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APPLICATIONS OF HDPE PIPING TO SUPPLY WATER TO RURAL VILLAGES IN MOROCCO

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SHORT SUMMARY

The Columbia University Engineers Without Borders Morocco team accepted a project to help 2 villages in rural Morocco facing water scarcity. In designing a gravity-fed water distribution system, high density polyethylene (HDPE) pipe was selected as the best solution for undertaking this project. In addition, HDPE pipe proved easy to work with and install, allowing a large construction process with the help of the community. On August 31, 2019, water was successfully delivered to the first of the two villages we worked with. HDPE serves as a simple yet effective solution for addressing water insecurity in rural areas.

KEYWORDS

HDPE, Water Distribution, Water Scarcity, Rural Villages, Morocco

ABSTRACT

In the rural commune of Ait Bayoud, Morocco, two of the most remote villages in the area, Ilguiloda and Izgouaren, live with water scarcity. To meet their water needs, women and children walk several kilometers to the nearest spring each day, often multiple times a day. Consequently, children cannot attend school consistently. In 2015, the Engineers without Borders Chapter of Columbia University was contacted by community members of these two villages, to initiate the design and construction of a sustainable water distribution system.

Due to large plates of hard igneous rock in the subgrade and extreme temperatures reaching over 35 °C in the summer, students installed 1.4 kilometers of 63mm Galvanized Iron (GI) pipe over the course of three years. However, the GI pipes leaked extensively and the project quickly became cost prohibitive. An alternative analysis was carried out and HDPE was chosen as the material of choice due to its monolithic joints, anti-corrosion properties, affordability, ease of construction and long design life. An on-grade pipeline was designed consisting of a three-kilometer pumped section with a volumetric flow rate of 1.4 L/s and a three-kilometer gravity fed section beginning with 2.5 L/s of flow. A hybrid of SDR 11 and 17 90mm, 63mm, and 50mm HDPE were used to manage water flow. SDR 11 was chosen for the sections that reached up to 7 bars of pressure, after a derating factor 0.5 at a maximal operating temperature of 60 °C which accounts for surface temperature of pipe.

Over the course of six weeks, ten students implemented a fully functional four-kilometer pipeline complete with a 38,000 L reinforced concrete tank, 5.4 kW solar pumping system, and four tap-stands. This system presently distributes water to 370 people with projected population growth up to 540 people. A second trip is planned for Summer 2020 to

complete the last two kilometers to the second village. Construction was done in close collaboration with the community, from uncoiling pipe to butt fusion. The community showed a promising understanding of many aspects of construction. HDPE serves as a simple yet effective solution for addressing water insecurity in rural areas.

INTRODUCTION

Water insecurity affects 785 million people, where these populations require 30 minutes or more to collect water from unprotected springs and wells or from untreated surface water from lakes, streams, and ponds[1]. Our work focuses on implementing a sustainable water distribution system for the communities using HDPE as the material of choice.

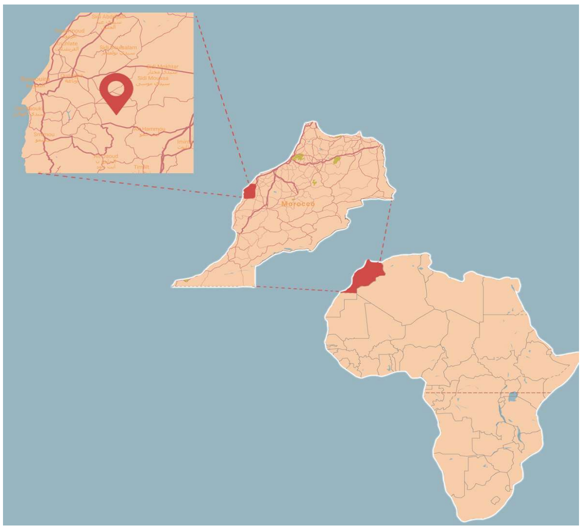

Figure 1: Map showcasing Izgouaren and Ilguiloda in relation to the continent of Africa and country of Morocco

Ilguiloda and Izgouaren are two of the poorest villages amongst a series of villages comprising the Ait Bayoud Commune of the Essaouira Province in Morocco facing severe water insecurity. Community members spend three to four hours per day to collect water from nearby unprotected springs and wells. Water scarcity is exacerbated during the summer months. As a result, throughout the year, women and children sacrifice economic and educational opportunity to obtain their most basic needs. To make matters worse, initial tests of the quality of current water sources indicated the presence of fecal coliform, posing an imminent health risk. Our goal is to co-design a reliable, safe, and sustaining water distribution system with the 370 community members that reside in this rural part of Morocco such that the community can experience a life free of water insecurity and are able to define a prosperous future for themselves.

