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GROUNDWATER AND RURAL WATER SUPPLY IN SUB-SAHARAN AFRICA

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Poverty and the lack of clean reliable water supplies are strongly linked throughout sub-Saharan Africa. The widespread development of groundwater is the only affordable and sustainable way of improving access to clean water and meeting the International Development Targets for 2015.

Sub-Saharan Africa can be divided into four hydrogeological provinces. (1) Crystalline basement occupies 40% of the land area and supports 220 million rural inhabitants; (2) volcanic rocks occupy 6% of the land area and sustain a rural population of 45 million, many of whom live in the drought stricken areas of the Horn of Africa; (3) consolidated sedimentary rocks occupy 32% of the land area and sustain a rural population of 110 million; and (4) unconsolidated sediments occupy 22% of the land area and sustain a rural population of 60 million. For an aquifer to sustain the yield of a borehole equipped with a hand pump transmissivity should generally be in excess of 1 m^2d^{-1} and storage coefficient greater than approximately 0.001.

Although there are now many choices of proven techniques to help site boreholes and wells for rural water supply these are not effectively used throughout Africa, primarily because they are too complex and costly or hidden in general textbooks or scientific journals. Hydrogeologists have a key role in communicating these techniques to those actually implementing rural water supply projects. Research and expertise can then be targeted to finding and developing groundwater resources in difficult hydrogeological environments, where some of the poorest and most vulnerable people of sub-Saharan Africa live.

INTRODUCTION

At least 38% of the population in Africa do not have access to clean reliable water supplies (WHO/UNICEF 2000). Many of those without access live in the rural areas of sub-Saharan Africa (SSA) where the consequent poverty and ill health disproportionately affect women and children. The international community has now set new development targets which commit the UN membership to reduce by half the proportion of people who are unable to reach, or afford, safe drinking water by the year 2015. Poverty reduction and sustainable development are now given highest priority.

In order to meet these new targets, strategies are being devised which draw on the lessons learned from past experience. Increasingly, the social and economic aspects of water projects are given priority to ensure that water supply solutions are easily and sustainably managed by local communities (e.g. DFID 2001). Whilst this approach is welcome, an unwanted outcome is that the focus on social and economic aspects of water supply is often at the expense of technical and hydrogeological considerations. It is within this framework that hydrogeologists now need to operate within Africa. Increasingly, emphasis on technical aspects of water supply, particularly if they involve new research, is seen as regressive and moving away from community development and demand responsive approaches. It is incumbent on the hydrogeological community to demonstrate that its skills are necessary to help meet the international development targets; indeed, without these skills, the ambitious goals will never be achieved.

This paper discusses the groundwater resources in sub-Saharan Africa in the context of the International Development Targets. An extended reference list is given to help follow up technical aspects of the hydrogeology of Africa, which are not discussed in detail here.

CURRENT APPROACHES TO RURAL WATER SUPPLY IN SUB-SAHARAN AFRICA

There has been a fundamental shift in the design, management and implementation of rural water supply over the past 30 years (Black 1998). Starting with the widespread adoption of appropriate technology in the 1970s, the focus of rural water supply evolved from ‘hardware’ to ‘software’ through the late 1980s and 1990s. Sustainability, community participation and the increased role of women are central to rural water supply projects. The Dublin Principles, agreed in preparation for the Rio de Janeiro Earth Summit in 1992 are a useful summary of the basis for policy among donors and government (Well 1998):

1. Freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment.
2. Water development and management should be based on a participatory approach, involving users, planners and policy makers at all levels.
3. Women play a central role in the provision, management and safeguarding of water
4. Water has an economic value in all competing uses and should be recognised as an economic good.

The fourth principle, recognising water as an economic good, has had revolutionary implications for the provision of community water supplies. The need for water in a community can be expressed in terms of ‘cost’ and ‘willingness to pay’. If consumers can attach a quantifiable value to their water supply it has a much better chance of being sustained. The same principles have led to the adoption of ‘demand responsive approaches’ (DRA). Successful projects are more likely if a community expresses a demand for water. However, these approaches can sometimes be at odds with poverty-focussed aid: the poorest and most vulnerable communities may be the least likely to articulate need.

