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Policy influence for ultra-deep reaching hand pumps

Case study for LifePump acceptance in Zambia and Malawi

Executive Summary

In rural areas where hand pumps are commonly used, extracting water from ultra-deep boreholes (up to 150 metres) poses a significant problem for communities since this is beyond the design limit of standard hand pumps. Demand for climate-resilient, ultra-deep hand pump technology is growing due to dropping global groundwater levels, along with the need for government policies to enforce best practices for year-round, safe water supply. Standard hand pumps are unable to reach ultra-deep water sustainably in certain situations, because of the water depth limitations and/or the reliability of the hardware. Moreover, non-governmental organizations (NGOs) that are willing to solve this problem with new, emerging technologies are unable to, because of existing government policies and bureaucracy related to hand pumps. In Zambia and Malawi, a partnership made up of government, NGO, and private sector entities came together to update government policy, focusing on a modern, appropriate hand pump technology called the LifePump™. This new hand pump can reach 150 metres deep using progressive cavity pumping technology (two models are available, one reaching up to 100 metres, and the other up to 150 metres). In addition to achieving a significant depth reach beyond the India Mark II and Afridev, the LifePump requires much less maintenance over time, thanks to its robust design and stainless steel materials.

This paper provides a case study of a practice-based overview of how the governments initiated an update of policies enabling the use of the LifePump in both Zambia and Malawi.

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Introduction

Overview of Climate Resilience Issues and Groundwater Extraction for Ultra-Deep Wells in Zambia and Malawi

The challenges referred to above arise partly from water receding to deeper levels, calling for technologies that are climate resilient to extract groundwater from deeper aquifers. The Governments of the Republics of Zambia and Malawi have both set objectives to be "a prosperous and climate resilient economy by 2030" and "to build and promote appropriate technologies and build the national capacity in order to fully benefit from the climate change technological transfer" (GRZ, 2017). The Zambian and Malawian governments equally complement the global Water Sanitation and Hygiene (WASH) agenda initiative in supporting the Sustainable Development Goals (SDGs) and Target 6.1, *"by 2030, achieve the universal and equitable, access to safe and affordable drinking water for all"*. The water and sanitation section (NDP, 2017) states that the direction of policy for the sector is to develop water supply and sanitation, which will include principles of mainstreaming and advocating appropriate technologies at national level. Given the above, a radical technology breakthrough, coupled with policy reform, appears to be part of the solution.

Quality of Groundwater Pumping Solutions for Deep Wells in Zambia and Malawi

Poor pump hardware functionality and climate change pose a serious threat to water resources availability in Zambia and Malawi, both in terms of groundwater levels and appropriate infrastructure. To better understand these challenges, the Scottish University of Strathclyde, in conjunction with various NGO and government partners (through the Malawi Climate Justice Fund Programme), has conducted an extensive study since 2011 on water point functionality, availability, access and more in Malawi. Their data suggests that only 58% of "improved water points" out of the total 121,506 water points are "functional". Furthermore, 63% of the Malawian national standard Afridev are functional with 52,173 installed. To make matters worse, at the end of the dry season in October, water is not available at over 17,000 water points (Malawi CJF, 2020), likely due to dropping water tables.

This data aligns with the Rural Water Supply Network (RWSN) reports showing that of the nearly 350,000 hand pumps installed prior to 2009 in Sub-Saharan Africa, 125,000 (36%) were no longer functioning (RWSN, 2009). A follow-up report in 2016 by RWSN on an 11-country research programme on water projects says: "High failure rates early after installation are troubling." It states that 15 percent of water points are non-functional after one year of operation and 25 percent after four years (Banks, Furey, 2016). Ten years later, with progress in water point mapping, updated hand pump statistics show that 26% are still non-functional (Deal, Furey, 2019).

The standardization of hand pumps occurred in the 1980's to help the private sector scale for high volume and to avoid "market fragmentation". However, more than 30 years later, standard hand pumps, including the most common India Mark II and Afridev, still pose challenges, such as training, supply chain and manufacturing quality (Bauman and Furey, 2013). With this in mind, Zambian and Malawian government officials started to reimagine rural water supply where standard hand pumps are unable to operate effectively.

Many hand pump policies set in the 1980's are still being followed today, despite the advent of significant technological improvements. Certain hand pump technologies are being or have been promoted in recent years in Zambia and Malawi, such as the Vergnet and PlayPump technologies, but they have not been widely adopted. Policy sector reform based on research and practice has evolved over the last decade, with an increasing demand for consensus and collaboration by government and NGOs, with the desire for research to help influence policies (Shucksmith, 2016; Renouf, 2017). One example reported by Tucker et al. (2013) shows that the government research had impacted health policy outcomes in Ethiopia. Young (2005) identifies positive impacts that beneficiaries experience thanks to policy changes.

Millions of people have enjoyed the advantages of standard hand pumps in the last three decades. Zambians have mainly benefited from the India Mark II (up to 50 metres depth) but also from the Afridev (up to 45 metres depth) hand pumps for rural water supply. Unfortunately, these pumps and supply chains are not without their drawbacks. Reportedly, 38% of communities in Zambia have experienced issues due to hydrological conditions, noting corroded, galvanized pipes and difficulty in use. In 40% of the cases where a repair was required, hand pump downtime (time waiting for repairs) was over four weeks. This is likely due to the inability to pay for repairs, and one survey shows that 72% of communities did not make regular contributions towards Operation and Maintenance (O&M), while 80% raised less than $30 USD per year for repairs (Nkhosi, 2020), which is insufficient for most major repairs.

Malawians have benefited from several hand pump types as well, including the commonly used Afridev. Further hand pumps include the Malda and PlayPump, with other lesser-known technologies such as the Elephant pump (Holm et al., 2015). Similar to standard hand pumps in Zambia, standard hand pumps in Malawi have faced limitations. Reportedly, 42% of "working" hand pumps surveyed in Malawi did not provide "sufficient yield or reliability" (Mwathunga et al., 2017). Leading, contributing factors to the non-functionality have been the corrosion of components resulting in hardware failure, improper borehole construction, an insufficient supply chain of spare parts and tools, and poor water quality.

While other hand pumps with reported depth capacity greater than 50 metres (BluePump, Afridev BSS, Vergnet HPV100, Poldaw and IMII ED) are available in Africa, an evaluation of performance, ergonomics and sustainability by Cornet (2012) found them all to fall short of end-user and WASH organization requirements. For example, the Afridev BSS experienced similar maintenance and reliability issues as the standard Afridev, and most women respondents indicated that the BluePump was not comfortable to use. Further, Design Outreach (DO) interviews with African WASH managers have revealed that the maximum "practical" depth of these pumps is less than that published, because flow rate and reliability drop considerably as the pumps approach their maximum depth. Such pumps are also accompanied by increased actuation force at these depths, negatively affecting ergonomics.

Even with these known issues, generally, "there is no clear agreement on the need to improve the design of public domain hand pumps, despite their limitations and known faults" (Furey, 2019). However, the governments of Zambia and Malawi have decided to take action. Selecting a new hand pump technology requires conforming to existing policies on Village Level Operation and Maintenance (VLOM). However, the popular concept of VLOM, as defined by the World Bank hand pump project in the 1980's, has not been overwhelmingly successful, and there is growing evidence that external support is needed for long-term sustainability (Furey, 2019). Additionally, the idea that local manufacturing of hand pump components is critical for sustainability is not as strong as it once was, leading to new, sustainable, business models where appropriate technology can, at least in part, be imported (Furey, 2019). A recipe for sustainability includes appropriate technology coupled with a resilient supply chain and training.

