G: MOZAMBIQUE

The country visit to Mozambique as part of current project was extended over a period of two weeks between 13-27 March 2002.

G.1 BACKGROUND

G.1.1 Physiography and Climate

Mozambique lies in the southern part of Africa and is bounded by Zimbabwe, Malawi and South Africa on the west, by Tanzania on the north, and South Africa and Swaziland on the south.

Mozambique has a tropical and subtropical type of climate, with a dry season that lasts from April to October. July (winter) temperatures average 21.1° C at Pemba in the north and 18.3° C at Maputo in the south. January (summer) temperatures average about 26.7° C along the coast and lower in upland areas. Average annual rainfall decreases from 1422 mm in the north to 762 mm in the south. There are some extremely dry arid to semi arid areas with average rainfall around 350 mm/a mostly in the interior of Gaza and Inhambane provinces in the south.

G.1.2 Water Resources

The country has a considerable amount of surface water. The mean annual runoff (MAR) is estimated to be 216,000 Mm^3 year of which about 100,000 Mm^3 are generated by rainfall within Mozambique. There are 13 major and 104 minor river basins in Mozambique. The Zambezi River Basin is the main source of runoff, which contributes 50% of the MAR. Lake Niassa, shared with Malawi and Tanzania, also contributes significantly to the surface water resources. The per capita availability of surface water is of the order of 15 m^3/d taking into account the runoff generated within the country and increases to 33 m^3/d if cross-border flows are included. Considering the expected increase on surface water consumption it is anticipated that the availability will drop somewhat (<1,700 m3/hab/yr) from its present surplus level by the year 2025 (SADC-EU, 1990).

Mozambique has yet to carry out quantitative assessment of its groundwater potential. However, groundwater is almost the only source of water supply for nearly all of the rural population and to a considerable proportion of the urban population. Over most of the country, borehole yields are generally sufficient for installation of handpumps. In certain areas extremely high yields (> 300 m^3/h) are encountered as well. Two factors greatly hinder the use of groundwater. Firstly, almost 60% of Mozambique is covered by crystalline rocks (where groundwater occurrence is limited to shallow weathered zones) and secondly, in some areas of the southern and central region, groundwater is highly mineralised. Agriculture, which in many countries is an important groundwater user, relies mostly on surface water.

The National Directorate for Water recently started a programme for rehabilitation of small piped systems in many villages, which primarily rely on groundwater sources. Therefore, the future increase in groundwater usage may be due predominately to urban water supply.

G.1.3 Overall Institutional Framework Of Water Sector

Until recently the Ministry of Public Works and Housing (MOPH) through its National Directorate for Water Affairs (DNA) was responsible for water resource assessment, planning, development and management. The water law approved and under implementation since 1995, introduced significant changes and shifting of responsibilities. New regional authorities are being established in order to remain responsible for water resources management at the catchment level. The MOPH is changing from executive and implementation roles to focus on regulation, management and policy making.

Since March 2001 a new ministerial diploma introduced changes in the National Directorate for Water, which in turn is likely to affect the way various institutions interact. The current organisational structure for water development and management is as follows:

- Department of Water Resources Management (DGRH) with two sections, Hydrology (SH) and Geohydrology (SdG);
- Rural Water Supply Department (DAR);
- Urban Water Supply Department (DAU);
- Sanitation Department (DES);
- Human Resources Department (DRH);
- Administration and Finance Department (DAF);
- Cabinet for Hydraulic works (GOH)
- Cabinet for International Rivers (GRI)
- Cabinet for Planning and control (GPC)

At national level the DGRH, DAU and DAR are key institutions for groundwater resources assessment, development, exploration and management. However this is only valid for domestic groundwater use. In the case of industry, agriculture or other commercial uses, there is no clear indication as to who is responsible for regulation and development assistance. Therefore, responsibilities are deferred to other governmental institutions such as the Ministry of Natural Resources and Energy (MIREN) through its National Directorate of Geology (DNG), Ministry for Agriculture and Rural Development (MADER) and Ministry for Environmental Co-ordination (MICOA).

The country is divided into 11 administrative provinces, except for Maputo City. With privatisation of the management of urban water supply, DAS are becoming more involved in supervision and policing of implementation.

While Geomoc, a former parastatal drilling company with large experience, has been privatised and competing reasonable well in the market, EPAR's (former DAR implementing contractor for rural water supply project) is still undefined in terms of its legal status and sometimes is still considered to be within government responsibility.

Regional Authorities (ARA's) are being implemented in Mozambique. ARA's are defined as regional water boards in a particular region, within the areas each catchment may have its own board with several stakeholders represented ranging from small farms to local Government.

The above described arrangements considers DGRH as the department within DNA responsible for water resources assessment, planning and management in general terms. However, under current circumstances, where ARA-Zambezi, Centro-Norte and Norte are yet to be implemented, DGRH is still operating according to its former position of central management and sometimes is called in for implementation of projects in these areas.

