Research Report

Sustainable WASH Systems Learning Partnership

NEAR REAL-TIME BOREHOLE FUNCTIONALITY MONITORING FOR STRENGTHENING WATER SUPPLY ASSET MANAGEMENT

John Butterworth, Anna Libey, Bret McSpadden, Joseph Pearce, and Jemal Seid

July 2021

PHOTO CREDIT: MICHAEL BLAIR

USAID FROM THE AMERICAN PEOPLE

SUSTAINABLE WASH SYSTEMS LEARNING PARTNERSHIP

Prepared by: Joseph Pearce, Bret McSpadden, Jemal Seid, and John Butterworth; IRC; Anna Libey; University of Colorado Boulder

Acknowledgments: The authors would like to acknowledge Asmelash Kebede and Petros Birhane of USAID Lowland WASH Activity for their contributions to this report.

Front cover: SweetSense gateway and solar panels mounted outside near the power source. Photo credit: Michael Blair

About the Sustainable WASH Systems Learning Partnership: The Sustainable WASH Systems Learning Partnership is a global United States Agency for International Development (USAID) cooperative agreement with the University of Colorado Boulder (UCB) to identify locally driven solutions to the challenge of developing robust local systems capable of sustaining water, sanitation, and hygiene (WASH) service delivery. The consortium of partners—Environmental Incentives, IRC, LINC, Oxford University, Tetra Tech, WaterSHED, Whave, and UCB—are demonstrating, learning about, and sharing evidence on systems-based approaches for improving the sustainability of WASH services in four countries.

This report is made possible by the generous support of the American people through USAID under the terms of the Cooperative Agreement AID-OAA-A-16-00075. The contents are the responsibility of the Sustainable WASH Systems Learning Partnership and do not necessarily reflect the views of USAID or the United States Government. For more information, visit www.globalwaters.org/SWS, or contact the USAID Center for Water, Sanitation, and Hygiene (waterteam@usaid.gov) or Karl Linden (karl.linden@colorado.edu).

Table of Contents

List of Figures

List of Tables

Acronyms

AMS	Asset Management System
ARWIEB	Afar Regional Water, Irrigation, and Energy Bureau
ETB	Ethiopian Birr
EFY	Ethiopian Financial Year
FEWS-NET	Famine Early Warning Systems Network
GSM	Global System for Mobile Communication
GTP	Growth & Transformation Plan
Lowland WASH	USAID Lowland Wash Activity
MTTB	Mean Time to Breakdown
MTTR	Mean Time to Repair
NGO	Non-Governmental Organization
NWI	National WASH Inventory
O&M	Operations & Maintenance
SWS	USAID Sustainable WASH Systems Learning Partnership
UCB	University of Colorado Boulder
USAID	United States Agency for International Development
WASH	Water, Sanitation, and Hygiene
ZFP	Zonal Focal Person

Executive Summary

Ethiopia's Afar Region relies on a limited number of deep, motorized boreholes for water during the long dry seasons, and especially during droughts. Their ongoing performance is critical for sustaining safe water supply services. However, the functionality of these boreholes is often low, in part due to a lack of prioritization and finance for ongoing or preventive maintenance, limited monitoring and accessible information on asset characteristics, and limited operations and maintenance capabilities at the community, woreda, and regional levels.

The United States Agency for International Development (USAID) Sustainable WASH Systems Learning Partnership (SWS) and USAID Lowland WASH Activity, in partnership with government at various administrative levels, hypothesized that innovations in monitoring and asset management in Afar would build lasting capacity to improve borehole functionality and therefore the water security of this arid, lowland region. These innovations include the installation of satellite and cellular-connected sensors for monitoring all mechanized boreholes in Afar. The sensors monitor near real-time borehole usage by monitoring pump runtime and are integrated into a regional digital platform for asset inventory data management and functionality tracking called the Afar Asset Management System (AMS). The Afar Region Water, Irrigation, and Energy Bureau (ARWIEB) uses the AMS for the creation of dispatch tickets for maintenance and support of functionality tracking for reporting and evidence-based planning.

This paper explores the rural water supply context in Afar and the establishment and operationalization of the Afar sensor monitoring network, including preliminary data analysis on uptime and downtime indicators for water service delivery derived from sensor reports. The sensors are part of the intervention and are a key measurement for project impact to see whether providing the ARWIEB with near real-time data from instrumented boreholes, in conjunction with training and capacity-building activities that Lowland WASH and SWS conducted, has resulted in improved water service delivery, measured primarily via functionality. A companion paper explores uptake and use of the AMS as a whole (https://www.globalwaters.org/resources/assets/afar-asset-management-system-uptake-and-use).

Results indicate that Zonal Focal Persons used sensors from November 2019 to February 2020 for updating scheme functionality within the AMS. The authors used sensor data to extrapolate regional functionality; these data were the most consistent piece of information, mainly due to lack of manual updating in the AMS and the lack of other data sets from the region. These data supported SWS efforts to justify additional finance for maintenance, but the region did not utilize the data. The sensors did not prove a reliable indicator for non-functionality because they had false positives of 50 percent. Overall, sensors are seen as an interesting and exciting piece of technology, but the region's lack of use indicates that more work needs to be done to convey their usefulness.

The authors include recommendations for the continuation of sensor-enabled borehole monitoring in the Afar Region following the project closeouts of Lowland WASH in February 2021 and SWS in September 2021. Although the University of Colorado Boulder will cover the sensor data costs as part of the NASA SERVIR project, this funding will not support sensor or borehole maintenance. Sensor maintenance currently costs project partners approximately 7,630 Ethiopian birr ($200) per sensor per

year, which the region will need to cover now that Lowland WASH has ended. Without new outside support to maintain sensors and conduct borehole repairs, it is unlikely that the regional government will continue to adopt the AMS.

While the sensor technology provided insightful data and proved to be robust in Afar's harsh climate, in the end, it did not meet the region's needs due to a lack of internal resources and low capacity to respond to or use the data. Going forward, it may be interesting to explore other uses of the sensors, such as monitoring usage or flow of select urban or high-use schemes only. Downscaling the number of sensor-monitored boreholes to just those deemed most drought critical and in need of rapid repairs when there is a breakdown may also be an area for further exploration. Improving the expert status classification system to better incorporate the irregular pumping of many schemes in Afar and improving scheme-level understanding of sensors and the maintenance needs may also improve sensors' usefulness and reliability. The paper concludes with recommendations for priority actions for the partnership to inform the handoff of the Afar AMS and the sensor-monitoring network.

USAID SWS and Lowland WASH Activities in Afar, Ethiopia

The Sustainable WASH Systems Learning Partnership (SWS) is a global United States Agency for International Development (USAID) cooperative agreement aiming to identify locally driven solutions to the challenge of developing robust local systems capable of sustaining water, sanitation, and hygiene (WASH) service delivery. Led globally by the University of Colorado Boulder (UCB), it emphasizes partnership and learning for catalytic change in the water and sanitation sector. By coordinating with and facilitating interactions among partners in four priority countries (Ethiopia, Kenya, Uganda, and Cambodia), the project works to meet the rapidly increasing needs of USAID's partner countries for sustainable WASH activities.

The USAID Lowland WASH Activity (Lowland WASH) delivers technical assistance, develops small-scale water supply and irrigation infrastructure, and builds the capacity of regional governments and stakeholders in the Somali; Afar; and Southern Nations, Nationalities, and Peoples Regions. Lowland WASH aims to increase access to improved drinking water supply sources on a sustainable basis; increase adoption of key hygiene behaviors; increase access to improved, sustainable sanitation; improve efficiency and sustainability of food production from irrigated and rain-fed agricultural systems; and improve water governance and data management. Lowland WASH subcontracts SweetSense Inc. (https://sweetsensors.com/) for the supply of telemetry-connected sensors (which are designed and manufactured in the U.S.), as well as training, installation, data visualization, and support for a sensor-enabled borehole monitoring network.

Figure 1. A SweetSense Inc. sensor gateway and solar panel installed at a water scheme in Afar

SWS partners are addressing rural water supply challenges in Ethiopia. During the first year of implementation, beginning in January 2017, SWS developed a strategic partnership with Lowland WASH, involving mWater (https://www.mwater.co/) and SweetSense Inc., to improve water scheme monitoring in Ethiopia. The SWS and Lowland WASH partnership provides an opportunity to build synergies between systems strengthening and learning activities within SWS, with a focus on improved monitoring and maintenance and implementation of a package of new construction, rehabilitation, and maintenance for rural water supply schemes through Lowland WASH.

SWS and Lowland WASH, in partnership with the Afar Regional Water, Irrigation, and Energy Bureau (ARWIEB), aim to strengthen government-led monitoring systems to improve data management and evidence use to better inform regional processes and decisions. In doing so, the partnership seeks to better understand the regional information requirements for improving and sustaining service delivery and the extent to which monitoring is an effective entry point to advocate for and support investment in the provision of maintenance services. The partnership has worked to strengthen regional water supply monitoring and asset management through building and operationalizing the Afar Asset Management System (AMS), including near real-time borehole functionality indicators collected through sensors.

