33rd WEDC International Conference, Accra, Ghana, 2008

ACCESS TO SANITATION AND SAFE WATER:
GLOBAL PARTNERSHIPS AND LOCAL ACTIONS

Cost-Effective Boreholes in sub-Saharan Africa

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The paper sets out a conceptual framework for Cost-Effective Boreholes (CEB) in sub-Saharan Africa. It breaks down the term CEB into several components. Using examples from the literature, it sets out six key factors and ten elements that affect CEB (borehole standards and design, drilling rigs, contract packaging, hydrogelogical knowledge and siting practice, test pumping, supervision, evaluation of groundwater resources, support to private contractors and enhanced management of public and private sector). An emphasis on, and critical investments into the development of human resources, institutions and monitoring and information systems is essential to improve CEB in sub-Saharan Africa. A tool for sensitivity analysis and proxy indicators for CEB would be useful, but change can only take place if local and international stakeholders recognise the importance of a developing a healthy drilling sector.

Introduction

It has been estimated that about 35,000 boreholes per year need to be drilled in sub-Saharan Africa to meet the MDGs for domestic water supply[1]. If one considers full coverage by 2050, and water for irrigation as well as industrial supply, at least 50,000 boreholes per year are required. Government, private sector organizations, NGOs and donors have all raised concerns about the high costs, variable construction quality and the inadequate volume of boreholes drilled in sub-Saharan Africa[2]. The cost-effective boreholes (CEB) flagship of the Rural Water Supply Network (RWSN) was set up to identify ways to improve the "health" of borehole drilling in sub-Saharan Africa so that water users are able to use high-quality boreholes and the sector is profitable as well as efficient.

Cost savings of 10% on conventional drilling would have a significant impact on extending access to improved water supplies. It has been estimated that use of manual drilling where feasible could provide even more savings. However, it is essential that cost-savings do not adversely jeopardise quality. Borehole drilling can only attract more private investment if it is a viable business venture.

This paper sets out a conceptual framework for the analysis of cost-effective borehole provision in sub-Saharan Africa. It is used to provide insights into borehole cost-effectiveness from Burkina Faso, Ethiopia, Kenya, Nigeria, Niger, Malawi, Mali, Mauritania, Senegal and Tanzania. The paper examines how some of the challenges facing the sector can be addressed and sets out requirements for action and further analysis.

The paper recognises sector reforms, which vary between countries, but emphasise a Sector Wide Approach (SWAP); a general shift in emphasis from Government implemented to contracting out of service delivery; decentralisation; and demand-responsive approaches.

Assertions, Information and Evidence

Concerns regarding the disparity between the relatively low costs of handpumps and the high costs of drilled wells were raised at the UNDP-World Bank International Handpump Workshop in 1992 (Doyen, 2003).

Accurate information on drilling and prices or costs in sub-Saharan Africa is not easy to access (Antea, 2007). Note that 'price' refers to the amount paid by the Government or project for the successfully completed borehole, whereas 'cost' is borne by the contractor, consultant(s) and in some cases Government.

One cannot make simplistic comparisons of borehole prices. Carter et al (2006) and Antea (2007) emphasise that every borehole is unique. National, or programme averages hide more than they reveal. Simple league tables of national drilling costs as an incentive to drive down expenditure on boreholes are therefore not very helpful (Table 1).

In order to address concerns regarding CEB, considerable in-depth analysis is required. This is a challenge given the poor, fragmented and non-standardized record keeping of many water supply projects and programmes in sub-Saharan Africa as well as concerns over release of data (Antea, 2007).

