Mobile for Development Utilities

Portland State University: GSM-enabled sensors for monitoring handpumps to improve water services in Rwanda

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Mobile for Development Utilities

The Mobile for Development Utilities Programme promotes the use of mobile technology and infrastructure to improve or increase access to basic utility services for the underserved. Our programme focuses on any energy, water or sanitation services which include a mobile component such as mobile services (voice, data, SMS, USSD), mobile money, Machine to Machine (M2M) communication, or leverage a mobile operator's brand, marketing or infrastructure (distribution and agent networks, tower infrastructure). The Programme receives support from the UK Government.

Author: Ilana Cohen

The Innovation Fund

The Mobile for Development Utilities Innovation Fund was launched in June 2013 to test and scale the use of mobile to improve or increase access to energy, water and sanitation services. In two phases of funding, grants were competitively awarded to 34 organisations across Asia and Africa. Seed grants were awarded for early stage trials, Market Validation grants for scaling or replication of business models, and Utility Partnership grants to foster partnerships between utility companies and innovators.

The specific objective of the Innovation Fund is to extract insights from the trial and scaling of these innovative models to inform three key questions for growing the sector:

- How can mobile support utility services?
- For a mobile-enabled solution to be adopted at scale, what building blocks are needed?
- What are the social and commercial impacts of delivering community services to underserved mobile subscribers?

These insights, as well as grant-specific learning objectives, are included in individual case studies such as this one, as well as thematic reports that will be published throughout 2016.

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Executive Summary

In January 2014, the Mobile for Development Utilities Programme awarded Portland State University (PSU) and their partners, SweetSense Inc.[1] and Living Water International (LWI), a Seed grant to test the use of GSM-enabled sensors to monitor rural water handpumps in Rwanda in order to improve service delivery. Handpumps are a common water service technology in much of rural Africa, yet an estimated one in three are not functional.[2] This largely reflects a lack of operations and maintenance services: non-governmental organisations (NGOs) and government institutions are typically not held accountable to deliver maintenance services after installation, and rural communities are often ill-equipped to solicit funds from users and carry out their own maintenance.

To address this, PSU's SweetLab and SweetSense Inc. tested their technology, GSM-enabled sensors, to improve service monitoring. SweetSense Inc. sensors were placed inside the pump-head to detect whether the pump is functional and send this information over the GSM network to a central database. In the case of non-functionality, the online dashboard displayed alerts for maintenance staff so they were able to make immediate repairs for better service delivery.

This service was trialled in Rwanda, where nearly 58 per cent of the population relies on groundwater resources.[3] While Rwanda's Ministry of Natural Resources is responsible for groundwater resources, water service delivery and maintenance are typically delegated to local districts, with local communities often responsible for routine maintenance of handpumps. Living Water International provides additional technical assistance to communities in 18 districts where Living Water has installed and maintained over 324 handpumps since 2007. Nonetheless, 44 per cent of these were found to be non-functional at the outset of the pilot with communities reporting this had been the status for an average of 214 days in the past year, highlighting the potential for effective monitoring to significantly improve water services.

The key objective of this grant was to test the use of GSM-enabled sensors to provide real-time, quantitative data on service delivery such as pump uptime, frequency of use, time to repair, volume of water pumped and other key indicators. Further objectives were to assess the cost effectiveness of GSM monitoring in comparison to traditional maintenance models, and the ability of local government to integrate the data for improved operations and planning. The intended business model was to eventually transfer ownership of the sensors and responsibility for the data to the Government of Rwanda. PSU partnered with MTN Rwanda for the provision of SIM cards for Machine-to-Machine (M2M) communication.

Key findings include:

GSM sensor-driven maintenance significantly increases average handpump functionality and reduces repair time compared to traditional maintenance models. A longitudinal cohort study was carried out on 181 handpumps divided into the three maintenance models described below. Sensors were equipped on all handpumps to monitor functionality, but only in the ambulance service model did the sensor data inform maintenance operations through alerts.

1. SweetSense Inc. is a private spin-off from Portland State University's SweetLab, which stands for the Sustainable Water, Energy and Environmental Technologies Laboratory.
2. Rural Water Supply Network, 2009. Handpump Data: http://www.rural-water-supply.net/en/resources/details/203
3. WHO/UNICEF, 2015. Joint Monitoring Programme, 2015 Update. Data from 2013. http://www.wssinfo.org/documents/?tx_displaycontroller per cent5Btype per cent5D=country_files

Maintenance Model	Description	Median Time to Repair (Days)	Uptime/Mean Functionality
Nominal Maintenance	Ad-hoc repairs made following random inspections or complaints	152	67.53%
Circuit Rider	Routine inspections made on a geographical circuit	57	73%
Ambulance Service	Sensors alert maintenance staff to breakages	21	91%

The cost of a sensor-enabled maintenance model is similar to traditional maintenance models, but is likely to decrease. The study tracked all capital and operational costs associated with each maintenance model, including transport and staff costs. For the ambulance model, this includes the sensor hardware cost of USD 500 over the expected sensor lifetime of two years, plus the costs of sensor maintenance. Total costs were roughly similar for maintaining a functional pump over one year when accounting for average pump functionality.[4] The sensor hardware and maintenance costs are expected to decrease with expanded production and improved design.

Sensor data for accountability of service delivery has a strong value proposition, yet international donors and NGOs may be more ready clients than governments. The ultimate objective for the Rwandan Government to take ownership of the sensors and responsibility for the data by paying a fee for services, has not yet been achieved. While the Government has been highly engaged and enthusiastic about the pilot since the outset, it is fairly restricted in its growth by its current dependency on foreign aid. Yet LWI valued the sensor data sufficiently to prioritise maintenance of existing handpumps over new installations during the pilot. It has since switched to the ambulance service model for all sensor-equipped handpumps and taken on the costs of sensor operations for at least five months following the end of the pilot. PSU subsequently revised their business model to focus on "sensors as a service" by leveraging hardware to provide data-driven decision aids. Their new contracts with NGOs and international donors, valued at over USD 2 million, suggest that this service offering has gained significant traction.