Rural Water Infrastructure Functionality in Afar Region

It is estimated that groundwater supplies more than 70 percent of domestic water use in rural Ethiopia. Although renewable groundwater resources are ample, groundwater storage capacity is low, at only 40 cubic meters (m^3) per capita.[1] Therefore, many of the arid regions of Ethiopia are subject to seasonal water scarcity due to hand-dug and shallow-drilled wells drying up. The most reliable groundwater sources in Afar Region are located at depths exceeding 100 m, requiring significant drilling, a pump, and distribution infrastructure to access. As a result, rural areas subject to borehole failures rely on water trucking during dry periods, a practice that can cost 70 times more compared to piped water supply per capita, according to UNICEF.[2]

Dependence on groundwater sources is particularly pronounced in the Afar Region. Annual precipitation is less than 500 millimeters (mm) in the semi-arid western escarpments and less than 150 mm in the arid zones to the east. According to the asset inventory data in the AMS, water supply borehole depths range from 20 m to 500 m, with the majority ranging from 60 m to 200 m deep. Many schemes are also remote and hard to access, with more than 300 kilometers (km) of driving from the farthest-away schemes to the regional capital, Semera. Rural communities in Afar are often highly mobile and practice agro-pastoralism but are known to cluster around boreholes during the dry season when

[1] Kebede, S. 2013. *Groundwater in Ethiopia*. Springer Berlin Heidelberg. Available at: https://doi.org/10.1007/978-3-642-30391-3
[2] Godfrey, S., & Hailemichael, G. 2017. "Life Cycle Cost Analysis of Water Supply Infrastructure Affected by Low Rainfall in Ethiopia." *Journal of Water, Sanitation and Hygiene for Development*, 07(4), 601–610. Available at: https://doi.org/0.2166/washdev.2017.026

surface water sources are unavailable.[3] Many boreholes in the region have high groundwater salinity, natural fluoride contamination, or produce high-temperature water, presenting further challenges to safe water supply.

Box 1. Afar Region: Key Water Supply Indicators

- Urban water supply coverage: 83 percent (Growth and Transformation Plan I [GTP I]), 39 percent (GTP II)[4]
- Rural water supply access: 60 percent (GTP I), 34 percent (GTP II)
- Health institutions: all hospitals have water facilities; 36 percent of health centers and 6 percent of health posts have water facilities
- Schools: water available at primary (43 percent), secondary (57 percent), kindergarten (93 percent)

Sources: ARWIEB 11 Month Report. 2008 (Ethiopian Fiscal Year). Presentation for annual national Hygiene and Environmental Health review meeting. Bureau of Education baseline data.

In early 2016, IRC prepared a scoping report on WASH monitoring and data use in the Afar and Somali regions for USAID.[5] The report identified major limitations on the part of the *woredas* (districts) and the regional water bureaus to improve water scheme functionality in existing planning and reporting processes; data for reporting or planning appeared to be inadequate or unavailable. The report found no information or decision-support system in place to manage operations and maintenance (O&M) activities. Maintenance responses appeared to be ad hoc, based on the availability of spare parts, a crane track or service rig, and transport. IRC also noted the lack of scheme-level information available prior to a visit, beyond the memory of technicians.

The consequences of lack of post-construction support, asset management, regular monitoring, and resources for maintenance can be seen in the high fluctuation in regional borehole functionality levels (60 percent to 90 percent uptime) reported since Lowland WASH installed the sensors, beginning in

---

[3] Whitley, L., Hutchings, P., Cooper, S., Parker, A., Kebede, A., Joseph, S., Butterworth, J., Van Koppen, B., & Mulejaa, A. 2019. *A Framework for Targeting Water, Sanitation and Hygiene Interventions in Pastoralist Populations in the Afar Region of Ethiopia*. *International Journal of Hygiene and Environmental Health*, 222(8), 1133–1144. Available at: https://doi.org/10.1016/j.ijheh.2019.08.001

[4] Note that service levels are defined differently under GTP I and GTP II. In the water supply sub-sector, the main objective of GTP I (2011–2014) was to provide safe water supply of 15 liters per capita (l/p/c) within a distance up to 1.5 km for rural population and 20 l/p/c within a distance of 500 m for urban population. The more ambitious targets of GTP II (2015–2020) aim to provide minimum service level of 25 l/c/d within a distance of 1 km for rural and between 40 and 100 l/c/d, depending on the town or city size, within a distance of 250 m for urban population.

[5] Dimtse, D., Getachew, H., Butterworth, J., & Pearce, J. 2016. *WASH Monitoring and Data Use in Afar & Somali: Scoping Report on Processes, Systems and Capacities*. IRC Ethiopia / AECOM. Available at: https://www.ircwash.org/sites/default/files/lowland_wash_me_final_report_15082016.pdf

2017, with borehole failures regularly occurring every 1 to 2 years.[6] This paper further discusses indicators for water service delivery reliability from sensor data in the section "Barriers to Use In operationalizing the system, the team identified some barriers to using sensor data through observation, reporting from the regional facilitator and interviews with users. These can be divided into two categories: (1) challenges with the sensors, mainly perceived accuracy and reliability of the sensors and data; and (2) underlying factors such as regional capacity to perform repairs, buy-in, accountability, and financial support.

When interviewed, the ZFPs perceived the data to be sometimes inaccurate and unreliable. This stems partly from the false reports of "no use" when clamps are disconnected. Woreda staff turnover also affects sensor report verification due to out-of-date contact information in the AMS. This reliability and data accuracy challenge may be improved through changes to the expert status algorithm by changing parameters (as outlined in Annex 3) or by utilizing a machine-learning algorithm that can adapt to each scheme and has been shown to be 15 percent more reliable. Improved training of local operators and maintenance technicians may also help.

The other major barrier to decision-making using sensor data is the lack of ability to actually perform enough repairs each week to keep on top of reports of breakdowns or to even maintain sensors. Maintenance is not done immediately upon receiving a breakdown report. Instead, technicians prioritize breakdowns: they respond to essential or emergency breakdowns immediately and batch lower priority breakdowns. For example, a team might organize to fix several breakdowns in an area during a 2- to 4-week maintenance trip. With the current size and capacity of the O&M team in the region, sensor data show a 14-day minimum delay between finding out about a broken scheme and conducting a repair, leading to such a backlog of schemes and sensors needing repairs that near real-time alerts of scheme breakdowns do very little to assist in the performance of maintenance. Without large increases in the regional budget for maintenance and rehabilitations, likely from outside sources, it is unlikely there will be substantial usage of the sensor data to inform maintenance activities.

The somewhat cyclical challenge of implementing the AMS is that the data are only useful when the system is being used and updated frequently, but there is less incentive to use the system when the data are poor or out of date. It has been difficult to prove the effectiveness or usefulness of data with lack of use and uptake. Use of AMS and sensor data for evidence-based decision-making in the regional planning and finance departments is hypothesized to improve both the data quality and utility, due to increased accountability, but uptake has been limited. The sensor data also improve the timeliness of functionality status updates on a subset of schemes, but to the detriment of up-to-date functionality status for non-sensor-equipped schemes. These schemes do not get as much day-to-day attention from staff in the regional office. Sensors may also decrease data quality through confusion around accuracy and information overload. The central challenge to improved asset monitoring and management using the

---

[6] Thomas, E., Wilson, D., Kathuni, S., Libey, A., Chintalapati, P., & Coyle, J. 2021. "A Contribution to Drought Resilience in East Africa through Groundwater Pump Monitoring Informed by In-Situ Instrumentation, Remote Sensing and Ensemble Machine Learning." *Science of The Total Environment*, 146486. Available at: https://doi.org/10.1016/j.scitotenv.2021.146486

Afar AMS and sensors lies in supporting system use, data quality, and frequency of updating simultaneously, as hypothesized in the causal loop diagram in Figure 8.

Sensor Data for Borehole Performance Indicators." Unreliable water service delivery, when combined with the Afar Region's severe and frequent droughts, regularly leads to drought emergencies, displacing people and livestock and stressing economic, social, and physical security. The cost saving theorized by improving borehole uptime is the main driver of the innovations in monitoring discussed in this paper.[7]

Role and Functions of Afar Borehole Monitoring Sensors

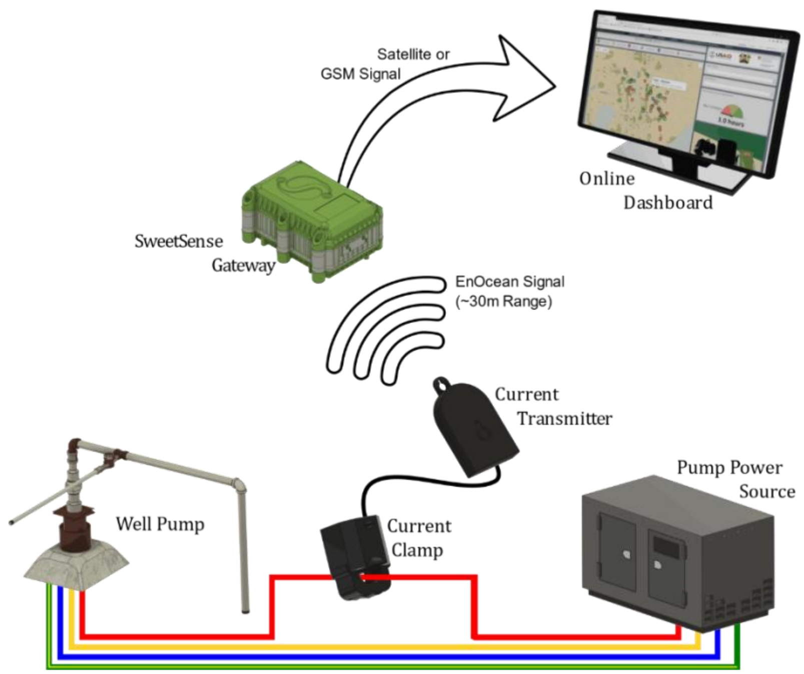


Figure 2. SweetSense sensor diagram

SweetSense sensors detect the electrical current flowing through a power line to the borehole's pump, using a Pressac current clamp. The current transmitter sends its readings to the SweetSense gateway, which uploads the data to an online dashboard via satellite or global system for mobile communication (GSM). Both the current clamp and the SweetSense gateway are self-powered. In detecting the electrical current, the sensor records how long the pump is on and reports this information once per day. This information from SweetSense is then incorporated in the Afar AMS. The sensors are designed to be one of four monitoring methods for detecting problems with a water scheme. The other three monitoring methods are site inspections, phone calls or messages, and review of the asset inventory data; each require manual detection, communication, and recording of issues.

