Piloting of an Innovative Deep-Reaching and Reliable Hand Pump in Africa for Rural Water Access: The LifePump

Authors:
Gregory Bixler[1], Tony Beers[2], Beatrice Chisenga[1], David Vader[2] - *1Design Outreach, [2]Messiah College*

Abstract/Summary
Design Outreach (DO) developed a new hand pump called the LifePump™ to alleviate the depth limitations and reliability issues of commonly used standard hand pumps. In partnership with World Vision and The Collaboratory at Messiah College, Design Outreach piloted its LifePump in five African countries, beginning in November 2013. Researchers at Messiah College independently evaluated the LifePump pilot in order to study its field and laboratory performance. The LifePump operates at twice the depth of (up to 100 meters) and requires much less maintenance than standard hand pumps. The design is less prone to sudden failures than standard hand pumps due to its progressive cavity pumping element and heavy-duty components. Additionally, select LifePumps are equipped with SonSet Solutions' remote satellite monitoring technology that transmits information on pump performance to DO so that it can be monitored via the web. This paper describes the LifePump technology as well as the pilot project context, activities, and implementation strategy.

Introduction

Rural inhabitants of developing countries commonly rely on groundwater as their primary source of safe drinking water. Many approaches and technologies have been introduced to access groundwater in regions such as sub-Saharan Africa where poverty and unsafe water is prevalent. Since the Decade of International Drinking Water and Sanitation from 1981 to 1990, appropriate technology has been advocated as one of the key pillars for safe drinking water access. In response, many sub-Saharan African countries have introduced shallow-well pumps (depths up to 10 meters) in addition to deep-well pumps. The commonly adopted hand pumps include the Afridev and India Mark II (IMII), but these "piston-style" pumps have limitations. While these technologies have helped to increase safe water access globally, further technological advances are necessary to continue progressing toward safe water for everyone.

Access to groundwater is based on the hydrogeological environment and the available pumping options. The LifePump impact countries lie within the hydrogeological province with Precambrian basement, volcanic, and consolidated sedimentary rock [1]. A reduction in rainfall across Africa is a key factor that has led to limited or erratic groundwater recharge rates. Global climate change is expected to continue to alter average rainfall and, correspondingly, the recharge rates [2].

Because of these conditions, WASH organizations often must declare boreholes "dry" and leave the well sites if sufficient water is too deep for standard pumps. A dry borehole means a potentially viable well is abandoned, having significant negative economic and human impact. This situation reinforces the need for ultra-deep-well pumping technology beyond 50 meters for rural water supply. The greater a pump's depth capacity, the greater the subsurface volume of earth available to explore in search of adequate aquifers (with sufficient yield and refresh rates). In other words, the deeper a pump can reach into the ground, the more likely the drilled well will find available groundwater, increasing the likelihood of providing year-round water supply (through both wet and dry seasons). Figure 1 shows the depth comparison of the LifePump (100 meters) to the Afridev (45 meters) and IMII (50 meters) standard pumps.

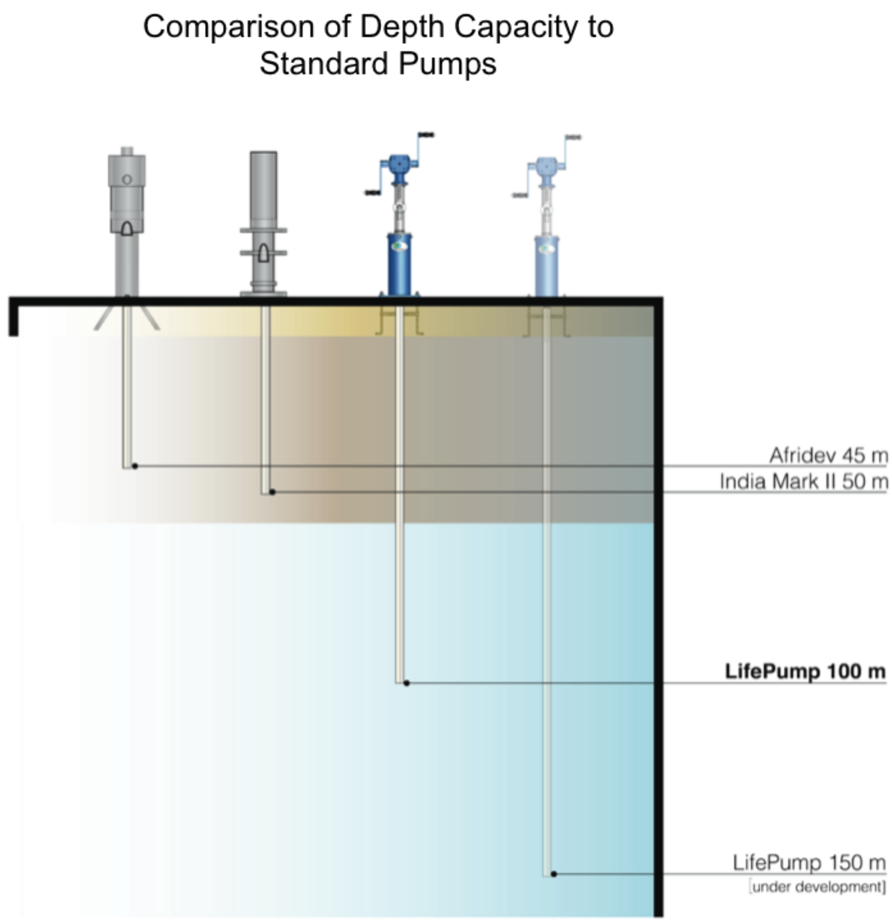

Figure 1. Depth comparison of the LifePump versus standard hand pumps Afridev and India Mark II. The LifePump currently reaches 100 meters, and a new model that will reach 150 meters is under development.

