November 2004

Field Note

Solutions for Reducing Borehole Costs in Rural Africa

Approximately 256 million people in rural Africa live without access to safe water supplies, in areas that could be appropriately supplied with water from hand-pumped boreholes. This field note contends that the current cost of drilled boreholes in Africa can be halved by relaxing borehole specifications in favor of smaller diameter bores drilled by more maneuverable, lower cost equipment.

Summary

Groundwater is generally a readily available source of water throughout Africa. However, high borehole construction costs are slowing progress on increased access. Higher costs are largely a result of using drilling equipment with specifications that are greater than those required for the vast majority of boreholes needed in Africa.

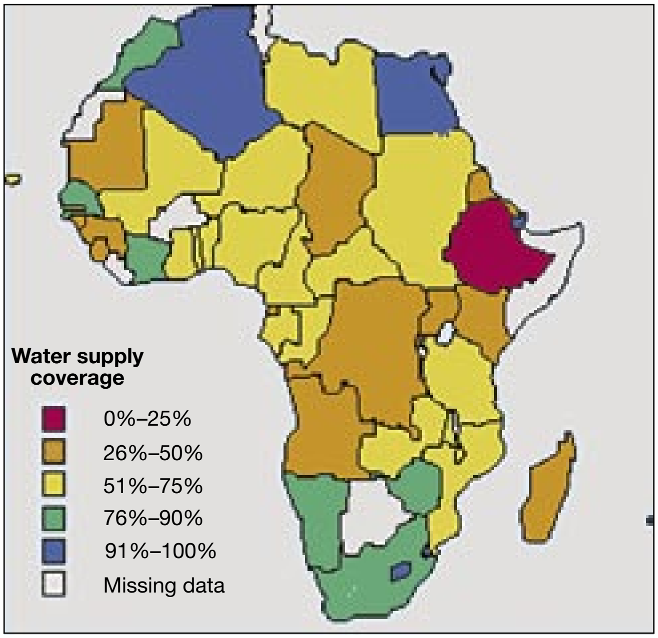
Using high cost machinery and support equipment leads to high borehole costs, which in turn results in fewer boreholes being drilled. The smaller volume of work per drilling rig creates inefficiencies in equipment usage, and results in increased overheads, driving up costs dramatically.

This field note contends that the current cost of drilled boreholes in Africa can be halved by relaxing borehole specifications in favor of smaller diameter bores drilled by more maneuverable, lower cost equipment. The average cost of drilling a borehole can be reduced from USD$6,000 to USD$3,000, and some technological applications could bring down the cost to less than USD$1,000. These sizable cost reductions have the potential to contribute to Africa's attainment of the Millennium Development Goals (MDGs) for water supply and sanitation[1] and the livelihoods of millions of rural Africans.

Clearly, new approaches are required to drill the one million or so boreholes that will help Africa to meet the MDGs for water and sanitation. This can be achieved by adopting these new approaches:

- **Review and revise outdated national standards that favor conservative borehole designs**
- **Develop an effective small business sector, made up of African drilling contractors, based in rural areas and spread amongst the communities they are required to serve**
- **Promote new, appropriate drilling technologies**
- **Provide continuity of work for local businesses.**

Figure 1. Africa: Water Supply Coverage



Source: Global Water Supply and Sanitation Assessment Report, 2000

Who drills in Africa?

To understand borehole drilling in Africa, it is important to know who is doing what, where and the equipment in use. Governments own, directly or indirectly, most of the drilling rigs in Africa, but drill fewer holes than other operators. Non-governmental organizations (NGOs) and contractors own about half of the remaining machines in operation. Despite the prevalence of appreciable market distortions, private contractors drill the greatest number of holes.

Government departments

Government departments responsible for drilling typically procure equipment as donations from external support organizations, but may then lack the management skills and resources needed to sustain a high-production drilling program. In many cases, the external support does not cater for training, operations, maintenance and spare parts.

[1] To halve, by 2015, the proportion of people without sustainable access to safe drinking water and hygienic sanitation.