Lowland WASH established the borehole sensor-monitoring network to provide near real-time runtime data on motorized boreholes in the Afar Region. Lowland WASH intended for the sensor data to inform maintenance processes and regional planning. A total of 173 sensors are currently installed on motorized boreholes in Afar, out of approximately 300 motorized boreholes in the region. At the beginning of the project Lowland WASH understood that the Afar Region had fewer than 200 motorized boreholes, and the activity intended to equip all of them with sensors. Most sensors have

[7] Thomas, E., Jordan, E., Linden, K., Mogesse, B., Hailu, T., Jirma, H., Thomson, P., Koehler, J., & Collins, G. 2020. *Reducing drought emergencies in the Horn of Africa*. Science of The Total Environment, 727, 138772. Available at: https://doi.org/10.1016/j.scitotenv.2020.138772

been installed since 2017 under Lowland WASH. Following an initial sensor installation test, Lowland WASH installed about 70 sensors at the end of 2017, an additional 50 in early 2018, and an additional 50 in early 2019 for a total of 176 sensors in the region.

The ARWIEB O&M team identified most of the boreholes to be equipped with sensors. However, Lowland WASH provided guidance and technical support throughout the process. The ARWIEB prioritized boreholes for sensor installation based on several criteria, including:

- The size of the population served; ARWIEB prioritized boreholes serving larger populations or multiple villages.
- Distance from a city center (mainly from Semera, the regional capital, where the expertise and resources for major maintenance responses are located); ARWIEB prioritized remotely located borehole sites because sensors enable the O&M team to remotely monitor the boreholes.

Sensors are connected over either satellite or cellular-based telemetry, depending on the version selected. From a technical point of view, the availability of Ethio Telecom cellular network (for GSM sensors) and borehole functionality at the time of sensor installation are also important selection criteria because the borehole's pump has to be started and kept running until the testing of correct sensor installation and/or signal transmission to the server is confirmed. That is to say, Lowland WASH only placed sensors on functional motorized boreholes at the time of installation. Lowland WASH also considered factors such as road accessibility and security for traveling staff during the site selection process.

The SweetSense sensors, designed for motorized boreholes, log and report borehole usage every 24 hours.[8] Sensors report daily usage in hours, measured from electric current to the submersible pump. Currently, sensor-reported daily runtime is run through a logical classification system that generates

Box 2. Sensor Expert Status Classification

Normal Use: Borehole is functional (pump is being used) and, in the last 7 days, average daily pumping hours are greater than or equal to the 20th percentile of daily runtime for this site.

Low Use: Average daily pumping over the previous 7 days is lower than the 20th percentile of that pump's average runtime.

No Use: The sensor is functioning but has not detected pumping in the preceding 7 days.

Seasonal Disuse: The sensor is functioning, has not detected pumping in the preceding 7 days (no use), and has detected >10 mm of rain by satellite in the 3 km radius of the site.

Offline: The sensor has not reported in the last 7 days.

Repair: The scheme has been marked as under repair in the Lowland WASH Site Reports form (this status is not currently in use).

[8] Thomas, E. A., Kathuni, S., Wilson, D., Muragijimana, C., Sharpe, T., Kaberia, D., Macharia, D., Kebede, A., & Birhane, P. 2020. "The Drought Resilience Impact Platform (DRIP): Improving Water Security Through Actionable Water Management Insights." *Frontiers in Climate, 2*. Available at: https://doi.org/10.3389/fclim.2020.00006

"expert statuses" representing the estimated status of the water system (see Box 2). Annex 1 provides the full flow chart of the expert status classification system.

The sensors, although not an asset management or monitoring system on their own, do report daily data on water scheme runtime that can inform maintenance or repair activities. Although there are circumstances in which functional boreholes are not used (due to seasonal patterns of water demand, pastoralist migration, high fuel costs, or borehole obsolescence), all boreholes with "no use" status require follow-up, as this highlights a potentially non-functional water system in need of maintenance and should trigger follow-up from the responsible maintenance team (woreda or region). Over time, by regularly monitoring sensor data, infrequently used schemes can be marked as such and responded to appropriately.

Sometimes breakdowns in other water scheme components will not prevent people from using the borehole (such as in partially functional cases). Non-functional is defined as incapable of delivering water. Even in cases where the breakdown is not in the submersible pump but in the reservoir, pipeline, genset, etc., it is likely the pump will be switched off and considered non-functional, which the sensor will detect. The section "Sensor Accuracy" addresses the accuracy of the sensors in detecting non-functional systems.

In the initial design of the AMS, sensors that changed to "no use" status (after 7 days of no runtime) generated an automatic issue (maintenance ticket) recorded in the AMS. However, SweetSense and mWater agreed to turn off this feature in April 2019 because it created a large number of "unaddressed"[9] tickets. In reverse, a status change from "no use" to "normal use" signifies a water system that has been repaired or brought back into service.

Figure 3 shows the initial workflow that mWater designed in June 2018 to initialize use of the sensors and the AMS for maintenance. mWater conducted data-needs assessments prior to the development of the tools and workflow. However, the partners did not implement the full process shown in Figure 3 as initially designed due to challenges in developing and implementing the system. For example, automatic ticketing from sensors was disabled due to tickets not being responded to, and mWater did not fully develop the printing of asset reports or repair reports. Annotations of crossed-out boxes represent the current operationalization of the sensor-monitoring network in the AMS. A companion paper, "Afar Asset Management System Uptake and Use (https://www.globalwaters.org/resources/assets/afar-asset-management-system-uptake-and-use)" further addresses implementation challenges.

[9] The term "unaddressed issue" here may refer to a maintenance request that has not been responded to. Or, even if a maintenance response did indeed occur, it may not have been properly captured or recorded using the "maintenance tracking" feature in the AMS.

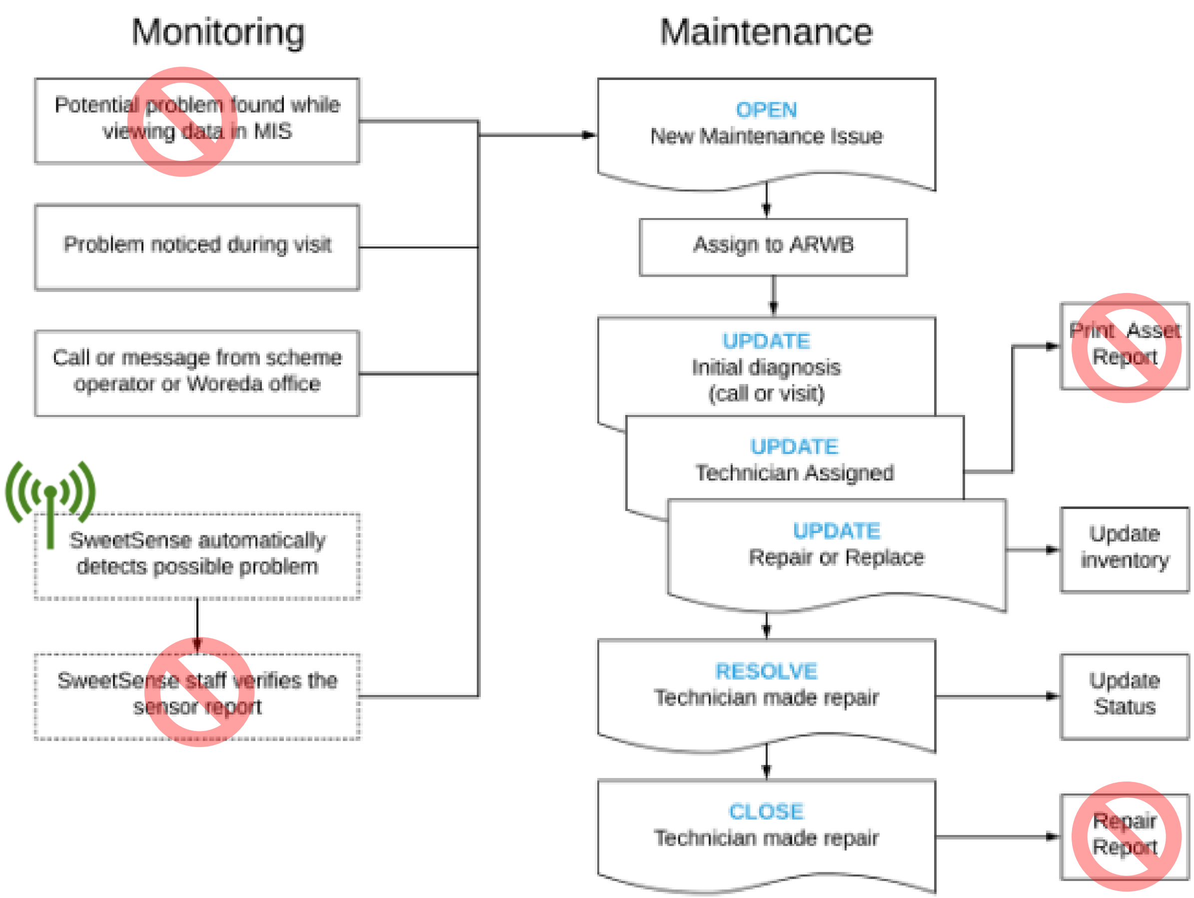


Figure 3. Original sensor data workflow designed for Afar (2018) versus execution
Crossed-out boxes represent features and workflows that have not been operationalized. ARWB denotes ARWIEB.