Standard pumps often fail to provide a reliable water solution because of inadequate and unreliable pump hardware and a lack of infrastructure [3]. Often, the range of operation of standard pumps, such as the Afridev or IMII, is limited to a depth of 50 meters [4]. In certain cases, sufficient water cannot be found within this range. At sites where water is deeper, pump options are limited and often do not meet user requirements such as flow rate, ergonomics, and durability [5]. Of the nearly 350,000 hand pumps installed in Sub-Saharan Africa prior to 2009, reportedly 125,000 (36%) were no longer functioning [6]. Over the last 20 years, pump failure has translated into US $1.2-1.5 billion of lost investment [7]. The durability issue is compounded by a lack of infrastructure, including technical support, supply chain, and an ability to pay for operation and maintenance (O&M) [7,8,9]. In an attempt to reduce the infrastructure problem, many countries have adopted standard "open-source" hand pumps like the Afridev or IMII [10]. However, such pumps lack durability [8,9,11], and their supply chains are still inadequate to support timely repairs. For example, a study in Kenya [12] showed that hand pumps fail, on average, twice per year, with an average repair time of 27 days.

The LifePump

The LifePump operates differently than standard hand pumps. LifePump users rotate handles mounted to a right-angle gearbox that spins the drive rods inside the riser pipes. The bottom drive rod and riser pipe are connected to the rotor-stator assembly called a progressive cavity pump (PCP) element (see Figure 2). The PCP is an auger-shaped, single-helix rotor that turns inside of a double-helix elastomer stator. As the rotor turns, pockets of water in each cavity are driven to the surface and out the spout. The PCP "lifts" only the water to the surface, while a piston-style pump lifts both the water and the drive rods. Often, children are unable to actuate a piston-style pump without jumping off the ground and using their body weight to push down on the handle. In addition, PCP hand pumps are not prone to catastrophic failure, unlike standard pumps that use pistons for the pumping mechanism. PCPs are able to withstand a high degree of wear and still continue to produce water because of the long seal line between the rotor and stator. Conversely, a piston-style pump relies on a relatively short seal line with O-rings and valves that are prone to failure. PCPs are commonly used in harsh industrial applications that routinely pump suspended solids. Suspended solids, such as sand and silt, may be present in boreholes and so therefore a pump able to withstand these abrasive elements is often necessary.

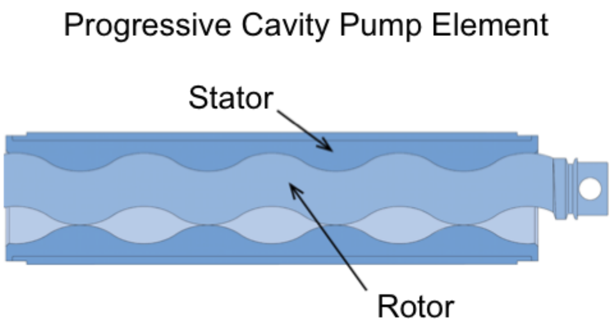

Figure 2. The Progressive Cavity Pump (PCP) element consisting of the metal rotor and the elastomer stator. As the rotor turns inside the stator, pockets of water are pushed to the surface.

When comparing the LifePump to other PCP hand pumps, quality, ergonomics, flow rate and handle torque must be considered. Past and present PCP hand pump manufacturers include Mono, Orbit, Cemo, Moyno and Play Pump. Reportedly, Mono, Orbit, and Cemo pumps are considered low-quality because of their design and materials selection [9], Moyno (discontinued in the mid-1980s) was considered reliable but difficult to use by "smaller users" [4], and Play Pump is called "largely inappropriate for community water supplies" due to its "cumbersome and ungainly pumping method" [9]. The flow rate at 100 meters is approximately 2.7 liters per minute (L/min) for Mono, 4.0 L/min for Orbit, 3.2 L/min for Cemo, 5.8 L/min for Moyno, and 10 L/min for the LifePump. Handle torque at 100 meters head is approximately 20% lower for the LifePump as compared with Moyno. The higher flow rates and lower torques are possible due to the high volumetric efficiency (90% at 80 meters, 77% at 100 meters) of the LifePump's PCP, which is made possible by its design, materials selection, and manufacturing processes.

While other non-PCP hand pumps are available with depth capacities greater than 50 meters (e.g. BluePump, Afridev Bottom Support System, Vergnet HPV100, Poldaw, Duba and IMII Extra Deep), an evaluation of performance, ergonomics, and sustainability by Cornet [5] found them to fall short of end user and WASH organization requirements. For example, the Afridev Bottom Support System experienced similar maintenance and reliability challenges as the standard Afridev, and most women respondents indicated that the BluePump was uncomfortable to use. Further, interviews with African WASH managers have revealed that the "practical" depth of these pumps is less than the maximum depth, because performance and reliability drop considerably as the pumps approach their maximum depth [13]. These pumps are also accompanied by increased actuation force at these depths, negatively affecting ergonomics.