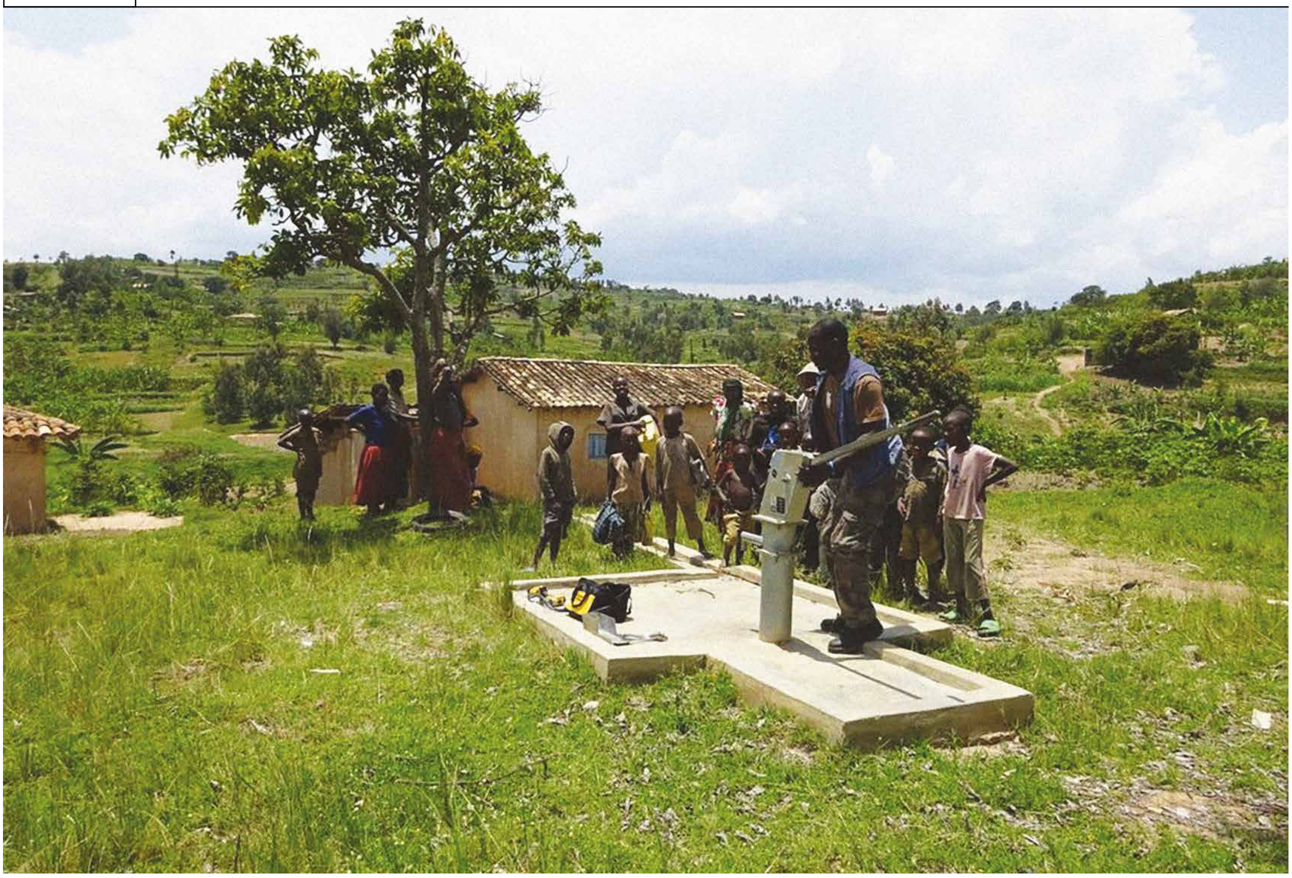
Sensor data has the potential to drive sustainable, market-based approaches for water service delivery. Monitoring with sensors could support performance-based models of financing to achieve more reliable water services. Many households served by LWI's handpumps in Rwanda have not traditionally paid for water services. However, a recent study has shown that water consumers are willing to pay five times more when service is improved by a tenfold decrease in downtime,[5] suggesting consumer payments could incentivise service providers to maintain reliable service levels. Given that consumer fees are unlikely to cover all capital and operational maintenance costs, subsidies from governments or donors for maintenance could also be disbursed based on proof of uptime through sensor data.

4. The cost for a functional year of handpump operations is based on the total costs of handpump hardware and maintenance, divided by the mean functionality (proportion of uptime).
5. Khoeler, J., Thompson, P., Hope, R., *Pump Priming Payments for Sustainable Water Services in Rural Africa*. World Development (2015). http://www.sciencedirect.com/science/article/pii/S0305750X15001291

GSM sensors for handpumps require advanced and iterative technical design of robust hardware. The sensors for this pilot were designed to operate inside the pump-head, however this led to attenuation of the GSM signal, and in some cases, sensor damage from moisture and the moving components of the pump. Furthermore, poor battery performance meant that the volume of water and flow rate could not be measured during the trial and the batteries had to be replaced more often. SweetSense Inc. is now rolling out a significantly improved sensor design with a long-life lithium battery and a watertight injection moulded enclosure that will be placed outside the pump-head.

More detailed analysis and statistics that led to the findings in this case study are included in PSU's publication in the Environmental Science and Technology journal titled "*Evaluating Cellular Instrumentation on Rural Handpumps to Improve Service Delivery- A Longitudinal Study in Rural Rwanda.*"[6]

Source: PSU



Community handpump in rural Rwanda

6. http://pubs.acs.org/doi/abs/10.1021/acs.est.5b04077

Introduction

Portland State University (PSU) launched the Sustainable Water, Energy and Environment Technology Laboratories (SweetLab) in 2010 to research how technology can support safe drinking water, sanitation, energy and environmental services in remote areas. This led to the launch of SweetSense Inc., to commercially develop sensors for data collection about usage and functionality of services that creates accountability for maintenance and enables data driven decision-making. Prior to this grant, PSU and SweetSense Inc. trialled 250 sensors in various contexts around the world. For example in Rwanda, the organisation DelAgua[7] used these sensors on clean cookstoves and water filters to verify actual household usage in order to receive financing from the United Nation's Clean Development Mechanism to pay for Rwanda's poorest households to receive the stoves and filters. As part of the Mobile for Development Utilities grant, PSU trialled these sensors for monitoring 181 handpumps to enable improved maintenance for more reliable water services. For the GSM-enabled machine-to-machine (M2M) communication, PSU partnered with MTN Rwanda for this pilot.

Partially based on the evidence from this pilot, PSU and SweetSense Inc. have attracted USD 2 million worth of contracts to further deploy sensors, including a large-scale handpump and borehole monitoring programme in Kenya, supported by USAID and the Millennium Water Alliance.[8]

Background on Living Water International and Water Services in Rwanda

PSU partnered with Living Water International (LWI) for this pilot. LWI is a non-governmental organisation (NGO), operating in 23 countries around the world, and operating in Rwanda since 2007. The organisation provides water, sanitation and hygiene infrastructure, maintenance and training and is financed through private donations.

LWI operates in Rwanda under the authority of the Government of Rwanda's Ministry of Natural Resources (MINIRENA), which is responsible for groundwater and all water services from this source. Typically, rural districts in Rwanda are responsible for operations and maintenance of water infrastructure, with private-public partnerships supporting piped services, and communities responsible for handpumps. This pilot took place in the Ruhango and Karongi districts where LWI has taken on this responsibility, having installed and maintained the majority of handpumps, which are AfriDev and India Mark 2 models.

Need for Improved Water Services

Prior to this pilot, LWI did not precisely monitor how many of their handpumps were broken; however it is widely accepted that one in three handpumps in Sub-Saharan Africa is non-functional at any given time,[9] reflecting ineffective or absent monitoring and weak local capacity to finance and implement repairs. LWI was carrying out maintenance with ad-hoc visits when possible, and planning to shift to a circuit rider model of periodic visits to pumps in geographic sequence. LWI found that communities often failed to notify them if a pump was broken because the community felt it had been installed by foreigners and therefore was not their responsibility to report handpump failures. LWI has been moving toward a more "demand-driven approach," in which communities are selected for pumps by demonstrating demand and commitment to management, and LWI encourages regular payments (which had not been previously collected). However, recent studies suggest that poor service levels may be one of the most significant reasons for non-payment,[10] and LWI has lacked real-time information about pump failures in order to maintain reliable service levels.

7. http://www.delagua.org/
8. http://www.mwawater.org/
9. Rural Water Supply Network, 2009. Handpump Data: http://www.rural-water-supply.net/en/resources/details/203
10. Koehler et al., 2015.

Key Facts about Portland State University, SweetLab and SweetSense Inc.