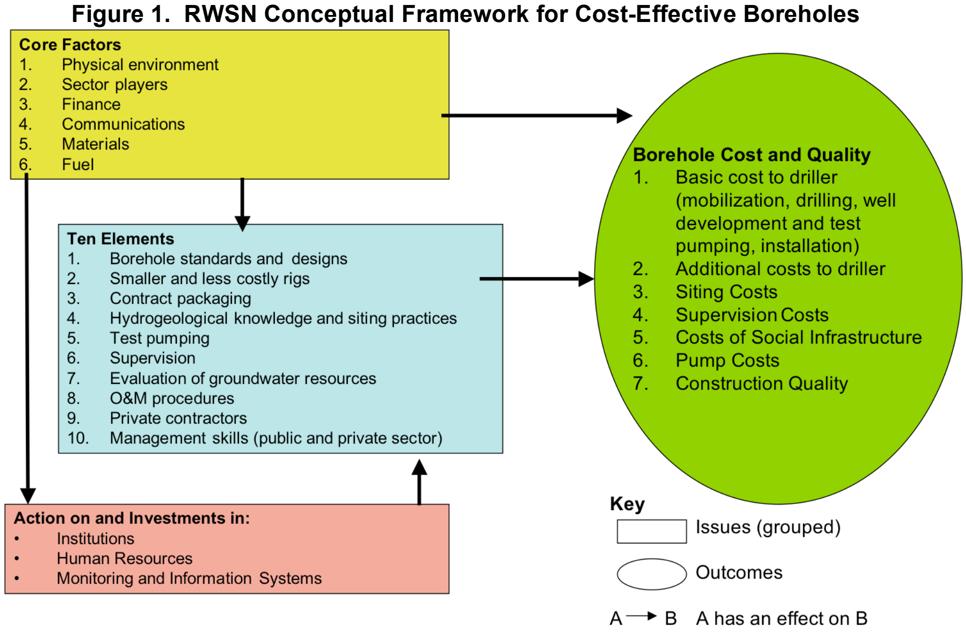
Table 1 Examples of Estimated and Actual Drilling Prices

Country, year (reference)	Price per well	Price per meter	Comments
Kenya, 1996 (Doyen, 2003)	$8,400	$120	Price estimated for 70m well in specific programme (includes drilling, testing but not siting, supervision or failure)
Nigeria, 2006 (Adekile, 2007)	$11,700	$195	Federal Ministry of Water Resources 2006 borehole price. PVC lined, 60 m depth fitted with handpump.
Tanzania, 2004 (Baumann, 2005)	$6,000	-	Budget for borehole with a handpump, as in the National Rural Water Supply and Sanitation Programme (2004), Main Report V 1.
Uganda, 2007 (MWE, 2007)	$8,700	-	Average price of private sector drilled deep boreholes (with handpumps) paid for by district local governments in F/Y 2006/7.
Malawi, 2001 (Mthunzi, 2004)	$2,730	-	Estimated average well cost including capital, recurrent, personnel & materials; assuming 45 wells drilled per year with small rig by NGO.
Burkina Faso, 06 (ANTEA 2007)		$152	Average cost of drilling and installation of casing and screen (PVC) but not the pump, as established by study of drilling costs.
Senegal, 2006 (ANTEA, 2007)	-	$500	Average cost of drilling and installation of casing and screen (stainless steel) but not the pump, as established by study of drilling costs.

Conceptual Framework

Borehole costs and quality are primarily influenced by six core factors and ten elements. Antea (2007) and Carter et al (2006) point to the need to address the parameters that affect drilling cost-effectiveness. Action on and investment in human resources, the institutional framework and the development of monitoring and information systems is essential to address the ten elements. In-depth analysis of specific borehole costs and contacts, and consideration of expenditure on boreholes at programme and national level can enable preliminary assessments of CEB to be made but the huge variations in inputs and overhead costs need to be taken into consideration. Analysis of the core six factors and the ten elements is required to determine the most effective ways to bring about improvements in a particular context.