Currently, some aspects of this workflow have been incorporated into regional processes while other functions were either never built (repair reports) or lacked engagement, training, or staffing to execute (identification of problems from asset inventory data, verification of every sensor report).

Use of Sensor Data for Operations and Maintenance

Despite positive feedback, uptake and use of the sensor data has been far less than expected. Challenges include a lack of incentives, dedicated budget, or skills to use the data, and the absence of a formal "work procedure" — with defined roles, responsibilities, and processes — for regional staff to regularly check sensor status, update information, and use the system. Overall, the supply of maintenance services — both government and private service providers — in the region is insufficient to meet the demand for maintenance that the sensors and other monitoring tools identify. The prospect of having a detailed, up-to-date monitoring data set has not led to additional maintenance activities in an overburdened organization.

The O&M team, with the support of an embedded facilitator, identified and requested several AMS design changes to improve the display of sensor data. Previously, the sensor dashboard showed daily sensor status reports but did not indicate which schemes had recently changed status (i.e., a scheme failure or a return to functionality). As an interim measure, SweetSense created a new dashboard in June 2019 that is emailed daily to provide actionable information on individual sensor status changes. The newest version of the AMS sensor dashboard, released in late 2020, incorporates a page with recent status changes (see Figure 4).

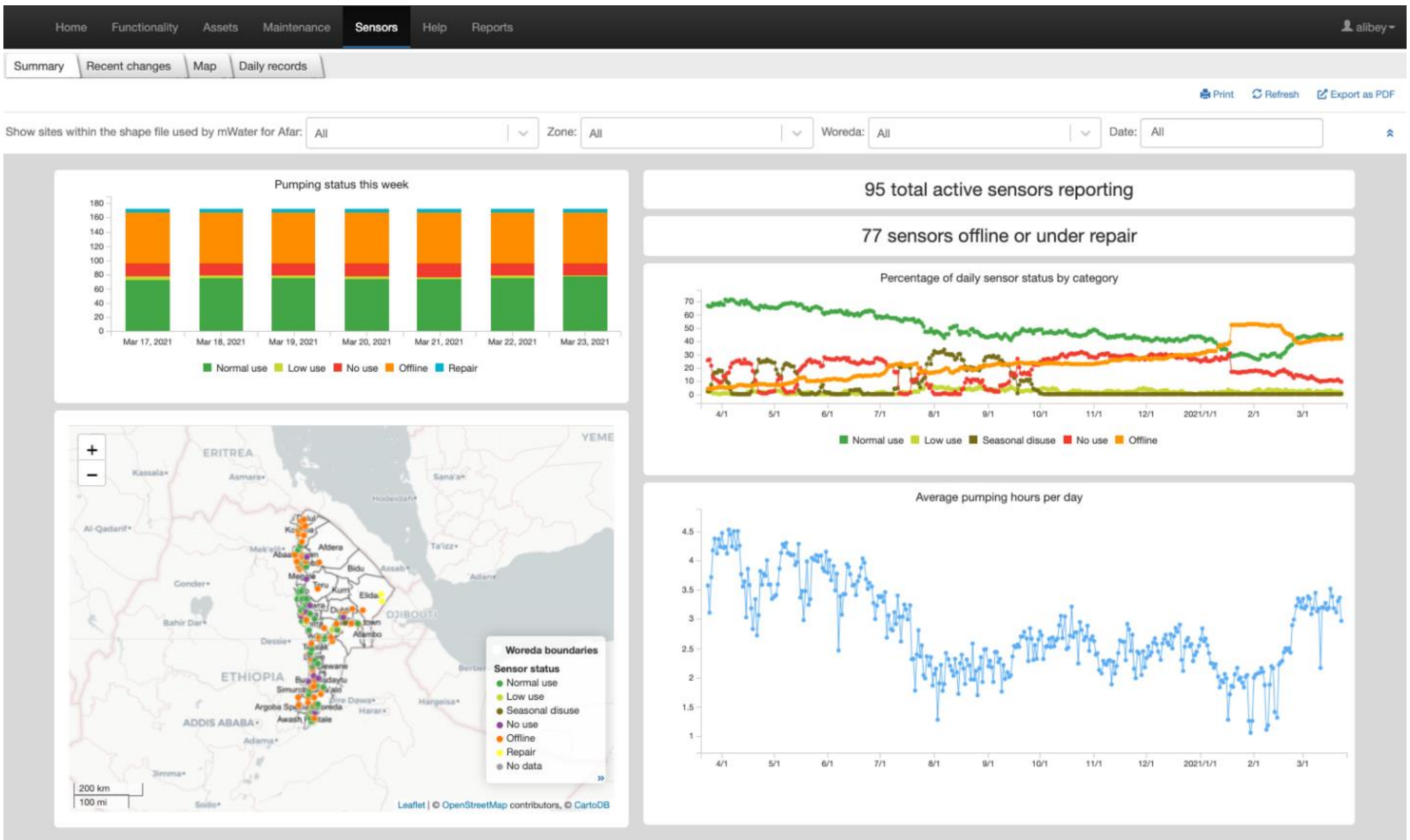


Figure 4. Afar AMS sensor summary dashboard in mWater, with tabs for recent changes, map view, and daily records (March 23, 2021 data)

With the changes in sensor status highlighted in automatic emails from SweetSense, the SWS regional facilitator checked sensor status daily and followed up on sensors that changed to "no use" with a phone call to the scheme operator or woreda water office. If the facilitator confirmed a problem, he created an issue ticket in the AMS and worked with the regional water bureau to respond. During this time, the facilitator reported many clamp disconnections, often due to local operators not understanding the sensor and how it connected to the scheme, which he tried to resolve remotely. He reported that this task of following up on sensor data was too much for one person and that the regional staff, especially the ARWIEB management, needed to take ownership and make use of the system more.

Following this feedback, the regional facilitator and regional leadership co-designed a new process to better utilize the sensor data for updating functionality and for proactively investigating sensor status. In November 2019, the deputy director appointed five zonal focal persons (ZFPs) to update functionality status from sensor data and phone calls for non-instrumented boreholes and to create issue tickets in each of the Afar Region's five zones.

Between November 2019 and February 2020, with assistance and leadership from the facilitator, ZFPs updated system functionality status and created issue tickets for non-functioning schemes. If a scheme changed to "no use," ZFPs attempted to confirm the problem with the system by calling the operator or woreda. If ZFPs confirmed the problem, they created an issue ticket in the system and assigned the O&M team to follow up and resolve the issue. Box 3 shares an example use case of the sensor data and issues feature in the AMS. ZFPs made most updates in December 2019 and January 2020. During this time, sensor data served as the main source of information for functionality updating (68 percent of issue tickets and 54 percent of updates). However, updating of functionality status ended in March 2020 due to COVID-19, as well as turnover in the region.

Box 3. Sensor Data Use Example

Gomodele Scheme (#15309804) had an issue opened in mWater on November 28, 2019 after a ZFP checked the sensor data and saw a change to "no use." The problem was a riser pipe leakage. Two days later, the O&M team assigned a technician to the issue, and the technician conducted the repair 1 month later, for a total downtime of 32 days. Although the time to mobilize a repair team, a replacement riser pipe, and a vehicle delayed the maintenance response, the sensor supplied warning likely decreased the overall scheme downtime experienced.

ARWIEB Technician Anteneh Tesfaye attached this photo to the maintenance issue in mWater.

Following up on the "no use" status proved challenging for ZFPs when they could not confirm the problem with the operator or when operators or woreda officials appeared to be unaware of the existence of the sensor. ZFPs also mentioned that sensor data prompted updating and follow-up for some schemes, but to the detriment of actively engaging with schemes without sensors. This may be partly due to missing contact information in the AMS for schemes without sensors, because Lowland WASH collected most of the asset inventory data during sensor installations. Because of the ease of confirming a functional scheme from a sensor status of "normal use" (meaning that usage had been detected within the last 7 days), ZFPs likely updated functionality status of these schemes more often. This has the effect of biasing upward the team's best estimates of regional borehole functionality levels since the start of the project (see section "Sensor Data for Borehole Performance Indicators").

Although this intervention was not targeted at the woreda level, the partners shared the Afar AMS dashboard with the Mille Woreda Water Office. The core process manager reported a small number of instances where it used the sensor-reported hours of pumping displayed in the mobile application to monitor whether a scheme had been overused.

The ZFPs' uptake of functionality updating using the sensor data created a reliable source of data on whether schemes worked. Although maintenance issues were communicated to the O&M team, it generally did not lead to a maintenance response. Additionally, SWS drove all data analysis and engagement, and data had to be extracted and processed outside the system. While the ultimate goal of having sensors inform maintenance responses and long-term budgeting and planning is yet to be achieved, sensor data have proved useful for a limited set of maintenance responses and as a more reliable source of functionality data than other manual updates to support the regional planning process.