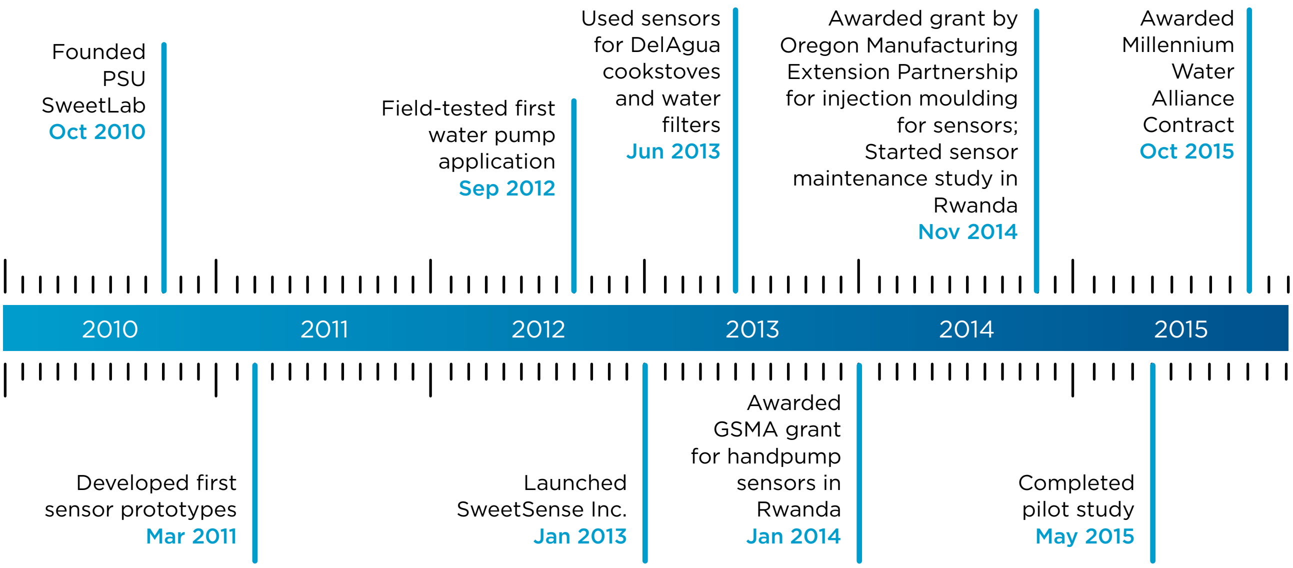
FIGURE 1

Company Overview as of November 2015

Name	Portland State University, SweetSense Inc.[11]
Sector	Water for grant pilot; focused more broadly on water, energy and sanitation
Year Established	SweetLab in 2010, launched SweetSense Inc. in 2013
Country Footprint	Rwanda, Kenya, India, Indonesia, Haiti, Guatemala, India, USA
Product/Service	A sensor that communicates remote information via GSM networks; can be modified to measure various indicators for water handpumps (e.g. pump uptime, frequency of use, time to repair, volume of water pumped) or other service contexts, such as cookstove use, water filter use, latrine use
Market Segment	NGOs, donors and governments that require data about remote services for accountability to ensure a good level of service or usage by water consumers
Total Systems/ Customers Served	181 sensors installed in this pilot; over 1,000 in 15 countries
Use of Mobile	• Machine-to-machine communication: 2G or 3G mobile network used to transmit sensor data via GPRS; and • Internet-based dashboard notifications to alert maintenance managers of breakages, also available on mobile app.

FIGURE 2

Company Growth



11. http://www.sweetsensors.com/

Project Objectives

The objectives of the PSU grant were to test GSM-enabled sensors on remote handpumps for real-time information on maintenance needs to support an improved level of service, and to test the business viability of providing this data to water service providers and governments. The ultimate goal was to transfer ownership of the sensors to the Rwandan Government, which would pay for the data service.

The intended learnings from the project were as follows:

- Compare quantitative indicators to actual performance for water pump uptime, downtime, frequency of use, time between system outage and reporting of the event, volume of water pumped per day, and other key indicators of overall water system usage and beneficiary behaviour;

- Compare the cost effectiveness of sensor monitoring with manual spot checks; and

- Assess the ability of local institutions (such as government ministries) to incorporate the data results into their health/water/access operations and future planning.

These expected learnings were deemed highly valuable given that M2M remote monitoring for water services is more nascent in comparison to energy services (e.g. widespread use of remote monitoring and control for pay-as-you-go solar home systems).

Source: PSU

Sensor installation

Market Opportunity

Addressable Market

PSU's addressable market for water services comprises the water service providers and their consumers who depend on handpumps for water and have access to GSM networks; this applies to Rwanda and many other developing contexts. In Rwanda, an estimated 45.6 per cent[12] of the population of 12.1 million[13] relies on protected springs or wells, which includes delivery through handpumps. At the same time, 2G GSM networks reach 99.9 per cent of the population (75 per cent for 3G).[14] In Sub-Saharan Africa alone, there are over 1 million handpumps[15] and GSM networks cover approximately 74 per cent of the population.[16] Given the high replicability of the technology across similarly designed handpumps throughout Africa and much of the developing world, there is a large market potential for this service.

Mobile Ecosystem

Rwanda has a growing mobile ecosystem with a 34.4 per cent market penetration by unique subscribers, which is just above the East African regional average of 30.3 per cent.[17] There are four mobile operators in Rwanda including MTN, Tigo, Airtel and Olleh, with MTN holding the highest market share of 50.4 per cent. Olleh Rwanda has recently begun providing 4G LTE infrastructure.[18] MTN, Tigo and Airtel all offer mobile money services, with MTN first launching in 2010, followed by Tigo in 2011.

Rwanda's Government has built a strong enabling environment for ICT innovation, as seen through the many mobile for development services that have launched there,[19] and entrepreneurship incubators such as kLab and Inkomoko, as well as Tigo's "Think" incubator.

Market Assumptions

At the time the project was proposed, it was assumed that it would target rural communities in the Eastern province where 67 per cent of the population had access to an improved source of water, which includes protected wells with handpumps. The market assumptions about this target population were as follows:

- Livelihoods are primarily pastoralism and subsistence farming
- Individuals live on less than USD 2 per day
- GSM coverage is available in most villages, and only those with adequate signal strength at the handpump would be targeted for the service

It was estimated that LWI was spending approximately USD 500 per handpump per year in maintenance, but these costs, nor actual handpump functionality, had been measured prior to this pilot.

Ultimately, the primary pilot activities were instead carried out in Ruhango in the Southern Province and Karongi in the Western Province[20] where 23 per cent of households are classified as living in abject poverty and 70 per cent of the remaining households are considered poor. In these provinces, between 73-76 per cent of households have access to improved sources of water, which includes the protected springs and wells on which 76 per cent of rural households rely.[21]

12. WHO/UNICEF, 2015. Joint Monitoring Programme, Estimates on the use of water sources and sanitation facilities for Rwanda, data from 2013.
13. World Bank Data Bank, 1014. http://data.worldbank.org/indicator/SP.POP.TOTL
14. GSMA intelligence, 2015 Q1.
15. RWSN, 2015. "*Handpump Standardisation in Sub-Saharan Africa*." Jess MacArthur. http://www.rural-water-supply.net/_ressources/documents/default/1-652-2-1421834932.pdf
16. GSMA M4D Utilities.
17. GSMA intelligences, 2015 Q1.
18. GSMA intelligence, 2015 Q1.
19. GSMA Mobile for Development Impact: http://www.m4dimpact.com/data/products-services - zone.isoCode=RWA
20. The change was based on the fact that LWI's new pumps were going to be installed in the Eastern District; it was therefore more indicative to carry out the study in areas with LWI's older pump installations.
21. National Institute of Statistics of Rwanda, 2014. *Thematic Report: Characteristics of households and housing.*

Business Model

The Value Proposition

PSU's business model creates value for at least three different stakeholders by enabling improved monitoring and maintenance through real-time access to remote data. Water service providers and potentially governments or donors are the primary customers of the sensor business, with water consumers the ultimate users of the water service.