In such circumstances, machines with capacity to drill more than 200 holes per year end up languishing in a broken-down state, with no spares in stock or budgeted for – effectively parked aside in perpetuity.

International or local NGOs

Borehole drilling by NGOs is associated with a number of disadvantages. Where regulations are inadequate, an NGO undertaking a drilling program may have to define its own policy, measurement and construction criteria, and quality standards. Coordination with public administration and between agencies is often problematic where NGOs operate independently and autonomously.

NGOs may also compete unfairly with local private contractors because some are able to import equipment and materials duty free and to work tax free. This gives them a distinct cost advantage over private-sector competitors who must pay local import duties and income taxes, and who regard the advantage of NGOs as being unfair.

Certain NGOs are able to respond to emergencies quickly and independently by mobilizing borehole drilling equipment and providing water to displaced and distressed populations. Many of such programs start off as quick-fix interventions, but continue to function on this basis for many years afterwards.

International contractors

International contractors are typically foreign-owned, expatriate-managed business ventures that remit profits out of the countries from which they operate. The motivation is strong to take substantial contracts; capitalize with large-scale, high-performance equipment; employ skilled, expatriate staff; and to aggressively chase high production rates for high-specification, high-value work.

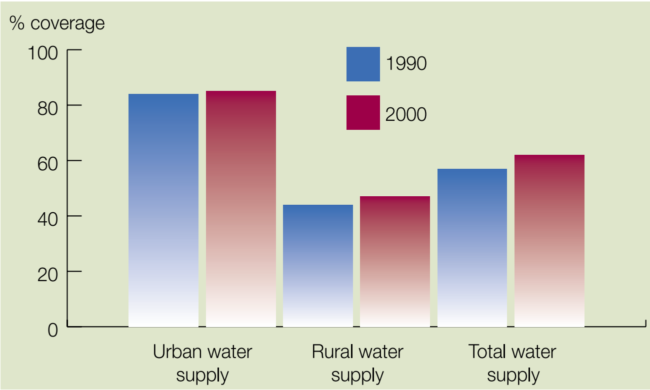
The host country receives neatly completed packages of boreholes, and only a few local employees inherit any transferable skills. The depth of professionalism and level of investment involved often overwhelms the capacity of NGOs, who generally do not compete at this level.

At best, these companies win contracts on the basis of their individual entrepreneurial skills and their inherent ability to compete in the particular market. At worst, they obtain work because of visible or invisible links to conditional donor funding.

Local contractors

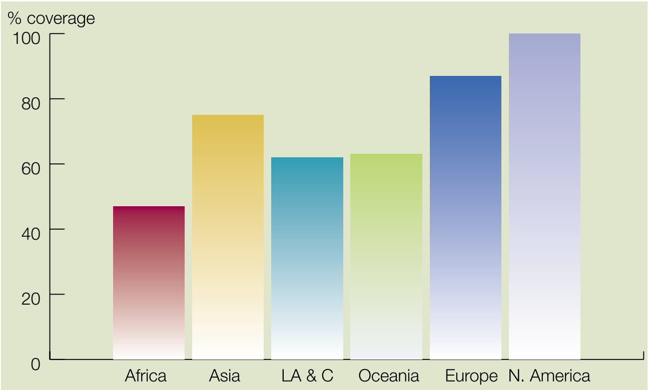
Some local businesses are able to seize opportunities in borehole drilling and possess skills needed to win and influence award of contracts. But they often encounter difficulties mobilizing equipment, materials and skilled personnel required to undertake a sustained construction program. The commercial risks involved in becoming a drilling contractor are reflected in the high cost of borrowing needed for financing such an enterprise.

Figure 2: Africa: Water supply coverage



Source: Global Water Supply and Sanitation Assessment Report, 2000

Figure 3: Rural water coverage by region



The drilling contract periods are often uncertain and afford little security of future work as holes to be drilled are offered in small numbers. In such an unpredictable market, lending institutions default to demanding 100 percent recoverable collateral in the form of property, land, or external securities.

