Guidelines for Community Supply and Protection in Africa

Cost-Effective Boreholes in sub-Saharan Africa

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Abstract

A common assertion is that the cost of water well drilling in sub-Saharan Africa is too high and that construction quality is regularly compromised. Over the last 20 years, several studies regarding this have been undertaken, covering more than ten countries in the region. Although drilling costs in sub-Saharan Africa are generally higher than in India, there are valid reasons for this. However, changes to borehole designs, procurement and contract management practices, well clustering for economies of scale, siting and supervision practices as well as support to and professionalization of the private sector can all serve to bring drilling costs down, and improve construction quality. This paper provides an overview of how drilling costs can be calculated. It pulls together the key issues that affect drilling costs and prices into a conceptual framework. The framework is subsequently used to compare policies and practices for the countries where information is readily available. The paper thus intends to raise awareness and improve the analytical capacity of implementers and decision-makers regarding measures that could be adopted to improve the cost-effectiveness of borehole drilling in their particular context.

1 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 enterprises, 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].

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). Cost savings on conventional drilling of as little as 10% would have a significant impact on extending access to improved water supplies. Use of manual drilling where feasible could also extend access at very low cost. However, it is essential that cost-savings do not adversely jeopardise quality and that water well infrastructure can be sustained over the long term. Further, in order to attract private investment, water well drilling must be a viable business venture.

In order to improve the health of the borehole drilling sector, decision-makers and implementers should be able to easily identify issues that reduce efficiency and compromise quality. This paper

[1] Based on Joint Monitoring Programme (JMP 2004) data: 12 million people served in 2004: MDG of 701 million people served in 2015 and full coverage of 1625 million served. Assumptions: 50% of people will be served with a hand dug well, treated surface water or spring; 37.5% of people will be served with a handpump (300 people per pump) and 12.5% with a mechanised borehole (2,000 people per system). Assumes 3% of existing boreholes are re-drilled annually.

[2] eg In Kenya, about 250 wells are drilled annually, compared to the required 650 to meet targets (Doyen, 2003); in Tanzania, the investment plan provides for 1,600 boreholes annually, requiring a doubling in capacity (Baumann et al, 2005)

sets out a conceptual framework for cost-effective boreholes and analyses policies and practices from several countries[3].

2 Assertions, Information and Evidence of High Drilling Prices

It is essential to distinguish between borehole 'price' and borehole 'cost'. 'Price' refers to the amount paid by the Government or a particular project for a successfully completed borehole, whereas 'cost' is borne by the drilling enterprise. The difference between the two is the sum of overheads, taxes, profit and a margin for risk (eg dry holes, payment delays, insecurity and breakdown).

Accurate information on drilling prices or costs in sub-Saharan Africa is not easy to access (ANTEA, 2007). Systematic analysis is a challenge because there is poor, fragmented and non-standardized record keeping of water supply projects and programmes in sub-Saharan Africa as well as lack of transparency. Table 1 provides examples of estimated and actual borehole costs and prices, ranging from $2,000 to $500,000 ($120 to $1,271 per meter).

Table 1 Estimated and Actual Drilling Cost and Prices

Country, year (ref)	Cost/Price per:		Description
	well	meter	
Burkina Faso 2006 (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.
Chad 2005 (Practica, 2005)	$12,000 - 15,000		Range of machine drilled well prices paid by different agencies.
Ethiopia, 2005 (Carter, 2006)	$37,800	$252	Estimated price for a 200 mm diameter, steel cased borehole to 150m. No pump or supervision (based on analysis of inputs).
Kenya, 1996 (Doyen, 2003)	$8,400	$120	Price estimated for 70m well in specific programme (includes drilling, testing but not siting, supervision or failure)
Malawi, 2001 (Mthunzi, 2004)	$2,730	-	Estimated average well cost including capital, recurrent, personnel & materials; assuming 45 wells per year with small rig by NGO.
Niger, 2005 (Danert, 2005)	$10,000	$160	Estimated price on a bill of quantities, 60m depth, 700km from capital city, excluding supervision and pump installation
Mozambique, 2006 (WE Consult, 2006)		$151	Average drilling price according to the report. Includes siting, pump installation and VAT.
Nigeria, 2006 (Adekile, 2007)	$11,700	$195	Federal Ministry of Water Resources 2006 borehole price. PVC lined, 60 m depth fitted with handpump.
Nigeria, 2008 (Adekile et al, 2008a)	$6,000	$120	Estimated price for a 110mm diameter, PVC lined borehole to 50m depth without pump or supervision (based on analysis of inputs).
Nigeria, 2008 (Adekile et al, 2008a)	$2,140	-	Hand drilled, 110 mm, PVC lined.
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.
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.
Nigeria, 2008 (Adekile et al, 2009)	$500,000	$2,500	Contract price for 200 m borehole in River State

[3] Including Burkina Faso, Chad, Ethiopia, Kenya, Nigeria, Niger, Malawi, Mali, Mauritania, Senegal, Tanzania and Uganda.