Lowland WASH handed the scheme over to the ARWIEB in February 2021 during a meeting with regional leadership and the various departments. Generally, regional actors viewed the system positively, but they recognized the general lack of use and institutionalization. During the handover, these actors discussed many of the known issues within the region, including the absence of a specific owner of the system, low staff commitment, the challenge maintaining sensors and obtaining spare parts, and the lack of financial support, including airtime for sensor report verification. Lowland WASH provided user manuals and other technologies and was supposed to hand over additional supplies for sensor repair, but it did not deliver sensor spare parts.

Sensor Challenges

Offline Sensors

Offline sensors are sensors that are not reporting data due to a failure with the hardware, firmware, or network. Offline sensors result in periods of no observation for boreholes, thus limiting the utility of the data for monitoring and maintenance responses. The estimated lifetime of an individual sensor is between 1 and 5 years, with some sensors that fail earlier and others that have not needed replacements since installation in 2017. To date, 170 sensors have been removed and replaced in the Afar Region. Addressing the causes of offline sensors and conducting timely repairs will ensure the longevity of the sensor-monitoring network. Repairs and replacements of offline sensors has generally not kept up with the failure rate, as can be seen from the general trend of accumulation in Figure 5. A large number of offline sensors was attributable at various periods to Ethio Telecom shutting off cellular service nationally or regionally for weeks or months.

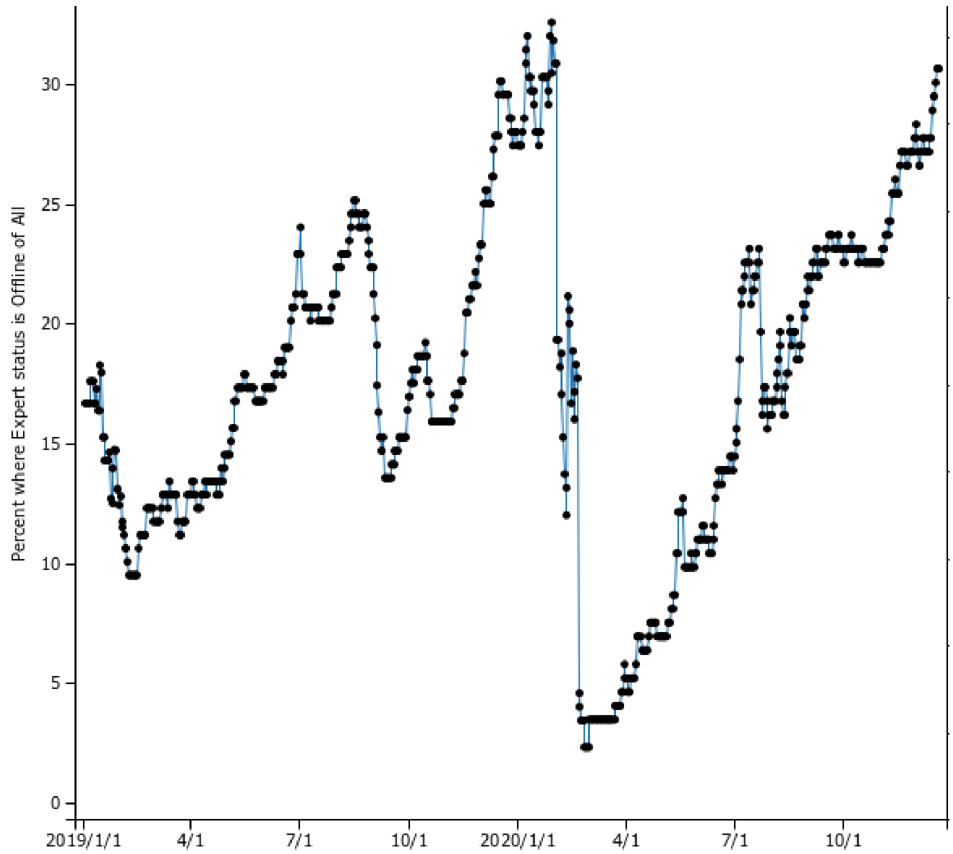


Figure 5. Percent of sensors reporting offline since January 2019
The drop in early 2020 occurred during a several weeks-long sensor repair trip supported by Lowland WASH.

SWS reviewed field notes from recent sensor repair trips to identify the most frequent causes of offline and false "no use" sensors: mobile network shutdowns (due to political unrest, when the federal government or the regional government shuts down the country's sole mobile network provider, Ethio Telecom, or non-payment of Ethio Telecom bills); damage from animals, including chewed wires; tampering of equipment; natural disasters, including floods and wind; and the disconnection of sensor clamps during equipment repairs and replacements (especially when switching schemes over to solar power and vice versa, if the sensor clamp is not reconnected).

SWS also found issues with the backend data, where sensors sometimes report garbled data. Sometimes, the sensors falsely report 0.67 hours of runtime at 12 a.m. Coordinated Universal Time due to signal interference in the cellular network-connected sensors. SweetSense addressed this issue by creating a filter to remove garbled data. Signal strength is also frequently an issue where cellular network-connected sensors were installed in areas with very low signal strength (<20 Received Signal Strength Indicator). Most of these occurrences have been identified and switched over to satellite-connected sensors.

SWS records causes of offline sensors and events when large numbers of sensors go offline. Table 1 provides an example of this project documentation.

Table 1. Causes of offline sensors

Problem Type	Examples
Mobile Network Shutdown	June 2019 – The internet was shut down intermittently starting June 11 to prevent cheating in nationwide exams, and then fully starting June 22 due to the assassinations of government officials. It was fully restored on July 2. July 2020 – The internet was shut down on June 30 following the murder of a local musician and activist. It was fully restored on July 23. Thirty-seven GSM sensors went offline during this period.
Animal Damage	Helefu Water System (7670114) – This solar power scheme was fenced in, but monkeys entered the fence and dismantled switchboard cables and clamps, resulting in a "no use" status. Desoyita 2 Water System (13894362) – Same due to monkeys, resulting in "no use." Offline sensors – A cable from the solar panel powering the sensor was chewed by mice approximately two or three times.
Equipment Damage or Theft (Human)	Talalak – Doroeesie (7833397) – A sensor was stolen, removed from the sensor dashboard. Other examples include damage from cooking fires and stone throwing.
Natural Disasters (Weather)	Hadele Ele – Baholi (7833586) – A sensor was damaged by flood and wind. Hawayti (13961986) – A sensor was damaged by flood and wind. Sheik Kebir – Bahrey Erebti (20939207) – A sensor was damaged by flood and wind.
Disconnection during Scheme Repair and/or Replacement	SWS documented 48 examples of clamp disconnections, most of which followed conversion from diesel to solar or vice versa, moving of the generator house, or borehole abandonment.
Hardware/Firmware Failure or Unknown	February 2020 – Technicians replaced many batteries. Batteries wear out over time, and this contributed to the high failure rate at the end of 2019. May 2020 – A large sensor problem May 17 to May 21 caused a spike of 40 sensors offline, including 10 new replacements. Undetermined cause.

Upon retrieval of some failed sensors, SweetSense identified that the lithium batteries used can, in some cases, fail after exposure to the high ambient heat in Afar, where the average temperature exceeds 105˚F. Figure 6 illustrates the toll the harsh environment can take on electronic equipment.

Figure 6. Illustration of the harsh environmental toll on electronic equipment
Left: New SweetSense solar panel, packaged heat-resistant batteries, and Pressac current clamp in pre-deployment condition. Right: Older version of sensor post-failure due to smoke and heat from the pump caretaker's cooking fire.

To reduce the numbers of offline sensors, SweetSense is currently piloting new hardware compatible with the Swarm Technologies satellite data network. When deployed, this hardware will enable global data coverage at a cost that is more affordable and reliable than cellular, thereby consolidating the telemetry choice to a single design that can be applied globally.

Sensor Accuracy

Verification of sensor-reported scheme possible failures (i.e., a status change to "no use") continues to be required via phone calls to woreda water offices or scheme operators in order to (1) inform the maintenance response based on breakdown severity and responsibility and (2) improve the accuracy of the expert status algorithms based on ground-truthing site reports. This section concerns the expert status and areas of improvement for accurate reporting of scheme failures.

Sensor status is an estimate of scheme functionality based on patterns of pump usage detected. The sensor "expert classifier" currently combines sensor-reported pump usage with satellite-detected rainfall to estimate the borehole's functionality status. Sensor accuracy is a measure of the number of times the sensor status matches the borehole status, or the rates of true positives (working, showing "normal use"), false positives (broken, showing "normal use"), true negatives (broken, showing "no use"), and false negatives (working, showing "no use").

A recently published validation paper on the sensitivity and specificity of the sensors for prediction of working and broken schemes indicates a functioning pump-detection sensitivity (true positive) of 82 percent for the sensor expert classifier (see Figure 7). When a pump is not being used, the specificity (true negative) is 48 percent for the expert classifier. This matches the ZFP estimates given for the accuracy of the sensor "no use" status.