Figure 1. RWSN Conceptual Framework for Cost-Effective Boreholes



Borehole Costs and Quality

The cost of a borehole comprises a number of components, and sub-components as given below:

1. The ***basic costs to the driller*** comprise costs of
    a. ***Mobilisation*** – all costs involved in transporting equipment to site and back to base.
    b. ***Drilling*** – allows for the per-hour (converted to per-meter) costs of equipment depreciation, labour consumption of fuel, lubricants and drill fluids and replacement of drilling tools. Affected by depth; diameter; drilling and standby time.
    c. ***Casing*** – includes the supply and installation of plain casing and screen, gravel pack, sanitary seal and well-head construction. As an example, PVC casing is used in Burkina Faso whereas stainless steel, at four to ten times the cost is used in Senegal (ANTEA, 2007).
    d. ***Well development*** refers to the cleaning of the borehole after construction and ***test pumping*** is the post-construction assessment of borehole and aquifer performance (Carter et al, 2006).

The time taken to undertake these activities affects the basic drilling costs. Antea (2007) report that while the average execution time for a borehole in Burkina Faso is 2 days; it takes 45 days in Senegal.

2. ***Additional costs to the driller*** include VAT, tax, overheads and kickbacks (when this is the common practice). Some of which these are hidden within the Bill of Quantities (BoQ). An astute driller will assess the requirements for a particular tender, consider the risks involved and load particular items in the BoQ accordingly (Carter et al, 2006).

3. ***Pump costs*** vary considerably and are in some cases included in quoted borehole prices.

4. ***Siting costs*** can be borne by the Government /programme, driller or consultant. Where consultants undertake this, the costs are clear and visible. In cases where supervision is undertaken by programme or Government staff, the costs are often concealed within programme expenditure. This may also be the case for costs of supervision and social infrastructure.

5. ***Supervision costs*** are generally borne by the Government or programme, or consultants (as above).

6. ***Costs of Social Infrastructure***, ie mobilising and training communities and forming management groups. These costs are also sometimes hidden within programme expenditure.

7. ***Construction quality*** refers to the degree to which the borehole is straight; the quality of well development and gravel packing; the casing/screen quality including its installation; the permeable backfill material and placement; the quality of the sanitary seal and headworks. From the user perspective, turbid water, low flow rates, seasonal functionality all represent compromises on quality of service.

The Core Factors

The core factors of CEB are independent variables that do not change at all or cannot easily be influenced from within the sector, but have a bearing on the cost, and quality of boreholes. It is important to understand what they are, and be realistic about the extent to which they can be changed in a given time frame.

The core factors are the physical environment (eg geology and hydrogeology, climate); sector players and programmes (donors, Government, private sector, NGOs and programme costs); availability of finance for sector investment; communications (eg road networks, which are often poor in remote rural areas and telecommunications, which is changing rapidly with mobile phone technology); materials (cost, availability, local manufacture) and fuel (availability is a problem in some areas and prices continue to increase).

Ten Elements: Policies and Practices

Policies and practices can be influenced and changed more easily than the core factors. Carter (2006) set out ten elements to reduce borehole costs. These are modifications of earlier work by Wurzel (2001); Smith (2003); Ball (2004) and Carter et al (2006). The ten elements were validated by participants at the 5th RWSN Forum in Accra (RWSN, 2006) and from published and grey literature as set out below.

Box 1. Ten Elements for Cost-Effective Boreholes (adapted from Carter, 2006)

1. Boreholes should be ***designed and constructed*** to fit their purpose in terms of diameter, depth, casing and screen.
2. Smaller and less costly ***rigs*** should be utilized to provide boreholes that are fit for their designed purpose.
3. Contracts should be ***packaged*** for multiple boreholes in close proximity and for boreholes with similar geology.
4. ***Knowledge of hydrogeology*** should be improved and appropriate ***siting*** practices utilized.
5. ***Test pumping*** requirements should be matched to borehole purpose while taking into account the importance of data to improve the understanding of hydrogeology and water resources.
6. High quality, timely construction ***supervision*** should be emphasized.
7. Rigorous evaluation of ***ground water resources*** should be undertaken and information made readily available.
8. ***O&M procedures*** to ensure the sustainability of pumped groundwater sources should be established
9. ***Private contractors should be supported*** regarding importation, local manufacture, taxation, workflow and to professionalize.
10. The ***communication networks*** and ***management skills*** of public and private sectors should be enhanced.

