UPGro Catalyst Grant Report (NE/L001969/1)

A Hidden Crisis: strengthening the evidence base on the sustainability of rural groundwater supplies – results from a pilot study in Uganda

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Unlocking the Potential of Groundwater for the Poor

Executive summary

Extending and sustaining access to rural water supplies remains central to improving the health and livelihoods of poor people, particularly women, in Africa, where 400 million rural inhabitants have no form of utility provided water, and universal access to water hinges on accelerated development of groundwater (UN 2013). The 'future proofing' of groundwater investments is therefore vital, especially in the context of global and local trends including demographic shifts, environmental impacts of human activity and climate change (Taylor et al. 2013).

The emphasis, in recent years, on accelerating access to new infrastructure has obscured a hidden crisis of failure. More than 30% of sources are non-functional within a few years of construction (Rietveld et al. 2009, RWSN 2009, Lockwood et al. 2011) and a greater number are seasonal (for example 50% in Sierra Leone) (MoEWR 2012). The accumulated costs to governments, donors, and, above all, rural people, are enormous. The original benefits generated by the new infrastructure – improved health, nutrition, time savings, education, particularly for the poorest – are lost if improved services cannot be sustained. The cumulative effect of rural water supply failure in Africa over the past 20 years has been estimated by the World Bank to represent a lost investment in excess of $1.2 billion.

Critically, there is limited data or analysis on *why* sources are non-functional and therefore little opportunity to learn from past mistakes.

This report provides a summary of the work undertaken by the UK-funded UPGro research programme ('Unlocking the Potential for Groundwater for the Poor') for sub-Saharan Africa (SSA) funded by the Natural Environment Research Council (NERC), the Economic and Social Research Council (ESRC) and the Department for International Development (DfID). The Catalyst Grant project 'A Hidden Crisis' was aimed at developing a methodology and toolbox to investigate the causes of failure in groundwater-based water services in SSA, which could form the foundation for more substantial and larger-scale research in the future to develop a statistically significant evidence base to examine water point functionality and the underlying causes of failure across a range of physical, social, institutional and governance environments in SSA. To test the toolbox and methodology developed, a pilot study was conducted in northeast Uganda

Overall, the approach and methods developed in the catalyst project have been shown to make a significant step towards developing a replicable and robust methodology which can be used to generate a systematic evidence base for supply failure. The work has gone a significant way to encapsulating the complexity of the interlinked aspects of the problem, balancing the natural science and engineering ("technical") aspects of the research with those concerning the ability of communities to manage and maintain their water points (the "social" aspects). The multiplicity of interlinked causes of water point failure was explicitly acknowledged and taken into account through the use of multi-disciplinary field and analytical methods within the toolbox and in selection of the research team. The multi-disciplinary methods of investigation used were highly practical and appropriate to the information sought, and based on detailed observational science.

The data collated by applying the toolbox and the diagnostic framework approach in the pilot study have enabled a clear insight to the importance of corrosion, poor siting and poor supervision of contractors to water point failures in the area, against a backdrop of weak institutional support and inappropriate practices of implementers. This is a significant finding from the pilot study, as water point failure in this region has traditionally been attributed to inadequacies in community management (both social and financial management facets) and evidence to suggest otherwise was largely anecdotal.

Key lessons learnt from the study approach and methods will need to be considered in future research on this topic. At present, the methodology of the pilot study remains multi-disciplinary, and does not undertake truly inter-disciplinary analysis of the research data. Future research will need to develop the toolbox and methodology to employ inter-disciplinary analysis methods to address this, and also broaden the scope to collect data on a wider array of the institutional, financial and governance arrangements which impact supply failure.

The results of the catalyst grant project have also shown the need for future research to include the perspectives of a wider array of different actors in defining the human and institutional dimensions of the problem – including, national Government, local Government, development partners, private sector, civil society and communities. Future work also need to include more comprehensive investigation of long-term trends in the natural groundwater resource, through changes in recharge, or demand, to fully understand long-term sustainability of rural water supplies.

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1 Project aims and objectives

New ambitious international goals for universal access to safe drinking water depend critically on the ability of development partners to accelerate and sustain access to groundwater (UN 2013). The ‘future proofing’ of groundwater investments is therefore vital, in the context of global and local trends including demographic shifts, environmental impacts of human activity and climate change (Taylor et al. 2013). In Ethiopia alone, over US$1.7 billion will be needed to meet the rural WASH target over the next 5 years, with the largest proportion targeted at groundwater-based water services (FDRE 2013). The returns – improved health, nutrition, time savings, education, particularly for the poorest – are well rehearsed, with women and girls benefiting most (UN 2013, Hunter et al. 2012). But these benefits, and the original investments, will be lost if improved services cannot be sustained.

The risks are real and the evidence on sustainability indicates that newly developed rural water sources are often abandoned, or provide only intermittent, poor quality services. Existing published evidence for SSA is fragmented and methodologically unclear, but suggests that 30% or more of groundwater-based water sources ‘fail’ within a few years of construction (Rietveld et al. 2009, RWSN 2009, Lockwood et al. 2011) and a greater number can be seasonal (for example 50% in Sierra Leone) (MoEWR 2012). Critically, there is limited data or analysis on *why* sources are non-functional and therefore little opportunity to learn from past mistakes. The cumulative effect of rural water supply failure in Africa over the past 20 years has been estimated by the World Bank to represent a lost investment of more than of $1.2 billion.

1.1 Aims and objectives

The UK-funded UPGro research programme ('Unlocking the Potential for Groundwater for the Poor') for SSA funded a one-year pilot study to develop a methodology to investigate the causes of groundwater-based service failure in sub-Saharan Africa. The intention is for this methodology to form a foundation for more substantial and larger-scale research in the future to develop a statistically significant evidence base and examination of water point functionality and the underlying causes of failure across a range of physical, social, institutional and governance environments in SSA.

The research hypothesis of the catalyst project was:

“The underlying causes of the widespread failure of groundwater-based water sources to deliver sustainable supplies are complex and multifaceted, but with the correct expertise and methodologies, the reasons for source and service failure can be understood, diagnosed, and ultimately predicted and mitigated”

The pilot project objectives are:

- **i.** To review existing available evidence of source failure.
- **ii.** To develop a robust methodology to examine the causes of groundwater supply and service failure.
- **iii.** To apply the methodology to project areas of WaterAid Uganda country programmes, to test the methodology and to provide a systematic assessment of supply failure in the area.

iv. Dissemination of the research results to key stakeholders at local and national level.
v. To develop a larger project proposal by the consortium to apply the research methodology over a much wider area of sub-Saharan Africa.

1.2 Research approach

The pilot study brought together a multi-disciplinary research team of groundwater, institutional, policy and governance experts, and practitioners in rural water supply. The research activities included:

1. Review of existing available evidence on groundwater supply failure
Although there are few published data on post-construction sustainability, there are a significant number of datasets held by WaterAid, RiPPLE, UNICEF, RWSN and partners, as well as within consultant reports in the grey literature, that could be re-analysed to provide an initial semi-systematic evidence base on the scale of the problem. The recent implementation of post-construction monitoring surveys of water supplies within WaterAid country programmes means there is now an increasing number of datasets from a number of different countries.

2. Development of a 'toolbox' to examine the causes of groundwater supply failure
Development of a diagnostic framework to examine causes of failure based on: evidence from the initial review (point 1); and expertise on water supply sustainability within the research team, in relation to both groundwater resources, social science and borehole engineering, in addition to the extensive in-country experience of WaterAid and its partners in developing, monitoring and supporting rural water infrastructure.

3. *Application of the toolbox – Pilot study*
Application of the methodology in one of WaterAid Uganda's country programme areas to provide a systematic assessment of causes of source failure in these districts (with a view to scaling up across Africa). The pilot study investigated failed boreholes fitted with handpumps in a mixture of WaterAid, local government, NGO and INGO programmes of different vintages. A strong field team of international experts and local practitioners and partners was assembled by the project in liaison with WaterAid Uganda.

4. Dissemination of the research results
To ensure the potential development impact of the research was realised, the research team actively engaged end users of the research in the pilot study from the outset. This led to co-production of knowledge, which is recognised as an effective pathway for uptake of research. The project engaged with national Government, local government, local NGOs and practitioners, as well as the communities dependent on failing supplies. This was facilitated through WaterAid Uganda's country partners and contacts in Uganda. A number of stakeholder workshops were conducted in Uganda, hosted by WaterAid Uganda.

5. *Development of a larger project proposal*
A larger proposal has been developed by the consortium to extend the research methodology to a much wider area of sub-Saharan Africa. If funded, this will enable a much fuller and statistically defensible investigation of the factors that affect sustainability of groundwater supplies, across a

range of hydrogeological environments and different settings of governance, community and institutional arrangements.

Programme of research

2013

Literature review

July-December: collation and review of existing post-construction statistics, and development of the diagnostic methodology.

Pilot study fieldwork

August: reconnaissance fieldwork by WaterAid Uganda and district officers to identify appropriate sites for the pilot study in northeast Uganda, based on criteria defined by the partners, and partner/district records of failed water points.

September: Phase 1 pilot study fieldwork – community surveys and discussions, at 24 identified failed water points.

November: Phase 2 pilot study fieldwork – technological investigations (hydrogeological and borehole construction) at 10 sites selected from the Phase 1 surveys.

2014

February-April: collation and analysis of field data.

June-September: compilation of report.

September-December: dissemination of results through: report publication; UPGro / ODI public event; RWSN webinar with donor organisations and practitioners; workshop meetings at a local level organised by WaterAid Uganda, and at national-level with partner NGOs and Ugandan Government ministry officials.

1.3 Purpose and scope of this report

This report will provide a summary of the work completed in the catalyst grant under the first four objectives. Lessons learnt from the project, particularly with respect to the methodology and 'toolbox' developed are reviewed in detail, for use by future work.

A larger consortium grant proposal was developed by the research team during the catalyst grant to undertake a much more significant piece of research in this area. The proposal was successful and a grant was awarded in November 2013 for a 4-year research programme in Ethiopia, Malawi and Uganda, from 2015 to 2019. Work commences in April 2015.

2. Background and rationale

2.1 A Hidden Crisis

Extending access to improved services for the estimated 300 million inhabitants of SSA currently without access to safe water is fundamental to many development efforts to improve health, reduce poverty and increase the resilience of households to climate change (Hunter et al. 2009; UNICEF 2012). Estimates suggest 340 million people have gained access to safe water over the period 1990 to 2010 under the umbrella of the Millennium Development Goals (MDGs; UNICEF 2012). However, the focus on increased coverage and building new infrastructure under the MDGs has meant there has been little assessment of the sustainability of new water points, and this is increasingly recognised as having obscured a hidden crisis of supply failure (DFID, 2012; Calow et al. 2013). Furthermore, there were 64 million more people unserved in the region in 2012 compared to 1990.

Available evidence for SSA, albeit fragmented and methodologically unclear, suggests that 30% or more of groundwater-based water supplies are non-functional at the time of monitoring and a greater number can experience seasonal problems (for example 50% in Sierra Leone) (e.g. Haysom 2006; Rietveld et al. 2009; RWSN 2009; MoEWR 2012). This failure of supplies is not a new problem. In fact the limited evidence available suggests that rates of failure have remained stubbornly high at around 30% over the past 40 years, despite a major shift towards increasing community management and demand responsive approaches in the 1980s by NGOs, governments and donors to try to improve supply sustainability (McPherson and McGarry 1992; Lockwood and Smits 2011; Foster 2014). There is now growing recognition that long-term functionality of supplies is dependent on a wide range of factors, but in the absence of an agreed diagnostic or evidence base on the extent and causes of failure, donors and national governments risk repeating mistakes and achieving poor value for money (de la Harpe 2012; Foster 2014).

Improving the sustainability of supplies is vital if the benefits – improved health, nutrition, time savings, education, particularly for the poorest – of original investments in WASH are not to be lost. DFID has earmarked over US$100 million for Ethiopia, with a similar sum set aside for Uganda, Sierra Leone and Malawi combined (Rietveld et al. 2009). However the benefits of these future investments will be lost if improved supplies cannot be sustained (Adow et al 2013). In Malawi, Engineers without Borders estimated that $50 million injected into improving access to water by around 100 NGOs and 10 donors within the country in the last 10 years has had little impact on the sector's overall ability to deliver sustainable supplies at scale (Triple-S, 2013).

New international goals for universal access to safe drinking water depend critically on the ability of development partners to *accelerate and sustain* access to groundwater (UN Water 2013). The characteristics of groundwater, and its relative ubiquity, favour its development for meeting dispersed rural demand at low cost and recent publication of maps of groundwater storage and expected borehole yields for Africa has intensified interest in its use to alleviate poverty and increase water security (World Bank 2009; MacDonald et al. 2012). These new international goals, known as the Sustainable Development Goals (SDGs) are also likely to call for higher and more sustainable standards of service than those used for the Millennium Development Goals (MDGs) (Onda et al. 2012; Bain 2012; UN Water 2013).

Achieving improved sustainability of supplies under the SDGs will require a step-change in understanding of the inter-related causes of water point failure and unreliability, and actions that can be taken to mitigate risks. In the absence of systematic evidence base or agreed diagnostic analysis on *why* sources are non-functional there is little opportunity to learn from past mistakes. Growing evidence indicates that this is not a simple problem solved by capacity building alone, additional finance, or a new design of pump. The roots of failure are likely to lie in a complex set of multifaceted issues in which there are immediate causes of failure (e.g. poor siting, lack of spare parts, basic maintenance) and more systemic, deep-rooted underlying conditions that shape an environment in which failure is more or less likely – Figure 1.

This pilot study has begun to develop a robust methodology and approach to the systematic investigation of the causes of groundwater service failure in sub-Saharan Africa (SSA). The methodology and techniques developed in the project form a springboard to underpin much more extensive research on the multi-faceted reasons for water point failures in SSA.

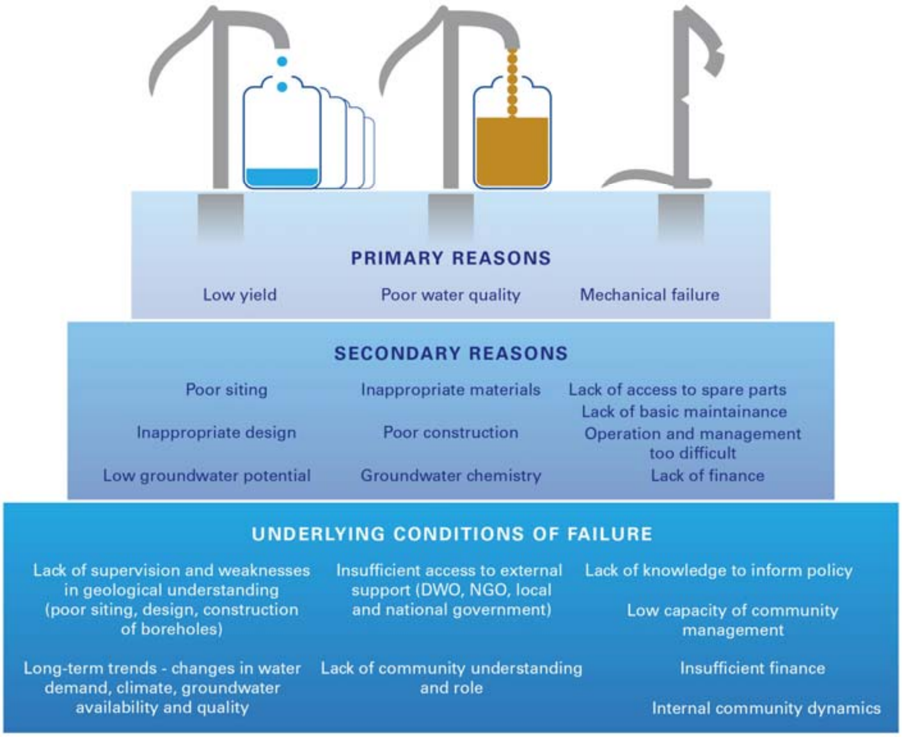


Figure 1: Some of the causal factors and underlying conditions which lead to water failure.

2.2 The evidence challenge and key research issues

Despite the scale of the problem, there is little evidence on why groundwater-based supplies continue to fail in SSA. There are many opinions amongst local practitioners, water users, hydrogeologists and government staff as to why supplies fail (Danert 2013). One of the main reasons cited is poor construction quality of boreholes – the use of cheap materials and borehole construction methods, which leads to early failure or deterioration of the service. Poor siting of water points, which fails to take full account of local hydrogeological conditions and to optimally exploit groundwater potential is another key issue raised by practitioners (e.g. Harvey 2004). The disconnection of siting, design and construction processes for new boreholes often leads to inappropriate siting and/or construction of water points (Danert 2013). Lack of maintenance, for example due to the inability of communities to raise the necessary finance or difficulty in accessing spare parts is another contributor to failure in many cases (Skinner 2009; Franceys and Pezon 2010). More recently, it has become convenient to blame problems on climate change.

It is likely that there are many different inter-related contributory causes, and that unravelling them requires an understanding of (1) groundwater resources, (2) water point siting, design and construction, (3) financing, management, external support and community arrangements, and (4) demand pressures. Each of these topics is discussed below, with some of the current uncertainties in how they contribute to supply failure highlighted.

Groundwater resources

Groundwater occurrence depends primarily on geology, geomorphology and weathering, soil, land use and climate (both current and historic). The interplay of these factors gives rise to complex hydrogeological environments with countless variations in the quantity, quality, ease of access, and renewability of groundwater resources (MacDonald et al. 2012). The result is that groundwater conditions vary significantly, often over very short distances (within tens or hundreds metres in some aquifer types), and good hydrogeological expertise and techniques are required to site and develop a water source in the most productive part of an aquifer. It is as yet unclear how much of a role the variations in groundwater resource availability and aquifer parameters (e.g. local-scale variations in permeability) play in supply failure in different hydrogeological settings.

Groundwater chemistry, in addition to being a significant health hazard in areas with elevated Arsenic or Fluoride, can also have a major influence on borehole and pump performance (Nash and McCall 1995; Selinus et al. 2013). This is particularly the case in areas with acidic, mineralised or reducing groundwaters, where metals can be mobilised including by the corrosion of pumps and borehole casings.

There remains considerable uncertainty about the direct and indirect impacts of climate change on groundwater resources (Taylor et al. 2013) and supply failure. Despite concerns that rural water supplies may fail due to a lack of recharge and local over-exploitation of groundwater resources (Robins and Fergusson 2014) there has been no substantial study to gather evidence of the contribution of falling water-tables, or sporadic and episodic recharge to rural water source failure.

Interaction between water availability and demand

Seasonal failure of shallow borehole supplies is often argued to reflect resource depletion, but in reality the failure may relate to a number of issues, for example: increased demand on water sources in periods of drought (Calow et al. 2009); competing groundwater users in the dry season; or, strong vertical permeability gradients particularly in laterite soils (Bonsor et al. 2014); and, inappropriate design of the water point for the aquifer conditions. As alternative sources fail significant pressure is put upon the remaining water supplies, often beyond the design use of the water points, which can lead to failure (Calow et al. 1997).

Engineering considerations – water point siting, design and construction
The design and construction of the borehole itself impacts significantly on handpump performance and can determine the wear that a pump will receive. For example: borehole inefficiency due to poor design and construction can considerably increase pumping water depths; the ingress of fines can clog up boreholes and rapidly wear pump parts; removal rather than replacement of rising main sections in handpump maintenance; borehole deviation from the vertical can cause rising mains to split; and encrustation with iron or manganese can limit water flow into the borehole. If a water source suffers from these issues then repeated handpump failures will be much more common.

A key factor for the success of a borehole supply is whether the borehole siting and design are appropriate to the aquifer properties and groundwater resource available – critically: whether the borehole is sited within the most productive part of the aquifer; whether the screened interval of the borehole, and overall borehole depth, are targeted at the main aquifer horizon; and if the borehole materials are appropriate to the groundwater chemistry.

What is unknown is the relative significance of these engineering and hydrogeological considerations, compared to community management issues, governance and access to external support. This remains a key question for future research programmes if they are to point the way toward more sustainable supplies.

Procurement processes and supervision for drilling and installation
Other studies have highlighted the critical importance of the procurement process for high quality construction of water points and the long-term functionality and sustainability of the points (RWSN 2010). Drillers can either be paid in a lump sum for the number of boreholes to be drilled, or according to a bill of quantities, wherein drillers are paid per metre drilled, and per hour for development (e.g. purging and test pumping) and completion (e.g. insertion of sanitary seal, cleaning of borehole) of a water point. Procurement by a bill of quantities has been found to be much more successful in creating the right environment and incentives for ensuring careful and higher quality construction of boreholes, as opposed to a one off payment, in which boreholes are often drilled too shallow, or completed unsatisfactorily (e.g. incorrect backfill, incomplete sanitary seals). In contrast, ‘no water-no pay’ contracts, for example, may encourage drillers to pass as “successful” boreholes which in fact have marginal yields at the time of construction and which may be even less satisfactory in drier times.

Effective and value-for-money contracting also requires adequate technical supervision of the key stages of the construction process, and the pricing of contracts is also important. If the ‘per metre’ drilling rate is very high compared to the ‘per hour’ or ‘lump sum’ rates, then in the absence of supervision there may be a temptation to drill deeper than strictly necessary and take short cuts on other parts of the construction process such as cleaning, developing and testing the borehole and completing backfill, sanitary seals and headworks.