Where groundwater is readily available, wells and boreholes can be sited using mainly social criteria qualified by simple hydrogeological considerations. However, problems arise in areas where communities are underlain by difficult geological conditions, where groundwater resources are limited and hard to find. In these areas, simple ‘rule of thumb’ criteria are not sufficient to site sustainable wells and boreholes, and following an exclusively social approach, with minimal technical input, can result in many dry wells and boreholes.

To have successful and sustainable rural water supply projects it is essential to understand the hydrogeological environment of the project area. Different methods are required for developing groundwater in different areas. For example, in some rock types dug wells are appropriate; in others, only boreholes will be sustainable. The hydrogeological conditions determine the technical capacity required for both finding and abstracting groundwater. Meeting the challenge posed by the International Development Targets to ‘scale up’ from small pilot projects to effective implementation across larger areas, appropriate and effective hydrogeological expertise is required by the engineers and technicians who actually implement projects.

GROUNDWATER IN SUB-SAHARAN AFRICA

Groundwater is well suited to rural water supply in sub-Saharan Africa. Since groundwater responds slowly to changes in rainfall, the impacts of droughts are often buffered (Calow et al. 1997). In areas with a long dry season, groundwater is still available when sources such as rivers and streams have run dry. The resource is relatively cheap to develop, since large surface reservoirs are not required and water sources can usually be constructed close to areas of demand. These characteristics make groundwater well suited to the more demand responsive and participatory approaches that are being introduced into most rural water and sanitation programmes.

WHAT CONSTITUTES AN AQUIFER?

The hydrogeology of sub-Saharan Africa has to be studied in the context of the amount of water required by rural communities. In rural Africa water is required mainly for basic needs and is hand-carried from sources to households. The WHO recommended daily minimum usage is 25 litres per capita (although many people make do with less if the source is more than a few hundred metres away (Kerr 1990)). Most social scientists involved in rural water supply suggest that community boreholes or wells should supply no more than 250 people (Davis et al. 1993) – anymore becomes difficult to manage. Therefore, one source should supply about 6.25 m^3d^{-1}. This small amount of water can be exploited from poor aquifers (see Table 1). Simple modelling using finite-well-diameter equations (Barker & Macdonald 2000) shows that transmissivity of greater than 1 m^2d^{-1} and storage coefficient of 0.001 is generally sufficient to sustain such a yield from a borehole or well (MacDonald 2001).

Recharge of less than 12 mm per annum should be sufficient to sustain such yields (given a well spacing of 500 m). Studies in an area in the Sahel with average rainfall 280 mm per annum indicated an active recharge of about 13 mm per year (Edmunds & Gaye 1994) and in Zimbabwe significant recharge can be measured from individual rainfall events (Butterworth et al. 1999).

Table 1 Summary of groundwater potential of hydrogeological domains in sub-Saharan Africa with indicative costs of development.

Groundwater Domains	Groundwater Sub-Domains	Groundwater Potential	Average Yields (Litres per second)	Groundwater Targets	Costs* and technical difficulty** of developing groundwater sources	
					Rural Domestic Supply	Small Scale Irrigation
Basement Rocks	Highly weathered and/or fractured basement	Moderate	0.1- 1	Fractures at the base of the deep weathered zone	£ - ££ # - ##	££ - £££ ## - ###
	Poorly weathered and/or sparsely fractured basement	Low	0.1- 0.5	Widely spaced fractures and pockets of deep weathering	£££ ###	Generally not possible
Volcanic Rocks	Mountainous areas	Moderate	0.5 - 5	Horizontal fracture zones between basalt layers. More fractured basalts	£ - ££ # - ###	£ - ££ # - ###
	Plains or plateaux	Moderate	0.5 - 5	Horizontal fracture zones between basalt layers. More fractured basalts	££ - £££ # - ###	££ - £££ # - ###
Consolidated sedimentary rocks	Sandstones	Moderate - High	1 - 20	Porous or fractured sandstone	£ - ££ # - ##	£ - £££ # - ##
	Mudstones	Low	0 - 0.5	Hard fractured mudstones; igneous intrusions or thin limestone/sandstone layers	££ - £££ ## - ###	Generally not possible
	Limestones	Moderate	1- 10	Karstic and fractured limestones	££ - £££ ## - ###	£ - £££ # - ##
Uncon-solidated sediments	Large basins	Moderate - High	1 - 20	Sand and gravel layers	£ - ££ # - ##	£ - £££ # - ##
	Small dispersed deposits, such as riverside alluvium	Moderate	1 - 20	Sand and gravel	£ - ££ # - ##	£ - £££ # - ##

