H: NAMIBIA

H.1 INTRODUCTION

The Namibian country visit was the first to be carried out as part of the preliminary study for compilation of the hydrogeological map and atlas for the SADC region. This was done since Namibia had most recently completed and published a hydrogeological map and explanation brochure (November 2001) out of the SADC Region countries, and it was thus considered desirable to gain experience from lessons learnt in Namibia. Gordon Maclear, of SRK Consulting undertook the country visit from the 18th to the 21st February 2002.

For background detail on groundwater development in Namibia, the reader is referred to Annex H of the Final Situation Analysis report on the Minimum Common Standards for Groundwater Development in the SADC Region, compiled for the SADC Water Sector Co-ordination Unit (Lesotho) by Groundwater Consultants Bee Pee (Pty) Ltd.

The main institutions and personnel visited are detailed below and summarised in Table 1:

- Ministry of Agriculture, Water and Rural Development (MAWRD): Geohydrology Division, Windhoek. Mr **Greg Christelis** – Deputy Director Geohydrology; and Mr **Hartmut Strub** – Senior Hydrologist on contract to MAWRD from BGR, Germany and co-author with Abram van Wyk of Hydrogeological Map of Namibia (HYMNAM). The Geohydrology Division of the MAWRD was the leading agent in the production of the HYMNAM and the accompanying explanation brochure;

- MAWRD: Department of Agriculture and Rural Development, Agro-Ecological Zoning Programme, Windhoek. Ms **Marina Coetzee** – Chief Agricultural Researcher who was the project leader for the 1 : 1 million soils map of Namibia and thus has experience in GIS and map making, and was a member of the HYMNAM steering committee;

- Namibia Water Corporation (NamWater), Windhoek. Mr **Abram van Wyk** – Senior Hydrogeologist and co-author with Hartmut Strub of HYMNAM, previously employed by MAWRD Geohydrology Division;

- Hydrogeological Association of Namibia, Windhoek. Dr **Jürgen Kirchner** – President of the Namibian National Chapter of the IAH and previous Director of the Geohydrology Division of the MAWRD and thus well experienced in the hydrogeology of Namibia; currently sub-contracted by MAWRD and was extensively involved in production of the HYMNAM as contributing author;

- Namibia Geological Survey, Windhoek. Mr **Karl-Heinz Hoffmann** – Senior Geologist and Ms **Uta Schreiber** – Contract Geologist who were respectively involved with the geological data as contributing author, and mapping aspect as cartographer for the HYMNAM project;

- Geo Business Solutions, Windhoek. Mr **Johan van Rensburg** – Director and GIS specialist who advised on GIS aspects of the HYMNAM;

- Raison Research and Information Services of Namibia, Windhoek. Mr **John Mendelsohn** – Director, involved in the recently compiled Atlas of Namibia project and experienced in aspects of map-making and meta-data.

Table 1: Contact Details of Persons Interviewed

Name	Title	Designation	Institution	Address	Telephone	Fax	Cell	E-mail
Greg Christelis	Mr	Deputy Director	MAWRD, Department of Water Affairs, Geohydrology Division	Private Bag 13193, WINDHOEK, 9000, Namibia	+264 61 208 7089	+264 61 208 7149	-	christelisg@mawrd.gov.na
Hartmut Strub	Mr	Senior Hydrologist	MAWRD, Department of Water Affairs, Geohydrology Division	Private Bag 13193, WINDHOEK, 9000, Namibia	+264 61 208 7089	+264 61 208 7149	-	strubh@mawrd.gov.na
Marina Coetzee	Ms	Chief Agricultural Researcher	MAWRD, Department of Agriculture, Agro Ecological Zoning Programme	Agricultural Laboratory, Private Bag 13184, WINDHOEK, Namibia	+264 61 208 7077	+264 61 208 7068	-	mec@iway.na
Abram van Wyk	Mr	Senior Hydrogeologist	Namibia Water Corporation	PO Box 13389, WINDHOEK, Namibia	+264 61 710 000	+264 61 713 805	-	wykb@namwater.com.na
Jürgen Kirchner	Dr	Namibian IAH Chapter President	Hydrogeological Association of Namibia	Private Bag 13193, WINDHOEK, 9000, Namibia	+264 61 208 7123	+264 61 222 207	-	kirchnerj@mawrd.gov.na; gwi@mweb.com.na
Karl-Heinz Hoffman	Mr	Senior Geologist	Geological Survey	PO Box 2168, WINDHOEK, Namibia	+264 61 208 5111	+264 61 249 144	-	khh@mme.gov.na
Uta Schreiber	Ms	Contract Geologist	Geological Survey	PO Box 2168, WINDHOEK, Namibia	+264 61 208 5111	+264 61 249 144	-	secretary@mme.gov.na