Community financing and management of supplies
The need for community participation in the planning and implementation of rural water supply development projects became increasingly apparent in the 1980s when it was recognised that top-down centralised approaches were neither affordable nor effective (MacDonald et al. 2005). The ability of a community to repair, finance and manage a supply was thus considered essential to the sustainability of the service. Considerable effort has since been devoted in development initiatives

in SSA to ensuring the proper establishment and functioning of community management committees and to build the capacity of local people to maintain the handpumps. Yet whilst there has been much work by Governments, NGOs and donors to enhance community-based management of handpump supplies, persistently high non-functionality rates have led some to question whether the emphasis on certain forms of community-based management is part of the problem (Sara and Katz 1998; Schouten and Moriarty 2003; Foster 2014).

There is now a growing acceptance that rural communities are unable to manage their own water supplies without some degree of regular external support that encompasses monitoring, technical advice and assistance, and training (Harvey and Reed 2007; RWSN 2010; IRC 2012; Foster 2014) although gaps in this support remain. It is also questionable whether cost-recovery is a feasible model for poor communities, many of whom struggle to finance minor repairs, and cannot afford initial capital costs, major repairs or rehabilitation. Finally, as with other causes of failure, there is very little knowledge or systematic evidence base to indicate when, or the extent to which, community finance and management of a supply can be considered a dominant factor of water point failure.

Wider institutional arrangements

With recent focus of WASH initiatives having been on strengthening the capacity of WUC and waterpoint committees at the community-level, the linkages between higher level socio-political water management arrangements and local level arrangement are less well explored and understood. Studies which have examined both local-scale and wider external management structures have found external support and policy to be as significant as community-management models to water supply failure rates (Jansz 2011). This is in part due to the wider institutional arrangements determining lines of communication between communities, local NGOs, district water officers (DWOs), and therein the ability of communities to access external support or to manage a water point is poorly understood.

2.3 Review of previous work

There are few systematic studies addressing the causes of groundwater based supply failure in Africa. Those that have been done have often been very small-scale. With increasing appreciation of how common failure is, DFID, WaterAid, and other NGOs such as UNICEF, have begun to monitor sustainability of new supplies, or implement sustainability surveys (e.g. RWSN 2010; Leclert 2012). These data are now providing useful insights on a broader-scale. The studies, however, are disparate in both their focus and methodologies, and the results are not directly comparable. In the absence of a common diagnostic framework varying definitions of failure are used and few of the studies consider all facets of service failure (many focusing on management of supplies, whilst others are focused on the quality of borehole construction, or the availability of groundwater resources e.g. Owolabi et al. 1991). Crucially, there is a lack of research on how the different facets of failure interact (e.g. technical and institutional factors) to cause failure of a water point. A few studies, such as those by Whittington et al. (2009) in Ghana, and Harvey et al (2002) in Zambia (part of the DFID-funded research project 'Guidelines for Sustainable Handpumps in Africa'), have evaluated the significance of different factors contributing to supply failure within an individual area, but in the absence of a common framework with which to compare these studies and extrapolate the results to similar hydrogeological or institutional settings. Many functionality surveys and data sets are collected during rapid assessments. It is rarely possible to discern the exact causes of failure with any great certainty from simply observing a water source and speaking to a limited number of users at a single point in time.

Despite these limitations, the available studies and post-construction audits examining water point functionality in SSA do provide some insight into the scale of non-functionality in handpump supplies, and also importantly, to the prevalent primary ***symptoms*** and ***causal factors*** of failure. The limited evidence suggests that rates of failure have remained stubbornly high at between 30 and 50% over the past 40 years (McPherson and McGarry 1992; Lockwood and Smits 2011). Non-functionality figures in Africa are indicated to be approximately 30%, and there are shown to be similar symptoms of failure across a range of physical, social and governance settings and in different countries – namely, insufficient yield, poor water quality, or a range mechanical failures (e.g. from breakdown of head works, or corrosion) – Table 1.

A review of UNICEF drilling programmes in Malawi by Anscombe (1996) found that 93% of the 100 supplies surveyed were functioning but a further 25% of these supplies had some problems with insufficient yield and inadequate quality. In up to 15% of supplies there was premature wear caused by high demands (>100 households using the supply), and in 10% poor maintenance due to unmotivated Water User Committees (WUCs) at the supplies. In Nigeria a post-construction audit of borehole handpump supplies found success rates varied by up to 30% between different drillers (varying from 70-100%) (Owolabi et al. 1994). There the primary symptom of failed supplies was seasonally low yield. The study focused heavily on the technical factors contributing to failures, but nevertheless provided useful insights into the most common causes of failure in the crystalline Basement Complex aquifers in southwest Nigeria: improper casing of the overburden and failure of the boreholes to penetrate the main water-bearing horizons being the main factors (Owolabi et al. 1994).

In contrast, an inventory of supplies in southeast Nigeria found supply failure to be on average much higher (typically 40%), and a further 40% had declining performance (Odoh et al. 2009). The failures were reported to be due to excessive sand pumping, muddy water extraction and long-term decline in the performance capability and increased drawdown in the borehole. The main contributory factors giving rise to these issues were identified to be: a lack of proper evaluation of the groundwater resources and poor siting of the boreholes in the sedimentary bedrock aquifer, poor planning, lack of appropriate expertise, inadequate financial resources, and inappropriate pumping rates for the groundwater resource available (Odoh et al. 2009).

The need for better hydrogeological knowledge to inform planning and design of supplies was a key recommendation for improving water point functionality in this region of Nigeria, alongside developing an effective maintenance culture – something also found to be an underlying factor to studies of supply failure in Botswana (Riekel 2002). These recommendations are also advocated by UNICEF post-construction audits in country programmes, particularly that there is a need for systematic procedures, or arrangements, for suitability and quality of construction materials to be checked before installation, and for a formal hand-over process to the community for management of the supply (UNICEF 2012). Table 1 summarises some of the functionality data available for sub-Saharan Africa from existing studies.

Country of local study	*Water point non-functionality*	*Source*
Angola	30%	RWSN 2009
Burkino Faso	25%	RWSN 2009
Benin	22%	RWSN 2009
Cambodia	22%	SNV 2013
DR Congo	33-55% non-functional or partially functional (*main issues*: poor quality, handpump failure)	SNV 2013
Ethiopia	18-35% (average, excl. abandoned supplies) (40% due to technical failure, 13% watertable drawdown, 7% water quality)	Deneke and Hawassa 2008
Ghana	21-30% (*main issues*: mechanical failure of handpumps)	Samani et al 2013 Adank et al 2012 (Triple-S)
Kenya	25% (*main issues*: 14% mechanical failure of handpumps, 11% seasonal yield) A further 45% affected by technical issues	Welthungerlife 2011
Madagascar	50%, with 16% not repaired within 1 year (*main issues*: , insufficient yield, mechanical breakdown of handpump)	UNICEF 2014
Mali	14-41% (average 34%)	Jones 2013
Malawi	27% supplies abandoned 25% remaining supplies have inadequate yield or quality (*main issues:* borehole construction, poor site selection)	Anscombe 1996
Mozambique	20%	Jansz 2011
Niger	35%	RWSN 2009
Nigeria	32% (*main issues*: seasonal depletion of water-table, improper borehole completion, and pump damage)	Owolabi et al. 1994
Rwanda	41% (*main issues*: insufficient yield, 50% supplies had mechanical breakdown of handpump at least once per year, 14% inadequate water quality)	WHO 2011
Sierre Leone	31-40%, with additional 17% abandoned (*main issues identified to failure*: seasonal yield, mechanical breakdown of handpump)	MoWR 2012
Tanzania	38%, with additional 7% functioning but in need of repair (*main issues*: seasonal depletion of water-table, insufficient yield, water quality, mechanical breakdown of handpump)	Taylor et al. 2009
Uganda	16-20% average, up to 33% (*main issues*: insufficient yield, water quality) 56% of functioning handpumps, reported to fail and need repair at least once a year	MWE 2013
Zimbabwe	38% (*main issues*: mechanical failure, typical repair time 3 weeks)	Hoko etal. 2009

Table 1 – A summary of some of the functionality data available from individual studies and audits across sub-Saharan Africa. The functionality figures do not reflect national average figures.

The Research-inspired Policy and Practice Learning in Ethiopia and the Nile Region (RiPPLE) programme has undertaken some of the most systematic studies of groundwater supply failure to date (Abede and Hawassa 2008; Deneke and Hawassa 2008). These studies collected qualitative and quantitative data on water point failure from community and district government-level surveys and discussion groups, resource mapping, and physical (external) observations of water points. Institutional, environmental and financial causes of failure were examined. The studies found that 30-60% of water points were non-functional in the Alaba woreda, and that whilst minor repairs could be completed within 2 weeks, major repairs often took 12 months to complete (Abede and Hawassa

2008). The main underlying causes of failures from both studies were identified to be: inappropriate design of boreholes relative to local hydrogeology; excessive demand on individual water points; poor capacity and lack of backstopping support from district government; lack of technical and managerial capacity to run groundwater supplies (at all levels: government, communities, private sector); lack of coordination and communication, and a lack of clarity to roles and responsibilities between all actors; and lack of spare parts and financing (slow speed of maintenance) (Abede and Hawassa 2008; Deneke and Hawassa 2008). The findings also clearly reveal that supply sustainability cannot be reduced to a single cause and a comprehensive diagnostic assessment approach is required (Dessaelgo et al. 2013).

The need for good quality siting, supervision, procurement, and management of drilling, as well as community engagement, financial capacity and external support are all common themes running through existing studies (Danert 2013), but as yet, there is little clarity as to which should be given priority for future investments in groundwater-based rural water supply to be able to deliver more sustainable supplies. To move beyond an understanding of ***how*** water points fail to determine ***why***, requires a systems approach which recognises the many different components of the service delivery chains, including the water point itself, and a wide variety of factors (technical, social, institutional) contributing to failure, which interact and/or are interlinked. Moreover, a systematic diagnostic framework that allows for comparative analysis is essential to begin to understand causes of failure across different socio-economic and physical environments.

3 Case study area – Amuria and Katakwi districts, Uganda

The Amuria and Katakwi Districts of Uganda were considered an appropriate location for the pilot study, based on: existing failure rates of groundwater based supplies in the region (typically around 30%); existing strong working relationships between the UK project team members and the WaterAid Uganda programme team in the region; and the existing strong links and collaboration between the research team and national-level decision makers in the Government of Uganda (GoU) – in the Directorate of Water Resource Management (DWRM) and the Directorate of Water Development under the Ugandan Ministry of Water and Environment.

Location and population

Amuria and Katakwi Districts are situated in north-eastern Uganda – Figure 2. The rural population of these districts is approximately half a million, of which it is estimated 65% have access to safe water (MWE 2010). In both districts the main water supply technology is deep boreholes (15-100 m deep) fitted with handpumps. These water points are largely community managed (90%), and funded by either NGOs such as WaterAid (70%), or by government programmes (25%) – the remaining 5% being privately funded (MWE, 2010).

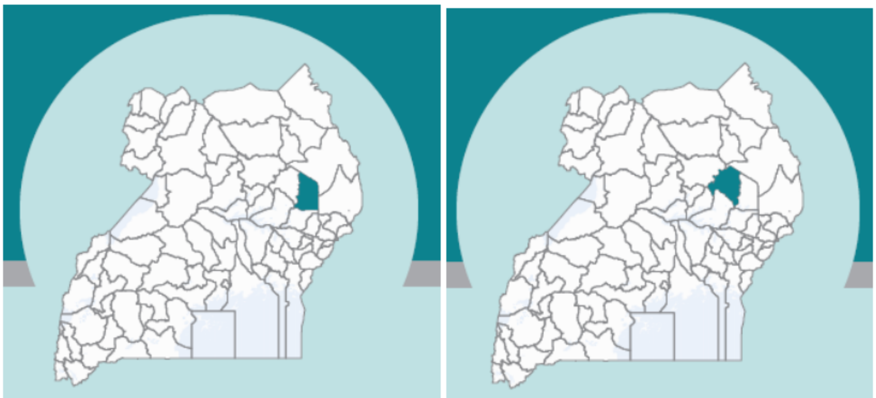


Figure 2 – the location of the neighbouring Amuria (left) and Katakwi (right) Districts of Uganda (MWE, 2010).

Climate

Uganda has a tropical climate, with average annual rainfall ranging from 1500 to 2500 mm/year across the country. Dry northeasterly and northerly air masses cause the northern regions of Uganda to be drier than southern Uganda, where Lake Victoria provides a continuous supply of moisture. Rainfall is seasonal in Amuria and Katakwi Districts, with two dry seasons (December to February, June to August) in which rainfall is generally 20-40 mm per month, and a wet season in which monthly rainfall ranges from 100 to 150 mm (DWRM, 2010). Mean annual rainfall in the two districts in the last ten years has been 1343 mm, with an inter-annual range of 1055 to 1765 mm (Cuthbert and Tindimugaya, 2010).

Hydrogeology

The geology of both districts is predominantly ancient Precambrian crystalline Basement Complex, covered by weathered regolith or overburden. These rocks occupy 36% of the land surface in Africa in some of the areas of highest rural population (MacDonald et al. 2012). They can provide a complex and sometimes discontinuous aquifer with low groundwater potential relative to some of the major sedimentary aquifers in Africa, but which generally supports borehole yields of 0.5-1.0 litres/second if the boreholes target the most productive parts of the aquifer and are properly constructed – Figure 3. Aquifer systems in the Crystalline Basement Complex of sub-Saharan Africa consist of a weathered regolith/overburden of variable thickness and the underlying fractured bedrock, both of which can contain and transmit water – Figure 4. Elsewhere in Uganda these two units are found to form an integrated aquifer system, in which the more transmissive (5-20 m^2/d) and porous weathered overburden provides storage to the underlying fractured bedrock (transmissivity typically 1 m^2/d) (Taylor and Howard, 2000). The thickness of the weathered overburden, and permeability of the deeper weathered zone, is therefore fundamental in controlling the sustainable yield of borehole supplies.

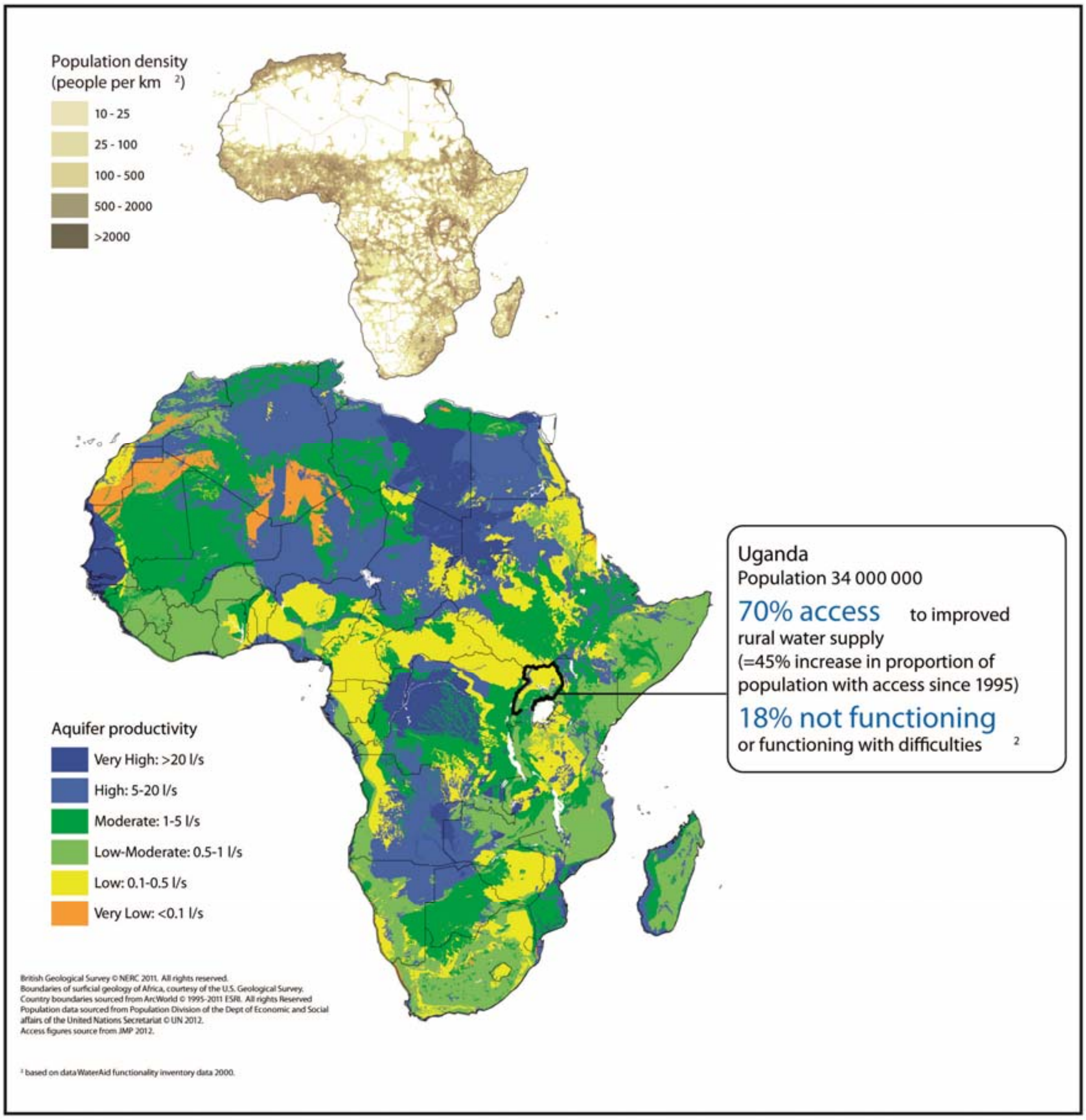


Figure 3 – Map showing location of Uganda within Africa, in the context of both aquifer productivity (main panel), and population density (upper panel).

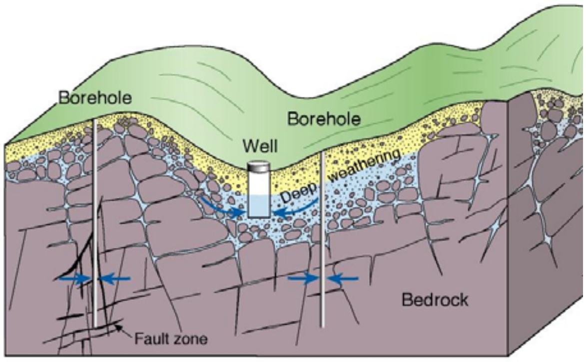


Figure 4 – A schematic representation of crystalline basement aquifer systems, with a weathered overburden and regolith on top of the underlying, lower yielding fractured bedrock aquifer (source: MacDonald et al. 2005)

The hydrogeology of the basement aquifer system in Amuria and Katakwi Districts has not been investigated in detail. If the weathered overburden is of sufficient thickness it could provide or supplement the potential sustainable yield of a borehole, and the design of the borehole should enable this by including screening within the deeper regolith horizon. However, without detailed hydrogeological investigations it is not possible to develop a good understanding of the aquifer processes, and what is the most appropriate borehole target and design.

Groundwater recharge to the system as a whole has been estimated to be 120-150 mm/year by Cuthbert and Tindimugaya (2010) at Soroti, 25 km to the south of the field area.

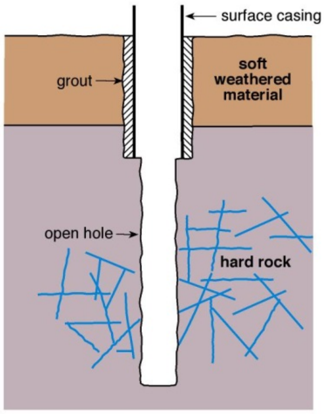


Figure 5 – Schematic diagram of a traditional open hole in rock design (source: MacDonald et al. 2005).

Water point design and construction

Nearly all groundwater based supplies in Amuria and Katakwi Districts are deep boreholes fitted with a handpump – the India Mark II, India Mark II Extra Deep Well, or U2 handpumps being the most common – Appendix 2. 'Deep' boreholes span a wide range of depths from 15 to 100 m, but are typically in the range 40-60 m. Groundwater piezometric levels are generally 1 to 5 m below ground. The standard construction of boreholes in the region is an open hole in rock design – Figure 5. Casing material used in the region is typically uPVC (125 mm diameter).

Siting and drilling of new borehole supplies are procured at district level in Amuria and Katawi. The general practice is for one contractor to undertake both the hydrogeological mapping/survey investigations as well as the drilling. The procurement process is such that a flat fee is paid per successful borehole, rather than by a bill of quantities in most cases. Where the survey and investigations are undertaken by a separate contractor, the liability for a dry borehole point is transferred to the surveyor, rather than the driller.

Supervision of the siting and construction of new water points is the responsibility of the District water office, and to a lesser extent, staff from technical support units. However, due to the limited-capacity at district-level, there is in reality often very limited supervision.