Apart from the MOPH, MIREN, through its National Directorate for Geology (DNG), is the only one interested in groundwater exploration studies. It is foreseen that in the near future it will resume its activities in groundwater projects. DNG has a small drilling company, which is still operational in the region of Maputo. Up until 1980, DNG implemented most of the groundwater investigations in Mozambique.

G.1.4 Role of Groundwater in the Water Sector

The general census of 1997 indicated a total population of 16 million, 85% of whom live in rural areas. The total yearly water consumption (surface and groundwater) in 1985 was estimated at 1612 Mm^3, of which only 4% was derived from groundwater sources. Agriculture accounted for nearly 90% of the total consumption, with 7.4% for domestic use and 1.7% for industrial uses (Hydrogeological Map, 1987). At present, it is estimated that groundwater contributes about 6% of the total water consumption while its contribution to domestic water supply is about 34% (Molapo, 2000).

It is estimated that irrigation water demand will rise to 1080 Mm^3/year in the next couple of years from the present consumption of about 540 Mm^3/year according to the National Water Policy (NWP). In terms of potable water, the urban water supply sector is the largest user. At present, approximately two-thirds of the urban population have access to safe drinking water. The present coverage of rural water supply is 36%. With implementation of the National Water Program (PNDA), funded by The World Bank, this coverage is expected to rise to 40% within 5 years. It is estimated that demand for urban and rural water supplies will rise to 60 Mm^3/year (2002) against the present consumption of only 25 Mm^3/year (NWP).

Groundwater abstraction will increase in the near future with the development of the Maputo Wellfield, the ongoing expansion of the Quelimane Wellfield, and the upgrading of Pemba water supply system. Since the introduction of municipalities in 1996, many villages have planned to upgrade their water supply systems, which are mainly based on groundwater abstraction systems. The DAR is co-ordinating and managing projects on small systems. The DAU is also co-ordinating implementation of small systems based on groundwater resources.

Some new industries are planning to use groundwater for their needs, such as two major industrial zones being built in Maputo and Beira.

According to the Hydrogeological Map of Mozambique, small groundwater based systems, each serving some 20.000 people or more, are present in several places. This also indicates the high dependence of small systems on groundwater

G.2 GEOLOGICAL AND HYDROGEOLOGICAL FRAMEWORK

G.2.1 Geology

The oldest geologic units in Mozambique are rocks belonging to the Precambrian Basement Complex including metamorphic rocks, basic igneous intrusions and granitic intrusions. Greenschists, gneisses and granites are the predominant rock types. The Complex occupies most of the northern and western part of Mozambique (57%) and occurs in the form of plateaux and mountains.

Basalt, rhyolite and sedimentary formations belonging to the Karoo Supergroup (5%) occur only in the eastern margin. The lower units are dominated by mudstones and contain some coal beds while the upper units are more sandy and coarse grained. The uppermost volcanic sequence consists of a number of superimposed basaltic and rhyolitic flows.

Post Karoo sedimentary formations cover almost the entire region south of the Save River, the coastal parts of Sofala and Nampula provinces and the lower Zambezi Valley (38%). The sediments were deposited in two Meso-Cenozoic basins; the northern or Rovuma Basin and southern or Mozambique Basin, associated with the East African Rift Valley System. The sedimentary sequences are characterised by predominantly arkosic sandstone in the western part of the basin and mainly marine transitional sequences in the coastal part. The sequences are intensively faulted with very limited folding. Almost 70% of these sedimentary basins have a cover of unconsolidated material commonly with a thickness of 5 to 10 m.

G.2.2 Hydrogeology

The overall hydrogeology of Mozambique was investigated as part of the hydrogeological mapping project (1987). In the map, about 60 % of the area is basement complex and volcanic terrain and 40% sedimentary. Considering that 40% of the more productive aquifers in the sedimentary basins contain brackish water, it was concluded that only approximately 17% of the country has groundwater resources with yield prospects of > 3 m^3/h of potable water.

Three main hydrogeological units correspond to geological units and are a) aquifers related to the crystalline basement complex, b) aquifers occurring in Karoo formations and c) aquifers related to post Karoo formations (Table 1).

Table 1. Summary of Aquifers (National Hydrogeologic Map)

Aquifer System	Occurrence	Typical lithology	Productivity
Crystalline Basement Complex Aquifers	North and centre of the country	Weathered material 25 – 40 m thick sometimes with fractured zones in the contact with bed rock	1 to 2 m^3/h occasionally up to 6 m^3/h. Fractures may increase yields to 40 – 70 m^3/h
Karoo Formation Aquifers	Occur sporadically in old deep valleys of Limpopo Rovuma and Zambezi Rivers	Clastic sedimentary units of Ecca and Beaufort, and aquifer formed in rhyolite and basalts	Low yields average 1.5 m^3/h and very saline waters (up to 7 000 mg/l)
Post Karoo Sedimentary Aquifers	Most of southern part of the country	Variable, the most exploited are sandstones, lime stone's, conglomerates and alluvials fills	In some areas exploration is hampered by high salinity from transgressions, and low permeabilities. However, at times, yields are very high especially in limestones (50 –120 m^3/h). Alluvial plains are the most productive (up to 200 m^3/h)

G.2.3 Natural Groundwater Quality

Groundwater is generally of good quality. Poor water quality (salinity) is common in some areas like the interior of Gaza and Inhambane which are more arid areas, with Tertiary formations, the most prominent aquifer, bearing saline water.

