Simple methods for assessing groundwater resources in low permeability areas of Africa

Groundwater systems and water quality
Commissioned Report CR/01/168N
Simple Methods for Assessing Groundwater Resources in Low Permeability Areas of Africa

WEBSITE QUESTION 3
How does one set about assessing groundwater and then siting wells and boreholes for a rural water supply, especially in a developing country where resources are limited?


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Simple methods for assessing groundwater resources in low permeability areas of Africa

A M MacDonald, J Davies and B É Ó Dochartaigh

Key words
Africa; groundwater; hydrogeology; assessment.

Front cover
Community members helping assess the yield of a borehole in Edumoga village, Nigeria.

Bibliographical reference

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Helping to meet International Development Targets is the number one challenge for the water sector. To increase access to sustainable supplies of safe water for the poor, groundwater resources need to be exploited successfully, sustainably and economically on a much larger scale than they are now.

Exploiting groundwater on a larger scale requires knowledge to be transferred more widely and effectively. Unfortunately, techniques for finding and exploiting groundwater are often hidden in scientific journals or project reports, and not widely disseminated. This manual aims to be a first step in providing useful information for project engineers working on rural water supply projects in sub-Saharan Africa. The focus of the manual is on low permeability aquifers, where groundwater is difficult to find. The techniques have been tested by the British Geological Survey for their effectiveness and by WaterAid staff for usability. However the manual is not static and suggestions and comments would be most welcome for future editions.

The manual is an output from a U.K. Department for International Development project (R7353 – Groundwater from low permeability rocks in sub Saharan Africa).

Alan MacDonald
April 2002
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1 Introduction

In many areas throughout Africa, a staggering proportion of wells and boreholes fail. Failure can occur for a number of reasons – inadequate maintenance and community involvement, poor engineering or a lack of water. Often it can be difficult to work out the exact reason after the event. However, in many geological environments the impacts of poorly sited and designed boreholes and wells are a major concern to funding agencies, implementing institutions and local communities. In such areas, good supplies of groundwater cannot be found everywhere, and boreholes and wells must be sited and designed carefully to make use of the available groundwater. To appropriately site and design water sources, the groundwater resources of an area need first to be investigated to understand how water occurs in the ground.

In this manual we present some techniques that allow a quick assessment of groundwater resources without requiring much expertise or expense. Some of the techniques are old and established while others are new. However, all techniques have been tested by BGS (and others) in assessing groundwater resources in Africa. This manual does not claim to be a detailed textbook for hydrogeologists – there are enough already (see reading list at the end of the chapter). Rather it is meant as a practical aid for those involved in the practice of rural water supply, particularly in Africa. Little training or equipment is required for the tests and they can all be carried out in a short space of time.

The manual is divided into six sections. The first gives an overview of the groundwater resources of sub-Saharan Africa (SSA) and discusses the scope and detail of investigations required in different geological environments. The remaining chapters describe simple techniques for assessing groundwater resources, from basic reconnaissance to assessing the yield of a borehole. In the appendix are summary sheets of the most common techniques which can be photocopied and used in the field.

FURTHER READING ON HYDROGEOLOGY
2 Groundwater resources in sub-Saharan Africa

2.1 WHY GROUNDWATER?

Groundwater is well suited to rural water supply in sub-Saharan Africa (SSA). Since groundwater responds slowly to changes in rainfall, the impacts of droughts are often buffered. 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.

Groundwater has excellent natural microbiological quality and generally adequate chemical quality for most uses. Nine major chemical constituents (Na, Ca, Mg, K, HCO₃, Cl, SO₄, NO₃ and Si) make up 99% of the solute content of natural groundwaters. The proportion of these constituents reflects the geology and history of the groundwater. Minor and trace constituents make up the remaining 1% of the total, and their presence (or absence) can occasionally give rise to health problems or make them unacceptable for human or animal use.

2.2 GROUNDWATER RESOURCES IN SSA

Figure 2.1 shows a hydrogeological map of SSA. Broadly, SSA can be divided into four hydrogeological provinces: Precambrian “basement” rocks; volcanic rocks; unconsolidated sediments; and consolidated sedimentary

Figure 2.1 Groundwater provinces in sub-Saharan Africa (based on a number of sources – see MacDonald and Davies 2000).
rocks. Groundwater occurs in different ways in these four provinces, and different methods are required to find and sustainably develop groundwater in each. Basement rocks form the largest hydrogeological province, occupying 40% of the 23.6 million square kilometres of SSA (Figure 2.2); volcanic rocks are the smallest hydrogeological province with only 6% of the land area. The relative importance of the hydrogeological provinces is best indicated by the rural population living in each one. Rural communities are most dependent on local resources for water supply, since transporting water over significant distances is prohibitively expensive and difficult to manage. Figure 2.2 shows the number of rural people living in each of the four main hydrogeological provinces in SSA.