The Ait Bayoud Water Project started in 2014 when Peace Corps Volunteer Nina Morency-Brassard stationed in Ait Bayoud, Morocco reached out to the Columbia University Chapter of Engineers without Borders (EWB) for assistance in developing a water distribution system. The same year, a partnership was established between Ait Bayoud Development Association, the Peace Corps, and the Columbia University Chapter of EWB. Early years oversaw the drilling of a 140 meter deep borewell with the permission of the official government representative of the community, Rais el Madi, installation of an electric pump with the construction of an electric room, pouring of a concrete foundation for a tank, and the on-grade laying of 1400 meters of two inch steel pipeline. In late 2015, student teams were unable to progress due to mounting costs and an unresolvable excessive leaking of the steel pipeline.

With renewed interests, the student team from 2018-2019 reached out to the HDPE industry for mentorship. Camille Rubeiz of the Plastics Pipe Institute presented an opportunity for the students to present this Water Project at the bi-annual HDPE Municipal Advisory Board (MAB) Meeting held in Tulsa, Oklahoma (MAB 21). The opportunity

[1] https://www.who.int/en/news-room/fact-sheets/detail/drinking-water

enabled three students to obtain butt-fusion and electrofusion training and experience with HDPE, establish industry connections, and onboard technical mentors.

From 2018 to early 2019, student teams designed and raised the money to implement the entire hydraulic system of the six-kilometer HDPE pipeline, a solar pumping system running off 20 solar panels framed on a steel rack, and a 38,000L reinforced concrete storage tank. Professional engineers in the HDPE industry and from Engineers without Borders verified all designs and reviewed all implementation plans. Implementation took six weeks, running from July 15 - August 31, 2019. Due to financial constraints in-country, the team decided to scale the system back, reaching until the first village which was four kilometers from the borewell. Water was successfully delivered on August 31st to the first village.

EXPERIMENTAL

DESIGN CONSTRAINTS

Figure 2: The extremely rocky terrain of Ait Bayoud

The landscape cannot be excavated and is characterized by extensive large plates of glassy igneous rocks embedded in the subgrade and surface (See Figure 2). The temperature extremes range from 25-45°C in the summer. There is no proper access road to the remote locations of these villages, that are only reachable by steep and poorly graded dirt roads.

In 2014, a community survey was conducted to determine water demands, livestock count, and population size. A 25 year exponential growth model[2] was applied to the current population of 370 to give a population design of 540. Our design needed to satisfy WHO standards[3] of 20 L/day per person, which provides minimum sanitation and domestic water needs. In addition, we considered the large livestock population which averaged 4.6 animals per individual since farming is the predominant occupation. We decided to provide 25 L/day per person as a basic water right that will cover domestic use and 52 L/day per capita to be used towards livestock or growing trees. Thus, our system design provides 77 L/day per capita, which surpasses the Sphere Standards that require a supply of more than 70 L/day per capita to satisfy all the needs for domestic water (drinking, cooking, growing food, sanitation/waste disposal). For comparison, we show the Sphere Standards recommendation of 90 L/day which includes water for future business and recreation in addition to that needed for domestic needs. The final design is summarized in Table 1.

[2] Jordan, T. D. (1984). *A handbook of gravity-flow water systems*.

[3] World Health Organization (WHO). (2004). Minimum water quantity needed for domestic uses. *WHO Regional Office for South-east Asia: New Dehli*.