Existing estimates of functionality

Functionality of groundwater based supplies in rural areas within the Amuria and Katakwi Districts is approximately 85%, based on Ministry of Water and Environment (MWE) surveys (MWE, 2010). Failed water points are found throughout the districts, with no obvious spatial clustering or bias (MWE, 2010). Reasons for non-functionality are put forward by the MWE to be largely technical failure (40-60%), or low yields (17-35%) in the two districts – Figure 6.

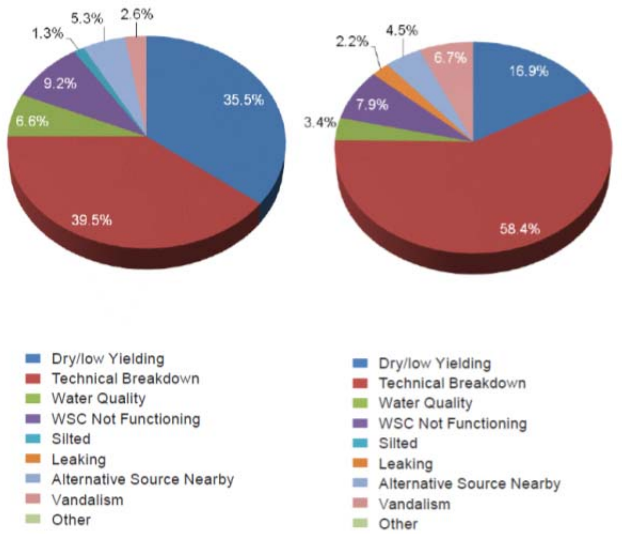


Figure 6 – Immediate reasons observable for non-functionality in the Amuria and Katakwi districts (source: MWE, 2010)

4 Development of a Toolbox – examining causes of supply failure

One of the main aims of the catalyst grant was to develop a toolbox – a set of robust and repeatable methodological approaches – which can be used to investigate the causes of water supply failure in SSA. The toolbox provides a basis for researchers and practitioners to begin to develop systematic data on functionality. This section describes the development of the toolbox, and an outline of the methodologies contained within it. Section 5 of the report describes the application of the toolbox within the pilot study in Uganda, and Section 9 at the end of the report provides a detailed review of the toolbox and the lessons learnt on the methodological approach from the pilot study.

A borehole-handpump supply in the Amuria pilot study area

4.1 Defintion of 'failure'

A working definition of 'failure' of a water point was developed at the outset of this work, so that the toolbox could be developed to be comprehensive, applicable to a range of failure 'types'. One of the key difficulties in examining functionality data is that different studies use different definitions of functionality or failure, and as a result, different data are collected, or it is not possible to compare the data meaningfully. For example, studies often only consider a few aspects of failure, and are biased towards new boreholes, excluding older boreholes which have gone through cycles of failure and repair, seasonal failure (e.g. low yielding) or which provide inadequate yield or water quality, but continue to be used in the absence of other water sources. As a result, a generous definition of failure and current functionality is often portrayed. 'Failure' is defined by this study as:

"*the inability to supply sufficient quantity or quality of water for domestic drinking needs, year-round*".

This encompasses supplies which have failed once catastrophically sometime after construction and initial use, and supplies which fail repeatedly and go through cycles of failure and repair, or seasonal failure.

4.2 Toolbox approach

The toolbox uses a variety of methodological approaches (e.g. community surveys, deconstruction of handpumps, pumping tests, water chemistry analyses) to collate a wide range of social science, engineering and hydrogeological data from a failed water point to provide a detailed post construction audit of the water point and the local governance arrangements. Equal emphasis is given to the social science and technical and engineering investigations within the toolbox. The data collated using the toolbox provides a detailed evidence base which can be used to assess the immediate causes of failure, as well unravel the deeper underlying root causes.

The toolbox is designed primarily as a field-based tool, with the different data collation methods being employed in a rapid phased approach; an initial phase of reconnaissance work to identity the total number and different immediate symptoms of water point failure in an area; then focused research at a selection of the sites involving community surveys to ascertain community capacity and management arrangements; and finally technical investigations examining the possible engineering and hydrogeological aspects of failure – Figure 7. Field methodologies and techniques are described in full in the following sections.

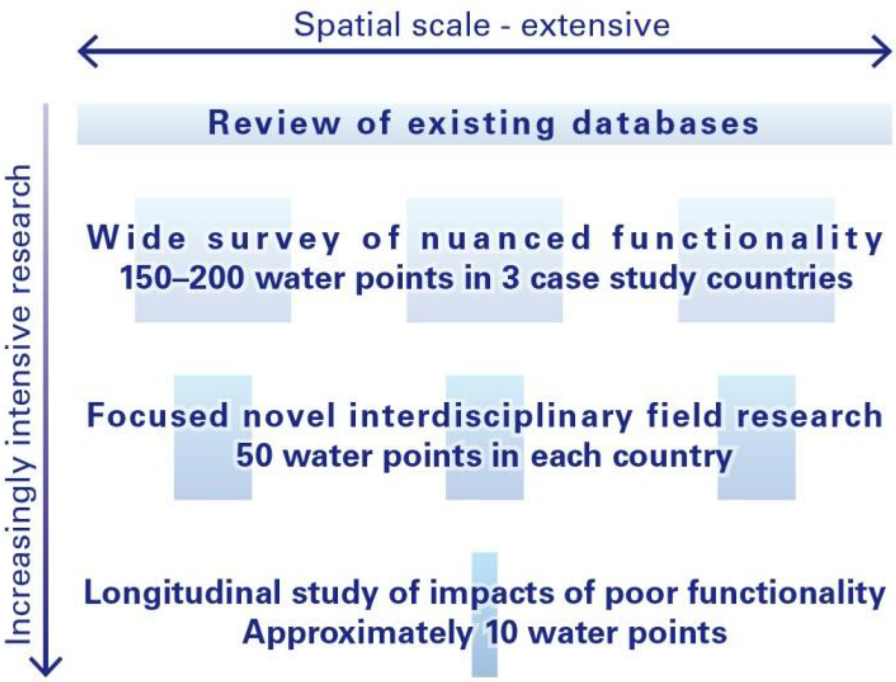


Figure 7 – A conceptual diagram illustrating the general strategy of the field methodology, with a phased approach combined community survey methods and technical investigations.

4.3. Toolbox methods

4.3.1 Reconnaissance surveys – identification of failed supplies

The aim of the reconnaissance survey is to identify the total number, and different symptoms of failed water points in a region. It is also essential to ascertain which communities are willing for more detailed investigations of the water point to be undertaken, some of which involve the removal of the hand-pump and pump rods, and downhole measurements and tests. Key secondary data (e.g. borehole log, drillers log, construction/completion log, and any water quality analyses and pumping test report completed) are collated in the reconnaissance phase if accessible. These are vital information to be able to accurately interpret data collated by some of the later investigations contained within the toolbox.

Local practitioners and NGOs play a key role in the reconnaissance survey work, based on their knowledge of the communities and location of failed water points, from their regular travels throughout the districts, and discussions with communities. They also are able to provide information to the typical frequency and types of water point failures in an area.

The information collated in the reconnaissance survey gives a sufficient platform to select a representative sub-sample of failed water points for future focused field research. Using a sub-sample of sites is often necessary due to the time and cost intensive nature of focused field research methods.

4.3.2 Community surveys – collection of data on local governance arrangements

The community survey is designed to collect basic information on community water use, reconstruct the history of the failed water point and, most importantly, explore the local socio-institutional factors that may have contributed to non-functionality. Key topics included:

- Community engagement in planning and construction of the water point
- Access to the water point (and alternative water sources)
- Water quality and yield
- Mechanical failures and repairs
- Water point management, rules and enforcement
- Fees and finances.

The survey methodology developed for the toolbox partly drew on the Water Economy for Livelihoods Systems (WELS) analysis approach developed and tested under the RiPPLE programme in Ethiopia (Coulter et al. 2010, Calow et al. 2013) and adapted by others (e.g. Dessalegn et al. 2013; Lapworth et al. 2011). The survey collects information on community water needs and access to different sources, as well as more detailed information on the non-functional water point, its history and management.

A survey template was generated to enable accurate repetition of the survey within different communities. The template includes sections relating to:

- Planning and construction processes
- Breakdowns and repairs
- The Water User Committee roles and rules
- Capacities for management and enforcement, and finances.

Table 2 below provides more detailed information to the different components of the community survey and the information to be collated, and the survey template form is shown in Appendix 1.

Where two sample water points were located in one village, the water point-specific sections of the survey were completed for each, whereas general questions regarding community attributes and available water sources were asked only once.

Community survey section	Information to be collected
Community attributes (general)	Village name and location Community size (households, total numbers, population growth since installation of the water point) Community representatives Register of all participants
Local water sources (general)	Water sources available to the community (all types) Which sources are used and when (e.g. seasonality) and for what (domestic and productive uses) Key changes seen over the last 5-10 years relating to water availability and use (e.g. droughts or floods, increasing demand)
Pre-construction narrative	Extent to which intervention was demand-driven Planning process and extent/nature of community engagement, including siting and design Existence of an MoU with the community Construction process (when, by who, whether there was any supervision) Community contributions (e.g. labour, materials, finance) Level of community understanding of the process Any perceived problems with construction/installation process
Post-construction narrative	Water quality perception (taste, appearance, odour, change over time) Water quantity perception (sufficiency, seasonality, queuing times, pumping difficulties) Persistence of poor quality or yield Pump performance, breakdowns, repairs over time, length of time broken, frequency of mechanical failure
Community management and capacity	Presence of a WUC Whether the WUC was established before or after construction, their roles, training received Existence of by-laws governing use and maintenance of the water point, and ability of the WUC to enforce these rules and regulations Any restrictions to on use of the water point (e.g. tariffs, opening times) Capacity of WUC to undertake or arrange for routine repairs and maintenance – skills, tools and spares availability Access to a handpump mechanic (HPM) Access to higher-level support (sub-county, district water officer, NGO)
Finance	Fees collected by WUC Expenditure (particularly costs of repairs) Perceived transparency of financial management Ability of community to raise necessary finance to maintain and repair the water point Willingness of community to pay for repairs of the water point

Table 2 - Data collected through the community survey

The design of the community survey reflects a trade-off between depth of analysis and the time taken to complete the survey. Detailed community surveys and WELs analysis take place over several days and require several visits to the communities (Coulter et al. 2010). The aim of the toolbox is to provide a relatively rapid survey method, and technical investigations, which take no more than 1 day – to enable a larger sample size to be surveyed, and a statistically significant evidence base on water point failure generated. The community survey template was designed to take two to three hours, allowing a survey team to cover two communities a day (including travel to sites) in sufficient depth to identify key causes of failure. Multiple survey teams can be working in parallel in an area, enables more sites to be sampled in a day.

The survey template was designed to be used flexibly, as whilst it was important to ensure that key information was obtained for each site (to enable comparative analysis) the complex nature of water point failure meant that there had to be opportunities to delve into site-specific issues as they arose in discussion, and to adapt questions to best draw out the relevant information, particularly around sensitive issues such as WUC performance or finances.

The primary survey data should always be triangulated with the information gathered in the reconnaissance visits wherever possible, as well as in the later technical investigations, which give additional opportunities for discussion with local community representatives alongside investigation of the technical causes of failure.

4.3.3 Technical investigations – collation of engineering and hydrogeological data

A suite of engineering and hydrogeological methods are used by the toolbox to develop a detailed post construction audit of failed water points. The technical investigations are designed to provide a comprehensive dataset on the hydrogeological and engineering factors contributing to water point functionality – including pump installation and condition, borehole construction, the surrounding environment and groundwater resource – see Table 3. None of the individual techniques used within the toolbox are new, but the use of all these techniques together with the detailed and careful deconstruction, measurement and photography of the failed pumps and boreholes, has not been done on a wide scale, or systematically, before by previous work in water point functionality, and is a major novel aspect of the toolbox. The different categories of investigations, and information and/or data collated within each of these sections are summarised in Table 3. Table 4 provides more detailed information on the different investigative techniques used.

Dis-assembly of a water point in Katakwi District; the fieldwork relied on strong support from and engagement with the local communities

The techniques in the toolbox include:

- **Deconstruction of a water point** to examine the conditions and performance of the pump, and rising main, as well as inspection of the construction and condition of the borehole using downhole CCTV.
- **Local physical hydrogeological investigations** – pumping tests, and bailer tests, to assess permeability and borehole performance
- **Groundwater chemistry and residence time sampling** using robust field sampling techniques for inorganic chemistry, stable isotopes and dissolved anthropogenic gases (CFC, SF_6, and tritium) to investigate local water quality and also groundwater residence times to help gain insight to recharge rates and sources.

Field data collated from the investigations should be compared, wherever possible, with secondary data (e.g. drilling records, borehole logs) collated in the reconnaissance survey phase.

Possible (technical) causes of to water point failure	Investigations performed to establish status of different factors
Non, or partly functional pump operation	Time to fill rising main Discharge measurement Water taste, smell and aesthetic appearance General mechanical condition
Poor pump condition	Condition of head, handle, bearings, chain, flanges Number and condition (visual, length, weight) of pump rods and rising mains Condition of cylinder, cup seals, foot valve Diagnosis of faults if present
Inappropriate borehole design for aquifer resource, and/or low quality borehole construction	Total depth Rest water-level Bottom of borehole (hard/soft) Verticality test (plumb line) CCTV survey inspection (casing joints, depth of screen horizon)
Limited groundwater resource potential and/or groundwater quality	Aquifer testing (either by bailer test and/or pump test) Well head chemistry measurements (pH, Eh, SEC, DO and temperature) Detailed inorganic groundwater chemistry sampling Dissolved gas sampling (groundwater residence time indicators)

Table 3 – The investigative techniques used to assess different possible technical causes of water point failure.

Observation	Methods	Equipment
Hydrological setting	Observation of position in the landscape: relative relief and proximity to drainage lines.	By eye
Location	Global positioning system, lat/long decimal degrees	GPS
Pump stand verticality	Spirit level placed in various positions on pump stand	Magnetic spirit level with verticality bubble
Dismantling of pump	Lifting of all below ground components by Hand Pump Mechanic (HPM) with help from team and community members	Full India Mark II tool kit including lifting spanners and vices, and camera
Pump apron information	Handwritten recording and photography of any markings on apron	Camera
Pump head manufacturer's plate	Reading and recording, photography.	Camera
RWL and Borehole depth	Dipping of water level, plumbing of total depth	Graduated electronic dip tape with extra weight for use as plumb line.
Pump condition	Observation and description of condition of rod and pipe surfaces, colouration, thread condition, perforations. Measurement of pipe and rod lengths and weights of selected components	By eye. Camera. 5m steel measuring tape. Weighing scale
Borehole verticality	Centred plumb line cord in top of casing, carefully lowered to 50m depth, observed and estimated horizontal drift of cord from centre line.	Camera tripod and plumb line on 4mm nylon cord
Groundwater resource potential/aquifer permeability	Pumping test and/or Bailer test	Generator, submersible electric pump / bucket or bailer and rope, timer, notebook
Groundwater chemistry	Well head measurements of groundwater chemistry (pH, Eh, SEC, DO and Temperature) Laboratory analysis of inorganic chemistry, stable isotope	Hand-held analytical probes (well head measurements) Laboratory
Groundwater residence time	Measurement of dissolved anthropogenic gases (CFC, SF6, tritium)	Laboratory (BGS, IAEA or Flinders University Australia)
Additional information	Discussion with members of community, WUC, Local Council office holders.	Notebook

Table 4– Field observations and techniques within the toolbox

The quality of the data collated from the technical investigations is optimised if the investigations are performed in a set sequential order in applying the toolbox, as follows:

1. Deconstruction of the pump, rising main and inspection of the borehole occurring first;
2. The bailer test and latter pumping test occurring second (the pumping test only conducted if sufficient aquifer permeability to sustain an electric submersible pump discharge rate)
3. Groundwater chemistry sampling (both well head measurements, and collection of laboratory samples)
4. A repeat CCTV survey downhole survey to inspect the borehole construction and repair status, whilst the water-level in the borehole is lowered as a result of the pumping test – clear images of the borehole structure, and main water inflows, can be obtained for a significant length of the borehole above the water-level (below the water-level the disturbed water is typically too murky to obtain clear camera images).

Bailer tests form a very useful investigative technique in areas of low permeability aquifers. A bailer test is comprised of removing a set volume of water from the borehole using a manual bailer (or bucket) on a rope, and then timing the rate of recovery of the water-level in the borehole, following the removal of the displaced water volume (MacDonald et al. 2005). Often in low permeability aquifers the local transmissivity is insufficient to conduct a full pumping test using a submersible electric pump. Carrying out the bailer test first gives a quick and reliable indication of transmissivity and whether it is worth undertaking a pumping test. In more productive aquifers the results of the bailer test can be used to select an appropriate pumping rate in the pumping test. If a pumping test is conducted after a bailer test, sufficient time should be left for the water-level to fully recover between the tests.

The groundwater chemistry samples and well head measurements should be taken after a suitable period of pumping (during the pumping test if conducted), to ensure the samples are of groundwater from the aquifer, and not water which has been residing in the borehole and in contact with air for a significant time.

4.4 Analysis approach

Existing studies and water point functionality surveys form an important knowledge base regarding the different symptoms and consequences of water supply failure. To understand *why* water supply services fail requires a systems approach which recognises the many different components of the service delivery supply chain, including the water point itself, and variety of factors (technical, social, institutional) contributing to failure, which interact and/or are interlinked. A systematic, diagnostic framework that allows for comparative analysis is essential to understand causes of water supply failure in different socio-economic and environmental settings. With this aim, a *root cause analysis* approach was used to begin to develop a diagnostic framework for understanding why the water points examined in this pilot study had failed.

Root Cause Analysis (RCA) has traditionally been developed in a health and safety context – examining the conditions and decisions made which ultimately led to an accident or emergency situation (Ragin 1999; Livingston et al. 2010). However, the approach is also useful for framing the issues of borehole and handpump failure, and identifying the underlying root causes of the failure, rather than just the immediate symptoms and causes. There are various approaches to RCA, of which we took two to develop a diagnostic framework approach for examining causes of failure in groundwater-based water supply systems.

The first RCA approach used was the **The 5 whys** approach. In this, a problem is stated and then five 'why?' questions are asked to delve into the underlying causes of water supply failure. For example:

Problem statement: borehole handpump has failed;
1 Why has the water supply service failed? – Because the yield was too low.
2 Why was the yield too low? – Because productive aquifer horizons were cased out of the borehole.
3 Why were the productive horizons cased out? – An inappropriate borehole design was used.
4 Why was the borehole designed inappropriately? – Because of inadequate understanding of aquifers and lack of application of good borehole design principles by implementing organisations

5 Why was there this lack of understanding and application? – Because of the absence of hydrogeological or engineering expertise in the design of programmes and contracts and a lack of supervision by someone competent to ensure the design was followed or to modify standard borehole designs on-site if necessary.

The first 'Why?' statement represents the ***primary symptom of failure*** (e.g. insufficient yield) which is generally captured by existing functionality surveys (e.g. UNICEF 2012; RWSN 2009, MWE 2010). The second, third and fourth 'Why?' statements all identify ***different factors contributing to water point failure***, whilst the fifth 'Why?' begins to undercover the ***underlying root causes of the failure*** – Figure 8. In the example above, the absence of supervision by a hydrogeologist or trained engineer points to the underlying conditions that might underpin the water point failure – 'why wasn't a competent technical person present on site to ensure appropriate water point design and construction?' This suggests either: the importance of having a competent individual present was not recognised by implementing agencies and local governments or there was not a sufficiently sized pool of competent individuals to draw from. Moreover, when implementing agencies and local governments outsource all aspects of drilling (including supervision) to contractors they may create an environment in which there is little interest in competent supervision; or implementing agencies and local governments are not willing to invest in the cost of technical supervision on site. Behind these answers there are further 'whys' linking to the deeper institutional capacities and arrangements which can make water point failure more or less likely.

A second RCA approach – **Causal Link Diagrams** – was then used to begin to examine how these different factors might interlink (Rooney and Vanden Heuvel 2004) – Figure 9. This was very useful in identifying the number and complexity of inter-linked factors, and to begin to frame water point failure as a system. One symptom of failure can arise from different causes. For example,

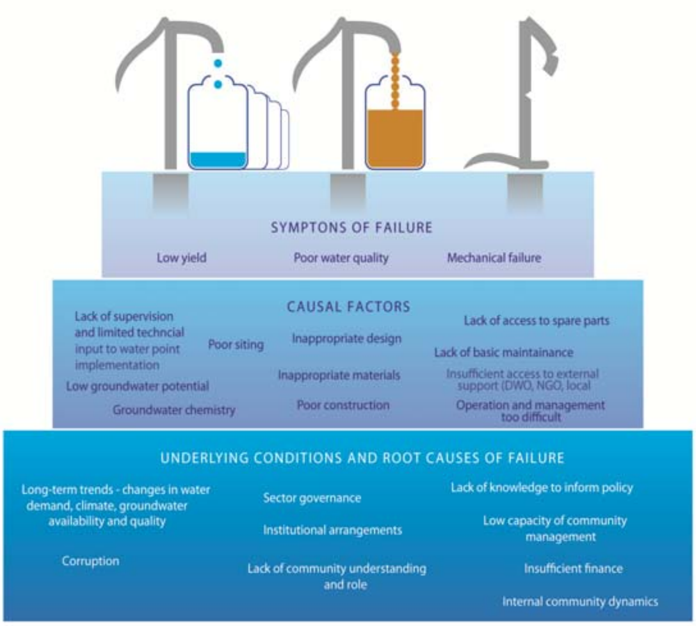


Figure 8: Hierarchy of symptoms, causal factors and underlying causes of water source failure

'insufficient yield' (a symptom of failure) can arise due to low groundwater resource potential; inappropriate design of the borehole in relation to the aquifer resource; or, inappropriate siting and borehole depth; or, high demand pressures. As another example, mechanical failure can arise from: poor installation of the pump and inappropriate construction materials; or the inability of the community to finance and facilitate repairs. These two sets of causal factors may be linked – the community may not be *willing* to raise the finance for repairs if the handpump construction is poor and repeatedly fails. The ability of a water user committee to repair the handpump is dependent on the underlying borehole construction and siting as well as access to spare parts and available finance.