- Water Service Providers: LWI is expected to reduce their maintenance costs by travelling only when alerted to handpump breakages via remote data, rather than ad-hoc repairs or periodic circuit rider inspections. This should lead to a better return on investment in infrastructure, by ensuring fewer days that handpumps are lying fallow.

- Governments and Donors: Sensor data on functionality is expected to bring transparency and accountability that funds are being well-spent on maintaining existing infrastructure for a reliable service to water consumers.

- Water Consumers: More responsive maintenance should provide consumers with reliable water service, so they do not sacrifice time and health accessing far away and unsafe alternate sources. Consumers are more likely to pay for a reliable service, suggesting this would create a virtuous cycle of better cost-recovery for continued maintenance.

PSU and LWI originally envisioned that their value proposition would be most crucial for the Government of Rwanda, which was anticipated to eventually provide maintenance and management of water points through district staff. The pilot also sought broader demonstration of this value to the international donor community and water service providers, which would bring commercial viability to SweetSense Inc. for sensor data on water and other utility or environmental services.

Pricing

PSU did not charge LWI or the Government for the hardware or the service during the pilot, in order to first test the technology and demonstrate the proof of concept. PSU produced the prototype sensors for this pilot at a cost of USD 500 each and at the outset anticipated eventually selling the sensors for between USD 400-1,000 (depending on the application), where the cost of manufacturing was expected to be cut in half within two years of development. Profits were expected from a 50-100 per cent mark-up at the point of high-volume production, plus a USD 100 annual fee for data-visualisation services.

Following the pilot, SweetSense Inc. envisions a business model that focuses on "Sensors as a Service" and leverages hardware to provide data-driven decision aids, rather than focusing on the commoditisation of hardware (see results section). Pricing therefore will depend on the service level required for each client, and the cost of the sensors will decrease in time depending on the volume manufactured.

Use of Mobile: Technology and Partnership

Technology: At the core of SweetSense Inc. technology, SIM cards enable communication of sensor information over the GSM network. The sensor components are listed below with images of the sensor and its placement within the pump-head. Movement detected by an accelerometer triggered reading of water pressure, sensor temperature and acceleration, which were stored on an SD card. The sensors were all tested prior to installation in PSU's SweetLab in Portland for heat resistance, waterproofing, durability, and data transmission reliability.

For the purposes of this pilot, PSU and LWI also used tablets for field mechanics to record maintenance activities and send the information to the database in real-time over the GSM network.

FIGURE 3

Sensor and its components

- Water-resistant enclosure (12 x 8 x 4 cm);
- Five AA alkaline batteries;
- Control Board;
- Cellular Radio Chip;
- SIM Card Holder;
- Accelerometer to detect motion;
- Differential water pressure transducer (one port open to atmosphere; other submerged in water pump overflow basin in order to record water level as pressure);
- External antenna to receive the GSM network signal; and
- Scannable barcode on exterior for tracking.

Partnership with a Mobile Operator: For this pilot, PSU and LWI partnered with MTN Rwanda. MTN provided all of the SIM cards free of charge for each sensor, programmed only for machine-to-machine communication (i.e. no voice calls), and with 12 MBs of data per month per SIM card.

Study Design

PSU tested the sensor technology and its cost effectiveness for improving maintenance by designing a longitudinal cohort study that ran from November 2014 – May 2015. The study was designed as follows:

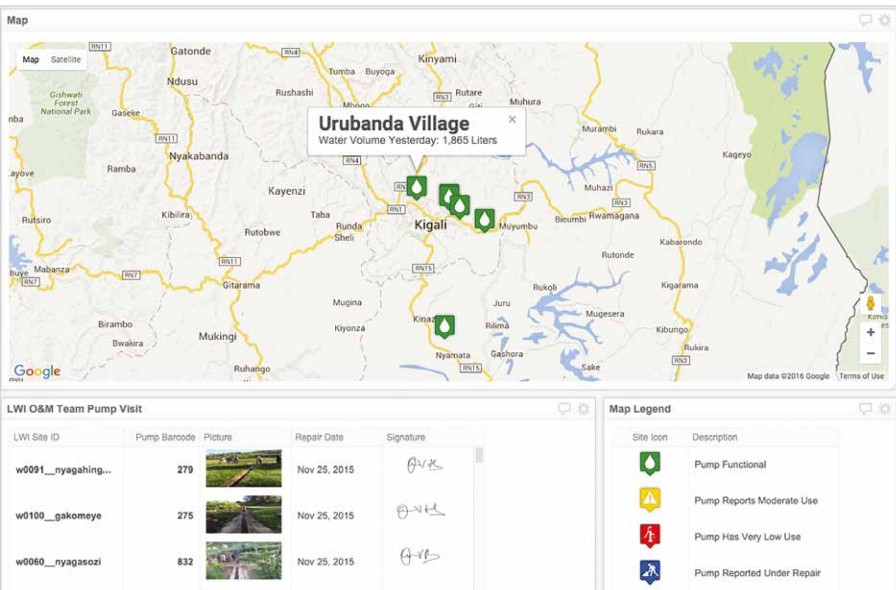
Site Selection: Prior to testing the sensors, a baseline analysis of LWI's 324 handpumps was carried out to assess initial handpump functionality and GSM network reception at each site. Those without network reception were excluded, along with pumps that were inoperable due to missing pieces, which would have left the sensors exposed to potential vandalism. All other non-functional handpumps were included, along with functional handpumps, in the 181 selected to have a sensor.

Sensor Installation and Maintenance: For each sensor installation, technicians used "IformBuilder," a data collection application on tablets to record GPS coordinates and scan the sensor barcode, in order to associate the data from each sensor with the specified handpump and location. Handpump and sensor maintenance teams also used the tablet tool to record their maintenance activities at each handpump in order to correlate this with sensor data on functionality and time until repair. They also used the tablets to record expenditures in order to compare cost effectiveness of the different maintenance models.

Data and Dashboard: Data was sent from the sensors daily at midnight over the MTN GSM network, and the sensors could also be re-configured remotely via GSM. Sensor data was sent to a database with algorithms to analyse frequency of use. This determined sensor status as functional for pumps showing more than 100 instances of use in 24 hours, potentially non-functional for 10-100, and non-functional for less than 10. The dashboard depicted below displayed sensor status as green, yellow and red respectively. If sensors did not report any data for seven days,[22] the handpump was given a status "sensor fault" to indicate the sensor required inspection and/or repair. Data from pump and sensor maintenance teams was integrated such that any maintenance activities would change the pump status to "under repair."

FIGURE 4

Sensor dashboard displaying sensor status



22. This time period was based on the weekly schedule of staff assignments to maintenance of sensors and handpumps.

Comparing maintenance models in a longitudinal cohort study: The cost-effectiveness of the sensors was assessed by comparing the sensor-informed “ambulance service” to traditional ad-hoc maintenance and circuit rider models (see Figure 5). Each model was tested in a different area in order to isolate impact and assign maintenance staff to particular areas.[23] Sensors were placed on all pumps in the study, but data from them was only made available to maintenance staff for the ambulance service pumps.

