Den Haag, The Netherlands, 12 – 14 March 2019

1. ALL SYSTEMS GO! WASH SYSTEMS SYMPOSIUM

A methodology for assessment of the physical sub-system of hand pumped boreholes: initial insights from Ethiopia.

DJ. MacAllister, Kebede, S., Dessie, N.,
Yehualaeshet, T., Zemenu, G., H. Fallas, and A.M. MacDonald [United Kingdom]

Perceived poor performance of hand pumped boreholes has been a persistent problem in Africa. The UPGro Hidden Crisis project has brought together an interdisciplinary team of researchers to examine boreholes equipped with hand pumps in Ethiopia, Malawi and Uganda. The project has (1) devised and applied a survey method to provide nuanced data on the functionality of the hand pumped system and (2) conducted a full physical sub-system, consisting of assessment of 150 hand pumped boreholes. The physical sub-system consists of the hydrogeology and hydrochemistry, the borehole and the hand pump. Results from the functionality survey show that although up to 80% of waterpoints may be producing water, much fewer (often <50%) are giving the design yield reliably for more than 11 months of the year.

Our physical sub-system analysis of individual hand pumped boreholes involved carrying out tests on hand pump materials, aquifer tests, water quality testing and borehole examination with a CCTV camera. The initial analysis of the data using three sites in Ejere district of Ethiopia highlights potential issues with aquifer yield and borehole construction that could contribute to failure. In parallel communities were asked detailed questions about their experience of the source, using focus group discussions and transect walks, and sanitary and geological surveys were also conducted. Data from the study will be examined using different approaches, including applying predictive and casual statistical approaches and systems thinking, to investigate, and understand, the relationship between, and influence of, the physical and social factors underlying poor borehole functionality.

2. Introduction

Anecdotal evidence, and studies by national governments, donor organisations and implementing bodies indicate that around 35% of improved water sources are non-functional at any one time. Furthermore, many water point fail within a few years of installation and then enter repeated cycles of failure and repair [*Bonsor et al.*, 2015; *Wilson et al.*, 2016]. Evidence also suggests that failure rates have remained at between 30 and 50% over the last 40 years [*Bonsor et al.*, 2015; *Wilson et al.*, 2016], despite innovations such as community management and demand responsive approaches which aimed to improve sustainability of water supplies.

Water point functionality is a multi-faceted issue and the factors that contribute to functionality outcomes. include [*HC Bonsor et al.*, 2015]: primary causes (e.g. mechanical failure, reduced yield, poor water quality); secondary causes (e.g. geology, poor siting, lack of spare parts, basic maintenance, local governance arrangements); the underlying conditions (including the institutional, financial and social factors that shape an environment in which failure is more or less likely); and long term trends (e.g. changes in demand for water, evolution of governance arrangements, reduction in regional groundwater availability, climate change, deterioration of water quality). In the Hidden Crisis project the issue of functionality is considered within a systems framework, and applied to study functionality of rural hand pumped boreholes in three countries in Sub-Saharan Africa, Ethiopia, Malawi and Uganda. The project has five main objectives:

1. To provide a nuanced definition of hand pumped borehole functionality which accounts for seasonality, quality and expectations, and is fit for purpose for tracking future progress towards the Sustainable Development Goals.
2. **SURVEY 1:** To apply this new definition to 600 hand pumped boreholes, 200 each in Ethiopia, Uganda and Malawi, and to carry out field surveys for a statistically significant sample of water points.
3. **SURVEY 2:** Conduct a full hand pumped borehole system assessment to unravel the multi-faceted factors governing hand pumped borehole failure and success. Interdisciplinary studies were conducted to investigate the inter-relations within the hand pumped borehole system, between governance arrangements, technology choice and design, material selection, demographic, and groundwater conditions within a broader institutional and hydrogeological framework. These detailed surveys were conducted on c.150 hand pumped boreholes, c.50 in each of the three countries.
4. To examine and forecast future rural water supply coverage by modelling the impact on water points of different future pathways, including groundwater recharge scenarios, different development approaches, and future rural water demand scenarios.
5. To develop a dynamic approach for building resilience into future rural water supply programmes, through detailed interdisciplinary analysis of the datasets developed in 1 – 3 and develop several pathways for uptake within the WASH community.

