British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL

# Southern African Development Community Regional Situation Analysis

Groundwater Management Programme

Internal Report CR/05/093N

BRITISH GEOLOGICAL SURVEY

GROUNDWATER MANAGEMENT PROGRAMME
INTERNAL REPORT CR/05/093N

# Southern African Development Community Regional Situation Analysis

J. L. Farr, R. Gumiremhete, J. Davies and N. S. Robins

*Keywords*

SADC, drought, resources, data.

*Front cover*

Victoria Falls from the Zimbabwe side during the 1992 drought

*Bibliographical reference*

FARR J L, GUMIREMHETE T, DAVIES J & ROBINS N S. 2005. Southern African Development Community Regional Situation Analysis. *British Geological Survey Internal Report*, CR/05/093N. 132pp.



Keyworth, Nottingham British Geological Survey 2005

## BRITISH GEOLOGICAL SURVEY

The full range of Survey publications is available from the BGS Sales Desks at Nottingham, Edinburgh and London; see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications including maps for consultation.

*The Survey publishes an annual catalogue of its maps and other publications; this catalogue is available from any of the BGS Sales Desks.*

*The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as its basic research projects. It also undertakes programmes of British technical aid in geology in developing countries as arranged by the Department for International Development and other agencies.*

*The British Geological Survey is a component body of the Natural Environment Research Council.*

*British Geological Survey offices*


**Keyworth, Nottingham NG12 5GG**

☎ 0115-936 3241 Fax 0115-936 3488

e-mail: sales@bgs.ac.uk

www.bgs.ac.uk

Shop online at: www.geologyshop.com

**Murchison House, West Mains Road, Edinburgh EH9 3LA**

☎ 0131-667 1000 Fax 0131-668 2683

e-mail: scotsales@bgs.ac.uk

**London Information Office at the Natural History Museum (Earth Galleries), Exhibition Road, South Kensington, London SW7 2DE**

☎ 020-7589 4090 Fax 020-7584 8270

☎ 020-7942 5344/45 email: bgslondon@bgs.ac.uk

**Forde House, Park Five Business Centre, Harrier Way, Sowton, Exeter, Devon EX2 7HU**

☎ 01392-445271 Fax 01392-445371

**Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF**

☎ 028-9038 8462 Fax 028-9066 2835

e-mail: gsni@detini.gov.uk

**Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB**

☎ 01491-838800 Fax 01491-692345

e-mail: hydro@bgs.ac.uk

**Columbus House, Greenmeadow Springs, Tongwynlais Cardiff, CF15 7NE**

☎ 029–2052 1962 Fax 029–2052 1963

*Parent Body*

**Natural Environment Research Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU**

☎ 01793-411500 Fax 01793-411501

www.nerc.ac.uk

# Foreword

Wellfield Consulting Services (Pty) Ltd, Gaborone, jointly with the British Geological Survey undertook a situation analysis of the region for the SADC Water Sector Co-ordinating Unit as part of the Regional Strategic Action Plan for Integrated Water Resource Development and Management (RSAP-IWRM). The project objective was to gather information from which to develop a strategic regional approach to support and enhance the capacity of SADC Member States in the definition of drought management policies, with specific reference to the availability and supply potential of groundwater resources. It also examined the reconciliation of demands for socio-economic development and those of the principal groundwater-dependent ecosystems.

This report represents the final report submitted to SADC on the Regional Situation Analysis of the SADC Member states. The client was the Global Environment Fund (GEF) of the World Bank. The Project Manager was John Farr, much of the field work and data gathering was hosted by Robert Gumiremhete, both of Wellfield Consulting Services, assisted by Jeff Davies and Nick Robins of BGS. Data gathering comprised in-country visits as well as regional workshops.

The report was originally issued to SADC within the standard SADC report template. It now also carries a BGS report cover and number for BGS identification purposes only. Copies of the report in the SADC format are available directly from the SADC administration in Gaborone, Botswana.

SOUTHERN AFRICAN
DEVELOPMENT COMMUNITY


REGIONAL SITUATION ANALYSIS
RFP # WB 1861-571/02

# FINAL REPORT

**June 2003**

**Submitted
By**

**Wellfield Consulting Services Pty Ltd
Gaborone
Botswana**

**British Geological Survey
Crowmarsh Gifford, Oxon.
United Kingdom**

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF INFORMATION BOXES

# CHAPTER 1 – GENERAL OVERVIEW

## 1.1 INTRODUCTION

The Southern African Development Community (SADC) groups fourteen sovereign states in the southern and eastern Africa region for the main purpose of fostering co-operation for mutual benefit from development of the resources of the whole region. The region accounts for almost 70% gross domestic product of sub-Saharan Africa and is home to almost a third of its people. In the context of water resources, conditions in the SADC region are highly variable with respect to the relative reliance of each of the Member States on surface or groundwater sources. However, studies already indicate that water resources will be scarce in 9 of the 14 Member States within the next 10 to 30 years, most especially in the southern and eastern portion of the SADC region. Clearly, water resource conservation and comprehensive national and regional planning is going to be crucial.

SADC recognised the critical importance of water to regional integration and economic development and established its own Water Sector in 1996. A SADC Protocol on Shared Watercourse Systems was adopted to set the rules for joint management of resources. A Regional Strategic Action Plan for Integrated Water Resource Development and Management has been compiled; this is being implemented to address key water management issues, concerning both surface water bodies and aquifers (groundwater).

The region is also characterised by rapid population growth. Extremes of climate bring frequent drought and substantial flood events that impact on rural populations as well as national productivity. The region is already highly dependent on groundwater for rural water supply, and it is clear that groundwater is a key element in the alleviation of the effects of drought on rural communities.

However, policy responses to drought have, in the past, been based on short-term crisis reactions, which have generally proved to be inefficient or ineffective. To address this undesirable situation, proactive, sustainable and integrated management of groundwater resources needs to be instigated, but with due sympathy to the requirements of ecosystems.

## 1.2 OBJECTIVES

The principal project, of which the current consultancy is a part, is entitled “Protection and Strategic Use of Groundwater Resources in the Transboundary Limpopo Basin and Drought Prone Areas of the SADC Region”. A grant, with the World Bank as the implementing agency, has been obtained from GEF (Global Environment Facility), under the “Project Development Fund B” (PDF B), to prepare a GEF Project Document for this programme in a participatory manner.

The project is intended to co-operatively develop a strategic regional approach to support and enhance the capacity of SADC Member States in the definition of drought management policies. It specifically aims to achieve this through the role, availability and supply potential of groundwater resources. It will also assist in reconciling the demands for socio-economic development and those of the principal groundwater-dependent ecosystems. The project is part of the Regional Strategic Action Plan for Integrated Water Resources Development and Management and is executed by the SADC Water Sector Co-ordinating Unit (WSCU) with backup from the SADC Sub-Committee for Hydrogeology.

The objectives of the current project are:

- to undertake a situation analysis of the whole of the SADC Region with respect to groundwater use, water demands and other water related issues in the context of drought preparedness and management,
- to ensure the equitable use of water resources for human and ecosystem needs.

An important component of the study is an appraisal of the data sets that may be/are already available for use in developing drought vulnerability or water scarcity maps, together with a review of regional monitoring practises. An overview of the capacity building and training needs of the region in the context of an integrated strategy of water resources management and drought preparedness will also be undertaken.

Recommendations made in the study and adopted by SADC will be applied through the SADC institutional network, which is financed by the Member Countries and through the possible development of a Regional Groundwater Research Institution / Commission.

In parallel with the current programme, a second study is assessing the role of groundwater in proactive drought mitigation in the semi-arid Limpopo river basin. This is being done on a conceptual level and at the field-scale in a pilot sub-catchment, simultaneously taking into account applicability and replicability for the region as a whole. Constituent countries in the "Protection and Strategic Uses of Groundwater Resources in the Transboundary Limpopo Basin and Drought Prone Areas of the SADC Region: Regional Situation Analysis" are Zimbabwe, Mozambique, Botswana and South Africa.

## 1.3 REPORT FORMAT

Previous SADC WSCU projects probably more specific in their brief and objectives have prepared final reports that essentially comprise a main report addressing the project background, methodology, results and overall conclusions/recommendations with 'country reports' describing data and conclusions for each individual Member State appended to this. It has not been the intention of this study that all the data gathered during previous SADC projects, in particular, the Hydrogeological Map Project, should be repeated here, and thus no specific 'country reports' of the same nature have been compiled.

Instead, and since the current project is somewhat more wide-ranging in terms its brief and the issues to be addressed, the Consultant has adopted a more 'user-friendly' and probably less repetitive format with this Final Report structured in a more thematic manner. Under this format the situation in individual Member States with respect to each of these themes is covered in the appropriate thematic section (Chapter 4), condensed wherever possible into thematic 'information boxes'. It is considered that this reporting structure will enable readers to more easily focus on and assimilate information on particular topics than the previous 'country report' arrangement, as well as providing a clearer regional situation overview than was readily available from country-based reports.

With this report structure in mind the Consultant submitted a draft Table of Contents to SADC WSCU and the Project Management Consultant and received comments that have been taken into consideration in the formulation of the Final Report.

As stressed by SADC WSCU and Project Management Consultant an important part of this Final Report has been the preliminary identification and elaboration of a number of key components that the Consultant considers could be incorporated into the project preparation documentation for the main GEF Project. These components have been included as a separate

Annex (Appendix A) as it is essential that they are discussed and agreed with SADC WSCU and the Project Management Consultant prior to their inclusion in the Final Report.

With respect to the large volume of information gathered and assessed, and to which some reference has been made in the text, this has been completed as a linked thematic bibliography on CD-ROM distributed with the Interim Report. The bibliography is in Word 2000 format with associated Pdf documents.

# CHAPTER 2 – PRINCIPAL THEMES

## 2.1 DROUGHT AND GROUNDWATER

Drought is probably the most complex and least understood of natural hazards, and in contrast to other hazards, has a relatively slow onset that is difficult to precisely determine. In addition, the absence of a universally accepted definition of "drought" creates confusion about the existence or severity of a drought event. Unfortunately, different disciplines incorporate different physical, biological and/or socio-economic factors into their definition of drought, so adding to the confusion.

Since there are a number of definitions of "drought", the impacts of drought will accordingly be widely diverse, and both direct and indirect. A tripartite classification into economic, social and environmental impacts has frequently been applied. However, since water is the common element in all discussions of drought, the key theme of the current study is the impact of drought on water resources, and in particular, groundwater resources. The historic perspective of drought in the SADC region illustrates its increasing severity and this, coupled with the prospect of the greater frequency of drought occurrence as a result of climate, land use and population changes, highlights the increasing significance of drought events.

### 2.1.1 Definitions and Identification of Drought Prone Areas

As noted above, with respect to the definition of ‘drought’ there are almost as many drought definitions as there are disciplines and professional standpoints. Meteorologists, for example, define drought solely on the basis of the degree of dryness (lack of precipitation) and the duration of the dry period; hydrologists link periods of shortage of rainfall to the effect on surface (and sometimes sub-surface) water resources; and agriculturalists link drought to soil water deficits and impacts on crops. Sociologists take drought as a relative phenomenon, which varies according to the demand placed on the resource by different users; hence the impact of drought in a semi-arid or arid area, where water use is mainly for livestock watering, is likely to be substantially different to a drought in a humid area that relies on rain fed agriculture. However, central to all definitions is the (relative) shortage of water.

One further definition is also required. ‘Groundwater drought’ is a term used to describe a situation where groundwater sources fail as a direct consequence of drought (Calow et al., 1997). However, the response of groundwater to meteorological drought is poorly understood, and may most commonly be out of phase with other more immediate impacts. This is due in part to the complexity of hydrogeological systems: different types of aquifer in different hydrogeological environments respond in different and unique ways.

However, other factors are also important, and perhaps the most significant aspect of groundwater behaviour in relation to meteorological drought is the time lag between changes in recharge and changes in groundwater levels and well yields. Aquifers can store much larger quantities of water than their annual recharge, with the result that reliable supplies can be maintained even during periods of low rainfall. This effect is sometimes referred to as the 'buffering capacity' of groundwater, and contrasts with the relatively 'flashy' behaviour of surface water sources. The result is that, while some wells and boreholes may respond relatively quickly to rainfall variations, problems in others may take months or even years to emerge, perhaps only after several years of low rainfall. Indeed, it is quite conceivable that a decline in well/borehole yield, or a fall in groundwater level, may only materialise after the rains have returned and the meteorological drought is perceived to be over. It also clearly indicates a serious need for careful management and continuous monitoring of groundwater supplies. Monitoring and assessment programmes that begin and end with meteorological (and agricultural) droughts - not untypical in many countries - may fail to pick up significant longer term impacts on groundwater, with the result that potentially predictable and manageable problems become emergencies.

The occurrence of a meteorological drought and its impact on groundwater is likely to depend on many different factors, including:

- severity and duration of the drought episode. Longer periods of low or negligible recharge are more likely to have an impact on groundwater resources and affect well and borehole yields. While the natural buffering capacity of groundwater systems may provide advantages in terms of the reliability of supply, the response of groundwater to drought conditions, and the subsequent non-drought period, can create other problems. Clearly, if groundwater responds slowly to rainfall deficit, it follows that groundwater will generally also recover more slowly after drought than surface sources. The result may be complex and seemingly unrelated linkages between rainfall events and their impact on groundwater resources.

- design and location of the groundwater well or borehole. In general, shallow, hand dug wells may be expected to be more sensitive and responsive to recharge variations than deeper boreholes. The onset of drought, and reduced recharge, will thus impact sources that are shallow and rely entirely on seasonal storage replenishment significantly more quickly than sources that tap deeper groundwater resources.

- hydraulic characteristics of the aquifer. Of particular importance is the connectivity of the aquifer to recharge sources and the storage properties of the aquifer itself. In basement aquifers connectivity may be good but aquifer storage can be highly variable and will depend to a large extent on the degree of near-surface weathering that has taken place. However, storage in basement aquifers is typically much lower than in more productive, unconsolidated aquifers.

  If an aquifer is highly permeable and contains a large volume of groundwater, boreholes and wells that penetrate the aquifer are likely to be productive. In such cases the source may be able to meet even the high demands placed upon it during a drought. If the aquifer properties are poor, on the other hand, or if the aquifer is of limited extent, a source might be unable to meet even normal dry season demand.

- excessive demand and source failure. Although there is generally an increase in the failure of wells, springs and boreholes during drought, the link between drought and source failure is not always obvious.

  Regional depletion of an aquifer is rarely a problem in basement aquifers that are common throughout the SADC Member States as abstraction from individual sources is low (10-15 $m^3$/day), and sources are sufficiently few in number that overall abstraction is highly unlikely to exceed long term aquifer recharge from rainfall on a regional scale. As a consequence, the amount of water that can be withdrawn from the aquifer is largely a function of the number of access points (wells and boreholes) to the resource.

  Localised depletion, resulting in falling groundwater levels in the immediate vicinity of a well or borehole, or group of sources, is frequently the principal problem and this is most likely to occur where the demands being placed on a groundwater source are high, and where the transmissivity of the aquifer is low. In these circumstances insufficient groundwater is transported to the well or borehole to replenish the water being withdrawn, and a dewatered zone may form around the source. The most likely time for this to occur is at the end of the dry season when demand for groundwater reaches a peak.

Increased stress on a groundwater source during drought also makes failure of the pump more likely. Prolonged pumping throughout the day can put considerable strain on the pump mechanism leading to breakdowns, especially if water levels are falling and pumping lifts increasing. The result of pump failure may be increased demand on a neighbouring source, and thus increased stress (and probability of failure) of that source. And so the cycle continues. The problem may be exacerbated by the cessation of maintenance activities as relief-drilling programmes take priority. In South Africa, many of the water supply failures experienced during the 1991-93 drought were blamed on maintenance problems made worse by the drought (Hazelton et al., 1994; du Toit, 1996).

In addition, there are several other longer-term factors that will impact on groundwater and its behaviour during drought cycles.

- long term increases in demand. Such changes can make a source that in the past may have provided reliable and perennial supply vulnerable to drought. Historically, seasonal and drought-related fluctuations in demand might have fallen within the ability of the source to provide adequate supply. A long-term increase in demand, however, can eventually push these fluctuations to such a level that demand will then over certain periods exceed supply. The cause may be population growth (natural, or as a result of migration), or possibly increases in per capita consumption resulting from economic change, such as the introduction of irrigation or other water-intensive activities.

- long term changes in climate. These changes could adversely affect recharge processes and amounts and would thus place both high and low yielding sources at risk. The recovery of groundwater is dependent upon there being adequate recharge during subsequent rainfall periods to replenish the volumes of groundwater removed during the drought period. Similarly, the removal of vegetation and erosion of the soil cover as a result of climatic changes may also increase the rate of runoff and reduce the amount available for recharge.

  A number of studies have concluded that the failure of wells and boreholes during drought is a function of both increased demand on low yielding sources and reduced groundwater flow to the borehole. This may cause some sources to dry up altogether, and precipitate mechanical breakdown in others. Identifying hydrogeological zones that have low permeability, wells and boreholes that are low yielding, and areas of high population density with few alternative water sources, is therefore almost certainly a ‘first-step’ towards to groundwater management.

### 2.1.2 Past Experiences of Drought in the SADC Region

What must be clearly stated is that drought is endemic throughout much of the SADC region, with Member States in the southern portion probably most susceptible. Drought is a regular occurrence that should be expected and which should thus be planned for. Unfortunately, this all too frequently does not happen, and the onset of a drought becomes a ‘crisis’ with ill-considered actions and subsequent detrimental impacts on population and other facets of the natural (and economic) environment.

It is apparent that climate and rainfall patterns in the southern portion of the SADC region have been highly variable for at least three centuries, leading to recurrent droughts of varying severity. The whole region experiences regular (and probably cyclic) wet and dry spells that comprise several years of abundant rainfall followed by periods of deficiency, and it is not yet certain whether the increasing frequency and severity of these drought periods are related to human activities or have some natural explanation, or both. One natural phenomenon that has been put forward in explanation for this trend is the changing pattern of the *El Nino* weather condition in the Pacific Ocean, which itself has been attributed to global climate change.

A number of extensive droughts have afflicted the SADC region in recent times, particularly during the periods 1946-47, 1965-66, 1972-73, 1982-83, 1986-88, 1991-92 and 1994-95. All these periods were also major *El Nino* events.

The southern Africa region 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 Africa poorly endowed with water, but demands are also increasing rapidly, and groundwater is clearly the only means of meeting rural community needs at relatively low cost.

Long-term flow data from Victoria Falls indicates that flows were below mean until 1945, above mean to 1980 and thereafter fell below mean to the present day. This indicates that the period 1945-1980 coincided with better than average rainfall, whereas the last twenty years or so 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 influences increased the stress on available water sources. This has been aggravated in a number of centres by war and the inevitable creation of refugees, and more recently economic instability. The consequences of drought are, therefore, both critical to health and livelihoods as well as to national economies.

The southern African drought of 1991/92 was arguably the worst ever experienced in the region (Magadza, 1994). It demonstrated that few governments were prepared for prolonged drought: 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 South Africa belatedly reacted with an 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 sources. In Malawi, by the end of the 1991-92 drought, normally reliable groundwater sources began to fail leaving some 3 million mainly 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 non-government organisations (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 (Clay et al., 1995).

In order to examine and illustrate the impact of drought on the region in general, and the water supply situation in particular, a number of recent case histories are presented below.

**Malawi**

In Malawi, considerable efforts have been made over the last two decades to increase water supply coverage in rural areas as a feature of poverty alleviation and drought relief efforts. External assistance has supported much of this work, and Malawi has taken on a mix of multilateral, bilateral and NGO input, as well committing funds from central government. Much of this support has been targeted on specific projects, in the form of capital assistance for borehole construction and hand pump installation. In more recent years, a change in approach has been occasioned by the Water Department's inability to service a growing population of water supply sources, and efforts are now underway to promote community based management and participation. The importance of groundwater as a relatively low cost source of potable supply is expected to grow, and groundwater sources already serve the majority of the rural population. However, at any one time it has been estimated that some 25% of wells and boreholes will be out of operation, malfunctioning and/or dry during an extended drought (UNICEF, 1995).

Like many other countries in eastern and southern Africa, Malawi suffered the worst drought in over 40 years following the failure of the 1991-92 seasonal rains. The 1991-92 rainfall was only 67% of the long term average, the second most severe shortfall of the century, with the highest shortfalls recorded in the south of the country, along the Lower Shire Valley, and in Mwanza, Mangochi and Machinga Districts. Coming on top of a refugee crisis and economic and social dislocation, the impact of the drought was severe, exacerbating an already bleak social and economic situation.

The impact of the drought on the nation’s water resources was profound. Many rivers and piped water systems dependent on them dried up for extended periods, causing hardship to towns and cities. However, perhaps the greatest effects were felt in the rural areas, where smallholders saw their crops fail and where the majority of the population are dependent on groundwater from boreholes and traditional sources such as shallow wells and river-dug outs. Here, most shallow wells were reported as drying up altogether, a hitherto unheard of phenomenon; traditionally shallow wells have been dug at the end of the dry season to ensure perennial supply. The result was growing reliance on groundwater where it could be accessed through serviceable boreholes, and use of unprotected water sources (including Lake Malawi) not routinely used for domestic use. With relatively limited borehole coverage at the time, especially in the most densely populated and worst affected south of the country, and with large numbers of boreholes and pumps out of commission because of maintenance problems, villagers (mainly women) were forced to walk long distances and queue for many hours, and sometimes days, for water. By November 1992, government reports indicated that some three million people across the country had inadequate water supplies, a situation exacerbated by the presence of over one million refugees in the south of the country fleeing war in Mozambique.

Although the drought undoubtedly affected the water supply situation in all areas of the country, national figures tend to mask important regional and sub-regional variations in impact. The lack of reliable and comprehensive spatial and time series data makes evaluation difficult. In particular, it is difficult to gauge the longer-term effects of the 1991-92 drought on groundwater resources and the cumulative effect of successive low rainfall periods. Nevertheless, some important patterns and points do emerge:

- rainfall is characteristically variable, and even adjacent villages reported starkly contrasting groundwater drought experiences. It seems likely that geological variation may also contribute significantly to differing regional experience;

- relatively few boreholes appear to have dried up completely; those that did were concentrated in hilly and mountainous areas, in aquifers of limited thickness and storage capacity. However, the drought exposed the shortcomings of the government run maintenance programmes, and the fact that so many wells and boreholes were not functioning before the drought significantly exacerbated its impact when it did occur;

- determining the cause of failure of boreholes is difficult, and pump failure, silting up of the hole, falling water levels and other problems may all result in an inability to pump water to the surface. Measurements taken from a comprehensive network of dedicated monitoring sites would have allowed technicians to distinguish between resource and source problems, but such a system was not (and is not) in place;

- while the majority of shallow wells were reported as drying up, some wells in areas with shallow water tables (e.g. in the vicinity of large dambo systems) remained viable.

The social and economic consequences of the groundwater drought are difficult to quantify, but indicators of stress included mounting health problems, long queues for water and inter-village conflicts over water supplies. The health information system in Malawi routinely collects large amounts of data most of which is never analysed, making it difficult to compare data across years and seasons. However, diarrhoeal and cholera outbreaks occurred during the drought, and an epidemic of shigella dysentery began in the Southern Region in early 1992, eventually spreading throughout the country (SADC, 1993). Rural clinics were reportedly inundated with sick infants. Rates of malnutrition, on the other hand, were relatively low, suggesting that the principal health problem may have been water, rather than food related. Drought conditions persisted into the 1992-93 and 1993-94 wet season, with the succession of drought years having a cumulative, though largely undocumented, effect. The result has been a continuation of water resource problems, lasting well beyond the end of the shorter-term food crisis. Significantly, monitoring and assessment programmes were wound down with the return of the rains.

Reliable information on the status of rural water supplies was unavailable at the onset of the drought, and is a continuing constraint on water sector planning and management (UNICEF, 1995). Instead, the government initiated a series of emergency assessments, with limited support from the donor community, and set up a Water Security Committee reporting to a National Committee for Disaster Preparedness. At the same time, and following government appeals, a massive capital programme of well drilling and rehabilitation was launched supported almost exclusively by ESAs and conducted by NGOs. The effectiveness of the emergency drilling programmes in relieving immediate water stress was questionable. In some cases, wells were sunk only after the return of the rains because of logistical and technical difficulties, and one emergency programme designed to address groundwater problems in 1992 was only completed in 1995. Concerns have also been voiced about the sustainability of such programmes, as the nature of the work effectively precludes community involvement in the choice, design, and siting of water points. Follow up funding for the creation of community support structures has also been difficult to obtain for emergency projects once the emergency is perceived to be over.

**Northern Province, South Africa**

One of the first tasks undertaken by the Government of National Unity in South Africa was to set targets for the provision of basic rural water supply and sanitation services. The challenge was a daunting one: it was estimated that over 12 million people (roughly 30% of the population) did not have access to an adequate water supply (Van der Merwe, 1995). Most of these people live in poorer rural areas, neglected under previous policies that favoured commercial agriculture and cities. The problem is being compounded by settlement of dispossessed communities on state land where adequate water supply systems do not exist or have been neglected. Not surprisingly, changing government priorities have entailed major institutional upheaval and, like Malawi, South Africa is focusing on demand driven approaches to the provision of services that emphasise community mobilisation and participation. At present a variety of different organisations are implementing rural water supply projects, including government, engineering companies, parastatal bodies and NGOs, and no structured or systematic framework exists to coordinate and guide development efforts.

South Africa has been afflicted by severe and prolonged droughts, often terminated by severe flooding. South Africa's average rainfall of 500 mm is well below the world average and the timing and distribution of rains is unreliable. Over the last two decades, the country has suffered two major droughts, most recently in 1991-92. Like Malawi, impacts on agriculture, food security and later, groundwater resources, were severe. In towns and cities, the imposition of water restrictions and other conservation measures caused little real suffering. In rural areas, however, the drought had an immediate impact on the livelihoods of subsistence farmers, and forced many to travel long distances for water.

About 80% of South Africa is underlain by secondary aquifers comprising weathered and fractured rocks, generally of low permeability and yield. This is especially so in the Northern Province. Limited surface water resources and the need to service communities remote from well-developed infrastructure mean that groundwater is an increasingly important source of supply as efforts are made to meet coverage targets with limited resources. However, like Malawi, this highlights the need for careful groundwater development and management. There is also a wide disparity between of levels of provision of water supply with, in general, areas with the highest population densities having the lowest coverage. In contrast to the more arid western part of the country where water is supplied almost exclusively from groundwater sources, a variety of different technologies and sources are important. These include traditional sources such as shallow wells and rivers, piped (surface water) systems, and 'improved' sources such as boreholes. A difficulty constraining the use of groundwater is uncertainty about yields and demands, and a major mapping and data collection exercise to overcome this problem was also required.

Shortcomings in the information system, especially with respect to the former homelands, make evaluating the impact of the droughts on groundwater resources and those dependants on them difficult. However, drought status reports drawn up by the government during the 1991-92 drought and anecdotal evidence highlights the following:

- in many areas the problem was not one of absolute water scarcity, but one of shortage of readily available and safe drinking water (Hazelton et al, 1994). In particular, the drought exposed a backlog of maintenance problems afflicting water supply infrastructure and a heavy reliance on traditional sources that proved unreliable during the drought. Many shallow wells dried up completely, and heavy demands placed on the few viable boreholes led to borehole failure, either because of drying up or breakdown;

- as the drought progressed, people had to travel longer distances to find reliable groundwater sources. It was not uncommon for people (mainly women) to fetch water from distances of 10 km or more, carried by hand in 20 l containers.

The government responded to the 1991-92 drought by setting up a Water Supply Task Force under a National Drought Steering Committee, charged with reducing water stress in the worst affected areas. In these efforts, the lack of reliable, timely and comprehensive information on the status of rural water supplies was a significant handicap to planning and the targeting of resources (Hazelton et al, 1994). In rural areas the response was ad hoc and highlighted the lack of a specific drought policy. Problems were addressed through a combination of rehabilitation and emergency borehole drilling programmes, together with water tankering operations. For the cities and commercial farming areas, in contrast, proactive measures were taken to lessen the impact of drought, and sophisticated drought relief programmes have been in place for many years. As Hazelton et al (1994) note, "For the rural subsistence inhabitants there have been no formal structures to monitor drought and to provide relief. Often the structures have been set up on an ad hoc basis, often when drought has reached disaster proportions".

The government, through the Department of Water Affairs and Forestry, are addressing these problems. A priority task is the collection of baseline information on rural water supplies and the communities they serve. Specific data needs identified include the names and locations of rural villages, demographic features, water supply coverage levels by technology type (shallow wells, boreholes, piped systems, etc) and basic hydrogeological data, including information on water quality. A comprehensive data base of borehole information, including at least the location, yield and depth of boreholes already exists for some areas, and this has been used to produce 'safe abstraction maps' delineating areas limited by yield or storage.

**Zimbabwe**

During 1984 emergency drilling of water supply boreholes was undertaken in the Masvingo area, a semi arid area underlain by low yielding granitic Basement Complex rocks. There the hydrogeological consultants supervising the installation and testing of the boreholes, in association with the Ministry of Water, were able to collect a significant amount of detailed point source data that could be of use during subsequent drought periods. In contrast, during the 1991-92 drought a similar emergency drilling of water supply boreholes supervised by an NGO in collaboration with the District Development Fund, while being much more sensitive to the needs of the affected communities of the Bikita and adjacent drought affected area, failed to collect any but the most basic information from the boreholes drilled. During the 1991-92 drought and the subsequent 1994-95 drought the main affects noticed in the rural areas was the total failure of any rains resulting not only in crop failure but also the destruction of pastureland. The latter resulted in the destruction not only of local cattle and goatherds but also the herds of wildlife in adjacent national park area. Also badly affected was the sugar growing area of Triangle where a substantial proportion of the crop area had to be abandoned due to the failure of irrigation water supplies from the almost dry Kyle dam.

### 2.1.3 Role of Groundwater in Drought Mitigation

As noted earlier, the response of groundwater to meteorological drought is slower than for surface water as a result of the time lag between changes in recharge and responses in groundwater levels and well yields. This delayed response then provides a potential 'buffer' in terms of reliability of water supply vis-à-vis surface water sources during the actual drought episode.

With respect to the greater use of groundwater during periods of drought it is imperative that there is a clear understanding of the resource base if development of groundwater is to occur in an appropriate and sustainable fashion. Similarly, the need for reliable and timely information on the status of rural water supplies would seem fundamental to any form of groundwater drought planning and mitigation. The lack of this information, at least in an accessible and useable form, has been a serious constraint on sector planning and management in the cases studies discussed in Section 2.1.1 (viz. Malawi and South Africa). In both countries, the situation has been exacerbated by the fact that data holdings that do exist are dispersed amongst a range of different organisations (government, consultants, NGOs) at different levels (international, national, regional, local). A typical result is that new groundwater development projects are designed without the benefit of existing data, the activities of different organisations are insufficiently coordinated, and groundwater development proceeds in an ad hoc manner.

In Malawi, UNICEF (1995) noted that up to date compilation of data has been constrained by lack of institutional stability and capacity, and the need to respond to drought and refugee emergencies. In addition, funding constraints and lack of transport are a continuing constraint to data collection at field level; it is not uncommon for district level technicians to be without transport for months, making compilation of monthly water supply assessments impossible. The government does recognise the need to instigate a comprehensive water level and water quality monitoring and databasing scheme, and to organise existing data (well and borehole records) in electronic form, but attracting donor support for these activities is difficult. Without this, little can be done to identify spatial variations on groundwater drought vulnerability over time and to target potential 'hot spots'.

In South Africa, efforts are already being made to develop a National Water Supply and Sanitation Management Information System. In all SADC countries, there is a pressing need for further groundwater development to take fuller account of the hydrogeological systems expected to furnish perennial supplies. In this way, drilling methods and technological choices can be matched to lithological and aquifer characteristics to ensure the sustainability of supplies, even in times of drought.

There are numerous strategies that can be adopted, but there is an urgent need to:

- recognise the importance of establishing (and maintaining) a sound hydrometeorological database that can be used routinely in the planning of new projects and in groundwater drought prevention and mitigation. Governments, ESAs and NGOs typically place a low priority on these activities. Reasons include: difficulties in quantifying benefits and verifiable indicators of success, especially over the shorter funding periods now being demanded by donors; a preference for dealing with immediately tangible problems which produce short term results (e.g. borehole drilling programmes and the installation of hand pumps); and reluctance on the part of hard pressed governments to divert resources away from more pressing, operational issues;

- establish monitoring systems which extend beyond rainfall, surface water and food security indicators to groundwater and groundwater supply status, recognising that antecedent conditions (e.g. river flows and groundwater levels of the previous year) are essential guides for predicting future hydrological (not meteorological) conditions. Ideally, these should be able to distinguish between the different factors contributing to well/borehole failure, in particular, the distinction between source and resource stresses and source/resource and maintenance problems. This indicates a need to collect data on groundwater conditions from a dedicated network of monitoring points

- ensure that the role of monitoring and assessment is clearly defined within the new institutional arrangements emerging in the region. In Malawi, for example, many of the operational tasks traditionally carried out by government are being turned over to local communities. A similar approach is being advocated in South Africa. In theory, this should allow water departments to devote more time and resources to matters such as monitoring and assessment, but tasks and funding arrangements have yet to be clearly defined.

A number of relatively simple measures could be implemented to reduce the impact of a groundwater drought. Examples include:

- well/borehole deepening in selected areas as a routine component of rehabilitation programmes, although this may be difficult if cable tool rehabilitation rigs are deployed;

- the routine sinking of an extra well or borehole in villages where, because of the nature of the aquifer, falling water levels are specific to individual sources;

- the sinking of deep boreholes in the most favourable hydrogeological locations, which could be uncapped and used in emergency situations. Such wells could be used by households from different villages should local village sources dry up.

- The sinking of collector well systems in shallow aquifer situations as in southern Zimbabwe and northeastern Botswana.

### 2.1.4 Drought Preparedness and Mitigation Policies

The cycle of drought and the availability of reliable groundwater fed sources is a key to drought proofing. The initial drying up of surface waters means that many unprotected sources used, for example by cattle, dry up. As the drought progresses, crop failure and pasture destruction is followed by loss of animals. Eventually village boreholes and wells suffer, either through mechanical failure induced by stress of pumping to greater demand and declining head on the water table, or very occasionally because the groundwater resource fails. More often than not groundwater is still available but cannot be accessed, either because of poorly located boreholes, wells or boreholes of inadequate depth or given their reduced seepage area boreholes may not be the optimum method of abstracting water from an aquifer with depleted resources.

In all cases it is the rural communities that suffer most. A progression of crop failure, loss of surface water and pasture, followed by death of animals, drying up of shallow wells, and failure of deeper boreholes (often mechanical failure rather than total groundwater scarcity) leads inevitably to severe hardship. Women are forced to spend a large part of the day walking to, and queuing at, whatever alternative groundwater sources are still available; some sources are then of indifferent quality and unprotected, others require payment. Lack of sanitation causes widespread occurrence of stomach disorders, dysentery and other disease, particularly in the young and the elderly. Normal lifestyles are put into suspense.

One of the peculiarities of groundwater drought is the lack of reliable quantitative indicators of its severity. Groundwater level hydrographs, abstraction figures, even the distribution of boreholes and the status of their pumping machinery are all data that are commonly lacking in pre-drought periods, and almost totally absent during the fire-fighting activity within the crisis itself. Often the best data are medical registration statistics for rural clinics and hospitals indicating changes in diseases of poor sanitation. Without these data, crisis reaction is frequently untargeted and ineffective, but availability of these data can enable proactive management to help alleviate the impact of drought as and when it strikes.

Groundwater sources may fail for a variety of different, though often unrelated, reasons. These include both local or regional dewatering of the aquifer, demography or institutional inability to satisfy demand, and technical or mechanical failure of the borehole/well or pump. Key factors towards sustainability include:

- community ownership and maintenance of sources (generally through a water committee),
- standardisation of pumps and local availability of spares,
- good communication between village water committee, tribal authority or local administration with local government and national ‘Department of Water’,
- good borehole siting using geophysics, remote sensing and other techniques as appropriate, adequate borehole design,
- monitoring,
- accessible national or regional database of groundwater sources: coordinates, village name, borehole/well depth, geology, yield, design, casing, water levels.

- an appreciation of how groundwater occurs within the local geology, especially within the near surface weathered horizons so that the effects of seasonal and drought affected groundwater resource changes (water level, yield and quality) can be explained to the user community

Possible specific strategies towards dealing with drought are:

- proper targeting of resources and thorough co-ordination of NGO activities within the Governmental "umbrella",
- adequate provision of sources to satisfy demand (although boreholes and wells may be the mainstay of supply, gravity fed spring sources and reticulated river off-take schemes do play a part, the latter prone to failure in many rural areas of South Africa due to under-design and lack of maintenance).
- in Malawi and Zimbabwe emergency drilling programmes were organised in response to the 1991-92 drought and efforts were made to speed up rehabilitation and maintenance programmes, although the limited effectiveness of emergency drilling programmes needs to be recognised by the donor community and greater emphasis needs to be placed on longer term pre-drought prevention and mitigation measures. In relation to groundwater data collected during emergency drilling programmes much improvement is desirable. An emergency drilling programme in southern Zimbabwe during 1991-92 produced 10 dry boreholes drilled before the rains broke, whereas in contrast nearly all boreholes drilled after the rains had started were wet and were therefore regarded as successful! Therefore beware of the data produced by drilling programmes that were undertaken after the drought broke!
- development and safeguarding of traditional coping methods such as river dug-outs and sand river dams.
- conjunctive use of surface water and groundwater given the time lag in groundwater reacting to climatic drought.
- the use of temporary, stopgap measures may be more effective than 'quick fix' solutions aimed at rapid installation of permanent water supply infrastructure. Such measures include assisting communities with the transport of water (e.g. through provision of water carts and the animals to pull them) and, where institutional capacity permits, the tankering of water by lorry or tractor drawn water-bowsers (South Africa, Northern Province). In Lesotho and Zimbabwe, butyl rubber water bags (bladder tanks) were used as reservoirs, facilitating rapid turnaround of tankers. During 1991-92 in the drought affected areas of southern Zimbabwe water was tankered to strategic schools where supplementary food was distributed.
- ultimately, decisions regarding the appropriateness of interventions need to be made at local level where problems can be assessed in context. Water stress tends to be much more localised problem than food insecurity as food can be transported further and more easily than water. The challenge is how to identify affected communities. However, this information is rarely available at national level, and there is a clear need to decentralise the response to groundwater drought within the context of a national strategy.

It is also clear that analysis of the causes of water source failure is a key to promoting strategies to alleviate hardship during times of drought (drought-proofing) and much can be done in pre-drought periods to improve the reliability of groundwater sources. As noted earlier, it is clear that sound information on the water resources base and identification of vulnerable areas can facilitate tailoring of water supply developments to local conditions. Ultimately, decisions need to be made on a pragmatic basis, reflecting both the wishes (and increasingly, ability to pay) of local people and sound hydrogeological assessment.

Drought-proofing strategies are many and varied, but some of the more viable and productive include:

- pre-positioning of relief resources, e.g. drilling drought relief boreholes in hydrogeologically favourable locations for use during drought conditions; local provision of construction materials with which to deepen hand dug wells,
- well and borehole deepening as a routine component of rehabilitation programmes in vulnerable areas,
- groundwater drought vulnerability mapping.