*The approximate costs of siting and constructing one source, including the "hidden" cost of dry sources: £ = < £1000; ££ = £1000 to £10 000 and £££ = > £10 000.

** The technical difficulty of finding and exploiting the groundwater is roughly classified as: # = requires little hydrogeological skill; ## = can apply standard hydrogeological techniques; ### = needs new techniques or innovative hydrogeological interpretation.

HYDROGEOLOGICAL PROVINCES

There have been various attempts at summarising the hydrogeology of sub-Saharan Africa (Foster 1984; Guiraud 1988; UNTCD 1988; UNTCD 1989). A simplified hydrogeological map is shown in Figure 1 based on a synthesis of these studies and using the 1:20 000 000 scale geological map of Africa (USGS 1997) as a base. The classifications reflect the different manner in which groundwater occurs, constrained by the geological information available throughout sub-Saharan Africa. The four provinces are: Precambrian "basement" rocks; volcanic rocks; unconsolidated sediments; and consolidated sedimentary rocks. Basement rocks form the largest hydrogeological province, occupying 40% of the 23.6 million square kilometres; volcanic rocks are the smallest hydrogeological province with only 6% of the land area.

The potential of each hydrogeological province to contribute to rural water supply is best indicated by the rural population living in each one. As discussed above, the rural communities are most dependent on local resources for water supply, since transportation is often prohibitively expensive and difficult to manage.