The factors underpinning failure of a water supply are, therefore, numerous and inter-related, and the causal link diagram (Figure 9) provides a useful diagnostic framework for visualising these layered and inter-linked sets of factors which can lead to failure. To investigate which linkages have led to supply failure at any one water point requires a systematic field methodology to collect comprehensive data on supply failure.

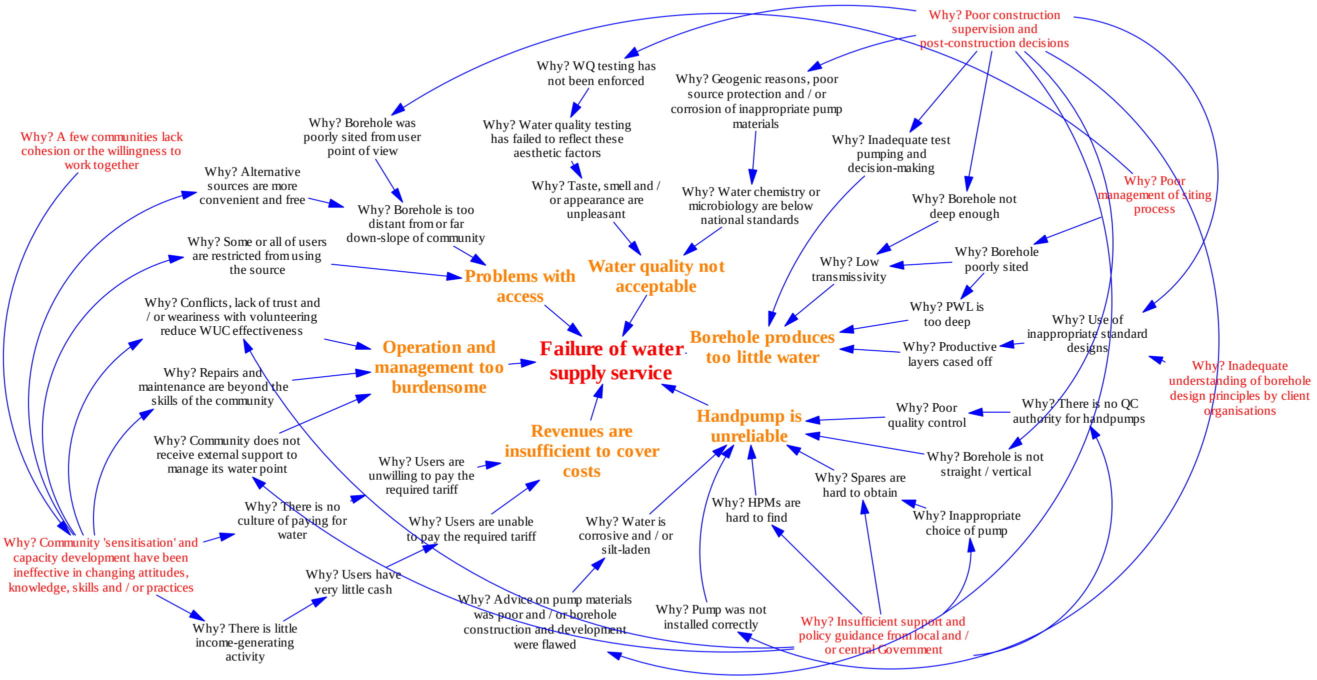


Figure 9 – A schematic causal link diagram of water point failure. Factors which can contribute to water point failure are shown in concentric rings around the failed water point in the centre. The arrows indicate linkages between different causal factors. Underlying conditions and root causes, which underpin these causal factors, and ultimately lead to the water point failure, are shown by the outer circle of red text.

5 Applying the Toolbox – A pilot study, Uganda

The toolbox was applied to investigate borehole-handpump failures in the Amuria and Katakwi districts of northeast Uganda by the catalyst grant as a pilot study. The main aim of this pilot study was to assess the applicability, replicability and overall success of the toolbox, to develop a detailed post construction audit dataset of failed water points, which can be used to examine the immediate, and underlying root causes of the water point failure, and to generate a systematic evidence base on water point functionality.

The water points examined in the study were selected according to clearly defined criteria to ensure a robust investigation of water point failure and a valid test of the toolbox and fieldwork methodology. These criteria were:

- The study focused exclusively on examining failed water points which had been out of service for more than three months, and considered 'abandoned'.
  This provided some guarantee that the failed water points identified by the reconnaissance fieldwork would still be available as failed water points for the subsequent fieldwork investigations. Water points which had only recently failed in the last few days or weeks, and had not been abandoned in the long-term, had a much higher likelihood of being repaired by the time the fieldwork took place. This meant the study did not capture water points which were non-functional for short (days and weeks) periods of time due to mechanical failure, or water points which are currently functional, but which have failed for some period in the past

- Failed water points were exclusively borehole handpump supplies.

  Whilst several different forms of groundwater-based systems are used extensively across the continent (boreholes and hand dug wells and protected springs being the main types) each type is likely to have different patterns of failure – for example, issues of demand pressures, resource availability, and engineering design, and level of community management, are all likely to interact slightly differently for each type of system. Focusing on only one type of system enabled the pilot study undertake a robust and focused investigation of reasons for supply failure. Borehole-handpump technologies have been the main choice in water supply programmes throughout sub-Saharan Africa in the last decade.

5.1 Reconnaissance survey

Failed water points were identified in the field area by WaterAid's local NGO partners – WEDA and TEDDO – and District Water staff in Amuria and Katakwi Districts, based on their knowledge and observations from their regular travels throughout the districts, and discussions with communities. The perceived causes of failure were recorded by partners and reported back to the research team. Each water point was visited to verify that it met the selection criteria of having failed for more than 3 months with some remains of the handpump still present, and to discuss with the community if they would be willing for a more detailed investigation to be undertaken involving removal of the hand-pump and pump rods, and downhole measurements and tests. Key secondary data (e.g. borehole log, driller's log, construction/completion log, and any water quality analyses and pumping test report completed) were collated if accessible.

The reconnaissance work identified 37 long-term failed water points in the Amuria and Katakwi Districts. Several different symptoms of failure were captured in this sample, including poor water quality, insufficient yield, and mechanical handpump failure. Detailed community surveys were carried out at 24 of these water points, and technical investigations at a sub-sample of 10 – time and cost being the main limiting factor. The 10 water points examined by both the community surveys and technical investigations were carefully selected to ensure a range of failure symptoms (e.g. inadequate water quality, insufficient yield and mechanical failure) and community arrangements (e.g. participation of the community in site selection, presence and capacity of a WUC, ability to finance repairs, access to the hand pump mechanic and other external support) were examined. Appendix 3 provides a full list of the different attributes of each of the sites and the basis of the final 10 sites selected.

5.2 Focused field research – Community surveys

Rapid surveys examining community capacity to manage and finance borehole-handpump supplies were carried out for 24 of the 37 failed water points identified in the reconnaissance fieldwork (Phase 1).

Well point community discussions in Amuria district

The survey consisted of a semi-structured discussion with each community, guided by a template providing key questions and sub-questions for more detailed enquiry. The survey took between two and three hours to complete with each community.

Participants included water users (both women and men) and representatives of the Water User Committee. Group sizes and composition varied from community to community, as there were no restrictions on participation. Although the groups were generally too large to ensure that every individual contributed, facilitators played an important role in maintaining a balanced discussion, particularly ensuring that women had the opportunity to voice their opinions. Market days and local holidays were avoided as far as possible, and where unexpected time conflicts did occur the groups were noticeable smaller.

The community survey fieldwork was led by ODI, and completed over 10 days by two fieldteams working in parallel. Each team included a researcher leading the survey, two WEDA or TEDDO staff who facilitated and translated the discussions, and one WaterAid programme staff member providing logistical support and technical backstopping. The local NGO organisations WEDA and TEDDO (partners of the WaterAid programme in the Amuria and Katakwi field areas) were vital in liaising with communities to ensure members of the Water User Committee (WUCs) or village elders were present to take part in the surveys, as well as to mobilise other participants. These individuals were particularly knowledgeable in reconstructing the history of the failed water point and of the WUC. Their presence was, moreover, a means to ensure legitimacy of the project in the eyes of the community. Visits were also made to the District Water Offices to seek approval to conduct fieldwork in the local area.

Based on the information collected in the community surveys, a smaller sub-sample of 10 water points was identified for more detailed technical investigation of the reasons underlying the failure. The sub-sample sites were selected to ensure a cross-section of the different symptoms of water point failure, and different local institutional arrangements and community management capacities were represented.

It is important to note that equal emphasis was given to community surveys and technical and engineering investigations in the pilot study, but due to time and cost, technical investigations were only carried out at a sub-sample of the total number of water points examined in the pilot study.

5.3 Focused field research – technical investigations

The technical investigations of the toolbox, were applied to 10 water points and completed over 10 days by two field teams working sequentially at each site – an advance team dismantling the borehole and pump and examining its condition and operation, and a follow on team undertaking the downhole tests, groundwater sampling and aquifer testing. Each field team included: a hydrogeologist leading the technical investigations; a member of WaterAid's programme staff and an engineer from Makerere University who led the borehole and pump inspections; a WEDA/TEDDO staff member and a WaterAid staff member who facilitated the fieldwork, led the community mobilisation and assisted with translations; and a handpump mechanic.

Team 1 – was the advance team, carrying out dismantling and inspection of handpump condition; investigation of pump operation; investigation of borehole construction, undertaking basic measurements (e.g. location coordinates, borehole depth, rest water-level, borehole verticality); and some further community discussions at the water point. These observations are essential to determine whether the factors causing water point failure stem from deficiencies in borehole construction.

Team 2 – followed on and undertook the below ground work: CCTV survey inspection of borehole construction; aquifer testing (by a bailer test and/or pumping test); groundwater quality sampling and well head measurements of water pH, Eh, SEC, DO, temp; and, dissolved gas sampling (groundwater residence time indicators). These investigations were pivotal to collating sufficient data to establish if siting, available groundwater resource potential, borehole design, construction, and groundwater chemistry were significant factors causing water point failure.

6. Pilot study results

6.1 Community surveys

The main findings from the community surveys are summarised below. The results include all 24 water points covered by the surveys.

Water demand

Village populations ranged between 200 and 1,260 people (averaging around 670) whilst the number of households ranged from 47 to 365 (averaging around 130), giving some indication of demand for water in each community, as well as the significant variation in community size.

The survey showed that communities collect water from a number of sources, both improved and unimproved sources, for different purposes. Boreholes with handpumps were the predominant type of improved sources available in villages surveyed and generally preferred over unimproved sources for drinking, and were used for cooking, bathing, washing and livelihood activities as well, depending on the availability and convenience of other water sources in the community.

Failure of water points (i.e. boreholes) in the community and in neighbouring villages was reported to place increased pressure on remaining water points, which were sometimes shared by several villages, and long queues were frequently reported.

Water point planning, siting and construction

The extent to which communities were consulted and/or participated in different stages of the planning processes for the water point in question varied considerably. Ideally a water point is developed because a community has expressed a demand or need for the intervention. This was true for at least two thirds of our sample. In most of these cases the community (or local school) had submitted a written request to the District Water Office (DWO) which was either honoured or passed on to an NGO. Another indicator of demand is willingness to pay. Four communities said they had contributed to capital costs (co-funding construction), typically paying 200,000 UGX (75 USD). One community (K13) was told to contribute towards construction but the borehole broke down before they had paid. Recurrent finance is discussed below. For six water points there was a Memorandum of Understanding (MoU) signed by the implementing agency and community, sometimes including the land owner. However, it did not appear that these MoUs had been an effective means of holding the relevant agency to account when the water point failed.

A good siting process would factor in both community preferences (needs) and technical suitability to ensure that the borehole was both accessible and productive. It is difficult to ascertain the technical details of the siting process from community discussions and unfortunately it was not possible to seek out the relevant experts in the time available. In all cases a survey of some kind was undertaken, but it was not always clear how extensive these surveys were or what kind of equipment was used. Some communities were entirely absent from the survey process (e.g. A5, A8, K10), most were involved to some extent, whilst a few clearly played a very active role in proposing and shortlisting potential sites (such as A1 and K1). In many cases, based on the data available, it was difficult to determine the rationale behind the selection of a particular site. In K5, for instance, the community were not involved in site selection and also claimed that the drillers did not construct the water point at the location selected by the surveyors.

The community survey data indicated that water point construction was rarely supervised properly, if at all. Ideally a technical expert such as a hydrogeologist or engineer would be present throughout the process. At two sites a non-technical expert from the local NGO was supervising throughout. In six other cases there were spot checks during construction by the DWO or NGO. Communities felt unable to judge quality of construction work or materials used and were generally poorly informed about the siting and drilling process.

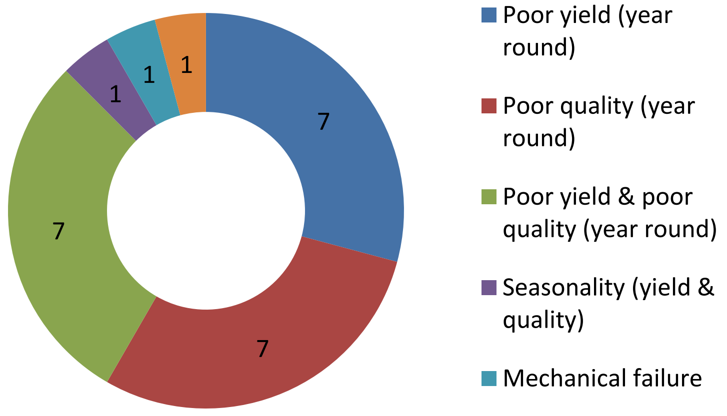


Figure 10 – Dominant symptoms of water point failure

Water quality and yield

According to the community discussions, many of the water points surveyed had quality and/or yield problems from the start, indicating an issue with siting or construction. Only three or four were functioning for one year or more before problems arose. Poor yield manifested itself in difficulties with pumping and/or having to rest the pump, whilst quality was primarily determined by sight (e.g. milky or rusty colour, presence of 'worms' or particles in the water), smell and/or taste. In five cases samples of the water had been taken away by local experts for testing at the time of the community complaints, but only one community had received feedback. There were few cases of seasonal failure (K12, A20) (see Figure 10).

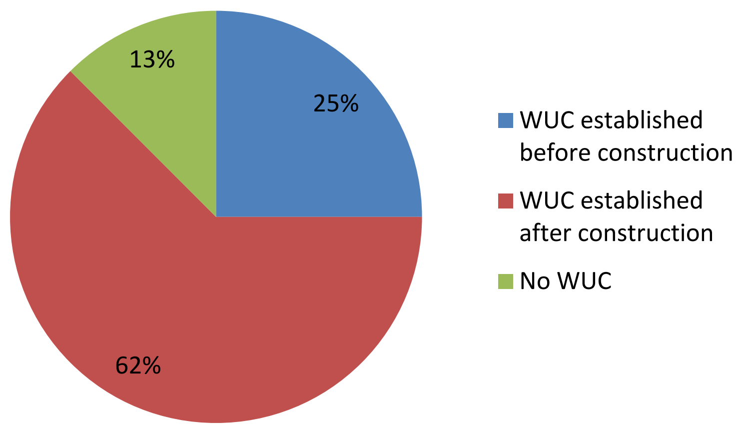


Figure 11 – Presence of a WUC for the water point in the communities

Access to the water point

Half of the failed water points surveyed had fixed opening hours, primarily to enable supervision by the caretaker, whilst the remainder were open at all times. In general there were no restrictions on what the water could be used for or how much could be taken, but in some cases access was limited by other factors such as convenience (relative to other water sources) or borehole yield. In two cases it was agreed to limit the number of jerry cans of water taken by each household to allow everyone to collect water. At K12 this applied only during the dry season whilst at K3 the borehole was low yielding. All community members (and even households from other villages) were eligible to use the water points surveyed, provided they had paid their user fees and adhered to other by-laws, although in some cases there were difficulties enforcing these rules (discussed below). In one case (K2) water used for brick making incurred an additional fee. Where the borehole was attached to a school the students and teachers tended to take priority, particularly at busy times. In many communities the elderly or disabled were given priority and assistance at the water point.

Often the failure of the water point has meant that people have to travel further to draw water from an improved source or resort to unimproved sources.

Community management of the water point

The data showed that 21 water points (~87%) had a Water User Committee (WUC) responsible for managing and maintaining the water point, enforcing by-laws and collecting user fees, and in most cases elected by the community. Only six of these WUCs were formed before water point construction, allowing their participation in the planning process. Of the three water points without WUCs (13%), two were managed by the local school. See Figure 11.

Typical roles on the WUC included: chairman, secretary, caretaker, treasurer, and sometimes health or sanitation and hygiene educator. Caretakers were responsible for day-to-day management of the water point, including enforcement of by-laws. Some WUCs met on a regular basis, others only when problems arose. In a couple of cases only certain members of the committee were active, usually the caretaker or chairman. WUCs became inactive when the water point was non-functional for a significant period of time, particularly where the problem was deemed beyond the Hand Pump Mechanics' (HPM) capacity to repair. Where communities have been affected by civil unrest, some of the older water points had been left unused (and therefore unmanaged) for several years. With the exception of four cases, communities generally appeared to be satisfied with their WUCs.

Six of the WUCs had received 2-3 days training by the implementing agency or, in one case, another NGO. Another three claimed to have received 'some' training, however half of the WUCs received no training at all (Figure 12). Training usually included subjects such as looking after the water point (e.g. fencing, using the pump properly), related sanitation and hygiene issues (e.g. using clean jerry cans, keeping animals away, location of latrines), and record and accounts keeping. Topics that were not covered were preventative maintenance and minor repairs (HPM's are expected to provide this service), information regarding the potential costs of repairs, or advice on how much money to collect from users. None of the WUCs reported follow-up training or other capacity building efforts.

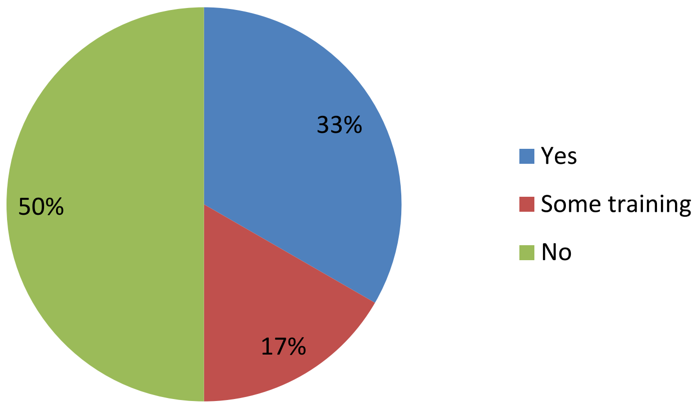


Figure 12 – Was training received by WUCs?

By-laws were established for all except four water points, which had failed soon after construction and/or did not have a WUC. These by-laws related to operation, maintenance and use of the water point, for example: opening times, proper use of the pump, keeping livestock away, use of clean jerry cans, keeping the apron clean, maintaining fencing, no bathing at the water point, or sweeping the area. A few communities explicitly mentioned punishments and fines, but these were not always enforced. Ten communities reported problems in ensuring adherence to by-laws, although the details depended on context. The most common challenge for caretakers was restricting use of the borehole, either out of hours, or in cases where households had not paid their fees.

Fees and finances for maintenance

User fees agreed by communities with their WUC varied from 200 UGX (0.08 USD) to 2,000 UGX (0.75 USD) per household per month. For more than half of the sample water points covered by the community surveys there were some problems reported in collecting fees. WUCs employed a number of tactics to encourage payment, for example going door-to-door, confiscating jerry cans or locking the water point. The extent to which WUCs were able to collect these payments depended on a number of factors such as: the size of the payments expected, the nature of the problem (e.g. people were reluctant to pay if the water quality was bad regardless of repairs), proximity of alternative water sources, trust in the WUC, and households' ability to pay. In most communities the elderly or disabled were exempt from contributions, and there was some flexibility where households struggled to raise the necessary finance. For example, although the WUC for K9 was strict they did allow payments to be made in instalments. Many communities were able to raise enough funds to pay for minor repairs by the HPM but few (if any) were unable to deal with the bigger/costlier problems. Fees were not collected when the borehole was non-functional for any significant periods of time (i.e. abandoned water points).