Name	Title	Designation	Institution	Address	Telephone	Fax	Cell	E-mail
Johan van Rensburg	Mr	Director	Geo Business Solutions	PO Box 90718, Klein Windhoek, WINDHOEK, Namibia	+264 61 226 929	+264 61 229 623	+264 81 1244650	javr@iafrica.com.na
John Mendelsohn	Mr	Director	RAISON Research and Information Services of Namibia	PO Box 80044, WINDHOEK, Namibia	+264 61 254 962	+264 61 254 962	-	mendelso@iafrica.com.na

H.2 BACKGROUND

H.2.1 Physiography and Climate

Namibia is located in the south-western part of Africa and is divided into three main topographic elements:

- An eroded escarpment giving way to dissected and rugged topography (500-1500 m amsl [above mean sea level])
- An extensive interior plateau (1000-1500 m amsl)
- A narrow coastal plain (0-500 m amsl).

It is the driest country in southern Africa and second in aridity only to the Sahara Desert within Africa with rainfall scarcity and unpredictability dominating the climate. The rainfall pattern and evaporation rates vary both temporally and spatially across the country. Rainfall varies from <100 mm/a over 22% of the land surface to >500 mm/a over 8% of the land surface, with a mean annual rainfall of 270 mm.

H.2.2 Water Resources

Perennial rivers occur only on the northern and southern borders, viz the Kunene, Okavango and Zambezi on the north and the Orange River forming the southern border with South Africa. Approximately 23% of water is derived from these perennial rivers, although most of the country does not have access to these rivers due to the distances involved. The rest of the rivers are ephemeral, flowing for short periods of time only following good rains in the catchments.

Namibia depends largely on groundwater with some 50 000 operational boreholes supplying groundwater for industrial, municipal and rural water supply to isolated communities over nearly 80% of the country. Groundwater comprises 45% of the total available water resources (660 Mm^3/a), followed by ephemeral surface water (30%), perennial surface water (23%) and unconventional sources such as reclamation and recycling of water (2%).

H.2.3 Overall Institutional Framework Of Water Sector

The Directorate of Resource Management in the Department of Water Affairs (DWA) of the Ministry of Agriculture Water and Rural Development (MAWRD) is the key water resource management organisation. Under this structure, the Directorate is given the prime responsibility as manager of the water resource base and comprises the following five divisions: Planning, Hydrology, Geohydrology, Water Environment and Law Administration.

Hydrology Division, DWA

The primary function of the Division: Hydrology is to collect and make available surface water data in order to ensure optimal and sustainable resources management.

Geohydrology Division, DWA

The Geohydrology Division's major responsibility is the sustainable management of the country's groundwater resources. This encompasses groundwater investigations, control of groundwater abstraction as well as monitoring of aquifers.

Water Environment Division DWA

The Water Environment Division's major functions are the monitoring and investigation of the quality of water resources (groundwater as well as surface water) in combination with the control of treatment processes of contaminated water. This division is also responsible for development of water quality guidelines and their enforcement.

