# *J:* SOUTH AFRICA

## *J.1 INTRODUCTION*

The South African country visit was undertaken by Peter Rosewarne of SRK Consulting from 24th to 25th February and 12th to 15th March 2002. The main institutions/personnel visited and interviewed are listed in Table 1 on page 2.

Some of the basic information on groundwater occurrence and institutional aspects have been taken from the country report for the 'Minimum Standards' project, updated where necessary. Use has also been made of information on the Department of Water Affairs and Forestry (DWAF) and Council for Geoscience (C for G) websites.

## *J.2 BACKGROUND*

### J.2.1 Physiography and Climate

South Africa is a largely semi-arid to arid country and is classed as one of the twenty most water stressed countries in the world (United Nations, 1995). The average annual rainfall of about 500 mm is well below the world average of 860 mm. Only a comparatively narrow region along the eastern and southern margins is moderately well watered.

### J.2.2 Water Resources

The combined average annual run-off of South Africa's rivers is about 53 500 $Mm^3$, of which it is estimated that only about 62% or 33 000 $Mm^3$ can be economically exploited. In addition, about 5400 $Mm^3$ of groundwater may be exploitable with total use in 2000 having been ~3360 $Mm^3$ (Vegter 2001). Estimated groundwater use in 1980 was 1790 $Mm^3$ (DWAF 1986).

## *J.3 GEOLOGY AND HYDROGEOLOGICAL FRAMEWORK*

### J.3.1 Geology and Hydrogeology

Over approximately 90% of the area of South Africa, groundwater occurs in secondary aquifers in the form of weathered and fractured hard-rock formations ranging in age from earliest Pre-Cambrian to Jurassic and comprising sedimentary, metamorphic and extrusive and intrusive igneous rocks. This compounds the water-stress of the country as recharge is limited and also erratic.

Vegter (2001) has divided the country into 65 Groundwater Regions. The first order division is in terms of interstice origin, i.e. primary or secondary. There are four regions consisting mainly of the former, developed in Tertiary-Quaternary formations. The remaining 61 regions consisting mainly of secondary water bearing formations are divided into five categories, viz:

B1 Crystalline metamorphic and igneous
B2 Intrusive
B3 Extrusive
B4 Sedimentary
B5 Composite

With respect to rock types and dependence for water supply, the two most important aquifers in South Africa are the Karoo Aquifers and the Karstic Aquifers. The Table Mountain Group Aquifer and

Recent coastal sand aquifers and some crystalline basement aquifers, e.g. Dendron are also of importance.

### J.3.2 Natural Groundwater Quality

The coastal and inland arid areas, such as Namaqualand and the Kalahari, are characterized by NaCl type groundwater. The Karoo is characterized by $CaMg/ClSO_4$ type groundwater, while the rest of the country is mainly characterized by $CaMg/HCO_3$ type groundwater.

In terms of potability, TDS ranges from 10 mg/l in mountainous areas of the Table Mountain Group Aquifer in the Western Cape to >1500 mg/l, in Namaqualand and the Kalahari. Most of the Karoo Aquifer groundwater is <500 mg/l dropping to <300 mg/l over the rest of the east-central, eastern and northern parts of the country.

Nitrate and fluoride levels are a problem in the arid north-western, north-central and north-eastern parts of the country.

## *J.4 DATA ACQUISITION*

### J.4.1 Institutional Framework for Data Collection

The institutions and personnel contacted as part of this project are listed in Table 1.

**Table 1: Institutions and personnel contacted**

| Component | Institution | Personnel |
|---|---|---|
| Institutional aspects<br>Information systems<br>Hydrogeological mapping | Department of Water Affairs: Directorate: Geohydrology | E Braune<br>J Girman<br>E Betram<br>PS Meyer |
| Hydrogeological mapping<br>General groundwater information<br>Geological mapping | Council for Geoscience | K Sami<br>F Harzer |
| Research issues | Water Research Commission | K Pieterson |
| General groundwater information | CSIR | R Meyer |

The water sector institution framework has undergone extensive transformation in recent years with an emphasis on decentralisation, wherein more and more responsibilities are rested in provincial and local governments (district municipalities), with only regulatory responsibilities left to central agencies.

The DWAF plays the key role in guiding the water resources development and management and is the national custodian of the water resources of South Africa. The department now has 9 regional offices in as many provinces, with a head office in Pretoria. The department consists of 9 Chief Directorates. The DG falls under the Chief Directorate of Scientific Services, together with directorates of Hydrology, Institute for Water Quality Studies, Geomatics and 'Social and Environmental Studies. These directorates function as service departments. However, further institutional restructuring is underway.

DG is mainly responsible for directing the protection and assessment of groundwater resources and for building capacity and managing information systems to ensure the sustainable development of groundwater (Business Plan, 1999). In the near future its main emphasis is on groundwater resources assessment and on marketing available relevant policies, tools and guidelines.