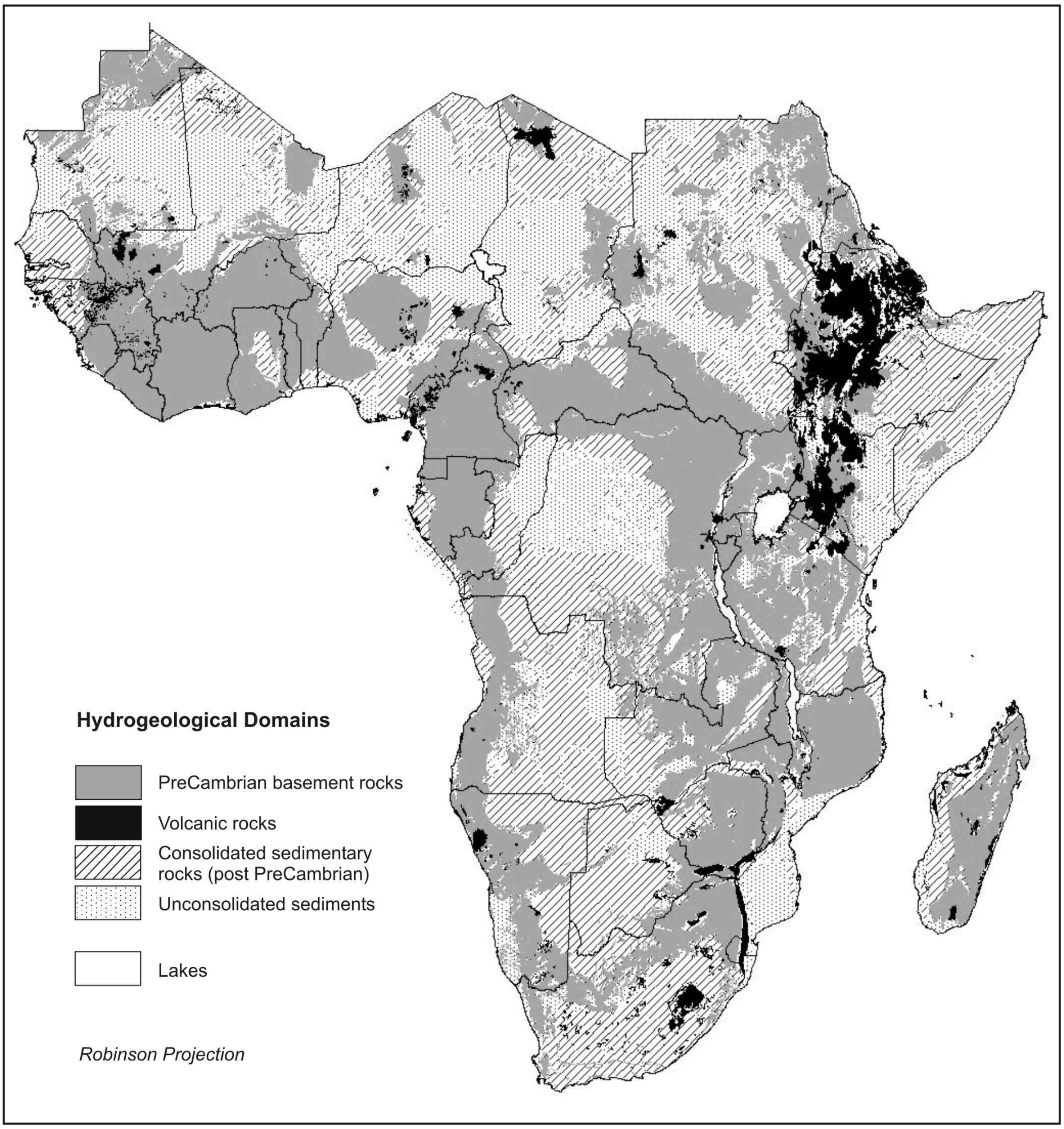

Figure 1 Hydrogeological provinces of sub-Saharan Africa.

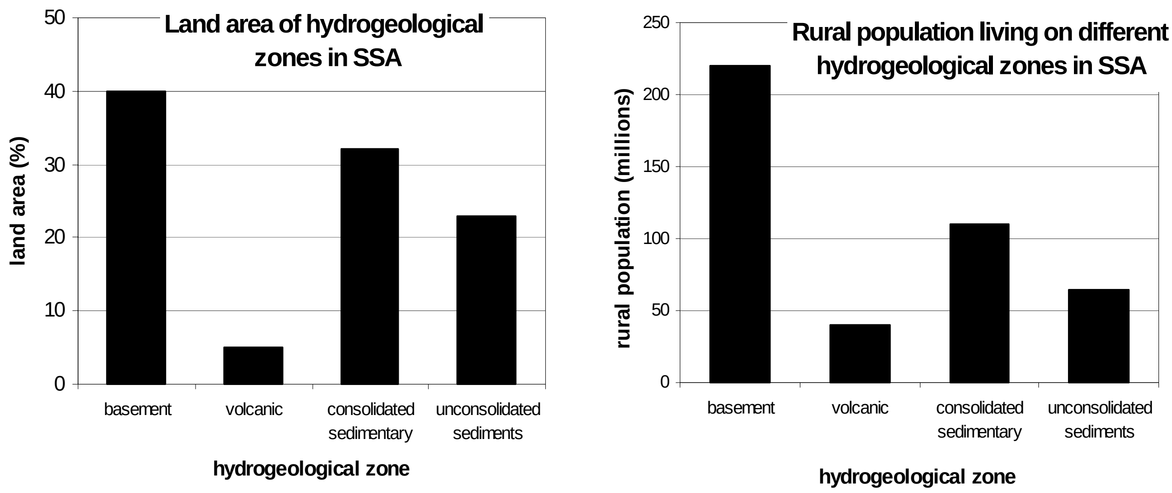

Figure 2 Land area and rural population of the different hydrogeological provinces of sub-Saharan Africa.