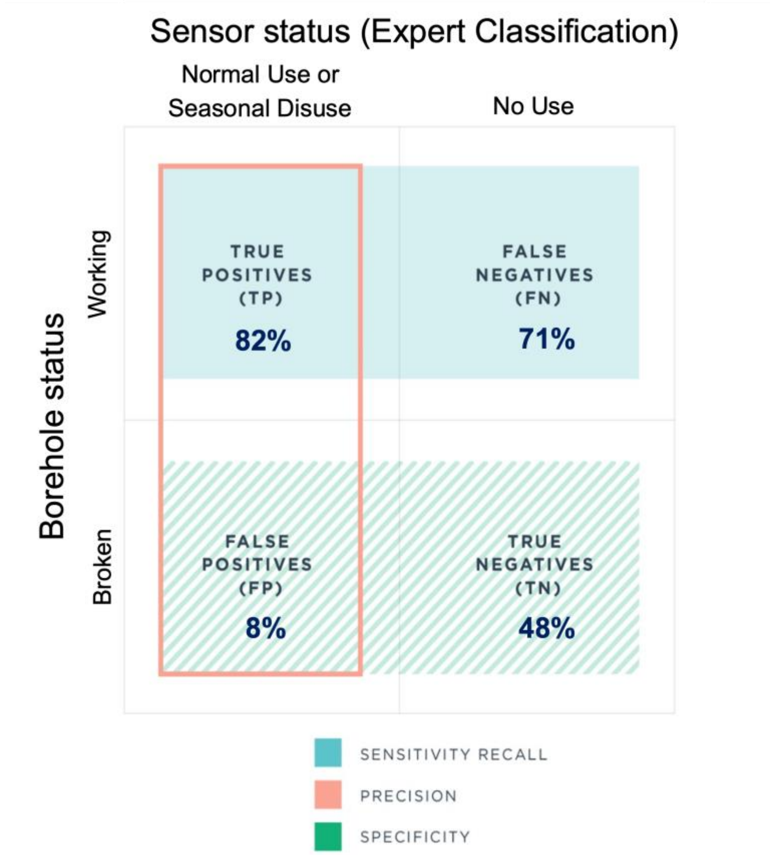


Figure 7. Measured sensor accuracy at predicting working boreholes and broken boreholes Methodology is described in Thomas et al., 2021.[10]

A "no use" status only has a 50 percent chance of being a broken pump. This means that sensors cannot distinguish broken pumps from pumps that are not being used on purpose (e.g., due to seasonal preference for surface water). Another cause of inaccurate sensor status is the disconnection of Pressac clamps at boreholes, which measure the current going from the power source to the submersible pump and transmit the hours of usage to the sensor. Since 2018, there have been at least 48 instances of sensor Pressac clamp disconnections, where a false negative "no use" is displayed because the functional sensor cannot detect any current going to the pump (see Table 1). When installed correctly, the Pressac clamps detect periods of "no use" of the pump greater than 7 days, which may signify a problem with the water scheme according to the current expert status classification system. Frequently, operators or technicians who conduct repairs or replacements of pumps and switchboards detach the clamp, not understanding what it is. Other causes include conversion to or from solar, moving the generator house, or borehole abandonment. According to the Kenya Resilient Arid Lands Partnership for Integrated Development SweetSense team, training and community sensitization has worked in Kenya to reduce

[10] Thomas, E., Wilson, D., Kathuni, S., Libey, A., Chintalapati, P., & Coyle, J. 2021. "A Contribution to Drought Resilience in East Africa through Groundwater Pump Monitoring Informed by In-Situ Instrumentation, Remote Sensing and Ensemble Machine Learning." *Science of The Total Environment*, 146486. Available at: https://doi.org/10.1016/j.scitotenv.2021.146486

clamp disconnections,[11] but these have not been conducted in Afar. There are also instances of clamp disconnections (and sensor damage) due to animals, extreme weather, or other accidents, which could be addressed by a more rugged design or more secure structure.

As a result of this high rate of false negatives and confusion about working pumps reporting "no use," there is less trust in the sensor data and limited understanding of how to interpret the expert status. Clamp disconnections also reflect limitations in achieving buy-in by borehole operators to ensure tamper-free operation of the sensors.

In March 2020, the team began cleaning past site reports in the AMS, including issue tickets, to identify periods of clamp disconnections and correct the sensor data accordingly. The team re-recorded known false negatives as periods of no observation, because there is no way of knowing the pump functionality from sensor data alone. This elimination of false negatives from historical sensor data greatly improves the accuracy of the estimated regional functionality levels (see section "Sensor Data for Borehole Performance Indicators" for more).

To increase sensor status accuracy and trust in the veracity of the data, SWS proposed changes to the sensor expert status classification system (outlined in Annex 3), which are currently being tested for adoption based on their calculated improvements to sensor accuracy per the methodology summarized above. These changes are intended to improve the reliability of expert status outside of "normal use," which is a reliable indicator for functionality. Other status is not reliable in predicting a problem and need to be improved to ensure trust in the data. Overall, the expert status classification is too stringent for many schemes that do not pump every week and are therefore marked "no use" when they are operational.

Barriers to Use

In operationalizing the system, the team identified some barriers to using sensor data through observation, reporting from the regional facilitator and interviews with users. These can be divided into two categories: (1) challenges with the sensors, mainly perceived accuracy and reliability of the sensors and data; and (2) underlying factors such as regional capacity to perform repairs, buy-in, accountability, and financial support.

When interviewed, the ZFPs perceived the data to be sometimes inaccurate and unreliable. This stems partly from the false reports of "no use" when clamps are disconnected. Woreda staff turnover also affects sensor report verification due to out-of-date contact information in the AMS. This reliability and data accuracy challenge may be improved through changes to the expert status algorithm by changing parameters (as outlined in Annex 3) or by utilizing a machine-learning algorithm that can adapt to each scheme and has been shown to be 15 percent more reliable.[12] Improved training of local operators and maintenance technicians may also help.

[11] Kenya-Ethiopia sensor learning exchange call on April 14, 2020.
[12] Thomas, E., Wilson, D., Kathuni, S., Libey, A., Chintalapati, P., & Coyle, J. 2021.

The other major barrier to decision-making using sensor data is the lack of ability to actually perform enough repairs each week to keep on top of reports of breakdowns or to even maintain sensors. Maintenance is not done immediately upon receiving a breakdown report. Instead, technicians prioritize breakdowns: they respond to essential or emergency breakdowns immediately and batch lower priority breakdowns. For example, a team might organize to fix several breakdowns in an area during a 2- to 4-week maintenance trip. With the current size and capacity of the O&M team in the region, sensor data show a 14-day minimum delay between finding out about a broken scheme and conducting a repair, leading to such a backlog of schemes and sensors needing repairs that near real-time alerts of scheme breakdowns do very little to assist in the performance of maintenance. Without large increases in the regional budget for maintenance and rehabilitations, likely from outside sources, it is unlikely there will be substantial usage of the sensor data to inform maintenance activities.

The somewhat cyclical challenge of implementing the AMS is that the data are only useful when the system is being used and updated frequently, but there is less incentive to use the system when the data are poor or out of date. It has been difficult to prove the effectiveness or usefulness of data with lack of use and uptake. Use of AMS and sensor data for evidence-based decision-making in the regional planning and finance departments is hypothesized to improve both the data quality and utility, due to increased accountability, but uptake has been limited. The sensor data also improve the timeliness of functionality status updates on a subset of schemes, but to the detriment of up-to-date functionality status for non-sensor-equipped schemes. These schemes do not get as much day-to-day attention from staff in the regional office. Sensors may also decrease data quality through confusion around accuracy and information overload. The central challenge to improved asset monitoring and management using the Afar AMS and sensors lies in supporting system use, data quality, and frequency of updating simultaneously, as hypothesized in the causal loop diagram in Figure 8.

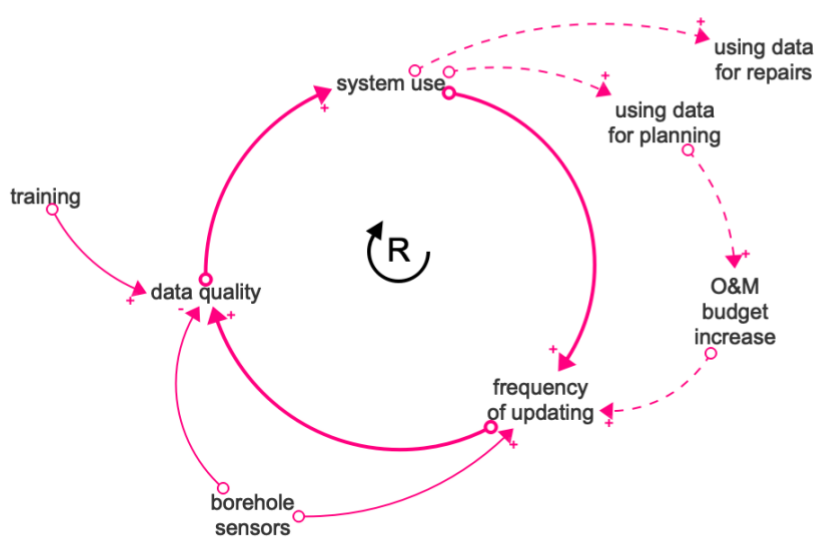


Figure 8. Causal loop diagram reinforcing (r) loop hypothesized to improve water scheme monitoring in Afar
The arrows with + or – signs denote positive or negative relationships, respectively, and the dotted lines denote hypothesized causal links.

Sensor Data for Borehole Performance Indicators

Although intended to inform O&M activities, the sensor data can be used to support calculations about the average percentage of borehole uptime, mean time between failures, mean time to repair, and the average number of scheme breakdowns per year. Data analysis performed by UCB researchers using statistical software on the subset of sensor data that align with an available status report in the AMS (60-day window) shows these parameters for the Afar Region. UCB suggested the use of these indicators to measure borehole functionality, failure rates, and repair response times in the absence of key performance indicators on rural water supply functionality approved by the regional water bureau. The values in Table 2, updated January 2021, represent the average values from 2017 to then.