Here we summarise the main findings from Survey 1 and consider the factors, based on the hand pumped borehole system assessment (Survey 2), that led to functionality outcome and categorisation of a subset of 150 Survey 1 hand pumped boreholes. Rather than examining the whole system, this paper focuses on understanding a key component of the hand pumped borehole system, the physical sub-system. In addition to the work reported, and to ensure the project focused on the whole system, longitudinal studies and social surveys were also conducted. The longitudinal surveys looked at water resource dynamics and community experience of the water resource. Social conducted detailed focus group discussions and transect walks to better understand social, economic and governance factors affecting functionality. The physical sub-system constitutes the borehole, hand pump and the broader hydrogeological regime. By adopting this system perspective we anticipate identifying the key physical factors that influence functionality, as defined in Survey 1, of the hand pumped borehole system. The paper begins by summarising the approach adopted in Survey 1 and the definition of functionality used. The methods used in Survey 2 are then outlined, and some initial results are reported. We focus on three sites in Ejere district of Ethiopia, hand pumped boreholes in this area draw from a porous igneous aquifer system and it has a relatively wet climate. Finally, we discuss the next steps required to build a deeper understanding of the relationships between the physical components of the hand pumped borehole system and the wider system including the social and governance factors. Potential analysis steps that might allow identification of causal pathways to functionality outcomes are highlighted and we identify a way forward to explain the key drivers of poor levels of hand pumped borehole functionality in Sub-Saharan Africa.

3. Background – Definition of System Functionality and Overview of Survey 1

The Hidden Crisis project adopted the following principals as the foundations for detailed functionality assessments of hand pumped borehole systems. Firstly, functionality should be measured against an explicitly stated standard and population of water points. It should be measured separately from the users' experience of the service it provides. The assessment should be tiered, allowing for a more detailed understanding of the status of the hand pumped borehole system, but always allowing assessments of functionality to be reduced to a simple measure (i.e. delivering water or not delivering water). Finally a distinction should be made between surveying functionality as a snapshot (e.g. for national metrics) and monitoring individual water point performance (including an assessment of temporal behavior of the system). The approach to functionality assessments adopted by the Hidden Crisis project is outlined in detail by *Bonsor et al.*, [2018]. The key components of the assessment approach are reproduced in Figure 1. The definition adopted provides four levels of functionality information about hand pumped borehole system performance, these are:

1. **Binary:** Is the water point physically working and producing some water at the time of the survey visit?
2. **Yield snapshot:** Does the water point provide the minimum design yield (e.g. 10 L/min)?
3. **Reliable yield:** Does the water point provide a reliable yield (meeting criteria 1 and 2 above) year round (less than 30 days downtime in the previous 12 months)?
4. **Reliable yield including water quality:** Does the water supply pass WHO inorganic and pathogen guidelines, as well as provide a reliable yield year-round?