Developing new, appropriate technologies for rural water supply is needed, and the RWSN has reported on popular hand pump technologies, namely the India Mark II/III, Afridev and the Zimbabwe Bush Pump (Bauman and Furey, 2013). With historical data in mind, it is recommended that new hand pump technologies should undergo a validation/pilot programme, be retrofittable with existing wells, and have an affordable total cost of ownership (Furey, 2019). Furthermore, it is recommended to involve partners such as central/district/local government, donors, NGOs, private sector, pump minders/area mechanics and community members (Oates and Mwathunga, 2018; Nkhosi, 2020). The governments of Zambia and Malawi took these recommendations into consideration when searching for new, appropriate, technology solutions for rural water supply. This paper focuses on policy reform in the Water, Sanitation and Hygiene sector initiated by the governments of Zambia and Malawi in partnership with the NGO Design Outreach (Ohio, USA, and Lilongwe, Malawi), who invented the LifePump. The paper provides an overview of the process that was followed to standardize LifePump in Zambia and Malawi.

The LifePump pilot programme

The Design Outreach LifePump, an Ultra-Deep Handpump

The LifePump has the capability to address many challenges of ultra-deep groundwater extraction. The initial model of LifePump reaches 100 metres ("LifePump"), and a new model launched in 2019 reaches 150 metres ("LifePump150"). The difference between LifePump and LifePump150 is the progressive cavity element's geometry and gearing ratio (1:1 in the LifePump150 and 1.5:1 in the LifePump). The LifePump150 pumping element is more expensive, so it is therefore only recommended for depths of 101 to 150 metres. Since groundwater levels in Zambia and Malawi do not require such ultra-depth, the 150-metre claim was not validated in either country but through laboratory testing (via backpressure) and in-ground testing in the Caribbean country of Haiti. In 2018, a LifePump was installed at 150 metres with a static water level (water level to spout) of 99 metres in Haiti. This ultra-depth is useful looking into the future, as groundwater continues to drop in Zambia and Malawi and will require deeper reach. Shown in Figure 1 is a comparison of LifePump to India Mark II and Afridev hand pumps, where LifePump can reach approximately three times the depth of commonly used hand pumps.

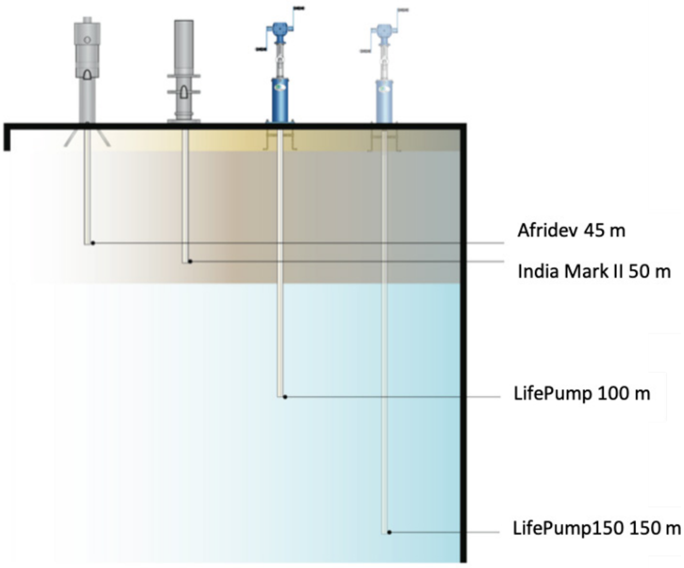

Figure 1: Depth comparison of LifePump to common standard hand pumps with new LifePump150 (adapted from Bixler et al., 2016)

Besides the depth advantage, the LifePump can operate maintenance-free for five years, thus providing a substantially smaller operation and maintenance cost. This is due to the progressive cavity pumping element design, lead-free brass foot valve, heavy-duty gearbox and stainless-steel components. Progressive cavity hand pumps have existed since the 1970's, with Moyno, Orbit, and Mono, which provided a baseline for the development of LifePump. The aforementioned progressive cavity pumps were analyzed and found to not meet user needs of ease of use, depth capacity, and thus sustainability (Cornet, 2012).

LifePump Pilot Programme Overview

LifePump was piloted in partnership with World Vision Zambia for six years and World Vision Malawi for seven years to determine its suitability. World Vision was selected as a pilot partner due to initial enthusiasm to solve the depth issues experienced with standard hand pumps. To date, LifePump has been implemented in ten countries and with seventeen NGOs, namely in: Zambia, Malawi, Mali, Central African Republic, South Sudan, Kenya, Ethiopia, Zimbabwe, Haiti and Guatemala.

In November 2013, World Vision Malawi installed the first LifePump at a location where an Afridev was struggling, thus kicking off the pilot programme (see Figure 2). Following this successful installation, a total of 11 LifePumps were installed in Zambia and Malawi during the years 2013 to 2015 as part of the original government compliance programme, with a total of 26 LifePumps evaluated during the pilot programme from 2013 to 2017, as shown in Table 1. This limited number of LifePumps were spread across World Vision's active catchment areas where depth and reliability were problematic.

Figure 2: First LifePump installed in Zolomondo Village, Kasungu District, Malawi, November 2013

Shown in the table are well depth, pump depth, installation date, longest interval between service and average usage (collected from remote sensors). Remote sensors were installed throughout the pilot programme, and the values shown were collected after completion of the pilot programme, but are included in the Table to provide an assumed, average value of use since installation. The continuous years of uptime is defined as the duration of time that water was available consecutive days. Select updates were performed (as described later) but did not lead to any days without water. When updates were performed, the clock on consecutive days was reset. By early 2021, a total of 140 LifePumps had been installed in ten countries worldwide, and the results from nine countries were shared with Zambian and Malawian government officials during update meetings (the 10th country was included after conclusion of the Zambian and Malawian pilots). The successful pilot has been a key input to the new policy reform for ultra-deep hand pumps in the respective countries.

Country	Community Name	Well Depth (metres)	Pump Depth (metres)	LifePump Installation Date	Longest Interval Between Service (Days)	Longest Interval Between Service (Years)	Longest Interval Between Service	Average Daily Usage Since Installation (HH:MM)
Malawi	Chilekwa	97	60	November 17, 2013	2144	5.87	5 years, 10 months, 13 days	9:13
	Mzondi Kasambara	72	60	June 1, 2015	1709	4.68	4 years, 8 months, 4 days	n/a
	Nyakose	66	57	May 29, 2014	1843	5.05	5 years, 16 days	5:40
	Vinyanda Chirwa	87	60	August 8, 2015	1301	3.56	3 years, 6 months, 24 days	2:35
	Yeremia Shumba	n/a	42	August 9, 2015	1600	4.38	4 years, 4 months, 18 days	6:39
	Yesaya Mbiko Shumba	60	45	August 10, 2015	1065	2.92	2 years, 10 months, 30 days	8:08
	Zolomondo	63	55	November 14, 2013	1514	4.15	4 years, 1 month, 22 days	7:49
Zambia	Big Concession	90	60	December 10, 2014	1756	4.81	4 years, 9 months, 21 days	3:22
	Chibwalu	78	60	August 25, 2017	1212	3.32	3 years, 3 months, 26 days	8:18
	Chisuwo	78	57	August 28, 2017	1171	3.21	3 years, 2 months, 16 days	1:35
	Chulungoma	51	n/a	October 5, 2017	1088	2.98	2 years, 11 months, 23 days	4:29
	Kafwikamo Camp	80	54	May 27, 2017	1254	3.44	3 years, 5 months, 7 days	n/a
	Kafwikamo School	60	40	December 11, 2014	1755	4.81	4 years, 9 months, 20 days	3:35
	Kanundwa school	52	42	January 23, 2015	1712	4.69	4 years, 8 months, 7 days	0:22
	Matambo A	90	73	October 4, 2017	795	2.18	2 years, 2 months, 5 days	3:09
	Matelo	65	45	May 26, 2015	1951	5.35	5 years, 4 months, 4 days	3:21
	Mukolochi A	68	51	October 6, 2017	1202	3.29	3 years, 3 months, 16 days	3:51
	Mwanjeleka	76	54	August 25, 2017	1209	3.31	3 years, 3 months, 23 days	2:42
	New Mbulu A	86	75	September 20, 2017	1094	3.00	2 years, 11 months, 29 days	5:50
	New Mbulu B	72	60	September 23, 2017	1091	2.99	2 years, 11 months, 26 days	n/a
	Nsaika	52	n/a	September 27, 2017	1177	3.22	3 years, 2 months, 22 days	n/a
	Shamutinta	60	51	August 27, 2017	1210	3.32	3 years, 3 months, 24 days	5:31
	Siakanzi A	74	57	August 28, 2017	1173	3.21	3 years, 2 months, 18 days	2:08
	Siakanzi B	66	54	September 26, 2017	1145	3.14	3 years, 1 month, 18 days	5:25
	Sikaneka Primary School	54	45	October 3, 2017	1137	3.12	3 years, 1 month, 10 days	2:50
	Simapumba	45	n/a	September 30, 2017	1139	3.12	3 years, 1 month, 12 days	4:09