The number of capable, indigenous African contractors continues to grow, though they operate at low capacities. Many other start-ups fail as a result of the handicaps and high risks that stand in the way of success. Of particular concern is the awarding of contracts on the basis of political connections or cash inducements, rather than on ability to fulfill the contract.

Drilling equipment graveyard

What drills in Africa?

A borehole is a round hole that penetrates the earth's surface to a level where groundwater flows. The water is pumped to a supply point on the surface. Proper lining, sealing, cleaning and evaluation of the borehole are essential for tapping clean water.

A drill rig is a tool that rotates a drill pipe and allows it to descend into, and be hoisted out of, a hole in the ground. It basically consists of a steel frame, a mechanism for rotating the drill pipe, and a hoist device. Some drill rigs are operated by complex hydraulic, mechanical, pneumatic or electrical systems.

Interestingly, procurement of drilling services has customarily emphasized the technical specifications of drilling equipment rather than the job in hand. Throughout the drilling industry, undue significance is attached to how a drill rig functions, diverting attention from the very job it is designed for - to drill a borehole (Box 1).

The preoccupation with specifications of drilling rigs undermines the impact that smaller diameter boreholes can make towards attaining the MDGs for water supply and sanitation.

Almost all government and private-sector contractors in Africa use heavy, truck-mounted drilling equipment. This equipment has the capacity to drill deep and wide boreholes, typically 500 meters and with diameters exceeding 200 millimeters. Yet such equipment are often deployed to drill holes only 30-80 meters deep.

Apart from the excessive technical capacity, the vehicle size renders these equipment inappropriate to meet the needs of rural communities.

In the past four decades, two technological advancements have revolutionized drilling of boreholes for water supply: the down-the-hole (DTH) hammer, and the extruded plastic pipe.

Down-the-hole hammer

DTH hammers are pneumatically operated tools that transfer high power from an air compressor mounted on the surface to a series of tungsten buttons underground, pulverizing the hard rock. DTH hammers were initially developed for use in rock quarries as an economic way of drilling blast holes for explosive charges.

The development and use of DTH hammer technology is still dominated by demands of the mining and construction industries where production hammers drill holes from 50 to 1,000 millimeters in diameter,[2] yet millions of water-supply holes would not exist in India today without the existence of this tool.

Extruded plastic pipe

Extruded plastic pipe can act as an alternative to steel for some general construction applications. The ease of production, strength-to-weight ratios, resistance to corrosion, low cost per unit length, flexibility, and the ease with which they can be joined, threaded, and slotted means that plastics have advantages over steel for many piping applications. They are also simple to handle and transport.

Pragmatically, current tools and materials to advance groundwater technology continue to be derived from established markets in other industrial sectors.

Box 1. Sample tender for drilling

> 'An all-wheel drive, truck-mounted rig, with a 15,000 kg capacity mast, capable of working with 6 m drill pipe. An onboard compressor, with water-cooled diesel engine, capable of delivering 750 cfm air at 20 bar . . .'

Instead of describing the equipment, the tender could be re-phrased to read:

> 'Required: a mobile set of drilling equipment capable of constructing 4" diameter holes in crystalline rock to depths of 80 m, and capable of accommodating plastic surface casing pipe and pumping system to depths of up to 25 m. Bidders must offer complete equipment sets, inclusive of transport and materials, to undertake the construction of 1,000 boreholes in four years.'

What defines the cost of drilling?

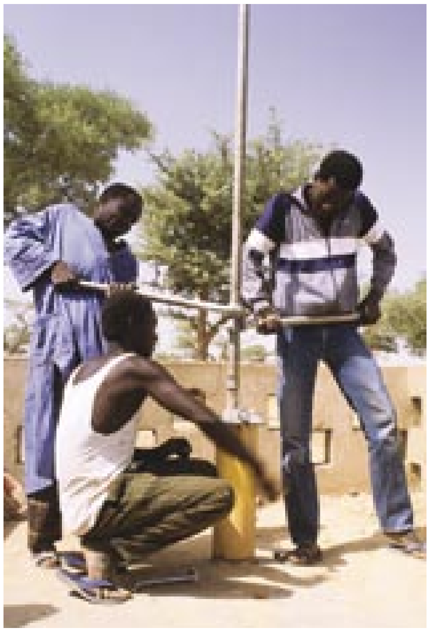
Four elements define the cost of a borehole:

1. The capital costs of construction equipment – the drill rig, tools and rig transport. The total outlay includes costs of shipping the equipment to the country of use, including import taxes and finance charges. This initial purchase price is amortized over the lifetime of the equipment, typically between 3 and 10 years. The sum is then further divided by the annual production rate to determine a cost per hole or per meter.