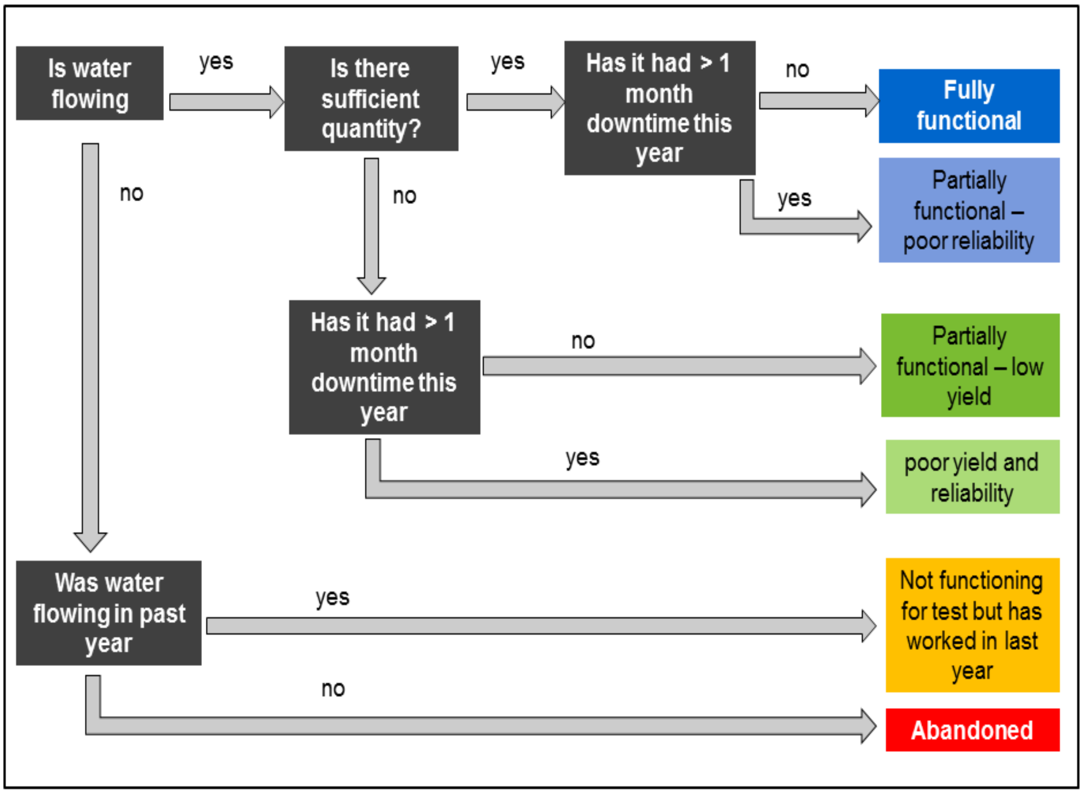

FIGURE 1. DEFINITION OF HAND PUMPED BOREHOLE FUNCTIONALITY. THE AREA SURROUNDED BY THE DAHSED BOX PROVIDES A BINARY ASSESSMENT OF SYSTEM FUNCTIONALITY. THE AREA SURROUNDED BY THE DOTTED BOX PROVIDES A SNAPSHOT OF SYSTEM FUNCTIONALITY AGAINST A DEFINED YIELD. THE REMAINING QUESTIONS PROVIDE AN ASSESSMENT OF SYSTEM PERFORMANCE INCLUDING TEMPORAL BEHAVIOUR OF THE SYSTEM.

Source: Bonsor, H., A. MacDonald, V. Casey, R. Carter, and P. Wilson (2018), The need for a standard approach to assessing the functionality of rural community water supplies, Hydrogeology Journal, doi:10.1007/s10040-017-1711-0.

This definition of functionality was then applied to assess 600 hand pumped boreholes, primarily equipped with Afridev and India Mark 2 hand pumps, across the three study countries. 200 hand pumped boreholes, were selected in each country using a stratified three-stage random sampling approach. At each hand pumped borehole a stroke test was conducted, well head water chemistry and microbiology were sampled and users were asked questions about their perception of functionality. Each hand pumped borehole was classified according to the functionality categories in Figure 1. The results are shown in Figure 2. More details on Survey 1 analysis and results can be found in [*Kebede et al.*, 2017; *Mwathunga et al.*, 2017; *Owor et al.*, 2017].

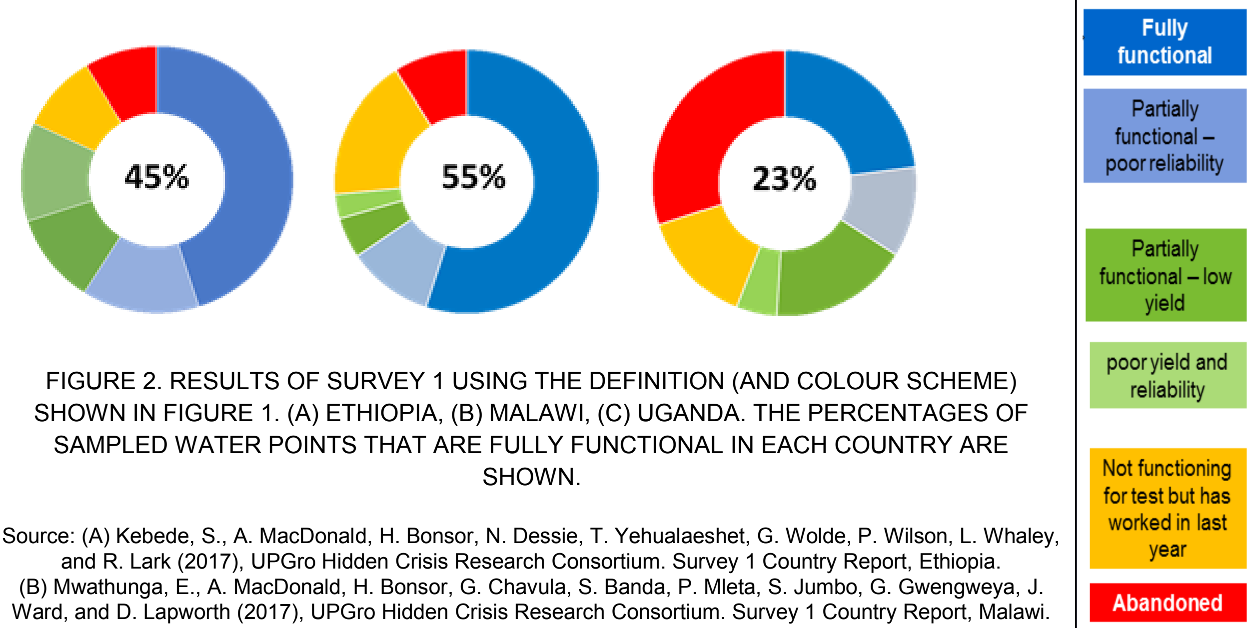

FIGURE 2. RESULTS OF SURVEY 1 USING THE DEFINITION (AND COLOUR SCHEME) SHOWN IN FIGURE 1. (A) ETHIOPIA, (B) MALAWI, (C) UGANDA. THE PERCENTAGES OF SAMPLED WATER POINTS THAT ARE FULLY FUNCTIONAL IN EACH COUNTRY ARE SHOWN.