Table 1: Longest running LifePumps evaluated in the Zambian and Malawian pilot programme (installed 2013-2017)

The innovative technology chain

The Zambian and Malawian LifePump programs were aligned with the Grubb (2004) model of the Innovation Technology Chain, with a main focus on Research and Development (R&D). The Innovation Technology Chain was adopted based on the government policy guidelines for Zambia (GRZ, 2016) and Malawi (GoM, 2016). These policy documents highlight the flexibility of adopting appropriate hand pump technology innovation as part of groundwater extraction. Grubb (2004) further complements six steps of the Technology Innovation Chain, which are aligned as process pathways in the form of action research in this paper. The steps included complementing the government R&D strategy, LifePump action research and LifePump pilot programme methodology. All of these steps were implemented in both Zambia and Malawi and are described below.

Complementing the Government R&D Strategy

The overall WASH government policy in both Zambia and Malawi includes the respective R&D guidelines. This government policy framework provided some concepts as a foundation of publicly available ideas to work within the LifePump programme. The ministry had prescribed a framework within which Design Outreach, as a stakeholder, had to operate. In the process, the government WASH policy guidelines were a basic, regulatory structure which influenced the LifePump pilot programme.

As reported in the 7th RWSN Forum article (Bixler et al., 2016), early design changes in the gearbox led to the replacement of gearboxes, switching from oil- to grease-filled. Furthermore, in manufacturing, tolerancing controls on the progressive cavity pump element were updated to provide consistent torque at the handles. Later design updates include drive rod coupler material changes and new handle grips. To validate the five-year claim, select LifePumps installed in May 2015 remained untouched from any maintenance, repair, or upgraded replacement parts. This also applied to Matelo community in Zambia. Over five years later, in September 2020, the DO team, along with district water officers, performed a complete inspection of these still-functional LifePumps. More details of these pumps are described later in this paper.

LifePump Action Research

The Zambian and Malawian R&D platforms also provided or identified guidelines for basic piloting in the LifePump programme, a form of action research. Tucker et al. (2013) concur that such a pathway rolls out a form of action research which directly responds to the needs of the WASH partners, namely the government as a policy maker, community members as hand pump users, World Vision as the NGO implementor and Design Outreach as the technology innovator. Key concepts aimed to explore viability of a new asset in terms of dynamic water level depth capabilities, end user acceptance or satisfaction of the new technology, reduced O&M costs, supply chain, capacity building (Training of Trainers [ToT] programme), and production and supply in paper or electronic form of the new installation and maintenance manuals.

The ToT programme is a three-day course of classroom and in-field, practical installation demonstrations designed to fully equip participants with the knowledge and practical skills to install LifePumps. Day one is pump theory and financial justification of the LifePump, day two is an installation in a community, and day three is a recap and question time to complete the learning process. Shown in Figure 3 is part of the Zambian government's ToT field component. So far, two trainings with 28 participants have been executed in Zambia. The theory training was held at a ministry headquarters conference room in Lusaka. The initial training sessions were conducted in 2019 during June and October. Participants were invited by the ministry officials, including province engineers and district WASH coordinators. The in-field, practical sessions involved removing the LifePump and reinstalling it at Bunga Village in Chongwe District, Zambia. This training will be on-going as LifePumps continue to be installed.

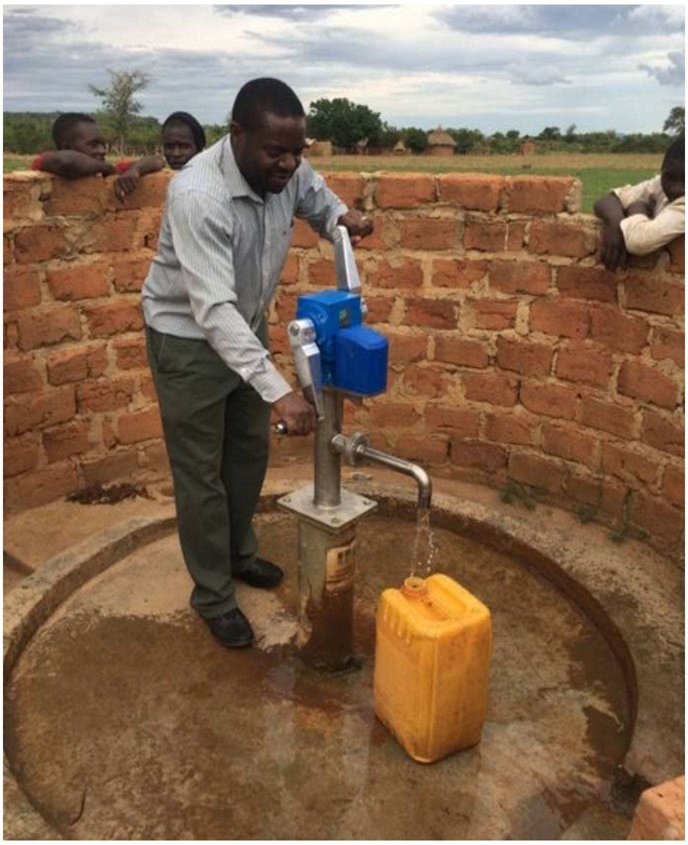

Figure 3: LifePump installed in Zambia as part of the Trainer of Trainers programme, December 2018

LifePump Pilot Programme Methodology

A significant part of the action research included the LifePump field tests. Results from the initial stages of the pilot programme co-funded by Design Outreach and World Vision were presented at the 7th Rural Water Supply Network Forum in Cote d'Ivoire in 2016. This formed the initial basis of analysis for the government evaluation for national acceptance that was completed in 2020.

LifePump locations were chosen by World Vision, working in partnership with the governments, with selected boreholes being newly drilled and other retrofits of struggling India Mark IIs or Afridevs. Presently, there are 38 LifePumps in Zambia and Malawi, including the 26 evaluated as part of the pilot programme, which are indicated in Figures 4 and 5 by yellow dots. Locations were chosen in different districts to evaluate performance in various hydrogeological settings and water level depths. Depths varied depending on hydrogeology (see Table 1), and some LifePumps were installed at high-use locations where standard hand pumps were requiring too much maintenance for the community to afford. Data was collected on community visits as well as by using satellite-based, remote-sensing technology (called LifePumpLink) in select locations. LifePumpLink was developed by Design Outreach in collaboration with SonSet Solutions (Indiana, USA) in order to collect and transmit daily usage information to the internet to be viewed anywhere in the world where an internet connection is available. It should be noted that during the pilot programme, the LifePumpLink was itself under development, and not a significant source of data acquisition. Some LifePumpLinks show LifePumps being used over 21 hours per day during the peak of the dry season in October.

