The changing role of hydrogeology in semi-arid southern and eastern Africa

N. S. Robins · J. Davies · J. L. Farr · R. C. Calow

Abstract Much of southern and eastern Africa is semi-arid and heavily groundwater dependent. Borehole drilling commenced over a hundred years ago with magnetic and electrical resistivity surveys for borehole siting being introduced from 1936. Formalised training of hydrogeologists led in the 1970s to an almost standard approach to hydrogeological investigation and a period of stability followed, during which some major investigations were carried out. A period of decentralisation and fragmentation has since taken place in many parts of southern and eastern Africa, and groundwater monitoring and management are inadequate in many countries. All but six of the 14 SADC (Southern African Development Community) member states reportedly have an adequate monitoring network in place. However, groundwater demand is increasing and hydrogeologists need to promote the use of appropriate methodologies as an essential part of tackling the severe issues now facing the water sector in the region.

Résumé Le sud et l'est de l'Afrique sont essentiellement semi-arides, et grandement dépendant des eaux souterraines. Les opérations de forage ont débuté il y a plus d'un siècle, les premières campagnes magnétiques et de résistivité électrique pour l'implantation des forages datant de 1936. L'entraînement officialisé d'hydrogéologues a mené au cours des années 1970 à une approche presque standard à l'enquête hydrogéologique et à une période de stabilité suivie, pendant lequel quelques enquêtes importantes ont été réalisées. Une période de décentralisation et fragmentation s'est depuis installée dans plusieurs zones de l'Afrique orientale et australe, et la gestion et le suivi des eaux souterraines sont insuffisants dans de nombreux pays. Sur les quatorze pays membres de la Communauté de Développement de l'Afrique Australe (SADC), huit possèdent officiellement un réseau de suivi opérationnel suffisant. Cependant les besoins en eau souterraine sont en pleine augmentation, et les hydrogéologues se doivent de promouvoir l'utilisation de méthodologies appropriées comme un moyen de lutte essentiel contre les problèmes graves menaçant actuellement le secteur de l'eau dans la région.

Resumen Gran parte del sur y oriente de África es semiárido y depende fuertemente del agua subterránea. La perforación de pozos empezó hace unos cien años con levantamientos de resistividad eléctrica y magnéticos para delimitación de pozos que se iniciaron en 1936. La formación formalizada de hidrogeólogos condujo en los años 1970 a un acercamiento casi estándar a la investigación hidrogeológica y un período de estabilidad seguida, durante que algunas investigaciones principales fueron realizadas. Desde entonces se ha registrado un periodo de descentralización y fragmentación en el sur y oriente de África, con una gestión y monitoreo inadecuado de aguas subterráneas en varios países. Seis de los catorce estados miembros de la SADC (Comunidad para el Desarrollo del Sur de África) han reportado contar con una red de monitoreo adecuada instalada. Sin embargo, se ha registrado un incremento en la demanda de agua subterránea y los hidrogeólogos necesitan promocionar el uso de metodologías apropiadas como parte esencial de atacar los problemas severos que enfrenta el sector hídrico de la región.

Keywords Africa · Groundwater development · Drought · Water supply · General hydrogeology

Introduction and background

Sub-Saharan Africa (Fig. 1) has a runoff to precipitation ratio of only 0.20 compared with a global continental mean of 0.35. This is due to lower overall rainfall, low relief, high evapotranspiration and low groundwater baseflow and recharge (Wright 1992). Not only is much of Africa poorly endowed with water, but demands are also increasing, and groundwater is the only practical means of

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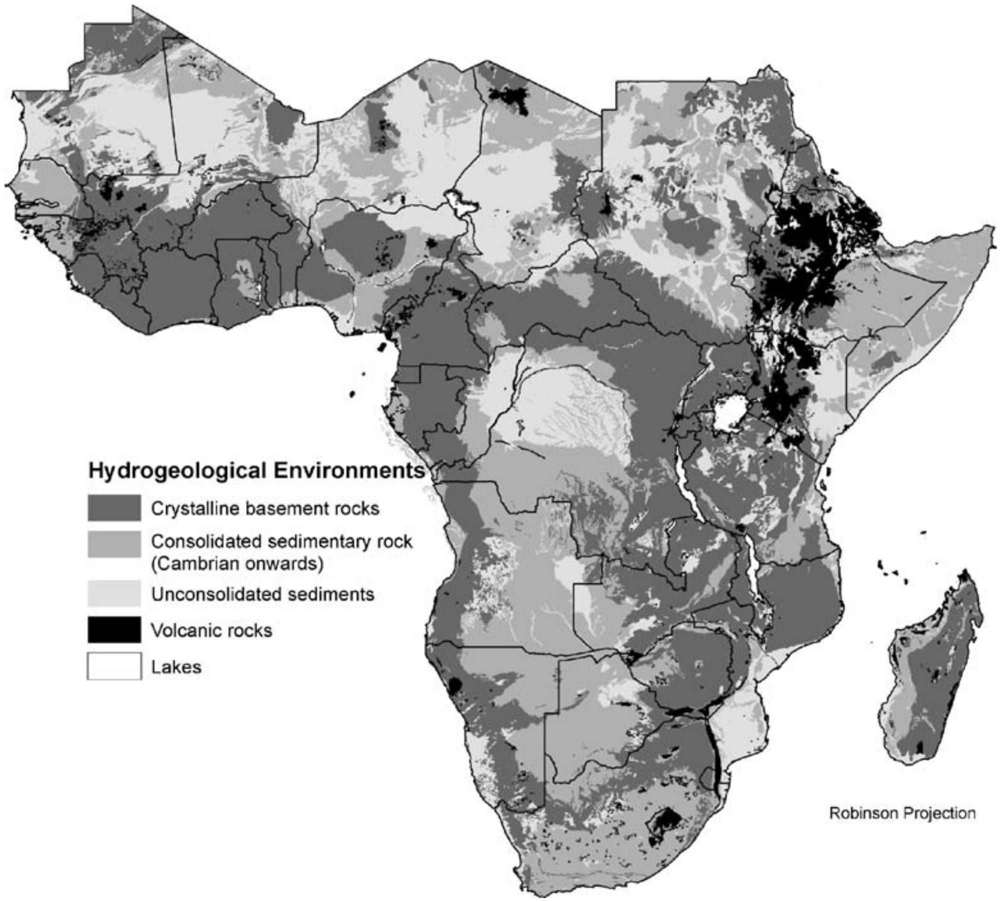
Fig. 1 Sub-Saharan hydrogeological domains and the semi-arid land



meeting rural community needs at relatively low cost. Hydrogeology has thus had a critical role to play in assisting the development and maintaining the survival of many of the semi-arid nations in eastern and southern Africa. Groundwater resources are by their nature out of sight and are, therefore, difficult to quantify by the non-hydrogeologist. A comprehensive understanding of the groundwater resources through applied hydrogeology is likely to be the key to the future economic and social well being of the region in the twenty-first century.