Source: (A) Kebede, S., A. MacDonald, H. Bonsor, N. Dessie, T. Yehualaeshet, G. Wolde, P. Wilson, L. Whaley, and R. Lark (2017), UPGro Hidden Crisis Research Consortium. Survey 1 Country Report, Ethiopia. (B) Mwathunga, E., A. MacDonald, H. Bonsor, G. Chavula, S. Banda, P. Mleta, S. Jumbo, G. Gwengweya, J. Ward, and D. Lapworth (2017), UPGro Hidden Crisis Research Consortium. Survey 1 Country Report, Malawi. (C) Owor, M., A. MacDonald, H. Bonsor, J. Okullo, F. Katusiime, G. Alupo, G. Berochan, C. Tumusiime, D. Lapworth, and L. Whaley (2017), UPGro Hidden Crisis Research Consortium. Survey 1 Country Report, Uganda.

The new definition of hand pumped borehole system functionality provides a clear indication of system performance, which includes system reliability and ability of the hand pumped borehole to deliver against design yield. By including these system properties, the new definition of functionality also provides an indication of the level of service provided by the hand pumped borehole system. There are striking differences in overall functionality levels between the three countries, but also clear differences between reliability and yield components of the system in the three countries. Survey 2 was designed to deconstruct the entire system in order to understand what underlying factors might affect functionality outcomes as shown in Figure 2.

4. Survey 2 Methodology

Survey 2 involved a full system assessment of 150 hand pumped boreholes across the three countries. 50 sites were selected in each country based on the results shown in Figure 2. The sites were selected to ensure that each of the six functionality categories (Figure 1) were represented in the Survey 2 dataset, approximately 8 – 9 sites were selected in each category. The inclusion of sites from each functionality category was designed to allow identification of key physical factors, which influence a particular functionality outcome. In order to do this the methods had to cover all physical components of the system, the aquifer and hydrogeology, engineering of the hand pump, borehole construction, water chemistry and geographical and hydrological context of the area surrounding the pump. Figure 3 shows the key methodological steps and the sequence in which the methodology was conducted at each of the 150 study sites. The full methodology adopted during the survey is outlined below, and some examples of the results, from three sites in Ejere district in Ethiopia, are presented.

FIGURE 3. FIELD METHODS AS CONDUCTED DURING SURVEY 2. CLOCKWISE FROM TOP LEFT; PUMP COMPONENT INSPECTIONS; PUMPING TEST, USED TO ASSESS AQUIFER YIELD; FIELD CHEMISTRY, USED TO ASSESS CORROSIVITY OF WATER AND OVERALL WATER QUALITY; BOREHOLE INSPECTIONS, USED TO ASSESS BOREHOLE CONSTRUCTION.

Source: ASG - Source

Pump component observations

Survey 2 began by making systematic observations of the pump and surrounding area, a detailed sanitary survey was conducted and observations of the pump condition were recorded using both photographs and visual observations based on a predefined list of hand pump problems. Next the hand pump was dismantled and pump cylinder, rising mains, rods and all other components were removed from the borehole. As components were removed they were clearly labelled and laid out systematically for further inspection. The condition of each of the downhole components was systematically recorded, again using photographs and recording visual observations against a list of pre-defined problems.

For rising mains and rods further measurements were made. Standard measurements included length and diameter measurements, but additional measurements were made to try and understand the condition in more detail. These additional measurements were dependant on the type of hand pump assessed and the material used. If metal pipes were used these were weighed and the wall and galvanising thickness were measured using an acoustic and magnetic device respectively. If PVC pipes were used the wall thickness was measured using an acoustic measuring device. The purpose of these measurements were to make quantitative estimates of corrosion and assess the quality of materials used in the hand pump.

An example of above and below ground observations for a fully functional, partially functional (poor reliability and low yield) and non-functional hand pumped borehole are shown, respectively, in Figure 4 for site EEJ10, Figure 5 for site EEJ06 and Figure 6 for site EEJ20. The fully functional and partially functional boreholes appear very similar from a quick interrogation of the images, the main difference is that the rods from the partially functional borehole appear to be more corroded. The non-functional borehole is in a very poor condition and has many missing components. Further work is required to utilise these images and the manually recorded observations and quantitative measurements to draw conclusions about influence of the component condition on functionality outcomes and whether these represent causes or symptoms of poor functionality.

Figure 4. Observations of pump components from site EEJ10, which was classified as fully functional under the Survey 1 classification scheme.

Figure 5. Observations of pump components from site EEJ06, which was classified as partially functional (poor reliability and low yield) under the Survey 1 classification scheme.

Figure 6. Observations of pump components from site EEJ20, which was classified as non-functional under the Survey 1 classification scheme.

Users perceptions – water quality, quantity and break down history

While component measurements and observations were being made, users were asked about their experience of the hand pumped borehole both with respect to quality and quantity. Users were also asked if they could help construct a breakdown history of the hand pumped borehole.