Using data from the World Bank (2000) and ESRI (1996), an approximation was made of the distribution of rural population throughout SSA. This was combined with the hydrogeological information on a Geographical Information System to assess the number of rural people living on each hydrogeological province. The results are shown in Figure 2. Basement rocks support the largest population (220 million) and volcanic rocks the least (45 million). Further analysis based on the proportion of clay material in sediments indicates that up to 70 million rural inhabitants of sub-Saharan Africa live directly on poor yielding mudstones.

Basement rocks

Basement aquifers underlie 40% of sub-Saharan Africa and comprise crystalline and metamorphic rocks over 550 million years old. Unweathered basement rock contains negligible groundwater. Significant aquifers, however, develop within the weathered overburden and fractured bedrock (see Figure 3). The presence and thickness of weathering depends on past and current geomorphology, tectonics, climate, and mineralogy (Key 1992). Permeability is generally greatest at the base of the weathered zone, where the rock is highly fractured (see Figure 2). Detailed descriptions of groundwater occurrence in basement aquifers are given in Wright & Burgess (1992), Chilton & Foster (1995), Singhal & Gupta (1999), Taylor & Howard (2000).

Volcanic rocks

Volcanic rocks occupy 6% of the land area of sub-Saharan Africa and are mostly confined to East Africa. Most of the volcanic rocks were formed in three phases of activity during Cenozoic times, associated with the opening of the East African rift valley. These events gave rise to a thick complex sequence of lava flows, sheet basalts and pyroclastic rocks such as agglomerate and ash. Thick paleosoils or loose pyroclastic material between lava flows are often highly permeable along with cooling joints at the top of lava flows (see Figure 4). Gas bubbles within lava flows, and porosity within ashes and agglomerates can provide significant groundwater storage. There have been few systematic studies of the hydrogeology of volcanic rocks in Africa, although good site studies are given by Kehinde & Loenhert (1989), Aberra (1990) and Vernier (1993). However, the Deccan basalts of India have been extensively studied (Kulkarni et al. 2000).

Consolidated sedimentary rocks

Consolidated sedimentary rocks occupy 32% of the land area of sub-Saharan Africa (Figure 1). Sedimentary rocks tend to be deposited in large basins containing several kilometres of sediment. Examples are the Karroo, and Kalahari sediments of Southern Africa (Truswell, 1970), sediments within the Somali basin of East Africa and the Benue Trough of West Africa (Selley 1997). Yields are highest where the sandstones are weakly cemented or fractured (see Figure 5). This makes the aquifers highly suited to large-scale development for reticulated urban supply, industrial uses and agricultural irrigation. However, rural water supply generally relies on shallow boreholes or wells close to communities. Only rocks immediately surrounding the community and to a depth of less than 100 m are usually considered. Although mudstone and siltstone are poor aquifers, groundwater can often be found in these environments with careful exploration (MacDonald et al. 2001).