Investigations carried out by the National Laboratory of Hygiene, Food and Water (LNHA) indicated high concentration of nitrates in the Maputo surroundings mostly due to a high concentration of houses and pit latrines. In general, these areas have phreatic groundwater conditions in dune formations of high permeability. The problem of high nitrate will be addressed in detail in a planned research project to be implemented first in Maputo as a pilot study and later to be extended to other over-populated areas which are using groundwater.

Iron and manganese are reported to be a problem in a few alluvial aquifers, the most noted case being the Pemba Wellfield at Muaguide Valley, where high iron concentration is aggravated by iron bacteria activity and poses a serious engineering problem to wellfield operation. Little research has been implemented to date in regard to the influence of mining activity on groundwater. However, it is believed that in some areas of coal exploitation, aquifers may be being polluted by mining activities.

G.3 DATA ACQUISITION

G.3.1 Institutional Framework for Data Collection

For governmental projects, data (drilling, test pumping, siting, water quality, lithological data) are collected in standard forms designed by SdG. Whenever a borehole is completed, copies of the data sheets are completed and stored in the SdG archive. A similar procedure is adopted by GEOMOC. However, GEOMOC does not have a separate computerised database and copies of their data used to be transferred to DNA for updating of the database. At present, GEOMOC is no longer transferring data to SdG unless a specific request is made.

At SdG, these data are filled to a 'Standard Format' which is in a very complex form and thereafter entered into an electronic database in DBase format. The quality of lithological data is questionable due to limited knowledge of geology by most of the people responsible for sampling. Staff at SdG found completion of the data entry form very complex and proposed changes.

At present no regular data collection is done outside of SdG, although occasionally some governmental projects send data to SdG. In future, data collection will be tasked to ARA's in their day to day management of regional water resources. In terms of water supply coverage, DAR will collect data regarding operational status of boreholes and equipment in rural water supply projects requiring involvement of authorities at district and provincial levels. At district level civil servants working in water supply departments will be responsible for data collection and will send data forms to the provincial authorities and from here to a central database probable at DAR.

A few private drillers have their own forms for data collection and keep databases in hard copies, although many of them do not record any data or produce technical reports about the boreholes, unless required by a client.

Currently, the only really national groundwater database at the central level is under the responsibility of the Department of Water Resources Management (DGRH) of the National Directorate of Water Affairs (DNA).

Several agencies play a role in data collection, such as the Urban and Rural Water Supply Departments of DNA, which are the governmental implementing agencies of water supply programs at the central level, while the Provincial Water Departments are in charge of these activities at the provincial level. Apart from these, data are also collected from groundwater related projects conducted by NGO's and private sector. However, it is important to mention that, in practice, it is difficult to get information from the private sector.

G.3.2 Data Acquisition Protocol and Quality Control

Groundwater data, particularly borehole data, are not generally available for boreholes drilled by private enterprises in Mozambique during the colonial period. However, the archives of these different firms and services were integrated into the archive of GEOMOC, the national drilling company, and periodic attempts have been made to update these data.

The driller or project supervisor does borehole numbering in Mozambique, therefore no consistent numbering system is used. When borehole data are provided to DNA for the database, a new borehole number is assigned by DNA based on a topographic map sheet reference.
In the former arrangement, where GEOMOC and EPAR's were the only national drilling companies, all information collected in the field was submitted to DNA and processed to the database. Currently, with many NGO's using different approaches and a proliferation of private drilling companies, much

information is no longer submitted to DNA and in many cases it is found that drillers do not produce technical reports for boreholes.

In principle, every firm operating in the country in the field of groundwater development is supposed to send all data to DGRH, in order to enter them into the national database. This informal "protocol" was functioning reasonably well when there were very few companies involved in groundwater development and the government owned them. More recently, many other private firms have begun operating in Mozambique with data flow to DGRH being minimal, compounded by the lack of a water law or regulation which requires them to do so.

The only way to collect data from private firms undertaking groundwater projects is to get the information through the provincial Water Departments, if they are involved in the implementation of any specific projects.

Quality control is done by DGRH before the received information is entered into the database. Inconsistencies related to geological description and technical data are checked and, whenever possible, corrected.