Pumping test

Once the pump was dismantled, the pumping test could begin. Prior to installing the submersible pump the water level and total depth of the borehole were measured. Then the submersible pump and a pressure transducer were installed. The submersible pump, a Grundfos SQ3-65 cable of pumping at 3m^3/hr with a 60 m head, was installed at or near the hand pump cylinder level or 1 metre from the bottom of the borehole if there was evidence that the borehole was low yielding. The borehole was then pumped at 1 litre per second for 2.5 hours, during which time the change in water level was measured manually and recorded. In some cases, for example if there was evidence that the borehole was low yielding, a lower pumping rate was used. Once the pump was switched off water level recovery was monitored manually for 1 hour. The pressure transducers were left in the borehole overnight, meaning a full record of the pumping test and water level recovery is available. The pumping tests were interpreted using BGSPT which solves Darcy's equation analytically and is designed to minimise the R^2 difference between observed and calculated drawdown.

Examples of pumping test results for fully functional, partially functional (poor reliability and low yield) and non-functional hand pumped borehole are shown, respectively, in Figure 7 for site EEJ10, Figure 8 for site EEJ06 and Figure 9 for site EEJ20. The results show that the estimated transmissivity is highest for the fully functional hand pumped borehole and lowest for the non-functional borehole. Although, these results are from a very small subset of the larger dataset they indicate the importance of aquifer yield on the functionality of hand pumped boreholes, particularly in Ejere district in Ethiopia. The transmissivity in the partially functional borehole (Figure 8) is also very low and suggests that a low yielding aquifer will have implications, not only for hand pump yield, but also for the reliability of the hand pumped borehole.

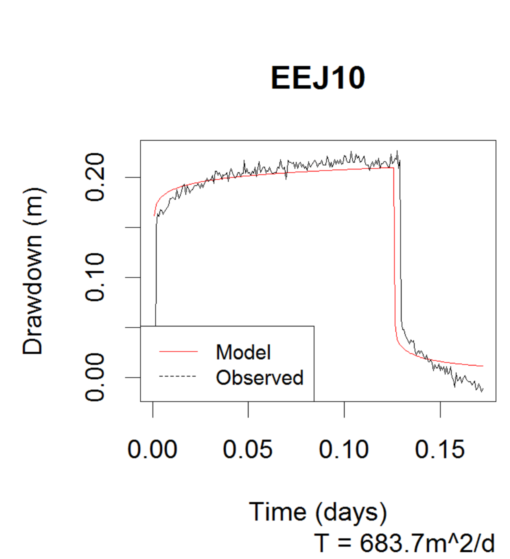

Figure 7. Observed and modelled pumping test drawdown, and interpreted transmissivity, for the borehole at site EEJ10, which was classified as fully functional under the Survey 1 classification scheme.

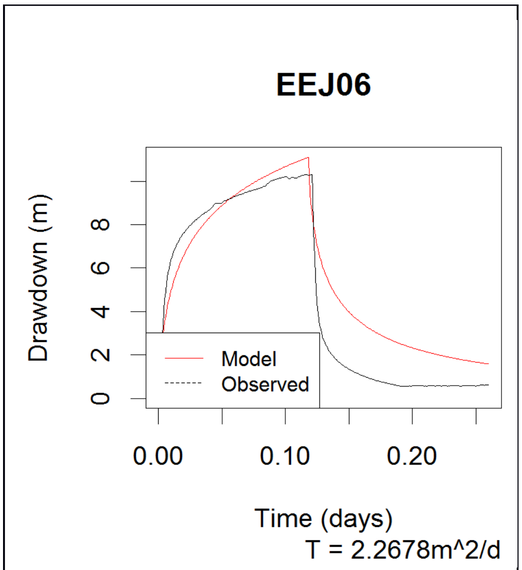

Figure 8. Observed and modelled pumping test drawdown, and interpreted transmissivity, for the borehole at site EEJ06, which was classified as partially functional (poor reliability and low yield) under the Survey 1 classification scheme.

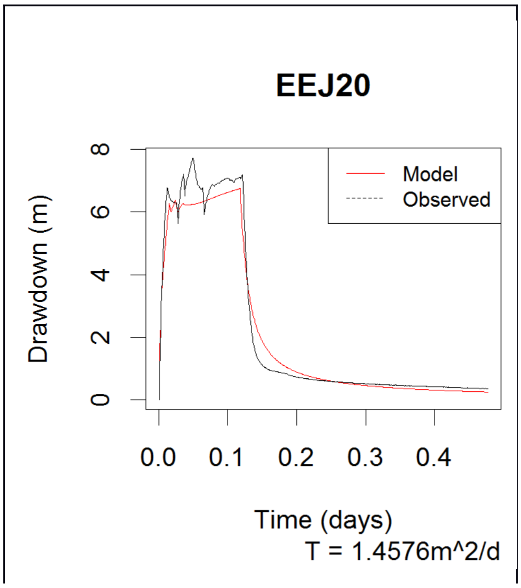

Figure 9. Observed and modelled pumping test drawdown, and interpreted transmissivity, for the borehole at site EEJ20, which was classified as non-functional under the Survey 1 classification scheme.