Namibia Water Corporation

As part of an overall plan to reduce the size of the former colonial civil service, the Government embarked on a programme of commercialisation. As part of this, the Bulk Water Supply Division of the DWA was transformed into what is now the Namibia Water Corporation (NamWater). At the time of formation, NamWater took over all former 'State Water Schemes', including wellfields and infrastructure. NamWater is responsible to secure the water supply to most of the major centres in Namibia and to operate the aquifers used on a sustainable basis. The controlling institution for NamWater in this regard is MAWRD.

H.3 GEOLOGICAL AND HYDROGEOLOGICAL FRAMEWORK

H.3.1 Geology

The geology is summarised, as follows:

Basement (2,500-900Ma [Ma = million years])

Igneous and metamorphic formations are exposed in the northwest and extreme south of the country and formed the depositional surface for younger sediments.

Damara Sequence (900-545Ma)

The Damara Sequence comprises metamorphic rocks (including dolomite, limestone, schist, marble, quartzite, diamictite and phyllite), with some volcanic material. A period, lasting till approximately 470 Ma, of intense mountain building (orogenesis) took place, as well as intrusion of granites, after the deposition of the sediments. During this latter phase the *Nama Group* was deposited mainly in the southern part of the country and extending into Botswana. Nama sediments, comprising shale, sandstone, limestone and conglomerate, are exposed in the south.

Karoo and Etendeka Groups (310-65Ma)

Tillite, shale and sandstone represent the Karoo Sequence and are mainly exposed in the southern half of the country. Much of this material was deposited on the eroded surface of the Nama Group. Post Karoo vulcanism resulted in extensive basalt layers capping the sediments and in the emplacement of dolerite dykes and sills into older strata.

Kalahari and Recent (24-0Ma)

Most of the northern and eastern areas are covered by a thick blanket of terrigenous Kalahari sediments, which comprises sand, sandstone, silt, clay, gravel, calcrete, ferricrete and pan deposits. This sedimentary pile obscures older strata and is in places covered by Recent dune formations.

H.3.2 Hydrogeology

Aquifers occurring are classified as follows:

- Alluvial or sand aquifers;
- Kalahari aquifers;
- Fracture aquifers;
- Karst aquifers;
- Artesian aquifers.

Alluvial Aquifers

Alluvial aquifers are of fundamental importance to development along the arid Namibian coastline. All ports and towns, (with the exception of Oranjemund) along the coastline depend solely on groundwater from alluvial sources. The economic significance of these aquifers is therefore great and their sustainable use in future years will continue to be of strategic importance.

Kalahari Aquifers

Kalahari aquifers underlie areas in the northern and north-eastern parts of the country and include phreatic, confined and artesian aquifers. Groundwater is not present everywhere in the Kalahari, but where it occurs it is relatively easy to locate. Boreholes drilled into Kalahari aquifers are generally low yielding and produce water of variable salinity. Layered fresh and saline waters are present in some places.

Fracture Aquifers

In the Karas Region and in the southern parts of the Hardap Region many successful boreholes are drilled along dolerite dyke contacts. Deep circulating groundwater, with elevated temperatures, may also be associated with dykes (e.g. Omburu near Omaruru). Litho-stratigraphic contacts may also form fracture aquifers where groundwater commonly moves along bedding planes. In marbles, groundwater is confined to solution features and interconnecting fracture zones. All hot springs originate from deep circulating water along fault zones.

Karst Aquifers

Large volumes of groundwater are stored underground in cavernous, karst aquifers such as those which typify parts of the Otavi Mountains. Solution weathering occurs along bedding planes, faults and joints, through the percolation of meteoric water containing carbonic acid from dissolution of atmospheric CO_2, which dissolves the carbonate rocks.

Artesian aquifers

Artesian aquifers are exploited in three main areas:

- The Stampriet Artesian Basin (a groundwater control area of nearly 65 000km^2), with artesian and sub-artesian conditions in boreholes in the Auob- and Nossob sandstones (Ecca Group).
- In an area 30 – 40 km west of Maltahöhe, artesian water occurs in black limestone and sandstone aquifers of the Schwarzrand Subgroup of the Nama Group.
- In the area of Oshivelo and Namutoni, the artesian aquifer draws its water from a highly permeable layer in the Kalahari sediments, which is overlain by a confining clay layer.