G.4 GROUNDWATER INFORMATION SYSTEM

G.4.1 Existing Databases

There are several existing databases in Mozambique, some of which are still in use. In terms of important databases the following are worthy of mention:

- Profuro – recently started in hard copies
- DGRH-SdG – the largest database with more than 12000 records, hard copy and computerised, updated only up to 1990
- GEOMOC – more than 9000 records, all in hard copy but are preparing to create a computerised database, up to date
- DAR – under plan, following the implementation of new rural water programme, beginning 2003
- ARA-Sul – a computerised Access database, with records obtained from SdG with 6.000 records, pertaining to the southern part of the country
- Profuro and Modrill – private drilling companies have their own databases: number of records not known but all in hardy copy.

Approximately 12000 borehole records are available in the SdG database. This database, although the largest in the country, represents primarily boreholes drilled by SdG or directly under their supervision. There are many other boreholes drilled outside control of DNA without records transferred to the SdG database. Most private drilling companies are now establishing their own databases.

Table 2. Summary of SdG Information Systems

Database / Source	In use	No. of records	Format	Useable[1]	comments
SdG	yes	12 000	DBase IV ACCESS	yes	Mostly excel and ASCII Format; coordinate accuracy is poor at present in > 50% of the records
Field data reports	Yes	> 13 000	paper	no	Borehole reports, papers, etc.; unreferenced library

[1] Easily useable for the regional hydrogeologic map

SdG has maintained a computerised DOS-based groundwater database since 1987. The database contains all data existing in the GEOMOC archives concerning drilled wells, as well as those boreholes since completed by DAR and DASU. Existing data on shallow dug wells (1800), springs and small dam's (800) are not represented in the computerised database. The data from borehole report forms from 1941 up to the present are also included. The database is not presently directly linked with a GIS system, but data can be manually imported and used in an existing GIS system present in the DNA offices mainly using the ARCView 3.2 platform.

This database has experienced various problems and has been down several times. The database was first developed in 1985 using FORTRAN language and in 1986 experienced a serious breakdown. In 1988 a new database was created using dBase^{+}3 software. In this new attempt, more effort was placed in organization of information and improvement of quality of data to input in the computer. The process of data input continued until 1993 when it was decided to start introducing chemical data into the system. However, database maintenance only continued up to 1995 and since then very little data were introduced into the system. In 1999-2000 there was a second breakdown of the database and the program and database was not operational for more than a year. Later in 2001 it was decided to convert the existing backup dBase format data copies into a database using ACCESS, which is in use at present.

In summary, SdG is now running an ACCESS database based on files recovered from previous programmes. Severe problems have been reported, most of them related to loss of existing data in the database. Chemical data became more difficult to obtain since they were stored in a different format to the basic borehole information. In 2002, DNA started to input existing hydrochemical data into an Excel spreadsheet for the Inhambane Province as part of preparation of the Inhambane Province Hydrogeological Map.

G.4.2 Hardware and Software Set - Up

SdG runs its database from 2 PC 's for backup purposes and maintains copies in floppy disks. GIS packages are stored in different PC's and backups are available in CD. Hardware is generally up-to-date but not linked in a network, thus the database cannot be accessed from other computers.

DAR is preparing a bird process for pilot database project of Inhambane Province, but has yet to define the software and format of database. GEOMOC is still studying the problem and has yet to decide the way forward. ARA-Sul ACCESS database is based on the SdG database but is limited to borehole records of the southern part of the country.

G.4.3 Structure of Information System and Graphical Interface

The national database does not currently have any graphical interface attached to it. However SdG has a GIS section that is able to produce thematic maps as needed. One experienced technician works in this section, which uses ArcView and Map Info as their primary software. Most of the work is carried out without coordination and not following any internal objectives in relation to larger macro projects. Some staff at DNA are using GWW independently in their projects.

A few hydrogeological thematic maps have been produced by this section, for example the Great Maputo Chemistry Mapping project (with emphasis on nitrate concentration in groundwater). The SdG also implemented, on request by CARE-International (an NGO), the Vilanculo's District Mapping project with emphasis on hydrogeological characteristics such as depth to water table, TDS and spatial lithological variability.

G.4.4 Quality of Data

Data are collected on standard forms designed by SdG. When a borehole is completed, copies of the data sheets are completed in the SdG archive. A similar procedure is adopted by GEOMOC. However, GEOMOC does not have a separate computerised database and copies of their data are transferred to DNA for updating of the database. In some cases the data for private boreholes drilled by GEOMOC are not transferred.

By the time of production of the National Hydrogeological Map in 1987 it was indicated that only 40% of the map area had reliable records with technical data and reliable geo-referencing. Since then the situation has not change significantly. DNA has implemented well inventory projects in a few provinces to try to obtain information related to existing boreholes. Zambézia, Nampulaa and Sofola Provinces were covered by a project implemented by Price WaterHouse and Coopers recently and a well inventory project of Inhambane province (1999) has been implemented to improve the reliability of data.

Borehole data from drilling activities by private contractors are usually of poor quality and presently do not get transferred to DNA. There are no existing laws or regulations to improve the quality of data recorded or to ensure the transfer of data to DNA.

The quality of data is dependent on the staff that are involved in a specific project. In general, the big governmental groundwater projects are supervised by experienced technicians in order to ensure the quality of works and data collection, while in private groundwater development activities, this kind of supervision tends to be avoided due to the additional costs involved.