2. Material or consumable costs – well lining materials, cement, drilling mud, gravel pack (if required), fuel, lubricants, and maintenance. These items are listed and calculated per borehole.

3. Labor costs for the construction crew.

4. Overheads – the provision of capital, administration, and logistics. The total sum is divided by the annual borehole production rate to determine a cost per hole or per meter. Assuming most organizations drill more than a single borehole, a method to calculate the total revenue of an individual drilling operation from the overall revenue is required.



Low-cost hand-drlling technique

Where is groundwater located in Africa?

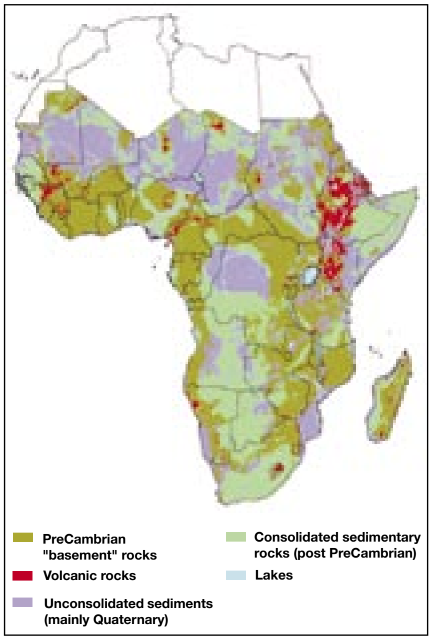
The main geological formations in Africa yielding groundwater are examined below, with a brief analysis of their potential.

Pre-cambrian basement or crystalline rocks

Pre-cambrian basement or crystalline rocks underlie the ground inhabited by

[2] Halco product range, 2001.

Figure 4: Hydro-geological domains of Sub-Saharan Africa



some 220 million people in rural Africa. Groundwater is mostly stored in the weathered overburden and feeds into fractures in the underlying rock. A good well site therefore needs to be located on an adequate depth of weathered ground. There must also be a good chance of accessing a fractured layer in the underlying rock. In some locations, weathering is deep and rock is heavily fractured, making successful drilling easy. In other places, the weathering can be thin and the rock fractures hard to locate, leading to very poor success rates. Geophysics can help to site boreholes by indicating areas of deep weathering and likely fractures, but this should be done in conjunction with a good common-sense appraisal of the site and location. Drilling to hit deep weathering and shallow fractures is the key: simply drilling deep is not a solution.

Volcanic rocks

It is hard to generalize on drilling specifications for volcanic rocks – on which some 45 million Africans are settled – as they often occur in mountainous areas. Generally, groundwater would be expected between lava flows or in lava that is heavily faulted or even porous. Sometimes water is located deep underground and the water quality can be poor. Skilled geological assessment, possibly assisted with some geophysics, can help to locate good drill sites.

Consolidated sedimentary rocks

Some 110 million people in Africa occupy areas of consolidated sedimentary rocks which include limestone and sandstone, and contain water in a mixture of circumstances. It is more important to first understand the general geology of an area to know the depth horizon at which water will be located than to select a drilling site on the basis of fractures. In this class of rock types there are rocks and mixtures that do not readily store groundwater, and in these cases more detailed investigations involving geophysics can assist.

Unconsolidated sediments

Some 60 million rural Africans live on unconsolidated sediments where water will be located in layers of sands or gravels. When unconsolidated sediments cover a large area, it is consistently easy to drill good sites repeatedly by drilling deep enough into the sand or gravel layer. There is also a useful range of sites based on very localized sediments (in small river valleys, for example), particularly in basement rock areas, as these can store appreciable amounts of groundwater from relatively shallow sediment layers.