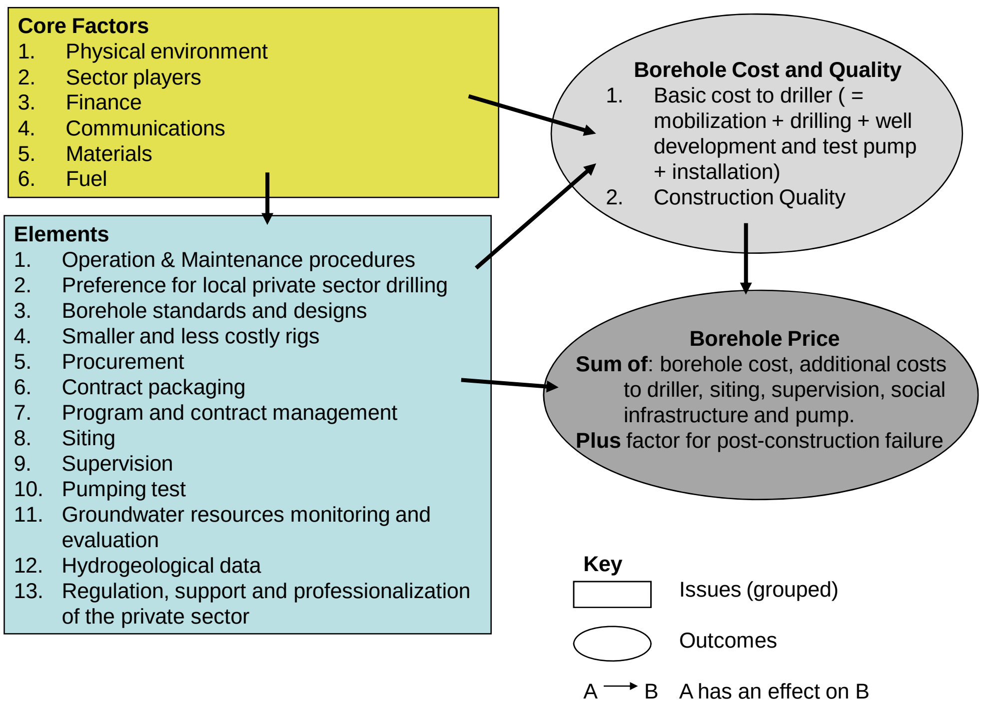
Some wells are shallow, and installed with a handpump while others are deep and use a motorised pump. There is variation in how they are calculated (e.g. what aspects are included or left out such as siting or supervision). The type and size of casing varies, as does the geology, distance travelled and equipment. This means that one cannot make simplistic comparisons of borehole prices between counties, or within the same country.

Carter et al (2006), WE Consult (2006), ANTEA (2007) and Adekile and Olabode (2008a) emphasise that every borehole is unique. Estimates of borehole prices are vital for budgeting but averages hide more than they reveal. International and in-country benchmarking would be useful to consider value-for-money in service delivery but simple league tables of national drilling costs are not very useful for driving down the price of boreholes and ensure construction quality. In order to make useful comparisons, a standard accounting framework is needed, as well a methodology for modelling the effects of key variables on overall cost.

3 Conceptual Framework

It is essential to understand and address the parameters that affect cost-effectiveness in context (ANTEA, 2007; Carter et al ,2006). Borehole costs and quality are primarily influenced by six core factors and thirteen elements as set out in the conceptual framework in Figure 1 and discussed below. Note that this framework builds on previous work by Wurzel (2001), Smith (2003), Ball (2004), Carter (2006), Carter et al (2006), Danert (2008) and Adekile and Olabode (2008b).

Figure 1 RWSN Conceptual Framework for Cost-Effective Boreholes



3.1 Borehole Costs and Quality

The recommended way to analyse **borehole cost** is to examine each of the following components:

- **Mobilisation** – all costs involved in transporting equipment to site and back to base (Box 1).

- **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 (Box 2).
- **Installation** – includes the supply and installation of plain casing and screen, gravel pack, sanitary seal and well-head construction.
- **Well development** refers to the cleaning of the borehole after construction and **test pumping** is the post-construction assessment of borehole and aquifer performance.

The time taken to undertake these activities affects the basic drilling costs. The average execution time for a borehole in Burkina Faso is 2 days and 45 days in Senegal (ANTEA, 2007). Note that while savings on say casing can have a considerable effect on the installation cost, the proportion saved on the total cost depends on how much the installation component affects the total construction cost.

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 head works. From the user perspective turbid water, low flow rates and seasonal functionality are a poor quality of service.

Box 1 Mobilisation Cost Component

The table below shows the mobilisation (and demobilisation) cost for a hypothetical project, 100 km from the contractor's base. Two examples are given: (a) equipment purchased at US$ 170,000 and (b) equipment purchased at US$ 85,000.