Groundwater traditionally sustained both the fixed communities and the more nomadic groups such as the San people throughout the semi-arid areas of southern Africa. Springs were easily developed for village and stock use and shallow wells were dug to provide water sources. Witch doctors (nungas) offered divining skills as well as advice on reticulation. The Arab influence along the east and central African trade routes encouraged more sophisticated lined wells to be developed, whilst missionaries brought with them hand pump technology that was developed in Europe during the nineteenth century, and the military brought the driven tube well or ‘Abyssinian well’ technology.

At the beginning of the twentieth century, the people of southern and eastern Africa were largely settled on the more productive lands where groundwater supplies were relatively abundant. Only the nomadic tribes inhabited the more marginal lands such as the Kalahari and the Karoo, as the demographic and political pressures to settle and utilise such lands did not develop until the latter part of the twentieth century.

The steam driven drilling rig arrived in the African continent in the late nineteenth century. Early water drilling was usually undertaken at sites selected according to demand rather than indications from the lay of the land or vegetation patterns that groundwater was likely to be available in the vicinity. Valley bottom alluvium was a popular first choice, but the requirements to supply steam locomotives on the expanding railway networks, of farmers wanting to irrigate fruit, vegetables and cash crops and of the burgeoning mining industry wanting to support its labour camps, soon required less hydrogeologically favourable locations to be exploited. However, railway workshops were specifically located at De Aar in the South African Karoo and at Mahalapye in Bechuanaland (Botswana) because of groundwater resources available at these locations. Many water supply boreholes were also drilled by Public Works Departments for road construction, township and institutional supply and latterly along cattle trek routes. When selecting borehole sites, use also began to be made of available geological knowledge, of surrogate indicators (such as vegetation, variations in soil cover and the occurrence of termite mounds), and topographic indicators of potential hydraulic features such as dolerite dykes.

The apparent success in satisfying demand in these many and remote locations was, even by today’s stan-

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dards, remarkable. However, the failure rate was then, and is to this day, not properly recorded, and dry and poor yielding boreholes or even sources of brackish water tended to be dismissed and not documented. Vegter (2001) estimates that 1,500 water boreholes (generally <20 m deep) had been drilled in the Cape of Good Hope and Orange Free states by 1896, compared with the estimated total of 100,000 in 2000.

During the first half of the twentieth century, geologists experienced in groundwater resource development collected and transferred their collective experience from the UK to India, Australia and Anglophone Africa while working for the Imperial Geological Survey. That borehole siting remained dependent on directions from the geologist is illustrated by some of the classic work described by Alex du Toit (du Toit 1906, 1915, 1928).

The application of essential geological work to borehole siting was, however, supplemented by the deployment of geophysical techniques at a surprisingly early stage in some areas of Africa. Vegter (2001) reports that magnetic and electrical resistivity methods were introduced for water borehole siting by the Geological Survey in the Union of South Africa during 1936, and electromagnetic techniques followed in 1945. Shaw (1935) described the successful application of the resistivity geophysical method in Southern Rhodesia (Zimbabwe) to investigate groundwater occurrence. Way (1939) reports on the successful application of resistivity surveying to site water boreholes in Uganda since the technique was first introduced there in 1937. This work is significant in that it highlights for the first time the benefits of finding topographic lows in the weathering of the basement rocks and recognises the importance of dolerite dykes either as hydraulic dams or conduits. Similar work in Nyasaland (Malawi) led to the publication of a handbook on resistivity surveying (Cooper 1950), which was widely acknowledged throughout the Africa region. Paver and Pretorius (1954) applied their experiences of hydrogeological investigations obtained in the western deserts of Egypt to areas of South Africa, although the existing Megger Earth Tester resistivity units were cumbersome and difficult to use (Barker 2004).

Jennings (1969) reports that 13,000 electrical resistivity depth soundings had been carried out in Botswana and these had helped increase the success rate of drilling for water on the African Shield Basement areas from 35 to 70%. The resistivity equipment that was applied used a direct current system and was jointly developed with the Council for Scientific and Industrial Research in Pretoria, South Africa specifically for the dry conditions in the Kalahari. Accompanying these developments was the retention of detailed notes and records of the geophysical surveys and the establishment of records systems for the resultant boreholes. Similar trends are recorded in many other eastern and southern African countries, although in a number of countries much of this information has been mislaid.

Noteworthy, are some significant pieces of hydrogeological investigation carried out in the 1950s and 1960s. In Botswana, for example, Van Straten (1955) used groundwater chemistry in conjunction with field capacity and porosity measurements of the Kalahari Sands to demonstrate that recharge in areas where the sand exceeded 7 m thickness was extremely rare. The water-bearing properties of the various lithologies in the region were described by Boocock and van Straten (1962). Experience gained from dewatering the deep gold mines in South Africa led to a detailed understanding of the Far West Rand dolomitic area (e.g. Enslin and Kriel 1959) and as early as the 1960s, groundwater provenance using isotope chemistry was being investigated in southern Botswana and South Africa (e.g. Vogel and Bredenkamp 1969). During this period, Southern Rhodesia (Zimbabwe) had hydrogeological input from a variety of sources including the US Geological Survey and some detailed catchment scale surveys were carried out. Dennis (1961) and Hindson and Wurzel (1963) also investigated the occurrence of groundwater in the lower Sabi Valley for irrigation usage.