The other aspect to be mentioned is that the reliability of the collected data differs from parameter to parameter. For example, most of the people involved in the groundwater development programmes have no geology background. Because of this, in most of the cases, there are inconsistencies in lithological logs of the boreholes, particularly in more complex geological environments like sedimentary basins.

G.4.5 Available Resources for Maintenance

One geologist and two technicians from SdG are currently responsible for the database. The main activity carried out at the section is to organize data and provide data to people who request information from DNA. In the past three other technicians were attached to this section and compiled the field data from drilling companies into DNA data protocol format. Thereafter, this information was introduced to the software package.

There is no budget available for database maintenance.

G.5 GROUNDWATER MONITORING

G.5.1 Institutional and Legal Framework

Until recently the Ministry of Public Works and Housing (MOPH) through the DNA was responsible for water resource assessment, planning, development and management. Within DNA, the DAR is the only department that is apparently still active in groundwater projects through its rural water supply initiatives.

The Water Law considers Regional Administration for Water as a key institution for facilitating an effective water resources management programme nationwide. Therefore, Regional Authorities (ARA's) are being implemented in Mozambique.

In summary groundwater planning, management and implementation projects will be executed with main involvement of MOPH, through ARA's or DNA departments. Research projects will probably have participation from DNG. To illustrate this, DNG is currently implementing a national geological mapping project, which will mainly cover seven provinces at its first stage.

The existing Environmental Law constitutes the basis for groundwater protection. However, lack of funds and personnel makes its implementation difficult. Currently, groundwater monitoring is carried out based on individual or project initiatives. Existing institutions, although they are concerned with groundwater management, are not financially or technically equipped to comply with monitoring regulations.

G.5.2 Monitoring Network and Frequency

There is no groundwater monitoring network in Mozambique at present. There are plans to establish a network, which will be maintained and co-ordinated by DNA with direct involvement of ARA's. Some *ad hoc* monitoring is carried out, usually as part of specific projects.

In the early 1980's a groundwater monitoring network was implemented for the aquifer system in the area of Greater Maputo. This network comprised a set of piezometers where water level data was obtained and input to a database at DNA. The network consisted of 53 piezometers in Infulene Area, 14 in Matola, 5 in Mahotas and 12 in Catembe. This network was operational for some time, but generally with severe problems from unprotected piezometers which were later vandalized, clogged or simply collapsed. In some cases the location of the screened interval is not known making the information collected difficult to use. In 1993 only 28 piezometers were operational, and at that time it was proposed to install one piezometer for each 25 km^2. However, this was never implemented. The network it self was supplemented by rainfall stations as part of groundwater recharge studies in the area. Through this data some research was undertaken, in one case leading to an MSc degree. However, the project itself never complied a technical report making it difficult to evaluate the outcome of the project.

Between 1994 and 1998 the SdG monitored a few piezometers approximately 30 km north of Maputo, although this process was suspended due to financial problems. However, some of these piezometers have since been equipped with data-loggers as part of a pilot project. Every two weeks, technicians from DNA used to download data from the loggers and input the information into DNA computers for future analysis, although this activity was discontinued in 1998.

As part of a long-term strategy, DAR is focusing on integrating its information flow system into the existing local government. The idea is to nominate within local government staff (civil servants) people who will be responsible for water affairs. These people will serve as a link between the database management at provincial level and local government in terms of collecting basic information related to operational status of borehole equipment, such as pumps breakdown.

In the existing wellfields supplying the urban centres, water supply companies do more systematic monitoring of water quality. The Ministry of Health is also involved in quality measurements, although not on a systematic basis.

For suburbs in the City of Maputo, AdeM (Water Company) is planning to have a more complete monitoring network including real time monitoring of water quality, pumping rates, water levels. A total of 100 boreholes will be monitored with some of them equipped with data loggers. AdeM is also planning to have remote control through radio or other communications means to control the operation of these boreholes. This project is still under plan and will be funded through World Bank sources. Currently, ADEM compiles annual reports, which include information related to water quality from boreholes and pumping rates in suburbs for Maputo City.

G.5.3 Quality of Monitoring Data

The quality of monitoring data is variable. In the case of the greater Maputo piezometric network the series of data are found to have many gaps. The longest continuous series is of about five years showing weekly piezometric level fluctuations. The data are presently unprocessed, although an undergraduate geology student from Eduardo Mondlane University is looking at the data for a possible thesis topic.

In regard to the Maputo-north piezometric network, these are perhaps the best available data in terms of groundwater fluctuation levels and comprise different time series from 30 minutes reading interval to weekly data. This network was designed to monitor groundwater piezometric fluctuation in an area of Incomati River margin affected by tides. Therefore it was decided to use shorter recording intervals to eliminate the tidal effect over the data.