Figure 4: LifePump pilot programme locations in Zambia, 24 installed since 2014 as part of the government pilot programme

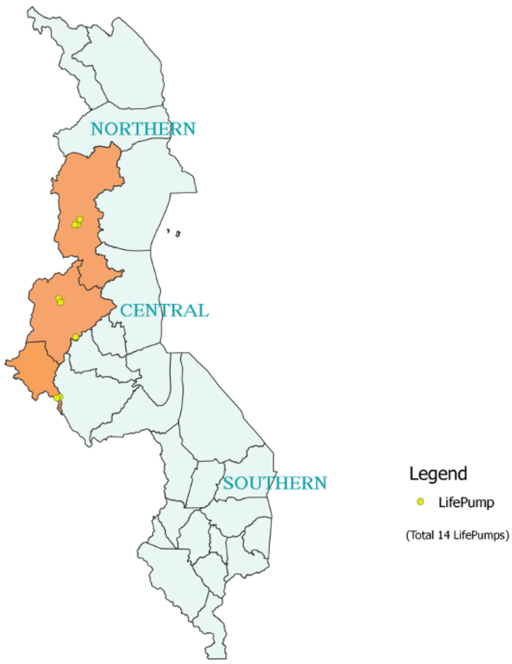

Figure 5: LifePump pilot programme locations in Malawi, 14 installed since 2013 as part of the government pilot programme

Selected data from LifePumpLinks, shown in Figure 6, highlights the ability to monitor seasonality and human-factor performance. There is a correlation between handle rotational speed and handle torque, where higher speeds and lower torques mean increased user acceptability. Furthermore, rotational data can be used with mean time between failure data to accurately predict a preventative maintenance schedule for government, NGO, and private sector stakeholders. Using the number of handle rotations taken to fill a 20 litre container provides flow rate and volumetric efficiency over time. This data is also helpful for site comparisons once a year by a LifePump technician, to see if the efficiency of filling the bucket changes over time. Such data can help policy-makers understand areas of high need and inform water utility providers about when preventative maintenance may be necessary to ensure 100% uptime.

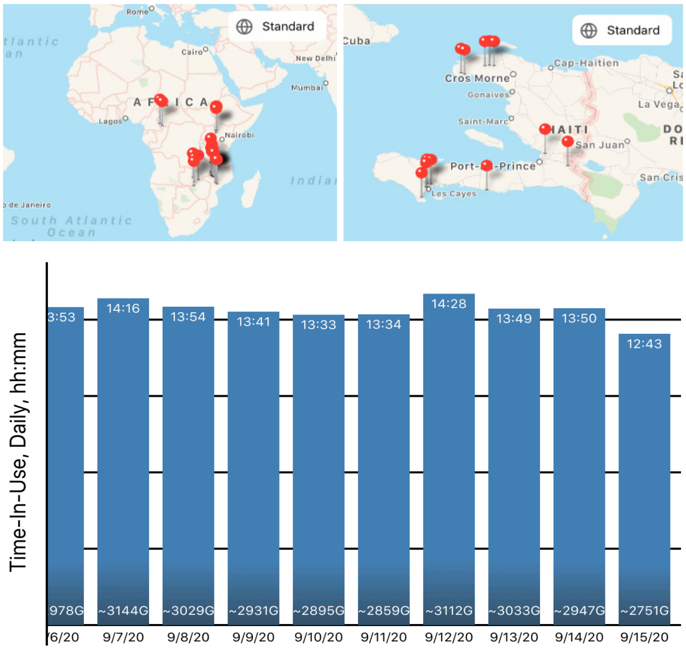

Figure 6: LifePumpLink locations shown in Africa and the Caribbean (above) and example data of performance over time for a LifePump in Malawi (below)

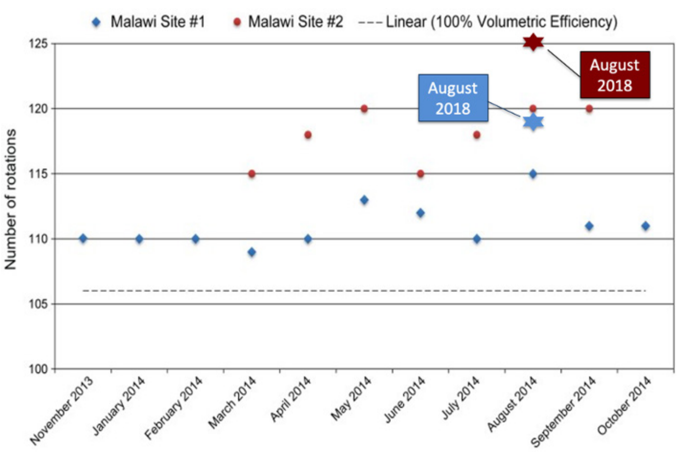

Figure 7: Volumetric efficiency test collected over 4 years and 9 months in Kasungu District, Malawi, LifePump communities (modified from Bixler et al., 2016 with new 2018 data points). Pump depths of Malawi Sites #1 and #2 were 57 and 81 metres respectively.

In addition to the number of rotations per day, LifePump performance was measured quantitatively by collecting the number of rotations and time to fill a 20 litre/ approximately 5 gallon container to calculate volumetric efficiency. Figure 7 shows this data collected over a four-year and nine-month period, where the number of handle rotations to fill the 20 litre bucket were recorded. Data was collected by Water Committee members, World Vision Malawi and DO staff. The data shows that the number of handle rotations increased by 5-10% over this period of time. This suggests that a small amount of normal wear and tear occurs between the rotor and stator in the progressive cavity pump element.

Handle torque was also collected using a rotating torque meter in order to quantify the user input. Feedback from interviews with women, children and "aged" users was considered to understand the acceptable level of effort to pump. There is a practical limit to how much effort users can exert, so the LifePump seeks to remain below that practical threshold. In general, teenage and adult users are able to pump solo, whereas children under ten years of age often work together to turn the handles (one per handle). Low torque often increases community acceptance, whereas high torque can deter some users. Initial LifePumps required a higher amount of torque before break-in would occur, which could range from three weeks to three months, at which point users were more comfortable turning the handles. A redesign of the progressive cavity pumping element and introduction of three gearbox gearing ratios alleviated this challenge.

Qualitatively, visible signs of development were observed during community visits, such as new schools, teachers accepting positions at schools, increases in attendance at schools, new brick homes, new latrines, new community gardens, fewer cases of diarrhoeal disease, and an increased number of animals and new businesses. For example, at the Kafwikamo Community School in Zambia, the headmaster stated that within two years, because of the LifePump operating continuously without needing repairs, they were able to start a new garden to grow vegetables to feed students and sell. They also made bricks with the water to build a teacher dormitory, eating/kitchen area, and six school pit latrines. According to the headmaster, these were possible, because they could depend on the LifePump operating during the dry season. The headmaster said the LifePump gave the school confidence to start a garden, because previously when their India Mark II would stop working, they did not have nearby water to keep their garden watered and their plants would not survive. The community used to have an India Mark II that required repairs every three to four months, which was a financial burden for the school. In Zolomondo, Malawi, the water committee chairwoman stated how brick making had become a business and that people in the community were starting new gardens and keeping animals thanks to the consistent water supply provided by LifePump. They also received a new school building from an NGO who wanted to invest, since there was a sustainable supply of water.