1. Borehole Standards and Designs
Carter et al (2006) argues for wells which are designed so that they are fit for their intended purpose, meaning that their depth, diameter, lining and backfill materials, screen open area and other design features are well-matched to need (expressed as water demand, longevity, hydraulic efficiency and cost). Differentiating between different magnitudes of abstraction requirements is particularly important. This sentiment is echoed by Doyen (2003), who points out that rural handpump boreholes are being constructed to give high yields, and are forced to conform to higher standards that are appropriate for boreholes in more densely populated areas.

Handpump boreholes diameter requirements and the small diameter submersible pumps that are now on the market mean that 4” (102mm) internal diameter boreholes are sufficient. In Tanzania the internal diameter for deep and shallow wells are specified at 150mm and 117mm respectively. In Mozambique 4” casing is installed. In Uganda 4-5” casing is specified. 6” casing is used in Ethiopia (Carter, 2006). Malawi specifies the installation of 110 mm casing (Mthunzi, 2004). Final drilling diameters in Burkina Faso and Senegal are 8” and 12” respectively. In Nigeria, there are five different borehole designs depending on the terrain and expected yield. Doyen (2003) estimates that in Kenya, reducing well diameter from 152mm to 125mm could save 7.5% of borehole costs.

In countries where boreholes are drilled into stable basement formation, it is possible to make savings by casing the collapsing formation only, grouting at the joint to the hard formation only and not casing the hole drilled into the basement. This is the policy and practice in Uganda (MWE, 2007a). In Tanzania, all boreholes are fully cased and gravel packed, although Baumann et al (2005) state that the specifications are not very precise. Concerns about silting of partially cased (PC) boreholes have been raised (Mthunzi, 2004). A study in Malawi (Mthunzi, 2004) of 60 PC and 23 fully cased (FC) boreholes found that 73% of the PC boreholes had no depth reduction over 4-6 years and that 5% of boreholes showed an increase exceeding 5% of datum depth. Borehole yields were comparable for both types.

In Kenya, drillers lobbied Government for six years to relax the drilling specifications and thus drilling and rig costs but did not succeed. Plans to upgrade these sources to motorised pumps with small piped distribution systems may explain this but, such forward thinking may be too advanced for the needs of rural people today and, even if the well yields are sufficient, the water resources may not be.

Drilling beyond the optimum yield depth is common in Ethiopia (Carter et al, 2006) and Kenya (Doyen, 2003). Doyen (2003) estimates that cost savings of 25% could be made in Kenya if drilling was not beyond the optimum yield depth. In order to avoid this, there is need for close on-site supervision, with the supervisor having the confidence and authority to decide when depth is sufficient. It is envisaged that the increased cost of better supervision would ultimately be offset by reduced drilling costs and improved construction quality.

2. Equipment - Smaller and Less Costly Rigs
Doyen (2003) found that rigs in use in Kenya were oversized for the purposes of rural handpump boreholes. This is also the case in parts of Ethiopia (Carter et al, 2006). In Mozambique, the only organisations using light rigs are NGOs while the private sector enterprises use large conventional rigs. When a driller can only buy one rig, they will try and invest in the largest possible rig, at it gives them flexibility. There is a tendency to overestimate required well depth and over-drill, which also has a bearing on the equipment that drillers decide to invest in (Carter et al, 2006).

