On-Site Design of a Water Filtration System in Rural Ghana

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Agbokpa is a rural community in southern Ghana with no access to clean or running water. Villages without access to water face significant hurdles in obtaining an education and developing their communities' infrastructure and economy. In August of 2019 Cal Poly students Eugene Long, Fletcher Podosek, and Mason Nolan traveled with professors Paul Redden and Dr. Nathan Heston to Agbokpa to fix this problem. The team spent three weeks living in the village and constructing a water tower, pumping system, and filtration system that communally serves the village. The team worked with local craftsmen and sourced nearly all equipment and material through the local economy. The project was conceived and designed at Cal Poly almost a year before it was built. However, differing site conditions, changes in available material, and significant delays warranted a significant redesign upon arrival. A near-complete project redesign for a time-crunched project required rigorous planning. On-site design, estimation, and procurement all were critical to the success of the project.

Key Words: Estimating, Procurement Design, Water Filtration, Ghana, Africa

Project Origins

Agbokpa is a village of five-hundred people that sits on the shores of Lake Volta, a large reservoir whose water level dramatically fluctuates seasonally. Agbokpa is only accessible by a twenty-minute boat ride from the town of Ahinasi on the south shore of the lake. There are no roads to the town. The town has no connection to the national power grid, nor does it have a source of water aside from the lake. With no electricity—aside from a few private solar panels—and no clean water, the village is markedly less developed than Ahinasi, even though the two communities are only fifteen minutes apart. Without access to clean water, the village relies on purified water that comes from across the lake in 0.3L bags. Villagers that can't afford bagged water use the lake water. The only restroom for most of the village is simply the bushes outside of their huts, which is uphill and not far from the water they drink. This results in persistent outbreaks of cholera and dysentery in the community, which slows the communities economic and educational development. Dr. Nathan Heston—who began the discussions around this project—was stationed in the Peace Corps near this village and envisioned a project that could deliver clean water to the village.

The Project

Over the course of three weeks, the team delivered a pump—run on solar panels—that pushes water from the lake to the village. The 1200' run of pipe ends at the top of a twenty-one-foot, two-story water tower built by the team. At the top of the tower is a 10,000L water tank that temporarily holds the lake water before it is gravity drained through four slow sand filtration systems, and emptied into a 5,000L tank that acts as a cistern, holding clean water for the village to draw from.

Material procurement and estimating was challenging leading up to the start of the project. First, getting materials to site was a logistical nightmare. The nearest town with a hardware store was an hour drive away over hazardous mountain roads. All power tools had to be brought over in carryon luggage while tools like shovels and picks were sourced from nearby shops. All the project material had to travel by boat across the lake. It was nearly impossible to find available material and prices before arriving. Almost all the hardware and equipment stores in Ghana are small businesses with no websites or contact information. This generated a lot of uncertainty over what the project would be built with, and how much it would cost. A significant unknown was whether pipe size would be standard or metric, which the team planned for by bringing pipe fittings and tools that would accommodate both. With little information on material availability, most of the project was redesigned on-site.

Local labor was critical to completing the project. Villagers assisted in digging an 18" deep, 800' long trench from the lake to the village. They loaded and unloaded the boats loaded with material and carried all of it up to the village on their heads in the traditional Ghanaian manner.

Design Estimation, and Procurement

System design was the most challenging part of the project. There were unknowns about site conditions, available resources, and project timing that all complicated the design of the project. The first questions on design revolved around the slow sand filters. After a significant amount of research and discussions with Cal Poly professors knowledgeable on the subject, the team mocked up a slow sand filter on campus. Lessons learned from the prototype—on leaks and filtration rates—were invaluable in the village. The second point of design contention was how the pump would be mounted. Floating the pump on a raft, sinking it to the lake floor, and mounting it on the edge of the village dock were all options the team seriously considered. In the end, the team opted to mount the pump on the end of the dock. The third design issue was the placement of the tanks. The tanks had to gravity feed through the filters and align to maximize flow rate. The final designed called for the upper tank to perch ten feet above the ground on a welded, HSS steel tower. The filters were to sit on the surface, and the cistern would sit underground.

Cost estimation was critical to the project. The team started fundraising the winter before the project, and by the start of summer, had over $30,000 in their project account. With materials, travel, and labor, the estimated cost of the project was set to be just over $28,000. Since no information was available on what materials would cost in country, the team used costs from American retailers to price out materials. The team originally planned to buy all the materials (except the tanks) in the U.S. and ship them over. This idea was quickly scrapped when the team found import duties would cost 50% of the material value. The team decided to buy all their materials in country to save money and support the local economy. Upon arrival, the team found Ghanaian material prices to be significantly lower than the original estimates.