By the early 1970s, groundwater investigation in eastern and southern Africa was set to blossom with the increasing employment of well-trained indigenous hydrogeologists returning from the newly created Masters Degree courses which were then becoming available in the UK and elsewhere. The application of the science of hydrogeology (or geohydrology as it is commonly called in South Africa) was very much in the ascendancy throughout the region, and was being applied to enable (supposedly sustainable) groundwater sources to be developed in marginal lands that were previously unsettled and unusable.

This report describes the important role hydrogeology assumed in the immediate post-colonial era throughout the semi-arid regions of eastern and southern Africa. The contrast is made with the present reduced status of groundwater monitoring and management apparent in some countries in the region today, and the preference of many of the implementers to deploy non-hydrogeologists to supervise groundwater development projects. To a large degree, this reflects a currently held, but misplaced, philosophy that sustainability is a management and financing issue with little if any technical dimension. The report identifies the development of hydrogeological understanding in eastern and southern Africa. It argues that appropriate hydrogeological application is essential to optimise the use of Africa's increasingly scarce water resources.

Capacity building

The 1970s was characterised by the improved well-being of humans and the consequent increase in water demand throughout the newly independent African nations (Table 1). This included roads, agricultural projects, rural community water supply, improved sanitation and the fight against disease, provision for schools and clinics, and the resettlement of refugees in marginal lands following periods of conflict (Mozambique, Zimbabwe, Angola, Namibia) which followed independence.

In the early 1970s, and as a consequence of the previous British colonial connections, young British hydrogeologists

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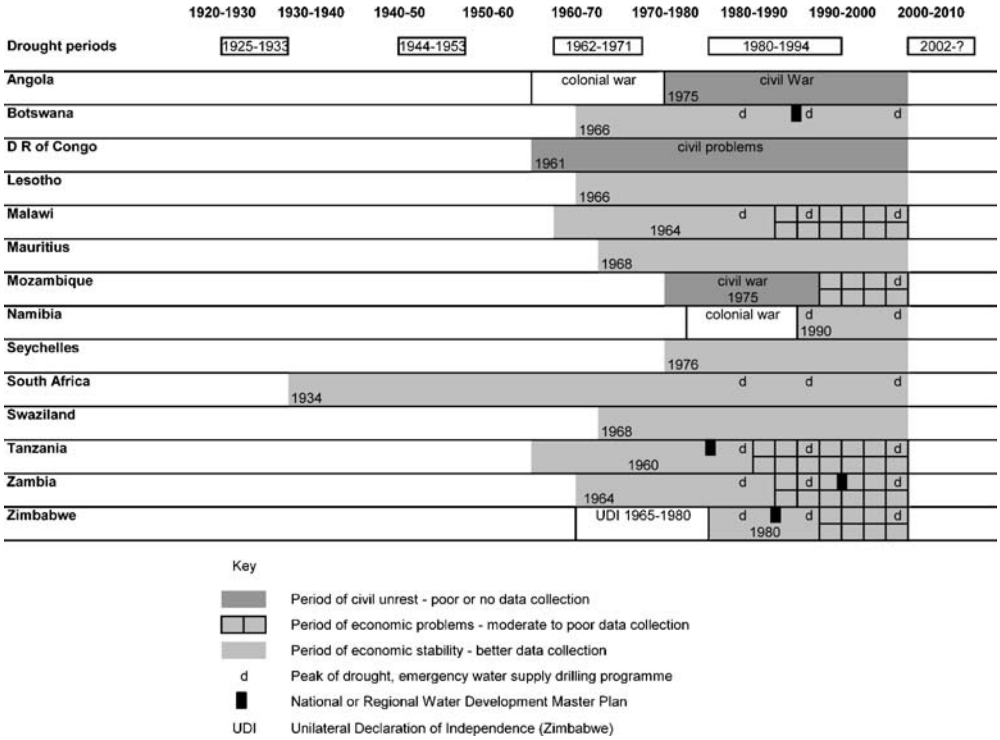
Table 1 Social, political and economic constraints since independence



were recruited or seconded to assist with national groundwater development programmes in a number of eastern and southern Africa nations. As well as providing a certain degree of standardisation between the various national Geological Surveys in their approach to groundwater exploration, drilling, borehole testing and data gathering, this also ensured cross fertilisation of ideas then coming out of Europe with standard approaches to groundwater development that had by then evolved in eastern and southern Africa. For the first time, suitably trained, albeit largely inexperienced, hydrogeologists were now available to design and undertake relatively sophisticated investigative programmes as part of the drive to optimise groundwater development in the difficult semi-arid terrain.

A period of stability

The 1970s was a period of stability in which a large variety of projects was undertaken, and from which data were gathered, collated and analysed. It was also a period when the science of hydrogeology was still being developed and hydrogeological input did not always benefit the African people as much it benefited the science. Nevertheless, groundwater dependent communities grew in number and allowed the settlement of new but marginal land. Farmers became even more dependent on groundwater for irrigation and the many new mining enterprises relied exclusively on groundwater to sustain their activities. These larger scale developments required not just single boreholes with hand pumps, but whole motorised well fields. To develop such well fields, modern air percussion drilling techniques were imported into southern Africa using water well drillers from Nigeria, the Middle East and eastern Africa and the well fields needed to be tested for both short-term potential and longer-term sustainable capacity.

Extensive experience was available from the South African mining industry and this was exported initially to Botswana and Zambia, where Australian based consultants were also active. Several sophisticated group pumping tests, supported by detailed hydrochemical investigations to assess groundwater recharge potential, were carried out by private sector consultants and contractors under the supervision of government agencies. The first of these included investigation programmes that supported the development of the Anglo-American Corporation diamond mines at Orapa in northern Botswana (Gibb 1969; Mazor et al. 1977) and Jwaneng in central Botswana. The initial Orapa project resulted in 32 boreholes being drilled through the Kalahari Beds and the Drakensberg Lava into the Cave Sandstone of the Karoo Supergroup to provide a combined yield of 2,100 m^3 day^{-1}.