Breakdowns, repairs and external support

HPM support and response times were generally good, although many of the problems encountered are clearly beyond HPM capacity, requiring major repairs, rehabilitation, or simply a new water point. Once the first breakdown had occurred, breakdowns thereafter tended to occur fairly regularly (every 2-3 months). Moreover, as noted above, many of these water points failed within the first few months after construction. This would indicate poor quality of parts or other underlying problems, for example relating to siting or construction.

Where there were delays to repairs these were largely attributed to difficulties the WUC faced in raising the necessary finance i.e. collecting money from community members, and therefore delays in contacting the HPM. Access to spare parts was sometimes a challenge due to the distance to the nearest sizeable town (Soroti) and associated travel costs, therefore a few communities purchased spares from the HPM or sub-county office. Beyond the HPMs, external support to communities was lacking. Many communities had attempted to report their problems to the DWO, another higher authority or an NGO but only a few had received a response. It is thought that the DWOs have limited human capacity or budget to cope with the scale of the problem of water point failure, although this requires further verification.

6.2 Technical investigations

The main technical findings of the fieldwork are summarised below.

Groundwater availability and aquifer productivity

The data indicate that the crystalline Basement Complex aquifer in the region is of low groundwater potential and there can be significant variations in transmissivity of both the fractured bedrock aquifer (dependent on the number of fractures), and of the weathered overburden (dependent on the thickness and nature of the regolith). The limited availability of borehole construction records restricted understanding of this aquifer system, particularly the thickness of the regolith and how it varied in the study area. The technical field investigations were hampered because the original depths, yields, regolith thickness and water levels were not available for most sites, and the results of the fieldwork in this study could not be compared with information from the time of construction.

Bailer (top) and pumping tests (bottom) being carried out in Amuria District.

Pumping tests indicated the aquifer transmissivity (T) to range from 0.01 to >100 m^2/d. Transmissivity measured from pumping tests in boreholes which included a screened section in the regolith aquifer ranged 0.01 to 15 m^2/d. In the boreholes which entirely cased out the regolith, and in which a pumping test was possible, transmissivity was indicated to be highly variable ranging from <1 to 632 m^2/d – Figure 11. At three water points transmissivity was too low to conduct a pumping test at a discharge rate of 0.5 l/s. Bailer tests at these points indicated the resource potential to be sufficient to sustainably support a hand pump. Two of these water points showed a primary symptom of failure of insufficient yield, suggesting other factors such as borehole design and construction or poor siting could be more significant to the low yield than the absolute groundwater availability. A range of borehole designs were observed , in which two cased out the weathered regolith, and one included some screen section within the regolith horizon, as discussed below.

Other work in crystalline basement complex aquifers in sub-Saharan Africa across a range of climates has found there can be sufficient storage and transmissivity in the weathered bedrock and overlying regolith to support handpump supplies (Chilton and Smith-Carington 1984; Chilton and Foster 1995; MacDonald et al. 2012; Lapworth et al. 2013). Based on borehole data from Malawi, Chilton and Smith-Carington (1984) concluded that the regolith aquifer would usually support borehole yields sufficient for a handpump where its saturated thickness was greater than 10-15 m, provided the borehole design was appropriate for these conditions. Appropriate targeting of borehole design relies, however, on sound understanding of the local hydrogeological conditions.

Borehole design and construction

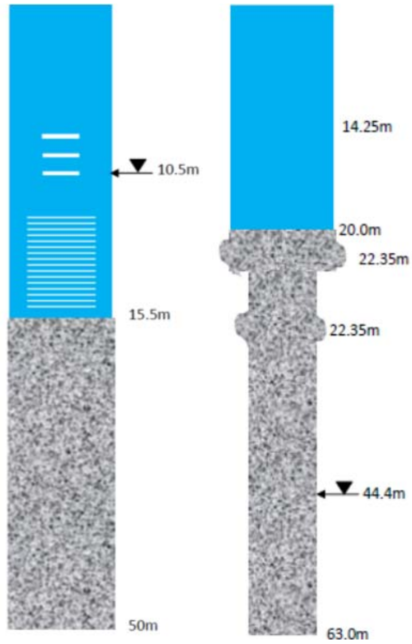


Figure 13 – Borehole designs observed from CCTV surveys in the field: (Left) Modified open hole design, with the borehole screened in the shallow weathered aquifer; (Right) traditional open-hole design, with the shallow weathered aquifer entirely cased out, and a narrower hole diameter with depth in the bedrock.

The water points examined in the pilot study (boreholes with handpumps) were all constructed between 1997 and 2012; the majority being constructed between 2007 and 2009. Five of the boreholes have an open-hole design in which the weathered regolith is cased out completely and inflow to the borehole is entirely from the fractured bedrock – Figure 13. The other five have a modified open-hole design, with the borehole being partially screened within the regolith, enabling inflow from this aquifer as well as the underlying fractured bedrock – Figure 13. In some cases, the drilling diameter in the bedrock was the same as that in the overburden, while in others a reduction in hole size is evident. All of the boreholes were cased with 5 inch (125 mm) uPVC casing, with the exception of the borehole constructed in 1997. The borehole depths ranged from 31 to 82 m (average depth 55 m). Two of the boreholes were measured as only 15 m deep, with the screened interval entirely within the weathered regolith. Siltation was apparent at the base of the boreholes, but in the absence of construction data for these it is impossible to know if the siltation has resulted in a significant reduction in the total borehole length. Significant siltation would indicate the boreholes had been inappropriately designed and/or poorly constructed and significant amounts of green-grey silt and fine sands have been able to enter, either through the screened sections in the regolith or around the base of the casing. Lesser amounts of siltation have probably occurred at the other sites, but could not be evaluated without knowing the original drilled depth of the boreholes. One of the boreholes was reported by the community to have partially collapsed due to inadequate installation of the casing.

In 6 of the 10 boreholes, significant inflows of water were observed in the upper 11 m section of the borehole, from the regolith and weathered bedrock – either from below the casing or through casing joints or screened intervals. In 5 of these, the shallow inflows were the only, or main, inflows observed. Half of the boreholes examined, however, cased out the regolith. Even so, if the annulus is left open and the bottom of the casing is not well sealed or seated, some water from shallower depths may pass down the outside of the casing and enter the borehole at this depth, possibly carrying fine material with it. This indicates that application of a standard borehole design leads in some cases to potentially productive aquifer horizons being cased out, and at some of the water points examined the borehole design did not match the aquifer resource.

Estimated verticality of all the boreholes examined was very good, with the maximum drift of the plumb line less than 1 mm per metre depth (or 0.1%). This is well within the guideline limit of 1% verticality to safe guard pump operation.

Groundwater chemistry

Groundwater quality issues were observed at all but one of the failed water points and inadequate water quality was reported by the community to be the primary symptom of water point failure at six of the supplies.

Within the exception of one water point (A16), all the abstracted groundwater contained large quantities of suspended solids, and was opaque in appearance with a pale brown to orange hue – Figure 14. In some cases, the quality improved with pumping (Figure 14), but, with the exception of one site, none of the groundwaters attained a completely transparent appearance, and remained 'milky' in appearance.

Well head chemistry measurements taken at the time of sampling are shown in Table 6, and indicate the groundwaters have slightly low (acidic) pH (8 of the 10 sites having pH <6.5, 4 of which are <6), moderately mineralised (measured as specific electrical conductance (SEC)) and moderately soft, with relatively low concentrations of calcium and magnesium minerals dissolved from the basement rocks into the groundwater.

Laboratory analyses of the groundwater samples taken indicate relatively high organic carbon content (material derived from decaying vegetation, bacterial growth, and metabolic activities of living organisms or chemicals), with average NPOC (Non-Purgeable Organic Carbon – commonly referred to as total organic carbon (TOC)) measured as 0.8 mg/l (range 0.47 to 2.37 mg/l), and high dissolved iron (Fe) content – average total Fe 600 µg/l (over half of the samples had Fe in excess of 200 µg/l, with three >1000 µg/l). The high iron content in abstracted waters is supported by corrosion and staining of the pump components and by observation of significant orange staining at all the boreholes investigated in the CCTV surveys. This is most likely attributable to the high iron content of the waters, but may also be contributed to by ingress of soil particles into the boreholes which have screened intervals in the regolith (Figure 14). Elevated concentrations of zinc (five sites having Zn over 200 µg/l) are indicative of corrosion processes having taken place. Manganese concentrations were <200 µg/l in nearly all the waters. Full laboratory results are shown in Appendix 4.

Figure 14 – (Top) opaque, milky appearance of groundwaters; (Middle) groundwater quality improved in some boreholes with pumping; (Bottom) significant orange staining on borehole casing observed in all.

Site	Temp (°C)	SEC (µS/cm)	pH	Eh (mV)	DO (mg/l)	HCO_3 (mg/l)	Estimated depth (mbgl)	RWL (mbgl)
A16	27.9	66.8	5.66	481	3.2	43.9	60	4.47
A15	31.8	260	6.58	324	2.35	24.8	62	2.775
A18	30.3	145.6	6.38	301.3	6.03	22.0	82	2.47
A17	27.9	366	7.2	439.7	6.32	38.9	62	3.132
A5	26.9	201	5.37	414.3		35.8	46	1.875
K3	27.4	152.9	5.66	386	5.46		Silted to 15m	
K4								
K8	29.4	118.9	6.24	393.3	2.07	33.3	40	
K13	29.4	577	6.10	305	0.22	22.5	52.8	4.68
K6	30.2	376	5.98	226	1.09	12.9	31	5.47
K12	31.5	315	6.33	277.6	3.99	19.2	52	3.035

Table 6 – Well head groundwater chemistry measurements taken at the water point after the borehole had been purged. A16 was the only water point to have a clear aesthetic water appearance. (Abbreviations: SEC – Specific Electrical Conductance; Eh – redox potential, measured in millivolts; DO – dissolved oxygen; HCO_3 - bicarbonate; RWL- rest water level in metres below ground level)

Groundwater residence time indicators

The analysis of dissolved anthropogenic gas concentrations (CFC, SF_6) indicates a difference in the ages of the waters abstracted from the water points. Half of the water points sampled are indicated to yield groundwater with a residence time less than 10 years old, whilst the other half of the water points yield groundwater which has a residence time of over 30 years old – Figure 15. This difference is most likely attributable to the difference in the borehole designs of the water points. Four out of the five samples which are indicated to have a residence time less than 10 years were from boreholes which contained a screened section within the shallow regolith. Inflows of shallow groundwater, which will be recharged from recent seasonal rainfall, will therefore inflow the borehole. These inflows were observed from the CCTVs in most cases in these boreholes.

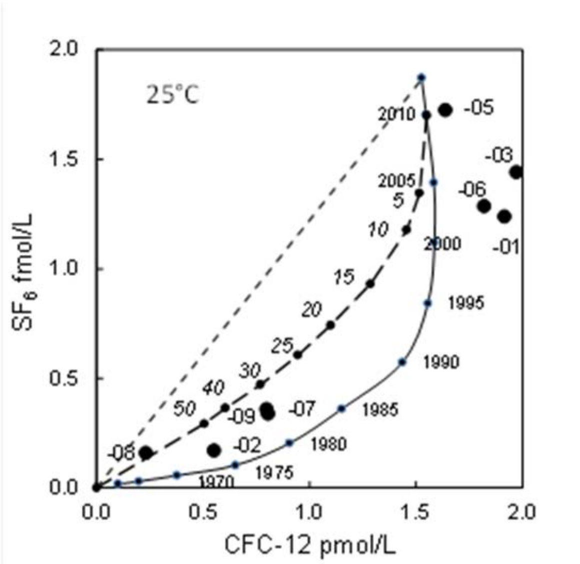


Figure 15 – analysis of CFC and SF6 data showing a bimodal age group between samples

Four of the five water samples which are indicated to have a longer residence time of over 30 years, were all collected from boreholes which cased out the shallow regolith entirely, and therefore the borehole could only abstract groundwater stored within the weathered and underlying fractured bedrock.

Handpump installation and condition

All the boreholes examined were fitted with India Mark II handpumps – Appendix 2 provides an assembly drawing of this handpump. Two of the handpumps (sites K3 and A18) had serious damage to the above ground components and could not be dismantled and removed for inspection. The above and below ground components of the other water points were inspected.

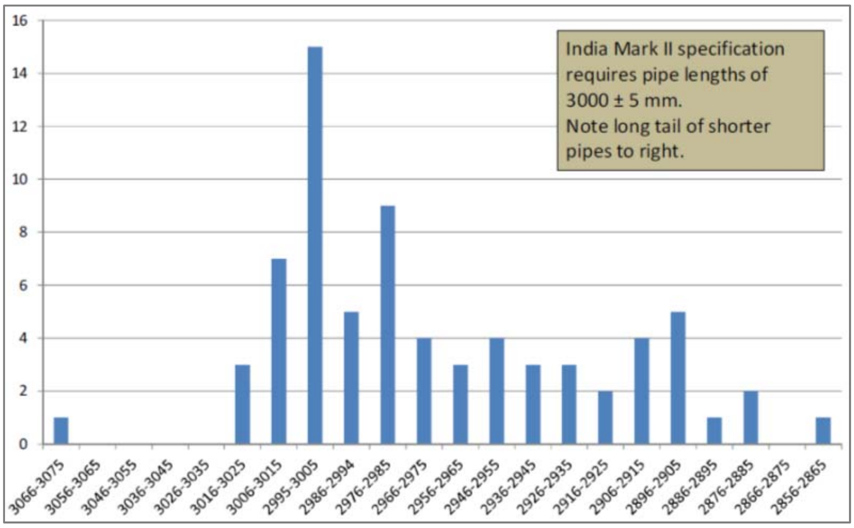
Handpump installation: none of the boreholes examined had truly vertical pump stands, indicating some compromises were made to the quality of the construction and installation of the handpump. Some of the installations also used short pipe sockets, leaving the joints more prone to failure than with longer sockets. All of the handpumps used galvanised iron (GI) rising main and pipe components. There is a high risk of corrosion of GI material within certain groundwaters, leading to potential joint failure and pipe parting, perforation and leakage. Use of PVC and or stainless steel materials for handpump components has been recommended by the RUWASA Programme in Eastern Uganda for this reason, since the 1990s. Despite this recommendation, there are very few India Mark II handpump installations in Uganda which use anything other than GI rising main and pump rods.

Handpump condition: Corrosion was a serious issue in most of the handpumps examined – with only 2 out of 8 pumps which could be inspected not showing serious signs of rising main corrosion. In six of the handpumps, there was significant damage or wear to the threads of the rising main pipes due to corrosion, which in one case led to loss of the pump components down the borehole when trying to remove the pipes – Figure 16. In five of the handpumps, significant elongated perforations in the rising main were present (Figure 16).

Figure 16 – (Top) corroded rising main thread; (Bottom) perforated rising main.

Corrosion of the handpump materials is most likely due to use of galvanised iron in groundwater of slightly low pH. Corrosion of the GI materials will contribute to the high dissolved iron content of the water, as shown by the groundwater chemistry data in the previous section. The widespread corrosion problem indicates GI is not a suitable material for handpump installations in this region. Furthermore, in relation to the ascetic and taste acceptability of iron-rich groundwater, the use of mild steel borehole casing and galvanised pump components can make an existing natural groundwater quality constraint significantly worse (Lewis and Chilton, 1989).

Handpump repairs: All of the water points are reported by the communities to have undergone some repair during their lifetime, the most common repairs being replacement of pipes, chains and the pump cylinder. Replacement of leaking or damaged rising main pipes had occurred at 9 of the 10 handpumps. In some cases this was reported to have been done by removal of the pipes – and thereby raising the pump cylinder by approximately 3 m for each pipe removed – or, by cutting out the corroded or damaged sections of the pipes and re-threading the remaining shorter pipes. On removal and inspection of the handpumps, there was evidence of either removal of the pipes, or shortening of pipes to remove damaged sections, rather than proper pipe replacement – Figure 17. Only one of out the 41 pumping rods examined in the nine study sites, conformed to India Mark II specifications – Figure 17.



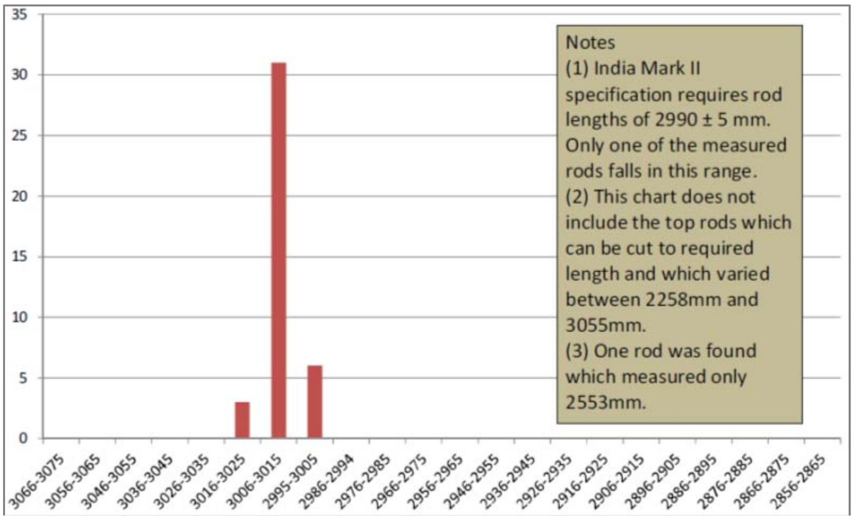


Figure 17(Top); frequency distribution of rising main lengths in mm (72 rising main lengths from 8 supplies examined); (Bottom) frequency distribution of pump rod lengths in mm (41 rods from 6 supplies examined).

Summary

The data from the 10 sites provide a post construction audit of the failed water points and local community governance and management arrangements. The data indicate that in some cases the borehole design does not match the aquifer resource available; handpump materials are inappropriate and possibly of poor quality; there has been a lack of supervision of the construction of water points; siting processes are often inadequate; there are problems with recurrent finance to pay for operation and maintenance due to inability or unwillingness of households to pay; in many cases there is a lack of adequate training and capacity building of Water User Committees; there have also been some challenges in community-based management such as enforcement of rules; most communities are unable to access higher-level support to maintain water points. All of these factors are likely to contribute, to greater or lesser extents, to water point failure. The data from the community surveys and technical investigations are brought together in the following section and analysed using the diagnostic framework and RCA approach developed by the pilot study, to see if it is possible to identify the different significance of these factors to failure and the underlying root causes.

7. Discussion of pilot study results – analysis of water point failures

The field data provide a detailed post construction audit dataset. The diagnostic framework outlined in Section 4.4 of this report, which utilises a causal root approach, was adopted to analyse the data to identify the main causal factors in water point failures, and, the underlying root causes.

7.1 Identifying the main causal factors in water point failures

The main symptoms of water point failure in the Amuria and Katakwi districts were found to be:

- Poor water quality and mechanical breakdown of the pump from corrosion (4 sites)
- Insufficient yield and poor water quality (2 sites)
- Insufficient yield, with adequate water quality (3 sites)
- Mechanical breakdown of the above ground headwork of the pump (1 site)

Half of the failed water points had displayed early one-off catastrophic failure within a year of completion, the other half having gone through a limited number of cycles (maximum two) of repeated failure and repair before failing within a few years, one failing seasonally over a longer time frame.

A matrix was used to integrate the different field data collated, and to help identify the dominant causal factors for each of the water point failures investigated using the diagnostic RCA approach – Box 1. Similar matrices have been used successfully in other work for integrating multi-disciplinary datasets in rural water supply research to examine relationships driving national variations in coverage (Hunter et al. 2009), and to explore origins of corruption in rural water supply (Calow et al. 2012). For the purposes of this work, a matrix approach was particularly helpful in identifying linkages between symptoms and causes of failure, but it did not show interactions, or inter-linkages, between different causal factors, or help identify the underlying conditions giving rise to these problems - the root causes.

The dominant causal factors associated with different symptoms of water point failure observed in the pilot study are summarised in Table 7.

Symptom	Dominant causal factors
Poor water quality and mechanical breakdown of pump components from corrosion	Low natural groundwater pH and Eh; use of GI materials in pump
Insufficient yield and poor water quality	Borehole design mismatched to aquifer resource; use of GI materials in pump
Insufficient yield	Poor siting; borehole design not suited to the aquifer; low groundwater potential
Mechanical breakdown of above ground head-work of pump	High water demand; limited capacity of community to maintain

Table 7 – identifying the main causal factors associated with different symptoms of water point failure observed in the Amuria and Katawki districts

Corrosion of GI handpump components is clearly shown to be a significant causal factor in many cases of water point failure in the study area, with corrosion having led to, or contributed, to mechanical failure and/or poor water quality in almost all of the water points examined. Corrosion of the GI handpump materials is attributable to the naturally slightly low pH of the groundwater in the area. The corrosion process itself is likely to have led to, or at the very least exacerbated, elevated dissolved iron concentrations and poor aesthetic quality of the abstracted water. If more appropriate materials had been used in the hand pump components (e.g. stainless steel or uPVC), little, or no, corrosion would have occurred and it is unlikely the groundwater quality by itself would have been of such poor quality, to have caused water point failure, although the natural iron content might have been a constraint on acceptability of the water for domestic use. The combination of the natural groundwater chemistry with slightly low pH and the use of inappropriate GI materials within these conditions are therefore identified as the main cause of failure.