Laboratory tests in the United States were performed by both Design Outreach and, independently, by Messiah College, collecting accelerated life testing data, as shown in a 7th RWSN Forum article (Bixler et al., 2016). Components were collected from selected community locations over a period of time to analyze in the laboratory. Data was collected as part of the laboratory studies, and values were correlated with data collected from LifePumps in communities. The tests included backpressure simulating depth (pascal), handle torque (newton-metre), and flow rate (litres/min).

The action research process was iterative and accommodated technology changes based on lessons learned. Design updates were made observing recommendations from government officials, NGOs and community members. These include offering three gearbox gear ratios selected according to water depth, switching from an oil to grease-filled gearboxes to prevent leaking, new metal handle grips to maximize life expectancy, drive rod coupler material changes to prevent galling (cold-welding between stainless steel) and galvanic corrosion (electrochemical process of ion exchange), base design to accommodate India Mark II or Afridev retrofits (where LifePump is mounted directly onto an existing base without any modifications), material changes in the stator to reduce handle torque, improvements on the installation and maintenance manuals, and improvements on installation and maintenance tools. With regard to the three gearbox options, the ratio can be chosen based on factors such as location and depth. For instance, if the LifePump is located at a primary school, a lower ratio may be preferred to make pumping easier, with the trade-off in flow rate (for example, higher gearing ratio equates to higher flow rate for a given RPM, where the ratio is number of drive rod rotations to number of handle rotations). As the LifePump reaches deeper, a lower ratio is generally recommended for average users. The recommendation for gearbox ratios includes 0-50 metres (2:1 ratio), 51-90 metres (1.5:1 ratio) and 91-150 metres (1:1 ratio).

In select locations, upgrades were performed during the pilot programme, and original components were analyzed for wear, but select LifePumps remained "untouched" for at least five years, meaning no repairs, maintenance or upgrades were performed during this period of time. Upgrades (based on pilot learnings) included drive rod couplers, gearboxes, handle grips and progressive cavity pump elements. All communities had access to continuous water supply from the LifePump, despite these upgrades, since work in each case took less than a day. LifePumps that remained "untouched" (from May 2015 to September 2020) included Mayanga and Matelo villages in Zambia. The Matelo village LifePump is shown functional in Figure 8 after five years and three months.

Since wear and tear, maintenance schedule and usage are directly correlated, Figure 9 shows key data for the 26 LifePump pilot locations in Zambia and Malawi. Shown is the longest interval between LifePump service and the average use since the LifePumpLink installation. Even though the LifePump use data was not available during the pilot programme (because many of the LifePumpLinks were installed in 2020, after the pilot was completed), it is useful to consider with regard to the longest interval between service values also shown. Assuming that the usage has remained relatively consistent over time, the data indicates that the average time between service was three years and nine months, with the maximum five years and ten months. The average usage was four hours and thirty-five minutes per day. It should be noted that the service intervals were cut short due to travel convenience and replacing components to study wear and tear in the laboratory.

Results were regularly shared in workshops or round table meetings with government and NGO officials describing opportunities, challenges and threats. Round table meetings to bind networks and engage policy-makers were arranged at different platforms. The new LifePump ultra-deep hand pump policy depended on key relationships with stakeholders and the government WASH sector as decision-makers. Presentations were conducted in a timely manner and with regular frequency to the governments and NGO partners (often every three to six months).

Figure 8: LifePump installed in Matelo Village, northeastern Zambia, after 5 years and 3 months of continuous uptime without any maintenance, repairs or replacement parts

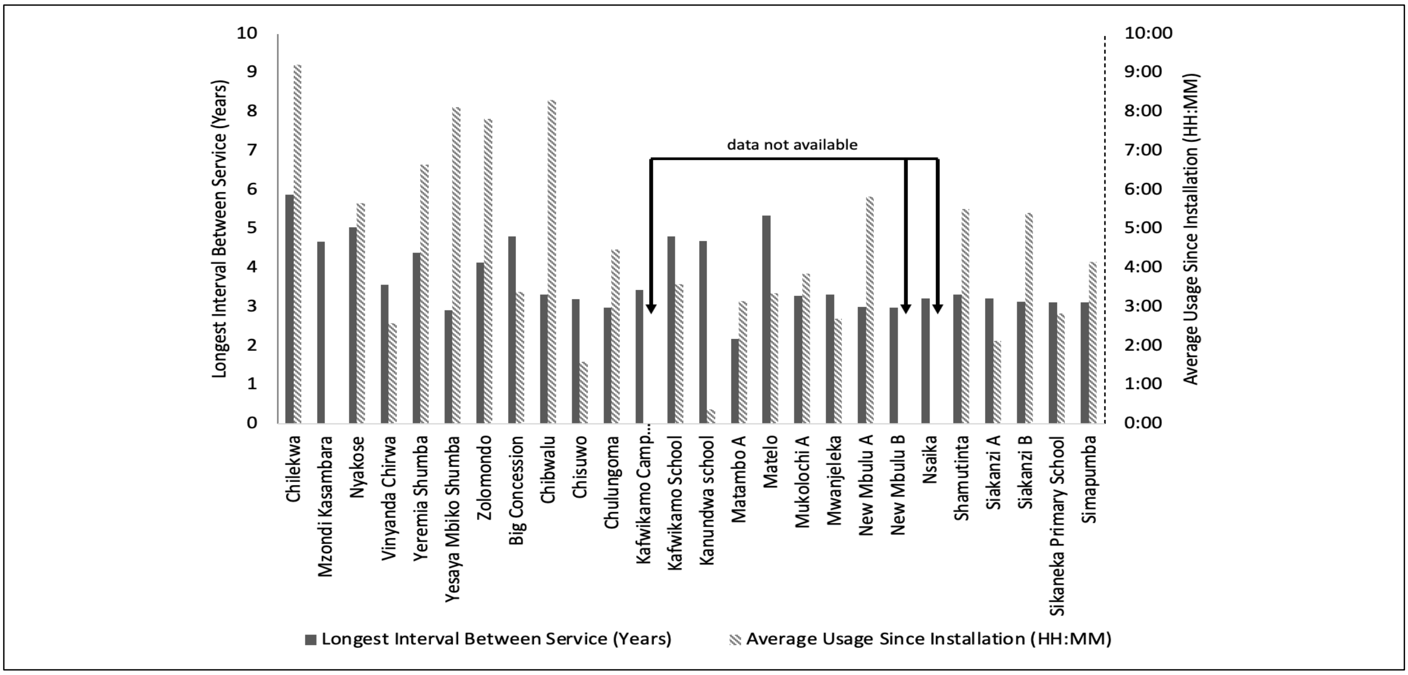

Figure 9: Zambia and Malawi LifePumps highlighting longest intervals between service and average usage since installation (borehole data shown in Table 1)

The LifePump policy update

In the case of LifePump, the decision to vote on adopting it as a national standard hand pump started with Design Outreach as the "decision developer" and the government as the "decision-maker". This was designed to discuss LifePump at policy level, based on a successful pilot programme in Zambia and Malawi. There had been many initiatives to strengthen the relationship between the decision-developer and the decision-maker. This included several round table meetings with ministry officials as part of sharing the pilot programme field data and arriving at a decision as a team. Personnel were appointed by the ministries of water in Zambia and Malawi to oversee the performance of the LifePump programme. They played key roles in policy decision making for ultra-deep wells by bringing together stakeholders who could be affected by or have an interest in the ultra-deep wells. The policy consistency issue was to ensure the ultra-deep wells policy resonated with and contributed to the overall ministry objectives, including inputs from international and local NGOs. WASH multisector advisory committees comprised of government, private sector and NGOs conducted field visits.