FIGURE 5

Maintenance Model and Pump Allocation

Maintenance Model	Description	Staffing	Location/Number of Pumps
Nominal	Ad-hoc repairs made following random inspections or user reported issues; *not informed by sensors*	Two mechanics and a pick-up truck	Southern Province (Ruhango District): 38 Western Province (Karongi District): 16 Central: 30
Circuit Rider	Best-known practice of inspections made on a routine geographical circuit; *not informed by sensors*	One mechanic and motorcycle for each district; when materials needed for repairs not carried, truck from nominal team sent	Southern Province (Ruhango District): 24 Western Province (Karongi District): 26
Ambulance	Office staff monitor dashboard with sensor data and notify maintenance staff of pumps for which sensors report limited or no usage	Two mechanics and a pick-up truck	Southern Province (Ruhango District): 23 Western Province (Karongi District): 24

Source: PSU

Sensor installation

Source: GSMA

Sensor troubleshooting

23. The ambulance and circuit rider models were tested in the Southern Province (Ruhango) and Western Province (Karongi) while the nominal model was tested in the central province. This was done to group the ambulance and circuit rider model pumps together, which exhausted the number of pumps available in this region. Full randomisation was not used, as criteria including location, cellular coverage and other factors were priority criteria.

Early Results

Business Model Viability

This pilot demonstrated the proof of concept and value for PSU's sensors to improve water services. The sensors led to a significant improvement in the level of service through increased uptime at a similar cost as other maintenance models. The sensors are being significantly improved based on operational learnings, and will be rolled out for future clients. However, the Government has not yet been able to integrate the new data into their operations and planning, which suggests the need for a longer-term strategy for working with governments. At the same time, PSU has revised their business model to focus on providing data to international donors and implementing agencies, rather than selling hardware. The progression of the pilot is depicted in Figure 6.

FIGURE 6

Progression of Pilot

2014

Ordered all sensors & began lab testing; started baseline study of handpump functionality & network connectivity
Jan 2014

Installed sensors; faced challenges with signal attenuation
Apr 2014

Re-designed study based on sensor challenges & more handpump maintenance required than expected
Jun 2014

Installed five retrofitted sensors with hard cover on external antennas;
July 2014

Prepared for full sensor re-installation: selected sites for re-designed study, founded private implementing partner, Amazi Yego Limited
Sep 2014

Began study; sensor batteries failed faster than expected; PSU received grant to do injection-moulded casings for version 2 of sensors
Nov 2014

Installed all sensors; integrated all maintenance data into dashboard
Dec 2014

2015

Tested low battery life to determine GSM network was not the problem; continued data collection despite sensor issues
Feb 2015

Switched from AA batteries to Nickel-Metal-Hydride batteries; continued to develop version 2 of the sensor in the lab
Apr 2015

Completed collection of data to achieve statistically significant results; LWI agreed to pay for sensor servicing until Oct 2015
May 2015

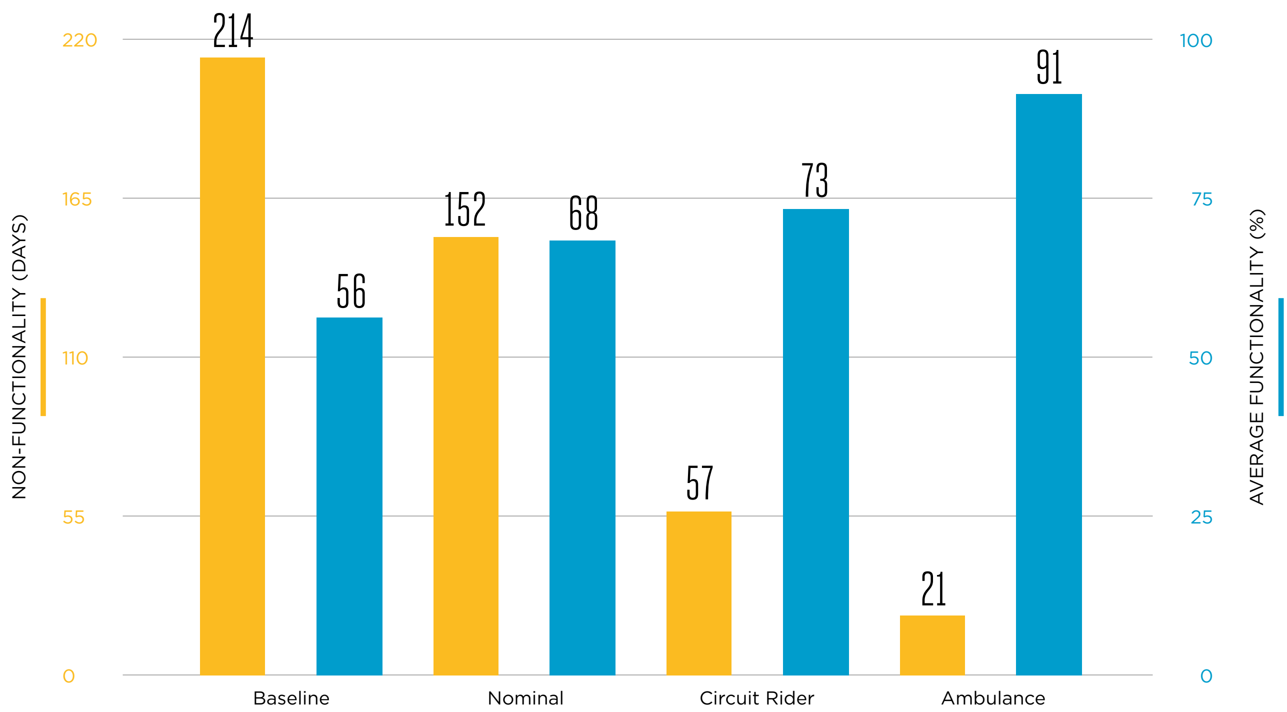
PSU and SweetSense Inc. secured a total of USD two million in contracts for new sensor services elsewhere
Oct 2015

Deployment and Functionality

A total of 181 sensors were installed in water handpumps as part of this study. The original target of 200 was decreased when it was realised that the proportion of broken pumps, and therefore the maintenance required, would exceed budgeted resources. Data from 14 of the 181 sensors was insufficient and therefore excluded from the analysis. At the outset of the study, 53 (31.5 per cent) of the pumps included were non-functional, and these were distributed equally across the three maintenance model groups. The results show a significant increase in the proportion of functional days for handpumps maintained through the ambulance model compared to the other maintenance models. These are depicted in the following figure and discussed in more detail below:

FIGURE 7

Water Pump Functionality



Sensor-driven ambulance maintenance results in a significantly higher proportion of functional days[24] than other models. Handpumps serviced by the ambulance model were functional nearly 91 per cent of the time, which was a statistically significant[25] difference when compared to the circuit rider model which achieved 73 per cent functionality, and the nominal model with 68 per cent functionality. The difference in functionality between the circuit rider and the nominal model was not statistically significant.

24. The proportion of functional days was calculated by dividing the functional days by the total days of data, where the total days was not the same for each pump due to sensor data gaps.
25. All assessed for a 95 per cent confidence interval.