Mobilisation	Calculation Method	Amount (a)	Amount (b)
Capital equipment depreciation	Cost of rig, freight insurance, loan charges converted to daily cost based on a 10 year lifespan and 60% utilisation	$78	$39
Vehicles	Rental market rate/real running cost of: (a) 2 trucks and 1 pickup; (b) 1 truck and 1 pickup.	$297	$186
Fuel and lubricants	For a travel distance of 100 km (20 l of fuel/vehicle at $0.58/l)	$46	$35
Human Resources	Salaries and per diems on daily basis for hydrogeologist, driller, assistant driller, 2 labourers, security person and 1 driver (rig a)/2 drivers (rig b).	$149	$141
Sub-total Mobilisation		***$570***	***$401***
Sub-total Demobilisation	Estimated at 80% of mobilisation cost	***$456***	***$321***
Total		**$1,026**	**$721**

Clearly, it is considerably more economical to spread the mobilisation cost over 10, 20 or 50 wells (i.e. a clustered contract with wells relatively close in distance) than to pay this amount for each individual well drilled.

Box 2 Drilling Cost Component (adapted from Rowles, 1995)

Item		Explanation	Cost (US$)	
Capital equipment		Cost of rig, freight insurance, loan charges	$170,000	
Fixed costs	**Lifetime (Hours)**			**Cost per hour**
Depreciation	20,000	Capital cost divided by lifetime (ie 10 years at 60% utilisation) US$/h		$8.50
Maintenance	-	Maintenance (5% of depreciation) US$/h		$0.43
Labour	-	US$/h		$17.00
Fuel and Lubricants	-	US$/h		$10.00
Mud/foam	-	US$/h		$13.00
Sub-Total (Naira/h)		***Sum of above US$/h***		***$48.93***
Cost per meter		***Convert to US$/m by dividing by drilling speed***		
Variable Costs	**Lifetime (Meters)**	**Explanation**	**Replacement Cost**	**Costs per meter**
Drilling string	20,000	Convert to US$/m by dividing replacement cost by lifetime	$15,254	$0.76
Hammer	3,000	Convert to US$/m by dividing replacement cost by lifetime	$8,136	$2.71
Hammer bit	300	Convert to US$/m by dividing replacement cost by lifetime	$1,186	$3.95
Drag bit	300	Convert to US$/m by dividing replacement cost by lifetime	$508	$1.69
Sub-Total Rock		***Sum of drill string and drag bit US$/m***		
Sub-Total Overburden		***Sum of drill string, hammer, and hammer bit US$/m***		
Example				
Formation	**Depth (m)**			
Overburden depth (m)	20			
Rock depth (m)	30			
Total depth (m)	50			
Drilling speed (m/h)	3			
Calculation			**Cost**	
Fixed costs		= 50m x (57.85/3)	$815	
Variable cost: overburden		=20m x (0.76 +1.67)	$49	
Variable costs: rock		= 30m x (0.76 + 2.7 + 4)	$200	
Total Cost - Drilling			**$1,065**	
Drilling cost per m			**$21**	

3.2 Borehole Price

Figure 1 differentiates between borehole cost and borehole price. The borehole price includes:

- **Borehole cost** (as described in section 3.1)
- **Additional costs to the driller** (eg taxes, overheads and kickbacks). An astute driller will assess the requirements for a particular tender, consider the risks involved and load particular items in the Bill of Quantities accordingly (Carter et al, 2006).

- **Pump costs**. These vary and may or may not be included in quoted borehole prices.
- **Siting costs**. These can be borne by the programme, driller or consultant. In the case of the latter, the costs are more visible. In cases where supervision is undertaken by programme or Government staff, the costs are often concealed.
- **Supervision costs** are can be borne by the programme, or consultants (as for siting).
- **Costs of Social Infrastructure** refers to community mobilisation and training. These costs are sometimes hidden within programme expenditure.

3.3 The Core Factors

The core factors indicated in Figure 1 are independent variables that cannot easily be influenced but have a bearing on the cost of boreholes. They are summarised in Table 2. It is important to understand them and be realistic about the extent to which they can be changed in a given time frame, if at all.