Water chemistry and residence times

In the final 1 hour of the pumping test water chemistry was sampled. Before taking water samples pH, electrical conductivity (EC), dissolved oxygen (DO), redox potential (Eh) and temperature were recorded. Iron was monitored using a field colorimeter for the duration of the pumping test. Once each of these parameters stabilised water samples were taken to allow analysis for a full suite of organic and inorganic parameters, microbiology (using Aquagenx compartmental bags for MPN), residence time indicators (CFC and SF6) and stable isotopes. The main function of the water sampling was to determine the risk of corrosion and/or scaling to the hand pump components. Residence time indicators and stable isotopes were used to assess aquifer recharge mechanisms a critical component of total water available to the hand pumped borehole system.

An example of field chemistry results from a fully functional, partially functional (poor reliability) and non-functional hand pumped borehole are shown in Table 1. The non-functional borehole has a very high electrical conductivity (EC) and a low pH, suggesting that these parameters might have an important impact on hand pumped borehole functionality. However, the pH is also quite low for the fully functional site so further investigations are required to fully understand the impact of these and other water quality parameters on hand pumped borehole functionality.

Table 1. Field chemistry from a fully functional (EEJ10), partially functional (poor reliability and low yield, EEJ06) and non-functional (EEJ20) hand pumped borehole.

Table cell heading	Temp (^oC)	pH	EC (µs/cm)	Eh (mV)	DO (mg/l)	Alkalinity (mg/l)
EEJ10	21.8	6.72	676	97	0.22	236
EEJ06	23.4	7.39	253	318	0.14	120
EEJ20	21.9	6.44	1028	308	0.36	140

Borehole construction assessment

On the second day borehole CCTV surveys were conducted. The CCTV surveys were designed to assess the borehole construction, and focussed on examining the positions and lengths of individual screen, blank casing or uncased sections within the borehole. The condition of each section was also assessed.

An example of a borehole construction log for a fully functional, partially functional (poor reliability and low yield) and non-functional hand pumped borehole are shown, respectively, in Figure 10 for site EEJ10, Figure 11 for site EEJ06 and Figure 12 for site EEJ20. The fully functional borehole has a pump in the screened section but there is approximately 15 m between the water level and the pump cylinder. In contrast the poorly reliable borehole has only about 5 m between pump and water level, although it also has the cylinder in the screened section. The smaller water column may well have an important impact on the reliability of the pump, with increased risk of the pump cylinder leaving the water column with intensive use, particularly because of the lower aquifer yield of this well (Figure 8). The pump cylinder is above the water level which is a clear explanation why this particular borehole is classified as non-functional. However, for the non-functional site there are important questions, which will be investigated further as the analysis progresses, as to why the pump cylinder was installed so high within the borehole given the poor aquifer yield, the positions of the screened sections in the bottom half of the borehole and the relatively deep total borehole depth.

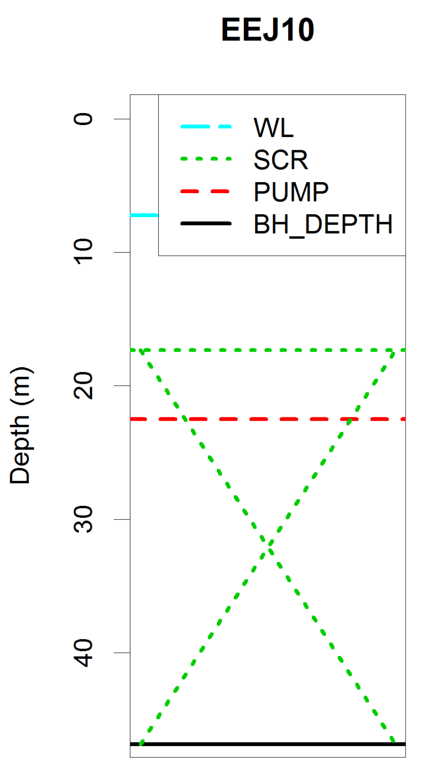

Figure 10. Borehole construction at site EEJ20, which was classified as non-functional under the Survey 1 classification scheme.