What is current technology offering Africa?

Borehole diameter

The DTH hammer has clearly carved a niche for itself in quarrying, and there are numerous benefits for this technology in tapping groundwater supplies. In quarrying, operators have learned that - where fuel and capital equipment are expensive to obtain and maintain they can reduce operational costs by reducing the diameter of their blast holes and by improving the performance of their explosive charges (Box 2).

In setting a suitable bore diameter for a water well, the first principles of well design should be followed. Basically, adequate room is required to install the water pump and to supply it with a flow that matches its maximum output. The India MKII technology, now in its third decade of operation, requires a minimum diameter of 4" (10.2 centimeters) for insertion. New MKIII cylinders combined with the Afridev handpump will fit in boreholes

[3] (Driscoll 1986).

Box 2. Borehole Efficiency and Costs

A borehole is defined by its diameter and depth, calculated as volume. The larger the volume, the more the construction work. The surface area of a 4” diameter hole is close to half that of a 6” diameter hole. When multiplied by its depth, this will equate to a 4” hole being half the volume of a 6” hole.

Hard rock drilling spoil is cleared out by blowing compressed air up the borehole in the space between the drill pipe and drilled hole (annular area). The compressed air must travel above a certain speed (drillers refer to this as ‘up-hole velocity’) to achieve sufficient lift of the spoil. This means that there is a direct ratio between the compressed air flow and the borehole diameter (a 6” hole requires twice the volume of compressed air than a 4” hole).

The same ratio applies to the direct cost of constructing a 4” diameter hole which should be half the cost of a 6” diameter hole when the proper selection of plant is made. This is because a 4” hole is half the work of a 6” hole. The drilled diameter has little effect on the volume of water available from the borehole. It has been established that every time a borehole diameter is doubled, the available water inflow will increase only by 10 percent. (Driscoll 1986).

with a diameter of less than 4”, and it is feasible to make installations for 3” (7.6-centimeter) holes.[3]

Tradition

The DTH hammer is still relatively new technology in a notoriously conservative industry. Without a DTH hammer, there are two options for penetrating rock. The first is to use a tricone bit with heavy drill collars and torque. But to get enough weight of steel into a hole in a short length, the optimum diameter would have to be at least 6” (15.2 centimetres). Alternatively, a cable tool with a chisel and sinker bars could be used. This set up calls for a similar critical mass and also leads to drill bits of 6” or larger. Prior to the introduction of DTH technology, it was easier and cheaper to drill boreholes at 6” diameter or above than it was to drill smaller diameters.

Drilling regulations and standards, worldwide, are based on the application of these now superseded technologies. With DTH technology, however, it is easier and cheaper to drill smaller diameters. A DTH hammer will produce the lowest cost per meter in hard rock by a wide margin. An important proviso is that the production rate has to be kept high to amortize the high capital costs of the equipment (Table 1).

Vested interests

Clearly, the adoption of alternative borehole designs constructed with smaller equipment departs from existing practice and would lead to the disappearance of high-cost equipment and high-value contracts. A realignment of existing markets would ensue and equipment that is too large and costly to operate would fall into disuse.

While such a scenario would be beneficial in terms of service coverage, it would clearly not go unopposed. Radical realignment of the business environment in favor of smaller bores would oblige established rig owners and contractors to make a stark choice – adapt to the change, or go out of business. New investors would be presented with considerable opportunities to win contracts, requiring a fraction of the resources currently needed. With smaller bore diameters, the establishment of rural-based African contractors who could drill directly for their own communities would become an attainable goal.

The diameter of the DTH hammer defines the drill-pipe diameter, compressor capacity, engine power, and rig size, weight and transportation method. Basically, the diameter of the borehole determines whether the compressor is towed by a small pick-up or mounted on a four-wheel-drive truck, and whether the rig package costs USD$60,000 or USD$150,000.

By adopting new borehole designs that specify smaller holes, large equipment is effectively made economically inefficient even though a small-diameter drill pipe can still be used on a large rig.