H.3.3 Natural Groundwater Quality

In the 1970's and early 1980's, the CSIR conducted a very extensive sampling programme which was used for the generation of the first national Water Quality maps. The four maps compiled and published from this survey showed distribution of total dissolved solids, F, NO_3 and SO_4 at a scale of 1:1 000 000.

Water quality in drinking water in Namibia is subdivided into four quality groups based on concentrations and/or threshold limits for certain determinands (determinands with aesthetic or physical implications, inorganic determinands and bacteriological indicators):

- A: excellent quality;
- B: good quality;
- C: low health risk; and
- D: water with a higher health risk (water unsuitable for human consumption).

The main determinands checked in (ground-) water on a regular basis in Namibia are: F, NO_3, SO_4 and Total Dissolved Solids (TDS). These determinands can occur naturally in relation to the host rocks or can be attributed to pollution. Increased abstraction of groundwater may cause changes in the chemical balance resulting in an increase of certain determinands. Examples of naturally high salinity are northwest of Etosha Pan extending into the Cuvelai.

Groundwater quality is indicated on one of the inset maps on the 2001 Hydrogeological Map. Group A groundwater predominates in the borehole record. Group D water occurs mainly in the north, between Windhoek and Swakopmund and in a belt from Windhoek to the south-east towards Mariental and east of Keetmanshoop.

H.4 DATA ACQUISITION

H.4.1 Institutional Framework for Data Collection

The Geohydrology Division of the DWA has a monitoring programme in which hydrogeological parameters are measured for a number of boreholes across the country. Personnel of the Division collect data from this network and it is planned to extend this network. In addition to the data collected by DWA, groundwater data are supplied on an ad-hoc basis by NamWater, hydrogeological and engineering consultants, drilling contractors and farmers (particularly in the Water Control Areas).

The hydrogeological parameters most routinely measured are water levels (taken both manually and with autographic recorders) and pumping rates, with data generally collected in the field and transferred to the office by pen and paper, and digital downloading in areas of high groundwater abstraction.

The same is the case with water quality sampling where selected water quality parameters are measured on a regular basis for a number of representative boreholes across the country. There is, however, no comprehensive national groundwater quality database with a high distribution density of boreholes for Namibia.

H.5 GROUNDWATER INFORMATION SYSTEM

The Geohydrology Division of DWA has conducted and commissioned numerous studies of the groundwater of the country and has built up and maintains a large Groundwater Database since 1960. A digital database was initiated in 1985 and implemented in 2002 as the National Groundwater Database comprising SQL Software running under an MS Windows platform.
This database provides co-ordinates and some locality information together with certain technical specifications and records for some 48 000 boreholes.

H.5.1 Hardware and Software Set-up

The hardware and software set-up of the authorities / institutions that are capable of contributing to the SADC project are summarised in Tables 2 and 3.

Table 2: Institutional Hardware Set-up (number of units indicated)

Institution	Server	Work-station	PC	Other
MAWRD – DWA	1	3	12	-
NamWater	1	1	1	-
Geological Survey	1	6	5	-

Table 3: Institutional Software Set-up (availability marked with an X)

Institution	Windows	MAC	MS Office	WP Office	GIS	In-house	Other
MAWRD – DWA	X		X		ArcView ArcInfo	HydSys Growas	Surfer
NamWater	X		X		ArcView ArcInfo	HydSys Growas (planned)	Surfer Geodin WISH
Geological Survey	X		X	X	ArcView ArcInfo ArcGIS		ER Mapper, Corel Draw, Rock Works

Since all of the above institutions were directly involved in the HYMNAM project (see Section 7), their hardware and software systems are up to date, user-friendly and will be usable in and relevant to the SADC mapping project.