	Design (25 Years)			Current			Overall
Model	Domestic Use (L/day)	Livestock Use (L/day)	Total Usage (L/day)	Domestic Use (L/day)	Livestock Use (L/day)	Total Usage (L/day)	L/day per capita
Base - minimum	10766.9	27968.5	38735.4	7400.0	19222.4	26622.4	72.0
Sphere Standards			48451.2			33300.0	90.0
Our System	13458.7	27968.5	41427.1	9250.0	18500.0	27750.0	77.0

Table 1: Summary of models used to determine the amount of water to supply

MATERIAL CHOICE

An alternative analysis was conducted and an on-grade[4] HDPE application was chosen after a careful review of risk, cost, and sustainability. The advantages of HDPE include availability of mechanical fittings in accordance to ISO 14236:2000 in the nearby cities of Marrakech and further, Casablanca; ease of installation with 100 meter coils versus two meter threaded steel pipes, ability to resist slow crack growth measured by PENT[5] hours, resistance to weathering[6], reduced maintenance, and monolithic leak proof joints. Consideration was taken to appropriately derate HDPE pipe for temperature and remove obtrusions in pipe path to eliminate point loading.

In addition, choosing HDPE allowed us to access a vast community of mentors and sponsors to check calculations, designs, and decisions. Using HDPE pipe on-grade allowed us to place a locally replaceable pipeline on the ground at the lowest cost and efficiently deliver water without leakage to our end users.

HYDRAULIC DESIGN

Prior to surveying the topography with an abney level, elevation data from Google Earth Pro (SRTM[7] at 1-arc spatial resolution) was used as the primary data source for designing the hydraulics of the pipeline (see Figure 3 for elevation data).

The pipeline stands at a total length of 5690m, and is divided into two parts: a 2830m pumped system (Figure 3a) leading into a 2860m gravity fed system (Figure 3b). Two tap stands at each village location Ilguiloda and Izgouaren were planned.

Our pipeline was designed using Hazen Williams equation and doubly checked with Darcy Weisbach, both of which reveal extremely similar head loss values. As a rule of thumb, we require 10m of head at every point of the pipeline to avoid vacuums or lack of

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[4] https://plasticpipe.org/pdf/chapter08.pdf
[5] https://plasticpipe.org/pdf/pe-100-pipe-the-precursor-to-pe4710.pdf
[6] Qureshi, F. S., et al. "Weather-induced degradation of plastic pipes." *Polymer-plastics technology and engineering* 28.7-8 (1989): 663-670.
[7] Farr, T.G., Rosen, P.A., Caro, E., Crippen, R., Duren, R., Hensley, S., Kobrick, M., Paller, M., Rodriguez, E., Roth, L., Seal, D., Shaffer, S., Shimada, J., Umland, J., Werner, M., Oskin, M., Burbank, D., and Alsdorf, D.E., 2007, The shuttle radar topography mission: Reviews of Geophysics, v. 45, no. 2, RG2004, at https://doi.org/10.1029/2005RG000183.

flow[8]. Once we know how much head we want at each point in the pipeline, we can choose pipes and respective lengths to satisfy head conditions.