The increased use of commercial drilling contractors would lead to construction

Table 1: Representative borehole costs for conventional and reduced diameter drill rigs

	Conventional Africa Rig	Purchase Cost US$	Per borehole	Reduced Diameter Africa Rig	Purchase Cost US$	Per borehole
Capital cost of a set of borehole construction equipment	Rig	150,000		Rig	25,000	
	Mounting vehicle	80,000		Drilling Tools	15,000	
	Drilling Tools	70,000		Compressor 250CFM x 10 bar	25,000	
	Compressor 750CFM x 15 bar	80,000		Pick Up Truck	30,000	
	Support Truck	60,000				
	Pick Up Truck	30,000				
	Total	470,000		Total	95,000	
	Amortized 30 holes per year over 5 years = 150 boreholes		3,133	Amortized 30 holes per year over 5 years = 150 boreholes		633
Drilling consumables	Surface Casing 6" 20m depth US$20 per metre	400		Surface Casing 4" 20m depth US$10 per metre	200	
	Cement - borehole seal & apron 10 bags @ US$8 per bag	80		Cement - borehole seal & apron 10 bags @ US$8 per bag	80	
	Sand & aggregate for apron	120		Sand & aggregate for apron	120	
	Fuel for compressor based on 400 litres consumption @ 80 US cents per litre	320		Fuel for compressor based on 200 litres consumption @ 80 US cents per litre	160	
	Drill bit wear & rig consumables	250		Drill bit wear & rig consumables	125	
	Hand Pump	600		Hand Pump	600	
	Total		1,770	Total		1,285
Labor costs	Driller			Driller		
	Drivers x 2			Drivers x 1		
	Asst Rig operators x 4			Asst Rig operators x 2		
	Masons x 2			Masons x 2		
			600			400
Overheads	Equipment is attached to an office with 50 staff - 2 rigs - 6 hand dug well teams and 5 pump maintenance crew. Base has 6 offices, store and maintenance facilities + 5 support vehicles	Per annum		Equipment is operated from a yard or a town plumbing shop - owner lives in his compound and employs 6 staff in his shop and stores	Per annum	
	Total spend on overheads	300,000		Total spend on overheads	30,000	
	Assume above attracts income of 1 US$ million per annum. 30 boreholes @ US$10,000 each = US$300,000 revenue			Assume above attracts income of US$300,000 per annum. 30 boreholes @ US$3,000 each = US$90,000 revenue		
	30% overhead cost assigned to Rig	100,000		30% overhead cost assigned to Rig	10,000	
	Divided by production of 30 boreholes		3,333	Divided by production of 30 boreholes		333
	TOTAL COST PER BOREHOLE		US$8,837	TOTAL COST PER BOREHOLE		US$2,652

programs that are more efficient and effective than the direct labor activities of many governments. If boosted by revision of drilling standards in favor of smaller bores, this outsourcing policy could also promote re-adjustment by the drilling industry to demands of the restructured market. Commercial contractors would then gradually phase out oversized drilling rigs in favor of smaller and more profitable equipment.

Borehole design in hard rock

The use of DTH hammer technology has made it easier to access water supplies in hard rock where the costs were too prohibitive to allow extensive drilling with older technologies. It was therefore generally preferable to drill for water in softer sediments and overlying areas. However, a clean water supply in loose ground requires a well screen to act as a barrier to prevent soft soil from collapsing into the hole.

In some countries, old regulations are enshrined in convention, and national standards insist on lining all boreholes to full depth. These regulations take no account of the inherent strength of underlying hard rock formations that DTH hammers are capable of penetrating. Having drilled through a fissure crack and reached a supply of 1,000 liters per hour of crystal clear water, the driller is then obliged to shield the water flowing into the hole.

A slotted pipe has to be first fitted in the abstraction zone, and then a curtain of gravel placed between the fissure and the pipe. Both these measures actively reduce the available water flow and create a structure likely to be clogged by chemical or microbiological action over time. Under such circumstances, neither measure is likely to improve the clarity of the original water.