Poor siting and borehole design in relation to the available aquifer resource are also shown to be significant causal factors associated with other symptoms of failure, in conjunction with the low groundwater potential of the aquifer. In half the cases where low yield was reported to have been the main, or contributory, symptom of the water point failure, the borehole design had cased out inflows from the shallow regolith aquifer, reducing borehole performance. Poor construction quality (e.g. repairs re-threading shorted pipes or removing pipes) was also found to be significant contributory factors in many of the water points, reducing the borehole performance further. These factors are found to override deficiencies in WUC capacity to manage and repair the water points (e.g. inability to collect fees, lack of training, and difficulty in accessing external help beyond a handpump mechanic) in the pilot study area. These community management issues identified would, however, be much more significant factors in determining water point functionality in the absence of underlying problems in borehole construction.

Problem statement: borehole handpump failed due to inadequate water quality.
1 Why is the water quality poor? – Because water chemistry is below WHO drinking water guidelines (not just poor aesthetic water quality)
2 Why is water quality below WHO standards – but what parameter? – Corrosion of handpump materials led to very high dissolved iron concentrations
3 Why have handpump materials corroded? – Due to low pH and Eh natural groundwater chemistry and use of inappropriate GI handpump materials
4 Why have inappropriate materials been used? – Due to lack of knowledge in design and construction of supply and cost and availability of alternatives?
5 Why lack of knowledge in design of supply? – Due to absence of supervision by hydrogeologist, or trained engineer in the design-siting-construction process.

Box 1 - Application of the 5 whys RCA approach to data collated

Figure 18 presents the full results from the fieldwork and the causal factors ascertained to be most significant for each of the failed water points. Symptoms of failure are shown across the left hand side of the matrix and a range of possible causal factors are listed across the right hand side of the matrix. The shading of the causal factors indicates the significance of each factor to the main symptom of failure for each of the different water points. The dominant causal factor(s) are coloured (orange, blue and purple) – orange denotes causal factors significant to water quality (taste, appearance, and chemistry); blue denotes factors significant to mechanical operation of the headworks of the pump; purple denotes factors most significant to the yield of the water point. Other factors that were present, but considered less significant in causing failure, are shaded grey.

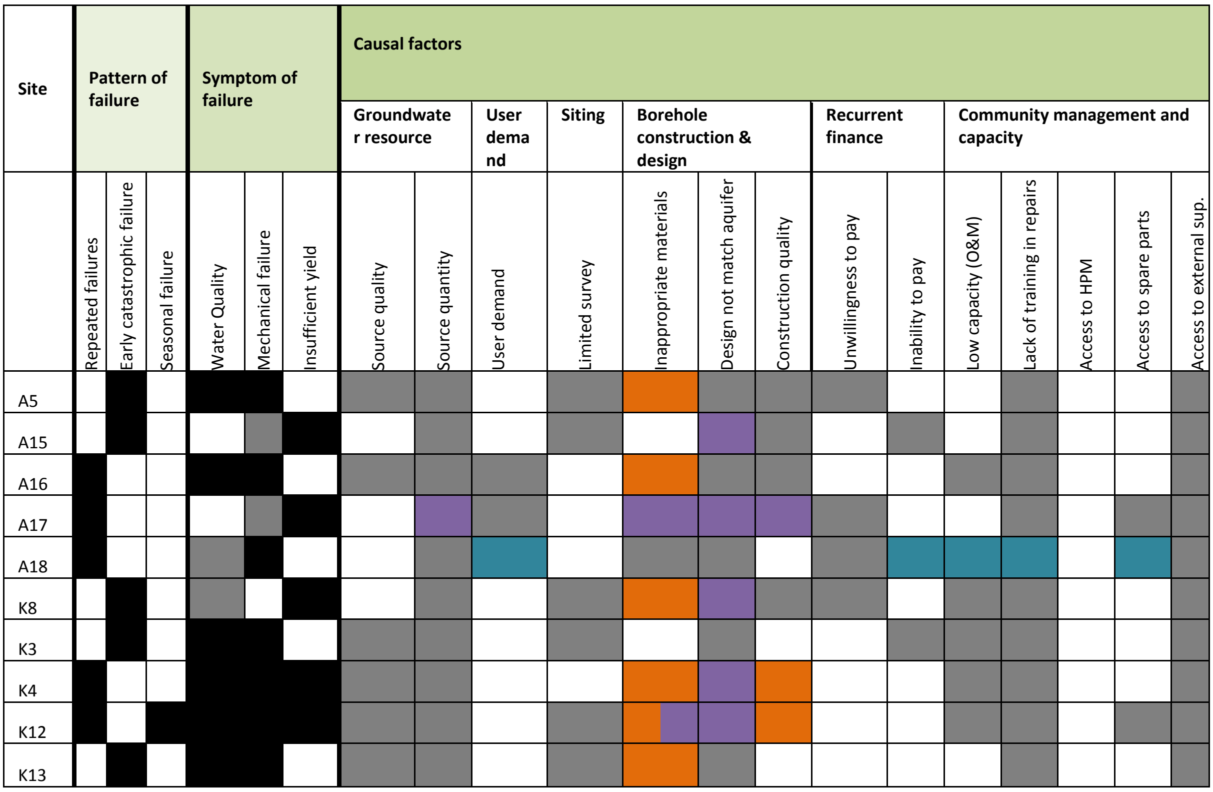


Figure 18 – Symptoms and causes of water point failure in the Amuria and Katakwi districts. The pattern and symptoms of failure are indicated at the left hand side of the table, with causal factors shown on the right hand side. Causal factors thought to be most significant to the failure of that particular water point are coloured – orange shading highlighting causal factors relevant to mechanical corrosion and inadequate water quality; purple, factors relating to insufficient yield; blue, factors significant to mechanical failure of headworks. Cells shaded grey highlight other factors that were present in each case.

Two of the water point failures are discussed in more detail below to illustrate: the level of information which could be collated in the pilot study using the toolbox; and, the level of analysis possible using these data within a matrix and RCA approach.

Water point A17: in contrast to many of the other water points which failed from corrosion and poor water quality, the dominant failure symptom at water point A17 was insufficient yield. A different set, or sequence of, causal factors are apparent at this water point which makes it an interesting case to detail further. Pumping tests indicated the aquifer to have a low transmissivity, but borehole inspection with CCTV also indicated several inflows of groundwater through casing joints from the weathered regolith aquifer which had been entirely cased out. Both low aquifer resource potential, and miss-match of the borehole design to the aquifer were identified as key secondary factors in the failure of water points to provide sufficient yield – Figure 18. It is possible that more appropriate targeting of the borehole design to include screening within the weathered regolith could have increased the yield of the borehole sufficiently. Siting of the borehole in a more productive part of the aquifer might also have achieved a better yield. It was unclear from the community discussions exactly what methods and investigations had been done and by who, to site the water point. Poor siting and water point design are the most likely main factors causing failure.

The limited capacity of the community to undertake repairs and limited access to spare parts, whilst important, are not thought to have directly caused the water point failure in this instance, or be the main factor limiting long-term functionality of the water point – the deficiencies in borehole construction and design serve to undermine the success of any repairs. The data and analysis indicate, therefore, that a low yielding borehole was put into service, severely limiting its subsequent functionality.

Water point A18: presents a different set of causal relationships; mechanical failure of the pumphead being the main symptom. High demand and intensive use of the water point (which served a school) and the pressure this placed on the handpump components, combined with the lack of training and limited management capacity of the WUC to raise finance for repairs, access spare parts or higher-level support, were identified as the main cause of water point failure. In this case, therefore, social and institutional factors, rather than technical problems were the dominant cause of water point failure. Nonetheless, mechanical corrosion of the downhole components of the handpump was also apparent, and is likely to have also contributed to failure, for example by increasing the frequency of repair and hence adding to the difficulties the WUC faced in raising sufficient finance to repair the water point– the community being un*willing,* rather than unable, to pay for repeated cycles of failure and repair of the handpump when other water sources were available in the community.

Deficiencies in different parts of the service delivery chain (planning, construction, sustaining) which contribute to water point failure

Figure 19 presents an alternative presentation of the research results. Here the emphasis is on identifying weaknesses in different stages of the water point delivery chain. A traffic light scorecard approach, similar to that used by the Water and Sanitation Programme (WSP) (2011) in their Country Status Overviews (CSO), is used to assess the status of processes related to 'Pre-construction' of a water point (e.g. the siting processes), 'Construction' (e.g. borehole materials, borehole design) and 'Sustaining' of a water point (e.g. capacity of community management to sustain and repair the water point). Whilst the causal matrix detailed above (Figure 18) is a valuable analytical tool to explore the complexities of water point failure and requires more rigorous scientific investigation to collect the relevant data, the scorecard approach described here (Figure 19) could be of value as a simple and practical tool for everyday use by local experts, decision makers and other sector practictioners (including NGOs and donors) to identify and address key areas of weakness in their water service delivery programmes.

Factors which are of poor status are shown in red (e.g. no active WUC or very weak management); factors which are of moderate status are shown in orange (e.g. WUC present and active but with some capacity constraint); and, factors which are of largely satisfactory status are shown in green (e.g. WUC present, active, and good capacity, adequate training received) – Figure 19. Note that the traffic light scores can be influenced by changes to the descriptive key and scores are somewhat subjective. Certainly the approach would benefit from further testing and adaptation. However, the scorecard does provide some useful insights. Deficiencies in the water point construction process clearly undermine water point functionality within the pilot study area – miss-match of design to local hydrogeological conditions, use of inappropriate materials and poor supervision are the dominant causal factors in this respect (Figure 19). Other problems are also shown to exist within the pre-construction and post-construction stages, although these are likely to be overshadowed by the issues in construction which, are the dominant cause of failure in many of the sites investigated.

Water point	Pre-construction			Construction			Sustaining		
	Process for siting	Community engagement	Demand	Design	Materials	Supervision	Management capacity	Recurrent finance	External support
A5	Red	Amber	Amber	Amber	Red	Red	Amber	Amber	Green
A15	Amber	Amber	Amber	Red	Amber	Red	Amber	Amber	Green
A16	Amber	Amber	Amber	Amber	Red	Amber	Red	Green	Amber
A17	Amber	Green	Green	Red	Red	UKN	Amber	Red	Amber
A18	Green	Amber	Amber	Amber	Red	Red	Red	Amber	Amber
K8	Amber	Red	Amber	Amber	Red	Red	Red	Amber	Red
K3	Amber	Red	Amber	Red	Red	UKN	Red	Red	Red
K4	Green	Green	Amber	Red	Amber	UKN	Amber	Green	Green
K12	Amber	Amber	Amber	Amber	Red	UKN	Amber	Amber	Red
K13	Amber	Green	Green	Red	Amber	Red	Amber	Amber	Red

	Pre-construction	Construction	Sustaining
	Process for siting (level of engagement of community, and use of hydrogeological survey)	**Design**	**WUC management capacity (or alternative management arrangements e.g. by school)**
Red	Siting not informed by a survey.	Borehole design not matched to resource.	No active WUC (or very weak management).
Amber	Siting informed by a survey of some kind but process limited e.g. survey restricted to small area (or one or two sites), or communities not consulted.	Design partially matched to resource.	WUC present and active but with some capacity constraints e.g. lack of adequate training, inability to enforce rules.
Green	Siting informed by a survey of wider village area with community involvement in the process.	Design matched to resource.	WUC present, active and with good capacity. Adequate training received including for maintenance and minor repairs.
	Community engagement	**Materials (adequacy of key components for India Mark 2 pump e.g. pipe and rod length; suitability for local conditions e.g. pipe material in relation to pH of water).**	**Recurrent finance**
Red	No (or very limited) community engagement.	Key components inadequate/unsuitable.	Very difficult to collect sufficient money for minor repairs
Amber	Some engagement e.g. visits by the implementing agency, but the community received little information and have little understanding of the process or their role.	Some components inadequate/unsuitable.	Some difficulty collecting sufficient money for minor repairs.
Green	The community were well informed and were clear on their role in the process.	Components adequate/suitable.	Able to raise funds needed for minor repairs.
	Demand	**Supervision (spot checks are not considered)**	**External support (access to HPM, DWO, spare parts)**
Red	No demand from community.	No supervision.	Limited access to support.
Amber	Demand from community (e.g. written or verbal request) but no monetary contribution to construction costs.	Supervision throughout construction by non-expert.	Some access.
Green	Demand from community and monetary contribution to construction costs.	Supervision throughout construction by expert.	Good access.

Figure 19 – (Top) A traffic light scorecard approach indicating the status of different facets of water pojnt implementation. (Bottom) A descriptive key of how the status of each of the different factors is defined in the Scorecard matrix. Where it was not possible to assess the significance, in the absence of data these cells are marked 'UKN' for unknown.

7.2 Underlying root causes of failure

Poor siting and construction of water points are identified to be the most significant contributory factors in supply failure in the pilot study area. This is a significant finding from the pilot study, as water point non-functionality in this region has traditionally been attributed to inadequacies in community management (both social and financial management facets) and evidence to suggest otherwise was largely anecdotal (MWE, *personal communication*). But what are the 'root causes' which ultimately drive these deficiencies in water point implementation? Why are inappropriate GI materials used in handpumps in the region, when GI materials have been advised against for reasons of corrosion in Eastern Uganda since the 1990s? Why is there often a mis-match between borehole design and the available aquifer? Why are many of the water points sited with limited technical investigation and expertise? Why is there a lack of technical supervision of borehole siting, design and construction? These are key questions which need to be answered to be able to elucidate the underlying root causes of water point failure in the region, and for future WASH investments to be able to deliver sustainable water services. For example, would providing more trained hydrogeologists by the key step to improving water point functionality? Or is improving community access to external support to manage and facilitate repairs a more important building block for improving sustainability, and hence the priority for future WASH investment?

Practices of water point construction

Siting, design and construction all require technical expertise to ensure: the borehole is sited in the most productive part of the aquifer close to the community; the design of the borehole exploits the groundwater resource to best effect; the construction of the borehole actually matches that of the design, and development, testing and completion are actually carried out. Weaknesses in, and disconnects between these different stages of water point construction, due to the absence of trained technical staff (i.e. a hydrogeologist or engineer) supervising water point installation and construction processes, is indicated to be critical in many cases of failure in Amuria and Katakwi.

High demand on water points in Amuria district, Uganda – just one part of the complex set of inter-linked factors lead to water point failure.

Understanding why there is a lack of supervision begins to unearth the deeper underlying causes of the water point failures in the area. The shortage of trained staff, available to supervise water point constructions is one reason. Profit driven incentives within procurement procedures of drillers is indicated to be another key reason. The deficiencies in both of these reflects underlying conditions of entrenched procurement practices within the implementing agencies, key shortages of trained staff, and a lack of knowledge of the importance of both of these factors to the success of a water point.

Siting and drilling of new borehole supplies are procured at district level in Amuria and Katawi. The typical procurement procedure is for drillers to be paid a lump sum per number of boreholes which yield water. Under these procurement incentives, rapid drilling and poor quality completion of boreholes is much more likely, which may result in common construction issues, such as: poor design of screening (and therein ingress of silt to the pump later), inappropriate borehole design for the aquifer (there being no hydrogeological or engineer present to modify the drillers construction procedure based on the information ascertained about the aquifer during drilling), or, lack of gravel packs. Procurement procedures wherein drillers are paid by a daily rate or bill of quantities – i.e. by the number of metres drilled, or number of hours spent cleaning and completing the borehole – are generally found to be generate higher quality construction of boreholes.

Due to lack of trained hydrogeologists, and also the knowledge amongst implementing agencies of the importance of the siting of water points, to their long-term success, drillers often undertake both the siting and surveying of a new water point in Katawki and Amuria, as well as the drilling and construction of the water point.

Future research needs to include a broader multi-level institutional analysis and further data collection in a range of different contexts to explore these underlying conditions in more detail and allow more founded conclusions to be made regarding causal relationships.

Community management models

Deficiencies in siting and construction of supplies are identified to undermine the ability of communities to manage and sustain water point functionality. However, significant deficiencies in the capacity of the community management arrangements to sustain and manage the water points were still present in the pilot study. Had the issues in borehole construction not been present, these deficiencies in community management are likely to have significantly impacted on water point sustainability.

All of the community WUCs reported limited, or no, training in repairs, several had difficulty in raising sufficient finance for repairs (in some cases due to users being unwilling to pay as a result of repeated failures and repairs), and all had limited or no access (i.e. immediate communication pathway) to external help beyond a HPM – there was little evidence of assistance from District Water Offices (DWOs) or sub-country level experts. Many communities had attempted to report their problems to the DWO, another higher authority or an NGO but only a few had received any response. Significant repairs or rehabilitation of a water point are therefore not possible, after repeated cycles of failure and repairs facilitated by a HPM. On the basis of the data collected through the rapid community surveys in the pilot study, and given the nature of our sample, it is difficult to ascertain which of these different factors (lack of training, problems raising finance, and weak external support) is most significant in hindering maintenance and repairs, or to delve into the underlying causes. For example, do problems lie predominantly within the community or WUC (e.g. tensions, fractions, disagreement), or does the issue lay with factors beyond the control of the community – i.e. due to disconnects in the chain of communication between community WUCs and DWOs, or NGO officers and thereby, little or no access to sub-country help? If the lack of access to external support is due to disconnects in communication chains, this indicates an assumption within governing and implementing agencies that community management capacity is greater than it is, and there is therefore an overreliance on the community management model to sustain water point functionality. Studies which have investigated both local-scale and external management structures have found external support and policy to be as significant as community-management models in determining failure (Jansz 2011).

It is unclear if different training of the community WUC would increase the ability of communities to access external support, or if different community management structures beyond WUCs are needed? Are WUCs uncertain of their role, and in accessing external support? What expertise is most needed in external support (technical/managerial/financial)? Answering these questions is vital to be able to develop improved water point sustainability in the future.

Lack of knowledge of water point failure to inform better practice and policy

Without a robust evidence base to determine the main factors causing water point non-functionality, it is very difficult, if not impossible, for implementing agencies and government bodies to develop and adopt new construction and procurement practices and improve institutional arrangements to improve water point functionality and support community management. The need for better hydrogeological knowledge to inform construction practices was highlighted by the Directorate of Water Development and the Directorate of Water Resource Management of the Ministry of Water and Environment (MWE) at the outset of the pilot study, and in longer ongoing discussions within the WaterAid Uganda programme in recent years. There is also a critical need for better knowledge within local and national government of how local communities function, and how they relate and interact with higher-level institutions to manage, finance or repair their water services, and how these interactions and social and institutional processes affect sustainability of community water services.

The results of the pilot study highlight the importance of a robust evidence base for understanding water point failure and developing appropriate policy and practices to improve service sustainability. Traditionally, poor community management capacity has been thought as the main causes of water point failure in Amuria and Katakwi Districts. Ad-hoc observations have challenged this and highlighted poor construction and implementation practices to be significant also, but in the absence of a robust evidence base the MWE have been unable to ascertain the relative significance of these factors. The results of the pilot study begin to provide this robust evidence base, and the results and the depth of the post-construction audit carried out by the field methodology developed have been well received by the MWE. Consequently, the Ministry is keen for expansion of the study to support the development of new policy and practice. In the light of the dominance of mechanical breakdown due to corrosion in water point failure in the pilot study, the MWE would also like to see the Uganda Bureau of Standards brought in to the discussion and to play an active role in the regulation of material quality.

This uptake and engagement with the research at a national government level (discussed in more detail in Section 7) indicates the need for developing a robust evidence base to ensure improved water point functionality and access to services in the future.

8. Dissemination and uptake of the research

The project engaged from the outset with national Government, local government, local NGOs and practitioners, as well as the communities dependent on failing supplies. This was facilitated through WaterAid Uganda's country partners and contacts in Uganda. A number of stakeholder workshops were conducted in Uganda, hosted by WaterAid. Several meetings were held throughout the project with the Directorate of Water Development and the Directorate of Water Resource Management from the Ministry of Water and Environment in Uganda. Results of the research were presented to the Directorate of Water Development in September 2014 and were well received, prompting an invitation from the Director of DWD to the research team to present at the DWD annual meeting and at the national annual meeting of District Water Officers from every district in Uganda (September 2014). The Director of DWD felt that this would be useful to help form a clear position on how to tackle the issues identified. The results were well received at both of these fora, sparking focused exchanges on the challenges faced by water source failure and possible ways forward. The UPGro findings were well circulated and embedded within the 2014 Sector Performance Report.

Overall, feedback from the Ministry of Water and Environment is that the research findings are valuable and support ad-hoc observations they have already made. They observe that users are usually blamed for water source failure for social/financial reasons but the UPGro research also highlights the role of other factors such as those arising from poor project implementation. They would like the District Water Officers and regional Technical Support Units to take up the issues emerging from the research and find ways forward. The MWE expressed concern that the investment that goes into a borehole can be completely wasted if a pump pedestal is installed incorrectly or if inappropriate materials such as corrosion prone galvanised iron are used in pump installation. They want more evidence to support the case for moving away from use of galvanised iron in boreholes and felt this research coupled with the water quality analysis carried out by WaterAid greatly added to this case. The challenge is to create demand for alternative materials nationally. The use of stainless steel in boreholes (rather than GI) may add a cost of 2 million UGX (700 USD) in each case. The Directorate did not feel that this was prohibitive and was a price worth paying for longevity of service.