Procurement was also critical to the project. Equipment like the marine grade wire, the pump, and the pump controller had to be ordered four months ahead of the project start date so they could be loaded into the shipping container and sent to Ghana far ahead of time. The team also had to determine what tools and materials were not available in-country that would have to be transported with them. The team decided to bring power tools, solar-panel connections, and standard to metric pipe fixtures instead of finding them in-country. The rest of the materials needed for the project were found in country, with the exception of float valves. Float valves were ordered by the team in Ghana and brought over by the arriving refrigeration team.

Table 1

Material costs for the project. All costs are in US dollars, though most costs were paid in the local currency—Ghanaian cedi.

Item	Cost
Concrete Water Tower	$3,430
Submersible, 120V Pump	$1,515
Pump Controller	$415
Marine Grade Wire (1200’)	$1,104
Pump Electrical Components	$210
HDPE Fittings	$350
PVC Fittings	$350
HDPE Hose (1200’)	$950
PVC Pipe	$350
Pump Cage Fittings	$307
10,000L Polytank	$850
5,000L Polytank	$412
500L Polytanks (4 Total)	$228
Scaffolding	$312
Import Duties	$556
Pump Cage Material	$483
Tools (Welder, Generator, etc.)	$1,580
Paint	$112
Cement and Rebar	$93
Miscellaneous Material and Tool Costs	$1,560
Total Material Cost	$15,118

Table 2

Labor costs for the project. All costs are in US dollars, though most costs were paid in the local currency—Ghanaian cedi.

Item	Cost
Airfare and Travel Expenses	$9,177
Local Transportation of People and Material	$2,335
Food and Accommodations	$808
Local Labor	$516
Donations to Agbokpa	$450
HDPE Fittings	$350
Total Labor Cost	$13,286

Evolution of the Design

Changing site conditions meant changing design. The steel tower was scrapped when, three weeks before the project began, the team received a bid from a local masonry company for a two-story concrete water tower that would cost the same as the steel tower. The team decided that the concrete tower would be more structurally suited to hold a 10,000L water tank. The adoption of the two-story tower changed the entire filtration design. Instead of placing the filters on the ground, the team opted to place them on the second-story platform. Instead of placing the clean water cistern underground, it was placed on the concrete pad right under the tower. Last minute changes in design meant last minute changes in material procurement. With little time to spare, the team went from shop to shop in the cities of Accra and Nkawkaw, looking for the right pipe, fittings, tanks and tools to finish the project. In Ghana, procurement isn't as simple as going to a hardware store or calling a supplier. There are hundreds of small stores in town, each one carrying a very specific and limited inventory. A significant amount of time is spent going from store to store—all of which seem like they sell the same thing—and being told by the store owner they don't carry the product and being directed to a different store. Meticulous planning was put into comprehensive lists for going to town to buy parts. If something was forgotten, that meant a trip across the lake, bargaining with a driver, and going all the way back to Nkawkaw.

The water tower wasn't the only last-minute design change. For the water-intake system, the team originally planned to connect the pump to the floating dock that sits on the edge of the village and rises and falls with the seasonal weather fluctuation. The team arrived at the site and found the most unexpected: giant, sixty-foot wide floating islands of grass piled up along the lakeshore and blocking the dock. With the islands in the way, the boats could not park at the dock. The boat parked on the shore, a mile away from the village, and the team walked all the way over. The island presented a significant problem to the team's original design. With the islands in the way, the pump could not be mounted on the end of the dock. In the village, the team came up with a new design. A pump cage was welded out of galvanized steel and loaded with gravel that acts as ballast. The pump was put in the center of the cage and housed in a 4" PVC cylinder filled with slits that protects it from intaking sediment. The pump was carried down to the lake and hooked up to the 1200' of HDPE hose and marine grade cable. But the islands were still in the way, though they had been coming and going with the winds. The day the MCAA team had to leave, the islands were in the way and the pump could not be carried out by boats to be dropped. Fortunately, Dr. Heston was staying in the village for longer, and performed the pump drop when the islands had cleared out a few days after the team's departure.

The slow sand filters also underwent a design change. Three were originally planned, but with the addition of a second deck and the variety of available water tanks, the team opted to build four filters. The filters were originally designed to use a fine-sized 0.2mm sand. The team was unable to locate any businesses that sold or could sort specific sized sand, so the river sand being used for the concrete was used in the filter. This turned out to be a terrible idea. The river sand was so fine, that no water could percolate through it. So, all the river sand was pulled out and replaced with common beach sand.

Future Projects

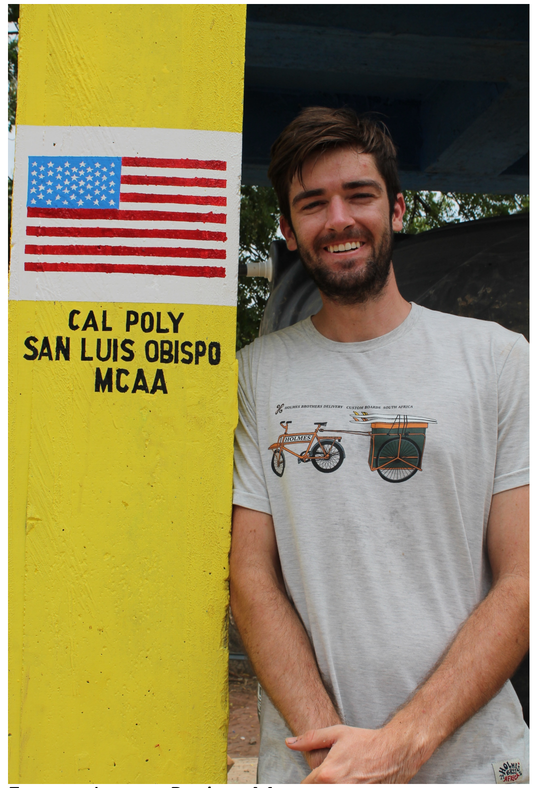
The filters were the main goal of the project, and the 10,000L water tank twenty-one feet off the ground was a welcome biproduct. The village, and the land around it, is quite flat. With that much water head and a limitless supply of water, the village is set for future development projects.

The next phase of this endeavor could be to run taps to different parts of the village. A 1” PVC pipe drops down from the top tank with a ball valve at the end. With some PVC, fittings, and glue, pipes could run across the village and finish at risers that act as public taps or showers. Installing a grid of running water across the village would save villagers a significant amount of time. Daily, the villagers make multiple trips on foot almost a quarter mile to the lake, fill up a bucket, and carry it on their heads back to their homes.

Without access to irrigation, fishing became the economic base of Agbokpa. The new water tower could be used to develop an irrigated farm. Irrigated farms produce higher quantities of valuable crops than non-irrigated farms. Instead of buying expensive grains and vegetables across the lake, villagers could produce their own and even sell them. The irrigation system is simple enough, but it requires a significant input of resources. Depending on the size of the farm, the project would require multiple large polytanks and a significant amount of PVC and drip tube.

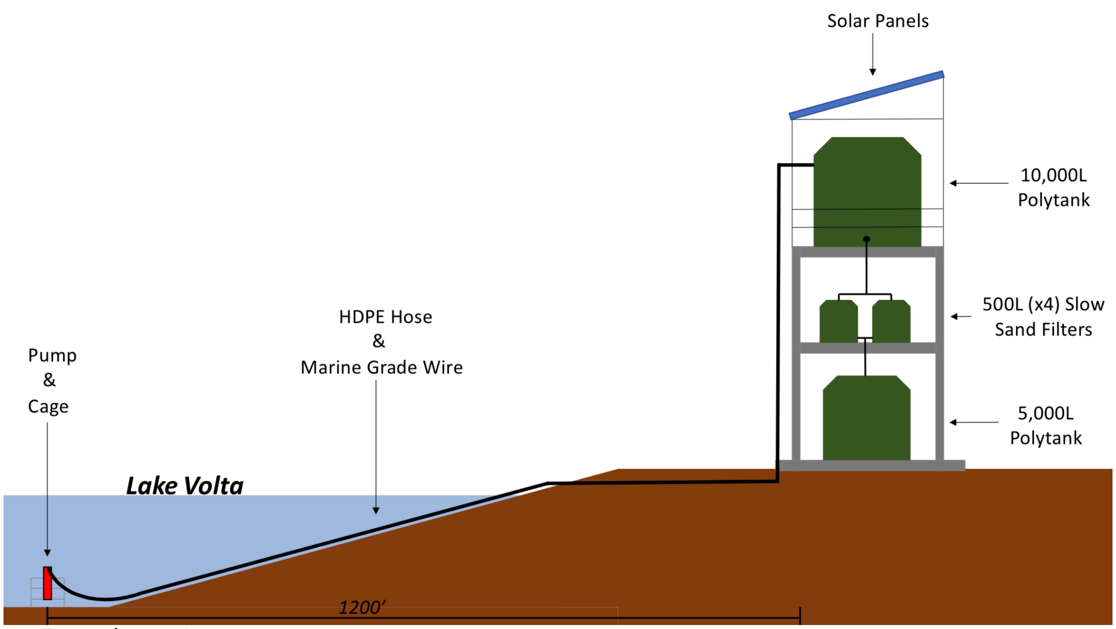
Photos

Completed water tower

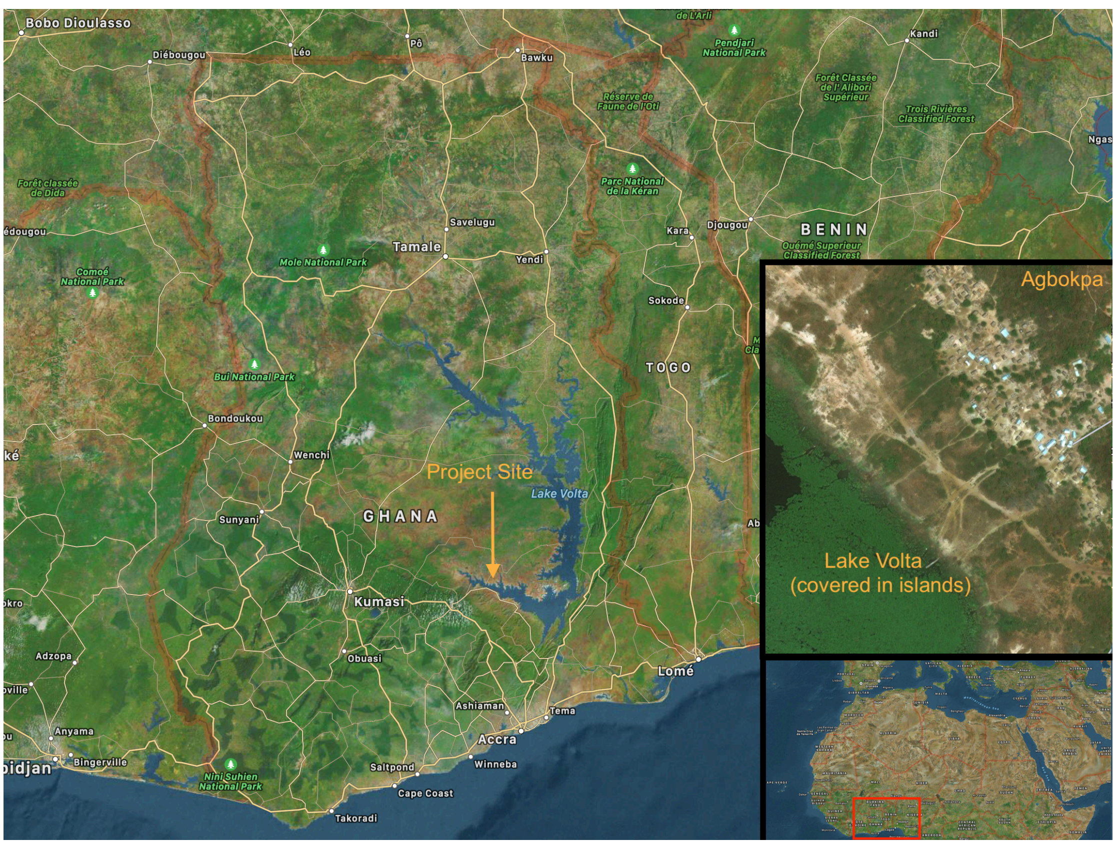


Eugene Long—Project Manager

Mason Nolan, Fletcher Podosek, Eugene Long—MCAA Ghana Team



Project schematic



Project map

Laying HDPE hose with locals

Lunch in the chief's hut

Welding the pump cage

MCAA Team with advisor Paul Redden

Trench digging

Completed pump cage


Final trenching & an unmounted polytank

Hauling materials across the lake

MCAA Team presented with gifts by Chief David and Dr. Heston

Slow sand filter mockup