Sensor-driven ambulance maintenance results in significantly fewer days of handpump downtime[26] than other maintenance models. Downtime across all sample groups came from 142 instances of non-functionality among 89 pumps, with only 78 repairs conducted on 57 different pumps. The mean time for successful repair[27] in the ambulance model was just under 21 days, while it was just under 57 days for the circuit rider model and just under 152 days for the nominal model. Therefore, the ambulance service led to an 86 per cent reduction in time to successful repair compared to the nominal model, while the circuit rider model achieved a 63 per cent reduction compared to the nominal model. The ambulance service model led to 64 per cent reduction in time to repair compared to the circuit rider model.

Considering these two key indicators together, both the ambulance model and the circuit rider model significantly reduced the repair time compared to the nominal model; however, only the ambulance model resulted in statistically significant improvements to functionality compared to both other models. Refer to Appendix 1 for further information about the analysis methodology in the study including the treatment of missing sensor data and accounting for variability in pump characteristics.

Time for attempted repair versus successful repair

The study considered the time for *attempted* repairs and *successful* repairs. Some attempted repairs were unsuccessful or required additional tools/materials, while a repair was considered successful if it resulted in at least seven days of functionality following the repair. The ambulance model had a 50 per cent reduction in time until *attempted* repair in comparison to the circuit rider model, while for *successful* repair there was a 64 per cent reduction in time. The reduction in time for successful repairs was greater because the circuit rider mechanics were only equipped with motorcycles to travel to and inspect all handpumps, rather than a fully supplied pick-up truck used by other maintenance teams when alerted by the sensors (ambulance model) or a call from the community (nominal model). In the case that a pump failure discovered by a circuit rider mechanic required tools or materials to be brought by a pick-up truck, a week's delay was experienced in having this truck come from the nominal maintenance team. However, some unsuccessful repairs also occurred in the ambulance and nominal models.

Cost Benefit

The overall costs of the ambulance model were relatively similar to the other maintenance models, yet it resulted in a better level of service, and costs are expected to decrease in the future. Capital expenditure (CapEx) and operational expenditures (OpEx) were tracked during portions of the study[28] for each maintenance model, including costs linked to direct management, field staff, vehicles and transport, and supplies and repair parts. The figure below shows that the costs of each maintenance model are relatively similar when considered per pump, per functional year. Therefore, if a handpump is only functional for a portion of a year, the CapEx cost for each functional day is higher based on the reduced days of functionality. This is calculated by dividing the annual cost by the mean pump functionality as shown below. The ambulance model has higher costs associated with the sensors and sensor maintenance (which are not included for the other models as they did not inform maintenance), yet the other models have higher estimated costs for the capital expenditure of functional pumps, based on the resulting lower proportion of functionality.

26. This was calculated as the number of days from the time when the pump was observed to be non-functional to the first subsequent repair (whether a successful outcome was achieved or not).
27. Successful repairs were those that resulted in functionality for a period of seven days or longer. In some cases, handpumps could not be immediately repaired upon the initial discovery of non-functionality without further equipment, or initial repairs were unsuccessful. See box for more insights.
28. Costs recorded for the ambulance and circuit rider models were collected over four months, while costs for the nominal service model were recorded over two months. This was due to logistical issues preparing and training the maintenance teams to record the costs.

FIGURE 8

Cost estimates of each service model[29]

	Ambulance	Circuit	Nominal	Sensor Servicing
Documented Monthly Costs by Service Model				
Per Pump Site / Month	**$39.43**	**$29.97**	**$15.41**	**$9.52**
Estimated Yearly Costs per Pump by Service Model				
Pump Install (Depreciated CapEx / Year)	**$1,500.00**	**$1,500.00**	**$1,500.00**	**-**
Mean Pump Functionality	90.82%	72.94%	67.52%	-
Pump CapEx Cost / Functional Year	**$1,651.62**	**$2,056.48**	**$2,221.56**	**-**
Service Model CapEx (Vehicles) - (Depreciated CapEx Value / Year)	$22.70	$61.65	$12.70	-
Pump OpEx / Functional Year	$520.94	$493.12	$273.90	-
Sensor CapEx / Year	$250.00	N/A	N/A	-
Sensor Servicing / Pump / Year	$114.65	N/A	N/A	-
Sensor Data / Pump / Year	$1.41	N/A	N/A	-
Total Cost / Pump / Functional Year	**$2,561.32**	**$2,611.25**	**$2,508.16**	**-**

The above figures show that the maintenance models have similar costs when the resulting functionality is considered, yet the ambulance model resulted in a better quality of service based on higher functionality and reduced downtime. This suggests it yields a more effective investment for providing reliable water services.

Institutionalisation and Payment for Service

Institutionalisation within government requires a long-term strategy. PSU and LWI began the pilot with strong Government engagement and support in order to ultimately see the Government use the data to improve their operations and planning, and in the

29. See Appendix with full data.

long-term, develop local technical capacity to replace LWI as the service provider. To pave the way for this, PSU established Amazi Yego Limited as the local implementing company, which would be incubated through direction and financing from LWI and PSU, and ultimately grow to be an independent maintenance company, with a public-private partnership with District Governments.[30] During the pilot, the Amazi Yego team initially maintained sensors with support from SweetSense Inc., Amazi Yego is now carrying out sensor maintenance independently, paid for by LWI. A further objective in the creation of the Amazi Yego partnership was to put the eventual collection of user payments into the hands of a maintenance company, rather than LWI as an NGO, to build a service model based on user revenues. However, this payment and collection model has not yet been tested.

International donors and implementing agencies may be the best clients in the near-term. PSU originally envisioned that the Government of Rwanda would become a paying client. While the Government has been very engaged and enthusiastic, it remains highly dependant on international aid, and it will therefore take time to build the budget for these services. At the same time, SweetSense Inc. has found international development organisations such as Mercy Corps, the US Centre for Disease Control and Prevention and the Millennium Water Alliance ready to pay for the replication of this service. In response, SweetSense Inc. has altered their business model to provide "Sensors as a Service" with a focus on designing monitoring programmes and data-based decision aids, rather than mass production of sensor hardware, and will therefore more likely target international donors in the near-term.

Refinements to Operations

GSM sensors for handpumps require advanced and iterative technical design of robust hardware. PSU performed laboratory testing on all sensors before placing them in handpumps; however, they still needed to improve their hardware in response to the following challenges encountered in the field:

- **Sensor and antennas need to be outside of the handpump to operate:** PSU first carried out a 2G network test at potential handpumps (eliminating from the study those not covered by the network). However, PSU found that the GSM signal from inside the pump-head was not strong enough and had to re-design their sensors with the antennas placed on the outside, connected by a wire to the sensor. Yet, this made the sensors more vulnerable to leakage at the antenna port and to damage by curious children. PSU made repairs by adding more sealant to the casings, using a desiccant pack to absorb moisture, and placing a hard carbon fibre cover over the antenna. Ultimately, this led PSU to design their next version with a more robust casing, and after this grant, they will install this version completely externally on the handpumps, with a single hole for the water port. This has the added value of simplified installation (see photos).

- **Battery life in extreme conditions is reduced and difficult to predict, impacting sensor functionality:** PSU anticipated the sensors would have a battery lifetime of 6-18 months from four AA batteries. However, in reality, battery life was significantly reduced to 3-6 months only, and in some cases, even less. The reduced battery life meant that it was not possible for the sensor to report on the flow rate and volume of water being pumped because the sampling rate needed to be reduced to conserve the battery and the resulting data was insufficient for analysis. Instead, the accelerometer data was used as an indicator of usage, and therefore functionality. The AA batteries ultimately had to be replaced with Nickel-Metal-Hydride batteries. SweetSense's upgraded sensors address this limitation with lithium batteries.