Holes drilled into the African basement or crystalline rock do not need lining to depth. In India, some three million handpump holes have been drilled into hard rock, all of which are unlined and unscreened. As well as doubling the drilling cost, screening and gravel packing block water from flowing freely into the hole.

The very few rock holes that genuinely require well screens and gravel packs to produce clean water can still use telescoping materials to minimize drilling costs.

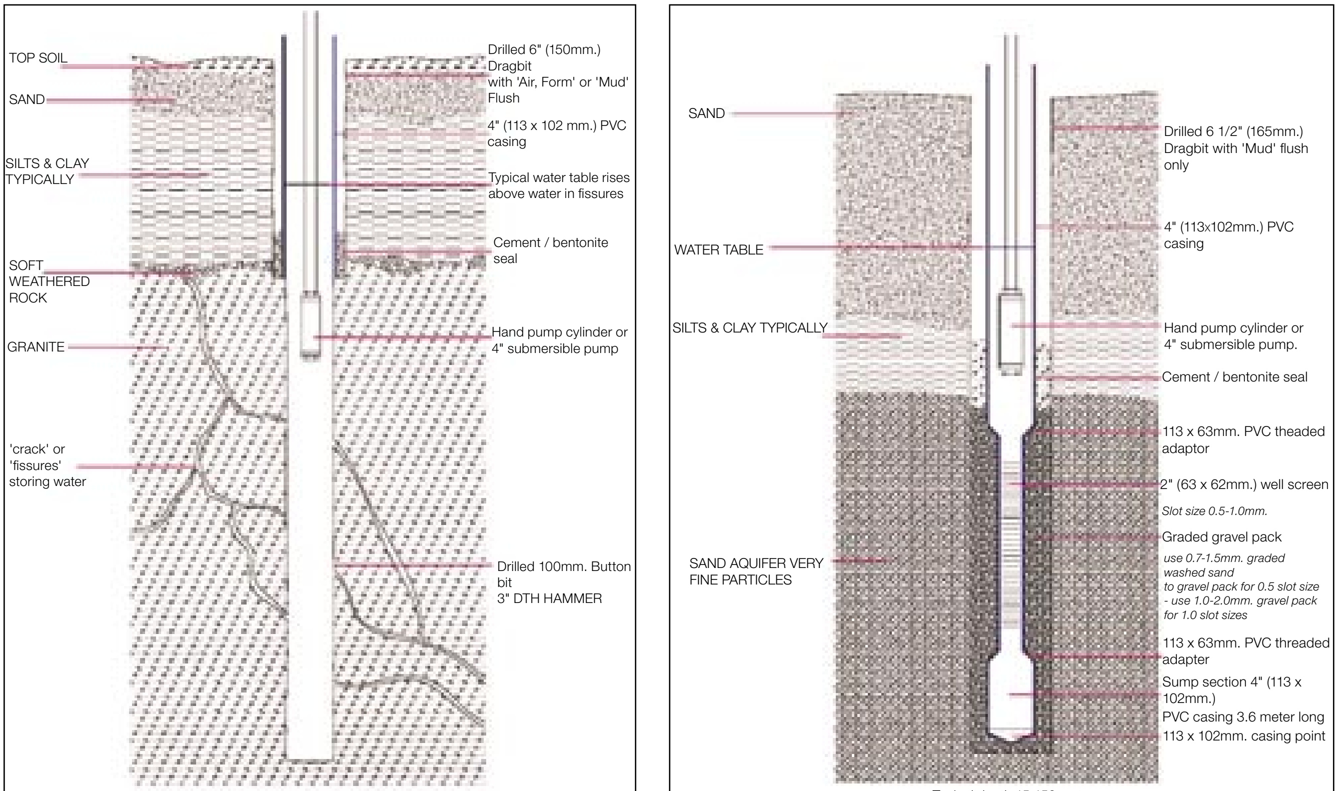
Soft sediments

An appreciable number of holes are drilled in soft sediments using mud pumps and mud pits to circulate drilling fluids. The borehole volume dictates the size of the mud pump needed, and the amount of water that must to be hauled and stored at the drill site. Reductions in borehole diameter therefore lead to savings, even when a DTH hammer is not required.