H.5.2 Data Saved

In the DWA Groundwater Database, boreholes are numbered using two different systems:

- The "borehole number" is a sequential number assigned to boreholes drilled for the Government. A prefix "WW" is used although some older boreholes might have the prefix G, A or T.
- A single numbering system was introduced that assigned a sequential number to each water point (borehole, well or spring) located in the area covered by a 1:50 000 scale topographical sheet. Each topographical sheet therefore has its own set of "well numbers" starting at 1. The numbering system uses an alphanumerical identification (6 digits) combined with the well number as the key field identification to refer to a water point in the database. Thus the fifth water point located on topographical sheet number 1920 AB would be assigned 1920AB5 as its key identifier.

During the early 1980's the CSIR (South Africa) conducted an extensive hydrogeochemical survey of Namibia in which 25 580 samples (including 250 river samples) were taken and analysed for major and minor ions. Maps, which are available from the DWA library, were generated showing the distribution of the following parameters: F, NO_3, SO_4 and TDS. These parameters have been incorporated into the Groundwater Database, which can thus be used to provide some indication of water quality.

A large hydrochemical database has been generated over the years by DWA (± 80 000 analyses) and stored in the form of typed out analysis reports. Since the late 1980's the particulars of the samples have been stored in a UNIX database. At the same time an attempt was made to add the earlier data to the system beginning with the oldest analyses. To date, approximately half of the older analyses have been entered and are available in digital format.

Five years ago the Geohydrology Division of DWA, in collaboration with NamWater, embarked on a programme to develop a new database for groundwater data. It is intended that the new system (**GROWAS**) will have certain analytical tools, which will enable users to plot the data in a readily useful form. The programme is ambitious and scheduled to be completed within a few years. A

consultant has been appointed to carry out this development in co-operation with DWA and NamWater.

H.5.3 Quality of Data

The data collected for the HYMNAM project was aimed at establishing a national, country-wide map at a scale of 1 : 1 million. Because of the scale, as well as the limited time frame of only two years, the information in the map is inadequate to allow zooming or enlarging.

More detailed high-quality and high-resolution data are available on geology, boreholes and groundwater for certain regions of strategic groundwater occurrence and subsequently high groundwater use. The positioning accuracy of the data points is generally 100 – 1000 m and a backlog of data to be input into the database of 1 year to >5 years results in a delay before the quality of the data can be checked and verified.

H.5.4 Available Resources for Maintenance

Within the Geohydrology Division of the DWA only a limited number of staff are available for monitoring (10), data management (5) and map production (5 on a project basis). The acute lack of staff is considered to be the most important deficiency in effective operation of the Division. In addition, the annual budget is limited, e.g. monitoring: Nam$1.5M, data management: Nam$2.2M, and map production: Nam$2.5M over a three year project life-span.

No budget is available to the Division for ongoing training and water awareness programmes for the general public. Whilst limited funds are being budgeted to upgrade the hardware and software system within the Division over the next two years (~Nam$1.5M in total) this is considered to be insufficient to adequately address the shortfalls in data management and database maintenance.

H.6 GROUNDWATER MONITORING

Although there are a number of pieces of legislation which impact on water resources, the Water Act (Act No 54 of 1956) is the primary legislation with regard to the ownership, allocation, access and management of the resource.

With regard to groundwater monitoring, the collection of groundwater abstraction data for government water scheme boreholes is now the responsibility of NamWater, where information on the number of boreholes drilled, the purpose for which they were drilled and groundwater abstraction volumes allows for effective aquifer management.

H.6.1 Monitoring Network and Frequency

The groundwater monitoring network exists on a national scale as well as groundwater supply scheme-based scale. Monitoring network boreholes are generally protected against over-abstraction and characterised by a monitoring frequency varying from *ad-hoc* to quarterly.