Context, Aims and Activities Undertaken

Presently, DO is completing a pilot program in conjunction with World Vision and The Collaboratory at Messiah College that involves installation of LifePumps in Malawi, Zambia, Kenya, Ethiopia, and Mali (see Table 1). The purpose of the pilot program is for Messiah College to independently verify the effectiveness of the LifePump from technological and cultural standpoints. The five countries were chosen based on initial interest by the World Vision National Offices and a need for the LifePump's depth capacity. The pilot began in Malawi with LifePump installations in November 2013 and expanded into Zambia, Kenya, Ethiopia, and Mali. Throughout the pilot, DO donated LifePumps to World Vision, and World Vision provided the in-country logistics, community mobilization, and evaluation with Messiah College. DO personnel provided in-field training to each of the countries, including installation and maintenance training to the pump technicians, WASH managers, and government officials. Researchers from Messiah College travelled three times (December 2014, August 2015, and April 2016) to selected LifePump installation sites in the pilot countries (namely Malawi, Zambia, Kenya, and Ethiopia) and gathered ethnographic as well as quantitative pump performance data. The researchers also collected pump hardware from the field for evaluation at Messiah College facilities in Mechanicsburg, PA, USA.

During the pilot program, an instrumented test stand was developed to provide accelerated life testing of LifePump critical components at DO's research and development (R&D) facility in Sunbury, OH, USA. Accelerated life testing evaluates the pump by exposing its components to higher than normal operating stresses in order to discover any potential failure modes in a relatively short period of time. As shown in Figure 3, the test stand is able to test three pumping assemblies in order to evaluate differing conditions such as simulated depths and water quality as well as pre-screen all pumps before they are installed. Flow rate, torque, revolutions per minute (RPM), back pressure (to simulate depth) and water temperature are continuously sampled and recorded. The system components include data logger (Hobo U30-NRC), pressure transducer (AutomationDirect SPT25-10-0300A), flow meter (Onset T-MINOL-130-NL), load cell (Omega LC302-50), chiller (Aqua-Euro MC-1/2 HP), filter (Culligan HF-150), and electric motor (IronHorse MTR-1P5-3BD18). The motor operates at 45 RPM, which is an average number of handle revolutions per minute by the user, and with the gearbox increaser this translates into 90 RPMs at the PCP. Two of the pumping heads undergo ongoing continuous pump testing, which is comprised of two minutes of pumping with 10-second breaks between pumping cycles. This testing is designed to simulate pumping habits in communities where users will pump for approximately two minutes to fill a 20-liter/~5-gallon container and then transition to the next user. When operating, PCPs can develop a boundary layer of water between the rotor and the stator at approximately 80 RPM. This boundary layer reduces friction, which minimizes the amount of wear between the rotor and stator. To account for this, the pumping heads cycle on and off as indicated.

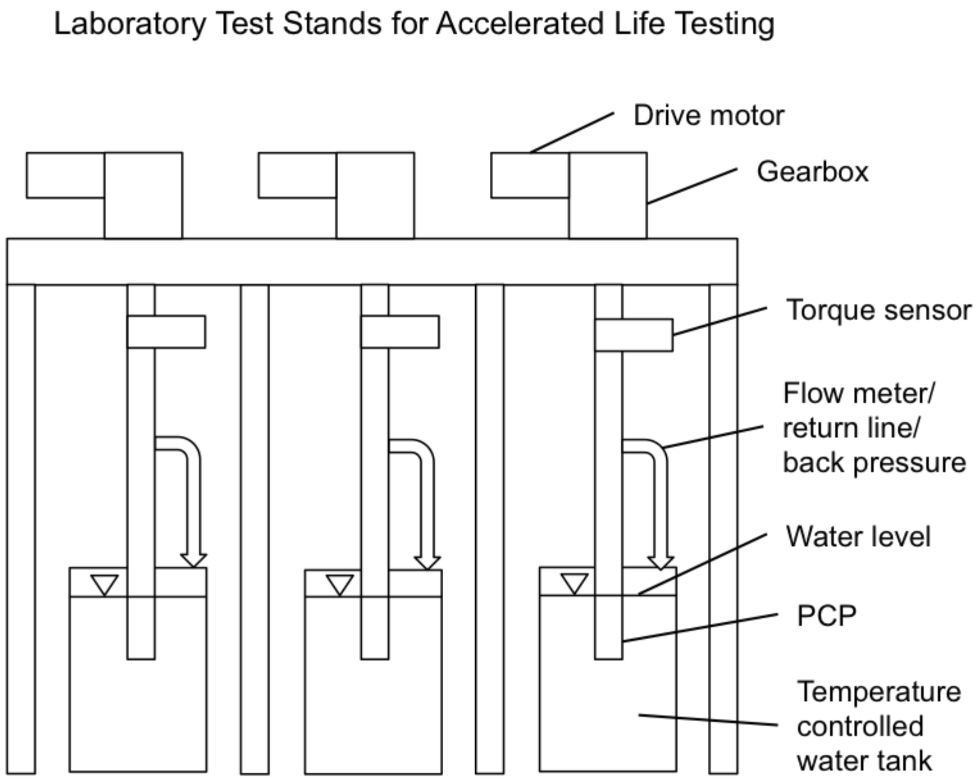

Figure 3. Laboratory test stand developed for accelerated life testing (4x) at DO's R&D facility in Sunbury, OH, USA. The test stand is capable of simulating real-life pumping conditions. The gearbox, couplers, and PCP element are tested. Water is circulated through a reservoir. Testing is conducted with on/off pumping, backpressure to simulate depth, and water temperature control. A load cell determines torque of the PCP and the flow meter the water flow rate. The system is computer-controlled and runs 24 hours per day, 7 days per week.