Table 2. Borehole functionality indicators from ground-truthed sensor data

Indicator	**Method of Calculation**	**Mean Value for Afar Region, January 2021**
Regional Uptime	Uptime = reported functional days / (reported functional days + reported non-functional days)	81–88 percent*
Regional Pump Usage	Days with usage > 0 hours	50 percent by day, 72 percent by week
Mean Daily Pumping	Average hours of pumping per scheme	5.4 hours
Mean Time to Repair (MTTR)	Average length of downtime; MTTR = “no use” / failures	42.5 days
Mean Time to Breakdown (MTTB)	Average length of uptime; MTTB = (“low use” + “normal use” + “seasonal disuse”) / failures	480 days
Failures per Scheme per Year	Average number of verified breakdowns per scheme, averaged per year	0.76 (228/300 expected)

**A range is given due to two different methods of calculation for regional uptime.*

The indicators in Table 2 represent the average behavior of sensor-equipped boreholes since 2017. Regional uptime for schemes with sensors in Afar is between 81 percent and 88 percent, meaning that, on average, up to 264 of 300 motorized boreholes are estimated to be functional on a given day. A goal of the project is to understand the trend in borehole functionality in Afar to evaluate intervention effectiveness. This is challenging for several reasons, one of which is selection bias, because Lowland WASH only installed sensors on functional pumps in 2017 and 2018. Additionally, more ground-truthed functionality updates are available for functional schemes, because ZFPs reportedly verified scheme functionality more often for working than for non-working schemes.

To account for these factors, as well as other strong predictors of borehole uptime such as rainfall, UCB is conducting an impact evaluation to further investigate trends in regional functionality. The goal of the impact evaluation is to assess changes in borehole functionality trends caused by program interventions in asset management and monitoring, including training on the AMS and sensors, maintenance, staffing changes, O&M policy changes, and assistance of the Afar facilitator to the region.

Average daily use of the sensor-equipped schemes has been steady at around 5 hours per day per scheme, a sharp decline since the start of the project, when fewer sensors were in place but average daily pumping per scheme exceeded 20 hours. This is likely due to sensors installed on high-use schemes at the beginning; as more sensors became installed, the average came down. The mWater Surveyor app and the AMS display hours of pumping over the last week for each scheme.

Mean time to repair is a measure of the average response time in days. Response times vary from a minimum of 14 days to greater than 90 days, with an average of 42 days. This metric warrants more investigation into the causes of delays in response time, whether it is mobilizing for site visits, procuring parts, or funding shortfalls. The O&M team also prioritizes certain drought emergency boreholes for faster repairs while waiting for more than one failure to occur in less-prioritized or more-remote areas in order to send repair teams to repair several schemes in a trip. The average response time for all sensor-equipped boreholes does not reflect this.

Failures per scheme per year, or the average number of periods of "no use," is the number of estimated breakdowns detected by sensors per borehole per year, after correcting for sensor accuracy at detecting borehole failures (50 percent). The best estimate is that boreholes experience a major failure (that is, one responded to by the region instead of locally) on average every 1.3 years or every 480 days (1/0.76 failures per scheme per year). This is also called the "mean time to breakdown" or the "average length of uptime."

Interviewees expressed that sensor accuracy and completeness of the AMS (coverage of all motorized schemes) was important to understanding the sensor data and that the uptime and downtime calculations are accurate, but only for the large schemes that have sensors, as opposed to small schemes, including hand pumps. Other measurements, such as the survey conducted by the Rural Water Supply Network in 2016, estimate functionality at around 78 percent for all schemes.[13] SWS expected that schemes in towns would be higher-priority repairs (since no alternative source exists) and therefore would have shorter downtimes and higher uptimes, but it is not possible to see that in the averages presented here. These calculations also conflict with the typical method of reporting downtime, because typically the region measures response time based on when it receives a formal request for maintenance, not from the day of breakdown. Additionally, the region is not always able to access schemes either due to conflict or due to a schemes' disuse because of communities' seasonal mobility, which they do not count as a breakdown.

[13] Banks, Brian & Furey, Sean. 2016. *What's Working, Where, and for How Long: A 2016 Water Point Update*. Available at: https://doi.org/10.13140/RG.2.2.31354.49601

Costs of Borehole Monitoring and Sensor Maintenance

Maintenance Estimates

From data obtained from the region, although incomplete, the authors estimate that the regional O&M team responds to approximately 94 maintenance issues per year and completes 15 additional intensive rehabilitations, with a total operational budget covering only per diem and transport of 1,330,000 ETB ($34,000). Of this, 1,030,000 ETB ($26,400) is budgeted for maintenance and 300,000 ETB ($7,700) is used for rehabilitation. The O&M team reports that money runs out before all maintenance activities can be completed, and it has been unable to access additional funding, partially due to the lack of data on needs.

Historical data have shown that half the sensors are "normal use" and the other half either "offline" or "no use" at any given time. Of these "offline" or "no use" sensors, approximately 30 percent indicate that scheme maintenance is needed and the other 70 percent indicate that the sensor is either offline or falsely reporting due to a disconnection or other technical issue. With 176 sensors currently in the field, this translates to approximately 88 visits per year, 26 scheme repairs initiated by sensor data, and 62 sensor repairs without the need to maintain the scheme. Increasing local capacity to maintain and troubleshoot sensors would likely reduce the number of sensor repairs and replacements needed per year and improve the reliability of data.

To maintain the current stock of 176 sensors, the authors estimate that additional staff and transportation capacity is needed. If 76 percent of mechanized boreholes are estimated to break down in a year (see Table 2), then every borehole in the region likely requires one visit per year. At that time staff will also be able to inspect and maintain sensors, reducing the estimated costs for logistics if funds and transportation are made available for all needed water scheme repairs and rehabilitations. The region is currently visiting approximately one-third of all schemes in a given year.

Cost of Maintaining the Sensors

At current regional budget levels, maintaining the sensor network is unlikely without additional funding. Table 3 demonstrates that the region needs approximately 2 million ETB ($52,500) per year in additional funds to maintain the sensor network. This does not include the installation of any new sensors. In the upcoming 2021–2022 fiscal year, the region has budgeted approximately 417,000 ETB ($10,681), or one-fifth of the total needed funds. This funding gap could be subsidized, because long-term donor support of data services can improve shared accountability for higher-quality water services.[14] Until now, Lowland WASH has imported and supplied sensor replacements and repair parts. It is working to set up a way for the region to purchase sensors manufactured in Kenya, but this has not yet been solved, and the region is unable to purchase additional supplies alone.

---

[14] Thomas, E., & Brown, J. 2020. "Using Feedback to Improve Accountability in Global Environmental Health and Engineering." *Environmental Science & Technology*. Available at: https://doi.org/10.1021/acs.est.0c04115

Table 3. Sensor operations and maintenance budget estimates in a year

Sensor O&M Budget Category	Unit Cost (ETB)	Number per Year	Annual Total (ETB)	Annual Total (USD)[15]
Airtime and Data Costs				
Airtime for Sensor Report Verification[16]	1	300	300	$8
GSM Yearly Bill[17]	150	76	11,400	$301
Satellite Yearly Bill[18]	6,960	100	696,600	$18,374
Total Data Costs			707,700	$18,683[18]
Sensor Repairs and Replacements				
Sensor Repair Logistics (O&M Team Travel)[19]	11,000	58 (33 percent of sensors)	638,000	$16,843
Sensor Replacement[20]	37,880	18 (10 percent of sensors)	681,840	$18,000
Total Repairs and Replacements			1,319,840	$34,843 ($201 per sensor)
Annual Sensor O&M Cost	11,520	173	1,992,960	$52,613 ($304 per sensor)

After 4 years of sensor installation in Afar, failure rates are higher than the 10 percent originally estimated in Table 3, with about 24 percent of sensors needing repairs or replacements in a year, on average. This suggests that the average lifespan of sensors in these conditions is up to 4 years, so cost estimates for replacement parts should likely be revised upward.

Analyzing the costs and benefits of the sensor network and its contribution to monitoring is difficult at this point in time without significant uptake of the tools or full data on previous or current spending on monitoring and maintenance. The cost implications of a monitoring service should also consider the expected benefits from improved functionality on the costs of service delivery per person served.

---

[15] Exchange Rate of 37.88 ETB to USD on November 18, 2020.
[16] 300 ETB is the current amount budgeted for airtime but is insufficient to verify all "no use" statuses.
[17] From USAID Lowland WASH Activity in Ethiopia, does not include startup data costs, which are 30 ETB per SIM card.
[18] UCB will cover data costs after the end of Lowland WASH and not the regional government.
[19] Estimated O&M team mobilization cost from the regional budget and reporting of maintenance activities and the number per year comes from 52–58 inspections conducted per year since 2018.
[20] Anecdotally, GSM sensors fail more frequently, but the replacement cost shown is an average of a new GSM sensor (27,040 ETB) and a new satellite sensor (40,560 ETB).

Conclusion

Achievements and Challenges

In working with the region to implement the AMS, regional actors saw the sensors as an exciting and useful component of the system. Unfortunately, the system and sensor data have seen little use, and understanding the gap between the enthusiasm and limited use has been challenging. During the few months in which the ZFPs operated, they used the sensor data more than other components, described the data as valuable, and used the data in updating scheme functionality, despite the challenge of accuracy. Schemes without sensors proved harder to monitor and update, largely due to better contact information collected during the sensor installations and a lack of updated AMS inventory data for non-instrumented schemes. Despite the improved contact information, ZFPs had difficulty contacting operators and woreda staff to verify scheme statues for both schemes with and without sensors. Overall, schemes reporting a "normal use" status can be considered functional, but other status require follow-up via phone or in-person visit.