The project engaged with communities dependent on failing water points as well as national and local government

The Ministry wish to embark upon more detailed investigations of the causes of water source failure across a greater number of districts and see an expanded UPGro II project as a suitable vehicle for this to be realised. Critically, they would like to see the Uganda Bureau of Standards playing an active role in the regulation of material quality.

9. Lessons learnt from applying the toolbox

The overall aim of this UPGro catalyst grant was to develop a robust methodology which could be replicated by wider research to develop a systematic evidence base for understanding the underlying root causes of failures in groundwater-based water supply in sub-Saharan Africa. To test the toolbox methodology developed, a pilot study was conducted in Eastern Uganda as has been described in this report. An important part of this process has been to assess and review the toolbox approach for future improvement. A critique of the approach is now provided below based on the experience of implementing the methodology in the pilot study, and the analysis which was facilitated by the data generated.

9.1 Overview

Overall, the approach and methods used in the catalyst project have been shown to make a significant step to developing a replicable and robust methodology which can be used to generate a systematic evidence base for water supply failure. The work has:

- gone a significant way to encapsulating the complexity of the interlinked aspects of the problem, balancing the natural science and engineering ("technical") aspects of the research with those concerning the ability of communities to manage and maintain their water points (the "social" aspects). The multiplicity of interlinked causes of water point failure was explicitly acknowledged and taken into account through the use of multi-disciplinary field and analytical methods within the toolbox and research team.
- the study was firmly rooted in the realities on the ground, in communities and (literally) in the boreholes on which communities depend for their water point. The methods of investigation used were highly practical and appropriate to the information sought. This was not a theoretical study, nor one which was highly reliant on modelling, but was based on detailed observational science.

Despite the improvements to be made to the methodology of the catalyst project discussed below, the data collated by applying the toolbox and the diagnostic framework approach in the pilot study, have enabled a clear insight to the importance of corrosion, poor siting and poor supervision of contractors to water point failures in the area, against a backdrop of weak institutional support and inappropriate practices of implementers.

The key lessons learnt from the study approach and methods will need to be addressed in future research on this topic, and are discussed below. Some of these were due to the limited time and scope of the catalyst project, and were known from the outset of the research; others are more fundamental and have been realised through the work and the results of the catalyst grant.

9.2 Key lessons

Scope of the study

Due to the limited time and scope given by the one-year catalyst grant, the study focused on information gathered from and about the community, and on the attributes of the water point itself. Therefore, the study was subject to several limitations which would need to be addressed in future studies.

i. The methodology did not explicitly investigate the role and actions of local or national Government, although many members of the research team have sound understanding of this important aspect. The limited ability of local Government to act in support of community management is well-known, as the GoU Community-Based Maintenance System (CBMS) permits only very meagre resources to be devoted to this task.
ii. The surveys did not explicitly include the perspectives of private sector handpump mechanics (HPMs) in the study, and our understanding of their role and actions were based primarily on

information provided by the communities (and to some extent, prior knowledge of the researchers and local partners). The HPM are the first line of support to WUCs when assistance is needed with handpump repairs.

Sampling bias was generated in the pilot study results, by the study explicitly examining only borehole-handpump water points which had been abandoned for several months. Those which were temporarily out of action pending repair were not included. While this approach was taken for practical reasons, it has limited the insights our data can provide regarding the full range of 'failure types'. For example, community management capacity and other non-technical factors may have been found to be more significant determinants of non-functionality in a sample characterised by 'repeated' or 'temporary' failure rather than in the one-off catastrophic terminal failures examined in the pilot study that had been abandoned for several months.

As some of the water points were quite old, siting reports, construction records, test pumping or water quality data were not readily accessible. As a consequence the information gathered from communities about aspects such as siting, WUC training and supervision of construction could not be cross-checked.

iii. Importantly, the community surveys were focused heavily on examining the effectiveness and capacity of WUCs, and it did not include other, wider community management arrangements which may exist. There was also no higher-level analysis of wider institutional arrangements. Recent work by Pahl-Wostl et al. (2011) and Cleaver (2012) have found that *polycentric* community management arrangements often exist, and are highly significant to the capacity of communities to sustain water point functionality. There is, therefore, a need to widen the analytical scope of the methodology beyond the WUC.

vi. The study involved a single 'snapshot' at the end of the dry season. Seasonal changes in water levels, yields and water quality and temporal variations in the significance of different causes of failure could not be examined in the study. The community surveys also relied heavily on a single visit to each village of 2-3 hours, so there were limited opportunities to follow up outstanding issues, or speak to different sub-groups within the community to establish whether the data were representative.

For logistical reasons the work took place in two neighbouring districts of one country. A greater diversity and number of field sites would have been preferable. This would be possible with the same methodology, within a wider research programme, and is not a limitation *per se* of the project method.

Field methods

The field investigations were conducted in two discrete phases: one undertaking the community surveys, which involved a 2-3 hour group discussion with community members and the water user committee; the second phase undertaking the technical investigations at each water point. This was found to be an effective and efficient means of carrying out the fieldwork, allowing sufficient time for the project team to review the data collected in each phase and make decisions against agreed criteria on where the subsequent phase would focus. Working with local communities through the local NGOs partners and the WaterAid programme was very effective in facilitating the fieldwork and gaining trust from the communities to examine the water points.

The methods of the technical investigations were successful in generating a comprehensive post-construction audit. There were, however, some mixed results in the effectiveness of some of the individual methods of the downhole investigations. Some form of yield test is essential, and our experience was that bailer tests were generally more useful than conventional pumping tests, although where the latter were possible, they should be carried out. In the low productivity crystalline basement aquifer, which characterised the pilot study area, the aquifer permeability was often too low to support a conventional pumping test – and the pump available to the field team had a relatively high fixed discharge rate (0.5 l/s).

Bailer tests were found to be very useful in these conditions and provided a reliable proxy estimate of aquifer permeability. CCTV inspection was found to be best used at the end of a pumping test of purging of the boreholes, so that clear images of the borehole construction and any inflows could be obtained. The use of dissolved anthropogenic gas was found to be very useful technique, in conjunction with the CCTV surveys, to gain a better understanding of the main sources of shallow groundwater (inflows from the regolith versus deeper underlying bedrock) into the boreholes, based on their design.

The range of investigations and number of organisations involved in the fieldwork meant that in both phases of fieldwork the field teams were relatively large (e.g. in phase 1, translators, surveyors, NGO local partners were all required; in phase 2, hydrogeologists, handpump mechanic, translators, NGO partners and generator operators were demanded. A more efficient approach in future could be achieved by smaller teams (3-4 people), who are skilled in several aspects of the investigations.

The absence for many of the sites of construction records precluded comparison of some of the findings of the technical investigations (borehole depths, yields, groundwater levels, regolith thickness) with equivalent data at the time of drilling and any deterioration in these over time could not be assessed.

Conceptual diagnostic framework

The study set out to investigate methods to determine why water points (specifically boreholes with handpumps) fail. The science, philosophy and logic of causation is a major field of research in itself, and at the outset it was not clear which approach or approaches would be most suitable for the study. We considered several different root cause analytical approaches which are used in medical diagnosis, and others which are used in accident investigations and management studies.

The shape and structure of the relationship between cause(s) and effect (the failure of a water point) is not yet firmly established. Is there a chain of contributory factors, the failure of any one of which means that the chain breaks? Or is the analogy of a bicycle or a motor car more pertinent – in which forward motion is possible as long as certain conditions are fulfilled (tyres inflated, motive power working), but other appurtenances (e.g. bicycle bell, car windscreen wipers) are less critical?

As discussed above, there is a known bias in our results due to the site selection process which shifts us towards terminal failures rather than sources that are brought back into service. A positive outcome here is that there has been an in depth analysis of the drivers of terminal failure which in this case would seem to indicate that some of the user related social aspects are less influential whereas the actions (or inactions) of implementers and institutions are more influential. This is a significant result, and one which the DWD of MWE of Uganda has also found significant.

Future research

The pilot study and methodology recognize the inter-disciplinary nature of the research issues, and that many contributory factors are interlinked in complex ways. However, the methodology of the pilot study remains multi-disciplinary, and does not undertake truly inter-disciplinary analysis of the research data. Future research will need to employ inter-disciplinary analysis methods, and also widen the field data collation to a wider array of the institutional, financial and governance arrangements which determine service provision.

Future research also needs to reflect the roles of all players – national Government, local Government, development partners, private sector, civil society and communities – in defining the human and institutional dimensions of the problem. Long-term trends in the natural groundwater resource, through changes in recharge, or demand also need to be examined, to fully understanding long-term sustainability of rural water supplies.

10. Future research

10.1 Key knowledge gaps

The work undertaken with this UPGro catalyst grant has gone a significant way to developing a methodology and framework with which the causes of water point failure (specifically boreholes with handpumps) can be examined, and the tools required to gather the necessary data. Analysing the data collected in the pilot study has enabled a much more thorough investigation within the Amuria and Katakwi districts of why systems fail, and the framework developed is transferrable and could be incorporated into other functionality studies and post-construction audits to generate a much wider understanding and in-depth dataset to determine why water points fail in other areas.

The results of the pilot study, and the efforts to analyse the data and identify underlying causes of water supply failure, have also highlighted several key gaps in the data and the research approach and toolbox, where more focused investigations, particularly in relation to investigation the wider governance and management arrangements surrounding water point functionality, is required to fully understand the underlying 'root causes' of failure:

- The results of the pilot study identified that nearly all of the communities had difficulty in accessing external support (e.g. DWO) to maintain and operate a sustainable water point. A better understanding of the wider institutional arrangements and how these are accessible to communities or WUC is needed in future research. For example, what direct external support is there in place from local Government, NGOs and the private sector; how is this support structured, and through what arrangements is it accessible to the community WUCs? Is access to external support more important to long-term functionality of supplies than the capacity and training of community WUCs? What expertise is most needed in external support (technical/managerial/financial)? Would greater access to private investment benefit community management capacity? What other community management structures exist away from the WUC?
- A better understanding of the processes by which supplies are sited, and the individuals and organisations involved – who commissions siting of new supplies, and the procurement of drilling and installation of supplies? What forms of communication exist between individuals in the siting process and construction process?
- The hydrogeology of the crystalline Basement Complex was variable within the Amuria and Katakwi districts – in some cases significant shallow inflows of water were shown coming into the boreholes from the weathered overburden by the CCTV surveys, rather than being supported by deeper flow at the base of the weathered zone. A more detailed understanding of how the aquifer properties vary between the overburden and underlying bedrock aquifer is needed to indicate how important matching the borehole design to the local variations in aquifer horizons is to the borehole yield and in ensuring long-term sustainability.
- Has long term recharge or demand changed the groundwater resources in the Amuria and Katakwi area? Little or no information was collected on these issues in the pilot study, but these are key factors to fully understanding the sustainability of groundwater-based water supply over the long-term.

10.2 UPGro Consortium grant proposal

A larger research consortium was developed within this UPGro catalyst grant, and submitted to the UPGro Consortium Call in June 2014 (Grant proposal NE/M008606/1) - *A hidden crisis: unravelling current failures for future success in rural groundwater supply*. The research proposal is centred on testing the hypothesis *"The underlying causes of the rapid failure of approximately a third of African rural groundwater sources are complex and multifaceted, but with interdisciplinary approaches can be understood, diagnosed, and ultimately anticipated and mitigated."*

The overall aim is to develop a robust, multi-country evidence base on water supply failure, and to develop the methodology of the research to be fully inter-disciplinary, extending the research and field methods to investigate some of the more nuanced questions about why water points fail, including a much fuller exploration of the local and wider institutional arrangements surrounding service delivery, the relative significance of these factors in determining failure, and the implications of long-term and seasonal trends in climate and demand pressures for sustainability of rural water supply. The project aims to deliver recommendations for diagnosing existing problems in country programmes, and for developing policy and practice to mitigate risks – overall, developing a 'critical public knowledge' of supply failure in Africa.

The research represents a more substantial and larger-scale investigation of supply failure in sub-Saharan Africa, which will be undertaken in three countries – Ethiopia, Malawi and Uganda –investigating supply failure in a range of governance environments and a range of groundwater resources, climate and demand pressures. The research team is composed of a wider consortium of leading researchers and practitioners in water governance, hydrogeology, systems engineering and groundwater recharge from the UK, Australia and Africa and three WaterAid country programmes.

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Appendix 1 – Community Survey form

The community survey form used within the pilot study is shown on the next page.

The social assessment (or community survey) is designed as a semi-structured focus-group discussion (FGD) with the Water User Committee (WUC) and other water users, with follow-up interviews where necessary. It is important to ensure that women are represented in the FGD as women are usually the ones responsible for water collection. The interviewer should encourage responses from both men and women. However, if the conversation is unavoidably male-dominant we may need to speak separately to women users. An ideal group size would be 8-10 to ensure participation from all, accepting that others may join the group without invitation to observe.

The survey is designed to take 1.5 - 2 hours. Flexibility will be important to allow time to probe the important questions and conduct follow-up interviews if necessary. The survey is structured in four sections: 1) basic information, 2) water sources and use, 3) borehole history and performance, and 4) borehole management and sustainability. Each section consists of key questions based with a checklist/set of probing questions to supplement. **There are 10 questions in total**, but be aware that some questions will take longer than others. Time guides are provided in the survey form. Questions are based on the analytical framework.

It is important to encourage respondents to describe the situation themselves before introducing our own terminology such as 'failure' or 'challenges', or pre-judging the problem. Therefore the key questions are fairly open. The checklist can be used to probe for details (use lots of 'Why? What? When? Where? How?' questions).

The intention is to conduct 18-20 surveys within a 10-11 day period. This will require splitting the field team into two groups on some days, to ensure that we collect sufficient data. Naomi Oates (ODI) will lead on the research, monitor quality and provide support/training to other team members in conducting surveys. WaterAid will lead on team coordination and logistics, conducting borehole inspections and collecting drilling records.

The necessary permissions will be sought from local government, chiefs and village elders prior to the FGD process. Before commencing the FGD the team will need to introduce themselves and the project to the FGD participants. We must be clear on what the project can and can't do – particularly in relation to repairing broken pumps or addressing any other issues identified. This is a research project and the results from the surveys will help to improve water supply services in general, but will not necessarily lead to direct benefits for these particular communities.

The main objectives of the community survey were to:

- Identify the range of water sources used by the local community and gain a basic understanding of usage patterns (which sources are used most/least, for what activities, in which seasons).

- To understand communities' perceptions of:
    - Water availability and water quality for different sources (particularly the borehole), at different times of year.
    - Borehole history and performance.
    - Institutional and financial aspects of community borehole management.
- To identify key social and institutional issues which contribute to borehole failure, and explore how these are linked (causal linkages) to one another and to technical issues.

Unlocking the Potential of Groundwater for the Poor

Community Survey Form

PART 1: BASIC INFORMATION[1]	
Date:	**Site reference number:**
Researcher:	**Facilitator:**
Village:	**District:**
Parish:	**GPS Coordinates:**
Photo number(s):	
Community representative / key contact *(name & number):*	
Participants in meeting: *Total:* *Female:* *Male:* *Names & role on WUA (if relevant):*	

[1] Complete this 'basic information' before arriving at the site, where possible.

PART 2: WATER SOURCES & USE (25 - 30 minutes for this section)

1. What water sources are available to the community? (5mins) *<u>Checklist for probing:</u>* - *Consider all sources types: rivers, protected & unprotected springs, shallow wells, ponds,seasonal pools, boreholes, rainwater harvesting, etc.* - *Do some households have private water sources?* - *Which of these sources are used most and why?* - *Are communal sources open access (available to all)? If there are restrictions, what are they? Are specific people or activities not allowed? Does it depend on the season?* - *Are people charged for the water? How much?* - *How far away are these sources (distance)?*		
Source type *(in order of importance)*	**Average distance** *(big seasonal differences?)*	**Notes** (restrictions, costs/charges)

2. Which sources do you use when, for what, and why? (15mins including calendar)

Once you have identified the main sources, complete the seasonal calendar. You don't have to include all the water sources in the calendar – just the most important ones. Include the borehole if it is partly-functioning or was functioning fairly recently.

Most of the information can be captured in the calendar. Use appropriate terminology for different times of year e.g. seasons. You can than match this to months in the calendar (short rains April-May, long rains Sept-Nov).

Checklist for calendar:
- *When is this source used? Why is a source used or not used at certain times of year?*
- *How do collection times vary seasonally (travel to/from source + queueing)?*
- *Does water quality vary seasonally?*
- *What is the water used for e.g. drinking, cooking, washing, laundry, irrigation, brick-making, cattle watering?*
- *How much is collected from this source per household per day?*
- *Roughly how much of this is used for each activity?*

Consider:
- *Does water availability in different sources vary seasonally e.g. do some sources dry up?*
- *Are there noticeable differences in quality and availability between different sources?*
- *If the borehole was functioning properly, how would things change? What would you use it for? Would it be your main water source?*

Notes:

UP Gro Unlocking the Potential of Groundwater for the Poor

Site Reference:

Seasonal calendar (indicate approx. volumes used for each activity – jerry cans are roughly 20litres):

		x	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Source 1	Source used ?													
	Collection time													
	Quality													
	Drinking & cooking													
	Washing & laundry													
	Irrigation													
	Livestock													
	Other (specify)													
Source 2	Source used?													
	Collection time													
	Quality													
	Drinking & cooking													
	Washing & laundry													
	Irrigation													
	Livestock													
	Other (specify)													
Source 3	Source used?													
	Collection time													
	Quality													
	Drinking & cooking													
	Washing & laundry													
	Irrigation													
	Livestock													
	Other (specify)													

3. What are the biggest changes you have seen over the last 5 to 10 years? (5-10mins)

Steer the conversation to factors that might shape water use. You can draw a simple timeline below.

Checklist for probing:

- *Drought and flood years? Or other big events (for timeline).*
- *Have any sources have become more or less important in recent years? Why?*
- *Have water uses changed i.e. types of activities and/or volumes used (relates to livelihoods)?*
- *Have water sources changed in the medium-term (availability and quality) i.e. not seasonal or droughts, but longer-term trends?*
- *How big is the community (population/no. of households)?*
- *Has the population changed (size or composition)?*
- *Are there any seasonal or annual fluctuations in population e.g. due to short-term migration?*

Notes:

PART 3: BOREHOLE HISTORY & PERFORMANCE (30-40 minutes for this section)

First ask the community to relate the 'story of the borehole' including pre-construction, construction and post-construction phases. You can then probe for details using the questions & checklists below.

PRE-CONSTRUCTION

4. How was it decided to build the borehole? What happened in terms or planning and preparation activities? (5-10mins)

Checklist for probing:

- *How was the need for the borehole identified? Was there demand from community?*
- *Was there community involvement in meetings to discuss service options?*
- *What other water supply options were considered? Why was the borehole preferred?*
- *How was the site selected? By who?*
- *Was there involvement of community in meetings to discuss borehole location, contribution arrangements, ability and willingness to pay?*
- *When was the WUC establishment & did they have a role at this stage?*
- *Was there an MoU between the community & project implementer? Were roles and responsibilities clearly outlined beforehand?*

Notes:

CONSTRUCTION

5. What happened during construction? (5mins)

Checklist for probing:

- *When was the borehole built (year & season)?*
- *Who built it? Who was supervising? Was anyone else involved? What was their role?*
- *Who contributed what e.g. finances, labour, materials?*
- *Was the borehole built properly e.g. the right design, materials, and location?*
- *Were there any problems during construction?*

Notes:

POST-CONSTRUCTION

6. How has the borehole performed since it was built? How is it currently performing? (15-20mins)

Most of the information on water quality & quantity should have been picked up in Section 2. This is an opportunity to probe for further details, particularly on breakdown & repairs. Use the analytical framework to assist you (Annex 1 – causal link diagram).

Checklist for probing:

- *What is the current status of the borehole? How long has it been non/partially functional?*
- *What is the cause of the current problem? Can it be repaired?*
- *Water quality (ask about now and in the past): Does the water taste or smell bad? Is the water clear? Are there seasonal differences? Any other problems with quality?*
- *Water quantity (ask about now and in the past): Is it enough to meet demand? Are yields unusually low? Are there long queues? Is water available throughout the year? Is it easy to pump? Is there any need to rest pump e.g. after heavy use, or at certain times of year?*
- *What is the frequency of breakdown? (Think about the pattern: Is there a cycle of breakdown & repair, or on-going deterioration, or permanent problems e.g. due to poor construction?)*

Ask for details of previous breakdowns & repairs:

- *When did the borehole break down?*
- *What was the problem(s)?*
- *How was the problem identified? Who reported the problem, to who and when?*
- *What action was taken, by whom?*
- *How easy was it to get a hand pump mechanic or other expert?*
- *Were there any problems with the repair e.g. did the hand pump mechanic have to return again?*
- *How long between breakdown & repair?*
- *What was the impact on the community?*
- *To what extent was the community capable of dealing with the problem(s)?*
- *To what extent is location a problem e.g. distance from road?*
- *To what extent is failure correlated with drought/flood years?*

Notes:

PART 4: MANAGEMENT & SUSTAINABILITY (35-45mins for this section)

7. What are the responsibilities of the Water User Committee? (5-10mins)

Checklist for probing:

- *Committee member roles? Who does what?*
- *What are the day-to-day activities for managing & maintaining the borehole (maintenance teams)?*
- *How often does the Water User Committee meet? And the Water User Association as a whole?*
- *How many members are there? Is everyone in the community a member? If not, why not?*

Notes:

8. What are the rules of the WUA? How are they enforced? (10mins)

Checklist for probing:

- *Rules governing water access and allocation: Who can take water, for what uses, how much, when (time of day/season)?*
- *Who participates in operation & maintenance? Who does what? Exceptions?*
- *Who enforces these rules? What do you do if someone breaks the rules? Is this common?*
- *Challenges faced in these enforcing rules?*
- *Are there any informal rules or agreements e.g. to cover gaps in formal rules?*

9. How does the WUA obtain, manage and utilise funds? (10-15mins)

Try to work out roughly how much money the WUC should have collected based on: no. of years since borehole construction x no. of users x tariff. Compare this to the account balance & expenditure. There is likely to be a shortfall – question why. Compare also to estimates or maintenance costs[2]. Think about ability & willingness to pay.