This pathway focused on building organizational strategies relating to a long-term influence through creating human capital, binding networks, and engaging policy makers (Stone, 2009). Participation differed depending on the workshop thematic area. Workshops aimed at determining credibility of the LifePump involved WASH NGO leaders, province engineers, District WASH Coordinators, donor representatives, members of parliament and ministry officials, as well as coordination bodies such as the Water Resources Management Authority (WARMA).

In Zambia, there had been five round table meetings on different occasions from 2017 to 2018, starting with a two-day workshop in Lusaka, to review the LifePump pilot in terms of its success, failures and lessons learned before the government adopted the new technology at policy level. Ministry officials and some NGOs were taken to see the nearest LifePumps installed at Kafwikamo and Big Concession in Mumbwa District. WASH stakeholders, including NGOs, were invited to a one-day, debriefing meeting at Cresta Golf View Hotel in Lusaka. More than 30 participants attended this meeting in 2017, which was followed by subsequent meetings at Village Water offices, an NGO in Zambia. The main topics were LifePump pilot programme debriefing, discussion, and debates on what had or had not worked during the previous three years of the pilot programme, and the path forward. Several formal and informal meetings were held with the Ministry of Water Development, Sanitation and Environmental Protection supply officials, as well as with WARMA.

In Malawi, there had also been several round table meetings on different occasions from 2017 to 2018 with top WASH government officials from the Ministry of Forestry and Natural Resources. In addition to the face-to-face meetings, the other key component focused on having interface of policy-level government officials with LifePump users. The government officials wanted to establish end-user, new technology acceptance and satisfaction, including usability for young and aged users. Government officials were especially interested in retrofit situations where LifePumps replaced Afridevs, such as Zolomondo and Nyakose, given the challenges faced by Afridevs of lifting water from greater depths. The end users were often asked by the government officials whether the LifePump should be replaced with the Afridev. This question gave a direct, clear picture of the users' perception of the LifePump as compared to the Afridev. In these sites, the LifePump was installed deeper than the Afridev in the existing boreholes, which helped ensure year-round water supply, despite dropping groundwater levels. In these communities, the users interviewed responded that they wanted to keep the LifePumps. They were thankful for no breakdowns and that water was available year round. A common question was about the supply chain in the future.

Additionally in Malawi, another platform for debriefing the new technology targeted the Women's Parliamentary Caucus. Women parliamentarians perceive access to clean water as women's right. Just like the ministry officials, the women legislators also asked to visit the LifePump sites to determine the new technology viability and the extent to which it was user friendly. Site visits included travelling to Kasungu District to witness the first LifePump installed at Zolomondo. Prior to the visit, there had been a debriefing with the Women's Parliamentary Caucus in 2017. Feedback from parliamentarians was positive, corroborating the message heard from community members during the site visits. The Women's Caucus key action point was to have a task force to work with the ministry on how the pump would be adopted at policy level. The ministry adopted the LifePump at policy level in August 2018 through a formal, written communication. This was followed by a series of debriefing workshops for the WASH stakeholders. One main debriefing meeting was held at Evelyn Conference Centre in September 2018 with a focus to orient the WASH-partners in Lilongwe. This meeting was followed by regional level debriefings. In 2019, a total of three meetings were held in each of the three Malawi regions. These were mainly for debriefing the WASH government officials at district level for all the 29 districts in the country.

Figure 10: Second LifePump installed in Chilekwa Village, Kasungu District, Malawi, August 2018

In May 2019, a letter outlining the conditional acceptance of LifePump as a national hand pump standard was distributed by the Zambian Ministry of Water Development, Sanitation, and Environmental Protection, signed by the Permanent Secretary. Final approval was given in 2020, following the initial distribution of spare parts, tools, and ToT programme. This was the result of five years of piloting and a vote by a delegation of stakeholders assembled in Lusaka, Zambia. Shortly thereafter, a similar meeting was held in Malawi with national acceptance of LifePump. Per the policy documents, LifePump is to complement existing standard hand pumps in each country, which includes the India Mark II (0-50 metres) in Zambia and the Afridev (0-30 metres) in Malawi. In boreholes exceeding these depths, the LifePump is the recommended national standard.

In summary, the LifePump was adopted at the national level by engaging key government officials, NGOs, private sector and community members, sharing hand pump pilot data with key stakeholders in a timely manner and following best practices (Young, 2005). There were several key components that helped promote the adoption of LifePump, including:

a. The governments in both Zambia and Malawi made a clear, political commitment to the need for emerging, appropriate technology to adapt to climate change challenges.The government of Zambia created a committee or core group which drafted the documentation to be part of the policy document.

b. In Zambia and Malawi, Design Outreach played a significant role in facilitating the formation of the core group task forces.

c. In Zambia and Malawi, World Vision played a significant role in LifePump piloting, as well as testifying as implementors, in government and NGO meetings.

d. Guidelines formed were endorsed through workshops and management of the ministries responsible for water and sanitation. In Zambia, two workshops were conducted. Stakeholders reviewed the new policy guidelines and adjusted accordingly. In Malawi, three workshops were conducted as part of the new policy dissemination process in each region. Key issues in the guidelines were as follows:

   "LifePump to complement India Mark II or Afridev at depth greater than 50 metres and 30 metres respectively; rolling out availability of spare parts; instructional manuals and training for installation and the new technology management at different levels"

e. LifePump field pilot lessons and experiences were considered.

f. There were Memorandums of Understanding (MoUs) to define roles and responsibilities. Design Outreach's key role was capacity building through the national ToT programme, production of manuals, and demonstrating to government officials the manufacturing site for due diligence.

g. Resources were committed for policy coherence, as there had been extensive discussions including round table meetings and workshops in the WASH sector.

h. Seeking political commitment through dialogue with the Women Parliamentary Caucus, a legislative/regulatory/juridical instrument in Malawi, played a role for the consideration of LifePump in national policy in Malawi.

Lessons Learned and Challenges of Implementing LifePump

Several challenges were encountered and lessons learned in the process of LifePump standardization at national policy level in Zambia and Malawi. Changing the status quo can be difficult. Some challenges were identified upfront, while others were discovered along the way.

In addition to designing, manufacturing, shipping and installing LifePumps in the pilot programme, the government procedures had additional expenses paid for by World Vision and Design Outreach. That challenge was overcome by Innovation Grant donors from World Vision as well as R&D donors from Design Outreach. Paying for the development and piloting of LifePump might have been the single largest challenge, and will continue to be it for future pilot programs in other countries. The hope is that early adopters will help reduce the barriers for acceptance in new countries.

Noteworthy challenges included policy updating, uptime debate, supply chain, scaling, cost and value proposition communication. Details are described below:

Policy Updating

There were political difficulties in the policy updating process which slowed the progress of the LifePump programme. For example, in Malawi, despite the successful five-year pilot programme, there were systemic bottlenecks, which to a larger extent were intervened upon by the legislative system, namely the Malawi Parliament Women's Caucus (comprised of 32 women legislators). They conducted an orientation of the new LifePump technology, including a field visit in Kasungu District. The outcome was that the female legislators viewed the LifePump as a needed, appropriate technology, based on end-user success stories. Therefore, they agreed *"the LifePump consistent supply of water was part of the rights of the women and the girl child in Malawi"*. The forum finally exerted some pressure on the ministry on the need for policy reform to accommodate the gap of the LifePump as an ultra-deep well in Malawi.

In Zambia, too, the key challenge was the bureaucracy, with key decision-makers in the ministry and NGO community. Decisions were centralized and perceived to be slow.