Testing is ongoing, 24 hours per day, seven days per week, giving an assumed 4x accelerated use (assuming six hours of use per day). Preliminary testing revealed an increase in temperature of the water (due to PCP element friction) as it circulates through the water reservoir, raising the water temperature to 90°F/32.2°C. Typical groundwater temperature is much lower, and such an increase in temperature can increase the starting and operating torque of the elastomer stator. To account for this, an in-line water cooler and filter was installed for each of the water reservoirs to maintain a constant temperature of approximately 59°F/15°C, which is the assumed average groundwater temperature in most sub-Saharan African countries.

To demonstrate the PCP's ability to pump from significant depths and maintain its efficiency over time, backpressure is applied to the PCP during the life testing. Deeper wells require the PCP to generate more pressure to overcome gravity, and this increases the PCP torque requirements. This increase in torque imparts more stress on the PCP elements, couplings, and gearbox. These components are part of the test stand assembly and are physically inspected periodically for signs of wear or degradation. Signs of wear are measured by changes in critical dimensions of the rotor and stator, as well as leakage in the gearbox seals. For the backpressure value, an average LifePump depth of 70 meters was chosen for life testing (or approximately 100 pounds per square inch [psi]/689 kilopascals [kPa] backpressure), which is the average depth of most installations. This backpressure is created by restricting the water flow with a valve and is monitored with a pressure transducer.

Main Results and Lessons Learned

Provided in this section are the main results and lessons learned from field and laboratory testing beginning in 2013. Results have been collected by a variety of sources, including community members and government officials as well as World Vision, Messiah College, and DO personnel. The LifePumps that are currently installed are listed in Table 1, which also specifies the borehole characteristics of each installation. Pumping tests and pump depths were determined and specified by World Vision hydrogeologists. Evaluations are ongoing, and further reporting is anticipated as data is collected.

Table 1. LifePumps Installed in World Vision Pilot Program

Village name	Location	Direct beneficiaries	Well depth (meters)	Pump depth (meters)	Static water level (meters)	Dynamic water level (meters)	Well commission date
Malawi							
Chilekwa	85 miles NW of Lilongwe	220	97	81	10	51	November 24, 2013
Zolomondo	82 miles NW of Lilongwe	256	63	57	13	52	November 14, 2013
Mynakose	90 miles N of Lilongwe	246	66	60	12	23	May 29, 2014
Mzondi Kasambala	141 miles N of Lilongwe	250	72	60	8	65	June 1, 2015
Vinyanda Chirwa	145 miles N of Lilongwe	121	87	60	8	81	August 8, 2015
Yeremiya Shumba	145 miles N of Lilongwe	250	51	42	13	46	August 9, 2015
Mbiko Shumba	141 miles N of Lilongwe	250	60	45	10	50	August 10, 2015
Zambia							
Kafwikamo Community School	91 miles NW of Lusaka	401	60	40	6	19	December 10, 2014
Big Concession	85 miles NW of Lusaka	472	90	60	16	24	December 9, 2014
Kanundwa School	73 miles SW of Lusaka	250	52	42	10	17	January 23, 2015
Mayanga	512 miles NE of Lusaka	658	40	30	8	14	May 24, 2015
Matelo Village	494 miles NE of Lusaka	146	56	45	14	17	May 26, 2015
Kenya							
Kibau	44 miles E of Nairobi	800	180	100	10	158	September 3, 2014
Kabur	144 miles NW of Nairobi	450	145	100	44	98	December 17, 2014
Buroiyo	161 miles NW of Nairobi	100	100	66	34	85	November 9, 2015
Kinyach	170 miles NW of Nairobi	200	135	66	73	132	October 10, 2015
Shivakala	188 miles NW	500	44	36	10	30	August 19,

Village name	Location	Direct beneficiaries	Well depth (meters)	Pump depth (meters)	Static water level (meters)	Dynamic water level (meters)	Well commission date
	of Nairobi						2015
Ethiopia							
Gamra Got	303 miles N of Addis Ababa	300	120	63	4	74	March 19, 2015
Kutich	236 miles N of Addis Ababa	300	110	54	55*	78*	September 24, 2015
Minziro-Robit	419 miles N of Addis Ababa	250	70	60	4	n/a	n/a**
Sorsaroha-Mina	403 miles N of Addis Ababa	250	66	57	8	n/a	n/a**
Sekecha-Kamise	271 miles W of Addis Ababa	250 + health center	80	60	15	n/a	n/a**
Mali							
Dombila Flabougou	n/a	n/a	46	28	18	n/a	n/a**
Djinidie-bougou	n/a	n/a	54	33	11	n/a	n/a**

**reported values; during installation, the pump was installed below the static water level*
***the official well commission date TBD, but each pump was installed June-July 2016*

Initial Field and Laboratory Results
Early volumetric efficiency data for two sites in Malawi, namely Chilekwa and Zolomondo, are shown in Figure 4 and demonstrate consistent performance from November 2013 through November 2014 [13]. The table shows the total number of handle rotations needed to fill a 20-liter/~5-gallon container over time. These initial results indicate that pump performance remained constant for the first year of operation, and the most recent site visit to these communities in April 2016 (30 months of constant usage with no repair or maintenance) indicated that flow rate performance remained unchanged.

To continue monitoring pump performance in real time, several LifePumps in Malawi, Zambia, Kenya, Ethiopia, and Mali are outfitted with spout-mounted satellite-based remote data loggers created by SonSet Solutions (Elkhart, IN, USA). These units record daily usage information and transmit the data wirelessly via satellite to DO for analysis (see examples from Malawi and Zambia in Figure 5). Total gallons pumped per day are calculated using efficiency information collected from the well site shortly after installation and the number of handle rotations for a given day. With regard to the laboratory testing, Figure 6 shows data (first 700 hours) from an example PCP that has been under testing for three months (4x accelerated life equating to approximately one year of community use). Data indicates consistent pumping performance with constant temperature, backpressure, and torque control. Temperature stayed constant at an average of 58.5°F /14.7°C.