30. The institutional structure for this in Rwanda is referred to as a "Joint Action Development Forum."

Source: PSU

Testing pilot sensor after installation, hard carbon fibre casing on the outside to protect the antenna

Source: GSMA

Pilot sensor placed inside a handpump

These challenges undermined the functionality of the sensors and increased maintenance costs, particularly with field staff replacing batteries more frequently than anticipated. In addition, their supplier discontinued the module that held the SIM card and PSU had to re-design the circuit board to have the SIM card separate from the GSM chipset. These factors led PSU to develop a new and more robust version of the sensor, with a USD 55,000 grant from the Oregon Manufacturing Extension Partnership. The key modifications included the following:

- Custom injection-moulded, watertight casing;
- Fewer circuit board components to reduce assembly time and potential for errors;
- Embedded SIM in circuit board which is smaller and cheaper;
- Universal SIMs provided by Aeris[31] instead of a local mobile operator which do not require programming SIM settings for local operators in each context;
- Bluetooth programming and data download when needed; and
- Lithium batteries with inductive charging.

As of March 2016, these new sensors have been installed on a sample of LWI's pumps in Rwanda, as well as other clients in Kenya and are reporting water volume, use and functionality reliably.

31. http://www.aeris.com/

Source: Water Project

New Version of Sensor

More pump maintenance than expected required funds to be re-allocated and the number of pumps in the study to be reduced. Through the baseline survey, LWI learned that the number of broken handpumps (44 per cent of the 324 included in the baseline study) exceeded their expectations of around 25 per cent. LWI thus decided to re-allocate budget earmarked for new handpump installations to increased maintenance efforts; an important statement in a sector where donor-funded organisations have historically focused on new infrastructure to please donors, rather than maintenance to ensure a good level of service. Nonetheless, the increased costs of maintenance during the study, particularly for the more active circuit rider and ambulance models, resulted in LWI and PSU agreeing to reduce the number of handpumps included from the proposed 200 to 181.

Customer Benefits

Sensor data enables service providers to provide a better level of service. LWI has been able to increase handpump functionality thanks to sensor data enabling more immediate maintenance, leading to reduced downtime. They have indicated the value of this by rolling out the ambulance maintenance service for all 181 handpumps equipped with sensors now that the study has been completed and have committed to paying for sensor maintenance for the five months post-grant. Since it is estimated that each handpump serves 250 people, this resulted in benefits to 45,250 people. While PSU and LWI must still secure a longer-term client to continue this service, PSU has recognised that it may take a long time for the Government to become the paying client, and in the interim, international NGOs may play an important role.

Sensors could enable a sustainable, revenue-driven model for reliable water services. LWI is looking to shift toward a business model for water services with Amazi Yego as a private maintenance company to eventually collect fees from consumers for water services. A recent study showed that water consumers were willing to increase their payment for water services from USD 0.2 to USD 1 per month when handpump downtime decreased from 27 to 2.6 days.[32] This suggests that a water service provider using sensors could operate revenue-driven maintenance services for more reliable water services.

Consumers received more reliable services, likely reducing dependence on potentially unsafe and distant alternate water sources. In the districts where the study was carried out, 23 per cent of households are classified as living in abject poverty or as very poor, and 70 per cent of the remaining households are still considered poor. Although not quantified as part of this study, other studies have shown that distance[33] and water quantity[34] have a positive correlation with improved health. This suggests that improved reliability in service through sensor-driven maintenance should lead to improved health outcomes, particularly for the poorest.

Mobile Industry Benefits

One of the key objectives of the Innovation Fund is to identify the types of mobile technologies that can support mobile-enabled utility services. This, in part, depends on the benefits that accrue to mobile operators from partnering to provide these services. For this pilot, PSU and MTN Rwanda established a "cooperative partnership," which is a low risk approach characterised by mobile operators providing information or connectivity.[35] MTN provided all SIM cards free of cost, pre-programmed for machine-to-machine connectivity with a monthly data allowance of 12 MBs for each SIM. During the pilot, approximately 2 GB of data was used in total to send data once a day from each sensor.

Revenue and Additional MNO Benefits

GSM sensors may be a gateway to a suite of mobile services: While the small amount of data used in this pilot would not likely lead to significant revenue for MTN, even on a national scale, it opens up the opportunity for broader partnerships and services from mobile operators. This pilot represents an increasing interest in the opportunity to connect water service infrastructure to mobile networks. Given the external evidence that water consumers have a higher willingness-to-pay for a water service that is reliably maintained, and the fact that LWI plans to collect consumer payments, there could soon be an opportunity for mobile operators to offer mobile money payments for water fees to consumers. Introducing rural consumers to mobile money as the secure and convenient way to pay water bills could help broader usage of mobile money. This combination of improved service levels and access to digital finance could lead to key improvements in living conditions and economic development.

Furthermore, this pilot highlights the opportunity for operators to further develop their Machine-to-Machine service offerings in emerging markets, including a suite of tools, such as improved SIM monitoring and management platforms, for clients with connected devices.

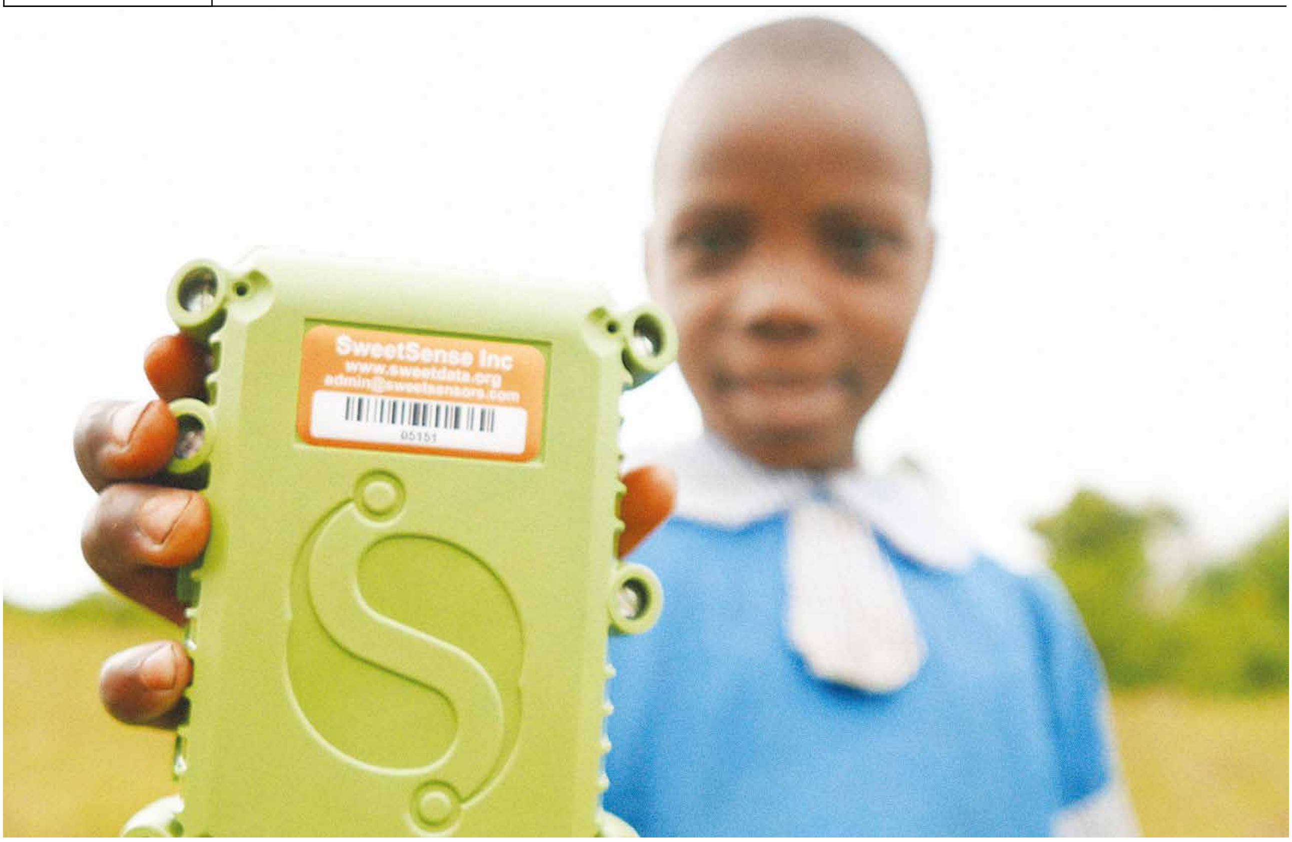
32. Koehler, J., Thompson, P., Hope, R., *Pump-Priming Payments for Sustainable Water Services in Rural Africa*. World Development (2015): http://www.sciencedirect.com/science/article/pii/S0305750X15001291
33. Esrey, S.S.; Potash, J.B; Roberts, L.; Shiff, C. Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis, and trachoma. Bull. WHO 1991, 69, 609–621.
34. Stelmach, R.D.; Clasen, T. Household Water Quantity and Health: A Systematic Review. Int. J. Environ. Res. Public Health2015, 12, 5954-5974.
35. GSMA, Mobile for Development Utilities, May 2014. *Predicting the Future of Mobile Enabled Community Services*. http://www.gsma.com/mobilefordevelopment/predicting-the-future-of-mobile-enabled-community-services-mecs-annual-report