Uptime Debate

The uptime debate influenced decision-makers when considering a minimum standard for water point functionality and the need for appropriate technology. With the definition that fully functional means "as installed within the design parameters of the hardware", preventative maintenance is key for 100% uptime (as defined by no more than 24 hours downtime). As demonstrated in the pilot programme, LifePump does not have a sudden, catastrophic failure mechanism and can be monitored daily with LifePumpLink, giving a real-time indication of performance. Without such quantitative evidence from other standard hand pumps, it is challenging to compare uptime values to LifePump.

In general, standard hand pumps such as the India Mark II or Afridev require more maintenance and repairs compared to LifePump, especially when reaching depth design limits. Providing 100% uptime with India Mark II or Afridev requires a robust supply chain for the communities, where trained personnel need to respond within 24 hours to restore functionality. Typically, communities must rely on locally available parts, but often local shops do not carry all of the necessary parts or tools. Even motivated NGOs are unable to respond during certain times of the year due to impassable roads during the rainy season, which can lead to downtime. The pilot programme demonstrated that LifePump does not depend on frequent repairs for 100% uptime, thanks to the long periods between service intervals. LifePump reliability is based on its high-quality, heavy-duty components and progressive cavity design, which requires less maintenance over time and reduces the risk of catastrophic failure, alleviating pressure on the supply chain. When catastrophic failure is not a high risk, planned maintenance is more feasible.

Supply Chain and Future Outlook

In order to be in compliance with national standards on hand pump technologies, the governments require a sufficient supply chain of spare parts, installation and service personnel. This includes Pump Minder/Area Mechanics, LifePump Technicians, LifePumps, tools and spare parts. The same personnel who install and maintain existing standard hand pumps are being trained to service LifePumps. Spare parts are stocked alongside existing standard hand pumps. Complete sets of LifePumps are stocked in each country, along with fast-moving spare parts and tools in each district where LifePumps are located. LifePump spare parts and tools can be further from communities in district offices or regional hubs and need not rely on local shops that often struggle to maintain a stock of spare parts and tools. Such a supply chain is to scale with the installation of new LifePumps.

The Zambian and Malawian pilot programs have provided much evidence of what maintenance is needed relating to use rate, thus leading to accurate calculations of cost to provide 100% uptime. With this data guiding decisions, Design Outreach, in partnership with the governments, is piggybacking on existing supply chains, as shown in Figure 11. In this model, the NGO or implementor initiates the process and partners with government officials, Water Point Committee members, Pump Minders/Area Mechanics and LifePump Technicians. This model helps provide 100% uptime and keep costs as low as $0.12 USD/person/year, using a proposed "water utility model". The concept of a water utility model is gaining traction globally, but the financial analysis shows the model is still being subsidized (McNicholl et al., 2019). Water utilities are based on the notion that communities will pay for water (vs. pump repairs). With such systems, the private sector is able to provide water service and is incentivized to keep 100% uptime so that the consumers continue to pay. In Kenya, Fundifix performs preventative maintenance with recurring costs of $1.5-2 USD person/year, and other NGOs report higher costs per person/year (Deal and Furey, 2019). The LifePump preventative maintenance model is based on $0.10-0.20 USD/person/year, which increases the likelihood of affordability for rural communities.

Design Outreach continues to invest in a supply of LifePumps, tools, and spare parts to be stocked in Lilongwe, Malawi, which serves as a regional hub for Zambia as well. Minor maintenance is performed by local Pump Minders in Zambia and Area Mechanics in Malawi at the community level. Major maintenance is provided by certified LifePump Technicians who are employed by the NGO or the private sector to operate a water utility programme. Design Outreach is committed to continue the ToT programme and stocking of spare parts and tools in each district to increase capacity. This will be initially paid for through donors and earned revenue from pump sales. The assumption is that each community is able to collect at most $0.20 USD/person/year. This translates to $50 USD for a community of 250 people. The funds may be collected by the Water Point Committee and deposited into a bank account or invested in other ways, as appropriate. This plugs into the existing government model for water point management but also supplements the model with lower cost O&M and centrally located LifePump technicians who help ensure 100% uptime.

Collecting fees is an ongoing struggle for many communities. The assumption is that when communities benefit economically from the continuous water supply, they are more likely to be able to contribute funds for maintenance. A pump that requires less maintenance and money at the village level is assumed to be better than one that requires more maintenance and money to operate. Future research on this claim could be funded and conducted. Total cost of O&M over a 30-year lifespan for each LifePump is estimated at $26 USD/year in Zambia or Malawi. This is assuming initial, upfront, one-time costs, such as the initial supply of spare parts, tools, storage and transportation, are covered by donors. The financial breakdown is estimated in Table 2, showing recommended minor and major maintenance, with an assumed 250 LifePumps per LifePump Technician and 6 hours of pumping per day per LifePump (thus assuming an average wear and tear based on number of handle rotations). Extreme high use such as 21 hours per day would increase necessary maintenance.

An assumption is that the LifePumpLink is being used in some capacity, either to provide a baseline understanding of average use and/or periodic data viewed from anywhere in the world. This average use data taken over a set period of time can be used to predict when maintenance is needed (i.e. averaging 6 hours/day versus 15 hours/day will require different maintenance schedules). The cost for LifePumpLink satellite data transmission is about $0.2 USD/transmission. New software and financial models are being developed to minimize data transmissions and thus lower the annual data cost, but yet still provide enough data for preventative maintenance. The governments of Zambia and Malawi are keen to see this