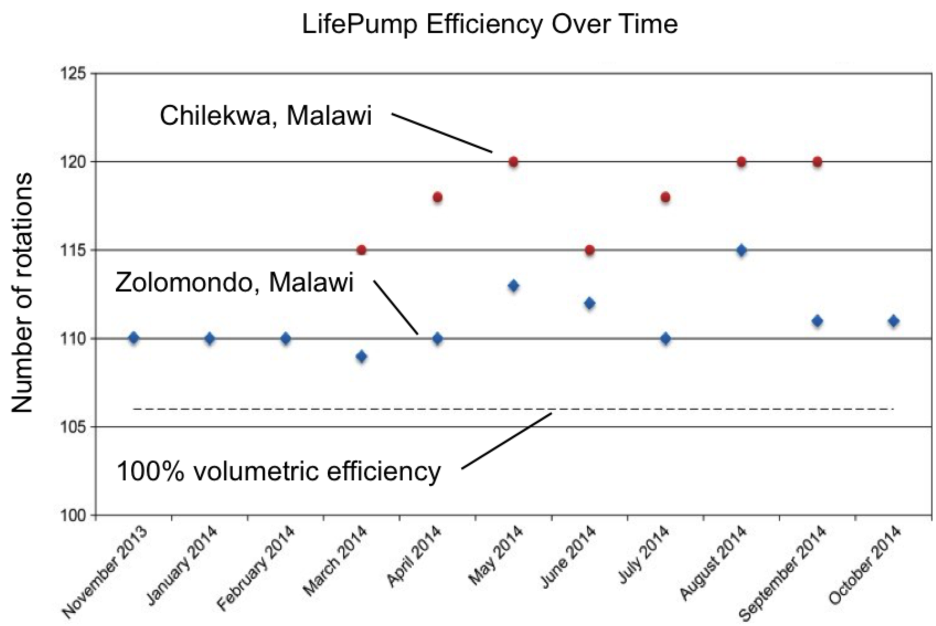

Figure 4. LifePump efficiency data collected from two communities in Malawi during the initial test phase of the LifePump pilot. The graph shows handle rotations required to pump 20 liters/~5 gallons. The 100% volumetric efficiency is shown, indicating a slight drop in efficiency as depth increases. The pump depths of Zolomondo and Chilekwa are 57 and 81 meters, respectively.

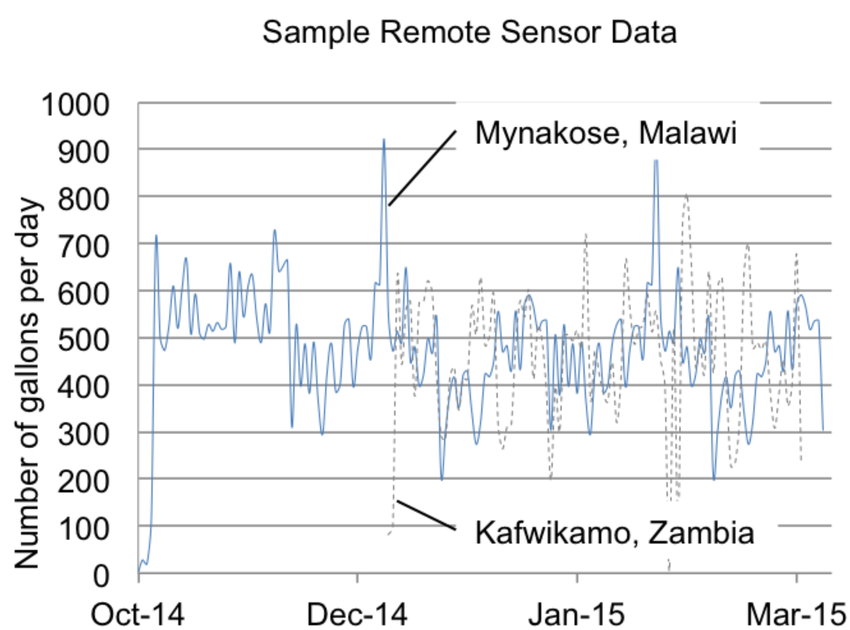

Figure 5. Satellite-based remote monitor data collected from two communities in Malawi and Zambia. The graph shows the number of gallons pumped per minute based on pumping efficiency and the number of handle rotations. This data is collected daily through satellite transmission and can be used by WASH organizations' monitoring projects.