Baumann et al (2005) state that most drilling operators in Tanzania use old equipment, with the result that breakdowns are frequent and the performance is slow. Most of the drilling equipment in Senegal, Burkina Faso, Mali and Mauritania is old (some over 30 years) and lacks adequate maintenance (Antea, 2007). 68% of drilling rigs in Ethiopia are older than 15 years (Carter et al, 2006). Maintaining ancient equipment is costly and time consuming. The wide variety of rigs in use means that spares need to be sourced from all over the world.

High borehole standards are not the only cause for use of large and expensive drilling equipment. Discussions with Government stakeholders and drillers in Niger (Danert, 2005) revealed a lack of awareness of new light conventional rigs on the international market. In other countries, stakeholders may be aware that the equipment exists but unsure of the rig capability and wary of the claims made by equipment manufacturers. Improved access to reliable information on drilling equipment is essential. Hoping that this can be found on the Internet is insufficient.

Manual drilling is a viable alternative in particular environments (soft formation and shallow groundwater) and is currently taking place in Niger, Benin, Burkina Faso, Nigeria, Chad, Ethiopia, Mozambique, Malawi, Madagascar, South Africa, Senegal and Tanzania. There have even been assertions that in some parts of Chad and Nigeria, conventional drillers win contracts and sub-contract the work to hand drillers. Unfortunately, very little has been documented about the experiences of such drilling enterprises, the challenges that they face or how they could directly contribute towards cost-effective boreholes in sub-Saharan Africa.

A preliminary analysis of the potential for hand drilled wells in terms of geology and hydrogeology estimates that 12% of the total population of sub-Saharan Africa (SSA), or 18% of the rural population of SSA, could be served with hand-drilled wells (Danert, 2007). Savings of US$ 1 billion could be made as a result of tapping 50% of the estimated potential for hand-drilled wells in rural sub-Saharan Africa[3]. This needs to offset against the cost of the required studies, training and support to realise this as well as protecting the sources from contamination.

3. Contract Packaging

A major cost is transport, which can be reduced by clustering wells to limit expenditure. However, decentralisation in its current form works against this. In the case of Uganda, each of the 80 Districts contracts out its own boreholes (MWE, 2007). There are cases in Tanzania where a contractor had to enter five or six contracts to drill nine or ten wells (Baumann et al, 2005). In Nigeria, many contracts are packaged as one or two boreholes (Adekile, 2007). Doyen (2003) states that in Kenya, costs could rise by as much as 25% if drilling campaigns are not in economic lots of 50 wells or more.

However, it is essential that community mobilisation efforts and response to the demand driven approach by end users is reconciled with clustering of wells to achieve economies of scale.

4. Hydrogeological knowledge and siting practices

MacDonald and Davies (2000) provide an overview of the four main hydrogeological environments in SSA (crystalline basement – 40% of land area; volcanic rocks – 6%; consolidated sedimentary rocks – 32% unconsolidated sediments – 22%) and the different methods for finding and abstracting groundwater from each. Different hydrogeology requires different levels of technical capacity for development, and much is still not known about groundwater in Africa (MacDonald and Davies, 2000). Drilling success rates influence boreholes costs. Unfortunately in-depth knowledge of national hydrogeology is lacking in many countries (eg hydrogeological mapping is underway in Ethiopia and Uganda).

Doyen (2003) reports on a Kenyan drilling programme where blind drilling and use of geophysical techniques achieved 51% and 89% success respectively. In the challenging hydrogeological conditions of Mauritania, there are between two and three reconnaissance wells drilled per successful well (Antea, 2007). Extremely high success rates however are not economic if the costs are more than the savings. In Tanzania, when siting, consultants are required to undertake a geophysical survey using at least two methods, including a VES resistively survey, which is not always necessary (Baumann, 2005).

Hydrogeological data is extremely important and insufficient attention to the storage, analysis and utilisation of drilling data is a lost opportunity. Although drilling records are often kept in Government ministries, the collation and analysis of information is rarely undertaken.

Improvements in knowledge of hydrogeology and enhanced experience in site survey can increase drilling success rates, and reduce the disparity between anticipated and actual drilling depths.