SdG also implemented a one-field campaign of data collection (2000) in the area of Greater Maputo focusing on groundwater quality (nitrate concentration) and water levels. Data quality is good but the campaign has not been repeated since it was designed merely for evaluation of current conditions in terms of groundwater contamination using nitrate concentration as an indicator. This activity was carried out as part of an undergraduate thesis aiming at producing a Hydrogeological Atlas of Greater Maputo.

Therefore, it can be said that there is very little experience in terms of groundwater monitoring in Mozambique. Most of the activities, except for the former Maputo monitoring network, have been implemented on a needs basis as part of some project at the time.

There are no active monitoring networks in the country. However, with minimum effort, networks can be restored.

G.6 HYDROGEOLOGICAL MAPPING

G.6.1 Existing Hydrogeological Maps

Mozambique has one National Hydrogeological map at 1:1 000 000 scale. The legend of the map follows the guidelines of UNESCO "International Legend for Hydrogeological Map", published in 1970 and revised in 1983.

This map is regarded as a reconnaissance map and is meant for use for general planning purposes and not for detailed interpretation. Emphasis was put on the upper aquifers in unconsolidated material that can be used by dug wells. Therefore, in some cases deeper, more productive aquifers are not directly represented by the hydrogeologic map units.

The Inhambane Province Hydrogeological Map is being compiled. This map will cover the Inhambane Province and will use the International Legend format as well. It is proposed to be on 1: 500.000 scale and wherever possible more refined maps at 1: 250,000 may be considered. It is expected to be ready by June 2002. The map is being produced as part of a World Bank pilot project for groundwater exploitation in Mozambican rural areas. DAR is the client for this project and it is being implemented by a consortium formed by Norconsult, TECNICA (Mozambican company) and Council for Geoscience from South Africa.

Besides the derivative maps of the main map, the map will include inserts, one related to water strike depth and the other related to specific yield probability. These two inserts will follow the same format as the South African Hydrogeological map.

It is also suggested to include as an insert a risk vulnerability map in relation to salt water intrusion in coastal aquifers.

G.6.2 Derivative maps

The following derivative maps accompany the National Hydrogeologic Map.

Information distribution map (1:8 000 000)

The information density map is called Distribution of Boreholes. This map-inset gives the number of tube wells per 1:50.000 topographic map-sheet, which represents 15' by 15' geographical minutes or about 700 km^2. The map shows the uneven distribution of tube wells over the country. Approximately 63% of the topographical sheets show no data at all and only 7% of the maps have a borehole density of > 1 per 100 km^2. Half of the tubes wells are located south of the Save River.

Water usage map (1:8 000 000)

The water usage map shows the distribution of small water supply systems based on groundwater with three levels, areas serving > 20 000 people, < 20 000 and < 1 500.

Water recharge map (1: 8 000 000))

This is a qualitative map to define the general recharge conditions in the country. It is based on annual rainfall (isohyets and colours) and on the recharge capacity of the terrain (tone). The recharge capacity is considered high if the actual evapotranspiration and runoff coefficient area is small, or if the water storage capacity of the soil and the slope of the terrain are small (leaving more possibility for the water to infiltrate).

Ground water development maps (1:2 000 000)

These maps give an indication in terms of prevailing conditions for groundwater development in terms of depth to water table, water quality and the most suitable infrastructure (borehole, dug well or spring catchments). It is also provides warnings in terms of risk of failure of boreholes.

G.6.3 Classification and Legend of Maps

The Mozambique National Hydrogeological Map follows the recommendations made by UNESCO in its publication " International Legend for Hydrogeological Maps" first edition 1970 and revised in 1983. The main items in this legend are: Groundwater occurrence, Topography, Geology, Surface Water, Groundwater, Water Quality and Abstraction infrastructures.

The legend is hierarchically divided into three classes, nine Groups and thirty-two Units. The classes are represented by their colour and the Groups by the tone of the respective colour and the Units are depicted by lithological ornaments and stratigraphic symbols (Table 2).

Table 2. Summary of Aquifer Delineation

	Classes and Groups of Groundwater occurrence		Groundwater Development Characteristics			
	Intergranular formation	Fissured formation	Average yield (m^3/h)	Maximum pumping period (h/day)	Possible water supply capacity	Recommended aim of surveys
Productive Aquifers Class A,B	**Class A**	**Class B**				
	Dark Blue (A1)	Dark Green (B1)	> 50	24	Large cities, industries and irrigation schemes	Determination of safe yield
	medium Blue (A2)	Medium Green (B2)	10-50	24	Towns (> 5000 inh), medium sized industries and irrigation schemes	Determination of safe yield
	light Blue (A3)	light green (B3)	3-10	16	Villages (2000-5000 inh) small sized industries and irrigation schemes)	Determination of safe yield + well sites
Areas With Limited Or No Groundwater resources	**Class C**					
	Light Brown (C1)		< 5	8	Villages (1000-2000 inh) Cattle (< 2000 head)	Determination of aquifer dimensions + well siting
		Medium Brown (C2)	< 3	8	Small Villages (< 1500 inh) Cattle (<1500 head)	Determination of aquifer dimensions + detailed siting
		Dark Brown (C3)	< 1	6	Groups of houses (< 250 inh) Cattle (<250 head)	Det. Aqu. dim + very detailed well siting

The division into **3 classes** (A, B, C) is based on the dominant porosity type, the extent of aquifers and the productivity of the formations.