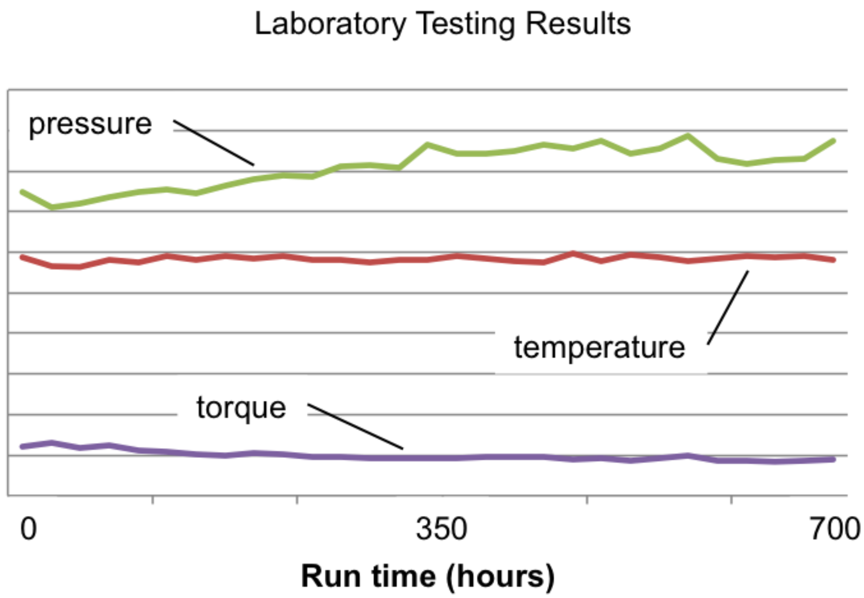

Figure 6. Laboratory test stand data for accelerated life testing of critical LifePump components. Results show the consistent water temperature, PCP element torque values, and flow rate. Testing conditions simulate 70 meters of depth. A comparison of results to field data validates the laboratory testing.

Initial Field Evaluation Results

This section provides data collected by researchers from Messiah College during field evaluation trips to Malawi and Zambia in December 2014 and August 2015 as well as Zambia, Kenya, and Ethiopia in April 2016. Also included are World Vision and Design Outreach evaluations from trips to Zambia and Kenya in June 2016 and Mali in July 2016. These findings are part of the preliminary learning that provides feedback for improvements and future recommendations. In summary, the LifePumps were found in good operating condition, and a summary of findings with highlights from observations is found below.

Figure 7. The first LifePump in Malawi was installed November 2013. The borehole was too deep for an Afridev and was declared dry until the LifePump arrived and could reach the water.

In Malawi, three LifePumps were visited in the Kasungu district, namely in the communities of Zolomondo, Chilekwa, and Mnyakose. All of the pumps were found in operational condition. Figure 7 shows the first LifePump installed as part of the World Vision pilot program. This pump in Zolomondo and another in Chilekwa have been operational since November 2013 without any maintenance or repair. Ten community members were interviewed at Zolomondo and Chilekwa, and seven were interviewed at Mnyakose. Community members answered questions related to sustainability, flow rate, ergonomics, and durability. An effort was made to capture a rough translation of the community members' comments even if the question format was multiple choice. Furthermore, video was taken to capture user interaction with the LifePumps, which was analysed with regard to acceptance and ergonomics.

In Zambia, three LifePumps were visited, two near Mumbwa (Big Concession and Kafwikamo Community School) and one in Monze (Kanundwa School). The pumps in Mumbwa were found in operational condition, while the pump in Monze was found to have a minor gearbox oil leak that allowed oil to drip into the riser pipe. The children only used the water for bathing and washing clothing. Even though the oil is food grade safe, the community decided not to drink the water due to a perception that the oil is unsafe. The LifePump at Kafwikamo Community School had a handle grip that was stuck. The grip was repaired by removing it and sanding away the corrosion and grime that had impeded rotation. It should be noted that the pump continues to operate even if the grip seizes. Ten community members were interviewed at Big Concession and Kafwikamo Community School, while only two were interviewed at Kanundwa School. As in Malawi, an effort was made to capture a rough translation of the community members' comments, even if the question format was multiple choice.

In Kenya, five LifePumps were visited, namely in the communities of Katithi, Buroiyo, Kinyach, Kapingi, and Killboti. All of the pumps were in operational condition but experienced some community mobilization deficiencies. In Katithi, community members believed the water was unsuitable for consumption due to high levels of iron. They reported that they really wanted an electric pump with a tank and distributed water supply as initially promised during the assessment phase. However, after learning that the water was safe and that the borehole was unfit for an electric pump, the community was satisfied with the LifePump. Two other LifePumps received positive ratings (Kapinigi and Killboti), and two received complaints of high handle torques (Kinyach and Buroiyo). Further investigation revealed that these complaints of higher torque values were not design-related; instead, negative perceptions of the water quality prevented regular usage, so the pumps were never "broken in." For instance, reports show that Kinyach runs dry and Buroiyo's water has high iron content, which deters community members from using the pump. The cause of the dry borehole in Kinyach was related to miscalculation of dynamic water levels during the installation phase. Both negative experiences were not related to the LifePump hardware.

In Ethiopia, two LifePumps were visited, namely in the communities of Gamra Got and Kutich. The Gamra Got pump was vandalized, resulting in a missing handle and debris in the spout. Further investigation indicated that the community was expecting an electric pump, but when the borehole was deemed insufficient, the LifePump was installed. This was not the expectation of the community, and they rejected the hand pump. Furthermore, the LifePump was found to be installed on disputed land. The Kutich LifePump was found in operational condition but locked because the borehole ran dry. The remaining three LifePumps were recently installed (incorporating lessons learned from the first two), and follow-up monitoring trips are in process.

In Mali, the latest country to receive LifePumps, two LifePumps were recently installed in Dombila Flabougou and Djinidiebougou. These communities provided positive initial feedback, and follow-up monitoring trips are in process.