In the 1970s in Zimbabwe, Jeremy Prince was the principal private sector consultant siting boreholes, and Whitehead and Jack was the main drilling contractor drilling boreholes for commercial farmers and Rhodesia Railways. Gear (1977) described the occurrence of groundwater in Zimbabwe and MacDonald (1970) provides examples of some of the railway activities. In Zambia, the hydrogeological resources of the Ndola dolomite aquifers were investigated and modelled. In Lesotho, groundwater

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resources were investigated by Binnie and Partners (1971) and Bonney (1975). In addition, the Swedes were active in Tanzania and the Germans in Botswana.

At the other end of the scale, less groundwater dependent nations such as Swaziland were only just completing their first well inventory and taking stock of the available resources (Robins 1980). An important feature of this period of relative stability in all the countries noted was that centralised national records were meticulously maintained of all activities from borehole siting, drilling and testing of major industrial development projects. This period also witnessed the first national groundwater reviews, including the report on the groundwater resources of Kenya (WHO 1973) which was followed in 1979 by the National Master Water Plan for the country. Other countries, such as Zimbabwe, were quick to follow.

Technological improvements in the field of hydrogeology included the introduction of the alternating current ABEM Terrameter in the late 1970s, which largely replaced the locally built direct current equipment that suffered the problem of interfering telluric currents. Borehole siting continued to be dominated by resistivity methods and it was only in 1984 that the EM34 system was given a successful trial in Zimbabwe. Satellite imagery also became available in the early 1980s, a welcome supplement to the 1:~50,000 scale black and white air photography which was produced in the 1950s and 1960s for much of Sub-Saharan Africa. Even the drilling rig changed at this time, with low-pressure down-the-hole hammer rigs coming in during the early 1970s and the high-pressure versions following a few years later. These largely replaced the old cable tool percussion, or jumper rigs in time for the massive drought relief programmes which were to characterise much of the 1980s.

During the late 1970s, the responsibility for groundwater development was largely moved from the 'geological surveys', where it had resided for half a century, to 'departments of water affairs'. This was designed to place the emphasis on provision rather than on the science, and happened in January 1977 in South Africa when the Groundwater Division of the Geological Survey was merged with the Geohydrology Division in the Department for Water and Forestry. However, it heralded a slow dissociation between the underpinning science of geology and the provision and management of water derived from groundwater sources. Also, around this time, a number of regionally based consulting organisations became established to provide specialist services in groundwater exploitation to government, industry and others.

Training in practical hydrogeology also became an important part of the hydrogeological remit during the late 1970s and early 1980s. With the onset of localisation in the government agencies responsible for groundwater development it was important that local staff understudied the outgoing expatriates so that the work programmes continued largely unaffected. International transfer also became significant so that the excellent hydrochemical facilities developed at the Geological Survey in Botswana could be replicated in other front line states such as Zimbabwe and Malawi.

Consolidation of data and encouragement of the data cycle—collect, collate, interrogate, apply and collect again (Mckenzie 1997)—was promoted at national centres throughout eastern and southern Africa. Considerable thought was given to how best to gather and collate the data (Worthington and Martinelli 1977; Sekwale 1984). However, the data cycle was often incomplete with the emphasis on collection and storage rather than use, and without establishing who the data users ought to be and what their needs were. Other problems from this era were the lack of application of major studies such as the national water plans, and it was generally a period when much unwanted infrastructure was put in place whilst engineers and other experts made decisions on behalf of, and in isolation from, the user communities.

UN World Water Decade

Groundwater was developed at an increasing pace throughout the 1980s. This was the UN World Water Decade (1980–1991), an initiative that attempted to enhance awareness but which was inhibited in areas of civil unrest such as Angola and Mozambique. The list of significant groundwater projects from this era that enhanced regional hydrogeological knowledge is extensive and include:

- The Botswana GS10 project was a 6-year national programme which included the investigation of the groundwater resources of the Kalahari Karoo and Transvaal aquifers (Farr et al. 1981)
- Investigation of the shallow weathered basement aquifers in Zimbabwe and Malawi (Jones 1985; Acworth 1987)
- A major village water supply programme in Malawi which featured the introduction of village level operation and maintenance hand pumps (Smith-Carington and Chilton 1983)
- Two separate emergency drought relief drilling programmes in Zimbabwe, Matebeleland in 1983 and Victoria Province 1984 (Houston and Lewis 1988)
- Dambo research in Malawi, Zimababwe and Zambia (McFarlane 1992)
- Development of collector wells in areas of poor groundwater potential to provide sustainable supplies (Wright et al. 1987)
- Sand river groundwater storage (Nord 1985)
- The hydrogeology of dolomite aquifers at Kabwe, Zambia (Houston 1982)
- Production of a series of 1:1,000,000 scale national hydrogeological maps for UNESCO of eastern and southern Africa produced using a standard format based upon limited non-digital data with high input of the field experience of in-post hydrogeologists
- Extensive research and groundwater investigation programmes, principally for urban, industrial and agricultural use, in the Republic of South Africa

The 1980s was also the decade of the 'national master plan', for example Zimbabwe (Interconsult 1985), Tanzania Tabora Region (Brokonsult 1980) and later in Botswana (DWA 1991) and Zambia (JICA 1995). Similar work has been carried out elsewhere with, for example, Scandinavian assistance in Tanzania, German assistance in Botswana and Namibia and Italian assistance in Lesotho. All of these documents have stood the test of time and remain definitive statements on the groundwater potential of the respective countries. These valuable documents are not easy to access and may not necessarily reflect current development philosophy and consequently remain little used.

Although the expatriate hydrogeologist communities in eastern and southern Africa remained buoyant during this period, there was a decline in the number of residential posts and an increase in the numbers of advisory and consultative visits. This reflected both the increasing availability of trained indigenous hydrogeologists and the increasingly specialist nature of the work required. Tasks now included remote sensing, hydrogeochemistry (e.g. Verhagen 1990), digitisation of records and design of databases (McKenzie 1997), geophysical and hydrogeological mapping. In South Africa, it was recognised that groundwater was an important contributor to the GNP and considerable effort was being made to develop and safeguard sustainable supplies and to provide safe and sustainable water to rural communities (Pieterson 2005). This effort continues to this day and sets South Africa apart from the remainder of the region, although there are still some areas where coverage still needs to be increased. Considerable regional level research is also being promoted from South Africa throughout much of sub-Saharan Africa (e.g. Woodford and Chevallier 2002; Zu and Beekman 2003).