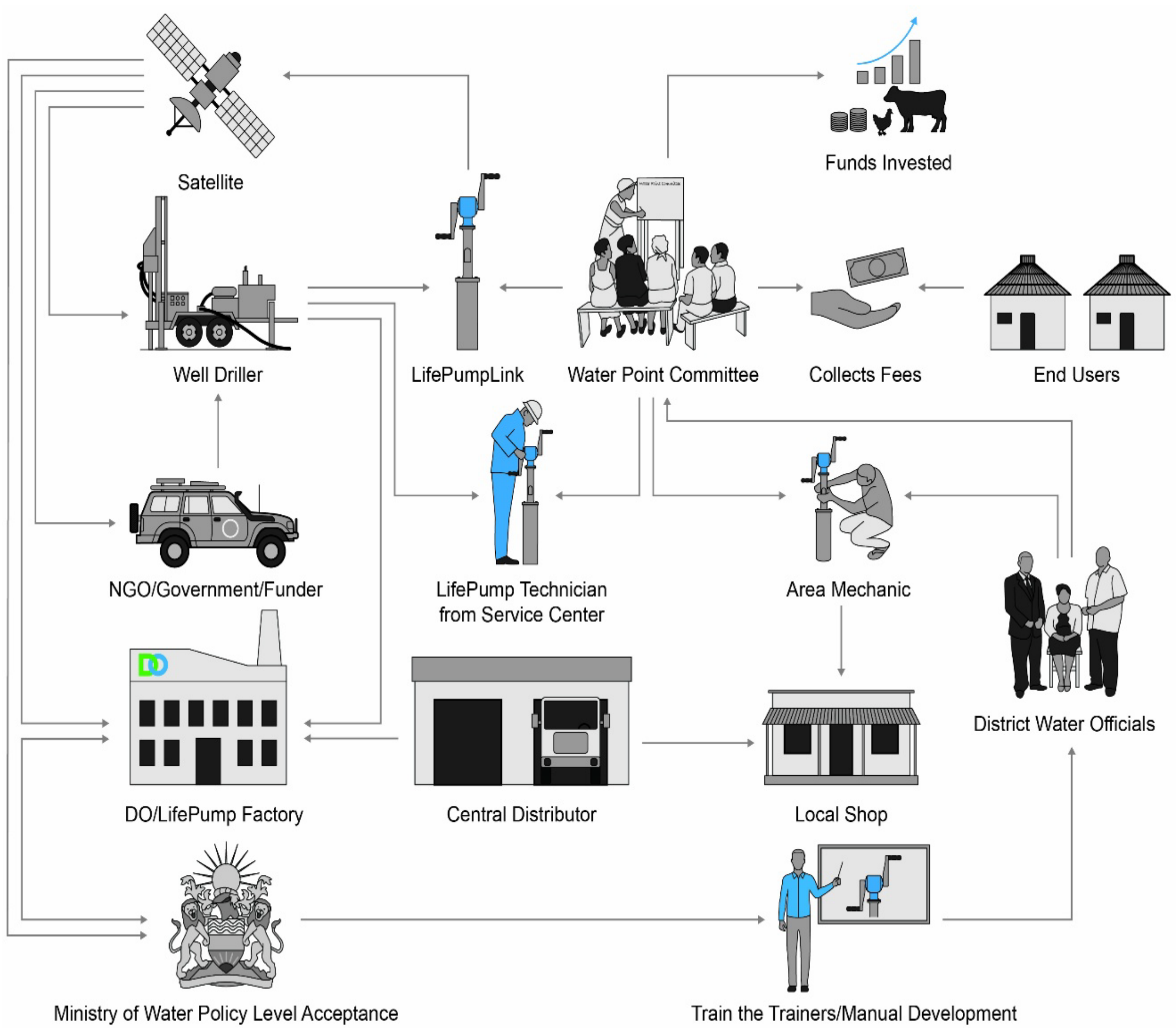

Figure 11: Sustainable LifePump Water Utility Model for preventative maintenance, complementing existing models

data to remotely (and cost effectively) monitor country-wide water supply and know where to dispatch additional resources in areas of greatest need.

Training the national government officials was performed by Design Outreach and then spread to the Sustainable Operation and Maintenance Project (SOMAPS) offices in Zambia and district offices in Malawi, stocked with spare parts and tools. The District Council SOMAP shops which have LifePump spare parts include Mumbwa, Sinazongwe, Monze, Mbala and Chongwe Districts. Well drillers may qualify as LifePump installers by completing a certification programme. LifePump Technicians (performing major maintenance) are responsible for ensuring 100% uptime of LifePumps and annual check-ins with the Water Point Committees. There will be a ramp-up stage for financial independence as the number of LifePumps increases. LifePump Technicians will be staff members of implementing partners and are to be self-sustaining when the volume of pumps reaches 250 LifePumps per LifePump Technician. This is achieved through scaling up across districts in both countries. While volumes increase, the first LifePump Technicians will act to raise awareness within communities and provide quality assurance for training Pump Minders or Area Mechanics, who perform minor maintenance. With every 250 LifePumps installed, a new LifePump Technician will be hired. There will be an apprenticeship programme in place that scales with sales volume.

A new innovation underway includes motorizing the LifePump and connecting to piped water systems, where the LifePump can be manually operated when necessary. Such a technology could increase

	5 years	10 years	15 years	20 years	25 years
Service Personnel	Pump Minder/ Area Mechanic	LifePump Technician	Pump Minder/ Area Mechanic and LifePump Technician	LifePump Technician	Pump Minder/ Area Mechanic
Preventative Maintenance Recommended	Topside check out – fasteners, battery change*, volumetric efficiency measurement	Topside check out – fasteners, battery change*, volumetric efficiency measurement, gearbox refurbishment	Topside and downhole check out – fasteners, battery change*, volumetric efficiency measurement, rotor and stator, rollers, and foot valve replacement	Topside check out – fasteners, battery change*, volumetric efficiency measurement, gearbox refurbishment	Topside check out – fasteners, battery change*, volumetric efficiency measurement
Estimated Costs to Community (USD)	$75	$175	$275	$175	$75

*Battery changes only applicable if LifePumpLink is installed

Table 2: Service interval for LifePump in normal operating conditions (6-hours/day)

flow rate by three to four times, providing more water to larger communities, and be a cost-effective upgrade for an existing LifePump. This new technology is being developed by Design Outreach and is expected to pilot in Malawi as soon as 2022.

Scaling and Cost

Scaling poses challenges regarding upfront investment needed to stock LifePumps, tools and spare parts in country. This is being funded by Design Outreach with a long-term commitment in place and is expected to scale with and through the sale of LifePumps. A portion of the earned revenue from the sale of LifePumps is being reinvested by Design Outreach in supply chain. A subsidized supply chain is needed as sales are growing, as such additional funding is needed by philanthropic sources to support NGOs complying with government policy to use LifePumps. Furthermore, Design Outreach is investing in tooling and manufacturing equipment to increase volumes, reduce per-unit cost and bring manufacturing to Africa. This is expected to help create local jobs and reduce shipping costs for LifePump parts.

LifePump's upfront hardware cost is higher than that of commonly used India Mark II or Afridev pumps due to its stainless-steel construction. This initial cost creates a barrier for adoption, since NGO budgets are based on commonly-used technology. But when considering the cost of dry boreholes (beyond the practical depth limit) and repair/maintenance costs of standard hand pumps in deep wells or high use situations, the LifePump can be less expensive when complementing standard hand pumps. Details on how this works economically will vary between NGOs with factors such as depth, accounting practices, uptime strategy and community population. Additional financial analysis will continue to validate the cost savings.

With proper investment in tooling, inventory for higher volumes, and with a minimum of 100 LifePumps/month or 1,200 per year, Design Outreach estimates that the price can be reduced significantly and still maintain a sufficient margin to cover operations costs and continually invest in the supply chain. Manufacturing suppliers for LifePump were presented to the Zambian and Malawian government officials, with commitments from the suppliers to scale as necessary. This was originally planned as in-person visits, but responding to COVID-19 travel restrictions, DO provided video interviews with key suppliers, highlighting their commitments and scaling capacity.

LifePump costs are based on depth, and the present average cost, for example, of a 60-metre LifePump is approximately $5,500 USD in low volumes (100 LifePumps per year). The governments of Zambia and Malawi extensively discussed the higher upfront costs compared to other standard hand pumps and the total cost of ownership. This was reviewed at length by considering upfront capital and long-term O&M expenses. The conclusion was that the value proposition, based on the pilot programme, is strong for LifePumps where the dynamic water is beyond where the India Mark II and Afridev can effectively reach. This debate will continue among NGOs who are looking to donors for additional funding.

Conclusion

Appropriate technology innovation and policy adoption is critical to solving challenges of water access for rural areas of Zambia and Malawi. Decision-makers in Zambia and Malawi have concluded that LifePump has shown itself to be effective as a long-lasting ultra-deep well water solution. A supply chain is necessary for any technology to be appropriate, although supply chains are dependent on the definition of success as well as the hardware itself. Assuming the goal is 100% uptime, the LifePump addresses the supply chain issue by requiring fewer repairs and avoiding "catastrophic" repairs that lead to imminent downtime.

This paper highlights the national acceptance overview for the Design Outreach LifePump hand pump technology as well as challenges, value proposition, supply chain, ToT programme, operation and maintenance, and lessons learned. Design Outreach realized the need for ultra-deep reaching hand pump appropriate technology, developed the LifePump, piloted it in nine countries and implemented it with World Vision in Zambia and Malawi. Continued innovation and advocacy will be needed to help change the status quo.

In general, policy reform requires a flexible, dogmatic and strategic approach while persevering through uncertainties or bottleneck experiences in normal government systems. The necessary process is time consuming and requires a strategic approach in piloting new appropriate technology, constant review of progress, monitoring and field visits to determine effectiveness, supply chain, cost, functionality and user acceptance.

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