Table 2 Core Factors that Affect Drilling Costs

Physical Environment (geology, hydrogeology, climate)	Water well construction in different formations has different requirements in terms of equipment, casing and depth requirements. If plentiful groundwater is available at shallow depths, it can be cheaper to drill than for deep groundwater. If formations are soft, and groundwater is within the first 15 to 20m, low cost hand drilled wells may be feasible. Rainfall and recharge affect groundwater availability and sustainability. Although the physical environment cannot be changed, the understanding of it by sector professionals and practitioners can be improved.
Sector Players and Sector Structure	There are numerous sector reforms throughout the region comprising a shift to public sector coordination, regulation, and policy formation with private sector implementation (eg Uganda, Ethiopia, Malawi and Ghana). These provide more opportunities for private drilling. There is a growing interest in the Sector Wide Approach (SWAp), although forms vary, which can make the market for borehole drilling more coherent and transparent. Where major structural changes are taking place roles and responsibilities are in a state of flux and the introduction of cost-saving measures is not always easy. In most countries there are numerous discrete water supply projects being implemented with different objectives, standards and conditionalities. A coherent legal and regulatory framework is key for cost-effective borehole provision but takes time to develop and be enforced.
Communication networks	Road networks are often poor, particularly in remote rural areas. This can render large parts of the country inaccessible for the rainy seasons (eg South Sudan), which impacts on equipment down time and amortisation costs. Telecommunications is changing rapidly. Mobile phone technology can have a huge impact on decision-making of junior field staff, and thus impact on waiting times considerably.
Finance	Coherent finance for investment in water supply development and maintenance over several years provides continuity of work and thus encourages investment by private drilling enterprises in equipment and human resources.
Materials and Equipment	The cost and availability of materials such as casing, gravel pack, cement and drilling fluids and equipment such as drilling rigs and spares varies widely. Some countries are fortunate that casings are manufactured in-country while others have to import. Landlocked countries tend to be at a disadvantage as the raised cost of transport renders everything more expensive. This has to be carefully considered when making any comparisons.

Fuel	Fuel prices vary widely, not only over time (as we have seen over the last two years with fluctuating prices for a barrel of oil), but also between and within countries. Some countries (eg Egypt) have for many years operated a policy whereby oil prices are highly subsidized. In other countries, fuel taxation is a key contributor to Government revenues. In some areas, fuel is not readily available and mainly sold, at a higher price from plastic containers by the roadside. Kano, Nigeria is a case in point

3.4 Key Elements

Given that the core factors change very little, if at all, in order to improve borehole cost effectiveness it is essential that proper attention is paid to the 14 elements given in figure 1. Box 3 outlines the basic principles that should be adhered to with respect to these twelve elements. These principles are drawn from on-going work to develop a code of practice for cost effective boreholes.

Box 3. Key Elements for Cost-Effective Boreholes

1. ***Operation and maintenance (O&M) procedures*** to ensure the sustainability of pumped groundwater sources for the expected lifetime of the facility should be established, adhered to and monitored.
2. ***Who drills?*** The preferred option is that local private sector enterprises undertake construction of water wells and pump installation. This should encourage in-county capacity to grow and foster competition.
3. ***Standards and design:*** Boreholes should be designed and constructed so that they are fit for their intended purpose in terms of diameter, depth, casing and screen.
4. ***Drilling equipment***: Smaller and less costly rigs should be utilized to provide boreholes that are fit for their designed purpose. Manual drilling should be brought into the mainstream of water supply programmes, with appropriate quality control.
5. ***Procurement***: Systematic, transparent and timely processes of advertising, pre-qualification, tendering, evaluation and award need to be established and followed.
6. ***Contract Packaging:*** Contracts should be packaged for multiple boreholes in close proximity and for boreholes with similar geology.
7. ***Programme and contract management.*** It is essential that drilling programmes have sufficient skills to design and manage the programmes or bring in expertise. Payment for works must be timely.
8. Appropriate ***siting*** practices should be utilized.
9. High quality, timely ***construction supervision*** should be emphasized.
10. ***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.
11. Rigorous evaluation of **ground water resources** should be undertaken and information made available
12. ***Hydrogeological data*** collection and storage should be undertaken.
13. **Regulation and private sector professionalism**: A strong public sector is needed to oversee and regulate the private sector. The private sector needs better access credit and should professionalise.

4 Analysis of the Thirteen Elements of Cost-Effective Boreholes

This chapter sets out each of the key elements of CEB and provides examples of policies and practices from within the continent.

4.1 Operation and Maintenance Procedures

Operation and maintenance (O&M) procedures to ensure the sustainability of pumped groundwater sources should be established, adhered to and monitored.

Post-construction failure increases actual borehole costs significantly. A 50% failure rate effectively doubles the well price. Unfortunately broken down handpumps and abandoned boreholes are a frequent site across the continent. An estimated 30% to 50% of installed facilities in **Nigeria** are broken down at any one time (Adekile and Olabode, 2008b). Comparable figures for **Malawi** and **Uganda** are 30% and 20% respectively. Reliable and comprehensive data in this regard is lacking, but recent water point mapping work (eg Malawi, Angola) is capturing more information. Alas, update mechanisms are often weak.

Unless initial construction quality is high, water is of an acceptable quality and long term operation and maintenance procedures are established and adhered to, cost-effective borehole provision will never be realised. Drilling programmes often neglect the much-needed community sensitisation and mobilisation aspects. Water users rarely contribute more than a small proportion of the capital cost, towards construction of the borehole, if anything, and ownership tends to be unclear. The development of and support to social infrastructure is often neglected and spare parts are frequently not available. These, combined with lack of follow-up support (eg to retrain committees and mechanics; ensure spares are available) contribute to poor operation and maintenance and thus broken down sources. **Uganda** has developed an operation and maintenance framework and a similar initiative started in 2008 in **Malawi**. Standardisation of hand pumps to two or three types has been undertaken in several countries in order to simplify maintenance procedures and reduce the different types of spares required.