Holes in sediments usually require well screens (and possibly gravel packs) to create a filter, ensuring clean, clear water in the well. Convention generally keeps the construction diameter of the bore uniform from top to bottom. However, telescoping sizes opens up all sorts of possibilities for minimizing the

A reduced-diameter drill rig in operation.

Figures 5 & 6: Low cost borehole designs for crystalline rock and unconsolidated material



Typical depth 20-80 meters

Typical depth 15-150 meters

Reduced diameter well screen for very fine sands requiring an even gravel pack

diameters of drilled holes. Interestingly, telescoped designs would also contribute hugely to the enhanced performance of bottom-supported uPVC rising mains for deep-set handpumps.

Appropriate Equipment

By defining the minimum requirements of a community water supply based on groundwater access rather than on the equipment to be used, the local contractor can then be left to determine how the hole is constructed. Where the groundwater is shallow and the water level is relatively stable through dry seasons, a hand-dug well remains a sound option.

When groundwater is a little more difficult to access, there are a number of tripod-based drilling methods, largely hand operated, that produce fully acceptable water supplies at very modest costs up to depths of 20 meters.

As drilling gets deeper and involves the penetration of hard rock, larger machines are needed. These machines should be based on the borehole construction required where the smaller the borehole diameter, the lighter the corresponding drilling rig (and its support equipment) can be.

By definition, hard rock aquifers are fragile in terms of their recharge potential. It is very easy to over pump them, as has happened in India over the past two decades. Large diameter bore holes lend themselves to power pumping, the abstraction of large volumes of water and heavy draw down – beyond the reach of most handpumps. Advocating for smaller diameter wells is also more environmentally friendly since handpumps do not damage aquifers.

Conclusions

This analysis of borehole drilling techniques suggests that the following measures could make possible a huge increase in borehole construction, and rural water supply coverage throughout Africa.

Relax the outdated national standards that favor conservative borehole designs

Smaller diameters holes should be drilled to reduce the cost of the construction equipment and the infrastructure needed to support them. Borehole designs need to embrace variations in geology, the occurrence of groundwater, and innovations in drilling technology.

Develop an effective small business sector made up of African drilling contractors, based in rural areas, and spread between the communities they are required to serve

The alternative technology choice opens the door to huge cost reductions in borehole drilling for water supplies, but this technology needs skilful operation based on both knowledge and experience.

An ideal world would see rurally based small businesses operating drilling machines for local community water supplies. Such businesses would drill new schemes, as well as have the capacity to undertake well rehabilitation, pump improvements, and maintenance duties.

A portable drilling rig with DTH capacity.

However, lack of specialized technical and business skills hinders the ability of local enterprise to undertake such activities. Seed schemes that could provide technical and business training to entrepreneurs, linked with credit for capital equipment purchase, would improve the success rate of such firms.

Promote new, appropriate drilling technologies

Acceptable borehole constructions need to be established and then broadened to the application of simple machines capable of achieving these standards. Minimum quality control thresholds for all new or modified borehole designs need to be developed.

Provide continuity of work for local business

Contractual frameworks that allow small practicing businesses some continuity of work should be created. Advantages would include maximizing machine usage and availability within a fixed set of overheads, and increasing the confidence levels of commercial lending institutions in the local drilling industry. Such confidence would be increased by training and other methods designed to control quality of drilling construction.

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wsp water and sanitation program

The Water and Sanitation Program is an international partnership for improving water and sanitation sector policies, practices, and capacities to serve poor people

RWSN

A global knowledge network for rural water

The Rural Water Supply Network RWSN is a global knowledge network for promoting sound practices in rural water supply.

November 2004

The Rural Water Supply Network

RWSN is a global knowledge network for promoting sound practices in rural water supply. RWSN grew out of the need to focus greater attention on rural water supply challenges and to encourage the exchange of experience and knowledge of what works between the many public, NGO and private agencies involved in rural water development.

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