Actively monitoring sensor data and following up on status changes did sometimes indicate a problem before it had been communicated to the region, but the system did not increase the number of issues reported to the O&M team. Overall, more data are not necessarily helpful, because the region is unable to respond to all maintenance requests and still depends on formal, paper-based processes to request and use their funds and spare-part stores.

Although the AMS has yet to be fully implemented or used regularly, the sensors did support SWS's understanding of scheme-level functionality. SWS calculated estimates of regional-level functionality to support the region's planning process, but the region did not use the estimates after presented with the data. Although incomplete, functionality data on 176 water systems via sensors are a better starting place than any other available data set and can be supplemented with manual updates of other systems. Additionally, sensors have initiated a few maintenance responses with the involvement of the embedded facilitator and alerted Mille Woreda to potential water wastage from overuse of a few solar-powered systems.

Paying for the sensors, whether to maintain or expand the network, is a major hurdle to furthering their use in the future. The cost of maintaining the sensor network may be offset, in part, through added utility and additional sensor data customers that have come on board. In particular, the sensor data are now being applied in a groundwater demand model developed under the NASA and USAID SERVIR program, and in partnership with the Famine Early Warning Systems Network (FEWS-NET), to improve near-time estimates and forecasts for groundwater demand and pump functionality. To this end, following the closure of Lowland WASH in 2021, UCB will fund data telemetry costs as part of the FEWS-NET and SERVIR groundwater demand monitoring service.

Recommendations

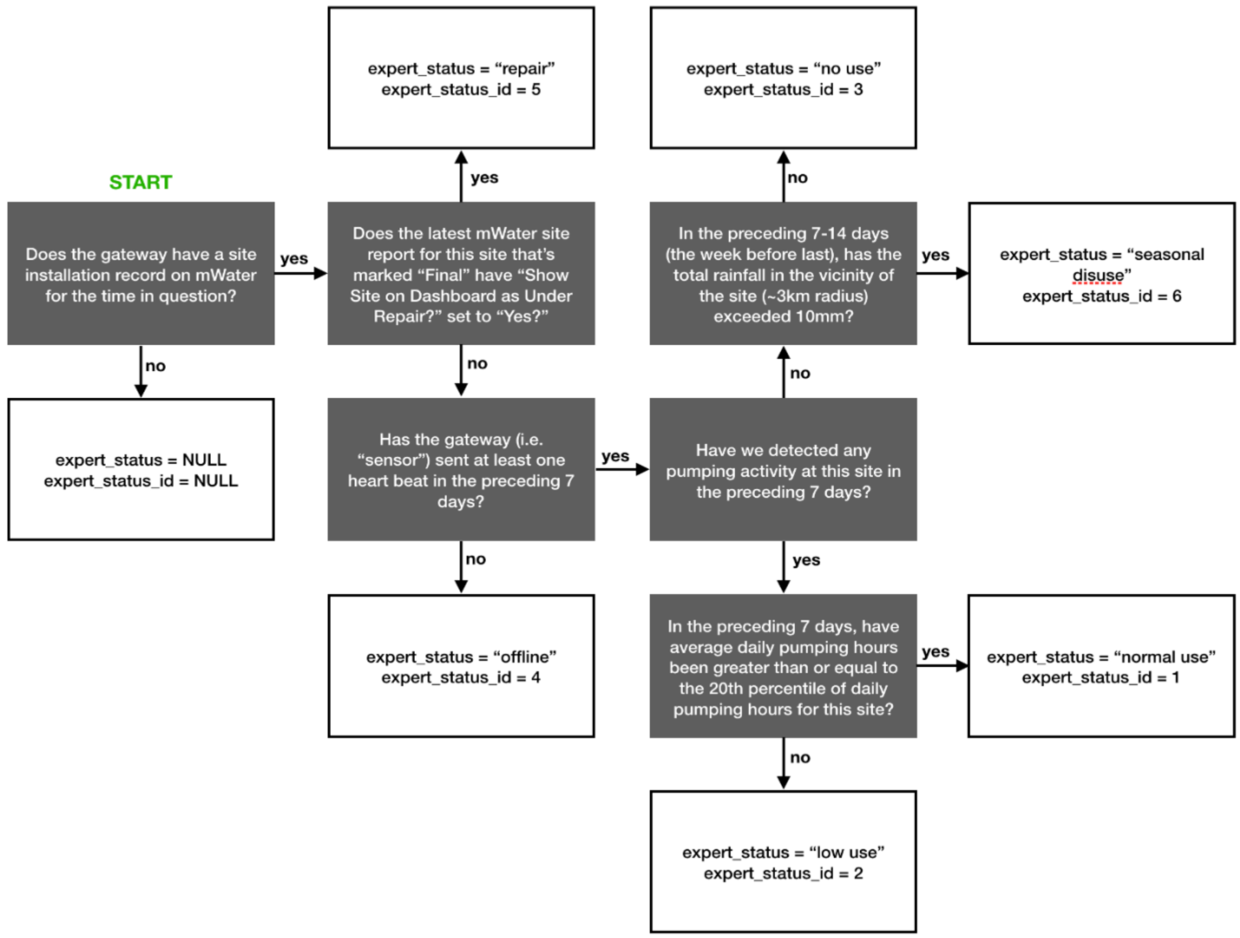
In the short term, enabling automatic updating of functionality from "normal use" sensor reports would expand the region's ability to utilize the data for day-to-day processes with less staff time. Adding key performance indicators for water supply functionality to the AMS would improve use of the data for planning. These indicators could be calculated only from sensors, like in Table 2, or the calculations could be developed in tandem with management, according to their reporting needs. Another requested feature is to enable comparison of the sensor-supplied data with the manually updated data for non-instrumented boreholes, allowing for improved use and understanding of the data sets available in the region. The regional leadership also needs to further understand sensor data and use.

The sensor-monitoring network will be more reliable with better local understanding of the sensors, improved maintenance of sensors, and sensor design changes to improve longevity (such as heat-resistant batteries and switching to satellite connections). Sensor status accuracy can also be improved through modifications to the current expert status classification system or adoption of machine-learning algorithms that better adapt to the individual usage patterns of a particular scheme to predict a breakdown. The current sensor expert status classification system was not designed for infrequently used boreholes, making it difficult to determine when a breakdown has occurred, because not pumping for more than 7 days is common in remote areas when the reservoir is still full. Improvements in sensor accuracy may increase confidence in the data for initiating maintenance responses and other decision-making. Overall, continued use, maintenance, and monitoring of usefulness may guide future use of the sensors and improve their reliability and utility.

Based on current functionality levels, the number of repairs the government is able to perform per year, and the low coverage levels in the region, the authors recommend large investments in the size and capacity of the regional O&M team to verify sensor reports and to respond to all requests for support for broken schemes. Without long-term planning and financing for the water sector in Afar, it is difficult to make the argument for expanding monitoring because finance, not data, is the main bottleneck to responding to breakdowns.

Potential other uses of sensor data to explore include monitoring usage of high-use schemes or downscaling the number of sensors to focus on more-remote and drought-critical schemes without alternative sources. Reallocating sensors to more important or more frequently used or failing boreholes may be a better use of resources than the current numbers and placements of sensors. However, before exploring these different uses and investing in redeploying or changing the placement of sensors, future projects should first identify the local need for data and the process, people, and finance required to support use. This should also include budgeting for user support, systematic troubleshooting, and sensor maintenance to ensure sensors are online and reporting accurately. Rapid borehole repairs informed by a smaller number of sensors may be possible to improve borehole functionality and the usefulness of real-time monitoring data for regional operations, but the partnership has been unable to show that sensor data improve the timeliness of maintenance responses without additional finance available for repairs.

Annex 1. SweetSense Expert System Status Classification



Annex 2. Interviews Conducted

	Individuals Interviewed February 2020	Individuals Interviewed at the AMS Handover February 2021
ARWIEB Leadership	4	
Regional Zonal Focal Persons	5	2
Regional O&M Team	1	
Mille Woreda Water Office	2	

Annex 3. Proposed Expert Status Changes

Change to "no use" status

To account for false "no use" status when Pressac clamps are known to be disconnected and there are no data on pump functionality, remove that period of observation from the data set and reclassify that pump as "offline" until the clamp is reconnected.

Change to "low use" status

To address the issue of schemes with infrequent pumping (between 7 and 14 days of 0 runtime), change calculation so that downtime periods shorter than 14 days are marked as "low use" periods; because the minimum maintenance response time is 14 days, a repair could not yet have been conducted. "Low use" was designed to capture infrequently used schemes or schemes with emerging problems that are lower priority. Therefore, fixing this calculation would lower the number of "no use" schemes the team must respond to.

Change to "seasonal disuse" status

Due to the impact of heavier rains that create larger pools of surface water and the established user preference for surface water over borehole water, extend the length of the "seasonal disuse" period from 7–14 days following rainfall >10 mm in the vicinity of the borehole to 14–28 days following a heavy rainfall event unless there has been 0 runtime for more than 7 days prior to the start of the rainfall. This will correct for the common pattern seen in which sensors report no runtime and there has been infrequent rainfall, so the status oscillates between "seasonal disuse" and "no use." If starting with a working "normal use" scheme and there is rain, instead of showing sensor status changes from "normal use" > "seasonal disuse" > "no use" > "seasonal disuse," etc., the corrected expert status will show just "seasonal disuse" for the entire period of no runtime. If starting with a possibly broken "no use" scheme, instead of showing sensor status changes from "no use" > "seasonal disuse" > "no use" > "seasonal disuse," etc., the corrected expert status will show just "no use" for the entire period of no runtime.