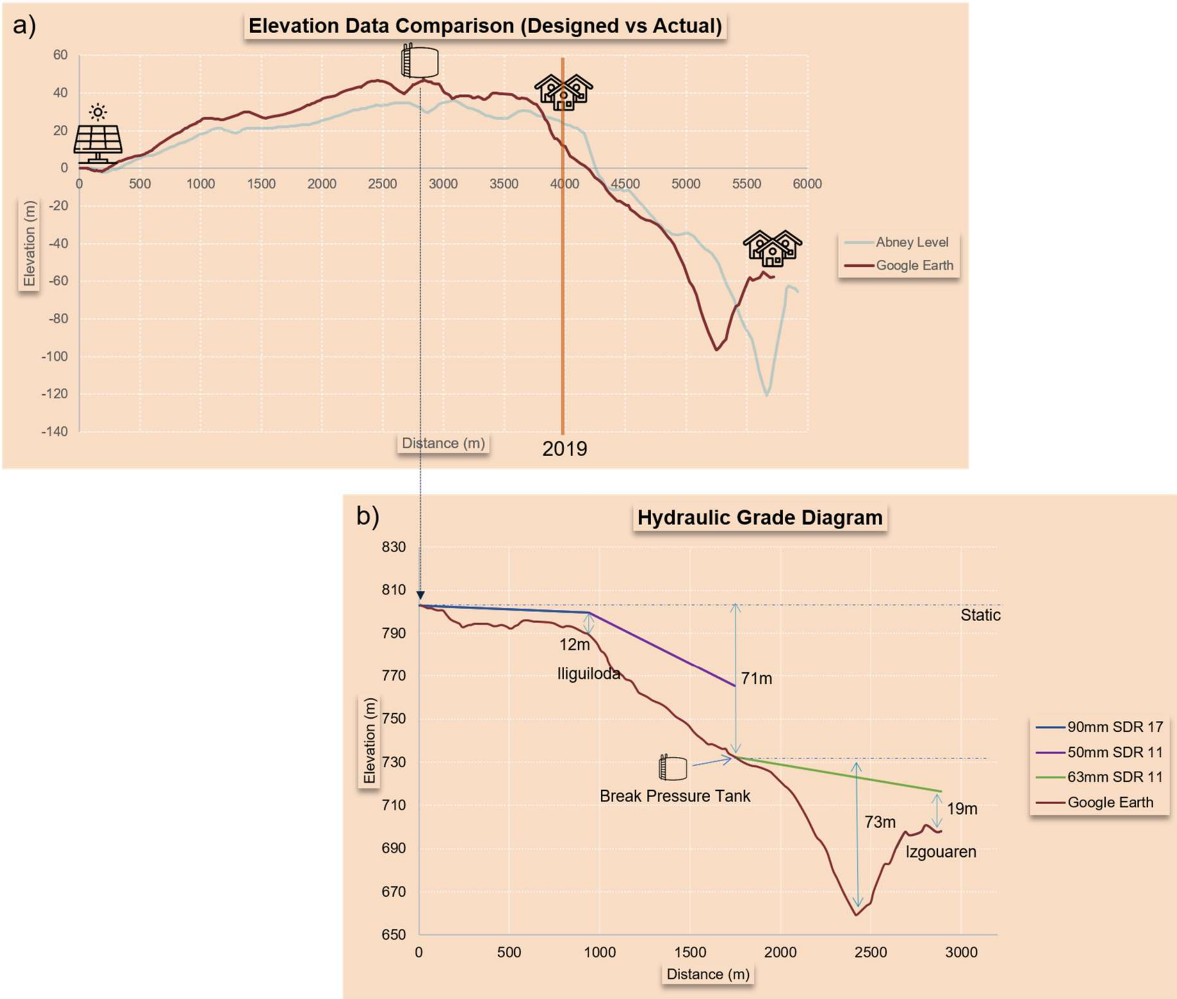

Figure 3a: Elevation profile comparison of data from Google Earth and from Abney level assessment in-country in reference to major project landmarks, including the solar panels, storage tank, and two villages.
Figure 3b: Hydraulic Grade Diagram showing hydraulic head against elevation profile, as well as the different pipes diameters used.

There is a 9.8m relative vertical inaccuracy which is why an abney level was needed to verify or modify this design while in-country. The hydraulic grade diagram also serves as a visual indicator that pipes were selected correctly and can withstand pressure demands. For the 60^{o}C maximum design temperature, a temperature derating factor of 0.5 (1.3% for every C above 20 C) was applied to the entire pipeline. Natural velocities and flow rates due to gravity were also calculated. Occasional surges, water hammer, and maximum pressure of each pipe segment were also calculated. Minor head loss due to valves and fittings was also calculated to ensure adequate head of at least 10m at each tap. All our calculations were housed in an excel program and served to help design the

[8] https://issuu.com/arnalich/docs/ligraven

water system and also reinforce our hydraulic understanding. All pipe specifications used for calculations were taken from ISO 4427-1 2007 & 2015.

The proposed and implemented design was an on-grade 50mm, 63mm, and 90mm PE100 pipeline, standard dimension ratio (SDR) hybrid of 11 and 17. Specifically, 2830m of 90mm SDR 11, 941m of 90mm SDR 17, 804m of 50mm SDR 11, and 1115m of 63mm SDR 11 with a break pressure tank needed before the valley. Included in our design is one check valve to prevent backflow to the community near the borewell, globe valves at each village, and air release valves and sediment drain valves at maximas and minimas. To meet water demands, a volumetric flow rate of 1.39 L/s runs through the pumped section of the pipeline. In the gravity sections, 2.5 L/s is supplied to both villages, with 0.8 L/s going towards the first village and the rest towards the second village.