Greater coordination of the collection and sharing of appropriate information between different players in the water sector is also required, especially as the number of NGOs with differing and multiple accountabilities increases. Past mistakes need to be avoided, and success stories - for example where the drought proofing of rural communities has been effective - need to be shared. In addition, experience from SADC countries underlines the importance of effective maintenance arrangements; the impact of a groundwater drought is potentially much worse if a large proportion of water points are already non-operational.
In all cases the effectiveness of emergency drilling programmes as the principal means of relieving water stress has been questioned. In Malawi, for example, some drilling programmes did not get underway until after the return of the rains, but hasty organisation left little scope for community mobilisation and follow up work to ensure sustainability. Low success rates are also the norm: this reflects the difficulty in finding productive boreholes in difficult terrain, and the fact that the pressure of the emergency often reduces the quality of the work. Nevertheless, such programmes remain attractive to donors. One of the principal reasons for this is that financial support continues to be much more easily mobilised for emergencies than for longer term efforts aimed at drought-proofing rural communities, or indeed for supporting much needed monitoring and assessment programmes.

## 2.2 GROUNDWATER, SURFACE WATER AND DEPENDENT ECOSYSTEMS

### 2.2.1 Definitions and Overview

The natural environment and its component ecosystems cannot be seen simply as another competitor for scarce water resources since it is the base from which the resource itself emanates, and without which water use and development cannot be sustained. Ecosystems and sustainable environmental management have to be considered as an integral part of water resources management policies and processes.

Particular ecosystems can be spatially defined by the demarcation of ecozones, each of which is influenced by a set of common climatic, hydrological and biological processes. The SADC Region has provisionally been divided into eight such ecozones, with a ninth transitional zone and wetlands being considered as a tenth special case. A number of these are dependent on or at least intimately associated with the groundwater system, such that their very existence, and thus the existence of all flora, fauna and human activity that are part of them, may be threatened by changes in groundwater levels, groundwater discharges and/or groundwater quality.

The seven main ecozones of the SADC Region range form the Lowland Tropical Forest of the Congo Basin and certain coastal areas, through scattered Afromontane or Temperate Forest, the Grassland of South Africa, the Savanna that occupies much of the region, the Nama-Karoo of west-central South Africa and Namibia, the Succulent Karoo of the south Namibian coast to the Desert ecozone of coastal Namibia/Angola. The eighth ecozone is the winter rainfall Fynbos of the extreme southern tip of South Africa, which has 7300 plant species

5000 of which are unique to the area. The Transition ecozone lies between the Tropical Forest and the Savannah and is governed by the seasonally of the rainfall.

Although Wetlands can be considered as the tenth ecozone they are not recognised as a formal ecozone since they are usually highly localised and controlled by the presence of abundant water. Five wetland systems are recognised in the SADC Region. They are grouped according to their common features such as landscape, water chemistry, vegetation and formation into palustrine, riverine, lacustrine, estuarine and marine systems. Each of these systems can also be subdivided into other components, representing a specific and usually highly localised environment that can be crucial to the existence of the ecosystem (including human involvement).

All the above can be categorised as natural ecosystems, but of crucial importance in a discussion of ecosystems and groundwater dependence is whether the human component is taken into the definition of an ecosystem. If so then the number of ecosystems in the region that are either dependent upon or have influence on groundwater grows considerably and is extremely difficult to unravel from the human developmental and social dependence on groundwater.

### 2.2.2 Significant Groundwater/Surface Water Interactions

Groundwater and surface water interaction can basically be divided into situations in which surface water is 'influent' and contributes directly and regularly from a recognised surface water body into the groundwater resource, or situations in which groundwater is 'effluent' and, at points where the local piezometric surface intersects the topographic surface, groundwater discharges into and contributes to a surface water body.

Clearly, the impact of drought on both the surface water body and the groundwater will impact on the balance of flow between the two bodies, and thus the relative magnitude of the bodies themselves as well as the security during drought periods of the water sources that draw upon them. If a surface water body is influent with respect to groundwater, then the obvious and rapid reduction in this water body during a period of meteorological drought will clearly adversely impact on the groundwater resource that may become the principal supporter of water supplies during the drought period. Conversely, if the groundwater body is 'effluent' with respect to surface water then the effects of a groundwater drought may reduce contributions to the surface water body, or even reverse the flow situation, a change that may significantly exacerbate the return of the surface water to 'normal' even after the cessation of the meteorological drought as a result of the delayed response of the groundwater to improved rainfall conditions.

Clearly, the most significant of these two situations with respect to natural groundwater dependent ecosystems is that in which the sustainability of the ecosystem is dependent on 'effluent' groundwater, for example if a wetland system is wholly, or even partially, dependent upon groundwater discharge to maintain the surface or near-surface water body. Any reduction in groundwater base-flow would then have serious impact on the ecosystem, with such impact possibly being prolonged beyond the visible cessation of the drought as a result of the long groundwater recovery period.

If the definition of 'ecosystem' is also broadened to include the human component and dependency on groundwater for rural water supply or possibly traditional farming practises, then the other interactive situation in which surface water is 'influent' with respect to the groundwater body will become more important, as any reduction in surface water input to groundwater during drought will ultimately adversely affect the ability of the groundwater body to support the human aspect of the ecosystem.

Also of importance in the consideration of the interaction of groundwater and surface water is the quality of the water body, whether it is surface or groundwater. If either is susceptible to pollution, then this will be transmitted to the other, and such transmission may become greatly exaggerated during periods of drought. If groundwater is ‘effluent’ and is polluted, then groundwater flow may increase in magnitude and proportion of surface flow during low surface water stages, with a consequent increase in the concentration of pollutants and a potentially large impact on groundwater dependent ecosystems such as wetlands. Similarly, in a situation in which surface water is normally ‘influent’ with respect to the groundwater body then low surface water stages may result in an increase in concentration of pollutants that enter the groundwater system, with a similar adverse impact on both natural or human-based ecosystems.

In South Africa the nature flows to and from river systems at quaternary basin level are being assessed for their input upon ecological systems. This will enable the effects of abstractions undertaken along the river length to be assessed, as they should not impact upon the ecological nature of the river system.

Within the SADC region it is clear that the impact of drought on surface water/groundwater interaction is likely to be most prominent with respect to natural wetland ecosystems such as those that occur in the Okavango Delta (Botswana), Zambezi, Kafue and Luangua flood plains (Angola and Zambia), Lake Malawi and Lake Chilwa (Malawi and Mozambique), the Oshana system (Namibia), the sand river systems (eastern Botswana, southern Zimbabwe and northern South Africa) and the dambo/mbuga/vlei valley systems (Zimbabwe, Zambia and Tanzania) amongst others. However, the nature of this interaction in all instances has not been reliably established, and in many cases has not been even considered in the study and description of the wetland system itself. This may be a function of the difficulty in defining this interaction, but it may also be a reflection of the nature of wetland studies and the normal range of scientific disciplines involved in such studies (e.g. mostly undertaken from a botanical/wildlife/natural environment perspective). It has, however, resulted in a definite paucity of data on surface water/groundwater interaction, and thus on its variation and impacts during drought periods, and little specific information on this topic has been encountered during the data collection process.

## 2.3 GROUNDWATER POLLUTION

### 2.3.1 Definitions and Overview

Pollution is the degradation of natural systems by the addition of detrimental substances and is usually associated with industrial and agricultural development, and the rapid increase in human population density.

Groundwater pollution, and the essential water laws that attempt to prevent it, is of the utmost concern in a world that has limited potable groundwater resources subjected to the pressures of an ever increasing population and human development that generates ever increasing amounts of waste. Examination of existing documents relating to the SADC region reveals that it is no different in this respect from other regions of the globe, and various sectoral activities that contribute to the pollution of the groundwater resources have been identified.

Of the many sources of pollution of water resources the following may be considered to be the most serious:

- Industrial and municipal waste, which can either be biodegradable or non-degradable, solid or liquid;

- Agro-chemical pollution, which is a product of the application of pesticides, herbicides or fertilisers.

- Discharges of toxic mine waters from abandoned mine workings due to water table rebound resulting in artesian flow into natural water courses

Many of these pollutants are termed 'ecological accumulators' since they are not broken down by plant or microbial enzymes and thus accumulate and concentrate in the food chain with toxic effects on humans and other animal life

With respect to groundwater by far the most significant source of pollution is anthropogenic, as deterioration of groundwater quality rarely occurs naturally and is usually caused by human activity. There are generally two main reasons for deteriorating groundwater quality:

- over pumping of the groundwater body that can lead to saline or polluted water being drawn into the aquifers or
- direct contamination through the leaching of wastes and chemicals from the land surface down into the aquifers. Contamination can take many forms: diffuse sources such as pesticide residues and fertiliser leached from agriculture or point sources such as leakage from underground tanks, waste water disposal or industrial/mining processes.

It is a significant fact that once groundwater is contaminated it is difficult to remediate and return to its unpolluted stated. Groundwater is generally in circulation for many years and it could take tens or hundreds of years for contamination to disperse or be diluted by means of natural groundwater flow. It is also a well-known fact that techniques to pump and treat the contaminated groundwater are expensive, and thus the cheapest and most effective method of maintaining good groundwater quality is to protect the resource from contamination in the first place.

A number of documents indicate that a ***groundwater contamination inventory*** is an indispensable part of any comprehensive groundwater protection strategy. Before appropriate protection measures can be designed and implemented, groundwater contamination and its sources must be identified and assessed, and their impacts on groundwater quality determined. An inventory of the number, type, and intensity of potentially contaminating activities and of the extent of existing contamination of groundwater can serve a twofold purpose for groundwater protection:

- It provides government officials, planners, and managers with an understanding of the potential for groundwater contamination needed for successful management programs.
- It provides basic data that can be used for the design of the type and location of various controls and of the monitoring programmes.

The results of a comprehensive, detailed inventory allows water managers to prioritise contamination sources according to intended purpose (e.g. to determine the level of risk to public drinking water supplies) and to develop differential management strategies to address these sources, thereby safeguarding public health and protecting groundwater in general.

### 2.3.2 Current and Potential Pollution Status

In examining the general status of groundwater pollution in the SADC region it has been necessary to follow a sectoral approach, as what limited data there is available tends to be restricted to documents and datasets related to the various sectors.

***Agriculture***

Agriculture is of major importance in the SADC region. Although many agricultural activities have been conducted on a small scale, the growth in commercial farming especially of specific crops for export has resulted in the increased use of fertilizers that has resulted in the pollution of specific aquifers. The application of new dry land farming methods without the use of fertilizer can also result in the introduction of nitrogen to aquifers. The use of irrigation for crop production is increasing in some countries, but this may result in the salinisation of soils; for example, long-term abstraction of groundwater for irrigation from the Lomagundi Dolomite aquifer of Zimbabwe has resulted in a lowering of the water table and diminished borehole yields. It has also allowed pollutants from agrochemicals to be transported into the aquifer system. Concerns about over-exploitation and pollution of the valuable resource prompted geohydrological, hydrochemical and isotope hydrological studies since 1981 by various groups. The groundwater is a Ca-Mg-$HCO_3$ type at relatively low mineralisation. Time series of tritium values indicate mean residence times of 30 to 100 years, and recharge rates of some 50 mm $a^{-1}$ have been estimated. Stable isotope data show recharge only during major rainfall events and significant contributions from irrigation return flow. This emphasises long-term vulnerability, seen also in the correlation between nitrate and tritium.

Similar problems are being experienced along the middle reaches of the Kafue valley in Zambia where nitrates derived from fertilizers are entering the shallow alluvial aquifers.

Also in the agriculture sector, Du Toit, van Dyk, Ferris and Nel (2000) describe how in the Kalahari region of South Africa acceptable quality groundwater derived from the dewatering of manganese mines can provide a cost effective and sustainable alternative to provision of water by pipeline from a remote river source. Connelly and Taussig (1994) provide an example of nitrate contamination of groundwater in the Kutama and Sinthumule districts of Venda, South Africa derived from agricultural activities under a dry land cropping system.

The karstified Lomagundi dolomite in northwest Zimbabwe is being heavily exploited for irrigation agriculture. Concerns about over-exploitation and pollution of the valuable resource prompted geohydrological, hydrochemical and isotope hydrological studies since 1981 by various groups. The groundwater is a Ca-Mg-$HCO_3$ type at relatively low mineralisation. Time series of tritium values indicate mean residence times of 30 to 100 years, and recharge rates of some 50 mm $a^{-1}$ have been estimated. Stable isotope data show recharge only during major rainfall events and significant contributions from irrigation return flow. This emphasises long-term vulnerability, seen also in the correlation between nitrate and tritium.

***Mining***

The mining of precious minerals, metalliferous ores and fossil fuels forms a major part of the economy of a number of the SADC countries. Many of these activities are located within semi-arid areas and impact upon groundwater both in terms of its use as a guaranteed source of water for processing as well as in terms of the waste products produced by mineral processing plants. Such waste products invariably contain pollutants that can have serious adverse impact on the quality of underlying groundwater as well as any surface water resources.

Examples of the detrimental pollution effects of long-term and large-scale groundwater abstraction for mining is evidenced in the Witwatersrand area near Johannesburg which has resulted in the abstraction of vast quantities of groundwater and the introduction of bacteria and other pollutants at deep levels. Onstott, Moser and Wilson (2000) assessed the hydrochemical and bacteriological quality of waters within the Witwatersrand deep gold mines. Isotopic analyses indicate that the borehole water is of meteoric origin, but exhibits extensive rock/water interaction in some cases. Open boreholes are rich in metal-oxidizing and -reducing bacteria. Rosner, Vermaak, van Schalwyk and Viljoen (2000) undertook an assessment of the rehabilitation of reclaimed gold tailings dams areas in South Africa. They found that some gold mine tailings dams have been partially or completely reclaimed and left a contaminated subsurface which could pollute underlying aquifers. They outline remediation measures to prevent contaminant migration into the groundwater.

Evidence of the pollution impact of processing waste products includes the presence of arsenic in groundwater at various sites in Zimbabwe, and various heavy metals and sulphates in shallow (sand river) groundwater in Botswana.

Acid and neutralised acid mine drainage are arguably the most serious threats posed to the environment by coal mining activities that take place in South Africa, Zimbabwe and Botswana. Changes in South African legislation have focused attention onto water management in the coal mining industry and Salmon (2000) describes water management strategies employed by coalmines to prevent water pollution and methods of treatment of polluted water.
The distribution of mineral resources in Zambia by Coats, Mosley, Mankelow, et al (2001) can be used to identify past, present and potential areas of mining and metalliferous refining waste in Zambia. This report is accompanied by a map, a GIS and databases of mineral occurrences and bibliographic references on CD-ROM.

***Rural***

Groundwater forms a major source of rural water supply in much of the SADC region, but shallow groundwater is prone to contamination and there is an increasing awareness of the linkages between groundwater and rural development.

The protection of groundwater in rural areas is intimately linked with land-use management that needs effective land surface zoning to provide a rational framework for land utilization and groundwater protection. If this is to be achieved Foster and Skinner (1995) advise that the complex hydrogeology must be made intelligible to the farmer and that the water industry must acknowledge on what land and during which period their groundwater supplies originate. To protect groundwater water resources from surface contamination, policies such as land surface zoning, guidelines for activities in each zone as well as groundwater pollution vulnerability mapping should be undertaken. The zones include: (1) sanitary zone around the source; (2) a 50-day travel zone from the aquifer to the borehole; (3) a 500-day travel zone; and (4) the whole catchment (MacDonald, 2002). Burgess and Fletcher (1998) discuss methods used to delineate groundwater source protection zones that are an integral part of the production of groundwater vulnerability maps. Lewis, Lilly and Bell (2000) indicate that groundwater vulnerability maps need to reflect the lithology and permeability of the geological formations, and the physical and chemical properties of the overlying soils. Hantush, Marino and Islam (2000) describe models developed that describe leaching of pesticides in the root zone and the intermediate vadose zone, and flushing of residual solute mass in the aquifer.

For example, widespread use of on-site sanitation in rural South Africa may cause subsurface migration of contaminants resulting in disease and environmental degradation. In their review Fourie and van Ryneveld (1995) define the pollution risk from these systems, realising that bacteria and viruses are a problem in fractured or karst bedrock at shallow depths whereas nitrates are a problem in the unsaturated zone.

In Botswana Lewis, Farr and Foster (1980) observed nitrate concentrations far in excess of recommended limits in a number of village water supply boreholes in eastern Botswana. They evaluated the causes and mechanisms of nitrate and bacteriological pollution from pit latrines. Local hydrogeological conditions must be understood when developing low-cost village water supplies and sanitation if public health hazards are to be avoided. In addition, SWECO (1978) prepared guidelines for nitrate reduction of contaminated boreholes within existing rural water supply schemes in Botswana.

In Tanzania Nanyaro, Aswathanarayana and Mungure (1984) studied the occurrence of toxic levels of fluoride that cause a major problem in the aquifers in the northern regions. In addition, Nkotagu (1996) looked at the origins of high nitrate in groundwater within the weathered Basement Complex formation in the Dodoma area, concluding its derivation as being primarily from sewerage effluents.

***Urban***

Key issues are the increased use of groundwater in peri-urban areas, the impact of the urban environment upon recharge and the pollution of groundwater resources by leakage from urban piped water distribution and sewerage systems, various light and heavy industrial processes, and their effective management. Over-exploitation and pollution cause degradation in the quality and quantity of groundwater at scales that depend upon aquifer vulnerability to pollution. Foster, Lawrence and Morris (1998) review the situation and highlight key issues to foster the sustainable management of groundwater resources in urban areas. Bruce and McMahon (1996) present the results of a study of shallow groundwater system pollution beneath an urban centre.

The rapid growth of population in Lusaka has overwhelmed the provision of basic needs and services by the local authority, resulting, among others, in inadequate collection and disposal of waste. Because karstified marble that underlies the city forms the unconfined aquifer from which the city draws most of its potable water such practices form potential sources of groundwater pollution. Nkhuwa (2000) and Nyambe and Maseka (2000) describe aspects of current waste disposal practices and uncontrolled drilling of abstraction boreholes that both threaten to contaminate and overexploit the aquifer system. The population of Lusaka, about 1.2 million people in 1998, has deposited effluent in landfills, rubbish pits, septic tanks and pit latrines that have contaminated the aquifers with high concentrations of nitrate-nitrogen (15-40 mg/1).

***Industrial***

Shallow aquifers are highly vulnerable to contamination from industrial activities associated with industrial processes, disposal of wastes and spillages of chemicals such as solvents and fuel oils. Cameron-Clarke and Palmer (2000) review the South African minimum requirements for waste disposal, and describe the development of closure plans for existing waste piles with examples from heavy metal refining operation, a slimes disposal area containing chlorinated organic chemicals and metals, and a chemical complex with hazardous and non-hazardous wastes. To avoid the costly and technologically difficult exercise of remediation, Xu and Reynders (1995) suggest a pro-active groundwater protection strategy in South Africa. A three-tier protection concept, with the emphasis on a zoning approach, is proposed that will allow the protection of groundwater at various levels (national, regional and local) and ensure protection in the short, medium and long term.

Morris, Allerton III and van der Westhuysen (2000) describe the nature and extent groundwater contamination from a metal plating factory, the hydrogeological setting, the corrective action plan and the results obtained. The contaminants included toxic amounts of zinc, chromium, nickel, copper, cadmium and cyanide released during metal plating and chlorinated aliphatic hydrocarbons used during the sheet metal cleaning and preparation prior to plating.

## 2.4 GROUNDWATER MONITORING SYSTEMS

### 2.4.1 Definitions and Overview

A monitoring system needs to be aligned to a set of objectives and outputs. Incoming data must be handled and processed such that meaningful reports can be generated for the user community. Objectives may range from supply status and demand to water quality objectives to drought early warning. Since monitoring and data handling are relatively expensive long-term activities where the benefits may not be apparent for some time, outputs must be in a form that clearly provide tangible evidence of present or future benefit if monitoring is to continue.

Groundwater system monitoring information falls into three broad areas:

- Water level monitoring,
- Water quality monitoring,
- Water supply and demand status monitoring.

The density of monitoring points needs to reflect the importance of the aquifer in terms of usage, the criticality of the aquifer in terms of drought warning and the vulnerability of the aquifer to pollution. Guidelines for the monitoring and management of groundwater resources in rural water supply schemes have recently been prepared in draft form for use in South Africa (Meyer, 2000). These guidelines could be applied elsewhere in the SADC region.

Monitoring networks and regional groundwater drought monitoring systems need to:

- Develop the data reliability, relevance and cost effectiveness of national monitoring networks,
- Develop the regional monitoring network to complement local and national monitoring activities, with focus on the major multi-national aquifers that might be subject to regional impact of drought, and on the joint management of surface and subsurface water resources in the main river basins.
- Be part of a common regional monitoring network, and
- Establish procedures for a regional groundwater drought monitoring and early warning system of drought events.

One of the key areas in drought preparedness is data gathering and data assimilation such that full knowledge of water resources availability and water point status is accessible at all times, most especially before the onset of a drought. Water resources, water demand and the nature of water use are continuously changing, but it is their relative values that determine the degree to which drought has an impact, and the specific responses that may be available in a given time. Monitoring should thus include measurement of all elements of the natural water cycle (meteorological, hydrological and water level data), measurement of water quality data, measurement of human activity (abstraction; land use) and measurement of abstraction point performance. Data on maintenance activities are also essential to ensuring that water development projects are successful, sustainable and cost effective. This may also include maintenance of monitoring installations and abstraction infrastructure.

Unfortunately monitoring is commonly only considered once a water resources system, aquifer or network of water points has suffered degradation, but monitoring systems are essential to sustainability and for early warning. An important part of a monitoring system is an effective database system that ensures that information is easily accessible so that mitigating actions can be taken in response to early warning of drought or resource degradation. It is also important to continue monitoring during and after the drought event.

Information on monitoring systems related to groundwater and hydrological monitoring is available from earlier SADC projects and has been updated wherever possible, but information on monitoring with respect to water demand, water usage, water system maintenance and environmental aspects are scarce.

## Groundwater Monitoring Data — Information Box 1

| Member State | Data Type | Format | Department/ Agency | Coverage | Comments |
|---|---|---|---|---|---|
| **Angola** | Gwlv, Gwab, Gwdm | | DW, DGS | * | Annual measurement of water levels, yield, operational status, depth, dynamic water level in 2632 bhs and 982 wells by DNA |
| **Botswana** | Gwlv, Gwqy, Gwab, Gwdm | M, T, C | DW, DGS, DRA, WSO | *** | DGS and DWA monitor 594 wellfield bhs, 513 national monitoring network bhs and village water supply bhs |
| **DR Congo** | | | | | No routine water level monitoring |
| **Lesotho** | Gwlv, Gwqy, Gwab, Gwdm | M, T | DW, WSO | *** | Dept Water Affairs - 122 springs and 89 Bhs, WASA – all supply Bhs |
| **Malawi** | | | | | No routine water level monitoring |
| **Mauritius** | Gwlv, Gwqy, Gwab, Gwdm | M, T | DW | * | WRU – 200 manual, 20 transducer bh water level systems |
| **Mozambique** | | | | | No routine water level monitoring |
| **Namibia** | Gwlv, Gwqy, Gwab, | M, C | DW, DGS, DRA, WSO | ** | National bh monitoring system |
| **Seychelles** | Gwlv, Gwqy, Gwab, Gwdm | M | DW | *** | PUC-27 monitoring bhs, 2 bhs for EC and abstraction |
| **South Africa** | Gwlv, Gwqy, Gwab, Gwdm | M, T, C | DW, WSO | *** | DWAF - >1000 bhs for water levels and 360 bhs for water quality |
| **Swaziland** | Gwlv | M | DGS | * | DGSM–50 bhs installed but system not maintained |
| **Tanzania** | Gwlv, Gwqy, Gwab, Gwdm | C, M | DW, WSO | * | 10 bhs at Makutapora Basin in Dodoma, some bhs at Arusha and Moshi, several on Zanzibar Island |
| **Zambia** | Gwlv, | M | DW | ** | Monitor 500 bhs country wide on 3 monthly basis |
| **Zimbabwe** | Gwlv, Gwqy, Gwab, Gwdm | M, C | DW, WSO | ** | Monitoring bhs are located in the Nyamandlovu, middle Sabi and Lomagundi aquifers |

Data Type:
Gwlv – Groundwater Level
Gwqy – Groundwater quality
Gwab – groundwater abstraction
Gwdm – Groundwater demand

Format:
M - manual
T - transducers
C – chart recorders

Department/Agency:
DW – Dept of Water
DGS – Dept Geological Survey
DRA – District/Regional Authorities
WSO – Water Supply Organisations

Coverage
*** - Good
** - Moderate to patchy
* - Poor to non-existent.

### 2.4.2 Current Status of Monitoring

It must be stated that adequate hydrogeological monitoring in the SADC region is a key deficiency. As shown in Information Box 1 only five of the Member States have monitoring systems involving water level and some type of water quality measurements that may be regarded as some form of national network. Some monitoring is going on in the majority of the remaining countries but it is generally carried out by various institutions 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, Mozambique and DRC) no time series hydrogeological data of any type are being collected. This is particularly significant in a country such as Malawi where groundwater is such an important resource to rural communities.

The bulk of water level monitoring in member countries is carried out manually, although the use of digital recording devices (e.g. transducers) is increasing. South Africa and Botswana in particular is planning to move toward using transducers exclusively for water level monitoring in the next few years and is increasing the use of digital EC data loggers. Automatic chart recorders are used in some countries. A comment on monitoring methods and number of monitor points (where available) for each country is also provided in Information Box 1.

Recharge monitoring is at present a relatively limited aspect of monitoring in the SADC region. In terms of national recharge monitoring networks, the most advanced is that in Botswana where not only is chloride deposition being monitored (for the chloride mass balance method of recharge estimation), but there are also recharge stations where groundwater level and meteorological data are continuously measured for use with remote sensing data (i.e. with SEBAL type algorithms). Zimbabwe is also in the initial stages of setting up a national recharge network based on chloride mass balance. Furthermore, a considerable number of detailed local and regional studies have been carried out in several countries as part of specific projects or university research (e.g. Botswana, Namibia, and South Africa).

### 2.4.3 Constraints and Aspirations

There are a number of fundamental causes of inadequate monitoring that can be recognised in many of the SADC Member States. These are summarised below:

- Manual data collection and sampling in countries having limited financial resources with large land areas and poor road networks is expensive. Although the use of automatic recorders is widely recognised as cost effective, the cost of initial installation maybe prohibitive.

- The long term benefits and importance of hydrogeological monitoring are not clear to the non-hydrogeologist. The need for hydrogeological monitoring usually only becomes apparent to non-technical administrators and financial controllers during a crisis, but interest soon wanes when the crisis ends and staff and funds are then reallocated to more immediate water supply provision.

- Donor (and country) funded groundwater projects are usually of short duration with little if any hydrogeological monitoring input in their design.

- Even in countries where adequate national monitoring is carried out, considerable difficulties are still reported, most commonly related to training levels of data collection staff, limited resources and/or lack of data management facilities/manpower.

- The primary objective of monitoring in most countries is aquifer protection and resource allocation. However, in countries with limited monitoring, there is frequently no clear or documented objective, which often results in inadequate networks and poor distribution of monitored points, inappropriate monitoring frequency (both too frequent and excessively infrequent), and limited use or analysis of collected data.

- A major cause of poor monitoring or poorly defined monitoring programmes is the lack of an identified person or group that are specifically responsible for national monitoring. In some cases this results from a lack of qualified professionals available to fill such a post and in other cases is simply due to limited importance attributed to monitoring activities.

- In most cases the distribution of any monitored stations is uneven, with some large areas often not represented at all. Significant locally developed groundwater resources (i.e. wellfields for industry, towns or cities) are commonly monitored to some extent, but the national groundwater authority even in states where national monitoring programmes are well developed rarely captures data.
- Regular quality monitoring is most often present in local areas where some problem has been identified previously (e.g. seawater intrusion, aquifer contamination, cholera epidemics).

- The understanding of data quality and consistency is rarely recognised and QA/QC protocols for monitoring data are not implemented in any of the SADC member states.

Having outlined the general constraints with respect to groundwater monitoring in many of the Member States it is, however, apparent from many of the technically responsible persons in groundwater management agencies that there is an understanding of the need for better monitoring systems and practises. It is also clear that there are aspirations that some progress may be made towards this if clear guidelines (and financial assistance) can be incorporated as part of the drive towards the regionalisation of groundwater and drought management. Maybe a groundwater level monitoring facility could be incorporated within each of the HYCOS automatic recording sites currently being established throughout the SADC region.

## 2.5 GROUNDWATER INFORMATION SYSTEMS

### 2.5.1 Definitions and Overview

Since there is often confusion as to the difference between a basic groundwater database system and a Groundwater Information System, and the nature, establishment, operation and usefulness of each, a simple definition of each is presented.

A ***Groundwater Database*** is a straightforward repository of groundwater data collected as part of monitoring procedures and during development work, preferably stored in digital form in database software such as Ms Access or similar such that it can be imported into more sophisticated analytical or display software as need arises. More complex groundwater database systems that include a wide variety of in-built analytical, display and query functions have also been developed and are in use.

A ***Groundwater Data System*** is a comprehensive data storage and dissemination system that incorporates all elements of a groundwater database with other groundwater management related information (climate, water use, water demand data etc). The data are usually held in a spatial environment (i.e. with in-built GIS functionality) designed with full cognisance of the end-user and the broad information dissemination requirements. Such a system should also encompass the storage and distribution of specific types and categories of groundwater related documents and research papers relevant to the region and groundwater environment covered by the system.

In specific terms Groundwater Data Systems bring together all the various data layers that are needed to develop tools with which to plan and manage resources. The layers are held separately, but can be integrated one with another in order to best show particular aspects of the data suited to a particular issue. Layers may typically include:

- Solid and superficial geological map line work and legend,
- Land elevation, typically as a digital terrain model,
- Outline geographical features,
- Surface water catchment divides,
- Land use,
- Depth of regolith,
- Soil types,
- Rainfall and evapotranspiration distribution,
- Borehole well and spring locations, and all data pertaining to them, including time series monitoring data,
- Borehole and pump status,
- Piezometric surfaces,
- Demand distribution,
- Groundwater quality as potability distribution,
- Vulnerability to pollution,
- Susceptibility to drought,
- Groundwater availability.

Some of these layers contain just primary data, whilst others (lower down in the list) are derived layers depending on data held in other layers of the system. The list is not comprehensive but it serves to indicate what can be held in a Groundwater Data System. It is important that the GDS, once created, is accessible and responsive to enquiries made of it. It should be accessible at national level to promote optimum use of available resources planning, at regional level to assist in planning and management and at local level to facilitate operational activities. It must be available to both Government and NGOs, and above all must be presented in a simple manner that all comers can understand.

If at all possible it should also be closely linked to both national and regional monitoring networks such that dynamic data sets can be regularly updated for the purposes of analysis and prediction.

Considerable attention needs to be given to end user requirements and who the end users of the data are at various levels. Interest at national level is usually in overall resources, whereas at local level it is on specific area or groundwater production issues. A simple GIS database that provides easily assimilated derived data layers that can readily be used for decision-making and planning by technical and non-technical users alike may be a preferred option. The type and nature of data to be gathered, and the form of data storage and recovery are also critical to the successful use of the information.

Accessibility and dissemination of data/information needs to be very seriously considered in order to optimise the use of such a Groundwater Data System beyond local operational concerns to include national and regional drought prediction and mitigation measures and vulnerability evaluation.

### 2.5.2 Current Status

The responsibility for groundwater data collection and storage is everywhere recognised as a national function, although the institutional framework to execute this function varies from country to country. It is also widely acknowledged that groundwater data storage and dissemination at regional level is beneficial, but there are currently few proponents and only very limited avenues for achieving this. There are also concerns expressed from some states with respect to data release to an information system located outside national borders and under the control of a regional entity. There is thus a clear need for the maintenance or, in some cases, the establishment of national groundwater databases and data systems in parallel with and interacting with a regional Groundwater Data System. It is also unavoidably the case that a groundwater information or data system cannot exist in any useful form in the absence of a functional groundwater monitoring system - both are interdependent and essential to national and regional groundwater management aspirations and plans.

It is also, therefore, not surprising that further enquiry into presence and nature of any national Groundwater Data Systems reveals that the shortcomings and problems outlined with respect to monitoring and monitoring systems in Chapter 2.4 also broadly apply, and no Member Sate can be regarded as having a comprehensive or fully functional GDS. As indicated in Chapter 3.1, there are *groundwater databases* of some form or another in existence in a number of countries, and it is apparent that there are also ‘partial’ Groundwater Data Systems often containing fragmented or localised information in various national agencies, institutions, donor projects or private sector organisations. However, no single entity appears to hold a comprehensive GDS that is immediately accessible for the purposes of developing groundwater management tools either at a national level or, ultimately, at regional level.

### 2.5.3 Constraints And Needs

As noted above, the constraints that have been voiced during the regional data gathering exercise in relation to establishing and maintaining a Groundwater Data System are very similar to those pertaining to a groundwater monitoring system, and essentially revolve around the key issues of finance and technical capacity.

In addition, however, there are several other factors that have emerged. Important amongst these is the issue of the usefulness and relevance of a GDS, especially at regional level, in the management of (national) groundwater resources, and the potential necessity to divert scarce resources to establish and maintain such a system. Clearly, the appreciation and conviction of the *need and priority* for a GDS is not very strong and has not been particularly apparent from the current survey.

Accessibility and dissemination of data/information is also important, as this will hugely contribute to awareness education in the value of groundwater and related data. It is apparent that a totally Web-based approach, either on a national or regional basis, will probably not be either operable or appreciated by the potential end-users, as in many Member States (as has been voiced in earlier studies) the ability of potential users to usefully access the Web is severely restricted by problems with telephone networks, server access and a myriad of other local factors.

In terms of the needs of the various Member States with respect to the actual establishment of a GDS these relate to technology (appropriate hardware/software and the training to use it), available technical manpower of a suitable cadre, and finance and facilities with which to operate. Again, these constraints are similar to those pertaining to the establishment and operation of an adequate groundwater monitoring system.

## 2.6 INSTITUTIONAL AND CAPACITY BUILDING ISSUES

This particular theme of the study has been required to identify the capacity building needs for national regulatory bodies and implementing agencies in the realm of groundwater management, with particular focus on drought management issues, as well as to identify the need and possible options for co-operation at regional level in the form of professional training, research and joint management of shared aquifers, and establishment of a groundwater Commission/Institute.

It was noted that during the launching workshop of the overall GEF Project several possible alternatives for the establishment of a regional Groundwater Commission/Institute were envisaged, such as strengthening existing national and regional institutions, developing networks (WaterNet model for academic training), making the best use of the international River Basin Commissions, support and develop the Sub-Committee for Hydrogeology, etc. The study was thus to assess these various options, including their sustainability, human resources and cost implications versus the need to create, update and manage SADC regional tools, especially in the context of the on-going SADC restructuring and its possible impacts on the proposed management structure.

In addition, specific issues to be addressed were to advise on capacity building issues, options for co-operation mechanisms, the criteria established by SADC for selecting implementing agencies, functioning of the network, and the location of any possible regional Groundwater Commission/ Institute.

It has, however, proved to be an extremely difficult task to fully execute, as there are a considerable number of complex and inter-related aspects to try to assess. Although some of these aspects are addressed in the sections below and others can be gleaned from other Chapters of this report, it must be conceded that this particular theme has not yet been comprehensively evaluated.

### 2.6.1 Current Status

Implicit in this task has been an attempt to review the role (and effectiveness?) of national institutions in charge of groundwater in each of the Member States, as well as the objectives and institutional philosophy of a variety of regional and international organisations and initiatives. Also within this very broad brief has been to examine any possible role for private sector initiatives (national groundwater organisations etc) or NGO's.

First and foremost it should be stated that the hugely disparate approaches and establishments in the various Member States to the different aspects of groundwater development and management have proved to be difficult to unravel and then reconcile for comparison purposes. Historically in many States the role of different governmental departments such as Geological Survey or Water/Water Affairs have evolved over time, with different responsibilities for groundwater management or development being originally based in one and then moved to the other. Moves towards decentralisation of government and thus water development and operational activities by a number of States has also complicated the picture with respect to overall responsibilities for groundwater development and management, most especially roles involving data gathering, archiving and evaluation that form the basis of any planning and management structure. An illustration of the progression of institutional changes that have occurred in many of the SADC Member States is presented in Information Box 2

Also in the picture in relation to national and regional ***knowledge*** of groundwater resources, as well as constituting the basis of geological and hydrogeological education in the region, are a number of university and technical/scientific institutions, some of which are essentially academic and some of which are essentially government (wholly or partially funded) research bodies. The role of such institutions is clearly not one of actual groundwater development, but their contributions in terms of knowledge (and internally held data) can be very significant in relation to groundwater management and the role of groundwater during periods of drought.

**Information Box 2**

**Apparent Trends in Institutional Change Within the Groundwater Sector In Southern Africa During the Last 50 Years (Individual SADC states have been affected to different degrees)**

| **Institution** | **1950's >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>> 2000** | | | | | |
|---|---|---|---|---|---|---|
| **Geological Survey Department** | Gpbs Bhdc Bhtp Wlqm Hgmp Pfsv Hgdo | Gpbs Bhtp Wlqm Hgmp Pfsv Hgdo | Gpbs Bhtp Wlqm Hgmp Pfsv Hgdo | Gpbs Bhtp Wlqm Hgmp Pfsv Hgdo | Wlqm Pfsv Hgdo | Wlqm Hgdo |
| **Department of Water Affairs** | Bhpm Snwi | Gpbs Bhdc Bhpm Snwi Pfsv | Gpbs Bhdc Bhtp Bhpm Snwi Wlqm Pfsv Hgdo | Gpbs Bhtp Bhpm Snwi Wlqm Pfsv Hgdo | Gpbs Wlqm Pfsv Hgdo | Wlqm Hgdo |
| **Contractors** | | | Gpbs Bhdc | Gpbs Bhdc Bhtp Bhpm Wlqm | Gpbs Bhdc Bhtp Bhpm Wlqm | Gpbs Bhdc Bhtp Bhpm |
| **Consultants** | | | | Hgmp Pfsv Hgdo | Hgmp Pfsv Hgdo | Hgmp Pfsv |
| **Non-governmental organisation** | | | Bhpm Vlom | Bhpm Vlom | Bhdc Bhpm Vlom Snwi Hgdo | Bhdc Bhpm Vlom Snwi |
| **Utility** | | | | Snwi Wlqm | Snwi Wlqm | Snwi Wlqm |
| **Main institutional drivers** | Central government Minerals sector | Central government Water sector | Central government Water sector Part privatisation | Privatisation reduced government involvement in field operations | Privatisation with increased NGO involvement Decentralisation | Minimum government inputs, international NGOs and consultants, limited to no in-country expertise. |
| **External influences** | Secondment of staff to government departments | Project oriented Aid packages | Specific sector Aid packages by Donors | Impact of the privatisation of government functions and NGO involvement in projects | Impact of decentralisation and privatisation of government functions. Increased involvement of NGOs | Government involvement restricted to formulation and supervision of projects all other functions undertaken by consultants/contractors and by NGOs at community level |

Key to functions

Gpbs - Geophysical borehole siting
Bhdc - Borehole drilling and construction
Bhtp - Borehole test pumping
Bhpm - Borehole/pump maintenance
Snwi - Supply network installation
Wlqm - Water level and quality monitoring
Hgmp - Hydrogeological mapping
Pfsv - Project formulation and supervision
Hgdo - Hydrogeological database operation
Vlom – village level of maintenance

In order to illustrate the regional situation with respect to academic and training institutions in the groundwater sector information has been compiled into an Information Box (Box 3). In addition, some information on the present set up of the WaterNet scheme is given.

**Information Box 3**

## Groundwater Academic and Training Institutes

| Member State | University | Course Level | Training Institute | Course Level | Comments |
|---|---|---|---|---|---|
| **Angola** | Geology Department University Agostinho Neto | BSc Geology – no hydrogeology | | | |
| **Botswana** | Geology Department University of Botswana | BSc Geology, MSc Hydrogeology | | | |
| **DR Congo** | Department of Geology, University of Lubumbashi | | REGIDESO has training centres in Kinshasa and Lubumbashi. | Modules for groundwater development methods | |
| **Lesotho** | University of Lesotho | General BSc | | | Training through workshops and seminars |
| **Malawi** | Chancellor College, University of Malawi | BSc Geology, MSc Environmental Science – some groundwater | University of Malawi, Blantyre | Groundwater technicians short course | World Bank funded course with BGS |
| **Mauritius** | Department of Physics, University of Mauritius | Engineering Geology with some hydrogeology | | | |
| **Mozambique** | Geology Department, University Eduardo Mondlane, Maputo | Geology and some environmental science taught | No government technical training | | Hydro-geologists trained abroad |
| **Namibia** | Department of Geology, University of Namibia. Desert Research Institute | Module in basic hydrogeology | Technicians trained in South Africa | | Hydro-geologists trained abroad |
| **Seychelles** | | | | | No training facilities |
| **South Africa** | University of Pretoria<br>University of the Witwatersrand<br>Rhodes University<br>University of the Orange Free State<br>University of Zululand<br><br>University of the Western Cape<br>University of Venda | Part of BSc Geology<br>Part of MSc in environmental Science<br>Part of MSc in Geology<br>Geohydrology BSc and MSc<br>Part of various BSc Hydrology courses<br>BSc and MSc in Hydrogeology<br>BSc and MSc in Hydrogeology | College of Advance Technical Education<br><br>Pretoria Technicon | Diploma course for geological technicians<br><br>Diploma course in Geotechnology includes hydrogeology | Research in aspects of hydrogeology funded by the Water Research Commission |
| **Swaziland** | University of Swaziland | No geology - General BSc | | | |
| **Tanzania** | Geology Department University of Dar es Salaam | BSc Geology with some hydrogeology<br>Water Resources Engineering MSc | Rwegarulila Water Resources Institute (RWRI) | Water supply engineering, hydrology, hydrogeology and water quality. | |
| **Zambia** | School of Mines, Geology Department, University of Zambia | BSc Geology – some hydrogeological research | | | |
| **Zimbabwe** | Geology Department University of Zimbabwe, Harare | BSc in Geology, MSc Exploration Geology – no hydrogeology | | | |

As can be noted from Information Box 3, the training of MSc level hydrogeologists and groundwater technical personnel within the SADC region is currently being undertaken at a limited number of institutions located in South Africa, Botswana and Tanzania, although most Member States have Universities with Departments of Geology offering BSc degree courses. Unfortunately, only about half of these include hydrogeology within their curriculum. At a slightly lower level the training of groundwater technicians "on the job" has also been attempted in Malawi with a World Bank sponsored course undertaken jointly by the University of Malawi and the British Geological Survey.

Also very much in the picture is the regional WaterNet network of academic institutions that are promoting groundwater and water resources training. The SADC Water Sector has identified WaterNet as one of the priority projects for the region, and each of the component members endorse the Southern Africa Vision for Water, notably the "Equitable and sustainable utilisation of water for social, environmental justice, economic integration and economic benefit for present and future generations in Southern Africa." The mission of WaterNet is to enhance regional capacity in Integrated Water Resources Management through training, education, research and outreach by sharing the complementary expertise of its members.

The founding member institutions of WaterNet have expertise in water supply, sanitation, groundwater, wetlands, irrigation, water law, water economics, community based resource management, flood forecasting, drought mitigation, water conservation and information technology. They include:

1. Department of Geology, University of Botswana, Gaborone
2. Institute for Meteorological Training and Research, Nairobi
3. Faculdade. de Agronomia e Engenharia Florestal, Universidade Eduardo Mondlane, Maputo
4. Depto. de Engenharia Civil, Universidade Eduardo Mondlane, Maputo
5. School of Engineering, Polytechnic of Namibia, Windhoek
6. School of Natural Resources and Tourism, Polytechnic of Namibia, Windhoek
7. Department of Earth Sciences, University of the Western Cape, Cape Town
8. Department of Civil Engineering, University of Dar es Salaam, Dar es Salaam
9. Institute of Environmental and Natural Resources, Makerere University, Kampala
10. Department of Civil Engineering, University of Zambia, Lusaka
11. Faculty of Agriculture and Natural Resources, Africa University, Mutare
12. Institute for Water and Sanitation Development, Harare
13. D/Civil & Water Engineering, National University of Science &Technology, Bulawayo
14. Department of Civil Engineering, University of Zimbabwe, Harare
15. Department of Geography, University of Zimbabwe, Harare
16. Department of Soil Science and Agricultural Engineering, University of Zimbabwe, Harare
17. Desert Research Foundation of Namibia, Windhoek
18. Programme for Land and Agrarian Studies, University of the Western Cape, Cape Town
19. Centre for Applied Social Sciences, University of Zimbabwe, Harare

WaterNet has established a Master Programme in Integrated Water Resources Management to which institutions will be able to contribute and share their water-related expertise. The taught part of the programme will consist of course modules, each of two to three weeks duration, followed by an examination. The Master programme will consist of four parts:

1. Common compulsory part
2. Specialised programmes with compulsory modules
3. Elective modules
4. Dissertation/thesis project

The common compulsory part comprises:

- Principles of Integrated Water Resources Management

- Principles of Hydrology
- Socio-economic Aspects of Water and Environmental Resources
- Principles of Environmental Management
- Policies, Laws and Institutions

The common core establishes the foundation and the key concepts. Participants will then choose between six specialisations:

- Water Resources Management
- Water and Environment
- Hydrology
- Water and Land
- Water for People
- Water and Institutions

Each programme will define compulsory modules and a number of elective modules. After completing the taught part a post-graduate diploma will be issued. To obtain the degree of Master a dissertation/thesis project will have to be completed.

Course modules in Integrated Water Resources Management comprise:

- Principles of Integrated Water Resources Management
- Principles of Hydrology
- Socio-Economic Aspects of Water and Environmental Resources
- Principles of Environmental Management
- Policies, Laws and Institutions
- Water Supply and Sanitation
- Wetlands, Ecology and Management
- Environmental Impact Assessment
- Coastal Management
- Environmental Flow Requirement
- Introduction to Hydrogeology
- Groundwater Modelling
- Groundwater Management (including recharge mechanisms)
- Hydro-geochemistry
- Irrigation Design and Water Management
- Drainage & Soil Degradation
- Remote Sensing
- Geographic Information systems
- Data Base Management Systems
- IWRM Planning and Analysis
- Catchment Management
- River Engineering
- Early Warning Systems for Droughts and Floods
- Water Quality Management
- Waste Water Management
- Water Quality Modelling
- Water Demand Management
- English for Water Managers
- WaterNet structure

### 2.6.2 Constraints and Aspirations

Clearly, within the various Member States there are many specific constraints with respect to establishing and operating an 'ideal' groundwater data collection and archiving process, some of which are inherent in the governmental structure and the manner in which institutions and roles have changed over time. Some of these, unfortunately, would require substantial restructuring of water sector institutions if they were to be overcome, but there would appear to be many instances where the 'education' administrators and financial controllers as to the national and regional importance, and value, of groundwater would be beneficial and may result in the establishment of better groundwater data collection and evaluation systems.

In addition, decentralisation of departmental functions requires the positioning of professional staff in regional offices, a procedure that imposes associated difficulties with communications as well as producing serious strains upon limited staff, vehicle and other support facilities. With the effects of the HIV/AIDS pandemic becoming increasingly apparent the shortage of professional staff to fill the present government staff complement let alone newly created posts becomes impossible. The increased responsibilities and activities of international and national NGOs and consultants has resulted in a movement of government staff to the private sector often with the resulting loss to government of a large chunk of its hydrogeological institutional memory. This is especially the case in states where there are only a limited number of hydrogeologist present, as in Angola (12), Zambia (14) and Malawi (12).

With respect to water law and its control and influence on the groundwater sector the legislative framework in each Member State has, by and large, been supportive to but focussed on the development and management of individual groundwater sources rather than the groundwater resources as a whole. Recent moves towards decentralisation and towards demand driven activities also tend to confuse the existing legal structure resulting in the formulation of complex policies.

In the past the provision of adequate legislation relating to groundwater resources as opposed to groundwater sources has been lacking in many states, often as the result of outdated and inappropriate 'ex-colonial' legislation being allowed to remain relatively untouched on the statute books. Particular problems have arisen in some states in relation to the statutory definition of *public* and *private* water and the rights thereto. Of the SADC nations, South Africa now appears to have the most comprehensive Water Law. However, even if comprehensive, the application of Water Law also appears to vary between government departments (Department of Agriculture, 1995 and Department of Water Affairs and Forestry, 1996 in South Africa). In Botswana there has been a recent attempt to introduce improved and more broad-based environmental geosciences law but this is not yet written into law. In Zambia the exclusion of any specific reference to groundwater in that countries water law is due to be corrected.

Other constraints that have been voiced about the ability of existing institutions to perform well and improve their data gathering capacity again centre around the availability of suitably trained manpower, funds and equipment, but in most cases this constraint is a function of the national economic situation, and would thus seem fairly insurmountable from a purely national perspective with a very great reliance placed upon international donor assistance.

In terms of aspirations most technical personnel in institutions all Member States would wish to see an improvement in data quantity and quality from a personal professional point of view as well as from a realisation of the benefits it could potentially bring to national planning and groundwater resource development.

However, few are hopeful of such changes without some form of assistance from regional or international bodies.

# CHAPTER 3 –GROUNDWATER MANAGEMENT TOOLS

The Terms of Reference for the study call for an examination and evaluation of possible tools that can be developed and that will assist in the establishment of some form of regional groundwater management system that will be effective, and may be particularly crucial, during periods of drought.

In the development of any such tools the key component is the availability of adequate reliable data at national level and the determination of this has been the prime focus of the study.

In this chapter we present a brief historical overview concerning the status of data availability in the region, together with an outline of the types of tools that may be required. This overview is also presented pictorially in Tables 1, 2 and 3.

## 3.1 DATA AVAILABILITY

### 3.1.1 Historical Review

Before the 1970s the use of groundwater in terms of extensive rural water supply coverage was fairly limited, with boreholes most often drilled for the watering of livestock on farms, operation of steam locomotives and the construction of roads. Only in relatively few cases was it used for village or town water supply. During this early period groundwater was generally perceived as a geological resource and it therefore, most usually, came under the preserve of departments of geology. As a result geophysicists in these departments became involved with geologists in locating groundwater. At this time there were also few accurate topographical maps, few geological maps and only poor quality aerial photography available, with aerial photographs used primarily for geological mapping. Although the primary function of the departments of geology was geological mapping much of the detailed mapping in the SADC countries has been undertaken comparatively recently to assist mineral exploitation, and large areas still remain unmapped.

Hydrogeology was only recognised as a profession in the late 1960’s and 1970’s. The first hydrogeological maps were produced, for example in Botswana and Malawi, but prior to the advent of GPS there remained a major problem of locating boreholes accurately on maps even though the 1:50 000 scale topographic map coverage was improving. During that remote sensing techniques were being developed and have since become an important tool. As a result of growing rural populations and the increasing demand for water, greater emphasis began to be placed on village/community borehole supplies, but in general there was a lack of trained and experienced professional and, equally importantly, technical field staff.

During the 1980’s emphasis slowly swung more and more towards community water provision and the subsequent maintenance of a rapidly increasing number of boreholes. Responsibility for groundwater exploration and development consequently passed from geological surveys to departments more appropriate to these development and operational tasks, generally to departments of water/water affairs/water development, with a consequently reduced interest in the geological constraints on groundwater resources. Usually the first transfer was the borehole drilling section – in Botswana this was done with the assistance of Swedish donors who provided the first high capacity down the hole hammer rigs, to be followed by sections related to borehole siting, record keeping etc. As demand grew and governmental output of boreholes lagged due to lack of capacity, overwhelming bureaucracy and inefficient operations there was also a move towards the use of private sector drilling contractors, which tended to increase the drilling capacity considerably but created different problems in the form of contract management, reliable data gathering and workmanship. This situation encouraged the development and use of private sector consultant companies to assist the government institutions in the task of groundwater development, with a consequent 'decentralisation' of data gathering and archiving. Although this situation did bring about an improvement in data reliability, in most cases there were inadequate structures in place to ensure that this information became a 'national asset' in a centralised repository, with result that private sector consultants became important sources of essential groundwater information.

Also during this period broader district or regional hydrogeological surveys applying many investigative techniques and utilising the latest hydrogeological methods were becoming more commonplace, either in response to large scale water demands for urban supply or mining, or in a national effort to more fully delineate and quantify the groundwater resources of the country. Regional groundwater development plans, such as those undertaken in Tanzania, were also undertaken and are still the most comprehensive guides to regional hydrogeology even though a great deal of work has been carried out subsequently. Similarly, a valuable series of regional hydrogeological reconnaissance maps and country descriptions were funded by UNESCO and prepared by UK consultants Mott MacDonald during this period.

In many cases donors or other external agencies not only provided funds, personnel and equipment but also defined to approach and type of information that was gathered when these larger surveys were undertaken. Although comprehensive, such surveys frequently resulted in little knowledge transfer or continued development of expertise to the appropriate government institutions, sometimes even to the point that accumulated data was not archived or handed over to the national data repository.

A second progression that has influenced the availability and veracity of groundwater information in some Member States has been the political drive towards decentralisation of government structures, with the transfer of responsibilities for water provision being devolved to district or regional institutions. In general terms this tended to reduce the ability of the particular institutions to undertake all tasks adequately, with the gathering and information being one of the main casualties. For instance, in Zimbabwe significant decentralisation occurred after the 1984 drought and refugee resettlement schemes. This eventually led to the collapse of the central database, with local databases thereafter being maintained to various standards at district level.

A further progression that has profoundly influenced the collection of reliable and useful groundwater data in a number of Member States has been the much greater concentration by the donor agencies on 'community-focussed' groundwater development and a corresponding increase in involvement and use of NGO's to undertake such work. A number of factors impact on the generally totally inadequate data gathering aspects of groundwater development under this approach. These can be summarised as:

- Much greater concentration on the 'social' aspects of water provision and management, with a loss of emphasis on the science of understanding the resources on which everything is based.

- An understandable desire to maximise the use of limited funds and provide the maximum number of water sources in the shortest possible time at minimal cost. This has resulted in the use of inadequate technical staff, frequently unreliable contractors, dispensing with 'unnecessary' tasks (data gathering activities) and, commonly, no understanding of the need to contribute to the national knowledge of groundwater resources.

- A tendency by national groundwater institutions to allow NGO's to 'take over' the groundwater sector for reasons of expediency with respect to their ability to mobilise funding, execute development and minimise the institutional workload, with a consequent loss of data provision and knowledge transfer to very institutions that are delegated the responsibility for the nations groundwater resources.

- Unfortunately, it is frequently apparent that NGOs do not fully appreciate the role of hydrogeologists in a groundwater development project, and few attempts have been made to understand the hydrogeology of the proposed development area through development of conceptual models and data analysis.

However, it must be conceded that many NGO's are now beginning to realise the importance of understanding the groundwater resources and the longer-term value of data, generally as a result of inadequately planned, 'poor value for money', limited success programmes in the past.

With respect to databases, and digital data in particular, it is known that at the time of the first World Water Decade attempts were made in Malawi and Zimbabwe to collate and digitise available groundwater data, and some form of digital national groundwater data archive has been in existence in Botswana since the early 80's. However, in general digital data storage has only been more widely used in the last 10 years.

As noted above, many groundwater databases are now held by external agencies, notably NGOs and consultant organisations, with the result that collation of data on a national and regional basis by governmental institutions is not simple, as first all the data holders need to be identified and secondly persuaded to part with their data.

### 3.1.2 Data Occurrence

Data scarcity is a universal problem. Within most SADC Member States the numbers of trained local hydrogeologists are relatively few – Zambia currently has 14, Angola has 12 and Malawi has 12 and few of these have much field experience or the opportunity to acquire it. In other Member States the total number of hydrogeologists appears to be large (in South Africa, Botswana and Namibia for instance), but amongst this number are many expatriate hydrogeologists employed by consultant firms. Many of these consultant personnel are highly knowledgeable about local conditions, and they frequently have access to some of the most complete data sets that are available, but these are generally stored only within the consultant company and not centrally. Unfortunately, although such hydrogeologists may show great commitment to the host country they are by definition a mobile group, as is their collective memory and data sets.

It is often apparent that the collection and storage of essential data by central government institutions may depend largely on specific incentives, and even individual will. Attitudes can be galvanised in the medium term by the requirements of, for example, a National Water Development Plan. Such plans are frequently compiled by outside consultants funded by international donors and usually take the form of reviews that contain some of the most up-to-date data. For example, the 1995 compilation undertaken for the Government of Zambia by consultants funded by the Japanese now forms the main national reference set, but little attempt has been made to review and update this on a periodic basis. Unfortunately, the monitoring systems that were then established have been downgraded and even the location of the primary database is now in doubt. In Botswana, the National Water Master Plan, undertaken in a similar manner in 1991, is scheduled to be updated and will be revised during 2003 –2005.

Quite frequently anecdotal evidence about how groundwater systems perform during drought is usually all that is available. For example, it is known that in southern Zambia at the time of the 1984 drought, ponds and ephemeral rivers that formerly formed the main supply dried up and hand dug wells had to be sunk. During the 1990-92 drought it appears that these wells dried up and were deepened and boreholes were also drilled. Then during the current drought, further deep boreholes are being drilled. Little recorded data on each of these occurrences actually exists, and this same pattern of crisis intervention with resultant poor documentation has also been observed in Zimbabwe, Malawi and Tanzania. Critical data sets that will be of future use to those who depend upon drought prone aquifer systems clearly were not identified or gathered, and no monitoring was implemented.

With respect to the study it is apparent from the results of an intensive information search and contact with many different organisations and individuals, as well as resident in-house knowledge, that the occurrence of groundwater information can be divided between six broad source areas, namely:

***Source 1: Hydrogeological Mapping Programmes***

The most recently completed hydrogeological map is that for Namibia. Mauritius produced a hydrogeological map in 1999 and a series of 1: 500 000 scale maps is now being produced for South Africa (commencing in 1995). All other hydrogeological maps in existence in the region (Botswana, Tanzania) may generally be regarded as ‘first attempts’ often using local formats and legends and are more than 10 years old. In addition, Mott Macdonald gathered data for the production of 1:1,000,000 hydrogeology maps of the southern and eastern parts of Africa for UNESCO. These maps, although not in digital format, represent a baseline data set that may not have changed much, particularly in Angola and Mozambique. Although only 20 paper copies of each were supplied to individual countries, they could now be scanned in colour layer vector format so that hydrogeology and geology layers could be utilised to create an interim digital map if this was desirable in the short term.

The OACT is currently digitising as set of small scale hydrogeological maps that cover the whole of Africa that were produced in hard copy format in the 1990’s.

***Source 2: National Water Development Plans***

The hydrogeology synopses produced as part of National Water Development Plans form a major source of baseline data on hydrogeology and related climatology, hydrology, water use, sanitation, etc.

Plans in existence include:

- Zambia – 1995 JICA funded.

- Zimbabwe National Master Plan for Rural Water Supply and Sanitation (1985). The hydrogeology section was partially updated during 2000.

- Botswana - the National Water Development Plan is the most comprehensive statement, completed in 1991-92. To be updated/revised in 2003.

- Tanzania – Region Water Master Plans were produced on a regional basis during the early 1980’s for all regions except for Dodoma, Arusha, Singida and Morogoro. This series of reports, funded by the International Bank for Reconstruction and Development, forms a baseline study that has not been updated).

- Namibia – database produced for the production of the national hydrogeology map dated 2001.

***Source 3: Donor Aid Agencies***

Databases from individual projects are normally held within both the donor and recipient countries. Frequently data may be mislaid in the recipient country and the database held by the donor country then becomes unique. An example is the 6000 borehole data entries 'lost' in Malawi, which was reinstated from archives held by BGS. JICA hold similar databases from surveys undertaken in Tanzania (Singida), Zimbabwe (Midlands), and Zambia (Southern and Western Provinces).

Other specific donor led activities that also can constitute a source of data in the region have included:

- UK-ODA/DFID who are now working through Water Aid, Oxfam and Concern, and providing funding to UNICEF. Some project specific activities (see bibliography) including major inputs such as the Tabora Rural Integrated Development Project, Tanzania, undertaken by the Land Resources Development Centre for the Overseas Development Administration.

- DANIDA –active in rural water supplies in various parts of Africa.

- SIDA – used to fund water supply activities and provided drilling rigs to Tanzania and Botswana during the 1970s.

- JICA – working in Zambia (Siavonga and the Drought Prone Areas Project in Southern and Western Provinces) at the present time, recently in Tanzania and in the past in Zimbabwe. (See bibliography).

- German Agency for Technical Cooperation (GTZ) – has funded hydrogeological mapping in Botswana and Namibia, recently operating in Zambia and Malawi.

- Russia – undertook some geological mapping in Tanzania in the 1980s.

- Netherlands Ministry of Foreign Affairs – funded DHV to undertake rural groundwater supply schemes in Tanzania notably in the Shinyanga area.

- International NGOs such as Water Aid together with local water NGOs take a lead role in the provision of rural water supplies.

***Source 4: Consultants and Institutions***

A variety of consultant organisations have been active in the region. Many have offices in centres such as Harare, Gaborone and in various centres in South Africa. Others are based in Europe and elsewhere.

Prominent consultants that operate in the SADC region include Mott Macdonald, Gibbs, Hydrotechnica (UK), VIAK (Sweden), Interconsult (Norway), Kampsax Kruger, COWI, CarlBro (Denmark), SMEC (Australia), Wellfield Consulting Services, Water Resources Consultants (Botswana), SRK, Ninham Shand (South Africa).

Unfortunately private sector organisations are beginning to realise the commercial value of their data, especially long-term time series and detailed point source data that would be very expensive to replicate. To organise the collection and compilation of effective geo-referenced databases from such sources could thus in future be a relatively expensive undertaking.
Ex-colonial data archives for a number of countries are also available in the UK (Rhodes Library, Oxford), Belgium (Royal Museum for Central Africa, Tervuren, Belgium) and Portugal as paper records. However, as corporate memory of the work disappears so the value of such archives decreases. Other UK sources include by way of example: Geological Society of London library, Ratcliff Science libraries at the University of Oxford, Department of Overseas Surveys (maps) and Hunting Geotechnical Surveys (aerial photography).

The British Geological Survey has recently undertaken geological mapping projects in Botswana, Zimbabwe and Zambia and is contracted to map areas of northern Mozambique. The output of the most recent of these surveys is in digital format.

***Source 5: District Level Institutions***

As noted earlier, decentralisation of rural groundwater supply schemes has occurred in a number of Member States and is advocated by the World Bank among others. This has created difficulties in countries such as Zambia and Malawi where there are insufficient qualified personnel to take an active role in data collection.

In Zimbabwe the District Development Fund (DDF) who organise drilling campaigns, borehole maintenance and hold the district database undertakes groundwater development activities. In Zambia data are produced by projects that are controlled at district level, especially those undertaken by NGOs, and there are potential problems with the quality and nature of the data collected. Decentralisation is ongoing in Tanzania with the formation of the Drilling and Dam Construction Agency, but the main database currently remains with the Ministry of Water.

***Source 6: National Level Institutions***

A number of the most comprehensive national databases are those originally collected by geological surveys when they controlled groundwater development. Databases generated by water departments when they took over control have suffered from the effects of decentralisation and privatisation of siting and drilling. Archives of geological surveys in Southern Rhodesia/Zimbabwe, Nyasaland/Malawi, Northern Rhodesia/Zambia, Bechuanaland/Botswana, Tanganikya/Tanzania and Swaziland include some of the first hydrogeological works undertaken in the SADC region, with annual reports covering borehole drilling, geophysical surveys, hydrochemical data and test pumping details. They include hydrogeological surveys undertaken in Botswana, Malawi, Swaziland, and Zimbabwe as well as details of projects and collections of geological maps and memoirs.

### 3.1.3 Essential Data Sets

Essential data for all groundwater related activities includes spatial information on topographic and geological maps, as well as imagery, and point source data derived from drilling and geophysics. Typical borehole information could include borehole dimensions, depth to water, pumping test data analysed at least to a specific capacity value, water quality data, pump type and status, water use, details of headworks etc. It may also include temporal data such as water level and chemistry as well as pump status. In addition details of survey work should include field data and analysis from geophysics and records justifying borehole siting and design decisions.

However, a number of more specific items of knowledge are needed to fully understand what data sets are required with which to determine the interaction of surface occurring phenomena upon the subsurface hydrogeology. These include:

- An adequate understanding of the geological and geomorphological/soils relationship in a particular region.

- An adequate knowledge of the water transmitting and storage properties of the earth materials in the region (i.e. soils, aquifers, aquicludes etc).

- An adequate understanding of various temporal factors

*Adequate geological and geomorphological/soils understanding*

A full understanding of the variations in the nature of the subsurface soils, regolith/weathered zones and underlying geology in each of the climatic and palaeoclimatic zones present is essential. This allows understanding of the patterns and rates of groundwater movement and the potential for rainfall recharge to occur. Such understanding can really only be achieved through the collection and evaluation of an adequate number of samples and data during borehole drilling.

For example, in the basement terrains that are common throughout many of the Member States it is the regolith zone that is of prime importance to hydrogeology, and thus the provision of rural water supplies. Unfortunately, however, despite the many thousands of boreholes drilled each year into this main water bearing zone very little detailed information has been acquired and consequently our knowledge of this zone remains very poor.

In the case of other aquifer types (deeper Karoo or Palaeozoic aquifers) where the presence of groundwater is not controlled by surficial weathering processes then knowledge of the inherent lithological nature of the strata and the existence of fractures and fissures is important and again can only be obtained from borehole drilling information.

*Adequate knowledge of the water transmitting and storage properties*

Knowledge of the groundwater-related properties of the sub-surface materials is crucially important in conceptualising modes of groundwater replenishment and groundwater movement, which are critical components of the hydrological cycle.

In any aquifers this information can only be derived from detailed data gathered during borehole drilling, specific depth sampling and test pumping.

*Adequate understanding of various temporal factors*

Knowledge of any temporal variations in groundwater levels and quality are essential in understanding the behaviour of an aquifer system under differing external influences, most especially during drought conditions.

Unfortunately, the availability of long term time series groundwater level and quality data is generally very poor throughout the region, with some medium-term groundwater data available for South Africa, Botswana and Namibia. In contrast long-term rainfall, runoff and river flow data are available in many States. Patchy, project related, groundwater level data may be available in other countries, but it is likely that these will be insufficient for assessment of the impact of drought upon local groundwater systems.

Collection of temporal data is totally dependent upon the existence of suitable monitoring systems that have been properly maintained and operated for a considerable period of time. There are, however, numerous examples of groundwater level monitoring systems that have been established by groundwater projects that have operated during the life of the project and then have failed for reasons of lack of impetus and will, and the short term perception that they have little cost benefit.

## 3.2 DROUGHT VULNERABILITY MAPS

The concept of Drought Vulnerability Maps is central to the whole idea of the optimum use of groundwater during periods of drought. A Drought Vulnerability Map in its most fundamental form will indicate regions in which groundwater resources are more vulnerable to groundwater drought than others, therefore providing an indication of the ability of the resource to continue to provide a supply during drought events.

Clearly, some areas will be much more vulnerable to groundwater drought than others. Key determinants of vulnerability include features such as aquifer type, depth of the weathered zone, well and borehole yields and rainfall (amount and variability). By themselves, however, these factors do not determine vulnerability to the actual adverse impacts of groundwater drought, and some *communities* will be more vulnerable to groundwater droughts than others. For example, in areas where water supply coverage is low and population density is high, and in areas heavily dependent on traditional sources, the impact of groundwater drought might be expected to be more severe. In this case, the inclusion of other influencing factors and the development of vulnerability maps incorporating a variety of different indices, or 'layers' (Figure 1), can provide an extremely useful management tool. This type of spatial mapping depends on the superposition of two sets of information, a sociological dataset that analyses the distribution of demand, and a physical dataset that identifies availability of resource and ease of access. For example, the central part of the Kalahari is not significantly at risk from the impacts of drought simply because the demand for water from the sparse population in this area is low. Conversely, the more densely populated areas of, for example, parts of the Northern Province of South Africa, are at significantly greater risk from the impacts of drought.

Such composite Drought Vulnerability Maps could then be used to help identify vulnerable communities and allow effort to be targeted at these communities in order to provide them with an element of drought proofing in pre-drought periods, and to ensure that appropriate technical choices in terms of drilling methods and design of wells and boreholes are made in different areas. In the growing number of instances where communities themselves make their own choices from a menu of different water supply options, the menu offered could be tailored to ensure that the options on offer are appropriate to local hydrogeological conditions. In addition, such maps might provide a useful focus for coordinating the efforts of the different organisations undertaking water supply projects, prompting discussion and exchange of data and ideas on water supply priorities.

Examples of Groundwater Drought Sensitivity (or Vulnerability) Maps prepared for the Northern Province of South Africa show quite clearly that all the former homelands are at risk due to the combination of coverage, concentrated demand and difficult hydrogeological conditions (Figure 2). A similar map of Malawi (Figure 3) picks out the escarpment and the Lower Shire Valley as vulnerable to drought, even though less data are available.

It should be noted that the concept of drought vulnerability mapping and the issues that it needs to consider are separate from the issues of early warning based on longer-term meteorological forecasting and those of food security and although adequate early warning systems are in place with regard to regional food security and meteorological drought, there are no comparable systems in place to predict the onset of groundwater drought.

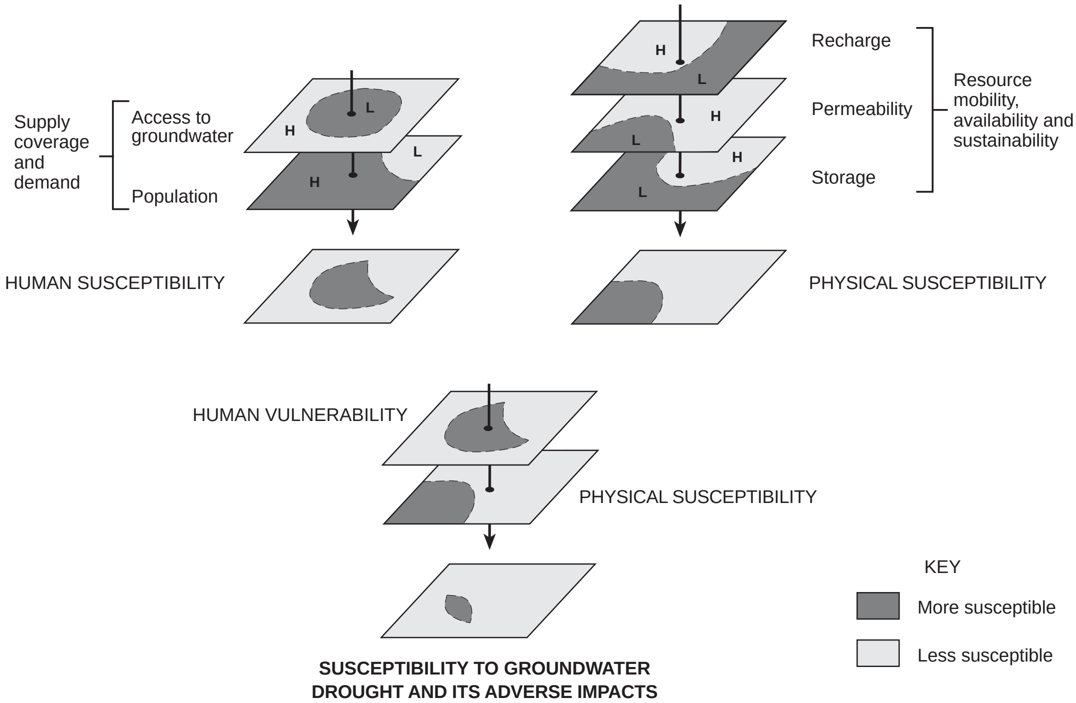



**FIGURE 1 Layers of Drought Vulnerability Assessment**

Groundwater drought early warning can be carried out sensibly at two levels. One is the global level of climate and climate variation (including possible long term change) and the other is on a regional scale, using local signals to flag the progress of groundwater drought and the likely consequences given certain courses of intervention. The former is in the hands of the international meteorological community, whereas the latter is the responsibility of governments, donors and NGOs.

In terms of groundwater drought early warning, there is a clear need to develop national drought plans for the water sector to include simple early warning systems to warn of groundwater problems and adverse impacts. Here, developments are very much tied to progress made in establishing long term monitoring and assessment programmes; reliable early warning systems depend on reliable data and long term tracking of meteorological and hydrological trends. In South Africa, Hazelton et al (1994) suggest that a key element of any drought plan should be the establishment of a Water Inventory Outlook Committee, whose principal aims would be to (a) compile and analyse data from observational networks operated by government and NGOs, enhancing those networks where necessary; (b) determine user needs in terms of specific data requirements, format and presentation; (c) develop triggers and an early warning system, using a combination of indices to initiate specific and timely actions by different organisations; and (d) identify drought management areas.

It follows that an early warning system designed to warn of groundwater drought would need to monitor antecedent meteorological and hydrological conditions as well as groundwater indicators (e.g. water levels and yields). Thresholds would also need to be established such that once exceeded, actions defined in the drought plan are triggered. Indicators of water stress could also be incorporated, for example incidence of water-related diseases from clinics. In this way, the system could be strengthened through incorporation of data generated by other departments and by other (non-water) projects. Experience from some countries in the region (e.g. Zimbabwe) indicates that responses need to be flexible and not centrally prescribed; problems may be highly localised, and it is only at lower levels (the lowest level at which capacity exists) that problems can be assessed in the proper context and solutions recommended.

Possible strategies in relation to a groundwater drought early warning system could include:

- groundwater drought vulnerability mapping using various indices and manipulative processes is a potentially useful groundwater management tool. In South Africa the current hydrogeological mapping exercise, when coupled with climatic, demographic and other baseline data, will go a long way towards regional drought sensitivity analysis. It is anticipated that similar systems can be developed for other countries in the region at relatively low cost, using data already held by different organisations;

- vulnerability maps can potentially incorporate many different layers of information, reflecting the fact that combinations of factors (physical, demographic, socio-economic) conspire to create problem areas. Useful additions, for example, could include demographic and well/borehole coverage data, so that areas where the impacts of groundwater drought may be most severe can be identified;

- although early warning systems monitoring food security are now commonplace, there is a need to develop drought plans which incorporate water resources assessments, including groundwater. An early warning system for groundwater drought could be based around a combination of indices indicating both occurrence and impact of groundwater drought, and linked to a response system in such a way that, once key thresholds are exceeded, mitigating actions are triggered.

**FIGURE 2 Northern Province Drought Vulnerability Map**

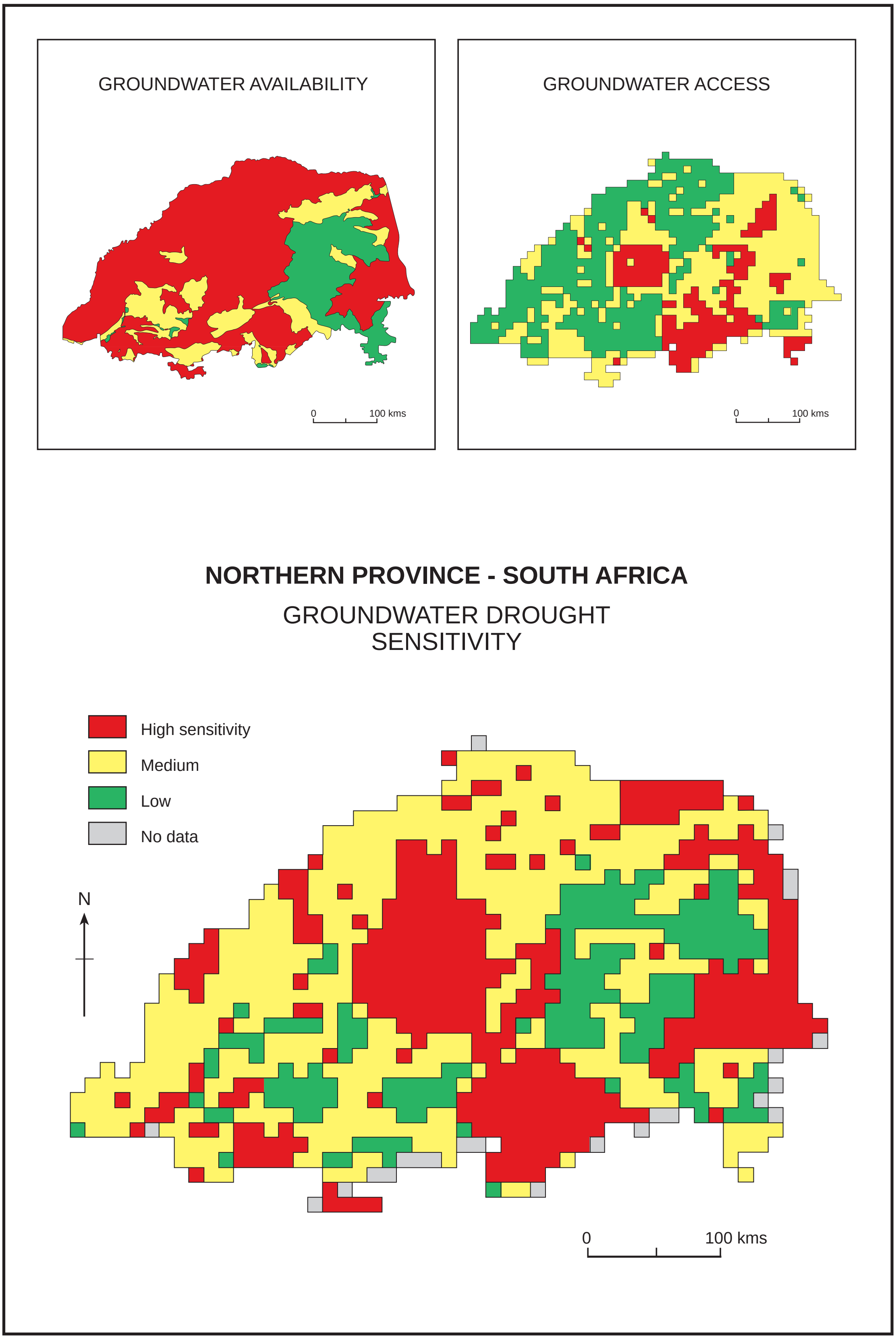
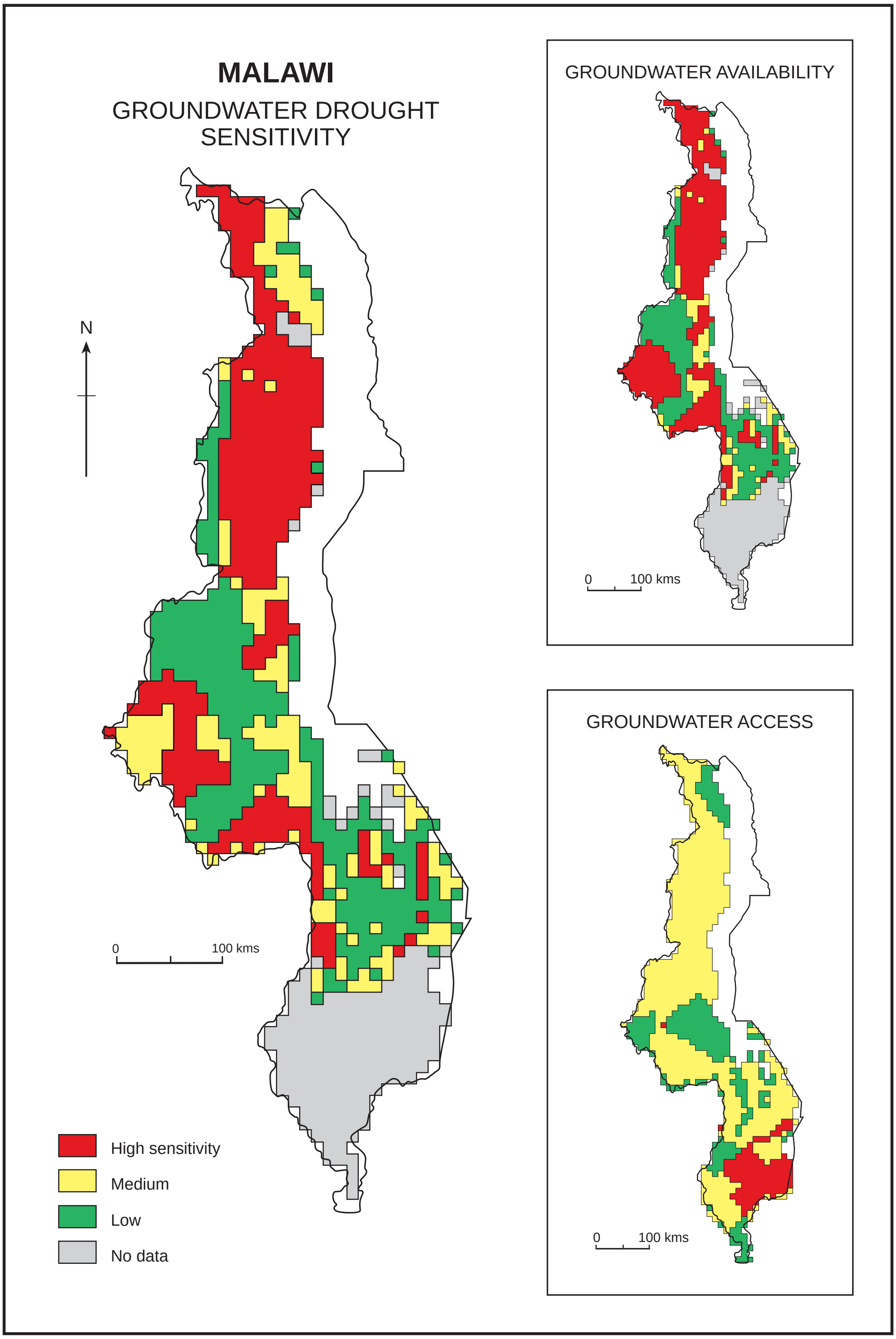


**FIGURE 3 Malawi Drought Vulnerability Map**



## 3.3 POLLUTION VULNERABILITY MAPS

The potential for an aquifer system to receive pollutants from the surface is called groundwater vulnerability and in order to assess the potential for groundwater pollution the concept of *groundwater pollution vulnerability* has been developed and actively researched.

The term 'pollution vulnerability' is most frequently used to indicate the relative susceptibility of aquifers to anthropogenic pollution and a formal definition is still a matter of debate. In the U.K. and most other European countries groundwater vulnerability is defined as: “the tendency and likelihood for general contaminants to reach the water-table after introduction at the ground surface”. Under this definition, the vulnerability of an aquifer to pollution is dependent on the intrinsic characteristics of the strata separating the saturated aquifer from the ground surface, and is largely independent of the transport properties of specific contaminants. This intrinsic vulnerability concept has limitations because every contaminant behaves differently. Some are poorly soluble, or degrade rapidly in the soil. Others are subject to chemical reactions in the unsaturated zone. Intrinsic vulnerability is independent of the saturated aquifer itself. It deals with the unsaturated strata between the ground surface and the water table. Once the contaminants have arrived at the water table the resource is polluted. To help assess the impact of any contamination, groundwater vulnerability is best considered along side an assessment of the actual groundwater resources.

It should be noted that groundwater vulnerability is not an absolute term - it cannot be directly measured. Rather it is a simplification of complex and varied conditions between the ground surface and the water table.

Numerous methods have been developed for assessing groundwater vulnerability. These fall into three broad categories: (1) those that use indices to weight critical factors (e.g. DRASTIC (Aller et al. 1987) and GOD (Foster and Hirata 1988) see bibliography); (2) overlay methods, which display interpreted information but do produce combined indices (e.g. U.K. method (Robins et al. 1994) and Irish method (Daly and Warren 1988)); and (3) complex models of the physical, chemical and biological processes in the unsaturated zone. The third category is used mainly for site-specific pollution, since there are rarely sufficient data available to develop models over wider areas.

The four methods are different in their approach. The index methods such as DRASTIC and GOD suffer from providing single digit output, the meaning of which may be obscure. The overlay methods are more transparent, but combine only a few parameters. The overlay methods generally have the vulnerability assessment overlying an aquifer type map.

The DRASTIC methodology is well suited to gridded information sets of factors influencing groundwater vulnerability and has been adopted for preliminary vulnerability mapping in South Africa. However, it is a data demanding indexing system that is only applicable to data-rich regions and thus, together with the other indexing systems, is not easy to apply in the SADC region for this reason.

Since vulnerability is a function of the intrinsic properties of the soil zone and unsaturated rock column or unsaturated zone of the aquifer, groundwater pollution vulnerability can, therefore, be defined as a function of:

- The nature of the overlying soil,
- The presence and nature of any superficial material,
- The nature of the geological material forming the aquifer,
- The thickness of the unsaturated zone or thickness of any confining beds.

These layers are shown in Figure 4

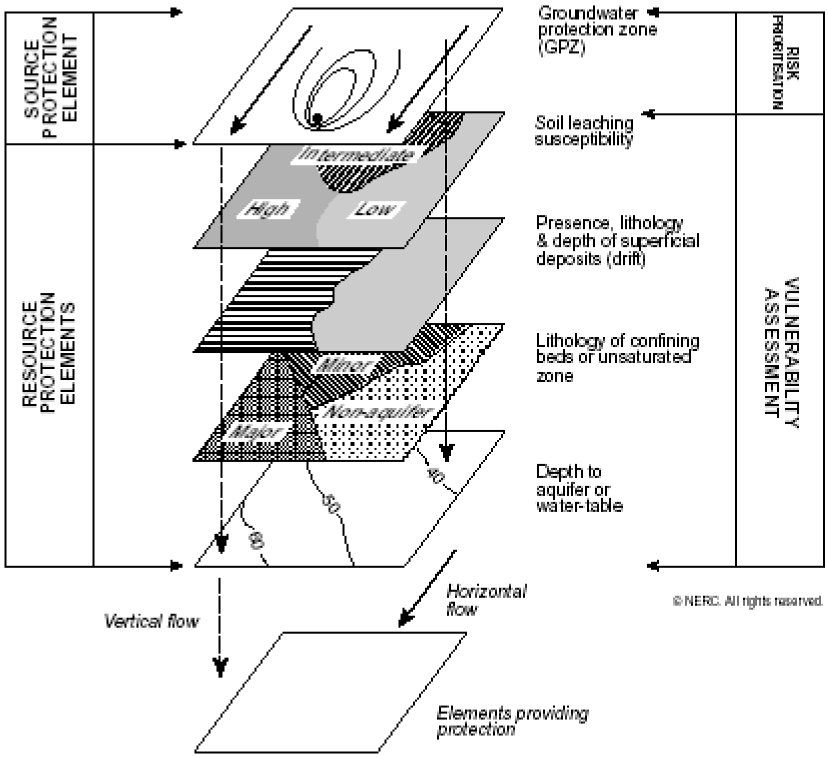



**FIGURE 4 Layers of a Pollution Vulnerability Map**

In the SADC region it is suggested that a GIS-based approach to vulnerability classification may be most appropriate. This should be based on the four parameters identified above: the nature of the overlying soil, the presence and nature of any superficial material, the nature of the geological material forming the aquifer, and the thickness of the unsaturated zone or thickness of any confining beds.

Each of the four critical parameters can then be divided into three parts: high, medium and low, or just high and low. For example soil can be subdivided according to its leaching potential. In areas where detailed soil maps are not available and where the leaching properties of the soil are not known a simple division between soils that are free draining, soils that impervious to percolating surface water, and an intermediate class can be made as surrogates for leaching potential. Similarly bedrock geology of the unsaturated zone can be classified between highly permeable, moderately permeable and weakly permeable. These classes can then be combined in a matrix with the soil leaching classes to provide a first pass at aquifer vulnerability.

The third consideration is whether superficial materials conceal the bedrock, and if so, what modifying influence do these materials have on vertical percolation of contaminants. Superficial strata may be divided into free draining and water retentive clays and cretes. These provide the third layer of information and identify only whether the superficial material is protective or are not protective of the underlying bedrock from surface pollutants. In some instances the superficial material may form a local aquifer such as a gravel or fluvial deposit, in which case it becomes an aquifer that qualifies for a vulnerability assessment in its own right.

The fourth and final layer of information is the depth to the water table. This may only be known at a handful of pumping wells and boreholes but for the most part a generic depth to water can be devised based largely on local knowledge, the aquifer type and the topography. In general the greater the depth to water the more protected is the aquifer, but this is only the case for the unstable pollutants that may be absorbed or altered to less harmful forms during transit through the unsaturated zone.

Since the vulnerability assessment process is dynamic and iterative it is itself instructive even without direct application, although groundwater vulnerability maps can have several uses. Before establishing a methodology for making vulnerability maps it is thus important to be clear how they will be used, as this will determine what detail is needed and which scale they should be produced at.

Four of the key uses are:

- Policy analysis and development.
- To target resources for investigation.
- To inform planning decisions.
- To improve general education.

At scales of 1:250 000 and less the maps are generally schematic, whilst 1:100 000 and 1:50 000 maps are generally constructed for operational uses (e.g. to inform land use decisions). Pollution vulnerability maps can clearly be important in zones of increased potential for pollution, such as urban, mining and intensive agriculture areas, as they will guide planners in decision making that will minimise impact on groundwater resources (e.g. industrial development permits etc) as well as indicating zones to be monitored for pollution occurrence.

In compiling the first national-scale groundwater vulnerability map of Southern Africa, Lynch, Reynders and Schulze (1994) used the DRASTIC methodology. They used a series of gridded information sets of factors influencing groundwater vulnerability to take advantage of the analytical capabilities of the ARC/INFO geographic information system (GIS) to manipulation and displaying the data analysed by the DRASTIC model. They compiled the required data sets for those factors that influence the susceptibility of groundwater to contamination over Southern Africa and after manipulating these using the DRASTIC model were able to produce a colour paper groundwater vulnerability map that will be useful in presenting the concept of groundwater vulnerability and groundwater protection to the layman.

Another example is the 1/1,000,000 scale national groundwater vulnerability coloured paper map of Botswana, that has a series of insert maps showing mean annual rainfall variation; depth to groundwater; and groundwater resources potential.

## 3.4 GROUNDWATER DEMAND MAPS

The demand for groundwater can take many forms and can vary enormously both spatially and over time dependent on a large number of factors.

Groundwater plays a very significant role in the provision of domestic water supply in most SADC Member States, accounting for water supply to between 30 and 50 % of the population and being especially crucial with respect to the rural population sector. A summary of groundwater development and usage in the SADC region has been presented in the Inception Report, and is thus not reproduced again here.

In rural communities with scattered population or small village concentrations groundwater is often to only economically feasible source of water supply. In addition, groundwater also plays a significant role in the stock-watering and small scale farming activities crucial to the survival of rural society in many parts of the SADC region. In this rural environment the application of low-cost appropriate technology abstraction methods most usually imposes a relatively small and often dispersed demand on resources, with supply generally limited only by the abstraction methods and the economic and technical viability of installing an adequate number of abstraction points to serve the population.

Urban supply from groundwater is also increasingly important throughout the region, providing total supplies to many small towns and contributing significantly to even large cities such as Lusaka and Dar-es-Salaam. Such supplies from groundwater generally apply considerable demand in highly localised areas often determined by infrastructure requirements, with the volume and sustainability of supply critically governed by aquifer parameters and dimensions and, extremely importantly, by the replenishment potential of the resource.

With respect to the spatial representation of demand on and usage of groundwater the development of this type of map will largely depend on the availability of reliable population distribution data for the widespread rural demand sector, since there are no records available of monitored rural consumption and there are no systems in place for such monitoring. Overall demand is then simply estimated on the basis of population and an assumed average per capita or per household consumption. Unfortunately, such simple calculations are not always a true reflection of the annual pattern of demand, most especially if traditional or other seasonal sources of supply are available and are used during the rainy season. In such a setting the demand on groundwater may then decrease, and then increase significantly during the dry season and especially during drought.

The preparation of a Groundwater Demand Map for rural regions must therefore take cognisance of the changing pattern of demand governed by the existence of alternative sources, seasonal population movement and other local influences that may be related to agriculture or other factors.

With respect to urban or other major groundwater demands such as irrigated agriculture, industry and mining the definition and quantification of demand ought to be considerably simpler, as monitored statistics relating to usage are available from utilities, agricultural organisations etc. largely as a result of payment or charging systems that are in place. The focus of such demands with respect to the resource is also much better known as specific wellfield developments (usually accompanied by some form of groundwater monitoring) are generally the primary source of supply, and thus aquifer behaviour can at least be determined to some degree of reliability. However, even in this major demand sector, seasonality can also be a factor with agricultural demand, and even urban demand, varying according to crop requirements or other factors.

Groundwater Demand Maps would essentially be constructed in the same manner as the Drought Vulnerability Maps, with various layers such as rural population distribution and water source distribution and specific demands such as urban, industrial and agriculture. As noted above, cognisance would have to be taken of the seasonal or other changes to the (rural) population distribution that could substantially influence demand patterns, implying that a series of Groundwater Demand Maps may be required.

## 3.5 GROUNDWATER AVAILABILITY MAPS

When discussing Groundwater Availability Maps care must be taken in defining the meaning of ‘availability’. Does ‘availability’ mean the natural occurrence of groundwater in the various strata i.e. does groundwater exist and what are the physical controls on its existence and movement? Or does ‘availability’ also include factors related to whether the groundwater is actually accessible/extractable as a supply by the potential users i.e. would individual sources be adequate in terms of yield and/or quality; are normally applied extraction systems such as rural hand pumps/wells able to access the resource etc.

Clearly the former definition is rather more straightforward and will solely require the appropriate information on aquifers and aquifer parameters in the preparation of maps indicating spatial distribution. In essence such ‘Groundwater Availability Maps’ would be rather similar to conventional hydrogeological maps, albeit in a possibly more simplified presentation of much of the same data set.

If, however, ‘availability’ is to be defined in a much broader sense to include factors relating to accessibility, potential demand (which may be seasonally variable) and usage then a number of other data sets will need to be incorporated into the mapping process.

The concept of ‘groundwater availability’ (or ‘scarcity’) has been examined and quantified by modelling on a broad grid over much of eastern and southern Africa by the GWAVA study Meigh, J R, McKenzie, A A, Austin, B N, Bradford, R B and Reynard, N S, 1998. Assessment of Global Water Resources, Phase II: Estimates of present and future water availability for Eastern and Southern Africa. Institute of Hydrology, DFID report 98/4 but it has been acknowledged that the complexity and inherent variability of many aquifer systems does not easily lend itself to this approach at such a coarse scale, and that the data required to present the modelling concept at a scale that may be more reliable is not readily available.

In order to provide an assessment of Groundwater Availability the GWAVA study estimated (for each cell of the model) the potential yield that can be expected from a well or borehole, and a likely maximum borehole density (over each cell) and hence calculated a practical annual availability of groundwater. The values calculated were then compared to figures for potential groundwater recharge derived from the surface water component of the model, and the overall groundwater availability was assumed to be the lower of potential recharge and the annual availability. These values were then converted from annual values to monthly values, with lower monthly groundwater availability in aquifers where the groundwater storage potential is low. These availability figures were then combined with a derived set of demand data to produce ‘availability indices’, but it was acknowledged that no cognisance had been taken of the questions of inherent geological variability, economic aspects of groundwater extraction or groundwater quality.

# CHAPTER 4 – COUNTRY STATUS REVIEW

This Chapter presents a summary of the status of hydrogeological and related data in the various Member States, largely in tabular format with some accompanying notes. It is not intended to be a comprehensive collection of actual data, as this would have been beyond the scope of the study and may have been somewhat repetitive in respect of previous regional SADC projects (Common Standards; Hydrogeological Map), but it illustrates the considerable variability in data availability, type and quality throughout the region.

## 4.1 GROUNDWATER OCCURANCE DATA

In most Member States hydrogeological data in the form of borehole records are held by a variety of organisations that can be located centrally, at district level or outside the country. The accuracy and comprehensiveness of the data collected are very variable and cannot be fully appreciated without sighting the original data and understanding by who and how they were collected. The borehole completion certificates used by most SADC states are usually designed to record the six basic parameters in Box 1. Unfortunately, although many thousands of groundwater abstraction boreholes have been installed only a small proportion of these forms accurately record these data. In addition, comparatively fewer forms record test-pumping data from which various aquifer parameters such as transmissivity or storativity can be calculated. Consequently, there are often insufficient data available for hydrogeologists to assess the nature of groundwater occurrence, quantify aquifer resources or make judgements of aquifer sustainability with any degree of accuracy. Some states are presently attempting to digitise their data collections by enhancing the quantity of data available by collation from various consultant project reports. In only relatively few cases do donors (such as JICA) and government institutions (e.g. Botswana) require consultants to present both raw and analysed data on CD-ROM in a specified software format with the final project report.

Information Box A indicates that virtually all the Member States gather the relevant types of data, but unfortunately only six of the fourteen Member States have any of this data in digital format. It is also apparent that in many States data occurrence is scattered between up to six different institutions or agencies, and thus would almost certainly be difficult to access and collate. Both these factors would certainly make the establishment and compilation of a central national or regional database problematical. In addition, data coverage in many States is poor to moderate, and only in probably four States can data coverage be regarded as ‘good’.

## 4.2 GROUNDWATER DEMAND DATA

Essentially, the assessment of groundwater demand is based upon the nine data types listed below. However, demand often varies with climate, season and drought; the latter may cause population migrations from dry to wetter areas as in Zambia and Tanzania. When assessing rural water demand in particular certain common assumptions are therefore made such as the distribution of the population at the time of the national census, and that water use in rural areas will be 25 l/day/head of the of the population. Other assumptions are also frequently made for rates of consumption of water by urban populations and various types of livestock. Average crop water demands can be produced given specific types of land use and irrigation practices. The water demand maps produced using these data must therefore be regarded as subjective and used with care.

Information Box B reveals that most States collect most of the data types, but that in nine out of fourteen States data is in hardcopy only. As a result of the wide spectrum of data types related to groundwater demand it is not surprising that data is gathered by a large number of different institutions and agencies in both the water and agricultural sectors. It is apparent that five States have relatively good data coverage, with the remainder moderate to poor (two States).

## 4.3 GROUNDWATER QUALITY DATA

Within the states of the SADC region, groundwater quality varies considerably between climatic regions and with aquifer geology and depth. There are often marked differences in quality between waters found in shallow near surface zones during the wet season and deeper waters within the underlying weathered zone during the dry season. Poor quality older groundwater often occurs at depth within sandstone aquifers within the Kalahari region. Detailed hydrochemical analyses can be used to indicate the relative ages of groundwater as well as their rates and directions of flow. These analyses are also necessary for assessment of groundwater potability.

Of the data sets listed below, those commonly recorded are borehole location, major ion contents and bacteriological quality. The determination of the full range of minor and trace ions is often beyond the scope of the laboratories located within some of the SADC Member States. Unfortunately, although groundwater may be generally of good hydrochemical and bacteriological quality, elements occurring in minor but toxic amounts according the WHO standards such as arsenic and uranium may be present but go undetected due to the lack of appropriate equipment and expertise. Possibly the higher level facilities present in some of the better equipped Member States could initiate a sample exchange programme in order to facilitate baseline minor and trace ion hydrochemical surveys in other states, thus ensuring that potentially toxic elements are detected.

Examination of Information Box C indicates that all Member States have some form of groundwater quality data. This is generally comprises major and minor ions, with a reduced occurrence of trace element or bacteriological analyses. Again, data is held by a number of different institutions and agencies, and, significantly, most data is only in hard copy format. Only in four of the Member States can groundwater quality data coverage be regarded as ‘good’, with poor to non-existent coverage in five States.

## 4.4 GROUNDWATER RECHARGE DATA

Although groundwater recharge data is highly significant in the evaluation and management of groundwater resources it is a particularly specialised aspect of the hydrological cycle and, in semi-arid and arid areas in particular, is not easily measured and quantified without substantial effort and investment in specific stand-alone recharge studies or project components. At the present time there are a number of approaches to recharge evaluation in the southern Africa region that have been and are being applied, with unfortunately little consensus on applicability or reliability of results, with the consequence that recharge data per se is largely in the field of research rather than groundwater management and development institutions. Outlined below is a brief review of some of the recharge evaluation work undertaken in the region.

Lerner, Issar and Simmers (1990) produced a guide to understanding and estimating natural recharge that was followed by a review of methods of estimating groundwater recharge using the water balance (Finch, 1998). Edmunds and Verhagen (2000) describe indirect methods of assessing recharge by using isotopes.

Within the arid to semi arid areas of southern Africa studies have been undertaken of the recharge potential of sand rivers by Andersen (1996), Nord (1985), MacDonald (1990) and Wikner (1980) in north eastern Botswana; Owen (1989) in southern Zimbabwe; and

Jacobson, Jacobson and Seely (1995) among others on the extensive ephemeral river environments in Namibia.

Within Botswana a number of studies have been undertaken to assess the recharge to groundwater potential of aquifers within the arid to semi arid Kalahari area. In Botswana the problem of recharge was first recognised by Boocock and Van Straten (1962). This initiated the first recharge studies in the Kalahari using isotopes reported by Verhagen, Sellschop and Jennings (1974) and Mazor, Verhagen, Sellschop, et al (1974) and by Mazor, Verhagen, Sellschop, et al (1977) undertaken in response to the groundwater demands for diamond mining in the Orapa area. Additional recharge studies prompted by the mining of groundwater resources for the mining of diamonds at Jwaneng were reported by Foster, Bath, Farr and Lewis (1982) and Foster, Mackie and Townend (1982). Latterly the assessment of groundwater recharge in other areas of the Kalahari has been undertaken by de Vries and von Hoyer (1988) and de Vries (1994) using groundwater balances and by Beekman and Selaolo (1994), Selaolo, Gieske and Beekman (1994), Beekman, Selaolo and de Vries (1997), De Vries, Selalo, and Beekman (2000) and Selaolo, Hilton and Beekman (2000) using isotopes of oxygen, chloride and helium. In areas adjacent to the Kalahari Gieske (1994) and Simonic, Adams, Carlson and Marobela (2000) assessed recharge to the dolomite aquifers of the Kanye area while studies of recharge to the Karoo sandstone aquifers were undertaken by Lubczynski (2000) at Serowe and Selaolo (1998) in the Letlhakeng –Botlhapatlou area of south-eastern Botswana.

Within South Africa recharge studies have been undertaken on a national basis with the production of a national recharge potential map based upon data gathered from an extensive series of monitoring boreholes. In addition local studies have been undertaken at a series of sites in a variety of hydrogeological and climatological environments across the country. Everson (2001) undertook water balance studies within a first order catchment in the montane grasslands. Isotope studies were undertaken to assess recharge rates by Kotze, Verhagen and Butler (2000) within fractured Karoo aquifers and by Verhagen, Butler, Levin and van Wyk (2000) to assess groundwater sustainability of the Taaibosch fault zone aquifer in Northern Province. Other studies include those by Reynders, Moolman and Stone (1985) of water level response in fractured rock aquifers beneath irrigated lands within the lower Great Fish River Valley; Sami (1992) of the potential recharge to and the geochemistry of aquifers within a semi-arid sedimentary basin in the Eastern Cape; Sami and Hughes (1996) comparisons of assessments of recharge to a fractured sedimentary aquifer using chloride mass balance and integrated surface-subsurface models; and Weaver and Talma (2000) study of recharge to deep groundwater in the Table Mountain Group quartzite.

Elsewhere in the SADC region in Zimbabwe the recharge of a weathered Basement Complex aquifer was studied in detail over a six-year period that included the 1991-1992 drought, at the Romwe catchment site. The results of the recharge studies are presented in Butterworth, Macdonald, Bromley, et al (1999) and the effects of rainfall upon groundwater fluctuations by Butterworth, Schulze, Simmonds, et al (1999). Earlier Houston (1990) described the rainfall – runoff – recharge relationships for Basement complex rocks in adjacent areas of Mashvingo Province. Elsewhere in Zimbabwe Sunguro, Froehlich, Verhagen and Wagner (2000) undertook recharge studies of the Lomagundi dolomite using isotope hydrology. Houston (1982) undertook a rainfall - recharge assessment f a similar dolomite aquifer at Kabwe in central Zambia. Further north within the semi-arid area of north-central Tanzania Nkotagu (1996) undertook environmental isotope groundwater recharge studies in crystalline basement of the Dodoma area. In contrast the recharge to groundwater on the Indian Ocean island of Reunion by Join, Coudray and Longworth (1997) could be applied to the situations of Seychelles and Mauritius.

Where there is insufficient recharge to groundwater due to drought and/or the effects of over abstraction from a low permeability aquifer in areas with seasonal rainfall artificial recharge of groundwater systems may assist. The methods and effectiveness of artificial recharge of groundwater was reviewed by Gale, Neumann, Calow and Moench (2002). Murray and Tredoux (2000) assessed the application of borehole injection for artificially recharge within the context of Southern Africa while Paling (1987) investigated aspects of artificial recharge of aquifers with treated waste water.
Although Information Box D proved somewhat difficult to assemble and may be incomplete, it is apparent that some information on groundwater recharge would seem to be available in all Member States but coverage is everywhere moderate to poor and data is almost exclusively only in hard copy format. This status is certainly a function of the research-orientated nature of recharge evaluation, as well as possibly the relatively low priority attached by most groundwater management institutions to this component.

## 4.5 HYDROLOGICAL AND CLIMATOLOGICAL DATA

Hydrological and climatological data are one of the key components to the understanding of the water cycle and the challenge for the international hydrological research community to develop better methods and tools to ensure more effective and sustainable management of an increasingly scarce resource and, through this, contribute to improving the quality of life for the poorest people in our global society is considerable.

FRIEND (Flow Regimes from International Experimental and Network Data) is one of the initiatives being undertaken by hydrologists to meet this challenge. FRIEND is a contribution to the International Hydrology Programme (IHP) of the United Nations' Educational, Scientific and Cultural Organization (UNESCO), and aims to develop better understanding of hydrological variability and similarity across time and space, through mutual exchange of data, knowledge and techniques at a regional level. As part of the FRIEND project the four data types noted in Information Box E together with related data types have been compiled as databases for the countries of the SADC region, primarily from the Climate Impacts LINK Project based at the Climatic Research Unit, University of East Anglia. They are all elements necessary for the assessment of the impacts of drought in the region, undertaken as part of the follow-up ARIDA project. The results of the FRIEND and ARIDA projects are available on CD-ROM. The types of data collected during these programmes include:

1. <u>Potential evaporation</u>: A polygon half-degree grid coverage of Penman potential evaporation data for the SADC region. The Climatic Research Unit at the University of East Anglia, UK, provided annual and mean monthly potential evaporation data, estimated by the Penman method, and averaged over the standard period 1961 to 1990. The gridded values were calculated by applying a spline function to data collected at national meteorological stations.

2. <u>Major river basins of Africa:</u> A polygon coverage showing the major river basins for the whole of the African continent. This coverage was based on the river network (derived from 1:1,000,000 scale maps) for the African continent, obtained from the Global Ecosystems Database CD-ROM (NOAA-EPA, 1992). Also, for South Africa, DWAF provided a river network derived at 1:250,000 scale. These two databases assisted in the determination of the nested hierarchy of FRIEND catchments and hydrometric areas.

3. <u>Mean annual runoff:</u> A polygon half-degree grid coverage of mean annual runoff data for the SADC region. Mean annual runoff values, averaged over the standard period 1961 to 1990, are given in units of millimetres depth. These data were derived using a grid-based rainfall-runoff modelling technique, based on a regular 0.5° by 0.5° grid. Each grid cell was treated as an independent catchment and the resultant product simulates the runoff

generated over each cell. The model used was a conceptual rainfall-runoff model, with parameters derived from physical and climatic characteristics, rather than by optimisation. The model was based on the Probability Distributed Model (PDM) comprising a soil moisture store with a capacity that varies across each grid cell, and a groundwater store (Moore, 1985). The input data to the model were the rainfall and potential evaporation values described above, as well as time series of monthly rainfall from the same source.

4. Hydrometric boundaries: A polygon coverage showing both catchment and hydrometric zone boundaries for the SADC region. This is a single, integrated coverage for all of Southern Africa. It has approximately 500 national hydrometric zones, more than 1000 gauged catchment boundaries (including all the FRIEND stations), and national boundaries for all eleven SADC countries involved in the project. It was created for the FRIEND project from 1:250,000 scale topographic maps (except 1:500,000 for Angola).

5. Precipitation: A polygon half-degree grid coverage of precipitation data for the SADC region. The Climatic Research Unit at the University of East Anglia, UK, provided annual and mean monthly precipitation data averaged over the standard period 1961 to 1990. The gridded values were calculated by applying a spline function to data collected at more than 1000 national meteorological stations.

6. Raingauge locations: A point coverage of the raingauges in the selected country, and for the whole region. These are national coverage of rain gauge locations, provided by National Hydrological Agencies. Note that national information for Angola, Lesotho, South Africa and Swaziland is not available within the FRIEND project. By selecting ‘All Southern Africa’, rather than an individual country, the user can obtain coverage of rain gauge locations for those gauges that are on the Climatic Research Unit database (CRU) at the University of East Anglia, UK. This shows rain gauges across the whole region, but does not include all the gauges that are in national coverages.

7. River network: A line coverage of the rivers for the whole African continent. This coverage was based on the river network (derived from 1:1,000,000 scale maps) for the African continent, obtained from the Global Ecosystems Database CD-ROM (NOAA-EPA, 1992). Also, for South Africa, DWAF provided a river network derived at 1:250,000 scale. Note that the accuracy of some of the river courses in the coverage may not be high.

8. Temperature: A polygon half-degree grid coverage of temperature data for the SADC region. Mean annual and mean temperature data, averaged over the standard period 1961 to 1990, were provided by the Climatic Research Unit at the University of East Anglia, UK, based on data collected at national meteorological stations.

It is apparent from Information Box E that hydrological and climatological data is much more widely available throughout the SDAC region than any other data sets, certainly as a result of the major regional programmes noted above. In virtually all Member States all data sets are available in digital format from the project programmes and national coverage is good.

## 4.6 GEOLOGICAL DATA

The types and sources of geological data listed below should form the basis of any regional hydrogeological assessment. Unfortunately, although a good density of boreholes and detailed geological maps may exist, data crucial to hydrogeological assessments such as thickness of weathered zones, lithological colour changes and water strike/loss zones are often absent from even detailed borehole logs, are not represented on geological maps or described in geological district memoirs. Field geologists can only map the exposed geology and it is frequently the case that thick weathered zones such as laterites or, in Kalahari regions, by thick surficial sand cover, mask much of the geology of many Member States. Given this situation, there needs to be available sufficient reliable and comprehensive geological data generated from borehole drilling operations to produce informed assessments of the variations in hydrogeological characteristics within each Member State. Unfortunately, this is often not the case, but at little additional cost effort could be made by institutions responsible for drilling boreholes to ensure the collection of representative additional geological and hydrogeological samples to be examined by the relevant geological institution from at least a proportion of the boreholes drilled. This would be especially important for boreholes drilled in marginal areas for which no data presently exists. Ultimately, the collection of such data will allow basic groundwater resource assessment to take place at district or sub-district level, something that cannot yet be achieved.

Examination of Information Box F indicates that all Member States have a national Geological Map, at various scales depending on the area of the country but with scales of 1: 1,000,000 and 1:250,000 being the most common. Related to these maps are a number of crucial data sets of borehole information. However, only four Member States have any form of digital geological map, and some map sets are relatively old and thus rather less detailed. There appears to be poor map coverage in Angola, DRC and Mozambique, and maps in Tanzania are reported to be out of print and unavailable.

## 4.7 ENVIRONMENTAL DATA

The definition of what constitutes a wetland varies from continent to continent. However, within southern Africa wetlands also include perennial swamps and lakes with ephemeral rivers, flood plains and dambo environments. All of the main wetland systems of Southern Africa are listed and outlined in “A Directory of African Wetlands” by Hughes and Hughes (1992). A polygon half-degree grid coverage of wetland data for the SADC region was created during the FRIEND project by sampling mapped wetlands. It provides information on several different definitions of wetland, floodplains and other water bodies as defined on national topographic map series. Reports on the wetlands of individual SADC states are available for Tanzania (Kamukala and Crafter, 1993) and in Zimbawe (Matiza and Crafter, 1994). Individual wetland sites have also been separately described, as in the Ramsar Information Sheet (1997) of the Bangweulu Swamps; the detailed description of the eastern Caprivi swamplands by Mendelsohn and Roberts (1997); the Okavango Swamps by Scudder, Manley and Coley et al, 1993; and a description of the Lake Chilwa wetland area of Malawi by Jensen, Munyenyembe and Watts (2000). Hughes and Hannart (2003) have modelled the ecological instream flow requirements of rivers in South Africa.

Although there is a wealth of information about the ecology, climate, hydrology and geomorphology of these wetland sites it is very apparent that little has been written to describe the interaction between perennial wetlands and any underlying aquifers. In contrast there is a growing literature that describes the surface-water/groundwater interaction within ephemeral wetland systems such as the dambo/mbuga environment and its dry land equivalent the sand river. Much work has been undertaken on the study of groundwater flow to dambos in Malawi and Zimbabwe (McFarlane, 1992; and McCartney and Neal, 1999) and Zambia (Boast, 1990) where, as in the ‘mbuga’ of Tanzania, they form important areas of rural seasonal crop irrigation.

Social issues related to the use of ephemeral wetland systems such as dambos have been studied by Woodhouse, Bernstein and Hulme (2000). The groundwater occurrence along sand rivers has been the subject of studies undertaken in N E Botswana by Davies, Rastall and Herbert (1998), Herbert, Barker, Davies and Katai (1997), Nord (1985) and Wikner (1980); in southern and eastern Zimbabwe by Owen (1989) and Broderick and Mutirwara (1995); in

Namibia by Jacobson, Jacobson and Seely (1995); and in south-eastern South Africa by Kotze, Breen and Klug (1994). A particular problem is that stream flows along sand rivers and outflows along dambo systems are very difficult to monitor and assess and there is thus little quantitative data relating to their interaction with underlying aquifer systems.

Although Information Box G reveals that virtually all Member States possess a data inventory relating to various water-related ecosystems (wetlands, swamps etc) and general coverage in most cases appears to be good, none of this information is in digital format that would lend itself to data basing and GIS applications. Most environmental information is in the form of reports held by a single institution in each Member State.

## 4.8 GROUNDWATER POLLUTION DATA

The pollution of aquifers by human wastes, urban run-off, and other types of point and non-point source pollution in cities of the humid tropics are described by Coughanowr (1994). He considers that in the developing world case studies of severe ground-water pollution by hazardous and industrial wastes are rare. However, in rural areas, there is increasing contamination of aquifers by fertilizers, pesticides and human and animal wastes. In his guide to the production of a groundwater contamination inventory Zaporozec (2002) summarises all kinds of contamination sources that planners and managers should be familiar with, and proposes inventory structures to help hydrogeologists in:

- designing and implementing an inventory of contamination sources,
- determining the extent and degree of existing contamination,
- explaining the impact of the existing and potential contamination sources on groundwater,
- presenting results of the inventory on maps, and
- using results of the inventory to suggest alternative strategies to protect groundwater.

Information Box H indicates that many Member States appear to have many of the data sets required to assess and define groundwater pollution vulnerability features. However, all data apparently is only in hard copy, data is held by a variety of institutions and coverage, in general, is only moderate to poor. Most data related to actual pollution occurrences is generally fairly site or project-specific and thus it could be problematical to utilise this in a national context.

## 4.9 OTHER DATA SETS

### Population

Successive sets of National Census data provide indications of the distribution and long-term change of population in a country that are an essential requirement for the assessment of water use and future water demand. However, such overall national data collected at wide intervals (often every 10 years) do not reflect short term population variations resultant upon drought that may cause temporary large scale population movements, or seasonal changes that result in annual temporary population movements, or the current impact of the HIV/Aids pandemic which may cause a reduction in water use and demand. Care must thus be exercised in the use of general National Census data for developing realistic water demand projections.

Information Box I indicates that all Member States have national census data held almost exclusively in hard copy by a National or Central Statistics Office. Coverage is good, except probably in the States that have suffered the effects of conflict, and repeat census is undertaken every 10 years.

## Land Use

Land Use data is required in order to identify areas that have undergone soil degradation due to overgrazing, cultivation and urban expansion that can result in soil erosion, river and dam siltation and rapid rainwater runoff. All these factors will impact upon the rate of recharge of rainwater to aquifer systems.

Land use information will include data on vegetation, crop distribution and livestock/farming practises, together with information on population.
With respect to vegetation polygon (half-degree) grid coverage of vegetation for the SADC region is available and has been developed by two different approaches. These are the Olsen Classification and the NDVI Classification methods. In both cases the values are simplified from the original classification into a range of vegetation types, and are presented as estimates of the percentage of forest cover (as opposed to grassland).

The Olson classification was originally derived from a combination of published vegetation maps, remotely sensed data and observations. The complete Olson World Ecosystems vegetation data are available on the Global Ecosystems Database CD-ROM (NOAA-EPA, 1992), and the associated documentation manual gives the full definition of the vegetation types used. For the purposes of the FRIEND project, the classifications have been translated into estimates of percentage forest cover.

The NDVI classification was created using the temporal variability of the remotely sensed monthly Normalised Difference Vegetation Index data for 1987 (chosen to be a representative year). These data were also obtained from the Global Ecosystems Database CD-ROM, and the classifications were again translated into estimates of percentage forest cover

As a result of the divergent data types it is apparent from Information Box J that land use data is held by a wide variety of national different institutions, apparently in both digital and hard copy format. Unfortunately, because of the diverse data sources it has proved to be problematical to gather much information on data format and coverage.

## Soils

Specific information on soils, especially relating to soil type and distribution, is a component of land use maps as well as other map types. Similar to the land use data there appears to be a regional data set in the form of a polygon coverage showing information on soils for the whole of Southern Africa.

This soil data was obtained from the Global Ecosystems Database CD-ROM (NOAA-EPA, 1992), which was initially derived from the FAO Soil Map of the World. It is, therefore, very general in definition at individual country level. Under this system each mapped unit is defined by a code that determines the soil unit or association of soil units. The codes can be interpreted in terms of dominant soil, component soils (more than 20% of the area), and the texture class and slope class of the dominant soil. More details of this soil map coverage can be found in FAO-UNESCO (1974) and FAO (1996).

As with the Land Use data, soils information is held by a variety of national institutions, largely in hard copy and almost exclusively (originally) based on the FAO soils maps. Coverage is thus good, but the scale at which the data is presented may be limiting.

## Groundwater Occurrence Data — Information Box A

| Member State | Data Type | Format | Department/ Agency | Coverage | Comments |
|---|---|---|---|---|---|
| **Angola** | Dpwa, Bhdp, Bhyd ,Bhlc | HC, D | DW, DGS, DRA | * | Weathered crystalline basement (Pre-Cambrian), coastal sedimentary (Cretaceous to recent) and recent alluvial sand aquifers. DNA – 3618 bh records country-wise Hidromina – 2546 southern 3 regions |
| **Botswana** | Gwlv, Dpwa, Bhdp, Bhyd ,Bhlc ,Bhgl | HC, D | DW, DGS, DRA, WSO | *** | Weathered crystalline basement (Pre-Cambrian), sedimentary (Cretaceous) and recent alluvial sand aquifers. DGS and DWA >20 000 bh records in National Bh Archive |
| **DR Congo** | Gwlv, Dpwa, Bhdp, Bhyd ,Bhlc ,Bhgl | HC, D | DW, DGS, DRA, WSO | * | Sedimentary (Cretaceous) and non-consolidated alluvial (Recent) aquifers. AIDR-about 800 bh records, REGIDSO-210 digitised bh records, SNHR-838 bh records |
| **Lesotho** | Gwlv, Dpwa, Bhdp, Bhyd ,Bhlc ,Bhgl | HC | DG, DW, DRA, WSO | ** | Crystalline basement (Pre-Cambrian), volcanic and sedimentary (Cretaceous) aquifers. Hydrocon -206 digitised bh records, Monitoring-89 digitised monitoring bh records, IGP-1047 bh records, TAMS-8070 bh records |
| **Malawi** | Gwlv, Dpwa, Bhdp, Bhyd ,Bhlc ,Bhgl | HC | DW, DGS, DRA, NGO | * | Crystalline basement (Pre-Cambrian), sedimentary (Cretaceous) and non-consolidated alluvial (Recent) aquifers. MWD-~6000 digitised bh records (BGS), 15288-bh records in project files, MASAF-2200 bh records, CPAR-bh records |
| **Mauritius** | Gwlv, Dpwa, Bhdp, Bhyd ,Bhlc ,Bhgl | HC | DW, DGS, DRA | *** | Volcanic (Cretaceous) and non-consolidated alluvial (Recent) aquifers. Unknown number of bh records with WRU and CWA |
| **Mozambique** | Gwlv, Dpwa, Bhdp, Bhyd ,Bhlc ,Bhgl | HC | DW, DGS, DRA,NGO, WSO | * | Crystalline basement (Pre-Cambrian), coastal sedimentary (Cretaceous) and non-consolidated deltaic and fluvial (Recent) aquifers. Sdg-12000 digitised bh records, GEOMOC-9000 bh records |
| **Namibia** | Gwlv, Dpwa, Bhdp, Bhyd ,Bhlc ,Bhgl | HC, D | DW, DGS, DRA, WSO | *** | Crystalline basement (Pre-Cambrian), sedimentary (Cretaceous) and non-consolidated alluvial (Recent) aquifers. 42,500 borehole data records of which 32 000 contain useful data |
| **Seychelles** | Gwlv, Dpwa, Bhdp, Bhyd ,Bhlc ,Bhgl | HC | DW, DGS, DRA, WSO | | Crystalline basement (Pre-Cambrian), and non-consolidated alluvial (Recent) aquifers. PUC-27 digitised monitoring bh records |
| **South Africa** | Gwlv, Dpwa, Bhdp, Bhyd ,Bhlc ,Bhgl | HC, D | DW, DGS, DRA, NGO, WSO, DA | *** | Crystalline basement (Pre-Cambrian), sedimentary (Cretaceous) and non-consolidated alluvial (Recent). DWAF – NGDB->220 000 digitised bh records, WMS->55 000 digitised bh records |
| **Swaziland** | Gwlv, Dpwa, Bhdp, Bhyd ,Bhlc ,Bhgl | HC, D | DW, DGS, DRA, NGO, WSO | ** | Crystalline basement (Pre-Cambrian), and sedimentary (Cretaceous) and non-consolidated alluvial (Recent) aquifers. DGSM–SWAZIDAT->2,600 digitised bh records |
| **Tanzania** | Gwlv, Dpwa, Bhdp, Bhyd ,Bhlc ,Bhgl | HC | DW, DGS, DRA, NGO, WSO | ** | Weathered crystalline basement (Pre-Cambrian), sedimentary (Cretaceous) and non-consolidated alluvial (Recent) aquifers MWLD-~7000 bh records |
| **Zambia** | Gwlv, Dpwa, Bhdp, Bhyd ,Bhlc ,Bhgl | HC | DW, DGS, DRA, NGO, WSO | ** | Crystalline basement (Pre-Cambrian), sedimentary (Cretaceous) and non-consolidated alluvial (Recent) aquifers |
| **Zimbabwe** | Gwlv, Dpwa, Bhdp, Bhyd ,Bhlc ,Bhgl | HC,D | DW, DGS, DRA, NGO, WSO | ** | Crystalline basement (Pre-Cambrian), sedimentary (Cretaceous) and un-consolidated alluvial (Recent) aquifers. ZNGD-~15 000 bh records |

Data Type:
Gwlv – Groundwater Level
Dpwa – Depth to WaterD – Digital
Bhdp – Borehole Depth
Bhyd – Borehole Yield
Bhlc – Borehole Location
Bhgl – Borehole Geological Log

Format:
HC – Hard copy

Department/Agency:
DW – Dept of Water
DGS – Dept Geological Survey
DRA – District/Regional Authorities
WSO – Water Supply Organisations
NGO – NonGovernmental Organisations
DA – Department of Agriculture

Coverage
*** - Good
** - Moderate to patchy
* - Poor to non-existent.

## Groundwater Demand Data — Information Box B

| Member State | Data Type | Format | Department/ Agency | Coverage | Comments |
|---|---|---|---|---|---|
| Angola | Popc, Rrwd, Lvst, Crtp, Urwd, Ldus, | HC | DW, ID, DRA, WSO, DA, NSO | * | Affected by drought and economic situation |
| Botswana | Popc, Rrwd, Lvst, Idtp, Urwd, Hdcn | HC,D | DW, ID, DRA, WSO, DA, NSO | *** | Affected by drought and economic situation |
| DR Congo | Popc, Rrwd, Lvst, Irar, Crtp, Idtp, Urwd, Ldus, Hdcn | HC | DW, ID, DRA, WSO, DA, NSO | * | Little groundwater used |
| Lesotho | Popc, Rrwd, Urwd, Hdcn | HC | DW, DRA, WSO, DA, NSO | ** | Groundwater supplies peri-urban and rural communities |
| Malawi | Popc, Rrwd, Irar, Crtp, Ldus, Hdcn | HC,D | DW, ID, DRA, WSO, DA, NSO | ** | Affected by drought and economic situation |
| Mauritius | Popc, Rrwd, Irar, Crtp, Urwd, Ldus, Hdcn | HC,D | DW, ID, WSO, DA, NSO | *** | |
| Mozambique | Popc, Rrwd, Lvst, Irar, Crtp, Urwd, Ldus, Hdcn | HC | DW, ID, DRA, WSO, DA, NSO | ** | Affected by drought and economic situation |
| Namibia | Popc, Rrwd, Lvst, Crtp, Idtp, Urwd, Ldus, Hdcn | HC,D | DW, DRA, WSO, DA, NSO | *** | Affected by drought |
| Seychelles | Popc, Rrwd, Urwd, Ldus, Hdcn | HC | DW, DA, NSO | *** | |
| South Africa | Popc, Rrwd, Lvst, Irar, Crtp, Idtp, Urwd, Ldus, Hdcn | HC,D | DW, ID, DRA, WSO, DA, NSO | *** | Affected by drought and increased demand from former homeland areas |
| Swaziland | Popc, Rrwd, Irar, Crtp, Urwd, Ldus, Hdcn | HC | DW, ID, WSO, DA, NSO | ** | |
| Tanzania | Popc, Rrwd, Lvst, Irar, Crtp, Urwd, Ldus, Hdcn | HC | DW, DRA, WSO, DA, NSO | * | Affected by drought and economic situation – demand for groundwater difficult to assess |
| Zambia | Popc, Rrwd, Lvst, Irar, Crtp, Idtp, Urwd, Ldus, Hdcn | HC | DW, ID, DRA, WSO, DA, NSO | ** | Affected by drought and economic situation |
| Zimbabwe | Popc, Rrwd, Lvst, Irar, Crtp, Idtp, Urwd, Ldus, Hdcn | HC | DW, ID, DRA, WSO, DA, NSO | ** | Affected by drought and poor economic situation |

Data Type:
Popc – population census
Rrwd – Rural water demand
Lvst – Livestock distribution
Irar – Irrigation area
Crtp – Crop type/distribution
Idtp – Industry type/distribution
Urwd – Urban water demand
Ldus – Land use
Hdcn – hydrocensus

Format:
HC – Hard copy
D – Digital

Department/Agency:
DW – Dept of Water
ID – Irrigation Department
DRA – District/Regional Authorities
WSO – Water Supply Organisations
DA - Department of Agriculture
NSO – National Statistics Office

Coverage
*** - Good
** - Moderate to patchy
* - Poor to non-existent.

## Groundwater Quality Data — Information Box C

| Member State | Data Type | Format | Department/ Agency | Coverage | Comments |
|---|---|---|---|---|---|
| **Angola** | Mjin, Mnin, Bhlc | HC,D | GVLB, DWLB, GSLB, DRA, WSO, NGO, UNLB | * | EC for boreholes and wells nationwide (paper) with DNA; chemistry analyses for 3 provinces (digital) |
| **Botswana** | Mjin, Mnin, Trin, Ecol, Bhlc | HC, D | GVLB, DWLB, GSLB | *** | |
| **DR Congo** | Mjin, Mnin, | HC | DWLB, GSLB | * | Few data mainly captured at borehole drilling |
| **Lesotho** | Mjin, Mnin, Trin, Ecol, Bhlc | HC, D? | DWLB | *** | Some waters have high F contents |
| **Malawi** | Mjin, Mnin, | HC | DWLB, WSO, NGO | * | |
| **Mauritius** | Mjin, Mnin, , Bhlc | HC | DWLB, WSO | *** | Monitored on a monthly basis |
| **Mozambique** | Mjin, Mnin, Ecol, | HC | GVLB, DWLB, WSO | * | High nitrates in Maputo area, high Fe and Mn in alluvial aquifers |
| **Namibia** | Mjin, Mnin, Bhlc | HC, D | GVLB, DWLB, WSO | *** | Maps of F, $NO_3$, $SO_4$ and TDS distribution |
| **Seychelles** | Mjin, Bhlc | HC | DWLB | ** | Water quality good – only EC monitored regularly to monitor sea water intrusion |
| **South Africa** | Mjin, Mnin, Trin, Ecol, Bhlc | HC, D (55000 analyses) | GVLB, DWLB, | *** | Nitrate a problem in the northern parts of the country. 360 monitoring stations. Problems with mine water pollution |
| **Swaziland** | Mjin, Mnin, Bhlc, Ecol | HC | GSLB | ** | Problems with fluoride and nitrate. Investigated by CIDA project 1992 |
| **Tanzania** | Mjin, Mnin, Trin, Ecol, Bhlc | HC | GVLB, DWLB, UNLB | ** | Dar es Salaam and Dodoma |
| **Zambia** | Mjin, Mnin, | HC | GVLB, DWLB, UNLB | * | Some F and NO3 problems, no regular monitoring outside Lusaka |
| **Zimbabwe** | Mjin, Mnin, Trin, Ecol, Bhlc | HC | GVLB, DWLB, | ** | No national monitoring system, regular monitoring at selected area |

Data Type:
Mjis – major ions
Mnin – minor ions
Trin – Trace elements
Ecol – sanitation parameters
Bhlc – Borehole Location

Format:
HC – Hard copy
D – Digital

Department/Agency:
DWLB – Dept of Water laboratory
GSLB – Geological Survey laboratory
DRA – District/Regional Authorities
WSO – Water Supply Organisations
NGO – Non-Governmental Organisations
GVLB – government laboratory
PRLB – private laboratory
UNLB – university laboratory

Coverage
*** - Good
** - Moderate to patchy
* - Poor to non-existent.

## Groundwater Recharge Data — Information Box D

| Member State | Data Type | Format | Department/ Agency | Coverage | Comments |
|---|---|---|---|---|---|
| Angola | | | | | No known data |
| Botswana | Rech, Hych, Rafl | HC, D | DGS | ** | Recharge monitoring network |
| DR Congo | Rech | HC | | * | 4 categories indicated on 1/10 000 000 hydrogeology map |
| Lesotho | | | | | No known data |
| Malawi | Rech | HC | DW | * | Average recharge rates for weathered Basement Complex and alluvial aquifers |
| Mauritius | Rech | HC | DW | ** | Recharge referred to on national hydrogeological map |
| Mozambique | Rech | HC | | * | A qualitative water recharge map at 1/8 000 000 used to show general recharge conditions, based on annual rainfall and recharge capacity of the terrain, detailed recharge studies for Maputo area only |
| Namibia | Rech | HC | DW | * | Vulnerability of Groundwater Resources map at 1 : 6 000 000 shows vulnerability to pollution, integrating factors including rainfall recharge.<br>Artificial recharge of aquifers in the Windhoek area |
| Seychelles | | | | | No known data |
| South Africa | Rech | HC | DW | ** | A national mean annual recharge map at 1:7,500,000 showing the distribution of recharge<br>A groundwater harvest potential map 1996 at 1/8 500 000 presents the available volumes of groundwater taking into account recharge and storage capacity.<br>A map at 1:8,500,000 showing the distribution of volume of recharge, variability of annual recharge and effective storage volume |
| Swaziland | Rech | HC | DGS | ** | Recharge studies as part of the Groundwater Survey Project (1986-1992). |
| Tanzania | Rech | HC | DW | * | Isotope studies have been used to estimate the age of groundwater recharge in the Makutapora Basin, Dodoma |
| Zambia | Rech | HC | DW | * | Limited studies of the dolomite aquifers at Kabwe and Lusaka |
| Zimbabwe | Rech | HC | DW | ** | Limited studies of the Lomagundi dolomite aquifer |

Data Type:
Rech – recharge

Format:
HC – Hard copy
D – Digital

Department/Agency:
DW – Dept of Water
DGS – Dept Geological Survey

Coverage
*** - Good
** - Moderate to patchy
* - Poor to non-existent.

## Hydrological and Climatological Data — Information Box E

| Member State | Data Type | Format | Department/ Agency | Coverage | Comments |
|---|---|---|---|---|---|
| Angola | Rafl, Evap, Rifh, Rifs | HC, D | DW, METO, FRIEND, HYCOS | ** | 19 stream gauging stations |
| Botswana | Rafl, Evap, Rifh, Rifs | HC, D | DW, WSO, METO, FRIEND, HYCOS | *** | 25 stream gauging stations |
| DR Congo | Rafl, Evap, Rifh, Rifs | HC, D | DW, METO, FRIEND, HYCOS | ** | |
| Lesotho | Rafl, Evap, Rifh, Rifs | HC, D | DW, METO, FRIEND, HYCOS | *** | 23 stream gauging stations |
| Malawi | Rafl, Evap, Rifh, Rifs | HC, D | DW, METO, FRIEND, HYCOS | *** | 197 stream gauging stations of which 45 used for Friends project |
| Mauritius | Rafl, Evap, Rifh, Rifs | HC | DW, WSO, METO, | *** | |
| Mozambique | Rafl, Evap, Rifh, Rifs | HC, D | DW, METO, FRIEND, HYCOS | ** | 16 stream gauging stations |
| Namibia | Rafl, Evap, Rifh, Rifs | HC, D | DW, WSO, METO, FRIEND, HYCOS | *** | 46 stream gauging stations |
| Seychelles | Rafl, Evap, Rifh, Rifs | HC, D | DW, METO, | *** | 34 rainfall stations |
| South Africa | Rafl, Evap, Rifh, Rifs | HC, D | DW, WSO, METO, FRIEND, HYCOS | *** | 294 stream gauging stations |
| Swaziland | Rafl, Evap, Rifh, Rifs | HC, D | DW, WSO, METO, FRIEND, HYCOS | ** | 35 stream gauging stations |
| Tanzania | Rafl, Evap, Rifh, Rifs | HC, D | DW, WSO, METO, FRIEND, HYCOS | ** | 111 stream gauging stations |
| Zambia | Rafl, Evap, Rifh, Rifs | HC, D | DW, WSO, METO, FRIEND, HYCOS | *** | 30 stream gauging station |
| Zimbabwe | Rafl, Evap, Rifh, Rifs | HC, D | DW, WSO, METO, FRIEND, HYCOS | *** | 86 stream gauging stations |

Data Type:
Rafl - rainfall
Evap - evaporation
Rifh – riverflow hydrographs
Rifs – riverflow stage reading (runoff)

Format:
HC – Hard copy
D – Digital

Department/Agency:
DW – Dept of Water
WSO – Water Supply Organisations
METO – Meteorological office
FRIEND
HYCOS

Coverage
*** - Good
** - Moderate to patchy
* - Poor to non-existent.

## Geological Data — Information Box F

| Member State | Data Type | Format | Department/ Agency | Coverage | Comments |
|---|---|---|---|---|---|
| **Angola** | Bhgl, Bhlc, Bhpd, gmap, gmem, crpt | HC, D | DGS, DW, DRA, MNCO, CONS | * | Geological map of Angola 1/1,000,000; 1982. 1/250,000 area maps (12), 1/100 000 area maps (36) |
| **Botswana** | Bhgl, Bhlc, Bhdp, Gmap, Gmem, Crpt | HC, D | DGS, DW, DRA, MNCO, CONS | *** | Geological map of Botswana at 1/1 000 000. Also preliminary digital copy. 1/125 000 area maps (51), 1/250 000 area maps (3) |
| **DR Congo** | Bhgl, Bhlc, Bhdp, Gmap, Gmem, Crpt | HC | DGS, DRA, MNCO, CONS | * | Geological map of Zaire, 1/2 000 000, 1974, 1/40 000 to 1/200 000 various area maps |
| **Lesotho** | Bhgl, Bhlc, Bhdp, Gmap, Gmem, Crpt | HC,D | DGS, DW, DRA, CONS | *** | Digital geology map part of DWA (TAMS) GIS Geological Map of Lesotho, 1/250,000; 1982 1/100 000 area maps (4) 1/50,000 area maps (12) |
| **Malawi** | Bhgl, Bhlc, Bhdp, Gmap, Gmem, Crpt | HC | DGS, DW, DRA, CONS | ** | Geological map of Malawi at 1/1 000 000, 1/100 000 area maps (24) |
| **Mauritius** | | HC | DW | *** | Geological map of Mauritius(on going) |
| **Mozambique** | Bhgl, Bhlc, Bhdp, Gmap, Gmem, Crpt | HC | DGS, DW, MNCO, CONS | * | Geological maps of Mozambique at 1/1,000,000 1/250,000 area maps (90) |
| **Namibia** | Bhgl, Bhlc, Bhdp, Gmap, Gmem, Crpt | HC, D | DGS, DW, MNCO, CONS | *** | Geological map of Namibia 1/1,000,000, Mainly 1/250 000 area maps, some 1/100 000 and 1/50 000 area maps |
| **Seychelles** | Gmap, Crpt | HC | DW | *** | Geology map of the Seychelles at 1/50 000 |
| **South Africa** | Bhgl, Bhlc, Bhdp, Gmap, Gmem, Crpt | HC | DGS, DW, MNCO, CONS | *** | Geological map of South Africa at 1/1,000,000, 70 area maps at 1/250,000, for seamless national coverage |
| **Swaziland** | Bhgl, Bhlc, Bhdp, Gmap, Gmem, Crpt | HC | DGS | ** | Some geological maps at 1/50,000 |
| **Tanzania** | Bhgl, Bhlc, Bhdp, Gmap, Gmem, Crpt | HC | DGS, DW, DRA, MNCO, CONS | * most out of print and unavailable | Geological map of Tanzania, 1967, 1/3,000,000, Structural map, 1/2,000,000; 1964, 1/125,000 and 1/100 000 area maps |
| **Zambia** | Bhgl, Bhlc, Bhdp, Gmap, Gmem, Crpt | HC D | DGS, DW, DRA, MNCO, CONS | ** | Digital geological map of Zambia, 1/1,000,000, 1961, digital 1/250,000 and 1/100,000 area maps of Central and mining areas. |
| **Zimbabwe** | Bhgl, Bhlc, Bhdp, Gmap, Gmem, Crpt | HC, D | DGS, DW, DRA, MNCO, CONS | ** | Geological map of Zimbabwe, 1/1,000,000 1/250,000 and 1/100,000 maps (2/3 of the country) |

Data Type:
bhgl – Borehole Geological Log
bhlc – Borehole Location
bhdp – Borehole Depth
Gmap – geological maps
Gmem – geological memoirs
Crpt – consultants reports

Format:
HC – Hard copy
D – Digital

Department/Agency:
DW – Dept of Water
DGS – Dept Geological Survey
DRA – District/Regional Authorities
CONS – Consultants
MNCO – Mining companies

Coverage
*** - Good
** - Moderate to patchy
* - Poor to non-existent.

## Ecosystem Data — Information Box G

| Member State | Data Type | Format | Department/ Agency | Coverage | Comments |
|---|---|---|---|---|---|
| **Angola** | Wtlds, Fdpn, Swmp, Sdrs, | HC | DW | * | Courses of main rivers, sand rivers |
| **Botswana** | Wtlds, Fdpn, Swmp, Sdrs, | HC | WD, DW | *** | Okavango Swamps and sand rivers |
| **DR Congo** | Wtlds, Fdpn, Swmp, | HC | ED | *** | Flood plains and swamps of the Congo River |
| **Lesotho** | Wtlds, | HC | DW | ** | Peat bog head waters of main rivers |
| **Malawi** | Wtlds, Fdpn, Swmp, Domg, Sdrs, | HC | ED | *** | Lake Malawi, dambos, Sire River flood plains and swamps and sand rivers |
| **Mauritius** | Wtlds, | HC | ED | | |
| **Mozambique** | Wtlds, Fdpn, Swmp, Domg, | HC | ID | ** | Deltas ad flood plains of Zambezi, Save, Limpopo etc and Cahora Bassa Lake |
| **Namibia** | Wtlds, Fdpn, Swmp, Sdrs, | HC | WD, DW | *** | Swamps and floodplains of the Caprivi Strip, sand river and pan systems |
| **Seychelles** | Wtlds, | HC | | | |
| **South Africa** | Wtlds, Fdpn, Domg, Sdrs, | HC | DW | *** | Coastal wetlands of Zululand, vleis and sand rivers |
| **Swaziland** | Wtlds, Fdpn, | HC | DW, ID | *** | Peat bogs and river floodplains |
| **Tanzania** | Wtlds, Fdpn, Swmp, Domg, Sdrs, | HC | ID | *** | Large swamp, lake and mbuga areas |
| **Zambia** | Wtlds, Fdpn, Swmp, Domg, Sdrs, | HC | ID, DW, WD, ED | *** | Kafue, Zambezi and Luangua flood plains, lakes, swamps, dambo systems and sand rivers |
| **Zimbabwe** | Wtlds, Fdpn, Swmp, Domg, Sdrs, | HC | ID | *** | Save, Zambezi and Limpopo flood plains, lakes, swamps, dambo systems and sand rivers |

Data Type:
Wtld - wetlands
Fdpn - floodplains
Swmp – swamps/ lakes
Sdrs – sand rivers
Domg – dambos/mbuga/vleis

Format:
HC – Hard copy
D – Digital
M - Map

Department/Agency:
DW – Dept of Water
ED – Environment Department
DRA – District/Regional Authorities
WD – Wildlife Department
ID – Irrigation Department

Coverage
*** - Good
** - Moderate to patchy
* - Poor to non-existent.

## Groundwater Pollution Data

### Information Box H

| Member State | Data Type | Format | Department/ Agency | Coverage | Comments |
|---|---|---|---|---|---|
| Angola | Dpwa, Rech, Sotp, Ldus, Geol | HC | DW | * | Urban pollution of groundwater |
| Botswana | Dpwa, Rech, Sotp, Ldus, Geol | HC | DW, DGS, DA | *** | Groundwater vulnerability map 1995 |
| DR Congo | Dpwa, Rech, Sotp, Ldus, Geol | HC | DW, DGS, DA, | * | Possible mine waste pollution in the east |
| Lesotho | Dpwa, Rech, Sotp, Ldus, Geol | HC | DW, DRA, WSO | ** | Periurban area pollution of groundwater, some fluoride |
| Malawi | Dpwa, Rech, Sotp, Ldus, Geol | HC | DW, DGS, DA | * | Possibly some agricultural and rural pollution |
| Mauritius | Dpwa, Rech, Sotp, Ldus, Geol | HC | DW, DA, ID | * | Nitrate pollution from farms |
| Mozambique | Dpwa, Rech, Sotp, Ldus, Geol | HC | DW, DGS | ** | Pollution associated with urban waste in the Maputo area, and with coal mine wastes |
| Namibia | Dpwa, Rech, Sotp, Ldus, Geol | HC | DW, DGS, DA | ** | Mine waste pollution of groundwater? |
| Seychelles | Dpwa, Rech, Sotp, Ldus, Geol | HC | DW | ** | |
| South Africa | Dpwa, Rech, Sotp, Ldus, Geol | HC | DW, DGS, DRA, DA, ID | *** | Pollution associated with mining, and agriculture, as well as industrial, urban and rural waste |
| Swaziland | Dpwa, Rech, Sotp, Ldus, Geol | HC | DGS, DA, ID | * | No known problem |
| Tanzania | Dpwa, Rech, Sotp, Ldus, Geol | HC | DW | ** | Pollution associated with urban effluent and fluoride |
| Zambia | Dpwa, Rech, Sotp, Ldus, Geol | HC | DW, DGS, DRA, DA, ID | ** | Pollution associated with mining, agriculture and urban waste |
| Zimbabwe | Dpwa, Rech, Sotp, Ldus, Geol | HC | DW, DGS, DRA, DA, ID | ** | Pollution associated with mining and agriculture |

Data Type:
Dpwa – Depth to Water
Rech - recharge
Sotp – soils type
Ldus – Land use
Geol - geology

Format:
HC – Hard copy
D – Digital

Department/Agency:
DW – Dept of Water
DGS – Dept Geological Survey
DRA – District/Regional Authorities
DA – Department of Agriculture
ID – Irrigation Department
WSO – Water Supply Organisations

Coverage
*** - Good
** - Moderate to patchy
* - Poor to non-existent.

## Population Census Data — Information Box I

| Member State | Data Type | Format | Department/ Agency | Coverage | Comments |
|---|---|---|---|---|---|
| **Angola** | Pop | HC | NSO | ** | 10 year interval |
| **Botswana** | Pop | HC, D | NSO | *** | 10 year interval, 2001 |
| **DR Congo** | Pop | HC | NSO | ** | 10 year interval |
| **Lesotho** | Pop | HC | NSO | *** | 10 year interval |
| **Malawi** | Pop | HC | NSO | *** | 10 year interval, 1997 |
| **Mauritius** | Pop | HC | NSO | *** | 10 year interval |
| **Mozambique** | Pop | HC | NSO | ** | 10 year interval |
| **Namibia** | Pop | HC, D | NSO | *** | 10 year interval, 2001 |
| **Seychelles** | Pop | HC | NSO | *** | 10 year interval |
| **South Africa** | Pop | HC, D | NSO | *** | 10 year interval |
| **Swaziland** | Pop | HC | NSO | ** | 10 year interval |
| **Tanzania** | Pop | HC | NSO | *** | 10 year interval, 1998 |
| **Zambia** | Pop | HC | NSO | *** | 10 year interval, 2000 |
| **Zimbabwe** | Pop | HC | NSO (Central Stats Office | ** | 10 year interval, 2002 |

Data Type:
Pop – population census

Format:
HC – Hard copy
D – Digital

Department/Agency:
NSO – National Statistics Office
DGS – Dept Geological Survey

Coverage
*** - Good
** - Moderate to patchy
* - Poor to non-existent.

## Landuse Data

**Information Box J**

| Member State | Data Type | Format | Department/ Agency | Coverage | Comments |
|---|---|---|---|---|---|
| Angola | Crtp, Sotp, Lvst, Popc, Vgds | | DA, ED, ID, NSO, UG | | |
| Botswana | Crtp, Sotp, Lvst, Popc, Vgds | | DA, ED, ID, NSO, UG | | LRDC land use survey of part of the Limpopo Belt |
| DR Congo | Crtp, Sotp, Lvst, Popc, Vgds | | DA, ED, ID, NSO, UG | | |
| Lesotho | Crtp, Sotp, Lvst, Popc, Vgds | | DA, ED, ID, NSO, UG | | |
| Malawi | Crtp, Sotp, Lvst, Popc, Vgds | HC, D | DA, ED, ID, NSO | *** | Digitised land use maps at Department of Land Husbandry |
| Mauritius | Crtp, Sotp, Lvst, Popc, Vgds | | DA, ED, ID, NSO, UG | | |
| Mozambique | Crtp, Sotp, Lvst, Popc, Vgds | | DA, ED, ID, NSO, UG | | |
| Namibia | Crtp, Sotp, Lvst, Popc, Vgds | | DA, ED, ID, NSO | ** | District land use maps available |
| Seychelles | Crtp, Sotp, Lvst, Popc, Vgds | | DA, ED, ID, NSO, UG | | |
| South Africa | Crtp, Sotp, Lvst, Popc, Vgds | | DA, ED, ID, NSO, UG | | |
| Swaziland | Crtp, Sotp, Lvst, Popc, Vgds | | DA, ED, ID, NSO, UG | | |
| Tanzania | Crtp, Sotp, Popc, Lvst, Vgds | HC, D | DA, ED, ID, NSO, UG | *** | Digitised vegetation maps from the University of Dar es Salaam, LRDC land survey of the Tabora Region |
| Zambia | Crtp, Sotp, Popc, Vgds | HC, D | DA, ED, ID, NSO | *** | Digitised land use maps at Department of Agriculture |
| Zimbabwe | Crtp, Sotp, Lvst, Popc, Vgds | | DA, ED, ID, NSO, UG | | |

Data Type:
Crtp – crop types
Sotp – soil types
Lvst – livestock distribution
Popc – population census
Vgds – vegetation distribution

Format:
HC – Hard copy
D – Digital

Department/Agency:
DA – Agricultural Department
ED – Environment Department
ID – Irrigation Department
NSO – National Statistical Organisation
UG – University Dept of Geography

Coverage
*** - Good
** - Moderate to patchy
* - Poor to non-existent.

## Soils Data

## Information Box K

| Member State | Data Type | Format | Department/ Agency | Coverage | Comments |
|---|---|---|---|---|---|
| **Angola** | Sotp, Geol, Dpwe, Vgds, Ldus | HC | DA, DGS | *** | FAO soils map |
| **Botswana** | Sotp, Geol, Dpwe, Vgds, Swrk, Ldus | HC | DA, DGS, ID, UG, ED | *** | FAO soils map |
| **DR Congo** | Sotp, Geol, Dpwe, Vgds, Ldus | HC | DA, DGS, DF, ID, UG | *** | FAO soils map |
| **Lesotho** | Sotp, Geol, Dpwe, Vgds, Ldus | HC | DA, DGS, ID, UG | *** | FAO soils map |
| **Malawi** | Sotp, Geol, Dpwe, Vgds, Swrk, Ldus | HC, D | DA, DGS, ID, ED | *** | FAO soils map, has been digitised |
| **Mauritius** | Sotp, Geol, Dpwe, Vgds, Swrk, Ldus | HC | DA, DGS, ID, UG, ED | *** | FAO soils map |
| **Mozambique** | Sotp, Geol, Dpwe, Vgds, Ldus | HC | DA, DGS, DF, ID, UG, ED | *** | FAO soils map, 1982 |
| **Namibia** | Sotp, Geol, Dpwe, Vgds, Swrk, Ldus | HC | DA, DGS, ID, UG, ED | *** | FAO soils map |
| **Seychelles** | Sotp, Geol, Dpwe, Vgds, Ldus | HC | DA, DGS, ED | *** | FAO soils map |
| **South Africa** | Sotp, Geol, Dpwe, Vgds, Swrk, Ldus | HC | DA, DGS, DF, ID, UG, ED | *** | FAO soils map |
| **Swaziland** | Sotp, Geol, Dpwe, Vgds, Swrk, Ldus | HC | DA, DGS, ID, ED | *** | FAO soils map |
| **Tanzania** | Sotp, Geol, Dpwe, Vgds, Swrk, Ldus | HC | DA, DGS, DF, ID, UG, ED | *** | FAO soils map |
| **Zambia** | Sotp, Geol, Dpwe, Vgds, Swrk, Ldus | HC | DA, DGS, ID, ED | *** | FAO soils map and own soils map at 1/1 000 000 |
| **Zimbabwe** | Sotp, Geol, Dpwe, Vgds, Swrk, Ldus | HC | DA, DGS, ID, UG, ED | *** | FAO soils map |

Data Type:
Sotp - Soils type
Geol – geology
Dpwe – Depth of weathering
Vgds - vegetation distribution
Swrk – Soil/weathered rock permeability
Ldus – land use

Format:
HC – Hard copy
D – Digital

Department/Agency:
DA – Dept of Agriculture
DGS – Dept Geological Survey
DF – Forestry Department
ID – Irrigation Department
UG – University Geography Dept
ED –Environment Dept

Coverage
*** - Good
** - Moderate to patchy
* - Poor to non-existent.

# CHAPTER 5 – REGIONAL SITUATION ANALYSIS

## 5.1 THEMATIC SUMMARY

This section essentially summarises under the various thematic headings the findings and information set out in Chapter 2 and 4 into an overall Regional Situation Analysis.

### 5.1.1 Drought and Groundwater

- Of the fourteen SADC Member States, eleven are directly and periodically affected by drought events. Of the other three, current information would indicate that DRC is not affected, but that although Seychelles and Mauritius may be affected to some degree as island states they are partly isolated from the rigours of continental drought.

- Meteorological drought can probably be regarded endemic in those Member States that straddle the Tropic of Capricorn, but increasing variability in climate attributed to *El Nino* variations appears to be possibly increasing the periodicity and severity of drought occurrence throughout the region.

- Since the definition of a ‘drought’ appears to be rather ‘sector-specific’ (i.e. defined by climatic changes as well as actual impacts) as well as even ‘nation-specific’ (a perceived ‘drought’ period with reduced rainfall in higher rainfall states would be considered as a relatively ‘wet’ event in say Namibia or Botswana), there frequently appears to be reduced level of cooperative understanding and coordinated forward planning with respect to drought, with a consequent increase in ‘crisis management’ actions then unavoidable.

- Groundwater has made a significant and increased contribution to rural water supply in many States during periods of drought but although the natural buffering capacity of groundwater systems provides advantages in terms of the reliability of supply, it can also create certain longer-term problems. Firstly, it follows that groundwater also recovers more slowly after drought than surface sources. Secondly, it indicates a need for careful management and continuous monitoring of groundwater supplies. Monitoring and assessment programmes that begin and end with meteorological and agricultural droughts - a not untypical situation in many countries - may fail to pick up significant longer-term impacts on groundwater, with the result that potentially predictable and manageable problems become emergencies.

- The need for a clear understanding of the groundwater resource base is essential if increased use of groundwater during drought periods can occur in an appropriate and sustainable fashion.

- It has been stated that reliable information on the status of rural water supplies was unavailable at the onset of the recent drought periods in southern Africa. (UNICEF, 1995). Clearly, the need for reliable and timely information on the status of rural water supplies would seem fundamental to any form of groundwater drought planning and mitigation. The lack of this information, at least in an accessible and useable form, has been a serious and continuing constraint on sector planning and management during recent drought events, a situation exacerbated by the fact that data holdings that do exist are most usually dispersed amongst a range of different organisations (government, NGOs) at different levels (national, regional, local).

- With respect to the acquisition of appropriate information on groundwater systems and for drought planning it is important that Member States should:
  - recognise the importance of establishing (and maintaining) a sound hydrometeorological database that can be used routinely in the planning of new projects and in groundwater drought prevention and mitigation. Governments, ESAs and NGOs typically place a low priority on these activities. Reasons include: difficulties in quantifying benefits and verifiable indicators of success, especially over the shorter funding periods now being demanded by donors; a preference for dealing with immediately tangible problems which produce short term results (e.g. borehole drilling programmes and the installation of hand pumps); and reluctance on the part of hard pressed governments to divert resources away from more pressing, operational issues;

  - establish monitoring systems which extend beyond rainfall, surface water and food security indicators to groundwater and groundwater supply status, recognising that antecedent conditions (e.g. river flows and groundwater levels of the previous year) are essential guides for predicting future hydrological (not meteorological) conditions. Ideally, these should be able to distinguish between the different factors contributing to well/borehole failure, in particular, the distinction between source and resource stresses and source/resource and maintenance problems.

  - shortcomings in information systems make evaluating the impact of past droughts on groundwater resources and those dependent on them difficult.

- There is a clear need for a greater degree of planning for drought. Crisis management is *ad hoc* and uncoordinated, rushed, poorly targeted, reliant on the international relief system, and a diversion of government resources. It also generally requires large scale drilling operations with little time for community mobilisation and there is rarely post-drought evaluation. Shifting the emphasis from crisis management to crisis prevention, however, provides a means of achieving sustainable development and least impact in terms of drought. It takes two forms:

  - *drought proofing*, including treating drought as a normal event, using vulnerability mapping as a planning tool, tailoring policies to suit local needs and coordination, propositioning relief sources and increasing coverage and accessibility of sources.

  - *monitoring and early warning systems*, need good data including predictive indicators and long term tracking with triggers for early warning drought response. Such response requires consensus on the objectives of intervention, phasing actions according to specific triggers and carefully coordinating the role of donors and NGOs. Unfortunately, institutional memory often appears to be very short and lessons learnt from past drought experiences may soon be forgotten unless a change in attitude towards defining and planning for drought is forthcoming.

- The development of any regional drought planning and (hopefully) alleviation ‘tool kit’ will need to draw on long-term data related to many facets of groundwater and other segments of the hydrological cycle. However, it would appear that effective data sets probably only exist in possibly of the fourteen Member States, and in at least three others the data is either extremely fragmented or does not exist at all.

### 5.1.2 Groundwater and Ecosystems

- Little specific information is available on the interaction between groundwater and surface water (i.e. rivers, lakes) in the region, although the fairly extensive hydrological monitoring network used in the region for the FRIEND project ought, by means of modelling, to enable the relative contributions of groundwater to surface water systems to be determined. (Hughes, Gorgens, Middleton, etal, 2002). Bridging the gap between research and practice (Proceedings of the Fourth International FRIEND Conference held in Capetown, South Africa, March 2002). IAHS Publication No. 274, 2002. pp 11-18. More recent river basin studies that looked at ecological and hydrogeological factors have been undertaken in the Usangu and Pangani river basins of southeastern Tanzania, as well as in wetlands of Kwazulu-Natal Province of South Africa.

- Although information on the various ecosystems of the region, and in particular, wetlands, is available in the scientific literature and in national reports and studies, data are patchy, even to the extent of definitions of what actually constitutes a wetland. Some data are also available in RAMSAR publications and there are also general country/region specific reviews. However, most such work has been undertaken very much from a wildlife/vegetation/environmental perspective with the result that there is very limited reference to groundwater and its role in the system.

### 5.1.3 Groundwater Monitoring

- Hydrogeological monitoring in the SADC region is a key deficiency. In the majority of countries, some form of hydrogeological monitoring is undertaken but the extent, frequency and duration of the monitoring programmes are generally inadequate.