Decentralisation and fragmentation

A number of significant changes came about in the 1990s (Ockelford and Reed 2002). The move towards 'bottom-up management' was partly driven by donor pressure whilst the role of implementer largely fell to the non-government organisations (NGOs). Although laudable in approach, it brought about a rapid fragmentation of interests and the longstanding institutional knowledge base as well as a noticeable collapse of record keeping and data gathering in many countries of the region (Calow et al. 2002). Perhaps more significantly, the 1990 decade started with probably the worst drought event in living memory to hit the region, but the need to provide a long-term technical response to such a wide scale emergency failed in favour of short-term emergency relief (Clay et al. 1995). In many countries, the resident technical capability to make the longer-term response was already inadequate, and was exacerbated by the massive short-term emergency effort and mobilisation of external consultants (Calow et al. 2002).

Drought: a focus for aid programmes

Drought is endemic throughout much of the region and it should, therefore, be an inherent part of any national planning. The principal recent droughts occurred in the periods 1946–1947, 1965–1966, 1972–1973, 1982–1983, 1986–1988, 1991–1992 and 1994–1995, all corresponding to major el nino events. Long-term flow data from Victoria Falls, on the Zimbabwe and Zambia border, indicate that flows were below mean until 1945, above mean to 1980 and thereafter fell below mean to the present day (Skofteland 1995). This indicates that the period 1945–1980 enjoyed more rainfall, whilst the last 25 years represent a period of reduced rainfall with greater frequency of drought. This latter period of diminished rainfall has been critical to rural communities throughout Sub-Saharan Africa, where demographic stresses have increased demand on available water sources. Demand has also been redistributed so that it is difficult to plan for in a number of countries, influenced by the effects of war and the inevitable creation of refugees, and more recently by economic instability.

The 1991/1992 southern African drought demonstrated that few governments were prepared for prolonged drought (Calow et al. 1997): Zimbabwe ignored warnings from technical experts about the onset of crisis; the scale of the drought in Malawi caused the Kwacha to devalue by 40%; and in South Africa the Government belatedly reacted with its own emergency relief programme. During this event drought-induced failure of groundwater sources forced people, often women and children, to walk long distances in search of alternative supplies. By the end of the 1991–1992 drought in Malawi, normally reliable groundwater sources began to fail leaving some 3 million rural people without adequate water supplies. One consequence was the use of unprotected sources for drinking, and outbreaks of diarrhoea, cholera and dysentery claimed many lives. In Zimbabwe, South Africa and Lesotho, severe water shortages affected large areas of the country and emergency relief programmes were hastily organised. With the exception of South Africa, these relied heavily on external assistance channelled through government or intermediary agencies and NGOs. Despite the broad success of relief efforts in averting famine, many weaknesses in drought preparedness and emergency response were exposed, particularly in relation to rural water supply. Since that time, little effort has been made to incorporate the lessons learned into longer-term development assistance or emergency responses to non-food needs (Calow et al. 2002).

Fragmentation and loss of focus

During the 1980s, emphasis in the groundwater sector in the region had slowly swung towards community water provision and community maintenance of an increasing number of boreholes. At the same time, growing demand for water and limited government capacity to develop and maintain new and existing infrastructure prompted a major

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rethink in the role of government. Under pressure from the donors, the funding agents themselves, many governments embarked on a major process of decentralisation and a rationalisation of government tasks. In particular:

- Decentralisation of tasks to lower levels of government, and drift in role of government from service provider to facilitator with the consequent shedding of responsibilities in, for example, drilling
- Emergence of partnership arrangements between governments, private sector, NGOs and community based organisations (CBOs) under which responsibilities for service delivery and groundwater development have shifted to institutes outside the government sector, but still with government oversight
- Much greater emphasis on community participation in the implementation process, with service providers working with, rather than on behalf of communities to offer informed, demand responsive choices

However, this created some unforeseen problems with respect to the technical elements of groundwater development and service delivery. One of these was the increased use of private-sector drilling contractors which created new problems in the form of contract management, reliable data gathering and workmanship. This also encouraged the growth of private-sector consultant companies to assist the government institutions in the task of groundwater development, with a consequent rapid ‘decentralisation’ of data gathering and archiving. Whilst there was an improvement in data reliability, with contractors being supervised by qualified consultants, there were inadequate structures in place to ensure that the ensuing hydrogeological information became a ‘national asset’ in a centralised repository. In addition, private sector consultants became important sources of essential groundwater information and government water departments typically lost experienced staff to the growing regional consultant industry with a resulting loss of inhouse capacity.

A further progression that profoundly influenced the collection of reliable and useful groundwater data was the emphasis on ‘community-focussed’ groundwater development and a corresponding increase in involvement and use of NGOs and others to undertake such work. This has induced a concentration on the ‘social’ aspects of water provision and management, with a loss of emphasis on the science of understanding the groundwater resource and its sustainability and replenishment. There has been a tendency by government to allow NGOs to ‘take over’ the groundwater sector for reasons of expediency with respect to the NGOs ability to mobilise funding, execute development and minimise the institutional workload, but with a consequent loss of data provision and knowledge transfer with the consequent effect of not being able to adequately manage the resource (Foster 2000). Many NGOs do not fully appreciate the role of, or incorporate a position for, a hydrogeologist in groundwater development for rural communities and few attempts have been made to understand the sustainability of the resource through development of conceptual models and data analysis.

A third progression that influenced the availability and veracity of groundwater information, is the lack of clear demarcation of responsibilities amongst different institutions now involved in service delivery (Maxwell 2001). The new oversight and support role is very difficult as numerous institutions are involved, and this ‘fuzz’ allows data issues to be downgraded or omitted completely. For instance, the 1984 drought and refugee resettlement schemes eventually led to the collapse of the central government database in Zimbabwe, with local databases thereafter being maintained to various standards at district level.