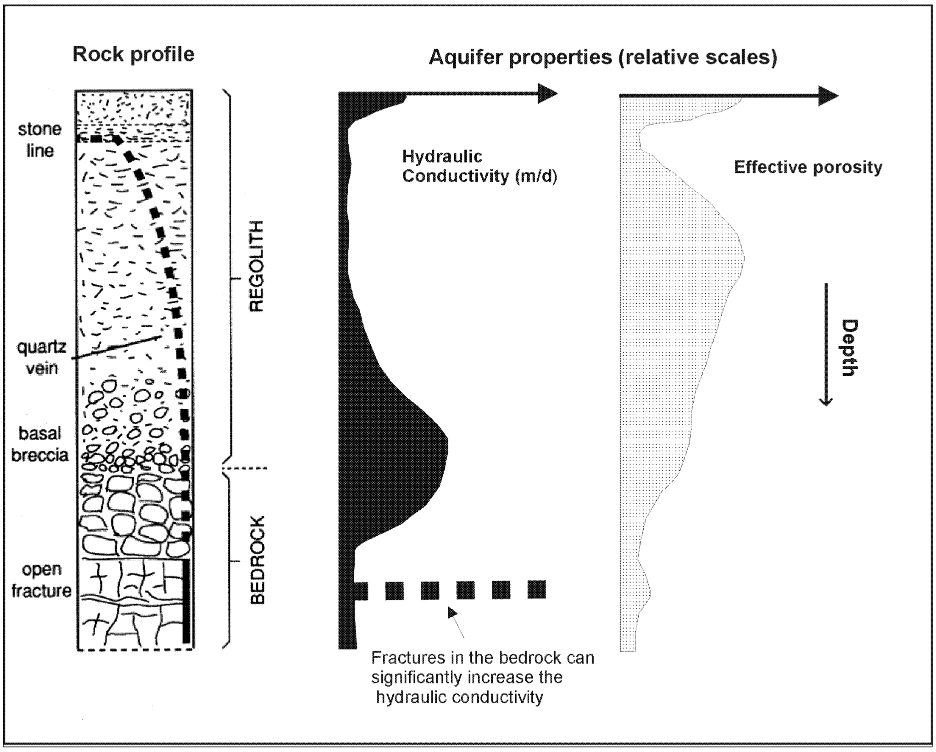

Figure 3 **Variation of permeability and porosity with depth in basement aquifers (based on Chilton and Foster, 1995).**

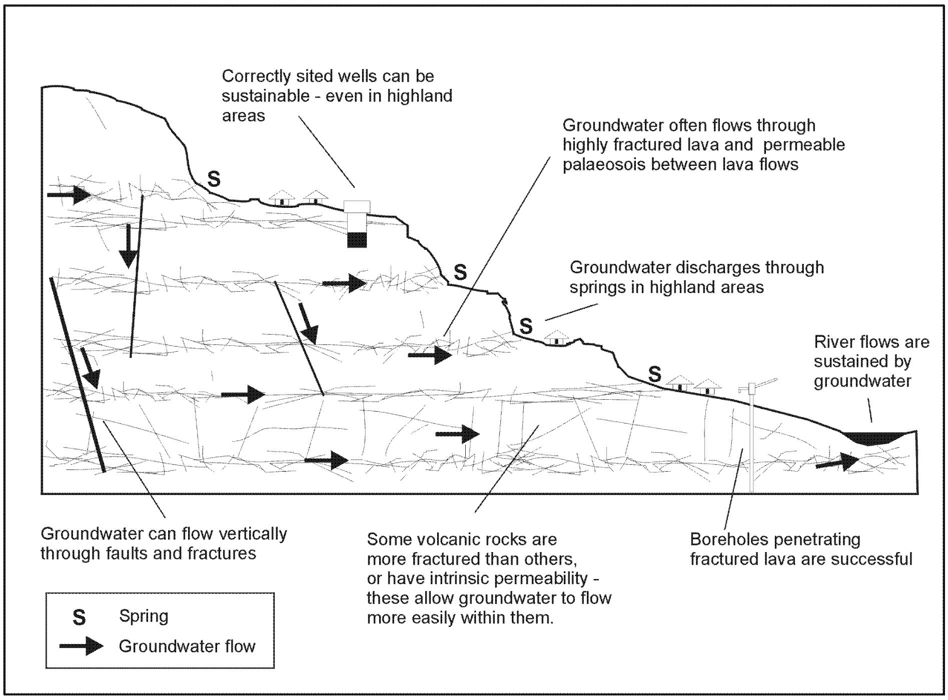

Figure 4 **Cross-section of flow in highland volcanic areas.**

Unconsolidated sediments

Unconsolidated sediments form some of the most productive aquifers in sub-Saharan Africa. They cover approximately 22% of the land surface (Figure 1). This is probably an underestimate of their true importance since unconsolidated sedimentary aquifers (UNSAs) are also present in many river valleys throughout Africa. Examples of extensive deposits are found in Chad, Zaire and Mozambique and in the coastal areas of Nigeria, Somalia, Namibia and Kenya. Guiraud (1988) describes several of the major UNSAs in Africa. The size and physical characteristics of the aquifer depend on how the sediment was deposited. Sand and gravel beds can be continuous over hundreds of kilometres, but are often multi-layered, with sands and gravels interbedded with silts and clays (see Figure 6). Small UNSAs are found throughout sub-Saharan Africa deposited by present day rivers. Here, groundwater is close to the surface, so pumping lifts are small; also the proximity to the rivers offers a reliable source of recharge. Carter & Alkali (1996) and Herbert et al. (1997) give some examples of the small UNSAs in Africa.