- The long term benefits and importance of hydrogeological monitoring are frequently not clear to the non- hydrogeologist. The need for hydrogeological monitoring usually only becomes apparent to non-technical administrators and financial controllers during a crisis, but interest soon wanes when the crisis ends and staff and funds are then reallocated to more immediate water supply provision.

- The primary objective of monitoring in most countries is aquifer protection and resource allocation. However, in countries with limited monitoring, there is frequently no clear or documented objective, which often results in inadequate networks and poor distribution of monitored points, inappropriate monitoring frequency (both too frequent and excessively infrequent), and limited use or analysis of collected data.

- Unfortunately monitoring is commonly only considered once a water resources system, aquifer or network of water points has suffered degradation, but monitoring systems are actually essential to sustainability and for early warning. As an important component of monitoring systems there must also be a database system in order that information is available in an accessible manner such that mitigating actions can be taken in response to early warning of drought or resource degradation.

- Groundwater and groundwater-related monitoring should include measurement of all elements of the natural water cycle (meteorological, hydrological and water level data), measurement of water quality data, measurement of human activity (abstraction; land use), measurement of abstraction point performance and measurement of source and monitoring installation maintenance activities.

- A major cause of poor monitoring or poorly defined monitoring programmes is the lack of an identified person or group that are specifically responsible for national monitoring. In some cases this results from a lack of qualified professionals available to fill such a post and in other cases is simply due to limited importance attributed to monitoring activities.

- The understanding of data quality and consistency is rarely recognised and QA/QC protocols for monitoring data do not appear to be implemented in any of the SADC member states.

### 5.1.4 Groundwater Pollution

- Pollution is the degradation of natural systems by the addition of detrimental substances and is associated with industrial and agricultural development, and the rapid increase in human population density. As elsewhere in the world, the increased quantities of anthropogenic waste being generated are adversely affecting the quality of the limited potable groundwater resources of the SADC region.

- The most serious sources of anthropogenic pollution are industrial and municipal waste, agro-chemical pollution, and toxic mine water discharges all of which contain ‘ecological accumulator’ type pollutants that accumulate in the food chain becoming toxic to humans and other animal life

- Other causes of groundwater quality deteriorating include over pumping that leads to pollutants being drawn into an aquifer or direct contamination through the leaching of wastes and chemicals from the ground surface down into an aquifer.

- In the SADC region the commercial farming of crops for export has increased use of fertilizers and irrigation that has resulting in water table lowering, borehole yield reduction, aquifer depletion, groundwater pollution and salinisation of soils. The Lomagundi Dolomite aquifer of Zimbabwe and the alluvial aquifers along the middle reaches of the Kafue valley in Zambia have been so affected. Dry land farming methods that use no fertilizers can also introduce nitrogen to aquifers.

- Groundwater is used for the processing of precious minerals (diamonds in Botswana, South Africa and Tanzania), metalliferous ores (gold and platinum in South Africa and Zimbabwe, copper in Zambia and Botswana) and fossil fuels (coal in South Africa, Botswana and Zimbabwe) as well as various industrial processes. The waste products produced contain pollutants (arsenic, cyanide and heavy metals) that contaminate groundwater and surface water resources. Acid mine drainage from closed mines is the most serious threat to the environment by coal and gold mining activities as water levels recover following the ending of mine pumping.

- Leakage from water distribution and sewerage systems are main causes of groundwater recharge and pollution in urban areas. In peri-urban area, where such systems do not exist, effluents introduced through soakaways and landfill sites are sources of aquifer contamination. These problems are of major concern in Lusaka and peri-urban areas in South Africa.

- Shallow groundwater that forms the main source of rural water supply in the SADC region is prone to contamination from human effluent introduced via pit latrines. Those engaged in fostering good sanitation practices amongst rural communities must be aware of this problem.

- Good groundwater quality must be protected as once groundwater becomes contaminated it is both expensive and difficult to remediate to its unpolluted state. Any groundwater protection strategy needs a groundwater contamination inventory to provide planners with an understanding of the potential for groundwater contamination.

### 5.1.5 Groundwater Information Systems

- A Groundwater Data System is a comprehensive data storage and dissemination system that incorporates all elements of a groundwater database with other groundwater management related information (climate, water use, water demand data etc), usually held in a spatial environment (i.e. with in-built GIS functionality) designed with full cognisance of the end-user and broad information dissemination requirements. Groundwater Data Systems bring together all the various data sets that are needed to develop tools with which to plan and manage resources.

- It is important that a Groundwater Data System is accessible at national level to promote optimum use of available resources planning, at regional level to assist in planning and management and at local level to facilitate operational activities. It must be available to both Government and NGOs, and above all must be presented in a simple manner that all comers can understand.

- In order to optimise the use of a Groundwater Data System beyond local operational concerns to include national and regional drought prediction, mitigation measures and vulnerability evaluation, end user requirements and accessibility and dissemination of data/information are crucial.

- It is unavoidably the case that a Groundwater Data System cannot exist in any useful form in the absence of a functional groundwater monitoring system - both are interdependent and essential to national and regional groundwater management aspirations and plans.

- It is also widely acknowledged that groundwater data storage and dissemination at regional level may be beneficial, but there are currently few proponents and only very limited avenues for achieving this. There are also concerns expressed from some Member States with respect to data release to an information system located outside national borders and under the control of a regional entity. In addition, the appreciation and conviction of the *need and priority* for a Groundwater Data System is not very strong and has not been particularly apparent from the current survey.

- It is apparent that there are ‘partial’ Groundwater Data Systems often containing fragmented or localised information in various national agencies, institutions, donor projects or private sector organisations in most Member States. However, no single entity holds a comprehensive Groundwater Data System that is immediately accessible for the purposes of developing groundwater management tools either at a national level or, ultimately, at regional level.

- In the context of regional activities, accessibility to and dissemination of groundwater information is extremely important, as this will hugely contribute to ‘awareness education’ in the value of groundwater and related data. It is apparent that a totally Web-based approach will probably not be either operable or appreciated by the potential end-users due to problems of Web access.

### 5.1.6 Institutional Capacity

- It is apparent that the role and effectiveness of Member State national institutions in charge of groundwater has changed with time in response to the demands of increasing populations and changes in the objectives and institutional philosophy of regional and international organisations and initiatives.

- Privatisation and decentralisation of government roles have resulted in involvement by contractors, consultants and NGOs in groundwater development programmes largely at the insistence of international funding agencies. Increasingly, these agencies undertake groundwater development and are therefore theoretically the main generators of groundwater resources data leaving the government departments in a supervisory role.

- University and technical/scientific institutions require national and regional knowledge of groundwater resources as the basis of geological and hydrogeological education in the region. Additionally, government research bodies develop aspects of this knowledge, especially the role of groundwater during periods of drought. Thus, although these institutions contribute to the management of the resource via knowledge they are not responsible for groundwater development, and therefore how and from whom do they acquire the data to develop this knowledge? .

- Decentralisation of government development and operational activities has fragmented groundwater development and management so responsibilities for data gathering, archiving and evaluation are often unclear. In addition, effective decentralisation of departmental functions is limited by the availability of experienced professional staff and inability to provide communications, staff, vehicles and equipment. Greater use of international and national NGOs and consultants has also resulted in government staff moving to the private sector with loss to government of hydrogeological institutional memory a situation worsened by the effects of the HIV/AIDS pandemic.

- Most if not all Member States possess some form of water law but many of these statutes make no specific reference to groundwater. Where comprehensive water legislation exists problems have arisen from the statutory definition of *public* and *private* water rights and how different government institutions interpret and apply the Water Law. Member States need to focus their water law not only on the development and management of groundwater sources but also on groundwater resources.

- The need for effective national regulation and implementing institutions in groundwater and drought related management issues is very clear but effective implementation is hampered by a shortage of sufficient numbers of competent staff. This may require short-term employment of expatriate personnel while additional national staff is being trained.

- There is a need for better utilisation of and co-operation between the limited number of training regional institutions to ensure maximum exposure of students to regional hydrogeological conditions and problems, possibly using the WaterNet model for academic training but with greater emphasis on hydrogeology. Similarly members of national institutions need greater exposure to the practicalities of groundwater development in adjacent countries to enhance professional training, research and joint management of shared aquifers.

- The question of the requirement for, and the location, establishment and sustainability of, a regional groundwater Commission/Institute has only been partly answered, in part due to a considerable number of complex inter-related issues related to capacity building and human resource/cost implications as well as the on-going SADC restructuring.

## 5.2 DEVELOPMENT OF GROUNDWATER MANAGEMENT TOOLS

One of the requirements of the study has been to assess the viability and possible usefulness of developing relatively simple tools that may help enable the future management of groundwater resources on a regional basis, with particular emphasis on drought.

A number of possible tools have been defined and discussed in Chapter 3. Clearly, a very important issue are the specific datasets that are required for the compilation of each of the map tools. Table 4 indicates the essential datasets that would be needed for the production of the map tools, and summarises which of these would be required for each map type.

It is clear from Table 4 that there is a certain degree of commonality between the maps and the datasets used in their production, with all maps requiring essential geological and recharge data. The former is generally available throughout the region, but the latter is considerably more problematical, generally fragmented and may require lots of assumptions to be nationally applicable.

With respect to actual development and usefulness of the potential regional groundwater management tools there are a number of crucial questions that may be immediately posed.

*Question:* Is the development of such tools possible in any meaningful manner given the hugely disparate status of the Member States with respect to basic data and monitoring abilities?

*Answer:* Based upon the present assessment it is apparent that the map tools discussed could possibly be assembled (and in some cases are already available) within a fairly short period of time at national level in a number of the Member States (Table 5) However, in some States the essential datasets that are required are not available and some considerable effort and time would be required to compile them. This situation is clearly very similar to that related to the preparation of the SADC Hydrogeological Map.

However, if it was considered sufficiently valuable and desirable in the short-term it is suggested that a preliminary version of some of the tools could be assembled at a regional level using broad-based continent-wide or regional information, tempered in certain areas by any suitable national data, in a manner similar to, or as a revision of, the GWAVA modelling approach to integrated water resources management. Tools so produced could then be updated as individual national inputs were developed, and may serve to provide an incentive for this to happen.

*Question:* How will the suggested tools contribute to the regional management of groundwater resources, especially with respect to drought and the alleviation of the seriously detrimental impacts that it inevitably brings?

*Answer:* It is assumed that the production of the various maps will be initially focussed at a national level, with the very fundamental benefit of bringing together a much available groundwater and groundwater-related data as possible into a composite and comprehensive national database, preferably in an ArcView environment. These data sets will then be available for many planning and analytical uses with respect to both overall national groundwater development as well as specific planning activities related to drought alleviation and intervention. These latter could involve important forward planning and ‘drought-proofing’ programmes to help minimise the effects of drought, in particular on rural communities in areas that are especially vulnerable.

Once such map tools can be assembled at a regional level, and an appropriate and a suitably widespread and reliable monitoring system is established, then they will need to be fully integrated with existing regional hydrological and meteorological monitoring systems such that, in its simplest form, information on the possible onset and hydrological impacts of a potential drought event can be utilised together with the groundwater tools to assess the potential direct effects on groundwater sources. This then will enable the regional 'knock-on' effects of a drought (food shortages, health problems, population migration etc) to be evaluated in advance such that intervention measures to minimise both the national and regional impacts of the drought event can be programmed.

# CHAPTER 6 –REGIONALISATION OF GROUNDWATER MANAGEMENT

## 6.1 COMMENT ON THE ECONOMIC AND SOCIAL VALUE OF GROUNDWATER

There are significant economic and social values associated with groundwater in most SADC member states (see Groundwater Dependency Summary below). First of all, **groundwater is extensively used for a range of productive and consumptive purposes. During** the last few decades, the use of groundwater for irrigation has increased considerably. Southern Africa is no stranger to this trend; groundwater now accounts for about 14% of the total irrigated area in Namibia, 18% in South Africa, and as much as 56% in Botswana (FAO AQUASTAT database). Apart from agriculture, groundwater is also an important input into small-scale production activities, such as brick making and brewing, that often contributes significantly to local employment and income generation.

**Groundwater Dependency Summary**

| Member State | Rural | Urban | Agriculture | Industry | Overall dependency |
|---|---|---|---|---|---|
| Angola | ** | ** | ** | * | ** |
| Botswana | *** | ** | *** | *** | *** |
| D R Congo | * | * | * | * | * |
| Lesotho | ** | ** | * | * | * |
| Malawi | *** | * | ** | * | ** |
| Mauritius | * | ** | ** | ** | ** |
| Mozambique | ** | ** | * | * | ** |
| Namibia | *** | *** | *** | *** | *** |
| Seychelles | ** | ** | * | * | * |
| South Africa | *** | ** | ** | ** | ** |
| Swaziland | ** | * | * | * | * |
| Tanzania | *** | ** | ** | * | ** |
| Zambia | ** | ** | * | ** | ** |
| Zimbabwe | *** | ** | *** | ** | *** |

Scale *** major, ** moderate, * minor

Botswana, Namibia and Zimbabwe are the most groundwater dependent countries in SADC. D R Congo is the least dependent on groundwater, being well endowed with surface water resources. All the other SADC nations are dependent to a greater or lesser degree on groundwater especially for rural communities. Small-scale irrigation using groundwater is set to increase in the near future.

Groundwater is often the primary source of domestic and livestock drinking water supplies in many SADC countries. It plays a very important role in maintaining human (and animal) health because it is usually of good quality and does not require much treatment to make it suitable for drinking. Groundwater sources, due to the ubiquitous nature of the resource, can be developed closer to the areas of habitation and, therefore, involve lower costs in terms of collection times for water. These costs are often borne disproportionately by women and children, leading to a loss of income-earning opportunities for women and lost schooling hours for children. They are also subject to deleterious health impacts from carrying heavy loads over long distances.

The use of groundwater for drinking water supplies is not restricted to rural areas. Many cities in the developing world are heavily dependent on groundwater for their municipal systems;

Lusaka is one such city in the SADC region. Many cities also have large peri-urban areas that may not be served by the municipalities, and are solely dependent on groundwater for drinking, sanitation and domestic purposes. In addition, urban areas also have a currently limited but growing utilization of groundwater for industrial purposes. However, the governing bodies of such groundwater dependent cities must become more aware of the threat of anthropogenic sources of pollution to the underlying aquifer systems.

There are several reasons for the widespread use of groundwater. They include the general availability and reliability of groundwater, the relatively low cost of developing it, and the fact that groundwater can be developed in a piecemeal fashion by individuals or small groups.

***Groundwater is reliable.*** As noted earlier, groundwater tends to respond slowly to changes in rainfall, and hence exhibit much less variability than surface water. The importance of an assured water supply to farmers cannot be overstated when one considers the risks they face when investing in costly agricultural inputs such as seeds, pesticides and fertilizer. Several studies have documented the importance of reliable supply to rural populations (see, for example, World Bank Water Demand Research Team, 1993). The reliability of groundwater also makes it a valuable buffer against drought, not just because of its impact on food security, but also because of the role it plays in maintaining the health and sanitation status of households and their small-scale production and income-earning opportunities (Calow et al, 2002). Experts predict that this buffering role will become even more important in the years to come, in the face of greater rainfall variability induced by global climate change (Burke and Moench, 2000).

***Groundwater is accessible.*** Not only is groundwater a fairly widespread resource, it is also relatively easy to access. To harness surface water for irrigation typically requires a lot of investment and capital; in contrast, farmers can access groundwater relatively easily and cheaply where beneficial aquifer conditions exist.

***Groundwater is cost-effective.*** This reflects the generally low levels of investment required to tap into groundwater sources. For instance, Burke and Moench (2000) point out that groundwater accounts for about 60% of the bulk water supply in Namibia, even though most of the water supply investment is tied up in surface water storage schemes.

***Groundwater is controllable.*** The spatial and decentralized access to the resource implies that the user is in control of it and this makes for its highly effective use. As a result, groundwater is a very attractive option for irrigation in developing countries, where shared surface water schemes often do not deliver water inputs in appropriate quantity and in a timely fashion. The flexibility and timeliness of water inputs, together with low variability in their application, means that land irrigated by groundwater is usually able to achieve higher agricultural yields. This is why the use of groundwater irrigation is not restricted to water-scarce regions, but is also observed in humid and water-abundant areas (Foster et al, 2000).

As discussed in Chapter 2 the **environmental value associated with groundwater** is often not given the recognition is deserves. Groundwater is the primary source of base flow in streams and rivers; it allows surface vegetation and wetlands to thrive; and it acts as a sink for the disposal of waste created by human activity. Putting monetary values on these functions is difficult, but there is little doubt about their importance to the economic and ecological cycles.

**Groundwater contributes significantly to the alleviation of poverty and community vulnerability**. Groundwater is widely used by people who are denied access to other water sources due to political, class or religious reasons, because it is a relatively inexpensive resource and can be accessed by individuals acting on their own or in small groups. Higher crop yields from groundwater-fed irrigation enable small farmers to generate surpluses and higher saving rates over time. The buffering role of groundwater during drought is very important from an equity point of view, since it is usually the livelihoods of the poor – those without a large asset base to fall back on – that are most affected by drought. Groundwater also makes it possible for poor people to undertake other more productive and income earning activities by enabling time saving in water collection. Moreover, when water does not have to be carried over long distances, people often use more of it, which has positive implications for sanitation and hygiene levels. Generally, the good natural quality of groundwater reduces the incidence of disease.

Groundwater contributes to rural livelihoods in a multiplicity of ways. However, water-related projects have tended to adopt overly narrow sectoral approaches in the past. Most interventions in the domestic water sector in the last three decades have focused on the need to provide safe water for domestic use, sanitation and hygiene. Concurrently, water resources have been developed for crop irrigation and for livestock watering, but there has been little or no coordination between the water supply and agricultural sectors.

Due to its narrow focus, the sectoral approach runs the risk of overlooking interventions that are possibly more complicated to implement, but can make a real contribution to poverty reduction. A case in point is that of collector wells – shallow hand-dug wells of large diameter that can support a number of uses, including domestic water supply and community gardening. Pilot experiments with collector wells have been very successful in Zimbabwe, among other countries, especially during periods of prolonged drought. Despite this, investment for further development has not been forthcoming. The main reason is that collector wells, by virtue of contributing to a range of possible uses, defy easy classification. Any one particular ministry is loath to make the sizeable investment, and the lack of coordination between ministries has resulted in lack of take-up.

**Estimating the Value of Groundwater**

Few formal attempts have been made to estimate the true value of groundwater in developing countries in monetary terms (Burke, Sauveplane and Moench, 1999). This is especially true of the ecological or *in situ* values associated with groundwater. Direct use values have fared better. In particular, several studies have been conducted to determine people's willingness to pay (WTP) for improved water supply systems.

In general, two kinds of approaches are used to determine WTP. Revealed preference approaches use data on people's actual water use behaviour (e.g. time costs of water collection or money costs of buying water from vendors) to arrive at their preferences for the good. Thus, revealed preference approaches are an indirect way of eliciting preferences for a good, since they use the actual choices made by people to reveal their underlying structure of preferences. Such techniques are usually more methodologically complicated, but have the advantage of being based on actual transactions and hence yield credible results. Stated preference techniques, on the other hand, represent a more direct approach to the problem. The most commonly used stated preference approach, contingent valuation, directly elicits preferences by asking people how much they would be willing to pay for a hypothetical improvement in water services. Contingent valuation is attractive since it is relatively simple to use. However, it is also subject to a number of potential biases, including the possibility that respondents may not give a seriously considered response when they do not actually have to pay for the good.

Both types of approaches have been used to arrive at estimates of WTP for safe water in developing countries. To illustrate the former, Mu, Whittington and Briscoe (1990) examine the water source decisions of rural households in Kenya and how they relate to socio-economic characteristics (including household income), while Whittington, Lauria and Mu

(1991) use data on costs of buying water from vendors to estimate the WTP for water in an urban area of Nigeria. On the other hand, Briscoe et al (1990) report the results of a contingent valuation study to determine the WTP for yard taps in rural Brazil, and Altaf et al (1993) also use the contingent valuation technique in the context of improved water services in rural Punjab, Pakistan.

Many WTP studies reveal the fact that, contrary to popular expectation, many households in developing countries actually pay a high cost for water (Whittington, Lauria and Mu, 1991). In recent times, this has led some governments and external support agencies such as the World Bank to promote what is often called a demand-responsive approach. Demand-responsive approaches argue that communities in developing countries should pay for improved water supply services, since public resources in these countries are limited, and providing water free of cost has traditionally resulted in very basic coverage, low quality of service, and inadequate funds for operations and maintenance (Briscoe et al, 1990).

Demand-responsive approaches are valuable in that they recommend water supply systems become self-financing, and hence less prone to the problems that hinder subsidized public services in developing countries. However, people may refuse to pay for water, not because of a lack of ability, but because of strongly held views about equity and the duty of government. It is also not clear that the demand-led approach will necessarily target the right people. WTP for improved water services depends not only on physical water scarcity, but also on socio-economic factors such as education and income (according to economic theory, both have the effect of increasing WTP). For instance, it has been observed that “people in the relatively wealthy, water-abundant region of south-eastern Brazil are much more willing to pay for improved water than people in the very poor, dry areas of southern Tanzania” (World Bank Water Demand Research Team, 1993). Finally, it is worth noting that, for households in developing countries, the issue of which water source to choose is often dominated by considerations of reliability, quality and convenience rather than price. In other words, consumers will not switch to public schemes merely because they cost less than their WTP; these schemes must compete on all of the above dimensions in order to attract customers.

In addition, in order to further address the issue of the value of groundwater, it may be necessary to introduce the concept of willingness to bear risk in areas where locating groundwater is difficult and the sustainability of often limited resources unknown. In areas such as northern Tanzania and southern Zambia, where comparatively low borehole drilling success rates are achieved despite low threshold yields, someone has to bear the cost of borehole siting and drilling at maybe two or three sites per locality before a ‘successful’ borehole is established. From current experience in southern Malawi it has been suggested that under the DRA scheme that exists there, where villagers themselves select the initial drilling sites, it is the villagers who should bear a proportion of the total costs so that they experience part of the risk of finding water. Although “successful” boreholes may be drilled in such areas this is no guarantee that such boreholes will be sustainable. By bearing part of the risk users can be made to realise that in marginal areas borehole yields may be unsustainable and sources can fail within a short period of time, an all too frequent fact that even the World Bank does not often fully appreciate.

## 6.2 POSSIBLE REGIONALISATION ISSUES

### 6.2.1 Perceptions of Groundwater as a Resource

The role and perception of groundwater in the national water supply strategy and planning of the individual Member States is overwhelmingly influenced by the availability and access to surface water sources i.e. by the ‘normal’ meteorological/hydrological regime resultant upon the location of the Member State in the Southern Africa region. In addition, and usually as a consequence of the above, the relative importance attached to groundwater is also influenced by the key decision makers, most usually engineers whose training conditions them to tap all possible surface water sources (that are both visible and hence reliably (?) quantifiable) rather than consider groundwater (which is neither visible nor easily quantifiable), as the main component of national water supply.

It is thus apparent that in countries where surface sources are plentiful, groundwater is poorly understood and managed, whereas in countries that have few potential surface water sources (e.g. Botswana, Namibia) groundwater resources play an important role, and thus hydrogeological data systems and knowledge are of necessity significantly better developed.

Apart from the above general comment about the importance of groundwater as a resource, it is also apparent that there are other factors that have influence on this issue. One of these is demography. i.e. the distribution and density of different population groups. In regions with populations having essentially arable agricultural traditions then apart from the overall density being generally higher the population is frequently well dispersed. This then requires a similarly well dispersed number of water sources for human consumption, which were traditionally surface or very near surface often unsanitary sources, but that have now become largely unacceptable in the global drive to improve the health of rural communities.

By comparison to surface water sources, groundwater resources are significantly more difficult to reliably quantify both in terms of useable volume, replenishment and hence longevity. These features often contribute to the reduced level of importance ascribed to groundwater in the financial decision making process related to national water supply, for why devote scarce budgetary funds on a resource that is not easily quantified and which will have minimal ‘visible development’ expression. This perception unfortunately has the ‘knock-on’ effect of realising minimal funding for vital groundwater monitoring, exploration and data gathering programmes, with the inevitable consequence that the nature and reliability of the resource is still poorly known when, in times of drought, it may contribute the only possible source of water for large sections of the population.

### 6.2.2 National Capabilities, Priorities And Aspirations

It has been apparent throughout this study (and previous studies) that there is a very large disparity between many Member States with respect to their ability to become meaningfully involved in regionally orientated programmes. The many and varied reasons for this have been detailed in several Chapters of this Final Report and they have also been expressed by many of the regional stakeholders from whom information has been sought, but they essentially come down to shortage of trained manpower, lack of funds and other material equipment and the weight of other national commitments and priorities.

In the case of persons in the employ of government institutions, who constitute the overwhelming majority of professionals in the groundwater sector in most Member States, it is understandable that national priorities related to their individual positions will inevitably have to take precedence over any regionally orientated activities, unless the importance and usefulness of such activities can be demonstrated and appreciated by senior management (and politicians?). In this situation the onus for promoting ‘regionalisation’ in the groundwater sector lies firmly with SADC and will form a key issue with respect to progress in this direction.

Although it is not always easy to judge and generalise as to what aspirations the many players in the groundwater sector in the Member States may have with respect to moving the 'regionalisation' process forward in their particular State, opinions have generally been positive towards SADC regional initiatives albeit tempered by the constraints and other priorities noted above. However, what is apparent is that most would aspire to 'putting their own house in order' before getting too committed or involved in regionally orientated schemes whose outputs and benefits are not yet altogether apparent.

### 6.2.3 Sectoral Integration

A major problem that has been highlighted during the search for information on the very broad range of groundwater-related topics to be covered by this study is a lack of integration or exchange of knowledge between the many different sectors of society and national development that either use or impinge on groundwater resources in some way except when responding to the effects of drought events. Under normal circumstances there is often no coordination with respect to groundwater development and consumption between different end users of the same groundwater resources (e.g. agriculture and urban supply), with a consequent potential loss of data, duplication of technical effort and hence wastage of funds, as well as the potentially detrimental affect the resource itself.

A similar situation frequently exists between the various developers of groundwater resources, which may include national/regional government, NGO's, private individuals and donor programmes all active in the same area developing the same resource. Again, lack of coordination, correct procedures (ref SADC Code of Practice) and knowledge exchange may be detrimental to the resource as well as to the nation in terms of data loss and potential waste of financial resources.

Also contributing to this lack of integration and coordination is the obvious polarisation of different components of the Hydrological Cycle (e.g. meteorology, hydrology, hydrogeology). Virtually all studies or projects undertaken in the water resources sector are severely focussed on one of these components with little if any emphasis or serious consideration of either of the other components, which by definition are part of a cycle in which all parts in some way influence the others. Even larger water resources programme that do attempt to integrate all the components of the Hydrological Cycle are rarely established in such a manner as to take the completely holistic approach that could result in a more comprehensive understanding of groundwater resources, their relationship to different ecosystems and their behaviour with respect to drought.

It is clear from our investigations that greater coordination and interchange between groundwater users as well as groundwater developers will help in the efforts that must be made at national level to improve the knowledge and hence maximise the benefits of groundwater resources both on a 'regular' basis and, more especially, during periods of drought.

A more holistic approach to major water resources programmes would also assist in disseminating groundwater information across various technical sectors, with a greater spread of knowledge then potentially available to water resources decision-makers.

Taken together any positive progress on the issues noted above will certainly help individual Member States progress along the route towards greater knowledge of their groundwater resources and hence improved integrated water resources management. In addition it would undoubtedly assist in harmonising IWRM approaches on a regional basis.

## 6.3 ESTABLISHMENT OF A REGIONAL GROUNDWATER INSTITUTE/COMMISSION

The very disparate approaches and establishments in the various Member States to the different aspects of groundwater development and management, generally governmental or parastatal in nature, serve to seriously complicate the comprehensive and compatible data gathering, archiving and evaluation that is needed to form the basis of any regional planning and management structure (Section 2.6). There are a number of technical and scientific institutions in Member States that serve both as centres of knowledge and as well as education in the groundwater sector, but that are not actually central to the mainstream groundwater management system. Neither of these different types of bodies would appear to be suitable candidates in either structure or outlook to take on the role of a regional groundwater management establishment – the former are too nationally focussed and structured and the latter are generally too academic and research orientated.

Since coordination of groundwater management and its most effective utilisation with respect to drought and poverty alleviation throughout the SADC region is a stated policy then the establishment of a separately constituted Regional Groundwater organisation may well be the most appropriate way forward. The early establishment of such an organisation would also ensure that maximum benefit in terms of data and results would be gained from all the proposed components of the upcoming GEF Project as a result of improved management and coordination of the Project as a whole.

It is quite possible that the existing River Basin organisations (RBO's) could be expanded/strengthened to undertake this role, as their mandates already cover all water resources (surface and groundwater). An obvious drawback to this would be that groundwater resources are frequently not 'hydrological-basin' bounded (i.e. there are numerous trans-basin aquifers) although adjacent RBO's could establish some form of management agreement in this respect. In addition, there are large parts of the SADC region where RBO's are not established, and may not be so for some time to come.

From examination of SADC documentation and discussions with SADC personnel it is understood that although the RBO's have a resource management mandate within their own hydrological basin but that essential (hydrological) data acquisition and evaluation that feeds this management role is undertaken by the separate and fully regional Hydrological Cycle Observing Systems (HYCOS) project. HYCOS coordinates and utilises data provided from a number of key hydrological monitoring points throughout the region, with the responsibility for operating and maintaining individual data collection stations incumbent on the Member State in which the stations are located, thus promoting sustainability of the system. RBO's then pass management information to the central SADC coordinating unit (formerly SADC WSCU, now SADC Water Division) who are mandated to provide regional coordination and strategic planning.

A Regional Groundwater organisation could be similarly structured but what is crucially missing is the vital regional data gathering/evaluation (monitoring) system. As noted earlier (see Section 2.4) groundwater monitoring exists to a greater or, more usually, lesser degree in many Member States, but is frequently under emphasised, under staffed, under funded and limited in both time and space. This issue of critical data gathering/ evaluation (monitoring) would thus need to be addressed by implementation, stimulation and coordination of such activities in the majority of the Member States before any regional groundwater resource management could hope to function. At this stage, and without an exhaustive and in depth assessment, it is considered that this requirement may be more efficiently and cost effectively organised by a single regional body that is also mandated to undertake the resource management role, i.e. by a composite Regional groundwater organisation or authority.

It is noted that the ToR use the term 'Regional Groundwater Institute/Commission'. However, although the title of such an organisation is largely a matter of semantics the following comments are offered:

- It is considered that the term 'Groundwater Institute' should not be considered as this has research and academic connotations and thus could be seen to impinge upon the roles of such existing institutions in the SADC region.
- Similarly, the title 'Groundwater Commission' may not be totally applicable and could be confusing, dependent on the envisaged role and structure of the body vis a vis the role of existing bodies (River Basin 'Commissions').
- An alternative title such as 'Regional Groundwater Authority' may be appropriate.
- Whatever the eventual choice of title for the regional body it is essential that its mandate and actual role fit into the re-structured SADC establishment in a manner that makes the new organisation a focal point of groundwater information and management in the region.

It is believed that to be fully effective as a regional groundwater management agency a Regional Groundwater organisation should:

- Be located in a suitably enabling environment providing adequate support services, accommodation and communications, and preferably having significant Member State public (and private) sector groundwater knowledge and awareness.
- Be appropriately staffed and funded. This implies a permanent establishment secretariat and a sufficiently large cadre of technical professionals to effectively undertake the regional role.
- Have an essential brief to initiate/stimulate groundwater monitoring activities as well as to coordinate/receive/evaluate all groundwater data (historic/monitoring) from Member States.
- Develop and hold a comprehensive regional groundwater database as well as develop and manage a regional groundwater information system. *However, since 'ownership' of data is still problematic this matter should be debated further.*
- Provide a regular synopsis of the status of regional groundwater resources, both specific to individual Member States and for the region as a whole.
- Contribute to the development of early warning and coping strategies with respect to the usage and management of groundwater in the SADC region during drought.
- Act in an advisory and facilitating role with regards to both individual Member State and overall regional groundwater development policy and implementation by providing necessary support to the SADC Water Division.
- Interact closely with the existing River Basin Commissions and other SADC bodies already established (e.g. Drought and Remote Sensing Units; Disaster Management Unit etc) to facilitate an overall IWRM approach within the region.
- Establish and coordinate individual Transboundary Aquifer Management Committees in order to directly involve individual Member States in specific bilateral or multi lateral groundwater management issues.
- Relate directly to the overall SADC Secretariat via the SADC Water Division established during the SADC Re-structuring Programme.

On the matter of sustainability it is suggested that since the proposed new organisation is designed to be truly regional then financing for the establishment and secretariat of such a Regional Groundwater body ought to be provided directly from SADC, with additional support for technical staffing sought from Cooperating Partners and other international donors. However, in order to bring about the formation of such a body, that would play an important role in the upcoming GEF Project, it is also possible that an international groundwater agency or major consultant company would have to be involved to facilitate establishment and operation of the organisation for a period of time until a regionally constituted staffing structure can be developed.

The crucial regional groundwater monitoring network could also be approached in the same manner as HYCOS, with donor funding sought for its initial establishment and/or strengthening and then individual Member Sates responsible for the operation and maintenance of their own segment of the system. In some cases this latter may also require international donor assistance to particular Member States to facilitate adequate technical capacity building and hence ensure long-term continuity.

## 6.4 KEY FACTORS TO BE CONSIDERED

As a result of the Regional Analysis study it is apparent that there are a number of specific issues pertaining to the development of groundwater resources management tools for use in predicting and alleviating the impacts of drought, as well as to the wider issue of the regionalisation of integral groundwater management, that need to be addressed in the formulation and execution of the upcoming GEF project if progress is to be made towards the realisation of SADC aspirations with respect to IWRM.

It is not an easy task to itemise all such issues, as many are cross cutting and appear in several sections of this thematic Final Report. However, what are considered the most crucial factors are noted, critically appraised and commented upon below.

- **Level of Essential Knowledge in Member States**

As has been identified by this and previous SADC studies, the actual level of knowledge (i.e. existence of adequate data sets) of groundwater resources and their quality, replenishment and behaviour under drought conditions is, in a large number of Member States, unacceptably low for the purposes of reliable quantitative and spatial evaluation. In addition, the relative level knowledge between Member States is hugely disparate and will have very significant impact on the development of regionally applicable groundwater management tools.

- **Level of Technical Capacity in Member States**

This crucial issue is closely linked to the former and has similarly been previously identified. It is obvious that in the absence of adequate numbers of appropriately trained (and experienced) personnel any data gathering and evaluation systems that may be in existence, or that may be proposed, cannot function to the level that will be necessary to initially develop groundwater management tools on a national basis, let alone develop and integrate such tools at regional level. Shortage of indigenous personnel at all levels is apparent in many Member States, and in the past two decades have been exacerbated by economic decline (lack of funding for training, salaries etc), conflict (insecurity; personnel exodus etc) and the HIV/AIDS pandemic (staff mortality; diversion of national funds to the health sector etc).

- **Appreciation of Groundwater as a Vital Resource**

As noted earlier, it is apparent that the attitude of many decision-makers, and even other technical cadres, towards groundwater resources is often not positive, largely due to a lack of knowledge and appreciation of the potential strategic and crucial role that groundwater can play in national water supply provision, most especially during periods of drought.

At the other end of the scale, at the rural community level, it is apparent that appreciation of the value of groundwater is much greater. The rural community user group is undoubtedly acutely aware that groundwater can provide a more hygienic, reliable and accessible water supply to a burgeoning and frequently dispersed population than any other supply alternative, and that groundwater, if properly developed and managed, can usually continue to support them during drought periods when other hardships are greatest.

It is thus important that the appreciation of the value of groundwater found at the lowest consumer level is inculcated into decision makers at all levels, most especially at the top, if groundwater development and management is to be improved and the need for appropriate management tools at national (and regional) level is fully supported.

In addition, such appreciation also needs to be clearly communicated to decision makers and translated into the development or revision of national water policy in many Member States for regionalisation to become a fact.

- **Improved Interaction between Groundwater Developers and Users**

It is apparent that the interaction and coordination between the many 'players' in the groundwater scene is often not good. Improvements in this respect will thus be important if levels of data capture and use of frequently limited technical capacity and finances are to be optimised, if most beneficial use is to be made of the regions groundwater resources, if the proposed management tools are to be effectively utilised, and if integrated water resources management is to be realised.

From a regional perspective it is also clear that all these factors will be contributory to the eventual 'regionalisation' of water resources management throughout SADC.

- **Sustainability of Systems and Initiatives**

Evidence from the current study indicates that in many Member States the ability to sustain even the groundwater data gathering archiving and evaluation systems that are now in place is often severely limited by shortage of funds and trained manpower. The exceptions are situations when donor agencies of various types support the groundwater sector with both finance and expertise, which may provide excellent results in the short term but generally does little to enhance long-term sustainability. There are, however, some Member States such as Botswana, South Africa and Namibia (due to their more favourable economic status and their inherent greater dependence on groundwater resources) that have groundwater data capture and management systems that have been developed and sustained over a long period, and whose experiences may be useful elsewhere in the region.

It is thus clear that if the sustainability of existing groundwater data gathering and evaluation systems is in doubt, then the sustainability of any new initiatives from the regional perspective will undoubtedly be in greater question in the case of many Member States. In a situation of limited finance and capability it is not unreasonable to assume that priorities will be focussed nationally rather than regionally, and thus for any regional initiatives to succeed there will have to be a clear demonstration of benefits as well as adequate technical and/or financial support.

- **Regional Coordination of Initiatives**

If initiatives geared towards the establishment of regionally based groundwater management are developed and instituted under the upcoming GEF Project then it will be imperative for their sustainability and success that an adequate and robust coordination and monitoring system is established on behalf of the SADC organisation. Such a body should have sufficient technical capacity to provide advice and to coordinate the activities of national implementers and/or other nationally based implementing bodies (consultants/donors), as well as those of any regional implementing agency that is selected for the various components of the GEF programme.

The current SADC coordination unit appears to be substantially occupied with the whole of the water sector in the region, including SADC administrative matters, conferences etc, and, although we stand to be corrected, would thus appear to be inadequately equipped to effectively execute such a task.

Without this strong 'SADC coordination' to form the focal point of the drive towards regionalisation it is difficult to see, given the short comings and difficulties at national level, how any real impetus can be maintained or SADC aspirations satisfied.

If this issue is not adequately addressed prior to the commencements of the GEF project it is considered that the risk to project success can only be increased.

- **Groundwater Policy and Regulation Development Aspects**

Although not part of the mainstream review activities it has become apparent during the survey of Member States that policy, legislation and regulations pertaining to the management of groundwater resources is in many States extremely old, scattered through various legislative articles, out of line with national/international environmental views, and is sometimes almost non-existent. The attempt to regionalise management of groundwater resources under the auspices of SADC will thus be difficult in the extreme unless there is some rationalisation and harmonisation of the basic tenets of water, and particularly groundwater, laws and policy in Member States throughout the SADC region. Clearly, individual Member States will have national water law requirements that are specific to their own circumstances and political and legislative structures, but efforts need to be made towards the harmonisation of some of the fundamentals of such laws as a common foundation for many of the other aspects of regional water resources management.

This issue is one of considerable importance if regional aspirations are to succeed, and is currently being addressed under a suite of projects forming part of the Policy and Legislation grouping of the SADC Regional Strategic Action Plan (RSAP) for the water sector. Specifically, Project AAA.9 titled 'Guidelines and Support for National Water Sector Policy and Strategy Formulation or Review in Member States' is reviewing existing water policies and strategies, is synthesising the results and is to provide guidelines for development of sound national policies to promote improved IWRM.