Structured Interview Data

In general, comments from community members, World Vision WASH personnel, and area mechanics were very positive. For instance, they appreciated the increased depth capacity, that components are durable, and that "pumping the LifePump is not a very hard job." Overall, the LifePump is well-received, scoring an average rating of 3.7 out of 5 based on survey responses taken during Messiah College’s visits regarding user comfort while operating the LifePump. All users surveyed claimed to have had experience with at least one other pump type. When asked to compare the LifePump to other pumps they have used, 88% preferred the LifePump overall, with 65% of those interviewed claiming that the LifePump is easier to use than other pumps. Despite this, 63% felt that the flow rate was low compared with other pumps, and 18% found pumping to be tiresome. When asked what improvements they would like to see made to the LifePump, 55% suggested making the handles easier to rotate, while 46% suggested a higher flow rate. It should be noted that the LifePump flow rate is almost identical to that of the Afridev or IMII at their maximum depth, but these are perceptions of communities with deeper water averaging a depth of 70 to 100 meters.

Twenty percent of those surveyed indicated that they have a medical condition or are pregnant. Of those respondents, 40% were pregnant, and another 40% indicated having hypertension. Eighty percent of participants who claimed to have a medical condition indicated that this had a negative effect on their ability to use the pump: 40% reported feeling tired, and 30% reported needing assistance. Other effects noted were a need for breaks while pumping, body aches, and heart palpitations.

From an implementer perspective, World Vision WASH personnel commented on the LifePump. They considered the LifePumps easy to install and reported that the LifePump met their need for a deep and reliable pump. They appreciated that the LifePump can reuse the IMII base stand in a retrofit situation. In countries with IMII, initial installation was quicker because the area mechanics are already familiar with metal riser pipes. A commonly cited benefit of the LifePump riser pipe was the fact that no tools are required and that the galling risk is reduced due to the LifePump’s drive rod and riser pipe designs. Table 2 lists general observations for areas of improvement as well as actions taken as an outcome of the pilot program.

Table 2. General Observations for Areas of Improvement

General observations/feedback	**Actions taken**
Oil has been seeping slowly from the bottom of the gearbox housing.	The gearbox was redesigned to accommodate food-grade grease instead of oil to avoid this situation.
Handle grips become unable to rotate on the handle.	The handles were redesigned with a stainless steel stud to prevent corrosion and handle sticking.
Retrofitting an IMII requires removing the concrete base.	The pump was redesigned to accommodate the standard IMII base as the LifePump base.
Pump prime leaks slowly, requiring two handle rotations to start producing water during the day.	The foot valve was redesigned with a guard to prevent potential damage during installation.
Approximately four to five Afridev pumps can be installed in a day, while the LifePump requires one day per pump.	New LifePump riser pipe currently available does not require wrenches, which saves significant installation time. Installation with experienced operators can be accomplished in less than 3 hours.
Some users prefer a higher volume of water per rotation to be produced.	DO is working to increase volumetric efficiency of the PCP, which will produce more water for the same amount of input energy. DO also is working on a PCP design that will increase the

General observations/feedback	Actions taken
	depth capacity.
Some users, including children, would benefit from a reduced pump height, and those with disabilities would benefit from a seat.	Ergonomic trade-off studies indicate that the LifePump accommodates the majority of women and children users. A seat or concrete step near the pump could help accommodate more people.
It was recommended that DO provide spare parts during the pilot phase.	Spare part kits were sent to World Vision for each installed pump. Presently, a franchising model for parts and service is being developed.
It was recommended that DO consider compatibility of IMII riser pipes.	The pump was redesigned to accommodate IMII riser pipes.
Some drive rod couplers experienced galvanic corrosion.	The couplers were redesigned with a new material to prevent the galvanic corrosion.

Quantitative Handle Torque Data

Two sets of torque data were collected from each LifePump, namely using one hand (see Table 3) and using two hands (see Table 4). The torque was measured using a torque sensor (Futek Sensit model TRS300) with a sample rate of 100 samples per second for the duration of time required to fill a 6-gallon/23-liter container. Each test was repeated five times. For both experiments, the flow rate and mean torque were tabulated. For the one-handed case, the starting torque also was recorded. This represents the initial short "static" torque required to start pumping. The starting torque was indistinguishable in the two-handed experiment. All curves were sinusoidal in nature.

Data corresponds to laboratory test stand and ergonomics data and is generally consistent between sites. For instance, the deeper wells (with an average well depth of 70 meters) show a higher average handle torque, with a range for one-hand operation of 12.4 to 17.3 ft-lbs or 16.8 to 23.4 N m. Values for two-hand operation are expected to be about half, which is the case. The exception is Kanundwa School where the depth is less than that of the other Zambian communities, and yet the torque is slightly higher. Measurement error may play a role (torque tolerance of +/- 5%). Starting torque is the peak torque required to overcome static friction and to start pumping, and users were able to provide enough initial power. Users turn the handles an average of 40 to 50 RPMs, and the average flow rates correspond to PCP manufacturing specifications. All the values are within the tolerance range of the PCPs and are considered ergonomically correct for the majority of users.

Results suggest that laboratory and field torque and flow rate values are similar when comparing Table 3 to Figure 6 torque values, validating the test stand equipment. Torque shown in Figure 6 represents the rotor torque, and Table 3 represents total handle torque. Values are within 15% of each other. Additionally, Figure 6 shows the break-in period of the PCP, with field-testing experience indicating that initial break-in occurs typically within 24 to 48 hours of installation (5 to 6 hours of actual pumping).

Table 3. One-Hand Pumping Data

Community	Well Depth (m)	Flow Rate (L/min)	Starting Torque (ft-lb/N m)	Average Handle Torque (ft-lb/N m)
Chilekwa	97	11.5	21.7 / 29.4	13.7 / 18.5
Zolomondo	63	10.9	19.6 / 26.6	12.4 / 16.8
Mnyakose	66	11.2	23.4 / 31.7	12.6 / 17.1
Kafwikamo School	60	10.4	37.2 / 50.4	15.0 / 20.3
Big Concession	90	9.5	29.8 / 40.4	17.3 / 23.4
Kanundwa School	52	10.4	33.8 / 45.8	15.6 / 21.1
Average	~70	10.6	27.6 / 37.4	14.4 / 19.5

Table 4. Two-Hand Pumping Data

Community	Well Depth (m)	Flow Rate (L/min)	Starting Torque (ft-lb/N m)	Average Handle Torque (ft-lb/N m)
Chilekwa	97	11.7	21.7 / 29.4	7.7 / 10.4
Zolomondo	63	10.4	19.6 / 26.6	6.1 / 8.3
Mnyakose	66	12.1	23.4 / 31.7	5.0 / 6.8
Kafwikamo School	60	11.5	37.2 / 50.4	8.9 / 12.1
Big Concession	90	9.6	29.8 / 40.4	8.9 / 12.1
Kanundwa School	52	13.8	33.8 / 45.8	9.1 / 12.3
Average	~70	11.5	27.6 / 37.4	7.6 / 10.3

Conclusions and Recommendations

A pilot program was conducted by World Vision, Messiah College and Design Outreach to study the feasibility of the LifePump in five countries. Design Outreach and World Vision also have involved Ministry of Water officials in each of the pilot countries at various levels. The LifePump pilot program has provided valuable insight into how this new technology can help communities. Qualitative and quantitative results were collected on 24 LifePumps installed in Malawi, Zambia, Kenya, Ethiopia, and Mali. Data was also collected from laboratory test stands and using remote monitoring technology. The longest-running LifePumps are found in Malawi and were installed in November 2013. To date, these pumps have experienced no need for repair or maintenance.

This study found that when community members compared the LifePump to standard hand pumps, they preferred the LifePump because of its high durability, reduced maintenance, and ease of use. Independent analysis of LifePump components, such as the PCP and gearbox, revealed that the LifePump showed no measureable signs of wear on critical components after 30 months of daily usage. Perceptions that the flow rate is lower than Afridev or IMII are due to pumping at different depths (when comparing at the same depth, LifePump flow rate is similar to Afridev or IMII). Some minor improvements have been made to the LifePump design based on lessons learned during the pilot program. These modifications include using a grease versus an oil-filled gearbox, adopting the IMII base stand, incorporating a drive rod coupler material resistant to galvanic corrosion, and improving community mobilization, including supervision and monitoring processes.

The success of the LifePump depends on proper community mobilization as evidenced by discrepancies in community perceptions of the LifePump. Upon investigation, the few negative perceptions were the result of perceived poor water quality, dry boreholes, and/or the expectation of an electric pumping system. These factors are deemed non-design related with regard to LifePump performance. The highest social acceptance of the LifePump is found in communities with a retrofit where they experience first-hand the reliability of LifePump as compared with Afridev and IMII. The lowest social acceptance of LifePump is found in communities that are expecting or promised something else (such as an electric pump or piped water system) but instead receive a LifePump.

In conclusion, the LifePump is an encouraging new innovative option for water access that should be considered by the WASH community. The pilot program shows promising community acceptance, durability and cost effectiveness—helping to lead to improved sustainability.

Future Plans

With the guidance of NGO partners, relationships with NGOs and government officials in Malawi, Zambia, Kenya, Ethiopia, and Mali have been established and are being further solidified. Supply chains are being developed with public (government), private, and NGO partners. A base of distributors and service technicians is being developed to provide in-country presence and accelerated market growth. DO's general strategy in Africa is to obtain necessary governmental approvals and develop in-country distribution through a proposed LifePump franchising model that expands existing pump supply chain partners. Such franchisees will sell, install, and service LifePumps. DO will facilitate or encourage LifePump support by the franchisee or project sponsors to align with the specific country community management models, which include forging partnerships with stakeholder end users and their coordinating local government committees. DO also will encourage LifePump operations to incorporate input and technical advice from hydrogeologists, particularly during the drilling phase. Such geologists will be advisors to LifePump project sponsors/drillers, providing input for locating favourable sites as they explore year-round groundwater resources.

Acknowledgements
Many people have given generously their time, talents, and resources to make the LifePump possible. These contributors include the volunteers, donors, and many partner organizations that believe safe water should be available to every person, every day of the year. Special thanks also goes to World Vision for their early partnering and shared investments in the LifePump pilot program. This includes the World Vision Innovation Fund that was able to provide Messiah College's independent evaluation.

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Authors

Gregory Bixler, Ph.D., P.E.
Executive Director, Design Outreach
Senior Lecturer, The Ohio State University
USA
greg@doutreach.org
Design Outreach
PO Box 82345
Columbus, OH 43230 USA
+1 614-578-2623

Anthony Beers
WASH Technology Projects Manager, Collaboratory for Strategic Partnerships and Applied Research
USA
tbeers@messiah.edu
Messiah College
Suite 3034
One College Ave.
Mechanicsburg, PA 17055 USA
+1 717-303-9306

Beatrice Chisenga, Ph.D.
Africa Field Director, Design Outreach

UK
beatricec@doutreach.org
17 Randolph Road.
Kearsley. Bolton. BL4 8EB. UK
011 44 7825 512998

David Vader, Ph.D.
Professor of Engineering, Messiah College
USA
dvader@messiah.edu
Messiah College
Suite 3034
One College Ave.
Mechanicsburg, PA 17055 USA
+1 717-319-8534