The hydrogeological parameters most routinely measured are water levels, taken both manually (dip-meter) and with autographic (float) recorders. Pumping rates are measured mostly by NamWater at groundwater abstraction schemes. Data are generally collected in the field and transferred to the office by pen and paper, with digital downloading in areas of high groundwater abstraction.

The same is the case with water quality sampling by DWA, where groundwater salinity is measured on a regular basis for a number of representative boreholes across the country. To date, there is no comprehensive groundwater quality database with a high national distribution density of boreholes.

Groundwater monitoring networks are detailed in Table 4.

Table 4: Monitoring Network Detail

Name	No of boreholes	Purpose of monitoring	Parameters monitored	Recording method	Monitoring frequency	Monitoring period
?	?	?	?	?	?	?
?	?	?	?	?	?	?

(Detail above to be kindly filled in by H Strub, MAWRD).

H.6.2 Quality of Monitoring Data

Whilst QA / QC measures are in place on an ad-hoc basis during the various stages of monitoring / sampling, data management and map production / GIS, these measures vary from random checks to no checks. As a result, the quality of monitoring data are accurate only where data exist for identified monitoring network boreholes. In some cases the positional accuracy of the monitoring point is >1000 m, and thus cannot be used for site-specific studies.

Borehole records for drilling on government or parastatal projects are mostly held on file at the Geohydrology Division but there is no legislation to date requiring the submission of records by other parties involved in the drilling industry, except in water control areas. Similarly, production records are maintained by certain local authorities and parastatals, but not necessarily by farmers and miners. Where the latter do maintain records they are not necessarily submitted to the Division to add to the National Groundwater Data-base.

No nationally accepted standards are applicable for professional supervision and reporting in the groundwater industry. In some cases, however, the DWA have stipulated the grade of personnel to be deployed on projects for specific tasks.

H.7 HYDROGEOLOGICAL MAPPING

H.7.1 Existing Hydrogeological Maps

In December 2001 a hydrogeological map was published following a two-year intensive co-operation project between the Republic of Namibia and the Federal Republic of Germany. The following institutions contributed to the project: the Federal Institute of Geosciences and Natural Resources in Germany (BGR); the Ministry of Agriculture, Water and Rural Development, Department of Water Affairs, Division of Geohydrology; the Geological Survey of Namibia; and the Namibian Water Corporation.

The product of this mapping project is the HYMNAM, and, with respect to cataloguing data, is referred to as: *The Hydrogeological Map of Namibia 1 : 1 000 000 by AE Van Wyk, H Strub, W Struckmeier (eds), Department of Water Affairs and Geological Survey, Windhoek 2001.*

The focus of the Map is to provide a countrywide overview of the occurrence and quality of groundwater resources, i.e. to provide a national-scale hydrogeological setting. The Map comprises two sheets, viz a 'Sheet West' on which the majority of the land surface of Namibia is displayed, and a 'Sheet East' on which eastern portion of the country, the Caprivi Strip to the north and inset / derivative maps are displayed.

The following features are displayed on the Map:

- Hydrogeology and groundwater potential;

- Main rock types and Hydrogeological Units;
- Topography, showing national and regional boundaries, roads etc;
- Geology, showing boundaries of geological units, faults etc;
- Hydrology, showing rivers, catchment areas, lakes etc;
- Groundwater Features, showing location of, eg springs, depth to groundwater, groundwater flow direction, delineation of artesian basins etc;
- Water use and Water Management Features, showing selected wells or boreholes, groundwater supply schemes, groundwater control area boundaries etc.

The cartographic projection detail of the Map is summarised in Table 5.

Table 5: HYMNAM Cartographic Projection Detail

Projection	Albers Equal Area
Units	Metres
Spheroid	Bessel (1841)
First Standard Parallel	26° 00 00 S
Second Standard Parallel	20° 00 00 S
Central Meridian	18° 30 00 E
Latitude of Origin	22° 00 00 S
False Easting (metres)	0
False Northing (metres)	0

The most important source of data for the compilation of the thematic data layers related to groundwater, was the groundwater database operated by DWA. The second main thematic layer displaying lithological units is predominantly based on the existing geological map of the Geological Survey of Namibia at a scale of 1 : 1 000 000, where the 164 units outlined on the geological map of Namibia were reduced to 12 units. These units are contained in the lithological data layer used as a basis for the HYMNAM.