The **blue** coloured **Class A** represents aquifers in which the water predominantly circulates through intergranular pores. The **green** coloured **Class B** represents aquifers in which water circulates through fractures and fissures. The **brown** coloured **Class C** comprises areas with limited or local groundwater occurrence and areas without any groundwater resources.

The subdivision of each class into three groups (A1-A3, B1-B3, C1-C3) is principally based on yield prospects.

In addition to the productivity criteria, the **sub-division of Class C** is based on geological and morphological characteristics. **Group C1** (light brown) consist of areas with local continuous or discontinuous aquifers that are unconsolidated towards the surface. Yield prospects are generally < 5

m^3/h. **Group C2** (medium brown) comprises areas with fissured formations of very low productivity and yield prospects < 3 m^3/h. **Group C3** (dark brown) represents areas with hardly any groundwater resources and morphologically defined as mountainous.

The areas of Group C2 have a less developed weathered mantle with a thickness that rarely reaches 20 m.

The areas of Group C3 are mountainous and have no significant weathering mantle or groundwater resources.

The degree of groundwater mineralisation is represented by iso-lines and is the only indication of groundwater quality. Orange hatching indicates the existence of mineralised aquifers. Inclined lines mark the probable existence of local fresh water.

The hydrogeological map contains a detailed legend and descriptive text and graphs which include:

1. Groundwater occurrence.
2. Topographic features
3. Geology.
4. Surface Water.
5. Water quality
6. Groundwater exploitation (development)

The groundwater development pattern is also provided in a separate map sheet at 1:2000000, and is represented as filled polygons in light colours with symbols (points and lines) and hatch patterns signifying different aspects. Legend details are tabulated in Table 3.

Table 3. Hydrogeological Map Legend Summary

LEGEND	DETAILS OF LEGEND
Groundwater occurrence and aquifers Aquifer extent defined by geology.	a) porous generally unconsolidated formations b) fissured aquifers (discontinuous) c) fissured, bedded and intergranular rock lithology indicated by hatch pattern within hydrogeologic units; description gives general potential and hydraulic characteristics of each unit
Springs	Mineral or thermal springs are indicated with circle partially filled.
Groundwater	• groundwater divide • contours of water struck, or depth to groundwater • Flow direction of shallow and deep aquifer systems • Dashes indicating areas with artesian flux conditions • Regional aquifers
Surface Water	• Rivers, seasonal river with dashed lines, permanent rivers in solid lines • Lakes and Dams • Salt water lake (> 3000 mg/l) • Existing dam (capacity indicated) • Planned dam • Catchment area and mean annual runoff for major rivers Hydrometric stations indicated with station code, mean annual discharge, minimum discharge and catchment area presented in the explanatory note.
Borehole Yield "potential yield"	Yield range indicated by colour tone, dark (>50) and tone reduces for 10-50, 3-10 m^3/h. This is only valid for intergranular aquifers.
Borehole Details Indicated for selected boreholes	Small table provides code, EC and temperature.

LEGEND	DETAILS OF LEGEND
Wellfield	Square box with number inside indicating abstraction in thousands of cubic metres.
Well with indication of formation exploited and pumping rate	Circle filled > 50, three quarters filled 10-50, half filed 3-10, ¼ filled 0-3 m^3/h , empty means unknown.
Captured Spring	Mean annual discharge of 0.5-4 l/s
Other Symbols	• geologic boundary; solid line followed by dashes • Fault; thick black solid line, • Rock exfoliation, • Volcanic chimney, • Line of hydrogeological cross-section • Oil exploratory borehole • Mine
Topographic symbols	Topographic symbols include: • International boundaries; • Altitude of reference points • Main towns, villages • Main roads, track, minor track • Railways • Electricity power lines

G.6.4 Existing Geological Maps

The National Institute of Geology (the same as Geological Survey) is the national institution responsible for geological investigation. Published and unpublished geological maps at a scale of 1:250.000 exist for the whole country, except for the north-western part of Gaza Province and extending to small areas of Inhambane Province (Table 3). The maps are available in printed format. Detailed soil and land classification maps of selected areas may be consulted at INIA (National Institute for Agronomic Investigations).

Table 4 Summary of Available Geological Maps

Map	Scale	Number of maps
National Geologic Map	1:1,000,000	1
Geological maps	1:250,000	About 90
Geological maps	1:50,000	For Maputo and a few other areas with economical interest

The national geologic map was digitised However, it was recently indicated that there are some problems with accuracy of references. For example, in the case of Inhambane, the available digital base map at 1:1000000 could not be used in the on-going hydrogeologic mapping project due to coordinate errors.