5. Test pumping

Doyen (2003) estimates that 7% savings would be possible in Kenya if a 3-hour, rather than a 24-hour discharge and 12 hour recovery was used to test pump rural handpump wells. The high standards test pumping requirements are intended to obtain as much hydrogeological information about the aquifer in the vicinity of the borehole as possible. Doyen (2003) states that although per meter drilling costs in Kenya fell by 35% between 1988 and 1996, the increased standards for well development, pump testing and well design increased costs by as much as 36% with the result that there were no net savings.

Tanzania specifies a 24-hour pumping test (Baumann, 2005). In Nigeria, pumping tests have been matched to borehole purpose for several years. In the basement complex pumping takes 2 to 6 hours followed by 6 hours of recovery monitoring.

6. Supervision

Doyen (2003) states: "over-drilling is roughly inversely proportional to the degree of supervision of drilling operations". The quality of drilling supervision, as well as authority is important. Some drillers complain about being supervised by inexperienced hydrogeologists who are just out of university. Others use their monopoly on knowledge to their advantage and exploit the situation. Unfortunately, degree courses in geology and hydrogeology do not provide their graduates with a solid foundation in drilling supervision. Kaduna State Ministry of Water Resources in Nigeria realised that they did not have sufficient competence to supervise their drilling programmes and invested in training (Adekile, 2007).

7. Rigorous evaluation of groundwater resources

MacDonald and Davies (2000) point out the following issues which demand more attention: sustainability of groundwater supplies; overexploitation in sedimentary basins; variations in natural water quality and contamination of groundwater and appropriate technology choice. Nigeria has seen cases where groundwater levels appear to have fallen (Adekile, 2007). Unfortunately coordinated research and data collection on groundwater in SSA has become increasingly difficult. Mistakes are repeated, while information from thousands of boreholes is not collected. In Tanzania, for example only 60% to 70% of boreholes drilled by the Parastatal are recorded in the central database and records from industry and mining are not included at all (Baumann et al, 2005).

Simple techniques for the collection and analysis of high value data from drilling programmes exist, but are inadequately used. This is a missed opportunity for significantly enhancing the knowledge base of groundwater Africa, and enabling issues for specific research to be identified and targeted. MacDonald and Davies (2000) advocate for the dissemination of simple techniques on groundwater resource assessment to stakeholders involved in rural water supply.

8. Sustainable O&M Procedures

The MGD target for safe water supply enhances the sense of urgency in the sector. There is a desire to drill fast but end users are not always so quick to respond. Drilling programmes often neglect the much-needed community sensitisation and mobilisation aspects. The fact that communities rarely contribute more than a small proportion of the capital cost towards construction of the borehole, combined with neglect of social infrastructure means that there is often a no ownership of the facilities and a lack of responsibility for their maintenance. This, combined with difficulties in accessing spares, as well as lack of follow-up support contribute to poor operation and maintenance, and broken down, or even abandoned sources. Post-construction failure is also caused by poor construction quality.

Carter et al (2006) emphasise the fact that post-construction failure rates increase actual borehole costs.

9. Private Sector

The extent of private sector capacity in the borehole-drilling sector varies. Some countries have more national expertise, eg Nigeria (Adekile, 2007), while others are still heavily reliant on foreign companies. Costs of expatriate staff are more expensive than local staff. Antea (2007) found that they cost four to eight times as much in Burkina Faso, Senegal, Mali and Mauritania.

Baumann et al (2005) point out that although the Drilling and Dam Construction Agency (DDCA) in Tanzania employs many well-trained drillers and hydrogeologists, and covers about 60% of the drilling market, their skills are underutilised. In contrast, private sector consultants are still lacking. There are 40 registered drilling companies of which only ten are fully active in rural Tanzania. Burkina Faso has an estimated 49 drilling enterprises, of which four have more than 20 rigs and capacity to drill 1000 boreholes per year while Mautitania has only seven companies (Antea, 2007). Adekile (2007) estimates that there are 1,000 drilling companies in Nigeria.