The country-wide quarter degree (1 : 250 000) topographical sheets as well as LANDSAT Thematic Mapper satellite images were used as base maps for the physiographic base data set for the HYMNAM.

H.7.2 Derivative Maps

There are five inset (derivative) maps and three geological cross-sections on the Map, providing complimentary information to the main Map. The five inset maps comprise:

- Rainfall and Main Catchments in Southern Africa (scale 1 : 10 000 000) – shows the major rivers and catchment basins in southern Africa, together with the rainfall distribution in southern Africa;
- Altitude of Ground Surface (scale 1 : 6 000 000) – shows altitude intervals in metres above mean sea level interpolated from a USGS digital terrain model;
- Groundwater Quality (scale 1 : 6 000 000) – shows TDS values in boreholes, classified into four groups according to the Namibian Guidelines for suitability for human consumption, ranging from excellent quality to high risk water;
- Density of Borehole Information (scale 1 : 6 000 000) – shows the number of database boreholes per 1 : 50 000 topographical map sheet and provides a good indication of reliability of the indicated information;
- Vulnerability of Groundwater Resources (scale 1 : 6 000 000) – shows vulnerability of groundwater resources to pollution, integrating depth to groundwater, aquifer type, predominant flow direction and rainfall recharge.

The three geological cross-sections are through important multi-layered aquifer systems in the country and highlight the fact that groundwater flow systems are 3-dimensional in reality.

Aquifer productivity is mapped and portrayed according to the International Legend for Hydrogeological Maps, recommended by the IAH and UNESCO with minor adjustments. This legend uses a colour scheme that subdivides sediments/rock bodies into aquifers and non-aquifers.

Aquifers are subdivided into porous aquifers (blue shades) and fractured, fissured or karstified aquifers (green shades), with rock bodies of little groundwater potential shown in brown shades (yields <3 m^3/hr) . Dark blue and dark green represent aquifers with high potential (yields generally >15 m^3/hr), with light blue or light green indicating aquifers with moderate potential (yields generally between 3 and 15 m^3/hr).

The detail of the hydrogeological map legend is summarised in Table 6.

Table 6: Hydrogeological Main Map and Inset Map Legend Summary

Legend	Details of Legend
Hydrogeology and Groundwater Potential of Rock Bodies shown as colour filled polygons in the main map sheet	Classification of aquifer: ➢ Porous Aquifers (blue) ➢ Fractured, fissured or karstified aquifers (green) ➢ Rock bodies with little groundwater potential (brown) Classification of yield: ➢ 0 – 3 m^3/hr: very low to locally moderate ➢ 3 – 15 m^3/hr: moderate ➢ >15 m^3/hr: high
Main Rock Types subdivided into surface cover deposits and main rock type of hydrogeological unit; with each sub-division further divided into predominant lithological unit	Rock types and hydrogeological units represented by various patterns, symbols, hatching and combinations
Topography and Geology	Boundaries, faults, roads, railroads and power-lines shown as lines of different styles and colours. Cities/ towns and settlements as well as mine sites depicted using standard topographic symbols
Hydrology	Symbols used are:- ➢ Rivers (perennial and non-perennial): solid and dashed blue lines respectively, brown line for dry river; ➢ Swamps, lakes and pans: blue polygons with varying pattern in-fills; ➢ Boundary of catchment basin: blue dotted line
Groundwater features	Features include:- ➢ Spring and thermal spring: purple and orange circle; ➢ Depth to groundwater: purple dashed line with depth value; ➢ Groundwater flow direction: purple arrow; ➢ Groundwater divide, limit of area of artesian flow and limit of area of sub-artesian groundwater: variations in purple dotted and dashed lines; ➢ Area of saline and poor quality groundwater at depth: orange hatched polygons; ➢ Line of hydrogeological cross-sections: A – B standard black line
Water use and water management	➢ Selected well or borehole: open red circle