A brief description of each hydrogeological zone is given below. This is a summary of information given in a companion report describing the hydrogeology of sub-Saharan Africa (MacDonald & Davies 2000).

1. Crystalline basement rocks occupy 40% of the land area of SSA; 220 million people live in rural areas underlain by crystalline basement rocks. They comprise hard crystalline rocks such as granite and metamorphic rocks. The occurrence of groundwater depends on the existence of a thick weathered zone (the uppermost 10 - 30 m) or deeper fracture zones (Figure 2.3). Much of the basement has been weathered or fractured. Groundwater in the shallow weathered zone can be exploited with boreholes, dug wells and collector wells; groundwater in the deeper fracture zones can only be exploited using boreholes. Borehole and well yields are generally low, but usually sufficient for rural demand. Good sites for wells and boreholes can be found using standard geophysical

![Land area and rural population of the different hydrogeological zones of SSA.](image)

**Figure 2.2** Land area and rural population of the different hydrogeological zones of SSA.

![Variation of permeability and porosity with depth in basement aquifers.](image)

**Figure 2.3** Variation of permeability and porosity with depth in basement aquifers (based on Chilton & Foster, 1995).
techniques. Groundwater is generally of good quality (occasional elevated sulphate, iron or manganese), but is vulnerable to contamination.

2. Volcanic rocks occupy 6% of the land area of SSA, and sustain a rural population of 45 million, many of whom live in the drought stricken areas of the Horn of Africa. Hard black basalts and ash deposits make up many of the volcanic rocks. Groundwater occurs in zones of fracturing between individual lava flows and within volcanic rocks which have themselves been highly fractured or are porous (Figure 2.4). Yields can be highly variable, but are on average sufficient for rural domestic supply and small scale irrigation. Groundwater in mountainous areas can be exploited though springs, wells and boreholes. Where the rocks are hard and the fracture zones deep, only boreholes are possible. Geophysical methods are not routinely used to site boreholes and wells, but may be valuable in certain circumstances. Groundwater quality can sometimes be poor due to high fluoride concentrations.

3. Consolidated sedimentary rocks occupy 32% of the land area of SSA and sustain a rural population of 110 million. Consolidated sedimentary rocks comprise sandstone, limestone and mudstone and often form

Figure 2.4 Cross section of groundwater flow in highland volcanic areas.

Figure 2.5 Groundwater occurrence in consolidated sedimentary rocks.
thick extensive sequences. Sandstone often contains large amounts of groundwater, particularly where fractured or friable; limestone can also contain significant groundwater. Mudstones, which may comprise up to 65% of all sedimentary rocks are poor aquifers, but groundwater can still sometimes be found in harder more fractured mudstone (Figure 2.5). Where aquifers and groundwater levels are shallow, wells can be used. However where the aquifers are deep, boreholes must be used and need to be carefully constructed and gravel packed to avoid ingress of sand. Geophysical methods can easily distinguish sandstone from mudstone and between hard and soft mudstone. Where sandstone or limestone aquifers are extensive and/or shallow, careful siting is often not required for domestic water supplies. Groundwater quality is generally good, but can be saline at depth, or have localised elevated sulphate, iron or manganese.

4. Unconsolidated sediments cover 22% of the landmass of SSA; at least 60 million rural people live on these sediments, but many of those living on less productive rocks types are close to small unconsolidated sedimentary aquifers (UNSA) associated with river valleys. UNSA comprise a range of material from coarse gravel to silt and clay. Groundwater is found within gravel and sand layers (Figure 2.6). Yields from thick deposits of sand and gravel can be high, sufficient for domestic supply and agricultural irrigation. Where aquifers and groundwater levels are shallow, wells can be used and boreholes installed using hand drilling. However where the aquifers are deep, boreholes must be used and need to be carefully constructed and gravel packed to avoid ingress of sand. Geophysical methods can easily distinguish sand and gravel layers and can be used to indicate the thickness of UNSA. In large UNSA, little siting is required. Groundwater quality problems can occur in UNSA due to natural geochemistry and contamination, such as high iron, arsenic and elevated nitrate.