Ideally, the private sector should not only survive, but also flourish. This is not always easy. Setting up in business can be extremely difficult which makes it very difficult for enterprises to enter the sector. There are cases in Mozambique where it has taken three years for a company to establish itself.

There are many examples of people with the skills, but not the finances to invest. Conventional drilling is a very capital-intensive undertaking. There are challenges with the banking sector across the continent. Interest rates on loans are high, eg 40% in Mozambique; 18% in Tanzania (Baumann, 2005). Repayment periods can be short, eg 3 years in Tanzania (Baumann, 2005). In Nigeria, people generally use their own savings and those of relatives as start-up capital. There are major difficulties of showing sufficient collateral to obtain credit throughout SSA. Commercial banks in Tanzania require a security of 125% and the assurance of continual Government work (Baumann, 2005). Existing, and potential drillers are often cash-strapped (Baumann, 2005). Delays in payment for work done are also a major problem (Antea, 2007).

Importation of equipment and spares can be very difficult if contractors do not have foreign connections (Carter et al, 2006; Robinson, 2006; Adekile, 2007). Regulation on number of employees and equipment is demanding in some countries, eg Ethiopia (Carter et al, 2006) and lacking in others, eg Nigeria (Adekile, 2007).

Equipment productivity is also a problem for private drillers thanks to use of old equipment, and the challenges of obtaining spares. Maintenance and repair of equipment can be difficult, and necessary skills are often lacking (Baumann, 2005).

Obtaining steady and regular work is essential to enable capital-intensive drilling enterprises to remain in business, and be cost-effective. Despite this, contractors generally have to tender for work every year, and to many different projects or local authorities. Only one documented case of a drilling concession, running over several years has been found in the literature (Robinson, 2006).

The capability and availability of skilled personnel (professionals and technicians) is an issue for both the public and private sector. Many drillers, supervisors and technical staff were originally working for Government and trained within projects. Given the shift in emphasis to decentralised service delivery by the private sector, there are serious questions regarding adequate opportunities for training and skills development. Ethiopia is a case in point, where an estimated 4,000 technicians are needed to enable the MDG water target to be met. However, there is only one training school where 200 are trained per year. Contractors in Nigeria and Ethiopia face problems in retaining personnel due to skills shortages (Adekile, 2007; Carter et al, 2006

Networking, collaboration and lobbying are recognised as important mechanisms to professionalize organisations and bring about policy shifts. A Mozambique Drillers Association was established in 2006 with donor support but has failed to take off as expected. The Ugandan Drillers Association had collapsed by 2003, although plans are in place to revive it having woken up to the need to associate. A process of forming a national Nigerian drillers association commenced in 2007 (Adekile, 2007). The Project Management Unit in South Sudan provides an interesting example of drilling enterprises are collaborating with each other. Documentation and analysis of the success of networking and collaboration of drillers is lacking, but evidence from other sectors indicates that it could be instrumental in bringing about change.

Despite the above challenges, it is possible for private sector drilling to flourish. Dar Es Salaam in Tanzania provides a case in point where a substantial private market for boreholes has developed with about 9,000 private boreholes now extracting from the aquifer in an unregulated manner. Several drilling companies only operate within the city.

10. Communications Networks and management skills of public and private sector

A strong public sector is needed to oversee and regulate the private sector. The public sector in many sub-Saharan countries is still struggling to fulfil its emerging regulatory role. Although drilling permits are issued in Tanzania, they are not based on consistent professional assessments of the companies, and quality is not monitored in a regular basis (Baumann, 2005). In Tanzania's case, model documents for tendering, evaluation and contracts are also lacking and there are no contract management guidelines (Bamann, 2005). In Uganda, central government issued model tender documents and drilling contracts to District Governments (who contract out borehole drilling) in 2002, but the have not subsequently updated pricelists.