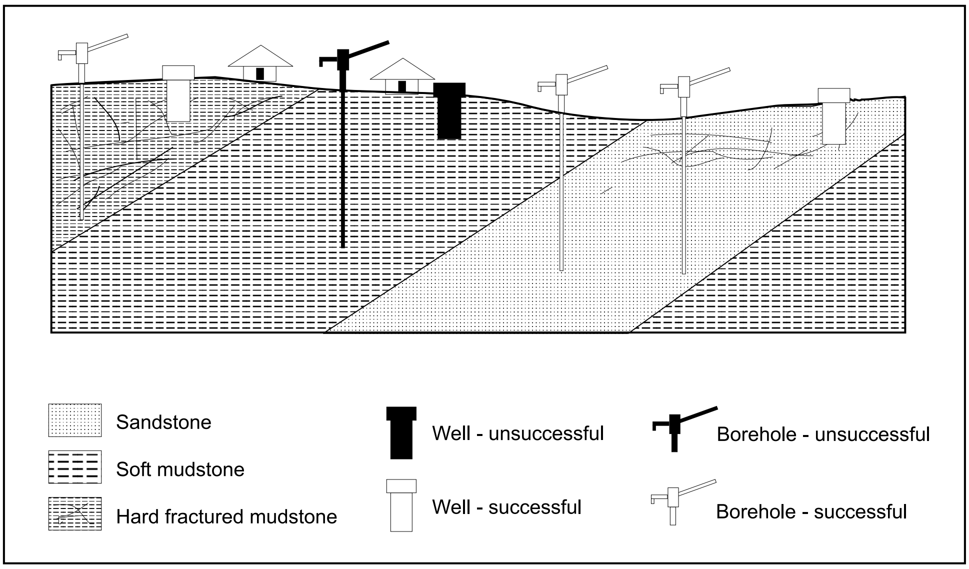

Figure 5 **Groundwater occurrence in consolidated sedimentary rocks.**

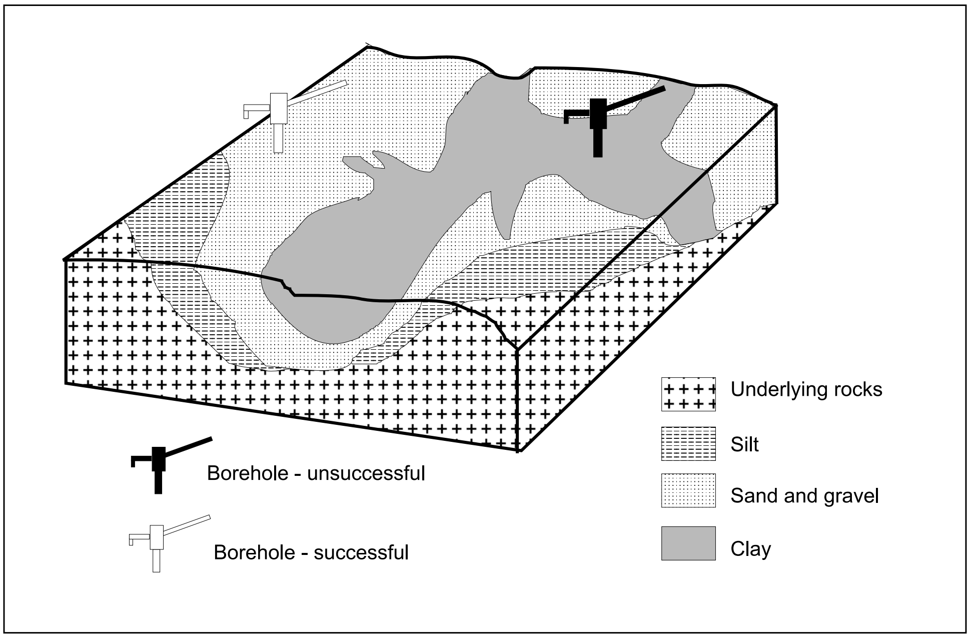

Figure 6 **Groundwater occurrence in unconsolidated sediments.**

HYDROGEOLOGY, HYDROGEOLOGISTS AND RURAL WATER SUPPLY

The basic models for how groundwater occurs in the various hydrogeological environments presented above have been developed from research and experience both in Africa and other similar hydrogeological areas worldwide. Despite much research there remain significant uncertainties and unknowns. Table 1 gives a summary of the current knowledge of the groundwater resources of each hydrogeological environment. Indicative costs of developing a groundwater source are given to help reflect the implications for rural water supply of the varying hydrogeological conditions and the current knowledge base of different aquifers.

Addressing the knowledge deficiencies of hydrogeology in sub-Saharan Africa has significant cost implications. Appropriate levels of investigations can be used for different environments. Simple cost-benefit analysis can help if data are available on drilling costs and success rates 'with' and 'without' different levels of investigation. As noted in Farr et al. (1982) the use of a particular search technique is only justified if it increases the chances of subsequent boreholes being successful, such that the overall saving in drilling costs (through drilling fewer unsuccessful boreholes) is greater than the cost of the search. In some environments, where groundwater is readily available, expensive methods may not be justified. In other environments, however, seemingly expensive methods or studies may be entirely justified by long term savings in drilling costs.

The technical capacity required to develop groundwater also changes with the hydrogeology: in some environments little expertise is required, while in others considerable research and money is required to develop groundwater. MacDonald et al. (2002) summarise geophysical techniques and interpretations in various hydrogeological environments.

1. Where groundwater is easily found (e.g. UNSAs, sandstone aquifers) little expertise is required for wells and boreholes. Although overexploitation and falling water-levels may be a problem.
2. In other areas where groundwater is not ubiquitous, but siting methods are well established standard techniques can be used (e.g. weathered basement rocks). In these areas project engineers and technicians can successfully site wells and boreholes using standard 'rules of thumb'.
3. There are many hydrogeological environments which are complex and no standard techniques are available for siting wells and boreholes (low permeability sediments, poorly weathered basement). In these areas, geophysical and other techniques must be tested to provide new rules of thumb that are appropriate for that environment.

Hydrogeologists have a key role communicating their knowledge to those involved in planning and implementing rural water supply projects. In environments where standard techniques have been developed these should be widely and effectively disseminated so that they can be used by project staff actually involved in implementing projects. Hydrogeological expertise and research budgets can then focus on more difficult hydrogeological areas where groundwater occurrence is not well understood and rural water supplies rarely effective.

Targeting research to difficult areas may not be justified using economic criteria alone. If water projects were judged only on the costs of individual boreholes, then water projects should all be concentrated on areas where it is easy to find groundwater. However, the areas where sustainable groundwater sources are hard to find often have the greatest problems with health and poverty. In these areas, women have to walk further to find water and waterborne diseases such as guinea worm are more common. Helping to solve water problems in these difficult areas may have greater impact on reducing poverty in sub-Saharan Africa than drilling many more boreholes in areas where it is relatively easy to find water.

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