Checklist for probing:

- *What are the arrangements for managing funds? Who is responsible? Are records kept?*
- *Is there a tariff? Has there always been i.e. since borehole constructed?*
- *How much should members pay? How many members are there (is it the whole community)?*
- *What are the rules for contributions e.g. are there exceptions?*
- *How much money is actually collected from members? Are there other income sources?*
- *How much is currently in the account?*
- *How much has been spent so far, and on what?*
- *Are funds sufficient?*
- *Why is there a shortfall i.e. what are the problems with collecting money?*
- *Can people afford to pay? What happens if rainfall/harvests fail (or other livelihood shocks)?*
- *Were community told how much it would cost to maintain the borehole?*

[2] For example, WASHCost estimates that borehole with handpump maintaiance costs USD 3-6 per year (UGX 7,655 – 15,310).

10. Do you receive any support from hand-pump mechanics, sub-county, district, NGOs? (5-10mins)

Checklist for probing:

- *Who supports you, to do what? What kind of support e.g. technical, financial?*
- *Arrangements for maintenance & repairs: Who does the repairs? Do they have the right skills? Are they available when you need them?*
- *Are spare parts available? How do you get them?*
- *What are (or should be) the responsibilities of hand pump mechanic, sub-county, district, NGOs?*
- *What training have you received? Who was trained? When? Topic? Was it sufficient?*

Optional extra (if time): What do you think could be done, and by who, to improve sustainability of water supplies in your community?

Summary

This table can be used by the field team <u>after</u> each site visit to give a quick overview of the key issues raised in the community survey. Note that this scoring is highly subjective and its use for analysis may therefore be limited.

Please tick the appropriate boxes based on the team's perception of the issues.

	Yes	**Maybe (or to some extent)**	**No (this is an issue)**
When the pump is working, the borehole can provide enough water to meet demand.			
The quality of the water is generally good.			
Borehole design and/or construction was good.			
The pump works well and does not break often.			
The borehole is accessible for most or all of the users (it is not too far away, and everyone can use it).			
The community was consulted during the pre-construction phase and participated in planning meetings.			
The WUC is strong and able to enforce rules for water access/use.			
Operation and maintenance is affordable for the community.			
The WUC has a good system for operation and maintenance. Breakdowns are reported quickly and mechanics are available when needed.			
The community receives adequate external support when needed.			
The community has an incentive to maintain the borehole because alternative water sources are not adequate.			
Other (please specify):			

Tips for semi-structured interviews (or FGDs)

Source: Adapted from Trainer's Guide to HEA, FEG Consulting & SC UK (2007)

1. Introductions

Always explain carefully the purpose of your visit to avoid raising expectations and misleading people.

1. *Welcome the participants* to the interview and thank them for coming.
2. *Explain carefully* that you are not part of an official delegation or mission (although DWOs may be present to observe), but that you have come to try and understand better the real situation of local people.
3. *Explain the objective of your visit:*
    - You have come to understand better the water services available to the community and how they are used, and to understand better the problems relating to the borehole.
    - This information may feed into the planning of future water services in this district, but is intended to be used more widely to better understand problems with boreholes.
    - Our visit is not linked to any intervention in the short term.
    - Our research in this community will not have any (negative) impact of future assistance given to the area, so please be free to speak.

4. *Give an overview of how the FDG will work (you don't need to give details):*
    - There are 4 sections on: basic information, water sources and use, borehole history and performance, and managing the borehole.
    - We have some questions to guide the discussion.
    - We are interested in your views/opinions, and would like to give opportunity for everyone to speak (but we should also try to keep to time).
    - The interview will take 1.5 – 2 hours.

Other tips:

- Never make any promises of assistance to the community.
- Put the group at ease by chatting informally before the start of the FGD.
- Make sure participants are comforatable with the seating arrangements, as this can affect the atmosphere of the interview.

2. Interviewing techniques

What is a semi-structured interview?

Semi-structured interviews are guided interviews. The interviewer knows the kind of information they want to obtain, but the questions are quite open and the structure is flexible and informal. Instead of a list of precise questions, there are guides for probing. The guide/checklist should be used as an aid, rather than a questionnaire. The interview should be more like a conversation.

DO

- Make project objectives clear
- Manage expectations (we are not promising to fix boreholes)
- Make sure participation in the discussion is balanced
- Follow the format
- Probe for details using the checklists provided
- Use 'What? Where? Why? When? How? What do you mean?' etc
- Cross-check information, and think about the reliability of different information
- Do quick calculations during the interview e.g. comparing repair costs to fees charged
- Keep a note of questions to go back to later in the discussion
- Manage your time well
- Be aware of group dynamics

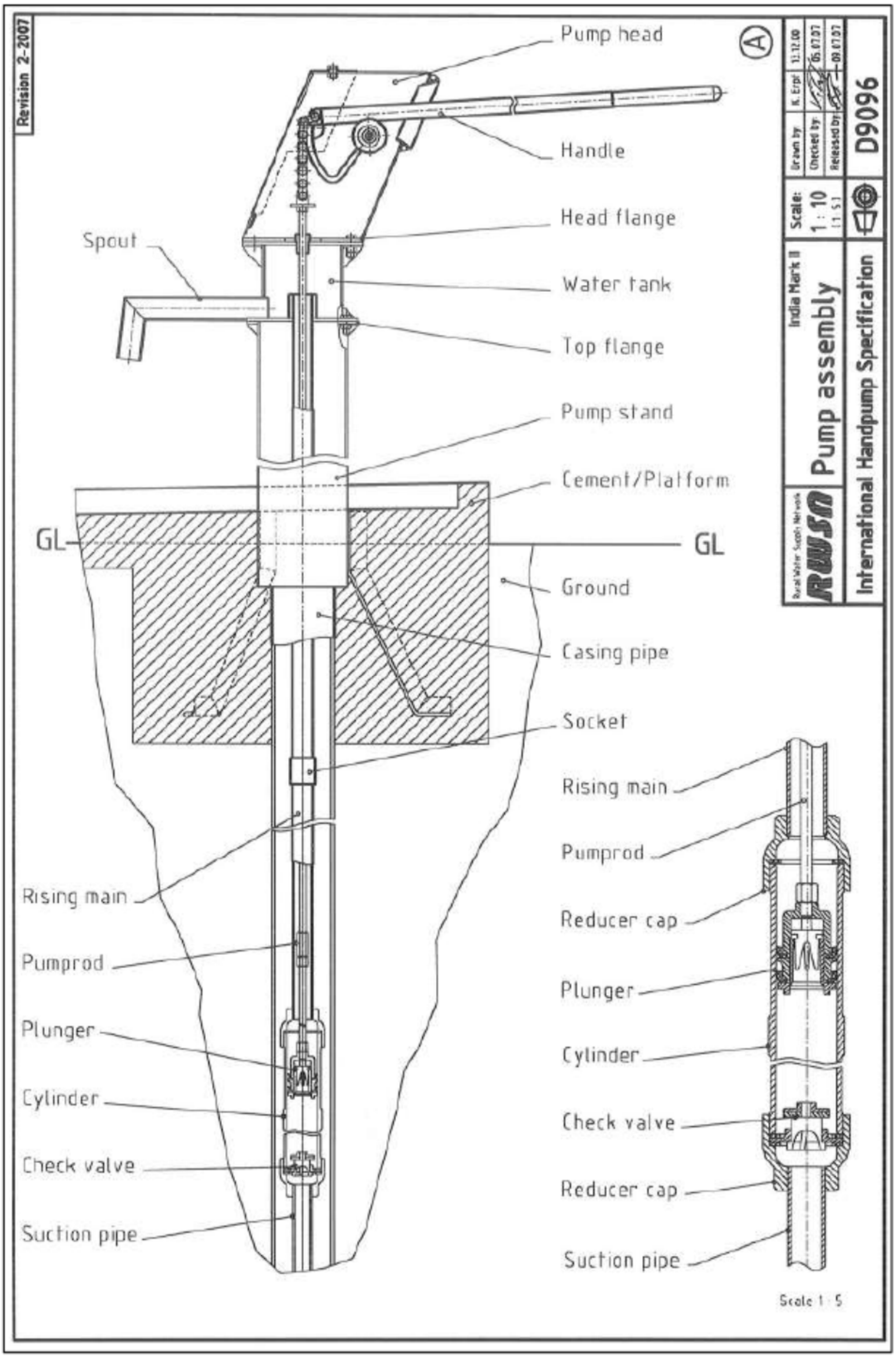
DON'T

- Assume you know the answers, or give your own opinion (you should be neutral)
- Accept the first answer (you must probe)
- Ask leading questions e.g. questions with a yes/no answer
- Provide answers if there is hesitation

- Indicate disbelief by criticising or even smiling
- Interrupt informants or each other (although if someone is dominating the discussion, politely ask them to finish their point to allow others to speak)
- Use the checklist like a questionnaire
- Miss the broader picture by spending too much time on detail
- Ask more than one question at once
- Ask sensitive information in front of the group

General tips for semi-structured interviews
➢ **Follow the format**.
➢ **Finish enquiries into one topic** before moving on to the next. But also follow the flow of the conversation, keeping a track of leads, so that you can follow these up later.
➢ **Ask follow-up questions**. The next question should often follow on from the answer to the previous question.
➢ **Only ask questions** to which the interviewee can be expected to know the answer.
➢ **Keep track of the story** you are being told. Is it consistent? Clarify inconsistencies.
➢ **Cross-check** as much as possible, both by asking the same question in different ways and by comparing the response of different people. But don't ask the same question over and over again.
➢ If you have time, **use participatory methods** – this can relieve boredom and can ensure everyone's point of view if heard.
➢ **Evaluate the interview** afterwards. How well did it go? Did you think the results were reliable?
➢ As you do more interviews, **identify knowledge gaps** before each interview so that you are particularly alert in seeking answers to those questions.

Appendix 2 – Hand pump construction schematic



Schematic diagram of an India Mark II hand pump (source: RWSN 2007)

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Appendix 3 – sites selected for technical investigations, based on data collected in community surveys, are highlighted in red text, with * indicating key attributes of failure

Source	Site visited in Phase 1	Early catastropic failure	Series of repeated failures	Borehole logs available	Technically recoverable supply	Technically un-recoverable supply	Seasonality in yield	Seosonality in quality	Supply yield poor	Supply water quality poor	Interesting site	Recurrent finance OK	Recurrent finance poor - inability to pay	poor - unwillingness to pay	WUC involved at outset of planning supply	WUC involved at later date	Management unable to enforce rules	Lack of capacity to maintain waterpoint	Siting based on community preference	Siting based on survey preference
Katakwi District																				
K1																				
K2																				
K3		*		*	*					*	*						*		*	
K4			*						*	*	*	*			*					*
K6																				
K8		*			*				*	*	*			*			*			
K9																				
K10																				
K12			*	*			*	*			*	*				*				*
K13		*		*		*					*				*					
K15																				
Amuria District																				
A1		*			*				*		*			*	*					
A2																				
A5																				
A7																				
A8																				
A9																				
A10																				
A14																				
A15		*							*				*		*		*			*
A16			*							*		*				*	*			*
A17			*						*				*	*	*				*	*
A18			*						*	*	*			*		*	*			*
A19																				
A20																				

Appendix 4 – laboratory analysis of inorganic groundwater chemistry

Report Number: 13256/1

British Geological Survey
ANALYSIS REPORT

Report date: 23 April 2014

LIMS Code	Field Temp	Field Eh uc	Field Eh	Field pH	Field HCO_3^-	Field Conductivity	Field DO_2	Ca	Mg	Na	K	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Balance
	°C	mV	mV		mg l^{-1}	µS cm^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	%
Detection Limit								0.3	0.02	0.2	0.02					
13256-0001	27.9	240	436	5.66	43	66.8	3.20	5.0	1.01	7.9	1.63	44.7	0.624	0.052	0.662	-2.48
13256-0002	31.8	83	275	6.58	166	260	2.35	28.1	4.74	16.8	4.62	160	0.808	6.49	<0.03	-2.64
13256-0003	30.3	60	254	6.38	91	146	6.03	14.2	2.83	15.3	3.57	111	0.932	<0.25	<0.15	-3.13
13256-0004	27.9	199	395	7.20	249	366	6.32	30.7	7.28	38.2	4.30	244	1.32	1.76	<0.03	-2.69
13256-0005	26.9	173	370	5.37	115	201	n/a	16.4	5.36	15.9	2.85	123	1.97	0.156	<0.03	-1.21
13256-0006	27.4	145	342	n/a	n/a	153	5.46	8.7	3.22	9.8	1.92	52.3	7.05	2.10	3.39	8.71
13256-0007	29.4	152	347	n/a	52	119	2.07	67.8	20.2	30.4	8.98	409	4.42	1.81	<0.03	-2.08
13256-0008	29.4	64	259	n/a	393	577	0.22	33.4	12.3	23.5	6.13	240	3.94	1.70	0.258	-2.81
13256-0009	30.2	-15	179	n/a	245	376	1.09	30.3	8.98	17.6	5.25	173	12.0	9.09	0.804	-3.20
13256-0010	31.5	37	229	n/a	188	315	3.99	nr	nr	nr	nr	nr	nr	nr	nr	nr

LIMS Code	Field HCO_3^{2-} Balance	Br^-	NO_2^-	HPO_4^{2-}	F^-	I	NPOC (NPOC split)	NPOC (F/UA Split)	Total P	Total S	Si	SiO_2	Ba	Sr	Mn
	%	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	µg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	µg l^{-1}	µg l^{-1}	µg l^{-1}
Detection Limit						0.06			0.01	1	0.05		0.2	1	0.2
13256-0001	-1.02	<0.01	0.017	<0.01	0.194	4.68	0.592	0.466	0.01	<1	24.0	51.3	78.1	73	78.4
13256-0002	-4.40	<0.01	<0.005	<0.01	0.363	7.47	0.469	1.29	<0.01	2	28.3	60.5	93.0	273	136
13256-0003	6.44	<0.05	<0.025	<0.05	0.198	9.76	0.842	2.38	<0.01	<1	31.1	66.5	570	206	3927
13256-0004	-3.75	<0.01	<0.005	<0.01	1.18	68.7	0.629	1.08	<0.01	<1	29.5	63.0	256	353	736
13256-0005	1.89	<0.01	<0.005	<0.01	0.171	4.07	0.644	0.579	<0.01	<1	27.9	59.8	98.0	168	214
13256-0006	n/a	<0.1	<0.05	<0.1	0.087	6.06	2.37	17.7	0.03	<1	27.5	58.9	63.1	90	17.3
13256-0007	72.71	0.02	<0.005	<0.01	0.690	31.7	0.492	1.70	<0.01	<1	28.9	61.9	419	581	180
13256-0008	-26.12	0.015	<0.005	<0.01	0.263	14.9	0.517	5.34	<0.01	<1	26.5	56.7	172	272	212
13256-0009	-17.86	0.055	<0.025	<0.05	0.295	12.0	0.779	0.995	<0.01	1	23.6	50.5	100	235	112
13256-0010	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr

LIMS Code	Total Fe	Li	Be	B	Al	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	As	Se	Rb
	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$
Detection Limit	1	1	0.01	10	1	0.05	0.1	0.05	0.01	0.1	0.4	0.5	0.5	0.02	0.1	0.01
13256-0001	272	4	0.03	<10	149	6.91	1.6	0.10	0.92	1.8	2.9	59.1	<0.5	0.03	<0.1	0.41
13256-0002	20	4	<0.01	<10	<1	0.07	1.0	<0.05	0.62	2.7	0.9	417	<0.5	0.05	<0.1	0.88
13256-0003	652	2	0.09	<10	1847	28.3	1.8	0.69	9.99	5.0	2.2	113	0.6	0.12	<0.1	2.31
13256-0004	29	4	<0.01	12	1	<0.05	1.4	0.20	4.03	3.9	1.6	357	<0.5	0.18	<0.1	2.58
13256-0005	22	4	<0.01	<10	2	0.09	5.1	<0.05	1.68	2.0	0.7	31.3	<0.5	0.03	<0.1	0.64
13256-0006	3763	2	0.28	<10	11672	240	7.8	6.48	1.09	9.1	6.7	50.0	2.2	0.50	0.3	6.55
13256-0007	6	4	<0.01	28	5	0.23	4.3	<0.05	1.40	1.4	0.7	220	<0.5	0.43	<0.1	1.40
13256-0008	107	5	<0.01	<10	4	0.20	1.0	<0.05	1.40	2.1	<0.4	276	<0.5	0.03	<0.1	0.53
13256-0009	532	7	0.03	<10	872	28.0	2.3	0.48	0.68	2.9	0.9	28.0	<0.5	0.19	0.4	3.59
13256-0010	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr

LIMS Code	Y	Zr	Nb	Mo	Ag	Cd	Sn	Sb	Cs	La	Ce	Pr	Nd	Sm	Eu	Gd
	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$
Detection Limit	0.005	0.05	0.02	0.03	0.05	0.01	0.02	0.005	0.005	0.002	0.002	0.002	0.02	0.002	0.002	0.002
13256-0001	0.048	0.18	0.04	0.12	<0.05	0.02	0.04	0.016	<0.005	0.140	0.238	0.021	0.08	0.014	0.002	0.012
13256-0002	0.016	<0.05	<0.02	5.90	<0.05	0.03	0.07	0.078	<0.005	0.009	0.005	<0.002	<0.02	<0.002	<0.002	<0.002
13256-0003	1.14	0.73	0.14	2.31	<0.05	0.03	0.04	0.026	0.020	1.22	1.83	0.318	1.29	0.240	0.052	0.240
13256-0004	0.039	<0.05	<0.02	2.99	<0.05	0.16	0.04	0.177	0.009	0.025	0.034	0.005	0.02	0.005	<0.002	0.004
13256-0005	0.010	<0.05	<0.02	0.27	<0.05	0.15	<0.02	0.023	<0.005	0.004	0.003	<0.002	<0.02	<0.002	<0.002	<0.002
13256-0006	5.03	7.68	1.48	0.18	<0.05	0.03	0.25	0.026	0.167	7.07	4.63	1.69	6.52	1.24	0.285	1.23
13256-0007	0.166	<0.05	<0.02	3.22	<0.05	0.02	0.04	0.076	<0.005	0.030	0.046	0.005	0.02	0.007	<0.002	0.007
13256-0008	0.011	<0.05	<0.02	0.37	<0.05	0.01	<0.02	0.013	<0.005	0.008	0.007	<0.002	<0.02	0.003	<0.002	<0.002
13256-0009	0.606	1.17	0.26	0.57	<0.05	0.03	0.02	0.022	0.027	0.673	0.389	0.152	0.62	0.105	0.022	0.107
13256-0010	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr

LIMS Code	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Tl	Pb	Th	U
	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$
Detection Limit	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.01	0.02	0.05	0.01	0.01	0.005	0.002
13256-0001	<0.002	0.009	<0.002	0.005	<0.002	0.004	<0.002	<0.01	<0.02	<0.05	<0.01	0.05	0.017	0.010
13256-0002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.01	<0.02	0.47	<0.01	<0.01	<0.005	1.50
13256-0003	0.033	0.174	0.034	0.103	0.014	0.086	0.014	0.03	<0.02	0.65	0.01	0.84	0.220	0.386
13256-0004	<0.002	0.003	<0.002	0.002	<0.002	0.004	<0.002	<0.01	<0.02	0.69	<0.01	0.40	0.008	5.28
13256-0005	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.01	<0.02	0.16	<0.01	<0.01	<0.005	0.043
13256-0006	0.180	0.987	0.191	0.546	0.071	0.444	0.063	0.25	0.08	0.36	0.02	0.91	0.552	0.147
13256-0007	<0.002	0.008	<0.002	0.008	<0.002	0.010	<0.002	<0.01	<0.02	0.09	<0.01	0.05	<0.005	4.56
13256-0008	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.01	<0.02	0.23	<0.01	<0.01	<0.005	0.276
13256-0009	0.016	0.089	0.018	0.054	0.007	0.047	0.007	0.04	<0.02	0.24	<0.01	0.11	0.073	1.05
13256-0010	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr

Unlocking the Potential of Groundwater for the Poor

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL