Executive Summary

Water, one of the most essential ingredients for life on earth. It provides plants with the necessary energy to produce food, shelter, and oxygen; is used for hydrating animals; and is of course consumed and used by humans for a multitude daily activities. Despite its widespread use and importance to all life, an alarming amount of people worldwide do not have access to clean, potable water, or in some cases any water at all. Some studies have even shown that by 2025 more than half the world’s population will be experiencing severe water deficiency in some form. Many occupants of Kenya are already familiar with such water-based vulnerability.

To help alleviate the efforts of obtaining water in Kenya, our team set about designing and fabricating a human-powered pump; making access to water more readily available. The project aimed to create a pump that can retrieve water from boreholes, whose depths can reach up to 100 feet, and output a minimum of 200 liters a day. To accomplish this, the team first specifically defined the design parameters, including factors such as performance and safety. Then, different design concepts where reviewed and evaluated based on the parameters. Afterwards, the final design was manufactured and tested throughout the entire process.

Ultimately, the final design came in the form of a rope pump. Basic concepts of water displacement are key in the successful design of such a system. Due to suction pumps being ineffective at depths past 30 feet, the team’s rope pump design utilizes positive displacement principals to retrieve water. Essentially, this means that the pump will physically push water to the surface instead of relying on pressure changes to pull up the water.
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Introduction

Due to recent droughts and desertification of the country, Kenya has been experiencing increasing water shortage in recent years. Women and children, the main gathers of water, must often travel many miles on foot just to collect the unsanitary water that is available. This is extremely time consuming and exhausting. Even if a family is lucky enough to have a nearby water source, such as a borehole, the current methods of water retrieval are strenuous and often dangerous. Innovative ideas aimed at improving such methods could greatly improve the quality of life for those in such a hardship.

Attempting to make such improvements, our team has developed a human powered device which is capable of extracting water from boreholes. While this pump was developed with Kenya in mind, it can be implemented anywhere that water shortage is a problem. In Kenya, boreholes typically range from 30 to 100 feet in depth and are generally less than 4 feet in diameter. Currently, the most common method of water retrieval from these boreholes is with a simple rope and bucket system. Using this method is not only time consuming, but puts major strain on the shoulders, arms, and lower back of the gatherer.

The extreme depth and narrow opening of the boreholes immediately imposed some harsh constraints for our design. Due to the extra atmospheric pressure at depths below 30 feet, all designs which “pulled” water out of the hole had to be thrown out. Only positive displacement (pushing up the water) methods could be implemented successfully. Once this was determined, our next issue was how to reduce the strain our pump would have on the operator. Designing the pump to be bicycle powered effectively satisfied this requirement. Using the largest muscle group in the body, displacing the water by peddling a bicycle at an efficient rate would reduce the amount of time and energy required to gather...
water from these boreholes.

Material selection was also heavily considered. For this pump to make any kind of change it had to be constructed out of material which was readily available in Kenya as well as be cost effective enough for families living on less than 2 dollars a day to be able to contribute to the cost of fabrication. This also holds true for the manufacturing processes used for construction. It was also determined for our design to be a success it must be able to retrieve a minimum of 200 liters of water daily.

Keeping all these factors in mind, our team designed and fabricated a working prototype of a rope pump. This design was ideal because it satisfied all the design parameters associated with the project. It can be manufactured solely out of material readily available in country, and is easily constructed and assembled using basic techniques. It can also reach depths greater than 100 feet and is compact enough to fit within the diameter of the borehole.

**Synopsis**

Access to clean, sanitary water is one of the largest issues facing our planet. Poor water quality increases poverty, impacts education and food security. Due to recent droughts and desertification of the country, Kenya has been experiencing increasing water shortage in recent years. Women and children, the main gathers of water, must often travel many miles on foot just to collect the unsanitary water that is available. The trek is long and dangerous, and water is often unsanitary and unsafe. Some studies have shown that by 2025 more than half the world’s population will be experiencing severe water deficiency in some form. Innovative ideas aimed at improving water gathering methods could greatly improve the quality of life for those in such a hardship.
**Design Parameters**

The purpose of this project was to reduce that burden and create steady access to drinking water. A water pump needed to be designed and built to save time and energy in gathering water; this system had to be more efficient than the current bucket and rope system currently used in Thika, Kenya. One key aspect to design around was that it has to be replicable in Kenya, which limited the types of materials that could be used. The pump had to work at depths up to 100 feet and output a minimum of 200 liters per day in order to be placed in any borehole and service the entire local community. Often times electricity is unavailable in these remote locations, or it is unreliable. Creating a human-powered pump would be essential to service all of these boreholes.