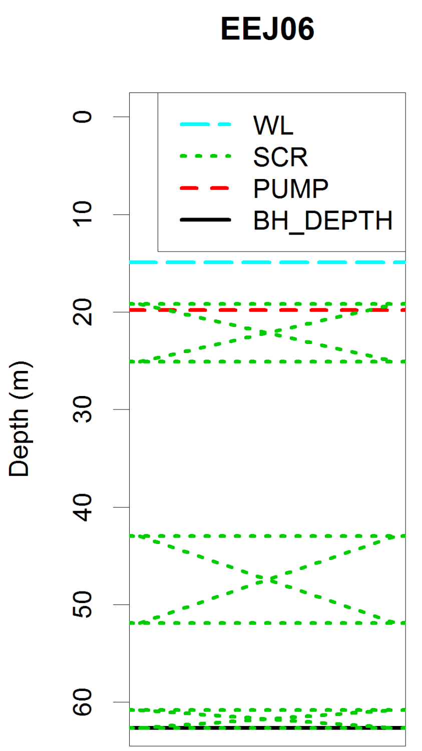

Figure 11. Borehole construction at site EEJ06, which was classified as partially functional (poor reliability and low yield) under the Survey 1 classification scheme.

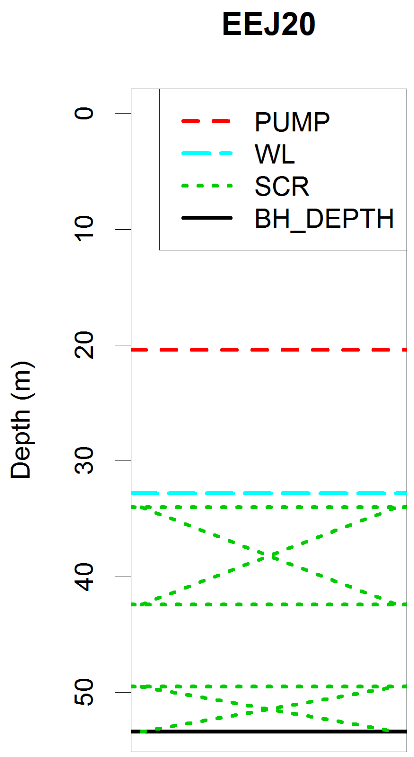

Figure 12. Borehole construction at site EEJ20, which was classified as non-functional under the Survey 1 classification scheme.

Geological survey and geographical contextualisation

Finally, a geological and geographic survey of the area was conducted. The aim of the survey was to try and assess the local hydrogeology and hydrology, surrounding land use and general features of the area that might have an influence on the hand pumped borehole system.

5. Next Steps

The methodology described above has produced comprehensive and detailed dataset of the physical causes of hand pumped borehole system functionality. The results presented are only representative of a very small subset of the overall dataset. However, they provide interesting insights into the importance of aquifer yield and borehole construction for the sites presented. Further work is required to extract the full value from this dataset. The immediate next step is to produce summary outputs from each component of the methodology and begin to extract meaningful indicators of functionality from these data. These indicators will then be used in conjunction with social science data, to understand causal factors and pathways to each of the functionality outcomes shown in Figure 1. The methods used to understand these relationships will include systems thinking approaches [*Liddle and Fenner*, 2017] and multivariate linear regression [*Andres et al.*, 2018; *Cronk and Bartram*, 2017; *Foster*, 2013; *Foster et al.*, 2018; *Kativhu et al.*, 2017]. Other techniques could also be explored such as fuzzy-set qualitative comparative analysis (QCA) [*K Gasparro*, 2017; *K E Gasparro and Walters*, 2017; *Marks et al.*, 2018] a method which combines qualitative and quantitative methods by applying principles of logical comparison. These methods could also be applied only to the physical components of the system, as described above. Much of the value in the dataset is related to the cross-country comparisons, but individual country assessments will also be conducted. Failure pathways will be mapped for individual sites in order to build a more comprehensive understanding of the mechanisms and properties of functional, partially functional and non-functional hand pumped boreholes.

6.

7. Summary and Conclusions

The Hidden Crisis project has defined a new functionality categorisation that allows a tiered assessment of the functionality of hand pumped borehole systems. The definition has been tested in three countries in sub-Saharan Africa. In Survey 2 these definitions were interrogated by fully deconstructing 150 hand pumped borehole systems. The methodology adopted considers the hand pumped borehole as a whole physical system, and provides quantitative and qualitative data on each individual component of the system. An initial analysis of a subset of the individual components of the system, namely hand pump components, aquifer yield, water chemistry and borehole construction, provide useful insights as to possible factors that lead to the classification at three sites in Ethiopia. In particular aquifer yield and borehole construction seem to have an important influence on functionality outcome. No causal pathways can be determined from this initial analysis. However, the dataset will be interrogated further using a number of different techniques to understand the likely causal pathways that lead to particular functionality categorisations of hand pumped borehole systems.

8.

9. Acknowledgements

The authors would like to thank Michael Owor and Joseph Okullo of Makerere University, Evance Mwathunga and Chikondi Shaba of Chancellors College at the University of Malawi and Patrick Makuluni and Theresa Mkandawire of The Polytechnic at the University of Malawi, all of these individuals were key to the data collection conducted in Uganda and Malawi. WaterAid country staff are also thanked for their assistance in the field in all three countries. NERC and DFID are thanked for funding this project.