4.2 Who drills water wells?

The preferred option is that local private sector enterprises undertake construction of water wells and pump installation. This should encourage in-county capacity to grow and foster competition.

In order to keep drilling costs down, a rig should be used for about 220 days per year (60% of the time) and be subject to regular maintenance and repair. This equates to drilling 20,000 hours over a ten year period. Unfortunately such high usage is rarely achieved within State-owned equipment. There are numerous rigs lying idle in Government yards, broken down or rarely used. There is a growing consensus (by the World Bank, several bilateral donors and African Governments) that private sector drilling tends to be more efficient and effective than direct implementation by the State. Governments and donor support agencies are encouraged to provide support so that the private sector can be built up rather than supporting the purchase of State-owned drilling rigs. Moves towards more private sector drilling vary widely in sub-Saharan Africa (Table 4) and is usually part of wider policy reforms. Note that it may be desirable for Government to retain at least some minimum drilling capacity to deal with emergency situations. There is a grey area with respect to NGO drilling wells directly. Clearly, this reduces the market for private drilling. Competition between NGOs and the private sector is clearly unfair if NGOs are able to cross-subsidise, or benefit from tax exemptions.

Table 4 Organisations undertaking Water Well Drilling in Sub-Saharan Africa

Country	Who drills?
Ethiopia	State enterprises are often the first choice for the Regional Bureau; private sector comprised 23 contractors with 64 rigs in late 2005; eight NGOs had 11 rigs in late 2005 (Carter, 2006).
Malawi	Drilling is undertaken by the State (mainly at regional level) as well as by 10 to 20 private drilling companies.
Nigeria	Nearly all drilling done by private sector although some Government agencies (eg Kano State RUWASSA) also construct water wells in-house. There are hundreds of private well drillers in Nigeria (Adekile and Olabode, 2008b).

Tanzania	The Drilling and Dam Construction Agency (DDCA) employs many well-trained drillers and hydrogeologists. It covers about 60% of the drilling market. DDCA staff skills are underutilised while private sector consultants are still lacking (Baumann et al, 2005). Private enterprises have drilled an estimated 9,000 private boreholes in Dar Es Salaam.
Uganda	All drilling done by private contractors.

4.3 Borehole Standards and Designs

Wells should be designed so that they are *fit for their intended purpose* (Carter et al, 2006). This means that the diameter, depth, lining and backfill materials, screen open area and other design features should be well-matched to need (expressed as water demand, longevity, hydraulic efficiency and cost). Differentiating between different magnitudes of abstraction requirements is particularly important. Unfortunately, this is not always the case, as shown by the examples below.

Doyen (2003) points out that often, wells drilled for rural handpump are being constructed to give high yields, and are forced to conform to higher standards necessary. Well yields of 0.25l/s are adequate for hand pump wells.

Handpump boreholes diameter requirements and the small diameter submersible pumps that are now on the market mean that 4" (102mm) internal diameter boreholes are usually sufficient. However, diameter requirements vary considerably between countries:

- **Tanzania** - the internal diameter for deep and shallow wells are specified at 150mm and 117mm respectively.
- **Mozambique** - 4" casing is installed, but there are no official standards (We Consult, 2006).
- In **Uganda** 4-5" casing is specified (MWE, 2007a).
- Six inch casing is used in **Ethiopia,** although drilling diameters are often 10" or 12" (Carter, 2006).
- **Malawi** specifies the installation of 110 mm casing (Mthunzi, 2004).
- In **Burkina Faso** and **Senegal,** final drilling diameters are 8" and 12" respectively (ANTEA, 2007).
- In **Nigeria**, there are five different borehole designs depending on the geology and aquifer depth in different parts of the country (Adekile and Olabode, 2008b).
- In **Kenya**, well diameters for boreholes with handpumps are 152mm (Doyen, 2003).

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, as is the standard 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. In Nigeria, boreholes are lined to the full depth. Concerns about silting of partially cased boreholes have been raised. A study in Malawi (Mthunzi, 2004) of 60 partially cased and 23 fully cased boreholes found that 73% of the partially cased 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. Part of the rational for this are plans to upgrade these sources to motorised pumps with small piped distribution systems at a later stage. However, given the enormous challenge of meeting the MDGs, the paucity of finance and difficulty in maintaining existing rural water supplies, such thinking may be too advanced for many countries. Higher levels of abstraction also raise questions with respect to water resources.

Drilling beyond the optimum yield depth is common, with examples documented in Ethiopia (Carter et al, 2006), Kenya (Doyen, 2003) and Nigeria (Adekile and Olabode, 2008b). Doyen (2003) estimates that cost savings of 25% could be made in Kenya if drilling was not beyond the optimum yield depth. In the basement complex, a geophysical survey can provide a good indication of depth requirements and for sedimentary formation; existing drilling records can be used to determine realistic drilling depths. 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.