G.6.5 Existing Physiographic Maps

All maps indicated in the Table below are available at the National Cartographic Centre (CENACARTA) or National Directorate for Geography and Cadastre (DINGECA) in printed and digital format.

Table 5. Summary of Available Physiographic Maps

Map	Scale	Number of maps
Soil map of Mozambique	1:1000000,00 1: 250 000	1 102
Climate map of Mozambique	1:2000,000	1
Geomorphological map of Mozambique	1:1000000,00 1: 250 000	1 102
Digital Terrain Map based on satellite images	1:1000000,00 1: 250 000	1 102
Topographic map	1: 250 000 1: 50 000	102 1632
Land Use (also in digital satellite images for both dry and wet season)	1: 250 000	102

Topographical data

Administrative boundaries
Cities
National parks and nature reserves
Rivers and other hydrographical network
Roads and railways
points

Thematic data

<u>Land use:</u>
Cultivated land
Non-cultivated land
<u>Land cover:</u>
Land cover with edaphic limitation Levelling (e.g. bare soils, meadow, spars grassland, mangroves)
Land cover without edaphic limitation (e.g. grassland, shrub land, ticket, bush land, woodland)

G.7 DATA AVAILABLE FOR A SADC HYDROGEOLOGICAL MAP

Based on the existing data sets and mapping, Table 6 summarises the data available for specific legend items that may be desirable to portray on a regional hydrogeologic map.

Table 6. Data Available for a Hydrogeologic Map

LEGEND	SOURCE DATA	PROCESSED DATA	NOT AVAILABLE
Aquifers Aquifer type and extent based on geology	National geology in digital form (Arcview 3.2)		
Springs		Data only on hydrogeological map	
Surface Water	Raw flow data available (hydata format) with DNA Catchment areas, divides in digital (Arcview 3.2) format with DNA (DGRH) Digital reservoir extents and infrastructure with DNA (DGRH)		
Meteorological Stations	Locations and rainfall data available		

LEGEND	SOURCE DATA	PROCESSED DATA	NOT AVAILABLE
	in Digital EXCEL format and other ASCII		
Borehole Yield	Data for more 6 000 boreholes with DNA (DGRH) ACCESS database format		
Borehole Details	EC and SWL data for more then 12 000 boreholes in DNA database (ACCESS)		
Well Point Pumping Station	Well field abstraction rates and locations in SdG reports (paper)		
Other Symbols	Major infrastructure, towns, and boundaries available with DINAGECA in Arcview 3.2 format.		
Topography	Topographic maps in digital (1: 250 000) and in paper format at present. For both 1:50 000 and 1: 250 000		

G.8 CAPACITY AND COMMITMENT FOR THE PROJECT

G.8.1 Existing Capacity

Relevant institutions for the Project in terms of information provision include:

- National Directorate of Water Affairs;
- National Directorate of Geology;
- National Directorate for Mining;
- National Directorate for Geography and Land Use Cadastre;
- National Institute for Agronomic Investigation;
- Department of Geology – Eduardo Mondlane University
- Water Supply companies
- Ministry of Health
- Drilling companies
- Provincial Water Departments

The available capacity in these institutions is mostly in terms of human resources for mapping activities, some of them with experience from previous projects. As described below, the actual availability of personnel for a mapping project is generally very limited.

G.9 COMMITMENTS AND CONCERNS

G.9.1 Commitments on Contribution to the Regional Mapping Project

Most of the institutions listed above are faced with serious financial constraints that will hinder their effective participation in the project. Other major problems in some of these institutions will be related to staff motivation to participate in the project. However, some of the existing constraints may be overcome if a good commitment from senior staff and managers at these institutions is shown and effective responsibilities are placed in people involved.

G.9.2 National Directorate for Geology

DNG is in a process of revitalization and is resuming some of its former tasks. Currently it is undertaking a major hydrogeological mapping project with assistance from the Council for Geoscience from South Africa. This project will produce hydrogeological maps of seven provinces of the country and will be extended later on to another three. DNG has qualified personnel and expressed its interest in participating in a SADC hydrogeologic map.

G.9.3 National Directorate for Geography and Land Use Cadastre

DINAGECA is very familiar with GIS activities and has produced most of the currently available thematic maps of Mozambique, including soil maps, land use maps, DTM etc. They are currently involved in the Geological Mapping project. They are a reference institution in mapping and have adequate manpower and resources to participate in the project.

G.9.4 National Directorate for Water

DNA, will play a key role in the process since it is the main institution in charge for groundwater. They also run the only existing national database and have qualified personnel in the field of hydrogeology. There is limited capacity in the field of GIS, since only one qualified GIS expert works there, but with good experience in hydrogeological mapping activities. Their participation would be very beneficial to the project.

G.10 CONCERNS

DNA senior staff expressed interest in having a few regional hydrogeological maps for some transboundary aquifers. This, in their view, would be more beneficial in improving the current understanding of common resources and also to facilitate management. Some of these catchments include Limpopo and Pungue as the most critical at the moment.