10. References

Andres, L. A., G. Chellaraj, B. Dasgupta, J. Grabinsky, and G. Joseph (2018), Why are so Many Water Points in Nigeria Non-Functional?: An Empirical Analysis of Contributing Factors.

Bonsor, H., A. MacDonald, V. Casey, R. Carter, and P. Wilson (2018), The need for a standard approach to assessing the functionality of rural community water supplies, *Hydrogeology Journal*, doi:10.1007/s10040-017-1711-0.

Bonsor, H., N. Oates, P. Chilton, R. Carter, V. Casey, A. MacDonald, R. Calow, R. Alowo, P. Wilson, and M. Tumutungire (2015), A hidden crisis: strengthening the evidence base on the sustainability of rural groundwater supplies: results from a pilot study in Uganda.

Cronk, R., and J. Bartram (2017), Factors Influencing Water System Functionality in Nigeria and Tanzania: A Regression and Bayesian Network Analysis, *Environmental Science & Technology*, *51*(19), 11336-11345, doi:10.1021/acs.est.7b03287.

Foster, T. (2013), Predictors of Sustainability for Community-Managed Handpumps in Sub-Saharan Africa: Evidence from Liberia, Sierra Leone, and Uganda, *Environmental Science & Technology*, *47*(21), 12037-12046, doi:10.1021/es402086n.

Foster, T., J. Willetts, M. Lane, P. Thomson, J. Katuva, and R. Hope (2018), Risk factors associated with rural water supply failure: A 30-year retrospective study of handpumps on the south coast of Kenya, *Science of The Total Environment*, *626*, 156-164, doi:https://doi.org/10.1016/j.scitotenv.2017.12.302.

Gasparro, K. (2017), Evaluating causal pathways to sustainable wash infrastructure in developing countries, STANFORD UNIVERSITY.

Gasparro, K. E., and J. P. Walters (2017), Revealing causal pathways to sustainable water service delivery using fsQCA, *Journal of Water Sanitation and Hygiene for Development*, *7*(4), 546-556, doi:10.2166/washdev.2017.053.

Kativhu, T., D. Mazvimavi, D. Tevera, and I. Nhapi (2017), Factors influencing sustainability of communally-managed water facilities in rural areas of Zimbabwe, *Physics and Chemistry of the Earth, Parts A/B/C*, *100*, 247-257, doi:https://doi.org/10.1016/j.pce.2017.04.009.

Kebede, S., A. MacDonald, H. Bonsor, N. Dessie, T. Yehualaeshet, G. Wolde, P. Wilson, L. Whaley, and R. Lark (2017), UPGro Hidden Crisis Research Consortium. Survey 1 Country Report, Ethiopia.

Liddle, E. S., and R. Fenner (2017), Water point failure in sub-Saharan Africa: the value of a systems thinking approach, *Waterlines*, *36*(2), 140-166, doi:10.3362/1756-3488.16-00022.

Marks, S. J., E. Kumpel, J. Guo, J. Bartram, and J. Davis (2018), Pathways to sustainability: A fuzzy-set qualitative comparative analysis of rural water supply programs, *Journal of Cleaner Production*, doi:https://doi.org/10.1016/j.jclepro.2018.09.029.

Mwathunga, E., A. MacDonald, H. Bonsor, G. Chavula, S. Banda, P. Mleta, S. Jumbo, G. Gwengweya, J. Ward, and D. Lapworth (2017), UPGro Hidden Crisis Research Consortium. Survey 1 Country Report, Malawi.

Owor, M., A. MacDonald, H. Bonsor, J. Okullo, F. Katusiime, G. Alupo, G. Berochan, C. Tumusiime, D. Lapworth, and L. Whaley (2017), UPGro Hidden Crisis Research Consortium. Survey 1 Country Report, Uganda.

Wilson, P., H. Bonsor, A. MacDonald, L. Whaley, R. Carter, and V. Casey (2016), UPGRO Hidden Crisis Research consortium: unravelling past failures for future success in rural water supply: initial project approach for assessing rural water supply functionality and levels of performance.

Keywords

Functionality, Hand Pumps, Boreholes, Rural Water Supply, Groundwater

---

Contact details

Donald John MacAllister
Lyell Centre
Research Avenue South
Edinburgh
EH14 4AP
Tel: +44 (0)131 650 0394
Email: donmac@bgs.ac.uk
www: www.bgs.ac.uk/staff/profiles/48591.html

Alan MacDonald
Lyell Centre
Research Avenue South
Edinburgh
EH14 4AP
Tel: +44 (0)131 6500 389
Email: amm@bgs.ac.uk
www.bgs.ac.uk/staff/profiles/0985.html