4.4 Drilling Equipment - Smaller and Less Costly Rigs

It is preferable that smaller, less costly equipment be used to match *fit for intended purpose* borehole designs. Manual drilling should be brought into the mainstream of water supply programmes, with appropriate quality control.

Borehole costs are affected by the type of equipment used, with cheaper and lighter equipment resulting in lower mobilisation costs. Box 2 shows the drilling component for equipment costing US$ 170,000. However, the total borehole cost also includes mobilisation, installation and pump test. Ball (2004) compares drilling with equipment costing US$ 470,000 and US$ 95,000 and estimates that the price per borehole (including overheads) for the larger rig is $8,837, while boreholes with the smaller rig cost US$ 2,652 (a factor of 3.3).

In many countries (eg Kenya, Ethiopia, Mozambique, Niger), the rigs in use are oversized for the purpose of drilling rural handpump boreholes (Doyen, 2003; Carter et al, 2006; WE consult, 2006; Danert 2007). In Mozambique, only NGOs use light rigs while private enterprises use large conventional rigs (WE Consult, 2006) whereas in Nigeria, half of the rigs encountered on a study by Adekile and Olabode (2008b) were classified as light to medium and 30% were locally manufactured.

There is a tendency to overestimate required well depth and over-drill, or specify large rigs which have a bearing on the equipment that drilling enterprises decide to buy (Carter et al, 2006). If a contractor can only invest in one rig, he may purchase the largest possible rig, to provide flexibility. Discussions with Government stakeholders and drillers in **Niger** (Danert, 2005) and **Ethiopia** revealed a lack of awareness of new light conventional rigs on the international market. Stakeholders may be aware of equipment exists but unsure its capability and wary of claims made by manufacturers. Improved access to reliable information on drilling equipment is essential.

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 and the wide variety of rigs in use means that spares need to be sourced from all over the world. However, lack of initial capital can seriously limit ones options with respect to drilling equipment purchase.

Manual (or hand) drilling techniques can provide a viable alternative in particular environments (soft formation and shallow groundwater). 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). Adekile and Olabode (2008b) found that the cost of a manually drilled hole in **Nigeria** was about one third of a conventionally drilled hole. While Practica (2005) claim that in Chad, they cost a tenth of machine-drilled wells.

Manual drilling techniques are used in **Niger, Benin, Burkina Faso, Nigeria, Chad, Ethiopia, Mozambique, Malawi, Madagascar, South Africa, Senegal** and **Tanzania**. In **Nigeria**, a drill rig manufacturing industry is growing, with rigs available at a much lower cost than for imported equipment, which is contributing to lower drilling costs with an estimated 30,000 hand drilled wells in existence (for domestic and irrigation water supply). Apparently in some parts of **Chad** and **Nigeria**, conventional drillers win contracts and sub-contract the work to hand drillers.

A concern raised repeatedly with respect to hand drilled wells it that of construction quality, as well as water quality. It is essential that these concerns are taken into concern with appropriate quality assurance mechanisms, as well as water quality testing and remedial action.

4.5 Procurement Process

Systematic, transparent and timely processes of advertising, pre-qualification, tendering, evaluation and award need to be established and followed.

Tendering procedures for private sector drilling in many countries are still weak and procedures can take a long time. This is not good for business and unnecessarily increases costs which in turn raises drilling price or compromises construction quality.

- 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. In Nigeria, numerous drillers complain of not being able to tender for Government as they do not stand a change (Adekile and Olabode, 2008b)
- In other countries (eg **Malawi and Uganda**), there are companies which will not tender for work with certain District Governments (Danert, 2008a).
- 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.
- In **Ethiopia**, considerable procurement is “unplanned”, which means that is rather sudden, and driven by the availability of funds. In such cases the sequence of steps followed for open and limited tenders are not adhered to.

4.6 Contract Packaging

Transport is a major cost component for borehole drilling, which can be reduced by clustering wells to limit expenditure (Box 2). Unfortunately, small contract packages are common in many countries (Table 5). Not only do these raise costs (and prices), but they do not allow for long term planning and investment by private enterprises.

Table 5 Summary of contract packaging arrangements in different countries

Country	Contract Packaging
Ethiopia	
Kenya	Doyen (2003) estimates that costs could rise by as much as 25% if drilling campaigns are not in economic lots of 50 wells or more.
Nigeria	Many contracts are packaged as one or two boreholes (Adekile, 2007). Up to 2008, UNICEF contracted in lots of 5, but paid for separate mobilisation on each bill of quantities rather than one mobilisation fee and payment for movement between sites (Adekile and Olabode, 2008b).
Tanzania	There are cases where a contractor had to enter five or six contracts to drill nine or ten wells (Baumann et al, 2005).
Uganda	Each of 80 Districts annually contracts out its own boreholes: numbers of wells drilled are small (ranging from 1 to 20 in 2007; average 9.5 in 2008 (MWE, 2007b; MWE, 2008),

Community mobilisation efforts and response to the demand driven approach by end users should be reconciled with clustering of wells to achieve economies of scale. This is not always easy.