In regard to water supply, there are no specific departments or organisation (unlike some of the other SADC Member States) that are clearly and separately responsible for water supply to urban and rural areas. In the recent past, water supply to urban centres used to fall under municipalities and for rural centres under the DWAF. Within the new structure and ongoing reforms, responsibilities of water supplies are laid on the local governments such as Transitional Local Councils (TLCs), District Councils (DCLs), Transitional Rural Councils (TRCs) etc, without any distinction between the urban and rural water supplies.

The WRC is a statutory organisation that promotes co-ordination, communication and co-operation in the field of water research, establishes water resource needs and priorities, funds water research on a priority basis and promotes the effective transfer of information and technology. The bulk of the research is undertaken by universities, the CSIR and consultants.

The C for G are involved in geological and hydrogeological mapping and general groundwater investigations. They have proposed a legend for the SADC hydrogeological map and are producing the SADC geological map. This is at a scale of 1:2.5 million and should be ready in draft form by early 2003 (pers comm. F Harzer).

## *J.5 GROUNDWATER INFORMATION SYSTEM*

### J.5.1 Hardware and Software

#### *J.6.1.2 Department of Water Affairs and Forestry*

The DG has a vested responsibility towards the custodianship of all groundwater information nationwide. The National Groundwater Database (NGDB) was brought into commission in 1986 to meet an urgent need to validate and store borehole and other groundwater-related data. The NGDB was initially housed on a large mainframe computer in Pretoria but currently the Open-NGDB runs in a server/client environment and contains records of over 220 000 boreholes countrywide, as well as various time-dependent variables such as groundwater levels. The populating of the NGDB is continuing as more borehole and groundwater-related data become available. The groundwater information system was later expanded with the introduction of data processing and graphics software, and with added facilities to support hydrogeological mapping, which are PC- or workstation-based. Lately the Dutch groundwater information system called REGIS has been added and soon this graphical interface, allowing limited spatial processing, will be available in four of the Regional offices.

The stored borehole data have provided an invaluable platform from which to launch the national and regional hydrogeological mapping initiatives being undertaken by the DG. The borehole and groundwater-related data capturing capacity of the DG is also being systematically extended with the development of customized software for use by local authorities, and later the agricultural sector.

The present groundwater information system was designed around the NGDB and has been progressively expanded as the needs for more versatility and improvement in data capture, data processing and integration with spatial data have demanded. The more recently supported application software embody a higher level of sophistication of information technology than that of the master database, which has resulted in some incongruency. Relational data models that are now universally adopted by DWAF as standard technology were not fully applied at the time of the design of the NGDB.

The NGDB's function is simply to store validated borehole records and other groundwater-related data such as groundwater levels on a national basis. It forms one component of DWAF's Hydrological Information System (HIS). The data structure design of the NGDB was based on the United States

Geological Survey WATSTORE specification, and was implemented as a hierarchical data base. The user-interface is character-based. Data up- and download are via a formatted ASCII transmission file, subject to strict validation procedures. Currently, 95% or more of the stored borehole data are loaded via terminals at DWAF's headquarters, with some support from the regional offices. Groundwater chemistry data are stored in the Water Management System (WMS) which is linked to the NGDB via a borehole site identification reference number.

A summary of DWAF information systems is provided in Table 2.

**Table 2: Summary of DWAF Information Systems**

| Database/ Source | In use | No of records | Format | Useable[1] | Comments |
|---|---|---|---|---|---|
| REGIS | ✓ | ? | Oracle | Yes | See Text. |
| NGDB | ✓ | >220 000 | Informix database | Yes | See text. |
| WMS | ✓ | >55 000 | Informix database | Yes | See text. |
| Hydrocom | ✓ | ? | DBASE 3 | Yes | PC-based groundwater information system with the function to capture, store and analyze groundwater and related data. Its data structure is very similar to that of the NGDB. |
| PC-Muniwater | No | None | Access and Visual Basic | Yes | Intended for groundwater data collection at the level of the local authority supported by DWAF, at the same time as providing management support facilities at that level. Never implemented due to 'politics'. |

[1] Useable for SADC Hydrogeological Map

The NGDB is now over 15 years old and was designed on now out-dated information technology principles. The software packages that were designed later, as support of the NGDB, are also limited in their application because of shortcomings in their compatibility and user-friendliness. The current system also lacks the ability to fully integrate with GIS functionality and does not provide an efficient service to the multitude of clients who use the system.

Steps were therefore taken in 1996 within the DG to instigate the development of a new groundwater information system to meet the challenges of technological development and client requirements. Plans are well underway to develop the National Groundwater Archive (NGA) to alleviate above-mentioned shortcomings. The new Water Act of 1998 also introduced new requirements in terms of legal aspects and also revolutionized the whole approach to water resources planning and use.