There are many exceptions to the general models presented here, and areas exist in each of the hydrogeological environments where groundwater is not easily found. More research and experience is required to help refine the models and shed light on the groundwater potential of different environments. Two of the most widespread problematic areas are poorly weathered basement rocks and sedimentary mudstones. Research into the potential for groundwater in these rocks types is limited, and water projects in these areas are rarely successful.

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. 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. 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. Throughout the remaining chapters we discuss which techniques are important for the various hydrogeological provinces.

**FURTHER READING**

**Table 2.1 Summary of groundwater potential of groundwater domains in sub-Saharan Africa with indicative costs of development.**

<table>
<thead>
<tr>
<th>Groundwater Domains</th>
<th>Groundwater Sub-Domains</th>
<th>Groundwater Potential</th>
<th>Average Groundwater Yields</th>
<th>Groundwater Targets</th>
<th>Costs* and technical difficulty** of developing groundwater sources</th>
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<td>Rural Domestic Supply</td>
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<td>Small Scale Irrigation</td>
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<td>Basement Rocks</td>
<td>Highly weathered</td>
<td>Moderate</td>
<td>0.1- 1 l/s Fractures at</td>
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<td>the base of the deep</td>
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<td></td>
<td>basement</td>
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<td>weathered zone</td>
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<td></td>
<td>Poorly weathered</td>
<td>Low</td>
<td>0.1 l/s Widely spaced</td>
<td>£££</td>
<td>Generally not possible</td>
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<td>deep weathering</td>
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<td></td>
<td>Mountainous areas</td>
<td>Moderate</td>
<td>0.5 – 5 l/s Horizontal</td>
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<td>basalt layers.</td>
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<td>More fractured basals</td>
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<td>Plains or plateaux</td>
<td>Moderate</td>
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<td>More fractured basals</td>
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<td>Sandstones</td>
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<td>fractured sandstone</td>
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<tr>
<td></td>
<td>Mudstones</td>
<td>Low</td>
<td>0 – 0.5 l/s Hard fractured</td>
<td>£££</td>
<td>Generally not possible</td>
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<td>mudstones; igneous</td>
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<td>limestone/sandstone</td>
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<td>Limestones</td>
<td>Moderate</td>
<td>1-10 l/s Karstic and</td>
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<td>fractured limestones</td>
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<td></td>
<td>Large basins</td>
<td>Moderate - High</td>
<td>1 – 20 l/s Sand and</td>
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<td>gravel layers</td>
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<td>Unconsolidated sediments</td>
<td>Small dispersed</td>
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<td>deposits, such as</td>
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<td>riverside alluvium</td>
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</table>

*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.
Every good football manager and army general knows the importance of reconnaissance. Only with accurate intelligence on key parameters is it possible to plan a strategy for success. The same is true for water projects. Before a water project can be planned, key socio-economic, institutional and physical information must be gathered – in this manual we are only concerned with the physical issues. There is no point in planning a groundwater project if there is no groundwater available, or in buying sophisticated exploration equipment where groundwater is ubiquitous. In this chapter we describe some simple ways to carry out simple, effective reconnaissance.

### 3.1 EXPERIENCE

It is always helpful to find someone who has worked in the area before. Not only can they give their own opinion of the area, but they can help point in the direction of other projects in the area or maps and reports that might have been written. Box 3.1 gives a list of information that would be useful to discuss with someone who has experience in the area. However, all advise and information given should be treated cautiously and always checked in the field. In our experience, people can often give misleading information in their enthusiasm to be helpful.

### 3.2 OBSERVATIONS - GEOLOGY AND PREVIOUS SUCCESS

The first visit to a project area is very important. It is at this time that lasting impressions are made. The project is also at its most fluid in the early stages so design alterations are much easier. If possible a visit should be made when the water problems are at their worst – during the height of the dry season. Several days should be spent visiting different parts of the area, trying to get a balanced overview of the water problems in the area. This will be easier if maps can be gathered before such a visit. The aim must be to cover much ground and make a rapid assessment, rather than making a detailed assessment in only one or two areas. Box 3.2 lists information that should be gathered.

### 3.3 MAPS AND REPORTS

Useful information often exists hidden away on people’s shelves or locked in government filing cabinets. For most areas it should be possible to gather basic information, such as topographic and geological maps. Often other information exists, such as aeromagnetic maps, aerial photographs and even hydrogeological maps. If other projects have been carried out in the area there will be project reports, and possibly databases of boreholes. Universities are also good sources of information. Geology Departments of nearby Universities will often know most about the current geology, and may have undertaken studies in the area. International consultants can often be useful sources of information and may have access to information that is now not available in country and also have access to academic literature. BGS for example has an extensive library of maps and reports from throughout the world and as a DFID resource centre offers a free enquiry service for people in developing countries. Table 3.1 lists different organisations that are useful to contact, and the information that may be available in each.