4.7 Programme and Contract Management

It is essential that drilling programmes (whether national or more local) have sufficient skills to design and manage the programmes or bring in expertise. Payment for works must be timely.

As more countries move over to national programmes, or adhere to sector wide approaches, there is a danger that expertise with respect to programme management as well as drilling contact is insufficient. Where governments are changing role from implementer to that of service provider, or as more responsibilities are given to District level, skills may be lacking. In **Tanzania**, for example, model documents for tendering, evaluation and contracts were lacking and there were no contract management guidelines (Baumann, 2005). Although poorly documented, anecdotal evidence suggests that this is an area which is particularly weak in many countries. To make matters worse, understaffed ministries and local Government offices are not uncommon.

Payment systems for water well drilling vary considerably. In **Nigeria**, **Malawi** and **Mozambique** it is common for drilling contractors to be paid for a geophysical survey and only to be paid for successful wells. In Uganda, payment is theoretically against a bill of quantities, but this is not always followed (Danert, 2008a). It has been strongly argued that such a mechanism increases prices, as drillers take into account of risk. In **Mozambique**, payment delays of three months are common in Government projects but there are examples where delays have been for several years (WE Consult, 2006).

4.8 Siting Practices

Appropriate siting practices should be utilized.

Improvements in knowledge of hydrogeology (see section 4.11 and 4.12) and enhanced experience in site survey can increase drilling success rates, and reduce the disparity between anticipated and actual drilling depths. Professional siting involves desk and field reconnaissance, but does not always require the use of geophysics (MacDonald et al, 2005). In many countries in the region, drillers themselves undertake the siting, and are subsequently only paid for a successful well.

In many countries there is a tendency to specify geophysics on drilling sites, even where it is not necessary. Adekile and Olabode (2008b) point out that on some of the consolidated sediments in Nigeria, a review of existing borehole data would be more applicable in determining depths than geophysics. 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). Doyen (2003) reports on a **Kenyan** drilling programme where blind drilling and use of geophysical techniques achieved 51% and 89% success respectively.

However when trying to locate water in fractured bedrock, geophysical techniques may significantly improve success rates. In the challenging hydrogeological conditions of **Mauritania**, there are between two and three reconnaissance wells drilled per successful well (ANTEA, 2007).

4.9 Supervision

High quality and timely construction supervision needs to be emphasised.

Doyen (2003) states: "*over-drilling is roughly inversely proportional to the degree of supervision of drilling operations*". The quality of drilling supervision (including knowledge of the local physical and hydrogeological environment) and on-site authority are important. Degree courses in geology and hydrogeology do not provide graduates with a solid foundation in drilling supervision. It is not uncommon for drillers to complain about being supervised by inexperienced hydrogeologists, straight out of university. Some drillers use their monopoly on knowledge and exploit this. When supervisors are not able to take a prompt decision, drillers will incur waiting time, which can significantly raise the cost of drilling. Unfortunately, supervision capacity is extremely limited in much of sub-Saharan Africa and is a key reason for borehole failure eg:

- In **Nigeria** "*the capacity for proper supervision, in terms of experienced personnel and equipment is limited at State level*" Adekile and Olabode (2008b). Kaduna State Ministry of Water Resources realised that they did not have sufficient competence to supervise their drilling programmes and invested in training (Adekile, 2007). The Nigerian Federal Government and external support agencies engage consultants to carry out drilling supervision (Adekile and Olabode, 2008b).
- In **Malawi**, there are only a handful of hydrogeologists in the country. Supervision of test pumping is often the only professional supervision that takes place. Communities are expected to undertake a certain amount of drilling supervision (for which they are given no more than two days training) (Baumann and Danert, 2008).
- In **Uganda** supervision is either undertaken by private consultants or by District Government depending on who is financing the work.
- In **Ethiopia,** supervision is undertaken directly by the Water Bureaux or through hired consultants with variation regarding the level of supervision and strictness. Contractors cite lack of timely decision-making by supervisors as a frequent problem (Carter, 2006).

4.10 Pumping Test

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.

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, both the Federal Ministry of Water Resource and State project usually specify pumping tests of 2 to 6 hours for handpumps and 8 to 24 hours for motorised schemes.

4.11 Groundwater Resources Monitoring and Evaluation

Rigorous evaluation of ground water resources should be undertaken and information made available.

MacDonald and Davies (2000) point out that: sustainability of groundwater supplies; overexploitation in sedimentary basins; variations in natural water quality and contamination of groundwater demand more attention. There is an urgent need for improved groundwater resources monitoring:

- Groundwater levels appear to have fallen in some parts of **Nigeria** and it has been suggested that intensive drilling in the urban areas of Lagos and Kano State could lead to water level decline (Adekile, 2007; Adekile and Olabode, 2008b).
- Arsenic has been reported in some parts of **Nigeria** but it is not tested for in water supply projects.