## 6.5 A POSSIBLE STRATEGY FOR THE GEF PROJECT

The following several points that result from the investigation and review undertaken during the current Regional Analysis represent the Consultants considered opinion with respect to possible strategic issues that should be seriously considered in the planning and formulation of the upcoming regional GEF Project.

- From a regional perspective it is believed that GEF Project emphasis and initiatives should be on further **defining** the **minimum requirements** required to produce **meaningful management tools** with respect to groundwater and drought, pollution and ecosystems and **implementing and supporting** such requirements (e.g. monitoring, data gathering and synthesis, GIS and manpower capabilities) **at individual Member State level** where this is necessary for such tools to be developed and utilised.

- A key regional role should also be on **dissemination of knowledge** (e.g. a Groundwater Information System including a document/project inventory) between Member States such that **all are aware of groundwater activities within the region** and can **share in the results, experiences and resultant benefits** of such activities on an ongoing basis**.** Similarly, there should be **dissemination of experience and expertise** between Member States that have relatively well developed groundwater sectors and those who do not, such that the latter can benefit and avoid too many pitfalls during their own accelerated development phase. Both these contexts will create a crucial enabling environment for SADC build both individual and national **interest and confidence in 'regionalisation' of the groundwater sector** and the benefits thereof, as well as an increased appreciation of the importance of groundwater in all aspects of national and regional sustainable development.

- It is believed that there is a definite need to **initially focus 'Nationally' rather than 'Regionally'** in an effort to gather and compile essential data, institute monitoring, build capacity etc in an effort to try to **'Level the playing field'** between the various SADC Member States. It is strongly believed that **regional systems and initiatives** will be impossible to develop and sustain if **national systems** are not first established and functional **to a reasonable level and consistency** throughout all of the SADC Member States.

- **To stimulate and drive forward the concept of 'regionalisation'** in the water (and particularly the groundwater) sector **a strong and dynamic regional 'prime mover' will be required** in order to motivate and coordinate the efforts of individual Member States and relevant organisations within them. This could be achieved by the strengthening and more active technical participation of the existing SADC Water Division (formerly SADC WSCU), or by the establishment of a separate and more substantial Regional Groundwater organisation (as outlined in Section 6.3), or by both. **In the absence of such a 'prime mover' it is difficult to see the current overall consensus between the Member States on the desire for regionalisation of groundwater management translating into genuine positive movement along this route.**

- **It is therefore proposed that SADC should concentrate many of the components of the upcoming GEF Project on adding to and/or sponsoring individual national programmes and other attempts to improve national level activities, but with some considerable effort dedicated to the development of a stronger, regional motivating and coordinating body (or bodies) within the SADC structure if there is to be any real hope of developing and implementing a sustainable regional groundwater management policy.**

# CHAPTER 7 – CONCLUDING STATEMENTS

Under the Terms of Reference and from subsequent pre-contract meetings this Regional Situation Analysis study has a very wide-ranging brief and has required the assessment of many diverse topics related to groundwater data and monitoring, drought, pollution, groundwater dependent ecosystems and institutional matters, with the ultimate intention of determining the feasibility of assembling a meaningful set of regional groundwater management tools.

A large volume of information has been gathered and many documents reviewed, but the limited time frame and project capacity has, unfortunately, precluded a fully comprehensive evaluation in each Member State of all the aspects mentioned in the Terms of Reference and also subsequently considered desirable by the Client. Certain topics, in particular those issues relating to institutional matters, capacity building and water resources policy/regulations, will thus require additional research if this is considered necessary.

It was not considered part of the study brief, or particularly beneficial at this time, to collect basic (numeric) groundwater data or databases from the region. However, in order to minimise the volume of the Final Report the information that has been gathered during the study has been compiled into an extensive thematic bibliography and made available with the Interim Report on CD-ROM.

In order to cover the range of topics and try to provide a clearer regional assessment the report has been arranged in a 'thematic' rather than a 'country report' manner. Each of the principal themes has been discussed with respect to their role and status in the groundwater sector in the region (Chapter2), and a small number of possible management tools have been defined and compilation explained (Chapter 3). The review of the status of essential datasets required for the creation of such tools in each of the individual Member States is presented in a series of Information Boxes (Chapter 4), with a subsequent summary of the regional situation with respect to the principal themes and the proposed management tools (Chapter 5).

Finally, a number of issues that the Consultant believes are important with respect to the SADC aspiration of regionalisation of groundwater management and other related matters are presented for consideration, and are integrated into a possible strategic approach to the upcoming GEF Project (Chapter 6). Potential components that could be included in the design of the GEF Project are thereafter set out in Annex A.

During the study the general impression gained from the Member States was one of overall support for the 'regionalisation' concept, but views were expressed that the possible tools ought initially to be developed nationally such that immediate and local benefits are apparent before being assembled into a regional scheme. Previously voiced concerns about 'ownership' and use of national information in such a regional scheme plus the organisational establishment required to successfully maintain it have also been apparent, and will have to be satisfied if the 'regionalisation' concept is to move forward.

A final but significant comment relating to the overall and highly laudable SADC concept of regional Integrated Water Resources Management that is envisaged to assist in the alleviation of the impact of natural disasters (droughts, floods, pestilence), facilitate economic development, improve the quality of life for the population of the SADC region and to avert the possibility of future conflict over scarce resources is that many of the issues raised and potential solutions/ideas proposed in this report (and by other similar reports) would be greatly facilitated if a formal SADC 'Regional Water Resources Protocol' specifically targeted at **all water resources** in a broad and all-encompassing sense could be developed.

Such a Protocol could be similar to, be amalgamated with, or developed from the Revised Protocol on Shared Water Courses, which is limited by its overwhelming emphasis on surface water resources, and would fully commit all Member State signatories from the highest level and as a matter of policy to the regional water resources management goal, as well as all the attendant aspects of this that will require implementation before this can be fully and equitably achieved.

# ANNEX A

# POSSIBLE GEF PROJECT COMPONENTS

In preparing this Annex there are a number of important assumptions that will have to be made with respect to the planning of the upcoming GEF Project. These assumptions are made on the basis of the findings of the Regional Situation Analysis study, but are in no way meant to imply failure of, or to be derogatory to, the national groundwater management institutions in any of the Member States.

These assumptions are:

- **All components of the GEF Project will have to be supported by external expertise (i.e. Consultants or International Institutions) if they are to have the required outcome and be successful.**

- **Although all components will have to be based in and be supported by national institutions as Implementing Agents it is apparent that there is almost certainly inadequate capacity (manpower, facilities, time/financial capability) at national level (except possibly in South Africa) to undertake any component in its entirety.**

In order to assist in the formulation of the GEF Project Proposal three Primary Components that address what are considered to be the priority issues of Groundwater Management Tools, Groundwater Knowledge and Awareness, and Integrated Water Resources Management have been defined. Each of these Primary Components has within them a number of Sub-Components that deal with specific aspects that are considered contributory to the Primary Component. Sub-Components are described in outline in terms of likely activity requirements and the rationale for the work, and a possible time frame and cost estimates are also presented in Table A1. It must, however, be cautioned that Table A1 contains only very preliminary budget figures for general guidance only, and could change considerably when the Primary or Sub-Component is more fully detailed in the GEF Project Proposal itself.

This listing of possible Project Components differs somewhat from that contained in the earlier Interim Report as the result of discussion and input from SADC Technical Committee Members and other parties at the presentation meeting for the Interim Report held in Gaborone in ---- 2003.

## PRIMARY COMPONENT 1

### Development and Application of Groundwater Management Tools.

This component is seen as the principal output required from the upcoming GEF Project, and will involve the further definition of the most appropriate tools, the establishment of data collection systems for their production and updating, the production of such tools on a pilot basis, and the integration of many aspects of this process into other ongoing (or planned) SADC projects (e.g. production of a SADC Hydrogeological Map).

### Sub-Component 1.1 Define and Implement Minimum Monitoring Requirements

- Using the SADC Code of Good Practice define minimum groundwater and groundwater-related monitoring standards for the SADC region, including optimum and practical monitoring scenarios for each parameter and basin/aquifer type.
- Gather all information on existing monitoring networks on national basis, including type and distribution of network, equipment details and data gathering frequency.

- Compare/optimise existing networks with minimum standard requirements and propose modifications/additions.
- Initiate regional network establishment; demonstrate equipment
- Define data gathering and storage procedures and QA controls.

*Rationale: to facilitate the establishment of monitoring networks were they do not exist, and to upgrade/expand existing networks, in order to provide for comparable and compatible time-series data collection throughout the region for the purposes of future updating of groundwater management tools*

**Sub-Component 1.2 Enhance Baseline Data Gathering, QA and Archiving**

- Comprehensively assess the methodology and approach to essential groundwater data gathering in each Member State, in line with relevant recommendations contained in the SADC Code of Practise for groundwater works.
- Define a standardised equipment and procedure for data collection and storage (at different levels i.e. field, district, national).
- Propose improvements wherever necessary to data gathering and QA procedures, including hands-on training if required.
- Examine and propose improvements to national data archiving systems, including digital database establishment where necessary. Possibly to include equipment and training.

*Rationale: to initiate/modify data collection procedures to ensure the gathering of comprehensive and reliable groundwater data that is fundamental to the development and upgrading of any national and regional groundwater management tools.*

**Sub-Component 1.3 Upgrade Spatial Data Processing (GIS)**

- Review the GIS capabilities of the various institutions responsible for groundwater data archiving and evaluation in each Member State, including personnel and equipment and basic communication technologies such as telephone line capacity and internet access.
- Assess the needs of the various Member States in respect to GIS facilities, keeping in mind the optimum regional situation of commonality of approach and technology as well as the potential requirements for the Hydrogeological Map programme.
- Identify short-term interventions in terms of equipment and training that will assist Member States in the field of GIS-based data processing.
- If possible, establish a programme designed to assist in the production of the proposed groundwater management tools at national level.

*Rationale: to provide the appropriate technological platform in all Member States that will be essential if groundwater information is to be manipulated and utilised in the form of management tools at both national and regional level.*

**Sub-Component 1.4 Develop Groundwater Management (Mapping) Tools on National Pilot Scale**

- Identify a suitable ‘pilot’ candidate Member State for management tool development, possibly on the basis Table 5.
- Re-verify the status of the necessary data sets in the pilot State, plus identify and ascertain the capacity of the national institution that would constitute an implementing partner.
- Design an implementation programme and input any necessary technical assistance and equipment that may be required to develop the mapping tools.

- Execute the development and report on outcomes, difficulties, constraints etc to the SADC regional body.

*Rationale: to test the level of assistance that may be required to produce useful groundwater management tools in a non-ideal situation in which datasets are incomplete and possibly fragmented.*

## PRIMARY COMPONENT 2

### Prioritising Groundwater as a Regional Resource

The second Primary Component proposed for the GEF Project is intended to raise the awareness of and prioritise groundwater as a fundamental and very critical resource with respect to sustainable development, or even existence, of much of the population of the SADC region. In order to promote management of the resource at all levels it is imperative that all stakeholders (users, suppliers, decision makers etc) are informed and empowered by the transfer of information and knowledge, and that the importance as well as fragility and limitations of groundwater resources not just in times of crisis (drought in particular) is emphasised. The myth commonly accepted by a majority of non-technical and non-groundwater related people that 'groundwater is everywhere, is always available when required and is constant' must be dispelled if effective and highly essential management is to succeed.

This Component should, however, be carefully considered and planned such that its Sub-Components are harmonised or integrated with other ongoing or planned SADC projects in order to avoid duplication of effort or conflict of approach.

### Sub-Component 2.1 Establish a Groundwater Information System

- Gather information on previous/ongoing groundwater work on a national basis. Should include information type and spatial coverage
- Gather information from publications/consultant studies/donors
- Compile into national information sets, by area, subject etc
- Compile national spatial distribution maps of information coverage
- Build Meta Databases nationally and regionally
- Disseminate information to national/regional groundwater practitioners via Web (existing networks) or actual CD's
- Establish update mechanism for database

*Rationale: to facilitate the spread of groundwater knowledge in the region, to encourage and enhance regional interaction and cooperation, to allow all practitioners to view the 'broader picture'.*

### Sub-Component 2.2 Develop and Implement a 'SADC Regional Groundwater Awareness' Campaign

- Determine the requirements and scope of the proposed awareness campaign in the different Member States.
- Establish the most appropriate media and mechanisms for raising groundwater awareness and disseminating information to all players, including the Web, newsletters, technical documentation, the mass media etc.
- Establish indicators and anticipated outcomes of such a campaign
- Implement an awareness campaign throughout the region, possibly piloting the approach in certain Member States.
- Provide a full evaluation of the success of the campaign to SADC.

*Rationale: to investigate the requirements and options for the planning and implementation of a campaign aimed at raising the awareness of all 'players' in both the government and private groundwater sector (NGO's) to the importance of groundwater in sustainable regional development and drought alleviation, and most particularly to the crucial needs for adequate information and reliable data.*

**Sub-Component 2.3 Develop a Common Approach to the Assessment of the Socio-economic Value of Groundwater in the SADC Region**.

- Synthesise all existing information on socio-economic assessments of groundwater in the region.
- Evaluate previous approaches used at national level in the Member States.
- Undertake appropriate data collection surveys in a selected pilot area (probably the Limpopo Basin).
- Develop and recommend methodologies that may be adopted in order to provide a common approach to the assessment of the socio-economic value of groundwater in the SADC region.

*Rationale: to provide a mechanism that may be used to quantify the value of groundwater throughout the region such that there is a common basis for management and allocation of shared resources.*

## PRIMARY COMPONENT 3

### Towards IWRM in the SADC Region

The third Primary Component proposed for the GEF Project is designed to contribute towards the development of a suitably enabling environment for the advancement of the underlying SADC objective of Integrated Water Resources Management in the region.

Within this Component there are a number of more generalised and cross cutting issues that may not appear to be directly related to the main themes of groundwater management tools, or groundwater and drought, but which must be addressed if these specifics are to be tackled within the framework of regional resource management. They include human resources assessment and capacity building, national and regional groundwater policy and regulations, establishment of a regional groundwater organisation (a 'prime mover'), and initiation of the development of a new or revised SADC Protocol dealing with both groundwater and surface water resources.

Again, in developing these Sub-Components into a GEF Project proposal cognisance must be taken of other ongoing or planned SADC projects that either directly cover or impinge upon the outline objective/activities presented here (e.g. current RSAP projects on policy development), and it may be necessary to modify or abandon them accordingly. They are, however, presented for the sake of completeness with respect to the topics covered by the study.

**Sub-Component 3.1 Capacity Building and Training**

- Undertake a Skills Audit throughout the region with respect to the groundwater sector.
- Identify critical skills deficits and training needs
- Review training capacity in the region and liase with training institutions on requirements.
- Examine the feasibility of intra-regional skills transfer and training incorporating some form of personnel secondment under SADC auspices.
- Recommend (and initiate?) a way forward with respect to improving the technical capacity within the SADC groundwater sector

*Rationale: to fully establish the overall regional skill capacity in the groundwater sector, and to propose interventions designed to improve the situation wherever necessary.*

**Sub Component 3.2 Identify/Strengthen Potential Implementing Institutions and Existing SADC Regional Units**

- Identify potential implementing institutions for the various components of the GEF Project.
- Assess the technical and administrative capacity of these institutions in the light of Project requirements, and advise on capacity-building measures.
- Recommend and implement possible capacity-building activities, possibly to be initiated as part of the other Project components.
- Review the role and coordinating capacity of SADC Water Division in relation to GEF Project implementation.

*Rationale: to evaluate the capacity of potential national or regional SADC implementing institutions to provide the basis for GEF Project execution and strengthen this capacity to become adequately involved in the process. In addition, examine and advise on the coordinating capacity of the SADC Water Division in the light of major project implementation.*

**Sub Component 3.3 Investigate and Initiate the Establishment of a Regional Groundwater Organisation**

- Undertake a detailed assessment of Member State views and recommendations for a Regional Groundwater organisation.
- Develop a mandate or charter for the proposed organisation, including relationship with existing SADC bodies and staffing/planning/financial aspects for an initial period of 5 years.
- Identify an enabling environment and physical location for the proposed organisation, including logistic requirements (offices, communications, IT set up etc).
- Investigate and recommend an appropriate and sustainable financing approach, including possible initiation by an international groundwater agency or consultant.
- Investigate need for a centralised regional groundwater database and information system to be held by the organisation, and define the possible structure and modus operandi of such a database/system.

*Rationale: to initiate the establishment of a specific regional groundwater organisation that will initially assist SADC Water Division in the successful implementation of the GEF Project, and that will also constitute the essential 'prime mover' for the development of IWRM and all its various aspects throughout the SADC region.*

**Sub Component 3.4 Contribute to the Development of Guidelines for National and Regional Water Policy**

- If still ongoing, contribute to the outputs and recommendations of RSAP Projects 9 and 10.
- If completed, review the results of RSAP Projects 9 and 10 with specific reference to groundwater and it's crucial inclusion in water policies.
- Undertake a review of regional groundwater legislation, regulations and legal instruments.

*Rationale: to ensure that the crucial regional importance of groundwater is suitably encapsulated in both national and regional guidelines and hence ultimate water policy and legislation.*

**Sub Component 3.5 Initiate the Development of a SADC Protocol on Water Resources**

- Undertake a detailed assessment of Member State views and proposals that could contribute to a formal SADC Protocol on Water Resources.
- Assess other similar international water protocols and agreements in place elsewhere

- Develop a framework for such a Protocol, including key issues of content and linkages with other SADC Protocols, especially the Revised Protocol on Shared Water Courses.
- Recommend a Draft Protocol on Water Resources for Member State discussion and further development and clearance by the SADC Legal Affairs Sector.

**Concluding Comments**

The three possible Primary Components presented above are what the Consultant would currently consider are those that will address virtually all the topics mentioned in the Terms of Reference for the present study, and which will contribute significantly to the regionalisation of the groundwater sector and the development of IWRM in the SADC region. The Primary Components are set out 1 through 3 in order of priority with respect to the requirements Terms of Reference, with Primary Component 1 setting out what initially and essentially needs to be done to move towards the development of regional Groundwater Management (Mapping) Tools.

The listing of Sub Components for each Primary Component is set out only in outline and is definitely not exhaustive, and each will require substantial amplification before they can be integrated into the GEF Project Proposal.

Critically, many of the proposed Sub Components recognise that at this stage it is very apparent that it will not be possible to ‘jump straight in’ and realistically and successfully execute them on a fully regional basis, and that in particular for Primary Component 1 to be eventually useful AND reliable a staged approach initially concentrating at a national level will almost certainly be necessary.

# Possible GEF Project Components and Input Estimates

| Primary Component | Sub-Component | Title | Time Frame (months) | Prefered Implementer | Man Months (months) | Team Size (No. persons) | Cost Estimate US$ |
|---|---|---|---|---|---|---|---|
| **1** | | **DEVELOPMENT AND APPLICATION OF GROUNDWATER MANAGEMENT TOOLS** | | | | | |
| | **1.1** | Define/Implement Minimum Monitoring Requirements | 12 | Cons. | 18 | 3 | 504,000 |
| | **1.2** | Enhance Baseline Data Gathering, QA and Archiving | 24 | Cons. or Int. Inst. | 30 | 4 | 840,000 |
| | **1.3** | Upgrade Spatial Data Processing (GIS) | 12 | Cons. | 12 | 2 | 336,000 |
| | **1.4** | Develop Groundwater Management (Mapping) Tools on National Pilot Scale | 12 | Cons. or Int. Inst. | 36 | 4 | 1,008,000 |
| | | Sub Total Cost (Primary Component 1) | | | | | **2,688,000** |
| **2** | | **PRIORITISING GROUNDWATER AS A REGIONAL RESOURCE** | | | | | |
| | **2.1** | Establish Groundwater Information System | 12 | Cons. or Int. Inst. | 24 | 4 | 672,000 |
| | **2.2** | Develop/Implement a 'SADC regional Groundwater Awareness' Campaign | 6 | Cons. | 6 | 2 | 168,000 |
| | **2.3** | Develop a Common Approach to the Assessment of the Value of Groundwater | 6 | Cons. | 8 | 3 | 224,000 |
| | | Sub Total Cost (Primary Component 2) | | | | | **1,064,000** |
| **3** | | **TOWARDS IWRM IN THE SADC REGION** | | | | | |
| | **3.1** | Capacity Building and Training in the Groundwater Sector | 8 | Cons. | 12 | 3 | 336,000 |
| | **3.2** | Identify/Strengthen Potential Implementing Insitutions or SADC Regional Units | 12 | Cons. or Int. Inst. | 18 | 3 | 504,000 |
| | **3.3** | Investigate and Initiate the Establishment of a Regional Groundwater Organisation | 24 | Cons. or Int. Inst. | 36 | 4 | 1,008,000 |
| | **3.4** | Contribute to the Development of Guidelines for National and Regional Water Policy | 6 | Cons. | 6 | 2 | 168,000 |
| | **3.5** | Initiate the Development of a SADC Protocol on Water Resources | 6 | Cons. | 6 | 2 | 168,000 |
| | | Sub Total Cost (Primary Component 3) | | | | | **2,184,000** |
| | | **TOTAL ESTIMATED PROJECT COST** | | | | | **5,936,000** |

Note 1: Cost estimates based on a general 'all-in' man month rate for senior Consultant or International Institution personnel of US$ 20,000

Note 2: Estimates of equipment and other material/support costs are included in the final Cost Estimate as 40% of the man month total.

Note 3: Cons. refers to Consultant; Int. Inst. refers to International Groundwater Institution

# APPENDIX 1

# COMMENTS ON THE DRAFT FINAL REPORT

# AND

# THE CONSULTANTS RESPONSE

## 1.0 Introduction

In order that the agreed framework and content layout of the Final Report is not substantially altered it has been considered prudent that the late comments on the report received from the Water Policy and Programmes Coordinator, SADC Water Division in a letter dated 25th October 2003 (Ref SADC-IS-WD/3.5) be appended to the Final Report as a separate Annex.

Appendix 1 thus contains the comments received from SADC Water Division verbatim (Section 2), followed by the Consultants considered response to these comments (Section 3). An additional data set that the Consultant has compiled and regards as relevant to the comments is included as Table A –1.

## 2.0 Comments on the Draft Final Report received from SADC on 25/10/2003

1. *Generally a thorough report although it does not provide all the information needed for development of a PAD.*

2. *The report provides useful information on groundwater droughts and recent examples in the region to support the Background section of the PAD.*

3. *Much of task 'e)' of the ToR for the study have been achieved through the detailed phase I of the French-funded hydrogeological mapping project rather than through this project. The French project provides extensive detail on hydrogeological mapping at the regional level, groundwater information systems, and data. However, the French report does not provide much information on drought-prone areas and the Wellfield report also omits this detail as called for in the ToR.*

4. *The boxes summarizing monitoring activities, data availability, technical institutions, etc in each country are good*

5. *Perhaps the weakest part of the report is the scarcity of information on groundwater dependent ecosystems (Section 2.2 and 5.1.2). In Section 4.7 and Box G it mentions a number of country-level environmental datasets it does not link this information to those that are groundwater dependent. Apart from some generalities about ecosystem dependence on groundwater, these sections offer little specific information on this critical topic. While the conclusion that there is little information on these interactions is probably fair, it would have been reasonable for the authors to have included details from those locations (Okavango, etc) where they clearly state that some ecosystem information has been collected. Instead they simply list examples of these locations at the end of Section 2.2.2 and make some speculative comments in the last point of 5.1.2. As they say, there is some literature on ecosystem dependence on ground waters in scientific reports and elsewhere, they avoid actually collating and summarizing it.*

   *It would help the PAD preparation considerably if the authors showed specifically the extent to which even a small number of important ecosystems were dependent on groundwater.*

*6.* *ToR 'h)' identifies the maps to be produced as 'water scarcity' and 'drought sensitivity' but not 'drought vulnerability' although vulnerability is specifically identified as an output of the project in the Background section. However, the authors investigated drought vulnerability mapping, in spite of the absence of a specific requirement to do so (Section 3.2). However, the do not define vulnerability clearly, given that the term could refer to ecosystem vulnerability (and consequently lead to vulnerability of those dependent on these ecosystems) or to human vulnerability. Their discussion of vulnerability is biased towards the latter interpretation – 'This type of spatial mapping depends on the superposition of two sets of information, a sociological dataset that analyses the distribution of demand, and a physical dataset that identifies availability of resource and ease of access'. While* ***it would be unreasonable to request you to rewrite this section, given the imprecision in their ToR, an attempt at bringing this out might be useful.***

***7.*** *The authors note some maps that are already available – e.g. the groundwater scarcity or availability map of the GWAVA study (Section 3.5) but don't comment on potential overlaps with this project. Are the existing maps of the wrong scale; wrong categorization; etc for our purposes?? Are we in danger of repeating existing maps?? If we do produce these maps in this GEF project, how should these existing maps be utilized?? Can you please* ***advise us on this matter.***

## 3.0 Consultants Response to Comments Received

### Comment 1

In undertaking the project programme the Consultant has attempted to follow the requirements set out in the Terms of Reference (ToR) issued for the Regional Situation Analysis Project together with the additional matters raised at the negotiation meeting between SADC and the Consultant held in Maseru on 8/7/2002 and recorded in the Consultant Contract.

Neither of these documents specifically referred to the nature of the information needed for the development of a PAD and the Consultant thus assumed that the information gathered and presented in the Final Report in the fulfilment of the ToR and Negotiation requirements would be adequate for this purpose. At no stage was any additional information specified or requested and the Consultant remains unclear as to what extra information is needed for the development of a PAD.

### Comment 2

In the execution of the work the Consultant gathered considerable information on the nature and definition of groundwater drought and examples of the effects of such droughts in the SADC region. The comment acknowledges the usefulness of this data for the background section of the PAD.

**Comment 3**

Section ‘e)’ of the TORs states:
*‘Review and analyse existing available information on hydrogeological mapping and current programmes at the regional level, location of drought prone areas, groundwater information data, water level and quality monitoring data’.*

As the comment indicates, much of the essential information required for this review was acquired by Phase 1 of the Hydrogeological Mapping Project (REF??) and only minimal, updated new information on hydrogeological mapping, groundwater information systems and basic water level and quality was gathered by the Consultant during the data collection stage of the project.

However, the review brought together and discussed this information in the context of the development of Groundwater Management Tools rather than solely hydrogeological maps as called for under the ToR.

With respect to the definition and delineation of ‘drought-prone areas’ it is acknowledged that this aspect was not thoroughly addressed in the report since as the Consultant was essentially dealing with ‘groundwater drought’ and not drought in its most general sense, the basic spatially distributed data required to reliably delineate areas prone to groundwater drought was not available throughout the region. This extremely important point of shortage of basic data was, however, stressed in the report as being the single most important issue in attempting to develop and produce any form of groundwater management tools on a regional basis. The concept of ‘groundwater availability’ was, however, illustrated by means of the GWAVA Water Availability Index maps produced by BGS for Malawi.

**Comment 4**

The Final Report adequately summarises monitoring activities, data availability and a number of other technical data sets for the region by means of thematic information boxes (Boxes 1 – 3 and A – K).

**Comment 5**

Although the comment indicates that the report is weak with respect to information on groundwater dependent ecosystems it should be noted that this topic was only introduced into the ToR during the negotiations and had not been set out in the Consultant’s Technical Proposal. Nevertheless, considerable effort was spent on attempting to gather the required information from as many sources as possible. In addition, the Consultant raised the issue as to whether the ‘ecosystems’ referred to were ‘natural’ systems or were deemed to include to a greater or lesser degree the human element, as this seriously impacts on the groundwater dependency linkage.

As noted in the report, much data is available in the region on natural ecosystems in general, but virtually none refers to the interaction of ecosystems and groundwater except at a very small number of specific sites (as per the Okavango Delta noted in Comment 5). As also noted, such data is generally contained in research reports, and whilst this may be important in its conclusions it is very ‘site-specific’ and, except in its generalities, was not seen to contribute greatly to a regional appraisal.

In the absence of any significant volume of 'groundwater-ecosystem' information the Consultant has, however, assembled an additional Information Box based upon a listing of natural wetland ecosystems in the SADC mainland region compiled by IUCN, 1992 (Information Box A-1 attached to this Appendix). To this has been added a comment on underlying geology/hydrogeology, the assumed link with groundwater, an assessment of the human impact on the system and a qualitative appraisal of the Water Scarcity situation (wet and dry season) and Drought Sensitivity of the ecosystem. Clearly, in the majority of these ecosystems systems a considerably greater amount of research would need to be undertaken to fully determine the groundwater linkage and the degree of interdependence between the surface water system and the groundwater system.

**Comment 6**

Section 'h' of the TORs states:
*'Prepare a Regional situation analysis report and guidelines concerning the possibility of preparing water scarcity and drought sensitivity maps as derivatives of a SADC Hydrogeological map, recommendations for a regional groundwater information system, a regional monitoring network, and recommendation on groundwater related environmental issues.'*

Clearly the ToR requires only' guidelines' on the 'possibility' of preparing water scarcity and drought sensitivity maps, not the actual preparation of such maps.

With respect to the concentration in the report on 'drought vulnerability' mapping as a tool in groundwater management the Consultant indicates that 'drought vulnerability' in its most fundamental form refers to groundwater resources that are more vulnerable to 'groundwater drought' than others, thus providing an indication of the ability of the resource to continue to provide a supply to whatever dependency (human or ecosystem) during periods of drought.

The term groundwater 'drought vulnerability' is considered synonymous with groundwater 'drought sensitivity' (see Northern Province of South Africa example - Section 3.2, Final Report) as well as 'drought susceptibility', and as part of the GIS assembly procedure a data compilation map or layer usually referred to as 'groundwater availability' (or conversely 'water scarcity') is utilised.

With respect to the definition of 'vulnerability' then the definition given above can be broadened to include the adverse impact of groundwater drought on the groundwater dependent systems, whether these are natural ecosystems or the human population. Such dependencies are included in the mapping process as individual GIS layers derived from appropriate datasets and, in the case of the more commonly considered 'human dependency' aspect, are illustrated in Figure 1, Section 3.2 of the Report.

Given that considerably more basic data is available for the definition of this interpretation of 'drought vulnerability', and that the human element invariably takes precedence over other approaches, the Consultant has to concede that the discussion of 'drought vulnerability' in the Report is biased towards this interpretation. However, **if** suitable quantity and quality of data were available with respect to the interaction of natural ecosystems and groundwater a very similar GIS 'drought vulnerability' ('sensitivity' or 'susceptibility') mapping approach could be taken in this regard.

**Comment 7**

The concept and definition of groundwater ‘availability’ is discussed in Section 3.5 of the Report, where it is noted that in its simplest form ‘availability’ can be taken to mean whether groundwater actually exists in the various formations and any map would then be a simplified presentation of the same data set used to construct a conventional Hydrogeological Map.

If, however, the definition of ‘availability’ is broadened to include factors such as accessibility, potential demand and usage then additional data sets will be required in the mapping process, as was the case with the DFID project that resulted in the GWAVA maps that also broadened the scope even further to include all water availability (ie included hydrological factors). Clearly, additional mapping layers could also be introduced to include other financial or sociological factors that, depending on the definition of ‘availability’.

With respect to the GWAVA mapping process the essential principal was a macro-scale numerical model, with the scale of the resultant maps governed by the model grid that was selected at approximately 50x50 km to coincide with an area of 0.5x0.5 degrees that would most realistically accommodate the spatial density of available data and a number of generalisations and simplifications related to the spatial distribution of several of the model parameters (eg recharge, demand). The approach and process was proven to be valid on the regional scale for identifying regional trends, but would not be appropriate at a ‘down-sized’ national or basin scale if it were required for specific planning or resources evaluation purposes.

In any spatial modelling exercise the size of the grid vis-à-vis the data density is critical in relation to the reliability and representativeness of the model, and it is the Consultants opinion that if the macro-modelling approach were to be adopted (with any agreed variation to the definition of groundwater ‘availability’) during the GEF project then the issue of data density will require thorough examination before any decisions could be made on model grid (and map) scale. Clearly, the GWAVA scale maps could be reproduced and modified by including additional data layers, but it is probably the case that unless the individual Member States found the map outputs to be useful on a national basis for ‘home’ use (ie the model grid was suitably small, implying improved national data density), then it may prove to be an interesting but rather academic exercise in terms of their overall usefulness.

The Consultant would thus recommend, if a macro-scale modelling approach to groundwater ‘availability’ or ‘scarcity’ were considered appropriate, that the GWAVA mapping process be re-examined following a detailed appraisal of the appropriate Member State national data sets, and if suitable data is not available then efforts be put into acquiring such data so that the modelling scale can be focussed, at least initially, at a national level in order to fully demonstrate in a practical manner the usefulness and benefits of these groundwater management tools.

## Information Box A-1 Initial assessment of links between major wetlands and underlying groundwater resources

(Based on list of wetlands in the SADC mainland area from: IUCN,1992)

| Country | Wetland areas | Geology | Groundwater link | Human impact | Water scarcity | Drought sensitivity |
|---|---|---|---|---|---|---|
| **Angola** | Cunene River System wetlands | Quaternary (Kalahari) and Precambrian Basement | Possible groundwater flow from flood plain sediments into river during dry season | Dams on river have greater impact on river flow than abstraction of groundwater for cattle watering | DS XX<br>WS X | X |
| | Cubango River System wetlands | Quaternary (Kalahari) and Precambrian Basement | Probable poor groundwater resources | Minimal but could increase with development | DS XX<br>WS X | X |
| | Southeastern Interior wetlands of Cuando River System | Quaternary (Kalahari) and Karoo sediments | Probable poor groundwater resources | Minimal but could increase with development | DS XX<br>WS X | X |
| | Interior Regions of Impeded Drainage | Quaternary (Kalahari) and Precambrian Basement | Probable poor groundwater resources, flow to swamps in dry season | Minimal but could increase with development | DS XX<br>WS X | X |
| | Central Eastern Interior wetlands | Quaternary (Kalahari) and Precambrian Basement | Probable poor groundwater resources, flow to dambos in dry season | Minimal but could increase with development | DS X<br>WS X | X |
| | Upper Cuanza System wetlands | Quaternary (Kalahari) and Precambrian Basement | Probable poor groundwater resources, flow to river in the dry season if groundwater has not been pumped for domestic or cattle watering needs | Numerous centres of population, water used for cattle and domestic supplies | DS X<br>WS X | X |
| | Coastal lakes and floodplains | Precambrian basement | Poor groundwater resources probably over developed | Large population centres, much deforestation | DS XX<br>WS XX | X |
| | Uige and North Lunda Provinces wetlands | Precambrian basement | Poor groundwater resources | Small population centres, accelerating deforestation | DS XX<br>WS XX | X |
| | Cabinda wetlands | Precambrian basement | Poor groundwater resources | Small population centres, accelerating deforestation associated with oil development | DS XX<br>WS XX | X |
| **Botswana** | Okavango Delta | Kalahari sands | Moderate groundwater resources difficult to abstract | Growing peripheral population centres expanding tourism, dams on Cubango in Angola have reduced flow to delta | DS XXX<br>WS XX | XXX |
| | Lake Ngami | Kalahari Beds | Very poor groundwater resources in arid area | Sparse population, flow from delta area has not occurred for several decades | DS XXX<br>WS XXX | XXX |
| | Makgadikgadi Pans | Kalahari Beds | Very poor groundwater resources in arid area | Sparse population, periodic accumulation of rainwater | DS XXX<br>WS XXX | XXX |
| | Savuti Marsh and Mababe Depression | Kalahari sands | Moderate to poor groundwater resources difficult to abstract | Growing tourism, seasonal connection with Zambezi | DS XXX<br>WS XX | XXX |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Linyati/Chobe Rivers wetlands | Kalahari sands and Karoo sediments and basalts | Moderate groundwater resources difficult to abstract | Growing peripheral population centres expanding tourism, seasonal connection with Zambezi | DS XX<br>WS X | XX |
| | Nogatsau Pans | Kalahari sands and black cotton soil above Karoo basalts | Poor fresh to saline groundwater resources difficult to abstract | Limited agriculture on some pans using groundwater for limited spray irrigation of maize | DS XXX<br>WS XX | XXX |
| | Lake Xau | Kalahari sands and black cotton soil above Karoo sediments | Poor fresh to saline groundwater resources difficult to abstract | Small population centres, some cattle rearing | DS XXX<br>WS XX | XXX |
| | Nxai and Kgama Kgama Pans | Kalahari sands and black cotton soil above Karoo basalt and sediments | Poor fresh to saline groundwater resources difficult to abstract | Small population centre at Nata, some cattle rearing | DS XXX<br>WS XX | XXX |
| | Artificial impoundments Shashe Dam | Precambrian basement | Some recharge to sand river system downstream, small quantities of groundwater abstracted for cattle watering | Water supply to Selebi Pikwe and Francistown, has resulted in much reduced flow along Shashie and Limpopo Rivers with consequent impact on wildlife | DS XX<br>WS X | XXX |
| **Democratic Republic of the Congo** | Bas-Zaire wetlands | Precambrian Basement with some Karoo sediments | Unknown groundwater resources | Cities of Kinshasa and Brazzaville are probable sources of river pollution | DS X<br>WS X | X |
| | South Bandundu, Kasai Occidental and Oriental wetlands | Quaternary sediments above Karoo sediemts | Unknown but probably moderate to large groundwater resources | Much deforestation of tropical forests | DS X<br>WS X | X |
| | *Shaba Province wetlands:*<br>1. High Country Plateau | Late Precambrian sediments | Unknown but probably poor to moderate groundwater resources, with dambo type drainage | Protected area | DS X<br>WS X | X |
| | 2. Lake Mweru | Quaternary sediments on Precambrian basement in small rift valley | Unknown groundwater resources | Little development | DS X<br>WS X | X |
| | 3. Luapula Floodplain | Quaternary sediments on Precambrian basement in small rift valley | Unknown groundwater resources | Undeveloped area | DS X<br>WS X | X |
| | 4. Lake Tshangalele and the Lufira River | Quaternary sediments on Precambrian basement | Groundwater is probably the source of the river flow and swamp area moisture | Limited development, some fishing and agriculture | DS X<br>WS X | X |
| | 5. Lake Decommune | Late Precambrian sediments | Unknown, but groundwater probably fed into the pre-lake wetlands | Lake is close to Kolwezi | DS X<br>WS X | X |
| | 6. Upemba Lakes and Lualaba River | Quaternary sediments on Precambrian basement | Groundwater is probably the source of the river flow and swamp area moisture | Limited development, some fishing and agriculture | DS X<br>WS X | X |
| | *Central Zaire Basin wetlands:*<br>1. Riverine swamps and forests | Quaternary sediments above Karoo sediments | Unknown but probably moderate to large groundwater resources | Undeveloped | DS X<br>WS X | X |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 2. Lake Tumba | Quaternary sediments above Karoo sediments | Unknown but probably moderate to large groundwater resources | Undeveloped, some local population centres | DS X<br>WS X | X |
| | 3. Lake Mai Ndombe | Quaternary sediments above Karoo sediments | Unknown but probably moderate to large groundwater resources | Undeveloped, some local population centres | DS X<br>WS X | X |
| | Eastern Highlands wetlands | Precambrian sediments | Unknown but probably poor to moderate groundwater resources, with dambo type drainage | Limited development | DS X<br>WS X | X |
| | Lake Tanganyika and Ruzizi Plain | Precambrian basement with Quaternary sediments and basalts within rift valley | Unknown but probably poor to moderate groundwater resources, with dambo type drainage | Limited development | DS X<br>WS X | X |
| **Lesotho** | Mountain bogs and spongelands | Karoo Basalts | Seepages of groundwater feed bogs and spongelands | Wetlands have been badly affected by over grazing, rangeland fires and diamond mining activities | DS XX<br>WS X | XX |
| **Malawi** | Ruwenya Hills marshes | Precambrian basement | Poor groundwater resources, with dambo type drainage | Little development | DS XX<br>WS X | XX |
| | Fort Hill Plain marshes | Precambrian basement | Poor groundwater resources, with dambo type drainage | Some shifting cultivation | DS XX<br>WS X | XX |
| | *South Rukuru River System wetlands;*<br>1. Northern Tributaries | Precambrian basement | Poor groundwater resources, with dambo type drainage | Some shifting cultivation | DS XX<br>WS X | XX |
| | 2. Vwaza Marsh | Precambrian basement | Poor groundwater resources, with dambo type drainage | Some shifting cultivation | DS XX<br>WS X | XX |
| | 3. Southern Tributaries | Precambrian basement | Poor groundwater resources, with dambo type drainage | High population density, water supply abstraction will impact upon wetlands | DS XX<br>WS X | XX |
| | Kusungu Plain and Bua River marshes | Precambrian basement | Poor groundwater resources, with dambo type drainage. High groundwater abstraction has altered flow pattern of rivers | Extensively deforested area | DS XX<br>WS X | XX |
| | Lilongwe Plain marshes | Precambrian basement | Poor groundwater resources, with dambo type drainage. High groundwater abstraction has altered flow pattern of rivers | Extensively deforested area | DS XX<br>WS X | XX |
| | *Lake Malawi associates wetlands:*<br>1. Karonga Lakeshore Plain | Quaternary sediment on Precambrian basement | Poor groundwater resources, with dambo type drainage. High gw abstraction for agriculture has altered water table levels | Plain is under cultivation with little wetland left | DS XX<br>WS X | XX |
| | 2. Limpasa Dambo | Quaternary clay sediment on Precambrian basement | Poor groundwater resources, with dambo type drainage. | Area undeveloped | DS XX<br>WS X | XX |
| | 3. Nkhotakota Lakeshore Lowlands | Quaternary sediment on Precambrian basement | Poor groundwater resources, with dambo type drainage | Water obtained from the Bua River for irrigation | DS XX<br>WS X | XX |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 4. Salima Lakeshore Plain | Quaternary sediment on Precambrian basement | Poor groundwater resources, with delta type drainage | Groundwater used widely for domestic supply | DS XX<br>WS X | XX |
| | Lake Malombe | Quaternary sediment on Precambrian basement in rift valley | Fed by southerly outlet from Lake Malawi. Some attempts made to abstract groundwater from alluvium | Limited development | DS XX<br>WS X | XX |
| | The Shire Marshes | Quaternary sediment on Precambrian basement in rift valley | Fed by southerly outlet from Lake Malawi. Some attempts made to abstract groundwater from alluvium | Limited development | DS XX<br>WS X | XX |
| | Lake Chilwa | Precambrian Basement | Although fed by rainfall runoff there may be a groundwater inflow component | Well developed as a fishery and source of irrigation water | DS XXX<br>WS XX | XXX |
| | Lake Chiuta | Precambrian Basement | Although fed by rainfall runoff there may be a groundwater inflow component | Well developed as a fishery and source of irrigation water | DS XXX<br>WS XX | XXX |
| **Mozambique** | *Riverine swamps and floodplains:*<br>1. Maputaland rivers | Quaternary above Neogene and Cretaceous sediments | Good to moderate groundwater resources within floodplain and underlying sediments | River flows regulated by reservoirs in neighbouring countries, some irrigated agriculture | DS XX<br>WS X | XX |
| | 2. Limpopo system | Quaternary above Neogene and Cretaceous sediments | Good to moderate groundwater resources within floodplain and underlying sediments | River flows regulated by reservoirs in neighbouring countries | DS XX<br>WS X | XXX |
| | 3. Inharrime River and drainage of interior Inhambane | Quaternary above Neogene and Cretaceous sediments | Moderate to poor groundwater resources within floodplain and underlying sediments | Un developed swamps | DS XX<br>WS X | XX |
| | 4. Save, Gorongose, Buzi and Pungue rivers | Quaternary above Neogene and Cretaceous sediments | Good to moderate groundwater resources within floodplain and underlying sediments | Very seasonal river flows. Limited agricultural development in the delta areas | DS XXX<br>WS X | XXX |
| | 5. Lower Zambezi River | Quaternary above Neogene and Cretaceous sediments | Good to moderate groundwater resources within floodplain and underlying sediments | River flows regulated by reservoirs in neighbouring countries eg Cahora Bassa and Kariba dams. Some irrigation | DS XX<br>WS X | XXX |
| | 6. Zambezia Province rivers | Quaternary, Neogene and Cretaceous sediments above Precambrian basement | Moderate to poor groundwater resources within floodplain and underlying sediments | Seasonal river flows, limited development | DS XX<br>WS X | XXX |
| | 7. NE coast rivers | Quaternary, Neogene and Cretaceous sediments above Precambrian basement | Moderate to poor groundwater resources within floodplain and underlying sediments | River flows regulated by reservoirs in neighbouring countries, some irrigated agriculture | DS XX<br>WS X | XXX |
| | Lake Cahora Bassa | Karoo sandstones overlying Precambrian basement | Moderate to poor groundwater resources | Construction of this dam has had bad effects upon the hydro-ecology of the Lower Zambezi valley | DS XX<br>WS X | XXX |

| | | | | | | |
|---|---|---|---|---|---|---|
| | *Interior Lakes:*<br>1. Lake Malawi | Quaternary sediment on Precambrian basement in rift valley | Unknown | Limited development | DS XX<br>WS X | XX |
| | 2. Lake Amaramba | Precambrian Basement | Although fed by rainfall runoff there may be a groundwater inflow component | Undeveloped | DS XXX<br>WS XX | XXX |
| | 3. Lake Chiuta | Precambrian Basement | Although fed by rainfall runoff there may be a groundwater inflow component | Well developed as a fishery and source of irrigation water | DS XXX<br>WS XX | XXX |
| | 4. Lake Chilwa | Precambrian Basement | Although fed by rainfall runoff there may be a groundwater inflow component | Well developed as a fishery and source of irrigation water | DS XXX<br>WS XX | XXX |
| **Namibia** | *Coastal Wetlands:*<br>1. Walvis Bay | Quaternary to recent sands | Groundwater derived from the inundated Kuiseb River | Protected | DS XXX<br>WS XX | XXX |
| | 2. Sandwich Harbour | Quaternary to recent sands | Fed by groundwater from sand dunes | Protected | DS XXX<br>WS XX | XXX |
| | 3. Cunene River Mouth | Quaternary to recent sands | Fed by groundwater from sand dune inundated sand river | Wetland may be adversely affected by upstream dam construction | DS XXX<br>WS XXX | XXX |
| | 4. Orange River Mouth | Quaternary to recent sands | Fed by groundwater from sand dune inundated sand river | Protected | DS XXX<br>WS XXX | XXX |
| | Oshakati Pan System | Kalahari Beds | Water flows through fossil drainage channels, groundwater beneath is saline | Water flows to Etosha Pan where there is a significant tourist industry | DS XXX<br>WS XXX | XXX |
| | *Caprivi Wetlands:*<br>1. Cubango Wetlands | Kalahari Beds | Water flows along Cobango from Angola. Groundwater resources abstracted in Caprivi area | Tourist industry and limited agriculture, Cobango flows south to the Okavango | DS XX<br>WS X | XX |
| | 2. Cuando-Linyanti-Chobe-Zambezi system | Kalahari Beds | Water flows from the Okavango from Botswana. Groundwater resources abstracted in Caprivi | Tourist industry and limited agriculture, Chobe flows north to the Zambezi in the wet season | DS XX<br>WS X | XX |
| | Etosha Pan | Kalahari Beds | Water flows through fossil drainage channels, groundwater beneath is saline | Water flows to Etosha Pan where there is a significant tourist industry | DS XXX<br>WS XXX | XXX |
| | Lakes Guinas and Otjikoto | Precambrian Dolomite | Sinkholes directly fed by groundwater | Water has been abstracted to supply Tsumeb and irrigation | DS XX<br>WS XX | XX |
| | Other floodplains and pans | Kalahari Beds – calcrete pans | Rain water collects in the pans during the wet season, groundwater beneath is probably saline | Undeveloped – too remote | DS XXX<br>WS XXX | XXX |
| | Sossusvlei and Tsodabvlei | Rivers originate from Precambrian Dolomite to run down to Kalahari Bed clay and calcrete pans | River water collects in the pans, groundwater beneath is probably saline | Undeveloped – too remote | DS XXX<br>WS XXX | XXX |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Periodic streams | Ephemeral sand rivers | Storm water collects in the sand rivers to run toward the coast. A proportion remains in the sand river | Undeveloped – too remote | DS XXX<br>WS XXX | XXX |
| | *Artificial impoundments:*<br>1. Hardap Dam | Dam on the Great Fish River | Unknown | Tourist resort | DS XXX<br>WS XXX | XXX |
| **South Africa** | *Tidal wetlands:*<br>1. Minor systems | Coastal mudflats, river estuaries and dunes | Unknown but very limited | Developed as tourist resorts – marinas, or heavily polluted as harbour/industrial developments | DS XXX<br>WS XXX | XXX |
| | 2. Kosi Lake System | Coastal lakes and swamps | Sands and mudflats, mainly saline with some freshwater | Undisturbed but threatened with harbour development. Some pesticide residues | DS XX<br>WS XX | XX |
| | *Coastal lakes and swamps:*<br>1. Minor systems | Coastal lakes and swamps | Sands and mudflats, mainly saline with some freshwater | Degradation due to tourist and residential development with sewerage pollution | DS XX<br>WS XX | XX |
| | 2. St Lucia Lake System | Coastal lakes and swamps | Sands and mudflats, mainly brackish to fresh-water | Siltation increased due to agriculture in hinterland, protected area | DS XX<br>WS XX | XX |
| | 3. Lake Sibaya | Coastal lakes and swamps | Sands and mudflats, mainly fresh-water from river and, groundwater inflow (seepage estimated to be 1-4 $m^3$/annum | Currently undisturbed but threatened by regional population pressure with demands for fresh water and protein | DS XXX<br>WS XXX | XX |
| | *Riverine floodplains and swamps:*<br>1. Minor systems | Includes the floodplains of the Limpopo, Pafuri , Orange, Great Berg and Touw rivers | Groundwater flow from underlying weathered basement and sandstone aquifers during dry season | Affected by dams and agricultural practices, irrigation , with pollution from fertilisers, pesticides and sewerage | DS XXX<br>WS XXX | XXX |
| | 2. Pongolo River Floodplain | Floodplain of Tertiary and Recent age alluvium | Groundwater flow from underlying alluvial sediment aquifers during dry season | Affected by operation of Pongolapoort Dams and irrigation agriculture, with pollution from fertilisers, pesticides and sewerage | DS XX<br>WS XX | XX |
| | 3. North Mosi Swamp | Dune swamp and alluvium complex | Groundwater flow from dunes and underlying alluvial sediment aquifers during dry season | Remote and undisturbed | DS XX<br>WS XX | XX |
| | *Lakes and pans of the interior:*<br>1. Minor Pans | Mainly in northern Karoo and southern Kalahari areas | Rainwater with some groundwater flow from weathered basement and pan dune complexes | Usually remote and unprotected | DS XXX<br>WS XXX | XXX |
| | 2. Barberspan | Ephemeral calcareous pan in former course of the Hart's river, on Precambrian sediments | Rainwater and surface water flow, some groundwater? | Protected nature reserve, undisturbed | DS XXX<br>WS XXX | XXX |
| | Montane Wetlands | Sponge bogs in highland areas of southern mountains/Drakensberg | Seepage water from basalt and sandstone aquifers with rainwater | Impact restricted to forestry developments and burning | DS X<br>WS X | X |

| | | | | | | |
|---|---|---|---|---|---|---|
| | *Artificial impoundments:*<br>1. Hendrick Verwoerd Dam | Dam developed on Caledon/Orange river on Karoo age sedimentary rocks | Some groundwater seepage | Artificial dam | DS XX<br>WS XX | XXX |
| | 2. Vaal Dam | Dam developed on Vaal river on Precambrian? age sedimentary rocks | Some groundwater seepage | Artificial dam | DS XX<br>WS XX | XXX |
| | 3. Bloemhof Dam | Dam developed on Vaal river on Precambrian? age sedimentary rocks | Some groundwater seepage | Artificial dam | DS XX<br>WS XX | XXX |
| | 4. P K le Roux Dam | Dam developed on Orange river on Karoo age sedimentary rocks | Some groundwater seepage | Artificial dam | DS XX<br>WS XX | XXX |
| | 5. Pongolapoort Dam | Dam developed on Pongolo river on Karoo age sedimentary rocks | Some groundwater seepage | Artificial dam, waters to be used for irrigation with detrimental effects on down stream wetlands | DS XX<br>WS XX | XX |
| **Swaziland** | Mountain bogs and spongelands | Sponge bogs in wetter highland areas and floodplain swamps | Seepage water from weathered basement and alluvial aquifers with rainwater | Irrigation schemes and overgrazing | DS X<br>WS X | X |
| **Tanzania** | Tidal wetlands | Coastal mudflats, mangrove swamps, river estuaries and dunes | Unknown but very limited | Mangroves have been extensively exploited for timber products | DS XX<br>WS X | X |
| | *Riverine wetlands:*<br>1. Kagera River | Rift valley system of lakes and swamps | River fed, groundwater inflow unknown | Affected by hunting and fishing, now partly protected | DS XX<br>WS X | X |
| | 2. Moyowosi/Malagarasi System | Extensive system of lakes and swamps developed on Precambrian Basement rocks that extend into the rift valley | River fed, groundwater inflow unknown | Affected by hunting and fishing, now partly protected | DS XX<br>WS X | X |
| | 3. Mara River | River fed papyrus swamp on Precambrian basement rocks | River fed, groundwater inflow unknown | Affected by fishing and is unprotected | DS XX<br>WS X | XX |
| | 4. Pangani River | Permanent swamps and flood plains fed by rivers and springs | Mainly river fed but some groundwater flow from springs | Affected by hunting and fishing with limited agriculture and forestry and is unprotected | DS XX<br>WS X | XX |
| | 5. Wami River | River fed papyrus swamps and flood plains | River fed, groundwater inflow unknown | Affected by hunting and fishing with limited agriculture and is unprotected | DS XX<br>WS X | XX |
| | 6. Ruvu River | River fed papyrus swamps and flood plains | River fed, groundwater inflow unknown | Affected by hunting and fishing with limited agriculture and is unprotected | DS XX<br>WS X | XX |
| | 7. Ruaha/Rufiji System | Extensive areas of river fed papyrus swamps and flood plains | River fed with some groundwater inflow | Extensively developed for hunting, fishing and agriculture. Some of area is protected | DS XX<br>WS X | XX |

| | | | | | | |
|---|---|---|---|---|---|---|
| | *Basins of Interior Drainage:*<br>1. Rukwa Basin | River fed rift valley lake and swamp – saline water | River fed, groundwater inflow unknown | Some fishing and hunting, area largely protected | DS XX<br>WS X | XX |
| | 2. Bahi Swamp | Semi-permanent swamp in small rift valley | Rain fed with some groundwater inflow, saline water | Hunting, area unprotected | DS XXX<br>WS XXX | XXX |
| | 3. Eyasi and Yaida Basin | Dry lake bed in elongate rift valley fed by ephemeral streams and some springs | Seasonally river fed with some groundwater inflow, water rapidly evaporates leaving salt pan | Occasional fishing | DS XXX<br>WS XXX | XXX |
| | 4. Lake Natron Basin | Shallow soda lake in rift valley fed by seasonal streams and peripheral springs | Seasonally river fed with some groundwater inflow, water rapidly evaporates leaving salt pan | Highly saline, unutilised and unprotected | DS XXX<br>WS XXX | XXX |
| | 5. Lake Manyara Basin | Shallow soda lake in rift valley fed by seasonal streams and peripheral springs with associated swamp areas | Seasonally river fed with some groundwater inflow, water rapidly evaporates leaving salt pan | Well developed tourism in protected area | DS XXX<br>WS XXX | XXX |
| | 6. Burigi and Ikimba Basins | Small lakes and swamps fed by seasonal streams and springs in small rift valleys | Seasonal streams and groundwater seepages | Isolated area is partly protected | DS XXX<br>WS XXX | XXX |
| | *Natural lakes:*<br>1. Lake Victoria | Large rift valley lake | Seasonal streams, rainfall and groundwater seepages | Extensive fishing and communication | DS X<br>WS X | X |
| | 2. Lake Tanganyika | Large rift valley lake | Seasonal streams, rainfall and groundwater seepages | Extensive fishing and communication | DS X<br>WS X | X |
| | 3. Lake Malawi | Large rift valley lake | Seasonal streams, rainfall and groundwater seepages | Extensive fishing and communication | DS X<br>WS X | X |
| | 4. Minor lakes and swamps | Small rift valley and crater lakes | Seasonal streams, rainfall and groundwater seepages | Some fishing and hunting, generally protected | DS XX<br>WS XX | XXX |
| **Zambia** | *Upper Zambezi Valley Wetlands:*<br>1. Kabompo River Swamps | Small swamps on Kalahari Beds | Seasonal river flood, rainfall and groundwater seepages | Fishing and cattle grazing, some protected areas | DS XX<br>WS XX | XX |
| | 2. Lungue-Bungo River Swamps | Swamps and flood plain on Kalahari Beds | Seasonal river flood, rainfall and groundwater seepages | Fishing and cattle grazing, some protected areas | DS XX<br>WS XX | XX |
| | 3. Luena Flats | Swamps and flood plain on Kalahari Beds | Seasonal river flood, rainfall and groundwater seepages | Fishing and cattle grazing, some protected areas | DS XX<br>WS XX | XX |
| | 4. Nyengo Swamps | Swamps and flood plain on Kalahari Beds | Seasonal river flood, rainfall and groundwater seepages | Fishing and cattle grazing, some protected areas | DS XX<br>WS XX | XX |
| | 5. Lueti and Lui Swamps | Swamp and Zambezi Flood plain on Kalahari Beds | Seasonal river flood, rainfall and groundwater seepages | Fishing and cattle grazing, some protected areas | DS XX<br>WS XX | XX |
| | 6. Barotse Floodplain | Zambezi Flood plain on Kalahari Beds | Seasonal river flood, rainfall and groundwater seepages | Fishing and cattle grazing, some protected areas | DS XX<br>WS XX | XX |
| | 7. Sesheke-Maramba Floodplain | Zambezi Flood plain on Kalahari Beds | Seasonal river flood, rainfall and groundwater seepages | Fishing and cattle grazing, some protected areas | DS XX<br>WS XX | XX |

| | | | | | | |
|---|---|---|---|---|---|---|
| | *Kafue Basin Wetlands:*<br>1. Upper catchments swamps | Swamps and dambos on Kalahari Beds and Precambrian basement | Seasonal river flood, rainfall and groundwater seepages | Fishing and cattle grazing, some protected areas | DS X<br>WS X | X |
| | 2. Busanga Swamp | Swamps on Kalahari Beds and Precambrian basement | Seasonal river flood, rainfall and groundwater seepages | Protected area | DS X<br>WS X | X |
| | 3. Lukanga Swamp | Swamps and dambos on Kalahari Beds and Precambrian basement | Seasonal river flood, rainfall and groundwater seepages | Fishing and cattle grazing, unprotected | DS X<br>WS X | X |
| | 4. Kafue Flats | Swamps and dambos on Kalahari Beds and Precambrian basement | Seasonal river flood, rainfall and groundwater seepages | Fishing and cattle grazing, some protected areas | DS X<br>WS X | X |
| | Luangwa Valley Wetlands | Luangwa flood plain on Precambrian basement and Karoo sediments | Seasonal river flood, rainfall and groundwater seepages | Mainly protected area, limited hunting, sparse population | DS XX<br>WS X | XX |
| | Bangweulu Basin Wetlands | Alluvium filed cratonic depression on Precambrian Basement | Lake with seasonally inundated floodplains and swamps, river floods, rainfall and groundwater seepages | Fishing, hunting and shifting cultivation, partly protected area | DS X<br>WS X | X |
| | *Lake Mweru System:*<br>1. Lake Mweru and Luapula Floodplain | Lake and flood plain on Precambrian Basement | Lake with seasonally inundated floodplains and swamps, river floods, rainfall and groundwater seepages | Fishing, hunting and shifting cultivation, unprotected area | DS X<br>WS X | X |
| | 2. Lake Mweru Wa Ntipa | Lakes, swamps and flood plains on Precambrian Basement | Lakes with seasonally inundated floodplains and swamps, river floods, rainfall and groundwater seepages | Some flood plain cultivation, protected area | DS XX<br>WS X | XX |
| | Lake Tanganyika | Lake on faulted rift in Precambrian Basement infilled with Karoo sediments and alluvium | Lake with seasonally inundated floodplains and swamps | Fishing, with some protected areas | DS X<br>WS X | X |
| | Lakes Lusi and Ishiba Ngandu | Lakes and swamps on Precambrian Basement | Lakes with seasonally inundated swamps, river floods, rainfall and groundwater seepages | unprotected area | DS XX<br>WS X | XX |
| | *Artificial Impoundments:*<br>1. Lake Kariba | Precambrian Basement and Karoo sediments | Lakeside seasonally inundated, some recharge to groundwater in karro sediments | Fishing. Limited hunting, some protected areas | DS XX<br>WS X | XX |
| | 2. Kafue Gorge Dam | Precambrian Basement | Seasonal river flows, some groundwater seepages | Limited hunting, some protected areas | DS XX<br>WS X | XX |
| | 3. Lake Itezhitezhi | Kalahari beds and Precambrian Basement | Seasonally inundated swamps, river floods, rainfall and groundwater seepages | Protected area, some fishing | DS XX<br>WS X | XX |
| | 4. Mulungushi and Mita Hills Dams | Precambrian Basement | Seasonal river flows, some groundwater seepages | Some fishing, unprotected | DS XX<br>WS X | XX |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Zimbabwe** | Mid-Zambezi Valley and Mana Pools | Precambrian Basement and Karoo sediments | Lakeside seasonally inundated, some recharge to groundwater in karro sediments | Fishing. Limited hunting, some protected areas | DS XX<br>WS X | XX |
| | Save river Wetlands | Recent river alluvium upon Precambrian Basement and Karoo sediments | Seasonal river flow, groundwater developed in sand river and flood plain sediments, and in underlying Karoo basalts and sandstones | Impounded river water and groundwater used for irrigation, lower reaches of Save in protected areas | DS XXX<br>WS XX | XXX |
| | Gorhwe Pan<br>Manjinji Pan | Underlain by Karoo mudstones | Seasonal runoff and rainwater | Watering of cattle and wildlife, some areas protected | DS XXX<br>WS XX | XXX |
| | Western Districts Pans | Underlain by Kalahari sediments and Karoo basalts | Seasonal runoff and rainwater | Watering of cattle and wildlife, some areas protected | DS XXX<br>WS XX | XXX |
| | *Artificial impoundments:*<br>1. Lake Kariba | Precambrian Basement and Karoo sediments | Lakeside seasonally inundated, some recharge to groundwater in karro sediments | Fishing. Limited hunting, some protected areas | DS XX<br>WS X | XX |
| | 2. Lake Kyle | Precambrian Basement | Lakeside seasonally inundated, some recharge to groundwater | Fishing. Limited hunting, some protected areas | DS XXX<br>WS XX | XXX |
| | 3. Impoundments on the Hunyani River | Precambrian Basement | Lakeside seasonally inundated, some recharge to groundwater | Fishing. Limited hunting, some protected areas, water supply for Harare | DS XXX<br>WS XX | XXX |

**Key**

**Water Scarcity: DS – dry season, WS – wet season, XXX – great, XX – moderate, X – low**

**Drought Sensitivity: XXX – high, XX – moderate, X - low**

## Social, Political and Economic Constraints on Groundwater Data Collection in SADC Countries since Independence

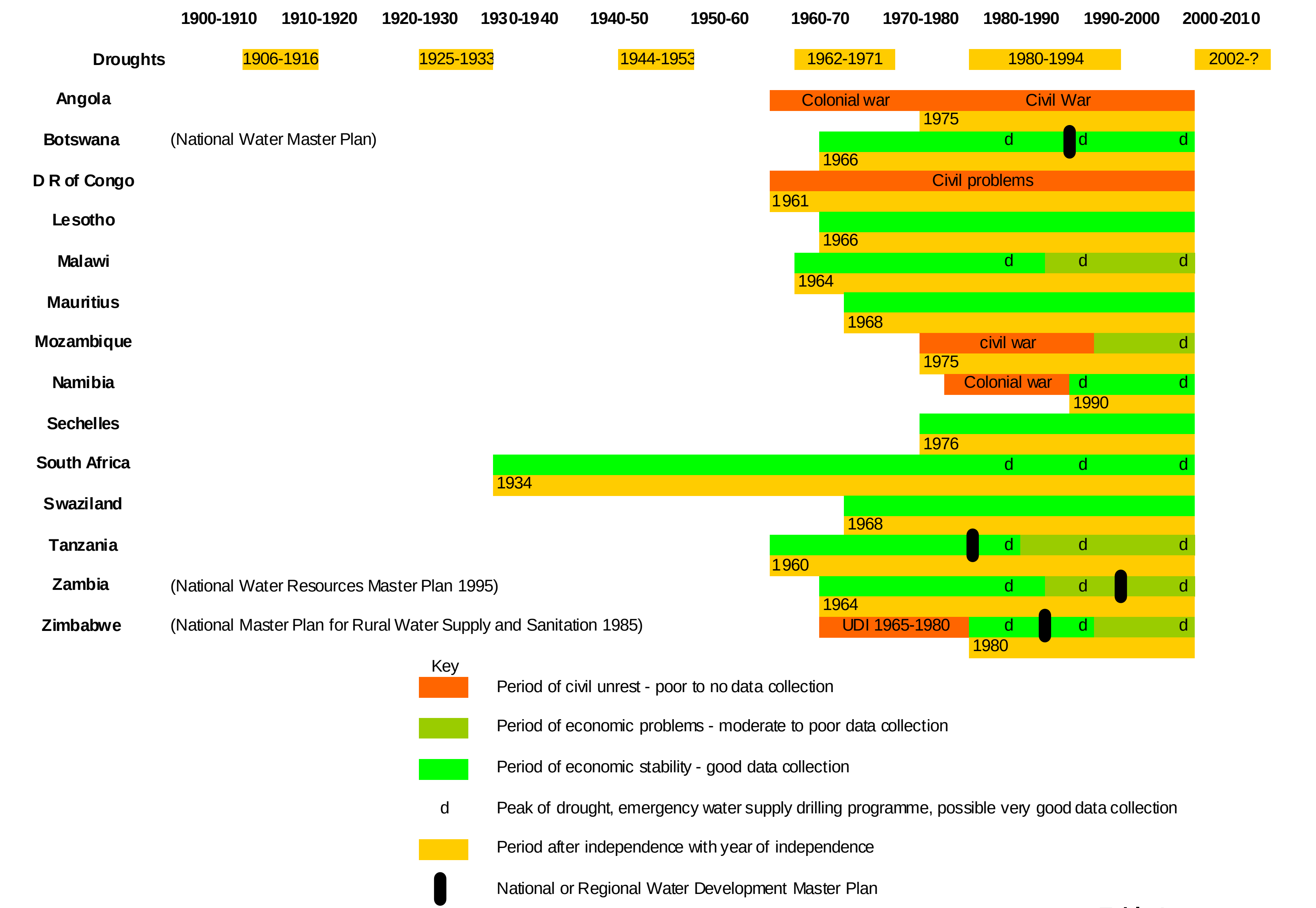



**Table 1.**

## Impacts of Major Events, Institutional Changes and Technological Innovations Upon Groundwater Data Collection in the SADC Region

| | Decades | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1900-1910 | 1910-1920 | 1920-1930 | 1930-1940 | 1940-50 | 1950-60 | 1960-70 | 1970-1980 | 1980-1990 | 1990-2000 | 2000-2010 |
| ***Topics*** | | | | | | | | | | | |
| **2.1. Major events** | | | | | | | | | | | |
| Warfare | | WWI | | | WWII | | colonial and civil war within some SADC states | | | | |
| Disease | | | | | | | | | | HIV/AIDS pandemic | |
| Droughts | 1906-1916 | | 1925-1933 | | 1944-1953 | | 1962-1971 | | 1980-1994 | | |
| | | | | | | | | | | | |
| **2.2. Institutional Building/Development** | | | | | | | | | | | |
| Groundwater at Geological Surveys | | | | | | | | | | | |
| Groundwater at Depts of Water/Water Affairs | | | | | | | | | | | |
| Period of granting of Independence | | | | | | | | | | | |
| Secondment of geologists to government posts | | | | | | | | | | | |
| Donor funded groundwater projects | | | | | | | | | | | |
| NGO led water supply projects | | | | | | | | | | | |
| Provision of village water supply bhs | | | | | | | | | | | |
| World water decade 1 | | | | | | | | | | | |
| World water dacade 2 | | | | | | | | | | | |
| Period of prolific data production | | | | | | | | | | | |
| General application of computer models | | | | | | | | | | | |
| Increased use of groundwater consultants | | | | | | | | | | | |
| Increased use of contract drilling companies | | | | | | | | | | | |
| | | | | | | | | | | | |
| **2.3. Transport Changes** | | | | | | | | | | | |
| Sea | | | | | | | | | | | |
| Rail | | | | | | | | | | | |
| Air | | | | | | | | | | | |
| Road (4x4 vehicles) | | | | | | | | | | | |
| Tarred roads | | | | | | | from 1960 Zimbabwe | from 1975 in Botswana | | | |
| | | | | | | | | | | | |
| **2.4. Evolution in groundwater supply/use** | | | | | | | | | | | |
| Provision of village water supply bhs | | | | | | | | | | | |
| Village level operation and maintenance of handpumps | | | | | | | | | | | |
| Crop irrigation using groundwater | | | | | | | | | | | |
| Urban water supply using groundwater in key cities | | | | | | | | Lusaka | | Bulawayo | |
| Mine minerals processing using groundwater | | | ???? | Pumped drainage water used for crushed ore processing | | | | Effects from closed flooded mines | | | |

**Table 2.**

# Availability of Tools, Techniques and Databases for the Assessment of Groundwater Resources in the SADC Region

| | Nos | 1900-1910 | 1910-1920 | 1920-1930 | 1930-1940 | 1940-50 | 1950-60 | 1960-70 | 1970-1980 | 1980-1990 | 1990-2000 | 2000-2010 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Main drought periods | | 1906-1916 | | 925-193 | | 944-195 | | 1962-1971 | | 1980-1994 | | 2002-? |
| **3.1. Maps and Images** | | | | | | | | | | | | |
| Topographic maps | | | | | | | 1:125 000 topo maps | | | 1:50 000 topo maps | | digital maps? |
| Geology maps | | | | | | | | 1:125 000 geology maps | | 1;100 000 or 1:250 000 geol maps | | digital maps |
| Hydrogeology maps | | | | | | | | | | | | |
| Soils maps | | | | | | | | FAO maps | | | | |
| Satellite images | | | | | | | | | | Landsat tm and Spot | | Landsat etm |
| Aerial photos | | | | | | | | | | | | |
| Wetlands/ecosystems maps | | | | | | | | | | | | |
| Land use maps | | | | | | | | | | | | |
| **3.2. AvailableTechnology** | | | | | | | | | | | | |
| Water level recorders -dippers | | | | | | | | | | | | |
| Drum water level recorders | | | | | | | | | | | | |
| Transducer water level recorders | | | | | | | | | | | | |
| Digital water level recorders | | | | | | | | | | | | |
| Cable too percussion drilling | | | | | | | | | | | | |
| Down the hole hammer drilling | | | | | | | | | | | | |
| Electric calculator | | | | | | | | | | | | |
| Personal computers | | | | | | | | | | | | |
| Global positioning systems (GPS) | | | | | | | | | | | | |
| **3.3. Databases Needed for Map Production (in part generated by data-gathering aids list above (3.2** | | | | | | | | | | | | |
| *Descriptive list of databases* | Nos | | | | | | | | | | | |
| Rainfall data | 1 | | | | | | | | | | | |
| River flow data, staged | 2 | | | | | | Phase 1 | | | Phase 2 | | |
| River flow data, hydrographs | 3 | | | | | | | | | | | |
| Evaporation data | 4 | | | | | | | | | | | |
| Population census | 5 | | | | | | | | | | | |
| Borehole locations/hydrocensus data | 6 | | | | | | | | | | | |
| Borehole hydrographs | 7 | | | | | | | | | | | |
| Soils data | 8 | | | | | | | | | | | |
| Vegetation distribution | 9 | | | | | | | | | | | |
| Water demand | 10 | | | | | | | | | | | |
| Geological data | 11 | | | | | | | | | | | |
| Hydrochemical data | 12 | | | | | | | | | | | |
| Land use data | 13 | | | | | | | | | | | |
| Recharge data | 14 | | | | | | | | | | | |
| Soils/weathered rock permeability data | 15 | | | | | | | | | | | |
| Borehole specific capacity data | 16 | | | | | | | | | | | |
| Groundwater storage data | 17 | | | | | | | | | | | |
| Depth to water data | 18 | | | | | | | | | | | |

**Table 3**

## Overview of the Databases Needed for Mapping Tool Production

| Database Type | Database No. | Drought Vulnerability Map | Pollution Vulnerability Map | Groundwater Demand Map | Groundwater Availability Map |
|---|---|---|---|---|---|
| Rainfall data | 1 | 1 | 1 | 1 | 1 |
| River flow data, staged (runoff) | 2 | 2 | 2 | 2 | 2 |
| River flow data, hydrographs | 3 | 3 | 3 | 3 | 3 |
| Evaporation data | 4 | 4 | 4 | 4 | 4 |
| Population census | 5 | 5 | 5 | 5 | 5 |
| Borehole locations/ hydrocensus data | 6 | 6 | 6 | 6 | 6 |
| Borehole hydrographs | 7 | 7 | 7 | 7 | 7 |
| Soils data | 8 | 8 | 8 | 8 | 8 |
| Vegetation distribution | 9 | 9 | 9 | 9 | 9 |
| Water demand | 10 | 10 | 10 | 10 | 10 |
| Geological data | 11 | 11 | 11 | 11 | 11 |
| Hydrochemical data | 12 | 12 | 12 | 12 | 12 |
| Land use data | 13 | 13 | 13 | 13 | 13 |
| Recharge data | 14 | 14 | 14 | 14 | 14 |
| Soils/weathered rock permeability data | 15 | 15 | 15 | 15 | 15 |
| Borehole specific capacity data | 16 | 16 | 16 | 16 | 16 |
| Groundwater storage data | 17 | 17 | 17 | 17 | 17 |
| Depth to water data | 18 | 18 | 18 | 18 | 18 |

Note 1: The 18 types of database listed are those required to understand aspects of the hydrological cycle and produce the tools for groundwater resources management

Note 2: To produce the four proposed Groundwater Management Mapping Tools only certain of these databases are required for each tool.

Note 3: The specific databases that are needed for each tool are denoted by colour shading

Table 4

# Databases and the Prospects for Mapping Tool Production in Individual SADC States

| Map types | Drought Vulnerability Map | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Database Nos | 1 | 4 | 5 | 6 | 8 | 10 | 11 | 13 | 14 | 15 | 17 | |
| Angola | M | M | M | P | G | P | P | P | P | P | P | no |
| Botswana | G | G | G | G | G | G | G | G | G | G | G | yes |
| D R of Congo | M | M | M | P | G | P | P | P | P | P | P | no |
| Lesotho | G | G | G | G | G | M | G | M | P | M | M | yes |
| Malawi | G | G | G | M | G | M | M | G | P | M | M | maybe |
| Mauritius | G | G | G | G | G | G | G | G | M | M | G | yes |
| Mozambique | M | M | M | P | G | P | M | P | P | P | P | no |
| Namibia | G | G | G | G | G | G | G | G | G | G | G | yes |
| Sechelles | G | G | G | G | G | M | G | G | M | M | M | yes |
| South Africa | G | G | G | G | G | G | G | G | G | G | G | yes |
| Swaziland | G | G | G | G | G | M | G | G | M | P | M | yes |
| Tanzania | G | G | G | M | G | M | M | G | P | M | M | maybe |
| Zambia | G | G | G | M | G | M | G | G | P | P | M | maybe |
| Zimbabwe | G | G | G | G | G | M | G | G | M | M | G | yes |

| Map types | Pollution Vulnerability Map | | | | | | |
|---|---|---|---|---|---|---|---|
| Database Nos | 8 | 11 | 13 | 14 | 15 | 18 | |
| Angola | G | P | P | P | P | P | no |
| Botswana | G | G | G | G | G | G | yes |
| D R of Congo | G | P | P | P | P | P | no |
| Lesotho | G | G | M | P | M | M | maybe |
| Malawi | G | M | G | P | M | M | no |
| Mauritius | G | G | G | M | M | G | yes |
| Mozambique | G | M | P | P | P | P | no |
| Namibia | G | G | G | G | G | G | yes |
| Sechelles | G | G | G | M | M | M | maybe |
| South Africa | G | G | G | G | G | G | yes |
| Swaziland | G | G | G | M | P | M | maybe |
| Tanzania | G | M | G | P | M | M | no |
| Zambia | G | G | G | P | P | M | maybe |
| Zimbabwe | G | G | G | M | M | G | yes |

| Map types | Groundwater Demand Map | | | | | |
|---|---|---|---|---|---|---|
| Database Nos | 5 | 6 | 10 | 11 | 14 | |
| Angola | M | P | P | P | P | no |
| Botswana | G | G | G | G | G | yes |
| D R of Congo | M | P | P | P | P | no |
| Lesotho | G | G | M | G | P | maybe |
| Malawi | G | M | M | M | P | maybe |
| Mauritius | G | G | G | G | M | yes |
| Mozambique | M | P | P | M | P | no |
| Namibia | G | G | G | G | G | yes |
| Sechelles | G | G | M | G | M | yes |
| South Africa | G | G | G | G | G | yes |
| Swaziland | G | G | M | G | M | yes |
| Tanzania | G | M | M | M | P | maybe |
| Zambia | G | M | M | G | P | maybe |
| Zimbabwe | G | G | M | G | M | yes |

| Map types | Groundwater Availability Map | | | | | | |
|---|---|---|---|---|---|---|---|
| Database Nos | 6 | 11 | 12 | 14 | 17 | 18 | |
| Angola | P | P | P | P | P | P | no |
| Botswana | G | G | G | G | M | G | yes |
| D R of Congo | P | P | P | P | P | P | no |
| Lesotho | G | G | M | P | M | M | maybe |
| Malawi | M | M | P | P | P | M | no |
| Mauritius | G | G | G | M | M | G | yes |
| Mozambique | P | M | P | P | P | P | no |
| Namibia | G | G | G | G | G | G | yes |
| Sechelles | G | G | G | M | M | M | yes |
| South Africa | G | G | G | G | G | G | yes |
| Swaziland | G | G | M | M | M | M | maybe |
| Tanzania | M | M | M | P | M | M | no |
| Zambia | M | G | M | P | M | M | maybe |
| Zimbabwe | G | G | M | M | M | G | yes |

**Note 1:** The scope to produce maps in each SADC state is assessed and listed as "no", "maybe" or "yes" to the right of the status entriesfor each categorisation

**Note 2:** The status entries indicate the usefullness of the individual data bases within the individual states (G - good, M - moderate to patchy, or P - poor to non-existar **Table 5**