It must be conceded that at the present time, many NGOs are beginning to realise the importance of developing, understanding and managing the groundwater resources and the longer-term value of data, although most usually as a result of inadequately planned (poor value for money) and limited success programmes in the past (Robins et al. 2003).

With respect to national groundwater archives and databases, it is known that at the time of the first World Water Decade in the 1980s, attempts were made in Malawi and Zimbabwe to collate and digitise available groundwater data, and some form of digital national groundwater data archive has also been in existence in Botswana since the early 1980s. However, digital data storage has only been widely adopted in the region in the last 10 years. The key challenge is to ensure integration of technical parameters and the data cycle into the new institutional arrangements which are emerging in many countries.

The twenty-first century

The country assessment evaluation (SADC 2002) carried out for the fourteen member states of the Southern African Development Community (SADC) reported the following inventory on groundwater monitoring in the region:

> Only six of the (SADC) member states (Lesotho, Mauritius, Namibia, South Africa, Swaziland and Zimbabwe) have fully fledged national monitoring networks involving water level and some type of water quality measurements. In the majority of the remaining countries, some monitoring is going on but it is generally carried out in an ad hoc fashion (both frequency and number of monitoring points) or is only carried out locally, usually for wellfields or areas of heavy groundwater use. Furthermore, much of the local scale and wellfield monitoring is undertaken by private companies, water utilities or as part of specific projects with little or no data reaching the national groundwater authority. In some countries (Malawi and Democratic Republic of Congo), no time series hydrogeologic data of any type are being collected, all data being collected

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Table 2 Groundwater dependency in SADC member states

Member state	Rural	Urban	Agriculture	Industry	Overall dependency
Angola	Mod	Mod	Mod	Min	Mod
Botswana	Maj	Mod	Maj	Maj	Maj
DR Congo	Min	Min	Min	Min	Min
Lesotho	Mod	Mod	Min	Min	Min
Malawi	Maj	Min	Mod	Min	Mod
Mauritius	Min	Mod	Mod	Mod	Mod
Mozambique	Mod	Mod	Min	Min	Mod
Namibia	Maj	Maj	Maj	Maj	Maj
Seychelles	Mod	Mod	Min	Min	Min
South Africa	Maj	Mod	Mod	Mod	Mod
Swaziland	Mod	Min	Min	Min	Min
Tanzania	Maj	Mod	Mod	Min	Mod
Zambia	Mod	Mod	Min	Mod	Mod
Zimbabwe	Maj	Mod	Maj	Mod	Maj

Scale: *Maj* major, *Mod* moderate, *Min* minor

during the drilling and installation of boreholes only. This is particularly significant in a country such as Malawi where groundwater is such an important source of rural water supply.

Today there is a twofold approach to groundwater investigation, development and management. On the one hand, industry and municipal undertakings take great care in applying appropriate technology to maximise exploitation of a recognised finite resource, and on the other, NGOs, CBOs and private sector organisations have led a progression towards uninformed drilling programmes to satisfy rural community demand. The number of failed boreholes tends to be high in marginal areas, but the cost benefit of appropriate technical investigation is difficult to assess.

There nevertheless remains an urgent need to support informed choice and groundwater management. Successful and sustainable projects require both good technical design and installation, and substantial investment in community sensitisation, mobilisation and participation. Ignoring either technical or social factors will compromise the sustainability of the water supply. If communities do not regard the system as theirs, and managing and cost-sharing arrangements are not adequately dealt with, the system is more likely to fail. If a well or borehole is poorly constructed, or developed and sited with little regard to the geology, the chances of mechanical breakdown or the source drying up will also increase.

Discussion around sustainability is often polarised. In the past, it was often true that technical considerations dominated many projects: engineers were trained to take important decisions on behalf of communities, using their knowledge to decide what was in a community's best interests. Consultation, if there was any, was often token—communities effectively rubber-stamped the decisions of sector professionals. A welcome retreat from this position, however, has not always led to more balanced approaches. Those who now maintain that technical and environmental issues are unimportant, and that sustainability is determined only by the quality of project 'software' are equally misguided (MacDonald et al. 2005), and the key to good project design lies in recognising the multiple dimensions of sustainability, not in engineering or social dogma (UNICEF 1999).

Changes in development aid emphasis and funding policies have also impacted on groundwater resource development. International donors have, in general, had limited involvement in the technical and engineering aspects of groundwater resource development, preferring to concentrate on socio-economic planning and policy development as well as the 'soft' side of agriculture, health and education (MacDonald et al. 2005). This has resulted in a significant increase in the use of donor-funded contractors and consultants in the regional water sector with a consequent marked decline in knowledge accrued by national government institutions (Robins et al. 2003). In the international donor community, Japan International Cooperation Agency (JICA) is one of few international donors still directly involved in the groundwater sector and is currently active in Zimbabwe, southern and western Zambia and central and northern Tanzania (JICA 2002).

There is currently a lack of research into the understanding of groundwater resources, renewability, apportionment and management in many countries in southern and eastern Africa (WB 2005). Whilst South Africa has forged ahead with a major programme of investigation and underpinning research, other countries have neither the resources nor the capacity to do likewise. Some effort, however, is now being made to recognise knowledge gaps and co-ordinate data and understanding between groundwater dependent nations (Table 2), principally under the auspices of the Southern African Development Community (Farr et al. 2005).

HIV Aids is a huge issue in the region, not least within the groundwater sector. Statistically, three people need to be trained for every single job to overcome personnel loss through HIV Aids and other pandemic disease in worst hit areas such as, for example, Malawi (Iliffe 2006). This clearly inhibits continuity and reduces 'corporate memory' to a point of inefficiency. Not only is experience lost, but so too are data under discontinuous personnel.

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Technical choice needs to reflect users' needs and priorities, but it must also be technically feasible, sustainable and environmentally acceptable (Brikke and Bredero 2003). This amplifies the need for technical input, which combined with local knowledge about resource conditions and availability, provides a powerful screening tool.

The future

The quantification of the groundwater resources is a major issue facing integrated water resources management in the region. It has yet to be faced in most countries, although South Africa is now working both in a national and a near-region basis, whilst SADC is only now realising the enormity of the task. Data gathering and dissemination are fundamental to the development and management of the resources.