A requirement of the new national Water Act is the implementation of water resource information systems. The state is the custodian of all water resources and this will have a major impact on the distribution of water. Water use will have to be authorized and licensed. New planning requirements which require information by means of information systems will be needed. National water information systems require national water monitoring and analysis and there will be large volumes of data generated and therefore a new information system is fully justified.
Under the National Groundwater Information System (NGIS) portfolio the NGA is being designed to meet the increasing demands for groundwater information in a rapidly changing water business

environment. The system will be distributed among regional offices and will integrate both spatial and non-spatial data. It will also accommodate an increased visualization and analytical functionality.

The portfolio of the NGIS project includes several subprojects. Amongst the most important are REGIS Africa and the National Groundwater Archive. REGIS is an acronym for Regional Geohydrological Information System. It is a complete hydrogeological information system, in which all relevant hydrogeological and related data are stored, managed, manipulated and queried in a uniform way. REGIS can be used for the evaluation of (geo) hydrological situations on a national and regional scale. The facilities in REGIS for storing, manipulating and interpretation can be applied on data of any scale.

REGIS is developed by the Nederlands Instituut voor Toegepaste Geowetenschappen TNO and is used by Governmental Organisations as well as by private organisations.

REGIS version 3 has been developed since 1998. This version is based on the latest possibilities for the accessing and usage of spatial and administrative data and it replaces the previous REGIS versions. In the first place, Version 3 is meant to access, manage and visualise the most important hydrogeological data in a simple way. Visualisation is done by means of maps, profiles, columns, graphs, forms and reports.

The system consists of a GIS and a relational database that is linked to it. The relational database is built in *Oracle* and contains all non-spatial data of the hydrogeological object that is added to the system, for example administrative data, technical data, and measured and derived hydrogeological parameters. The GIS consists of *ArcView* in which REGIS is implemented as an extension. Apart from some general functions, this REGIS extension contains hydrogeological functions and a catalogue with hydrogeological themes (objects). The spatial data on these objects (location and geometry) are managed in the GIS. From the GIS, direct communication is possible with the relational database, where the non-spatial data are stored. This enables one to make a spatial selection which forms the basis from which one can select data from the relational database and data that are accessed can then be visualised in the GIS in a graph, a profile, a column or a map.

The NGDB, WMS are still relevant to REGIS.

### J.5.2 Quality of data

Quality assurance and control measures are in place at monitoring/sampling stations, at the data management stage and at the hydrogeological map production stage. In the case of the first activity, QA/QC consists of random checks by a reviewer with a university degree. In the case of the second activity, QA/QC consists of full protocols. A Data Quality Audit Project has been initiated by the DG. The aim of the project is to evaluate the quality of some of the main attributes of borehole records stored in the NGDB, and to improve it as far as possible. The target is to enhance the reliability of the stored data, in relation to captured data, to the level of 95 %.

The following borehole attributes are being audited:

- Site ID, coordinates, accuracy of coordinates, map number, farm name, district number, drainage region code, comment field (all from Entry table);
- depth of borehole (from Hole table); and
- water level, borehole yield (from Aquifer table).

Additionally, borehole records are being linked to groundwater chemical analyses stored in WMS where available. A Data Quality Index is also being prepared for each borehole record (will be described and made available at a later stage).

The data quality audit itself is being undertaken in the PC environment and the audited data are returned back to Open-NGDB. To enhance the quality and efficacy of the undertaking use is being made of:

- ArcView-based procedures to determine basic statistical characteristics of the data sets, and, to visualize borehole locations; and
- purpose-tailored program checking the data integrity, and, transmission of audited data sets to the NGDB.

As the project proceeds audited data sets will become available for download in the form of plain text files for each printed 1 : 500 000 scale hydrogeological map sheet. Included in the download files will be the coordinates, Site ID and Data Quality Index of each borehole. The detailed data will be obtainable from the Directorate: Geohydrology on request (possibly based on list of site IDs provided by the user). Audited maps include Gauteng Province, Eastern Cape and Vryburg. The data from the Eastern Cape are available for download.

In the case of map production, a full editorial committee has been established (see Section J7.2).

## *J.6 GROUNDWATER MONITORING*

The new National Water Act makes it very clear that groundwater has become a strategic resource in South Africa and will largely provide the solution in meeting the basic water demands of the rural communities if managed correctly. Specific implications for groundwater include:

- The ownership of land will no longer be the prerogative for free access to groundwater on that property, in other words the status of groundwater will change to that of a public resource.
- A portion of the groundwater will be reserved to meet the basic demands for domestic water and to sustain downstream ecology;
- Large users of groundwater will require licenses to abstract groundwater at levels above general authorization thresholds, and will be levied on volumes abstracted;
- National groundwater information systems and monitoring networks need to be established and maintained to provide reliable groundwater information to information users.
- Operational functions will be devolved to lower institutional structures to manage catchment and local groundwater resources;
- Catchment management authorities will be established to ensure the equitable and sustainable allocation of water resources including groundwater at the level of the catchment;
- Sustainable allocation of water resources, including groundwater, at the level of the catchment.

### J.6.1 Monitoring Network and Frequency

#### *J.6.1.1 Department of Water Affairs and Forestry*

There are about 360 monitoring stations where a groundwater quality monitoring network has been established. Samples are collected twice a year, before the onset of the rainy season and once after the rainy season. The network was initiated in 1993 and currently covers the whole country except Kwazulu-Natal, where a system has not yet been implemented. The analysis is fairly comprehensive and includes trace elements, stable isotopes together with regular analysis for major elements and microbiological constituents. Over 55 000 groundwater analyses are stored in the WMS. In addition to the national network, many of the regional offices also conduct ad-hoc sampling and mechanisms are being put in place to ensure that these results also reach the WMS.

The objectives of the national water quality monitoring network are to measure the temporal changes of the ambient groundwater quality, i.e. natural changes in unimpacted conditions. This will supply baseline conditions when interpreting possible impacts.

South Africa also has a comprehensive water level monitoring network. At present the network consists of more than 1000 stations of hand measurements, 300 equipped with drum recorders and 65 with data loggers (all using the Orphimedes logger – working on the bubble principle). The frequency of measurement is monthly for manual stations and continuous for stations equipped with data loggers. There are plans to build capacity for weekly and daily measurements under a NORAD project.

The current monitoring networks are a mix between levels 1 & 2 & 3; i.e. unimpacted, possibly influenced by abstraction but not showing direct effects of pumping (used probably for aquifer management) and production hole monitoring (or compliance monitoring).

Using an autographic recorder the line drawn by a pen represents moment-by-moment recording, the resolution, depending on the chosen time scale, i.e. drum rotated in 20min, 12 or 24hours, or 31 days. Using electronic devices, any time-scale can be chosen starting from 1 second upwards (some data loggers even allow for a logarithmic time scale).

Classification of the monitoring network into three levels, starting from the regional level (Level-1) down to wellfield level (Level-3), is in process. Efforts are also directed in spreading the network more uniformly across the country, which is currently linear and is biased towards the main groundwater utilisation areas. Monitoring stations are indicated on the 1:500 000 scale hydrogeological maps.

One of the areas where monitoring is lacking is groundwater abstraction, where there is no monitoring in place.

#### *J.6.1.2 Private Sector*

Extensive monitoring of groundwater is carried out within the private sector. This relates to monitoring of water levels, abstraction and hydrochemistry in production wellfields. Some examples of large-scale abstraction and associated monitoring include Atlantis (Primary aquifer) near Cape Town, Klein Karoo Rural Water Supply Scheme (TMG Aquifer) near Oudtshoorn, Beaufort West (Karoo Aquifer), Far West Rand (Dolomite Aquifer), to name a few.

Some of these data have been/are entered into databases, such as WELLMAN, but these are outside of the main NGDB.

## *J.7 HYDROGEOLOGICAL MAPPING*

### J.7.1 Initial Hydrogeological Maps

As a first attempt towards hydrogeological mapping, a set of maps (National Groundwater Resource Map of South Africa) was compiled in 1995 at various scales by Vegter (1995). The maps are presented in two sheets with an accompanying explanation brochure and are aimed at direct application for day-to-day practitioners. These maps depict:

- Borehole Prospects (1:2,500,000) Map showing 18 categories of zones delineated on the basis of probability of drilling a successful borehole (yielding greater than 0.1 l/s) and one yielding greater than 2 l/s;

- Saturated Interstices (1:4,000,000) Map showing 16 categories of zones delineated on the basis of storage medium and recommended drilling depth;
- Mean Annual Recharge Map (1:7,500,000) showing the spatial distribution of recharge;
- Groundwater Component of River Flow (Baseflow) (1:7,500,000);
- Depth to Groundwater Level (1:7,500,000);
- Groundwater Quality Map (1:7,500,000) in terms of TDS, Nitrate and Fluoride; and
- Hydrochemical Types (1:7,500,000) of groundwater.

This contribution was followed by the Harvest Potential Map of South Africa in 1996 (Baron et.al., 1998) is a derivative of the above maps. It presents the exploitable annual volumes of groundwater taking into account groundwater recharge and groundwater storage capacity and consists of four maps:

- A Harvest Potential Map (1:3,000,000) classifying areas according to the maximum volume of groundwater that may be abstracted per square kilometre per annum without depleting the aquifers;
- A map (1:8,500,000) showing areas according to the factors that affect the harvest potential in terms of volume of recharge, variability of annual recharge and effective storage volume;
- A map (1:8,500,000) showing average borehole yield; and
- A map (1:8,500,000) showing groundwater quality in terms of TDS.

Paraphrasing from the accompanying explanatory report: "The map quantifies groundwater resources. It permits direct comparison of different groundwater areas and facilitates comparison with surface resources. Harvest Potential is the sustainable volume of groundwater that may be abstracted per $km^2$ per annum". However, according to Vegter (2001), these claims are not justified:

- The national groundwater recharge map is a provisional attempt. As stated in the accompanying explanation "Although mean recharge is expressed quantitatively, the map should be seen as depicting broad trends rather than laying claim to accurate regional recharge figures" (Vegter 1995). Furthermore, regional values may not be translated into values per $km^2$ because recharge conditions are variable, not homogeneous, within any categorised recharge area;
- In the absence of other relevant and better-suited information, effective rainfall has been taken as one of the guidelines in drawing the provisional recharge map. This does not mean that recharge is proportional to rainfall. There is no evidence to suggest that minimum recharge can be estimated from the ratio of $20^{th}$ to $50^{th}$ annual rainfall percentiles. In a poor rainfall season, especially in the drier parts of South Africa, recharge most likely is nil;
- Droughts and periods of less and no recharge, particularly in the drier parts of the country, are not limited to single years;
- There is evidence that recharge events, especially in the drier parts of the country, are limited to the occasional occurrence of abnormally high rainfall;
- The classification of storage and its depiction on the national map is qualitative. Within any category, storage coefficient values and thickness of water-bearing zones vary between wide limits;
- Recharge and storage are not the sole factors that determine groundwater availability or harvest potential. The ultimate factor is the extent to which natural groundwater losses may be eliminated and translated into a pumped water supply. Apart from economic and practical considerations, this is determined in any particular situation by the local hydrogeological configuration or geometry, the permeability and storativity of the saturated formation.

The CSIR has also developed an Aquifer Classification Map of South Africa (Parson and Conrad, 1998). It consists of four maps presented in a single sheet:

- Aquifer System Classification Map (1:3,000,000) that classifies the aquifers into 5 types;

- Aquifer Vulnerability Map (1:6,000,000) that defines the vulnerability to contamination using DRASTIC method;
- Aquifer Contamination and Susceptibility Map (1:6,000,000) that combines the above two maps; and
- Borehole Distribution Map (1:6,000,000).

### J.7.2 National Hydrogeological Map Series

South Africa embarked on a countrywide groundwater characterization programme in about 1992. Large amounts of groundwater data were obtained from thousands of old and more recent reports, the data of which were entered into the National Groundwater Data Bank, of which the Department of Water Affairs and Forestry is the custodian. Where areas of sparse information were identified, hydrocensuses were conducted in an effort to fill the gaps as far as possible.

It was realized early on that the characterization material had to be presented in some way, or that it had to be made available in some form and it was decided to compile groundwater maps in order to achieve this goal. DWAF embarked on the production of a general hydrogeological map series at the scale of 1:500 000 consisting of a total of 23 sheets in 1996/97. These are general hydrogeological maps and depict aquifer classes and typical yields of water boreholes together with simplified lithology of the underlying geology. Sixteen of the series are complete with five of them accompanied by printed explanation brochures.

The groundwater mapping programme was structured as follows:

1. It was decided to compile a countrywide map series at a scale of 1:500 000;
2. The country was divided into 23 map areas and each completed map was to be accompanied by an explanatory brochure.
3. A map author, preferably with a sound groundwater knowledge of a region, was allotted to each map area. The primary task of a map author was to analyse and manipulate the data in accordance with his knowledge of the area and to compile the map.
4. A Mapping Management Team, consisting of a Hydrogeological Manager, Cartography Manager, GIS Manager and a Secretary, was established. The task of the Mapping Management Team is to co-ordinate, guide, steer and drive the mapping project and to assure uniformity.
5. An Editorial Board, consisting of at least three senior members of the Directorate Geohydrology, was instituted. Members of this panel are required to have a moderate knowledge of the country's geology, groundwater, geochemistry and of being reasonably versed in editorial and publication procedures. The task of the Editorial Board is to oversee the draft maps and brochures and to scrutinize every detail before final approval for publication.
6. It was decided to hold regular meetings, in practise once every 5 or 6 weeks, between the Mapping Management Team, the Editorial Board and the author of a map under discussion.

Each groundwater map consists of the following components:

- The main map at a scale of 1:500 000
- A groundwater quality map at a scale of 1:1 500 000
- A schematic cross-section or cross-sections to illustrate typical groundwater occurrences and groundwater conditions pertaining to the map area
- A chronostratigraphic column to depict all the geological groupings and units within a particular map area, with the unit code in brackets and which also provide a time perspective
- Three inset maps, each at a scale of 1:2 000 000, depicting borehole data distribution, elevation above sea-level and mean annual precipitation

The rest of the legend depicts *inter alia* the aquifer types and yield categories, lithology, groundwater abstraction, springs, thermal springs, roads, rivers, dams, etc with regard to the map area. The main map depicts the aquifer types and their expected immediate borehole yields, which are governed by transmissivity, but ignore storage and recharge. It also shows groundwater use in terms of annual abstraction in areas of large scale groundwater use. These features are superimposed against a somewhat subdued surface lithology background. Due to the scale of the map, the lithology is simplified and its compilation warrants a separate discussion. The aquifer types recognised are:

**Intergranular aquifers**, which are depicted in shades of blue.

**Fractured aquifers**. which are shown in shades of green.

**Karst aquifers** which are displayed in shades of olive-green.

**Intergranular and fractured aquifers**, more descriptively also known as weathered and fractured aquifers. These aquifers comprise in general all the crystalline rocks. These are shown in shades of yellow/brown.

**Multi-layered aquifers**. Where the top aquifer is an intergranular aquifer and the bottom aquifer is one of the hard rock aquifers, the yield categories are shown in the appropriate colour bars.

Analysis of borehole data from the National Groundwater Data Bank can be regarded as the basis to determine the different yield categories. After completion of the lithology map, the GIS personnel make what is termed a splash map, the yield data from the data bank being splashed onto the lithology in different colour dots for the different yield categories. For instance, black dots for all the yields of less than 0.1 l/s, red dots for the 0.1 – 0.5 l/s yield range, yellow dots for the 0.5 – 1.99 l/s yield range, green dots for the 2.0 – 4.99 l/s yield range and blue dots for the yields in access of 5 l/s. The splash map will also indicate areas of sparse information, which if possible, will be filled in by means of new data collection.

The data analysis is done by means of the median method where the number of data points within a groundwater unit or geological units are calculated and the median value determined. A concentration of a particular yield range within the groundwater unit can be defined while the rest of the median value for the rest of the unit can be calculated according to median calculation. The same method can be used to compile the 1:1 500 000 scale groundwater quality map.

The primary aim of a General Hydrogeological Map is to produce a synoptic overview of the geohydrological character of an area. The maps with the accompanying brochures introduce the current state of groundwater knowledge and the basic hydrogeological characteristics of a map area and should be useful for both groundwater scientists, laymen and planners.

Some of the more critical lessons learnt from the South African mapping experience are as follows (S Meyer pers. comm.):

1. Establish a proper data bank.
2. Appoint a hydrogeological manager with knowledge of groundwater mapping procedures to co-ordinate and steer the project.
3. The appointment of a map author with at least fair knowledge of his/her area and a fair measure of enthusiasm a must.
4. With modern computer technology available it is very tempting, especially for non-hydrogeologists, to propagate entirely computer generated maps. This issue was debated extensively within DWAF and a few individuals tried their hand at it. However, serious mistakes resulted and the whole idea was abandoned. The consensus, especially in earth

science circles, was that due to the many variables, particularly in hard rocks and the geological complexities, total computer generated maps are, at least at this stage of the mapping programme, not viable, especially in view of the large areas covered by intricate hard rocks. The hand of a map author with field experience is indispensable in groundwater mapping.

5. It is very important, once all teething problems have been ironed out, to work within a time-frame and to set firm target dates.
6. Get hold of, or train competent GIS personnel.
7. Appoint suitable cartographers.

### J.7.3 Classification and Legend of Maps

#### *J.7.3.1 Classification*

Extensive use was made of Arc/Info for cartographic compilation, data display and manipulation. Available borehole data from the National Groundwater Database (NGDB) was used and supplemented by field visits to areas of sparse data coverage. The delineation of groundwater occurrence was outlined at a scale of 1:50 000 with extrapolation from hydrogeologically well defined areas into areas of data scarcity. The boundaries of groundwater occurrence types were then drawn by hand to final scale. Additional changes and minor boundary alterations were done within GIS. The same methodology was used in the compilation of the 1:1 500 000 scale groundwater quality map, using data from the national Water Quality Data Base (NWQDB). The quality parameter that is expressed is the electrical conductivity (EC) of the groundwater. The EC intervals shown are taken from the Department of Water Affairs and Forestry (DWAF) guidelines for human and stock water consumption.

Due to a shortcoming in the NGDB, which does not distinguish between dry boreholes and boreholes with no data, dry boreholes had to be excluded from the borehole analyses. This is unfortunate, as information on dry boreholes can be helpful to determine an area's yield potential.

The map portrays the principal aquifer when more than one aquifer is present. Thus the insignificant yield of a surface sand layer would not be depicted if the underlying bedrock has a higher yield potential.

The following data limitations marred the borehole analyses:

- Poor data quality;
- Unscientifically site boreholes, which often mask the true overall yield potential of a rock unit; and
- Large areas of sparse data distribution.

The lithostratigraphy of each region, taken from the published 1:1 000 000 Geological Survey map, was regrouped and, where necessary simplified to lithological types. These types are displayed as greyish ornaments on the map. The geological units are provided with black codes which, for reasons of countrywide uniformity, do not always coincide with the codes on the published geological maps, but are internal Departmental adaptations. The geological units and codes are explained in a chronstratigraphical column.

#### *J.7.3.2 Legend*

The National Hydrogeological Map Series is based on an adapted international hydrogeological legend (Anon/UNESCO, 1983). The main deviations from the UNESCO legend are:

- Removal of the division of aquifers between local/discontinuous or extensive and using only local; and
- Inclusion of fractured and intergranular as an additional mode of groundwater occurrence, since this was considered to be more appropriate to South African conditions.

The definition of the borehole productivity ranges has been left by the UNESCO authors for the local mappers to define. Consideration of the local conditions resulted in the productivity ranges shown in Table 5.3.1.

The terminology adopted by the European hydrogeological map makers was used. This refers to the productivity ranges of groundwater and further subdivides according to the mode of occurrence. The various modes are "intergranular" for the porous mode of occurrence, "fractured" for the faulted, fissured and jointed, "fractured and intergranular" for the weathered and fractured/jointed mode of occurrence and Karst for weathered zones, fractures, joints and cavities in calcareous rocks. These divisions are then depicted using the colour scheme in Table 5.3.1.

To increase the readability of the map, the lithology and the geology have been changed as follows:

- Lithological occurrences too small to carry a GIS polygon and a formation code, were omitted, lithology boundaries have in places been smoothed out and boundaries will not always correspond exactly to that of the geological maps, and, where a large number of faults are concentrated, some have been deleted.

A conceptual profile has been drawn to illustrate the regional hydrogeology in terms of geology and to highlight target areas for groundwater development.

The 1:2 000 000 scale inset maps, illustrating distribution of borehole data, elevation above sea level and mean annual precipitation, are entirely computer generated.

**Table 3: Hydrogeological Map Legend Summary: Principal Groundwater Occurrence**

| **Occurrence** | **Intergranular** | **Fractured** | **Karst** | **Fractured and Intergranular** |
|---|---|---|---|---|
| Description | Generally unconsolidated but occasionally consolidated. Groundwater within interstices in porous medium and in basal conglomerate. | Fissured and fractured bedrock resulting from de-compression and/or tectonic action. Groundwater occurs predominantly within fissures and fractures. | Water-bearing properties depend on fractures, joints and cavities in Namibian age calcareous rocks. | Largely medium to coarse grained granite, weathered to varying thicknesses, with groundwater contained in inter-granular interstices in the saturated zone and in jointed and occasional fractured bedrock. |
| Example | Tertiary to Quaternary coastal deposits. Alluvial deposits along river terraces. | Sedimentary and metamorphic rocks with limited overlying unsatu-rated residual weathered products. | Limestone and inter-bedded shale is particularly ground-water bearing in valleys where sizeable alluvial deposits occur. | |
| Yield (ℓ/s) | TYPE COLOUR AND COLOUR SHADES | | | |
| | BLUE | GREEN | OLIVE | YELLOW-BROWN |
| >5.0 | Dark blue (a5) | Dark green (b5) | Dark olive (c5) | Dark brown (d5) |
| 2.0-5.0 | Blue (a4) | Green (b4) | Olive (b4) | Brown (d4) |
| 0.5-2.0 | Light blue (a3) | Light green (b3) | Light olive (b3) | Light brown (d3) |
| 0.1-0.5 | Pale blue (a2) | Pale green (b2) | Pale olive (c2) | Pale brown (d2) |

| Occurrence | Intergranular | Fractured | Karst | Fractured and Intergranular |
|---|---|---|---|---|
| 0.0-0.1 | Blue tinge (a1) | Green tinge (b1) | Olive tinge (c1) | Yellow tinge (d1) |

**Table 4: Hydrogeological Map Legend Summary: Symbols**

| LEGEND | SYMBOLS |
|---|---|
| Surface lithology | Light grey ornamentation |
| Geologic features | Lithological boundaries (grey lines)<br>Faults (black lines)<br>Chronostratigraphy (black letters) |
| Large scale groundwater abstraction | Red infilled circles of increasing diameter depicting annual abstraction of 0.1 to 1 $Mm^3$, 1-2, 2-5 and 5-10 $Mm^3$.<br>I = Irrigation<br>D = Domestic use |
| Springs | Mauve circle, >5l/s - cold spring<br>Yellow double circle – thermal spring |
| Surface water | Rivers (perennial, non-perennial)<br>Main drainage regions<br>Dams<br>Vleis |
| Groundwater level monitoring point | Purple triangle with dot insert |
| Infrastructure | Towns (black circles)<br>Main roads (red lines)<br>Provincial, International boundaries (black lines) |

Geomatics has a spatial database and DG are busy creating links to this database. The individual maps are being merged and eventually will be saved as one map and, when required, any piece can be cut out and given to whoever requires it. The linkage to the raw data is managed through what is called a spatial database engine, theoretically allowing one to update the maps as required.

## *J.8 EXISTING GEOLOGICAL MAPS*

The country is extensively covered by geological maps at various scales produced by the C for G, viz:

- 1:1000 000. Recently revised and updated, this map formed the geological base for the 1:500 000 scale hydrogeological map series. A simplified Geology of South Africa, Lesotho and Swaziland at a scale of 1:1 000 000 has also been published;
- 1:250 000. Seamless coverage of the country;
- Some 1:50 000 scale maps are available, e.g. four sheets covering Cape Town and the same for Johannesburg/Pretoria.

## *J.9 EXISTING PHYSIOGRAPHIC MAPS*

The Chief Directorate: Surveys and Mapping of the Department of Land Affairs is responsible for production of topographic maps. As of 2001, the following coverages are available:

- 1:500 000. Whole country;
- 1:250 000. Whole country;
- 1:50 000. Whole country, but only about half according to the new specification.

## *J.10 SURFACE WATER*

A series of reports on the Surface Water Resources of South Africa was produced in 1969 and updated in 1981. The WRC then funded a complete revision of the work, which was completed in 1995. Extensive use of GIS techniques was made to perform such tasks as calculating the mean annual precipitation of each catchment and to draw all the maps. A series of maps at 1:1000 000 scale show, *inter alia*, evaporation, precipitation and run-off, for quaternary catchments as a basis of preliminary planning of water resources development.

## *J.11 DATA AVAILABLE FOR A SADC HYDROGEOLOGICAL MAP*

Based on the existing data sets and mapping, Table 5 summarises the data available for specific legend items that may be desirable to portray on a regional hydrogeologic map.

**Table 5: Hydrogeological map Legend Summary**

| LEGEND | SOURCE DATA | PROCESSED DATA |
|---|---|---|
| **Aquifers**<br>Aquifer type and extent based on geology | National geology in digital form with C for G | |
| **Springs** | Spring locations, discharges, EC in DWA monitoring database | |
| **Surface Water and Metereological data** | Raw flow data available from DWAF GIS coverages of MAP, run-off at Quaternary catchment level | |
| **Borehole Details** | >220 000 borehole records in NGDB | |
| **Groundwater Quality** | Records of 55000 analyses in WMS database | |
| **Other Features** | Major infrastructure, towns in digital format | |
| **Topography** | Topographic maps in digital format | |

## *J.12 COMMITMENTS AND CONCERNS*

### J.12.1 Commitments on Contribution to the Regional Mapping Project

The following commitments have been provisionally obtained:

- **DWAF: DGH:** They will strive to compile the South African part of the map/atlas according to guidelines of SADC;
- **Council for Geoscience:** GIS stations, ARCINFO software, 5 geologists/hydrogeolgists for 30% of their time;

### J.12.2 Concerns

The major concerns voiced include the following:

- Will effective use be made of the map(s)/atlas?
- What is the target audience and education in use of the map(s)/atlas?
- There is a lack of data comparable to a common standard amongst member countries;
- Will there be sufficient financial backing?
- A possible lack of will to complete the project.

## *J.13 CONCLUDING REMARKS*

South Africa has a sophisticated level of hydrogeological infrastructure development, probably unequalled in the SADC. The main features are:

- An extensive monitoring network covering 360 water quality sampling stations and >1000 water level measuring stations;
- A National Groundwater Database linked to GIS containing >220 000 borehole records and >55 000 chemical analyses;
- Approximately 70% of the country is covered by published 1:500 000 scale general hydrogeological maps;
- A lengthy evaluation process was undertaken to derive a legend most applicable to Southern African hydrogeological conditions;
- Various other derivative hydrogeological maps cover the whole country at scales varying from 1:250 000 to 1:8500 000;
- The whole country is covered by published seamless 1:500 000 scale geological maps;
- The whole country is covered by published 1:50 000, 250 000 and 500 000 scale topographic maps;
- The country has been divided into 65 hydrogeological regions. A series of reports is being produced on each one. An Introduction and two regional reports have so far been published;
- Various institutions such as the Directorate: Geohydrology and Council for Geoscience have pledged support for the SADC mapping project in terms of manpower and equipment.

## *J.14 REFERENCES*

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