Conclusions

The pilot demonstrates that sensor-driven maintenance can significantly improve rural water services by reducing downtime and increasing functionality of handpumps at a cost that is relatively similar (and potentially cheaper in the future) than traditional or best practice maintenance models. While the Government of Rwanda has remained an engaged and enthusiastic party, the pilot also points to the need for long-term strategies and financing to achieve the Government's incorporation of data into planning and to secure a solid business model - whether the paying client should be a government or an international donor.

Moreover, the findings point to a solid opportunity for stronger business models for water service delivery based on mobile technology. Sensor data can drive more effective maintenance, reduced downtime, and increased functionality for a service that consumers are more likely to pay for. At the same time, sensors enable governments and international donors to have assurance that their assets are being maintained and a good level of service provided. Thus, in both directions, the sensors provide new accountability and transparency to enable payment for an agreed-upon and monitored level of service. This paves the way for hybrid models that combine government or donor investment in assets with consumer contribution toward operations and maintenance for more sustainable water services for the underserved.

Source: Water Project



New version of sensor

Appendix: Case Study Methodology

Overview: This case study is based on learnings that emerged throughout Portland State University's Seed grant through the Mobile for Development Utilities programme. These were tracked through the following:

Grantee reporting: Monthly reports were completed on activities, project risks and mitigation, and key performance indicators. These were discussed during a one-hour call with the grant manager each month. Quarterly reports were completed to document progress on milestones, the grantee's learning objectives, barriers and other key project developments as well as financial compliance.

Longitudinal cohort study to compare maintenance models: This study ran from November 3, 2014 – May 31, 2015 and was carried out on 181 rural handpumps which had been installed and maintained by Living Water International. Ultimately, issues with the sensors, including vandalism, malfunction and lack of network connectivity meant that the data from 14 handpumps was not usable, leaving an analytical sample of 168.

Limitations to the study: Functionality problems with the sensors required more sensor maintenance than expected, so it was not possible to collect the originally desired 12-month's worth of maintenance data. Explanations of how data gaps were addressed, as well as potential variability in handpump characteristics are addressed below.

Addressing data gaps: In the case of sensor failure, missing functionality data was addressed with the following approaches. If the last recorded sensor-reported status was the same as the status after the data gap, the status of the pump was considered to have remained the same during the data gap. If the status changed before and after a data gap, the records of the LWI and sensor maintenance teams' activities were consulted by an investigator without knowledge of the maintenance model assigned to the pump.

Accounting for externalities in pump characteristics: Both univariable and multivariable models were used to associate the functional days with the service model and these were adjusted for pump type, pump age, and well depth. A sensitivity analysis did not find any potential for bias based on the use of maintenance team data in the absence of sensor data or differences in the baseline functionality of the pumps in each maintenance model.

Analysis of functional time: As noted in the published study, "when the proportion of functional time was calculated for each pump beginning on the first observed functional day [rather than the first day of the study], the observed improvement in functional time in the Ambulance Service model relative to the Circuit Rider and Nominal Models remained significant."[36]

Cost effectiveness: An indicative cost analysis suggests that the cost per functional pump per year is approximately similar between the three models. However, the benefits of reliable water service may justify greater focus on servicing models over installation. The complete cost calculations are included in the table below.

36. Nagel, C., Beach, J. Iribagiza, C., and Thomas, E. 2015. *Evaluating Cellular Instrumentation on Rural Handpumps to Improve Service Delivery – A Longitudinal study in Rural Rwanda*. Environmental Science & Technology., pg. G.

FIGURE 9

Detailed cost estimated for each service model

	Ambulance	Circuit	Nominal	Sensor Servicing
Documented Monthly Costs by Service Model				
Lodging & Meals	$348.08	$259.66	$107.32	$897.64
Salaries	$618.18	$706.42	$613.25	$326.40
Tools, Parts, Supplies	$606.54	$335.66	$494.33	$40.73
Transportation	$280.25	$196.94	$79.67	$457.55
Total Monthly Costs	$1,853.06	$1,498.67	$1,294.57	$1,722.32
Pumps Serviced	47	50	84	181
Per Pump Site / Month	**$39.43**	**$29.97**	**$15.41**	**$9.52**
Estimated Yearly Costs per Pump by Service Model				
Pump Install (Depreciated CapEx / Year)	$1,500.00	$1,500.00	$1,500.00	-
Mean Pump Functionality	90.82%	72.94%	67.52%	-
Pump CapEx Cost / Functional Year	$1,651.62	$2,056.48	$2,221.56	-
Service Model CapEx (Vehicles) - (Depreciated CapEx Value / Year)	$22.70	$61.65	$12.70	-
Pump OpEx / Functional Year	$520.94	$493.12	$273.90	-
Sensor CapEx / Year	$250.00	$0.00	$0.00	-
Sensor Servicing / Pump / Year	$114.65	$0.00	$0.00	-
Sensor Data / Pump / Year	$1.41	$0.00	$0.00	-
Total Cost / Pump / Functional Year	**$2,561.32**	**$2,611.25**	**$2,508.16**	**-**
Pump Lifetime Cost	$25,613.20	$26,112.52	$25,081.65	-
Beneficiary Lifetime Cost (250 per pump)	$102.45	$104.45	$100.33	-
Beneficiary Daily Cost	$0.03	$0.03	$0.03	-

For more information on the Mobile for Development Utilities programme visit:
www.gsma.com/mobilefordevelopment/programmes/utilities/

GSMA HEAD OFFICE
Floor 2
The Walbrook Building
25 Walbrook
London EC4N 8AF
United Kingdom
Tel: +44 (0)20 7356 0600
Fax: +44 (0)20 7356 0601