Tendering procedures for private sector drilling in many countries are still weak. Baumann et al (2005) found that there was no pre-qualification of bidders in Tanzania and that tender evaluations did not find out inconsistencies in the capabilities of different bidders. Baumann et al (2005) argue that uniform procurement rates are best suited to the Tanzanian environment as it optimises use of limited capacity and enables District authorities to quickly let out contracts. Adekile (2007) found that in Nigeria, contracts are often awarded to non-professionals who then sub-contract to the drilling contractor, lowering the profit margin and sometimes compromising technical standards.

How to Achieve Cost-effective Boreholes?

Human Resources

There is clearly a need for investment in improving the skills in the public and private sector. This paper does not argue that training of the private sector should necessarily be fully subsidised, but opportunities in-country to develop the necessary skills are essential.

Institutions

There are cases (eg Tanzania, Ethiopia) where the majority of borehole drilling is still undertaken and supervised by the public sector. Decisions on whether to maintain the status quo, try to improve public sector performance or move towards a private sector model need to be taken at country level. The extent to which Government should retain some capacity to deal with emergency situations requires careful consideration. Smooth changes from an implementing to regulatory and monitoring role require a high level of planning and management as well as sufficient time and support.

Monitoring and Information Systems

Good systems for data collection, collation and analysis are essential, as well as the skilled human resources and adequate finance to manage them. This is a key role for central Government, which has been neglected. Hydrogeological mapping, analysis of drilling and siting records is essential to build up the required knowledge base. Performance measurement systems which enable analysis of borehole costs, quality and the ten elements outlined above are needed. This need to be developed in country by local stakeholders, with external support as required.

Conclusions and Recommendations

The Conceptual Framework for CEB presented pulls together a wide range of variables as well as providing a starting point for more in-depth analysis and cross-country comparisons. In order to progress this work further, a simple model on borehole costs is required which enables sensitivity analysis regarding specific inputs such as depth, rig amortization, distance and drilling time. This will build on and verify the work by Doyen (2003), Carter et al (2006) and ANTEA (2007). Ultimately it could be developed into a tool for use by the private sector and Government.

Given the complexity of cost-effective boreholes, it would be useful to use the ten elements as a basis for developing proxy indicators for cost-effective boreholes. This would enable realistic comparisons to be made between countries and programmes and even allow benchmarks to be set.

Ultimately, recognition by national governments, the private sector, as well as donor organisations and NGOs, of the importance of addressing the issue of CEB is essential. This is the only way to enable the required analysis, investments and actions to be made. Further work is needed to build on the conceptual framework and raise stakeholder awareness of the prudence in supporting a healthy drilling sector.

Acknowledgements
The authors extend thanks to WSP-AF, which has supported the Cost-Effective Boreholes work of RWSN.

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Note/s
1. Based on Joint Monitoring Programme (2004) data of 412 million people served in 2004: MDG of 701 million people served in 2015 and full coverage of 1625 million served. Assumption made that 37.5% of people will be served with a handpump (300 people per pump) and 12.5% will be served with a mechanised borehole (2,000 people per system). Assumes that 3% of existing boreholes need to be re-drilled annually.
2. In Kenya, approximately 250 wells are drilled annually, compared to the required 650 to reach official targets (Doyen, 2003); in Tanzania, the investment plan provides a market for 1,600 boreholes annually, requiring a doubling in capacity from the current 900 (Baumann et al, 2005)
3. The following assumptions have been made: A hand drilled well with low cost pump serves 150 people, and can be provided at a cost of US$ 1,000 (per capita cost = US$ 6.67). A conventional well serves 300 people, and costs US$9,000 (per capita cost = US$ 30).

Keywords
Boreholes, drilling, cost-effectiveness, private sector, groundwater, wells.

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