**Design Concept**

After much consideration, the team decided to create a rope pump. A rope pump is a pump that has plugs or pistons tied on the rope, creating notches in the rope, a diagram is shown in *Figure 1*. As these notches move up a pipe, they carry the water up and out the pipe. At the top of the pump, there is a bike; allowing the pump to be human-pedal powered, which means, as the user pedals the bike, the rope is rotated through. At the bottom of the pump, there is an inlet system. The purposes of the inlet system is to: make sure the rope does not get tangled; serves as a pulley system for the bottom; and ensures that the notches do not get caught as they enter the pipe.

*Figure 1 - Diagram of a Rope Pump*
**Manufacturing Materials and Assembly**

Ideas were written down on paper, but needed to brought to life with the help of manufacturing and machine-shop tools. After examining other options closely, utilizing a decision matrix in order to determine the best design, it was decided that the rope pump proved to be the best overall idea due to its ease of manufacturing. Its advantages are a relatively low part count and can be manufactured from commonly available materials. A rope pump is the essence of a simple pump, using pipes and objects attached to a rope to act as a piston that pushes water up a pipe and out an outlet.

First, material selection needed to take place. Machining practices such as milling, turning, and general CNC machining were simply out of the question. Kenyans would be assumed to only have access to the most rudimentary tools such as hack saws, files, screw drivers, pliers, hammers and nails, rulers, and protractors, among some other basic tools.

At the very heart of the design was the bicycle. Riding a bicycle is a way of life for the Kenyans, who often cannot afford the luxury of using a motorized vehicle to navigate the terrain. They instead must rely on a bike to as a form of transportation. Additionally, it is known that the bike would utilize the most powerful muscles in the body, the thigh muscles, enabling continuous performance without fatigue. Using a bike frame would eliminate any imbalance experienced by the rider while operating the pump, while also making the bike easy to maintain. The team utilized a previously built bike frame.

*Figure 2- The steel bike frame securing the bike.*
that attached bike’s rear tire by bolts and nuts that held it in place as shown in Figure 2.

Next, a material for the pipe was to be selected. PVC is lightweight, weighing about 5.7 times less than comparative steel pipes, and the cost is very cheap as it is made out of a simple plastic. A diameter was chosen for the pipe to be 0.5” to create enough pressure to pump the water up to the surface from a depth of 100ft. Schedule 40 0.5” pipe, some couplings, and polypropylene rope were purchased at a local hardware store. Piping could easily be fitted together by hand using couplings that would slide over the 0.5” pipes and act as joints, joining them together. If a pipe was too long, it can easily be sawn to length using a hack saw. Piping cement should be used to permanently affix the pipes together. Figure 3 shows the outlet pipe, and demonstrates how it would look, while Figure 4 is a rendering of the outlet pipe set up itself.

Next, a set of objects needed to be selected to tie to the rope to act as pistons that would push the water up the pipe. Polyethylene rope was chosen for its water durability properties. Upon seeking out materials available in the shop, 5/16” nuts were chosen for the close tolerance with the 0.5” pipe. Other materials were considered for these pistons, but the
5/16-inch nuts outperformed the other options. Rope was taken and marked at every 6-inch or 12-inch increments. It was marked off to ensure even spacing when tying the knots to secure the washers as shown in Figure 5. These nuts were tied off by hand around the rope using simple square knots, with one knot each being tied off on with side of a nut, being tied to the nut as closely as possible to ensure the nut did not wobble as it was being pulled up the pipe, as shown in Figure 6. This process was repeated until four 45-foot sections of rope were obtained for use in our final design. Each of these four sections would be tied off into one long continuous piece to be used in the final 50-foot depth pump tested, Figure 7 is a rendering of a bike wheel in which the drives the rope.

A platform was placed underneath the bike to support the bike, the frame, and the pump, as shown in Figure 8. This is because the outlet and inlet of the pump were to be positioned over the borehole to obtain water. It was proposed to use wooden pallets because they are common and can be obtained for free since most local stores use them quite regularly. An array of extra pallets was picked up at on campus for no cost. A hole or a space was created in the pallet for the rope to go up the
outlet and down to the inlet. This was achieved by tearing off a plank and its nails using a hammer.

Following this, a bracket needed to be made to fasten the pipe to the pallet of structural support and vibrational dampening. It was proposed that an L-bracket be made out of bent metal. A sheet of rectangular steel plate metal was found in the machine shop scrap pile, which was then bent using the hand press into an L shape for the bracket. The distance at which the hole needed to be drilled was determined experimentally. A long piece of rope was placed around the circumference of the rear bike tire and pulled tight to simulate the working rope pump. Next, the distance between the edge of the pallet (where the bracket was to bolted and bent at) and the rope was obtained using a tape measure. This same distance was measured from the bend of the L bracket, and a pencil marking was made where that distance ended. Consequently, this is the spot where a hole was to be drilled in the L bracket so the outlet pipe could slide through it for support.

A hole was drilled using a drill press fitted with a bit size of 0.84”, which is the outside diameter of the Schedule 40 0.5” inch pipe. Using a file, the hole was made a bit larger so that it would snugly slide through the hole and not slip out of it due to friction. Using the location of where the rope was determined to be centered true and taught, the bracket was placed on the pallet and the pipe was slid through the bracket. A pencil was placed tangent to the edge of the pipe and locations were marked on the inside edge of the bracket where holes were to be made. Through these holes, screws would be placed to fasten the pipe and bracket to the side of the pallet. Two holes were drilled.
through the side of the bracket, as shown in *Figure 9*, after placing it in a clamp for steadying and were filled with a circular file, increasing their diameter until the screws were large enough to fit through. Holes were drilled just below the L bracket for a U-bolt to better secure the pipe to the side of the pallet. Nuts were placed over the threads of the U-bolt to secure it, and the U-bolt was tightened with a wrench so the pipe would not move.

With that, a crucial piece to the final design was the inlet system, a rendering is shown in *Figure 10*, where the rope would wrap around and transition from going down the inlet pipe and to up the outlet pipe. A cylindrical inlet system of the inlet and outlet pipes was made from a 1-foot-tall section of 8.5” diameter PVC pipe. Afterword’s, the outlet pipe was secured to the inside of the inlet system. Points in pencil were marked on either side of the outside of the outlet pipe along the length of it. Holes were drilled at these points using a hand drill, with U-bolts being fitted through these holes to secure the outlet pipe to the inlet system. A set of two large holes were bored across the side of the inlet system so a 2.5” PVC pipe could slide through the holes and across the inlet to act as a guide for the rope to travel around when transitioning from inlet pipe to outlet pipe. To ease the transition from inlet to outlet on the rope placing the inlet pipe guide on an angle and reducing fatigue loading and tension.

For determining what angle to place the pipe at, a mini model of the rope pump was assembled in the machine shop with shortened pipes and the rope was brought down on an approximate angle to reduce tension. At the point where the rope touched the side of the
inlet system, a point was dotted in pencil to note the location. Using a hand drill with a circular bit of 0.84”, a hole was made at an approximate angle for the inlet pipe. This angle can be adjusted using the two U-bolts that hold the PVC pipe in place, where the U-bolts can be seen in Figure 11. After all was done, the outlet pipe would be secured to the inlet system for support and provide connection point to the rest of the pump.

After initial testing, the rope was found to be slipping due to lack of tension and friction in the rope. This was fixed by install fittings that resembled gear teeth being placed evenly along the circumference of the bike rim. The nuts on the rope would catch on the fittings, creating tension. To create these fittings, simple U-channel pieces were cut in the band saw, with their length being cut to approximately an inch, these fittings are shown in Figure 12. Their width had to be less that the width of the bike tire rim. Using a hand drill, holes were drilled so screw could slide inside them and be screwed into the bike tire. This would connect the bike rim, the screws, and the fitting together as one piece. While in operation the brackets were found to catch on the nuts, and this problem was solved by filing down the edges, as demonstrated in Figure 13.
Conclusion

In closing, the Kenyan bike pump presented the team with a challenging set of design criteria, emphasizing low cost, acute functionality, and a true taste in product development. Looking at the final benchmarking results, the pump’s performance has exceeded expectations by pumping over 200 liters every thirty minutes, completely satisfying the 200 liter a day goal set by the team sponsor, Simon. Many minor tweaks were done to the project that affected pf improved the effectiveness in large ways, such as the tension in the rope and the spacing of the nuts attached to it. One of the most challenging aspects of the project was being able to pump to a depth of 100 feet, but based on a successful pumping at 50 feet, the pump will be able to generate enough pressure to pump effectively to 100 feet and even greater. This technical feat has far-reaching implications that will grow into the future, helping the better the lives of those less fortunate to have a steady of water for sustenance for years to come.
Meet the Team

From far left: Ha Anh Le, Brian Clark, Alex Arcaro, Kathleen Noblet

- Video of working pump: https://www.youtube.com/watch?v=anBLrRl12oY