PIPELINE INSTALLATION

Four kilometers were implemented this summer, which corresponds to the length required to reach the first village of Ilguiloda from the well site. This pipeline portion is composed of 90mm PE100 pipeline, SDR of 11 and 17. The pipe was laid on-grade, parallel, and adjacent to a one-meter-wide dirt road, cleared of rocks and point loading, from the well to the tank site. Any bump greater than 0.3m in local extremity was flattened using manual labor or a backhoe to reduce air entrapment within the pipeline. The pipe was buried at the road crossing within the village.

Figure 4: Community members uncoiling HDPE pipe

Pipes were loaded onto a community owned tractor and dropped off every 100 meters at marked locations along the pipe route. 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 a smaller team of three to four locals and a student fused the uncoiled pipes, ten locals staged the pipes into position and uncoiled their length.

Up to ten joints were fused per day with the McElroy PITBULL 14. Following ASTM F2620-13 procedures, 90mm SDR 11 pipe was installed. Heat soak time was 1 minute and 26 seconds while fuse/cool time was 3 minutes and 32 seconds. Temperature of the heating plate was 425 ^{o}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.

Last, 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. Community updates indicate the pipe is being covered with finely crushed local sandstone to protect from external damage and to insulate for cooler water.

TAPSTAND DESIGN & CONSTRUCTION

Following the main pipeline, 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.

The tapstands serve as the part of the system that the community interfaces with most frequently. As a result, its design had to be user-friendly. We proposed two separate tapstands for livestock and domestic use at each village. This separation improves sanitation and reduces conflicts between the two water needs. Galvanized iron pipes were chosen for the spigots, due to the wide availability of these pipes in the nearby towns.

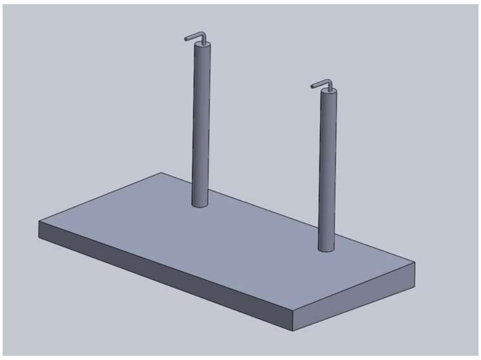

Figure 5: Preliminary CAD of Tapstand Design

To calculate the flow rates for these tapstands, we used assumptions from a study in Bolivia[9] stating that 65% of the water in a community is used in the morning. As this study was taken from an area similar in socioeconomic status, rural nature, and climate, we felt that the model was applicable to our project and designed the flow rates at the tapstand to withstand this increased usage in the mornings. Using the methodology from the Niskanen[10] report, we calculated the flow rates by dividing the total demand for water by the time during which that water is to be collected. We used the three hours of morning as our time frame, and took 65% of the total demand for water, separated into livestock and domestic uses.

Other aspects of tapstand use that informed our design included the ways that community members would interact with the tap stands. Additionally, the tapstand foundations were built on a slight grade, directing water towards the bottom-left corner. This was done in order to allow runoff water to drain properly.

The construction of the tapstands involved excavating a level surface on the rock. Since the surface area of the foundations was small, it was possible to get a completely level

Figure 6: Completed domestic (left) and livestock (right) tapstands

[9] https://issuu.com/arnalich/docs/ligraven
[10] http://horizon.documentation.ird.fr/exl-doc/pleins_textes/divers16-07/010048832.pdf

surface at enough of a depth to pour the foundation. PVC was used as a mold to create the concrete casing for the upright GI pipe. GI pipes were assembled, tested, and then placed in their respective places for the concrete pour. One tapstand was poured while we were in-country, however we ran out of time towards the end to pour the second tapstand. As a result, we simply assembled and tested the pipe for the second tapstand, and the community poured the foundations.

LARGER SYSTEM DESIGN

Other key aspects of the system included a large reinforced concrete tank, and a solar pumping system. These aspects, in conjunction with the piping system, provided a sustainable, long-term solution to water scarcity that took local conditions into consideration as much as possible.

Reinforced concrete tank was chosen due to its longer lifetime and due to lack of high quality locally available polyethylene tanks. The reinforced concrete tank allows for the storage of 24,000L of water, and includes a settling chamber of 14,000L capacity to allow for sediment filtration.

