operations. We are also determining whether the association will have access to the previously seeded $4,000 in local funds. We have contacts, including the governor of the Bizdad region that Ait Bayoud is located in, who we can interface with. However, this specific legal structure must be supported by the local residents, and it is thus ultimately their prerogative to renew the water association, especially given that they will be the ones determining the association's purpose and exact functions.

While it legally existed, the water association consisted of local community members who had a significant stake in the pipeline, i.e: members who have system facilities located on or near their land (with appropriate land easement contracts negotiated), as well as leader figures in the villages. Under a new water association, many of these members would most likely return to serve, especially those who interfaced with the project travel team during the implementation trip as well as helped with construction.

In terms of community maintenance skills with the pipeline, many community members are well-versed in construction work and, during implementation trips, demonstrated their skill with important tasks such as mixing and pouring concrete and moving pipe. In addition, piping team lead Donal Swen and piping mentor Robert ensured that they prioritized transferring knowledge regarding butt fusion of PE pipe to members of the community, especially younger members who also happen to be students. So far, these members have proven to be reliable communicators over Whatsapp (allowing for overseas communication) and were themselves able to direct the butt fusion with progressively less and less guidance by Donald and Robert during the trip. Additionally, we were kindly donated butt fusion equipment by McElroy, consiting of a pipe clamping/joining apparatus and tools to heat the pipe to the required fusing temperatures. We left this equipment in the hands of trusted members of the community near the Chateau site. The community has thus been developing the technical skills and has the equipment needed to maintain the piping and concrete facilities which make up the bulk of the project. More work will need to be done in ensuring maintenance of the solar energy infrastructure at the well site, and the technical skills for infrastructure maintenance will continue to be reinforced and transferred to a variety of community members of different ages on subsequent trips.

6.2. Training completed

The team held a meeting on the final day of the trip with men from the three communities to instruct them on how the system was constructed to provide water for both the distribution tank at the well site and the tap stands in Ilguilouda and how the valves in the valve boxes control water flow. The team also strongly urged the community to establish a new water association to replace the one that expired, which the community agreed to. The community chose one representative from each of the three communities to be in charge of the valve boxes for the time being.

7. Baseline Monitoring Data Collection

We spoke with approximately 30 adults, both husbands and wives, from Ilguiloda and the compounds near the well site. We discovered roughly 137 people live in Ilguiloda year-round who would need to receive water, and an additional 15 people living near the well site. The village population is mostly elderly or the sons and daughters of the elderly with young children ages 0-13 with the exception of one 18-year-old, Omar (junior) who is the acting point of contact for the team in the community. The older sons have either gotten married and permanently moved away, or work in the cities—Casablanca, Marrakesh, Essaouira, etc.—and they return to Ilguiloda for holidays such as Eid al-Adha, which occurred during the implementation trip. The older daughters have gotten married and moved away or live in the village of Izgoran. We learned that Izgoran and Ilguiloda have strong community connections with many marriages between families. Ilguiloda community members' primary occupations are construction and agriculture. Omar (senior, unrelated to Omar junior) is the most trusted and reliable person in the village; almost everyone respects him. Additionally, his mother has lived in Ilguiloda for 70 years and her children, Omar's three siblings are all married with families and also live in Ilguiloda.

We originally thought perhaps the children gathering water was a factor in why so few attended schools, but most often it was the women and elderly men who retrieved water. The long distance and dangerous roads between Ilguiloda and the nearest schoolhouse in Izgouaren are the two main factors for why few male and none of the female children attend school, according to the locals.

Community members from Izgouaran were willing to help us lay pipe and build the tank because they have relatives in Ilguiloda and expect our team to return next summer to bring water to their village as well. Before building the water project, the villagers were walking to the douar of Limtuga, a two-hour roundtrip, to gather water during the summer months. There is a well outside the village that water can be drawn from but it runs dry for approximately three months each year during the summer. When Fadma Lhadi, an elderly woman, aged about 60-65, was asked how often she was able to bathe, she laughed and said there was barely enough water to drink, how could they bathe? And certainly not during the summer months. Many of the villagers have bed bugs, fleas, and/or lice so perhaps with easily accessible water their hygiene and overall health can improve.

While the villagers do not suffer from any critical diseases, almost every family has lost one or more children – most less than 2 years old. From what we could gather through our questionnaire, several infant deaths were attributed to breastfeeding while pregnant. Though none of the infant deaths pointed explicitly towards non-potable water related diseases, water testing for infectious bacteria will still be conducted next summer.

The villagers are willing and skilled laborers for construction projects and proved to be invested in the sustainability of the water distribution system. They can build sturdy rock walls and have proficient understanding of concrete and wood construction, since many of them have construction experience. Ultimately, the villagers were invaluable to implementing and completing the project because they know their land and how to take care of materials in the desert area.

There is on-going, familial tension between Mohamed and his 9 brother's—three live next door to him—his step-mother, and the villagers of Ilguiloda due to the well site being on his land. The team observed that Mohamed acts out of self-interest, angers easily when decisions are made not according to his wishes, and tends to become aggressive and physically intimidating during disputes. He started several altercations with our translators and the other villagers during the summer and even after the team left. While he has been hospitable to Jessica, the Peace Corps representatives we worked with from 2014-2018, as well as EWB members in the past, his brothers claim that Mohamed seeks to build trust with our implementation team in hopes of having tap stands placed on his property for his own use. The team is concerned about the portion of the pipeline that crosses Mohamed's land towards Ilguiloda, since he has the ability to cut the pipeline if he desires to. The team believes that a new Water Association must be formed by next summer such that it can act as a governing authority in enforcing the land easement agreement that was signed with Mohamed regarding the well site.

8. List of Attachments

Attachment A: As-Built Drawing Package

Attachment B: Final Budget

Attachment C: Materials Testing and System Performance Data

Attachment D: Product Manuals for installed equipment

Attachment E: Field Calculations for Solar Rack

Attachment F: Original Calculations for Storage Tank

Attachment G: Operations and Maintenance Plan

Attachment H: Photo log

Attachment I: Final Grading Profile

Attachment J: Final Hydraulics Calculations