There is an urgent need to arrest the loss of institutional memory caused by data loss and fragmented recovery of information. Faced with declining loss of expertise in some countries due largely to the HIV Aids pandemic, there is an opportunity for South African hydrogeologists to export their technical skills throughout the southern and eastern Africa region as well as to provide training for foreign students through to the Masters Degree level.

Outside South Africa, there are a number of centres of groundwater excellence and the work of GTZ in south-eastern Malawi and in north-western Zambia, for example, provides examples of best practise. There are, however, many tracts of uninformed groundwater exploitation which might appear successful in relatively straightforward environments but will not produce best value for money in more difficult terrain. Where investigations help reduce the number of unsuccessful wells drilled, cost savings may be significant, at least covering the cost of the investigation procedure and providing value for money (MacDonald et al. 2005).

The important issue facing southern and eastern Africa in this early part of the twenty-first century is the material realisation of the right of individuals to safe water and sanitation. Thorough and systematic investigation of the groundwater resources need to 'plug' the knowledge gaps and minimise the many uncertainties facing the region.

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References

Acworth RI (1987) The development of crystalline basement aquifers in a tropical environment. Q J Eng Geol 20(4):265–272

Barker R (2004) The use of geophysics in borehole siting in hard rock areas of Africa. In: Mather JD (ed) 200 years of British hydrogeology. Geol Soc London Spec Publ 225:263–269

Binnie and Partners (1971) Lesotho: study on water resources development, inventory report. Report UNDP/IBRD, London and Maseru

Boocock C, van Straten OJ (1962) Notes on the geology and hydrogeology of the Central Kalahari Region, Bechuanaland Protectorate. Trans Geol Soc South Africa 65:125–171

Bonney G (1975) Estimates of groundwater resources in Lesotho. Report, Department of Mines and Geology, Lesotho Government, Maseru

Brikke F, Bredero M (2003) Linking technical choice with operation and maintenance in the context of community water supply and sanitation: a reference document for planners and project staff. World Health Organisation and IRC Water and Sanitation Centre, Geneva, Switzerland. (http://www.who.int/en/). Cited 4 Apr 2005

Brokonsult AB (1980) Tabora region water master plan. The Ministry of Water Development, Energy and Minerals, Dar Es Salaam, Republic of Tanzania

Calow RC, Robins NS, MacDonald AM, Macdonald DMJ, Gibbs BR, Orpen WRG, Mtembezeka P, Andrews AJ, Appiah SO (1997) Groundwater management in drought prone areas of Africa. Int J Water Resour Dev 13(2):241–261

Calow RC, MacDonald AM, Nicol A, Robins NS, Kebede S (2002) The struggle for water, drought, water security and rural livelihoods. Technical Report British Geological Survey, for UK Department for International Development, British Geological Survey, Nottingham

Clay E, Borton J, Dhiri S, Gonzalez ADG, Pandolfi C (1995) Evaluation of ODA's response to the 1991–1992 Southern African drought, vols. 1 and 2. Evaluation Report EV568, Overseas Development Administration, London

Cooper WGG (1950) Electrical aids in water finding. Report for Nyasaland Geological Survey, Mining Publications, London

Dennis PE (1961) Groundwater in the Sabi Valley, Southern Rhodesia. US Geol Surv Prof Pap 424D, article 372

Du Toit AL (1906) Underground water in south-eastern Bechuanaland. Trans South African Philos Soc 16:251–262

Du Toit AL (1915) On the porosity of the rocks of the Karroo system of South Africa. Trans R Soc S Afr (4):169–180

Du Toit AL (1928) Borehole water supplies in the Union of South Africa. Mining Proceedings of the South African Society of Civil Engineers 31, South African Society of Civil Engineers, Johannesburg

DWA (1991) Botswana national water master plan study: final report volume 5 hydrogeology. Department of Water Affairs (with SMEC, WLPU, and SGAB), Gaborone, Botswana

Enslin JF, Kriel JP (1959) Some results obtained from a hydrological study of a dolomitic catchment area in the Transvaal, Republic of South Africa. Transactions Specialists Conference on Hydrology, Yaounde, Cameroun, CCTA, London

Farr JL, Cheney CS, Baron JH (1981) GS10 Project Final Report: evaluation of groundwater resources. Government of Botswana, Gaborone

Farr JL, Gumiremhete R, Davies J, Robins NS (2005) Groundwater dependence and drought within the Southern African Development Community, vol 1. Biennial Ground Water Conference, Pretoria, March 2005, pp 97–105

Foster SSD (2000) Groundwater resources at the turn of the millennium: taking stock and looking forward. Groundwater, Past Achievements and Future Challenges, Proceedings of 30th IAH Congress on Groundwater, Cape Town, pp 27–33

Gear D (1977) The manner of occurrence of groundwater in Rhodesia. Report Ministry of Water Development, Salisbury

Gibb (1969) Botswana: Shashi River feasibility studies. Report on feasibility study to AK1 (Orapa). Report Sir Alexander Gibb & Partners, London

Hindson LL, Wurzel P (1963) Groundwater in the Sabi Valley alluvial plain. Rhod J Agric Sci 1:99–106

Houston JFT (1982) Rainfall and recharge to a dolomite aquifer in a semi-arid climate at Kabwe, Zambia. J Hydrol 59:173–187