A locally sourced solar controller was fitted to the electric pump. Students made a large steel rack cast into a concrete foundation that framed 20 solar panels. This tilt of the rack was made to 31 degrees from the horizontal. The solar panels provide 5.4 kW of power to the pump.

The use of solar power means that water will only be pumped during sunny days, which had the potential to mean that water shortages could occur if a series of cloudy days were to occur. To mitigate this issue, we over-designed the storage tank to hold water for at least four days.

DISCUSSION

EASE OF INSTALLATION

One of the greatest strengths of using HDPE pipe in this rural water distribution system was the ease with which we trained local community members to fuse pipe. Locals immediately understood the importance of protecting the pipe surface; this was demonstrated multiple times by slowly unloading the pipes from the tractors, uncoiling, and preparing a surface free of point loading. Near the end, locals were teaching other locals to keep the surface clean before fusion and were quick to point out any possible flaws in the joint. By employing these skills and co-constructing the pipeline with the villagers, we achieved greater buy-in, familiarity, and ownership.

Figure 7: Team members and community members working together to fuse two lengths of pipe

USE OF LOCAL MATERIALS ONLY

When sourcing materials, a strong emphasis was placed on ensuring that all items were procured locally. In the case of maintenance and repairs, locally available material is a necessity to ensure minimal interruptions in water service. Our aim was to make the community feel complete ownership of their water system. All of the materials that we used, including the HDPE pipes and tapstand components, were sourced within Morocco in the nearest towns and cities. In taking these steps, we ensured that the work we did during implementation can be maintained for years into the future.

LONGEVITY OF SYSTEM

When designing this system, we hoped to maximize its lifetime as much as possible, ensuring that the communities will have access to water for decades into the future. We took longevity into consideration in all of our engineering decisions—from material choices, to system structure, to routes taken by the pipeline. However, without a sense of ownership, local authority, and order around the system, organizing crucial aspects such as repairs become incredibly hard, posing a serious threat to the viability of the system. As a result, it is important to work towards a balance between both engineered longevity of the physical system, and social longevity through effective governance. We worked towards this through integrating the community and developing relationships with community leaders, and are continuing to work with the communities to revive the viability of the Ait Bayoud Water Association to ensure that the system will continue to positively impact the community for years into the future.

IMPACT & NEXT STEPS

As of now, the only information we have regarding the impact of our system is sporadic messages that we have continued to exchange with the community. On our next trip, it is a priority to survey the community about our project's impacts. Additionally, in our upcoming trips we are hoping to expand storage capacity through the construction of a second storage tank fitted with a slow sand filter to improve upon water quality. We are also slated to extend the pipeline to the second village of Izgouaren, installing two new tap-stands, and finally completely our goal of bringing safe drinking water to the entire community of Ait Bayoud.

CONCLUSIONS

In late August of 2019, water reached the first village of Ilguiloda. Within a short period of six weeks, we gained the trust of the community and worked with them to construct a 38,000 L reinforced concrete tank, a solar rack holding 20 solar panels, four tapstands, a solar controller, and laid four km of PE100 pipe. Working with the HDPE Pipe industry, we were able to design the entire hydraulic system, raised over $43,000 of sponsorship in cash and materials to carry out the project, and led a student team towards in-country implementation from start to finish. The use of HDPE pipe in this project was an instrumental component in its success, and sheds light on the enormous potential this material has to aid in combating water scarcity. Today, life is different for the community of Ilguiloda, and soon for Izgouaren.

ACKNOWLEDGMENTS

None of this would have been possible without the dedication of the entire community of Ait Bayoud. In addition, the generous mentorship of all the professionals is greatly appreciated. A huge thanks to our mentors: Robert Lawrence, Camille Rubeiz, Greg Scoby, Santiago Arnalich, and Andrew Wedgner. Also, thanks to tank and water quality mentors: Michael Conaboy, Sean Reischel, Ethan Cotton, and Robert Prager. Gratitude to our sponsors and supporters: HDPE Municipal Advisory Board, GF Central Plastics, PE Pipe Alliance, Borealis (Craig Halgreen, Dorothea Wiplinger, Tarik M'Bitel), Borouge, Plastima, CMGP, Menara Holdings and ISCO (Steve McDonald).