### 3.4 SITING BOREHOLES AND VILLAGES ON MAPS

Knowing where most of the villages are is an important part of the planning phase of a project. It is then possible to plot them on maps and therefore estimate what geology

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**Box 3.1 Questions to discuss with someone with previous experience of the project area.**

- What was their involvement in the area?
- How easy is it to find groundwater – what was their success rate?
- What do they know about the geology?
- Do they have records/reports of borehole drilling, or the project in general?
- Ask them to draw a map of the area, showing geology and easy/difficult areas to find water.
- Any poor water quality in the area?
- What techniques would they consider for finding groundwater?
- What other projects do they know of and people knowledgeable about the area?

**Box 3.2 A first field visit.**

Take a GPS (see section 3.4), magnifying glass, hammer, water level dipper, pH meter and compass-clinometer.

Drive along main roads cutting across the area and stop where there is rock at the surface (often in river valleys). Examine and describe the rocks, and take a sample. Take a GPS reading of any stop you made so it can be marked on the map.

At representative villages discuss carefully the water supply problems. Walk to the dry season water source and try to work out why there is water there, measure the water EC and pH. Note any successful or dry wells and boreholes and measure depth, depth to water level, EC and pH. Discuss any previous unsuccessful drilling and work out the geology for the village from samples at the bottom of wells, or nearby river valleys.

Note areas (discussing with local NGOs or government officials) where there are successful wells and boreholes, and areas where boreholes and wells have been unsuccessful.
underlies each village. At the reconnaissance stage this gives a good idea of the proportion of villages underlain by each geological unit. In the same manner each improved water source (such as borehole or improved well) can be located on maps, and each abandoned borehole. This will help assess which areas are easy to find groundwater and which are difficult.

With the advent of GPS (global positioning system) it is now very easy to locate wells and villages on maps. GPS are small inexpensive pieces of equipment about the size of a mobile phone or calculator (Figure 3.1). When switched on they track the position of satellites and from this information can accurately locate where they are on the ground. They can give a read out in decimal degrees or in many local grid systems. For greatest accuracy they should be set up to the same grid system as the maps on which the information will be plotted.

### Table 3.1 Information available from different organisations.

<table>
<thead>
<tr>
<th>Institution</th>
<th>Data &amp; Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mapping Institute</td>
<td>Topographic maps, aerial photographs</td>
</tr>
<tr>
<td>Geological Survey</td>
<td>Geological maps, aerial photographs, hydrogeological maps, aeromagnetic maps</td>
</tr>
<tr>
<td>Rural Water Department</td>
<td>Databases of boreholes, reports of previous projects or statewide surveys</td>
</tr>
<tr>
<td>Universities</td>
<td>Geological maps, local research in the area.</td>
</tr>
<tr>
<td>Local NGOs, local government</td>
<td>Databases of boreholes, consultant's reports, records of those who have worked in the area.</td>
</tr>
<tr>
<td>International Geological Organisations</td>
<td>Geological maps, Consultants reports, academic literature.</td>
</tr>
</tbody>
</table>

3.5 **FURTHER TECHNIQUES**

3.5.1 **Satellite interpretation**

It is sometimes useful to use information from satellites to help create a base map for the area. This is a specialised technique and will require the input of a good consultant or university. A satellite image contains information from the light spectrum and is interpreted to help give an indication of changing conditions on the ground. Under good conditions changes in geology can sometimes be observed. Fracture zones, rivers and roads are interpretable with experience. Information from satellite images can be presented on maps at about 1:50 000 scale. Although useful for a reconnaissance of an area, satellite images cannot normally be used by themselves for siting wells or boreholes.

3.5.2 **Geographical information systems (GIS)**

GIS are excellent tools for water supply projects. They allow map information to be combined, analysed and presented in many different ways. This means that tailor made maps can be easily created for different project stakeholders. However, to set up a GIS demands specific expertise and considerable effort to get all the data in the appropriate format. Universities and consultants however should be able to carry out this work.

To create a GIS for an area available data are put into digital form. That means digitising topographic and geological maps and making sure they are in the same map registration. Once this is done other information, such as village locations can be added and plotted on top. Once some investigations have been done preliminary groundwater potential maps could be drawn up and printed for use in the field.