DOI 10.1007/s10040-006-0056-x

Houston JFT, Lewis MA (1988) The Victoria province drought relief project: II. Borehole yield relationships. Ground Water 2:418–426
Iliffe J (2006) The African aids epidemic: a history. James Currey Publishers, Oxford, UK
Interconsult (1985) National master plan for rural water supply and sanitation: hydrogeology. Ministry of Energy and Water Resources and Development, Harare, Republic of Zimbabwe
Jennings CMH (1969) Groundwater in Botswana. Paper presented at Symposium on Groundwater in Southern Africa, April 1969, Pretoria
JICA (1995) The study of the national water resources master plan in the Republic of Zambia. Final Report October 1995. Japan International Cooperation Agency/Republic of Zambia Ministry of Energy and Water Development, Lusaka
JICA (2002) A study of Japan's ODI to Africa, towards sustainable and self reliant poverty reduction in Africa. Report, Institute for International Cooperation/Japan International Cooperation Agency, Tokyo
Jones MJ (1985) The weathered zone aquifers of the basement complex of Africa. Q J Eng Geol 18(1):35–46
MacDonald AM, Davies J, Calow RC, Chilton PJ (2005) Developing groundwater: a guide for rural water supply. ITDG, Bourton-on-Dunsmore, UK
MacDonald D (1970) The development of railway borehole water supplies on the Bulawayo-Dett section since 1950. Rhod Sci News 4(12):398–405
Maxwell S (2001) The evolution of thinking about food security. In: Devereux S, Maxwell S (eds) Food security in Sub-Saharan Africa, ITDG, Bourton-on-Dunsmore, UK
Mazor E, Verhagen BT, Sellschop JPF, Jones MT, Robins NS, Hutton LG, Jennings CMH (1977) Northern Kalahari groundwaters: hydrologic, isotopic and chemical studies at Orapa, Botswana. J Hydrol 34:203–234
McFarlane MJ (1992) Groundwater movement and water chemistry associated with weathering profiles of the African surface in parts of Malawi. In: Wright EP, Burgess WG (eds) Hydrogeology of crystalline basement Africa. Geol Soc Spec Publ 66:101–129
McKenzie AA (1997) Groundwater data management by the Malawian ministry of irrigation and water development: a case study. Technical Report British Geological Survey WC/97/9, British Geological Survey, Nottingham
Nord M (1985) Sand rivers of Botswana Results from Phase 2 of the SIDA Sand Rivers Project. Technical Report, Department of Water Affairs, Gaborone, Botswana
Ockelford J, Reed R (2002) Participatory planning for integrated RWS and sanitation programmes. Guidelines for planning and designing rural water supply and sanitation programmes. WEDC, Loughborough, UK. (http://wedc.lboro.ac.uk/). Cited 4 Apr 2006
Paver GL, Pretorius DA (1954) Report on reconnaissance hydrogeological investigations in the western desert coastal zone. Publications de l'Institut du Desert D'Egypt, Cairo
Pieterson K (2005) Basic human needs and the right to health; the contribution of ground water. Proceedings of the Biennial Groundwater Conference, Pretoria, South Africa, March 2005, pp 799–809
Robins NS (1980) A review of groundwater resources and well yields in Swaziland. Trans Geol Soc S Afr 83(1):1–4
Robins NS, Davies J, Hankin P, Sauer D (2003) Groundwater and data: an African experience. Waterlines 21(4):19–21
SADC (2002) Compilation of the hydrogeological atlas for the SADC region. Draft Final Version. Groundwater Consultants Bee Pee (Pty) Ltd and SRK Consulting (Pty) Ltd for SADC Water Sector Coordination Unit, Lesotho. 54 pp
Sekwale M (1984) Hydrogeological data collection, storage, retrieval and water law in Botswana. In: Challenges in African hydrology and water resources (Proceedings of the Harare Symposium, July 1984). IAHS Publication Number 144, IAHS, Wallingford, UK, pp 221–228
Shaw SH (1935) Geophysical prospecting - a study of the resistivity method in connection with the investigation of underground water supplies in the Nata Reserve, Southern Rhodesia. Trans Inst Min Metal 44:1–7
Skofteland E (1995) Background of water resources in the SADC region. Water resources management in Southern Africa: a vision for the future. Conference of SADC Ministers responsible for Water Resources Management, November 1995, Department of Water Affairs and Forestry, Pretoria
Smith-Carington AK, Chilton PJ (1983) Groundwater resources of Malawi. Report, Government of Malawi, Lilongwe
UNICEF (1999) Towards better programming: a water handbook. Water, Environment and Sanitation Technical Guidelines, Series 2, Untied Nations Children's Fund, New York (http://www.unicef.org/wes/). Cited 4 Apr 2006
Van Straten OJ (1955) The geology and groundwaters of the Ghanzi Cattle Route. In: Annual report for the geological survey of the Bechuanaland Protectorate for 1955, Geological Survey, Lobatse, Bechuanaland (Botswana), pp 28–39
Vegter JR (2001) Groundwater development in South Africa and an introduction to the hydrogeology of groundwater regions. WRC Report No. TT 134/00, Water Research Commission, Pretoria
Verhagen BTh (1990) Isotope hydrology of the Kalahari: recharge or no recharge? Palaeoecol Afr 21:143–158
Vogel JC, Bredenkamp DB (1969) A study of subterranean water in the southern Kalahari with the aid of carbon-14 dating and isotope analysis. Technical Report, CSIR, Pretoria
Way HJR (1939) Results of the application of the resistivity method to the water problems of Uganda. In: Bulletin no 3, Geological Survey of Uganda, Entebbe, pp 161–179
WB (2005) African Water Development Report, Interim Version. World Bank, Washington, DC. (http://www.uneca.org/awich/African_Water_Regional_Report/water_dvpt_report.htm). Cited 4 Apr 2006
WHO (1973) Sectoral study and national programming for community and rural water supply, sewerage and water pollution control: groundwater resources in Kenya. World Health Organisation, Brazaville, Government of Kenya
Woodford AC, Chevallier L (2002) Hydrogeology of the Main Karoo Basin: current knowledge and future research needs. Technical report TT 179/02 Water Research Commission, Pretoria, South Africa
Worthington PF, Martinelli E (1977) An improved format for the routine documentation of water-well data in Southern Africa. Civ Eng S Afr July:147–153
Wright EP (1992) The hydrogeology of crystalline basement aquifers in Africa. In: Wright EP, Burgess WG (eds) Hydrogeology of crystalline basement aquifers in Africa. Geol Soc London Spec Publ 66:1–27
Wright EP, Herbert R, Kitching R, Murray KH (1987) Collector wells in crystalline basement aquifers: a review of results of recent research. In: Proceedings of the 21st Congress of the International Association of Hydrogeologists, April 1987, Rome
Zu Y, Beekman HE (2003) Groundwater recharge estimation in Southern Africa. UNESCO, Paris

 DOI 10.1007/s10040-006-0056-x