4.12 Hydrogeological Data

Hydrogeological data collection and storage should be undertaken.

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).

Hydrogeological data is extremely important and insufficient attention to the storage, analysis and utilisation of drilling data is a lost opportunity. 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).

However, knowledge of hydrogeology in Nigeria has improved considerably over the years and data has been collected with a view to publishing hydrogeological maps (Adekile and Olabode, 2008b) and hydrogeological mapping is underway in Ethiopia and Uganda.

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.

4.13 Regulation and professionalism of the private sector

A strong public sector is needed to oversee and regulate the private sector. The private sector needs better access credit and should professionalise.

The public sector in many sub-Saharan countries is still struggling to fulfil its emerging regulatory role. 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). 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).

If 35,000 wells are to be drilled annually in sub-Saharan Africa, and each rig drills 100 wells per year, the continent needs some 3,500 drilling rigs. Even if as many as 20% of these are owned by NGOs and Government, this still leaves a requirement of some 2,800 privately owned rigs. However, the private sector has nowhere near this capacity[i4]. Some countries such as Nigeria and Uganda have considerable national expertise while others are still heavily reliant on foreign companies. Costs of expatriate staff (from Europe, Australasia, Japan and North America) are more expensive than local staff, ie four to eight times as much in Burkina Faso, Senegal, Mali and Mauritania (ANTEA, 2007).

Productivity rates are often low due to the use of old equipment, challenges of obtaining spares and lack of maintenance skills as well as lack of steady work. Obtaining regular work is essential to enable capital-intensive drilling enterprises to remain in business, and be cost-effective. However, contractors generally have to tender for work every year, and for 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). Low productivity of the private sector flies in the face of arguments against use of Government equipment due to low productivity.

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 (WE Consult, 2006).

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 20-40% in **Mozambique** (WE Consult 2006); 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 the region. 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 completed (see section 4.7) exacerbate this problem.

Importation of equipment and spares can be very difficult if contractors do not have foreign connections (Carter et al, 2006; Robinson, 2006; Adekile, 2007).

[4] Capacity in the region includes an estimated 49 private enterprises in Burkina Faso, 10 in Malawi, about 21 in Mozambique over 1000 in Nigeria, about 40 in Tanzania (of which only ten work in the rural areas).

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 (Carter, 2006). 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. Drillers Associations in **Mozambique** and **Nigeria** have recently been established, initially with donor support. In **Mozambique**, the association successfully lobbied for more realistic contract terms and conditions. The **Uganda** Drillers Association had collapsed by 2003, although drillers have recently collaborated to demystify tax procedures. The Project Management Unit in **South Sudan** provides an interesting example of drilling enterprises which 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 positive change.

5 Conclusions and Recommendations

Simple comparisons of borehole costs between countries and programmes can be misleading. In order to better understand cost variations, a standard accounting framework is needed, as well a methodology for modelling key variables. The costing of boreholes needs to be demystified to sector stakeholders so that they can better understand how they are calculated. This could improve tender evaluation. A simple but robust tool for sensitivity analysis regarding depth, rig amortization, distance and drilling time could prove very useful.

The conceptual framework set out in this paper provides insights into the issues that affect borehole costs and prices, as well as construction quality. There are no single, simple magic bullets. Each particular country and specific project has its own strengths and weaknesses with respect to cost-effective borehole provision. The paper shows a number of initiatives which are already taking place (eg drillers associations in Nigeria and Mozambique). In addition, steps are being taken to develop national codes of practice for cost-effective boreholes (eg Nigeria).

In order to better move towards improving the cost-effectiveness of borehole drilling in specific context, it is recommended that as a first step, stakeholders use the conceptual framework to analyse borehole costing, appreciate the core factors, and undertake a preliminary analyse of the key elements at national level and for specific programmes. This should enable aspects that can be dealt with relatively quickly and easily, and those which need longer term efforts to be identified. In some cases, the scope for improvement is closely confined within the narrow confines of a particular project, while in others, national consensus or change of legislation may be required. In the case of very large countries, or those where there is considerable decentralisation, prioritisation and action is likely to be required at a sub-national as well as at national levels.

It should be well appreciated that underlying all of the elements set out in this paper are inherent structural strengths and weaknesses. In general, there is need for concerted and long term investment in human resources, institution-building and better monitoring and information systems as well as strengthening the regulatory framework. Improved transparency in terms of reporting and publishing inputs and programme outputs is also critical to enable better scrutiny of programmes. However, without sufficient financial resources decision makers will be faced with very hard decisions such as whether to focus on groundwater resources monitoring, improve supervision capacity or to develop robust operation and maintenance systems.

It would be prudent to utilise the thirteen elements as a basis for benchmarking the drilling sector in a particular country or for a particular programme. Such benchmarking could be undertaken under the umbrella of a generic and national code of practice for cost-effective boreholes. However, there is need for political and technical buy-in at international as well as national level to enable such an initiative to have a significant impact.

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