Legend	Details of Legend
features	➢ Groundwater supply scheme and irrigation scheme using groundwater: open red square and diamond; ➢ Canal, water pipeline and boundary of groundwater control area: patterned red line variations ➢ Dam: red curve line showing capacity of reservoir in Mm^3 as a value figure
Rainfall and main catchments in Southern Africa showing mean annual rainfall depicted as polygons	➢ Ten hypso-metric tints ranging from dark brown (0 – 50 mm/y) to light purple (>1400 mm/y) ➢ Major catchment boundary and country border shown as dotted blue and dashed black line respectively
Altitude of groundwater surface in m above mean sea level shown as polygons	Eleven hypso-metric tints ranging from light green (0 – 200 m) to dark brown (>2000 m)
Density of borehole information showing number of boreholes per topo-sheet (1 : 50 000)	Five shade classes of topo-sheets covering Namibia varying from light yellow (0 boreholes) to dark green (>150 boreholes)
Groundwater quality based on TDS values and ranked according to suitability for human consumption. Data point shown as a coloured circle	Classification:- ➢ Group A: Excellent quality – blue ➢ Group B: Good quality – green ➢ Group C: Low risk – orange ➢ Group D: High risk – red
Vulnerability of groundwater resources showing the risk of pollution assessed on the basis of aquifer type, groundwater flow, depth to groundwater and annual recharge	Polygons coloured according to four shade classes: ➢ Very high: red ➢ High: orange ➢ Moderate: yellow ➢ Rather low: blue
Cross-sections of multi-layered aquifer systems through the Stampriet Artesian Basin, the Owambo Basin, Otavi Mountain Land and the Kalahari Basin	Vertically exaggerated hydrogeological cross-sections using the same colours, features and symbols as the main map. Selected boreholes shown on the main map are depicted as red lines with borehole reference number.

H.7.3 Existing Geological Maps

Geology is presented on a published 1 : 1 000 000 Geological Map (2001) and is available from the Ministry of Mines and Energy (MME). The geological units on this map were arranged according to rock types (lithology) to prepare a thematic data set for the HYMNAM.

The majority of the country is covered by published 1 : 250 000 scale geological map sheets, available from the MME in paper format, as well as digital (scanned TIFF images). The systematic coverage of the country at a scale of 1 : 100 000 is ongoing and some 1 : 50 000 geological maps are available.

H.7.4 Existing Physiographic Maps

Topography is covered by 1 : 250 000 (quarter degree sheets) maps in paper format, available from the Surveyor General, Windhoek, Namibia. These maps are based in part on LANDSAT TM satellite images (1996 – 1998).

The accuracy of the geographic locations of topographic and physiographic features (eg roads, rivers) needs to be checked and corrected according to the topo-sheets in the north-western corner of Namibia (especially along the Kunene River).

For additional data on the topographical maps of Namibia, the reader is referred to the Namibian Surveyor General.

H.8 DATA AVAILABLE FOR SADC HYDROGEOLOGICAL MAP

The contributions of each of the institutions contacted with respect to the SADC Map and Atlas project is summarised in Table 2 below:

Table 7: Contributions of the Institutions to the SADC Project

Institution	General groundwater information	Monitoring / time dependant data	Map production
MAWRD	X	X	X
NamWater	X	X	X
Geological Survey			X
Geo Business Solutions			X
Raison			X

The availability of the individual data-sets / maps for the SADC project map is indicated in Table 8.

Table 8: Data-set / Map availability

Data-set / Map	Source data available	Processed data available	Not available
Boreholes	X	X	
Geology	X	X	
Physiography	X	X	

The borehole database used for the HYMNAM (MAWRD's National Groundwater Database) is created and owned by the MAWRD and its use is restricted to the MAWRD. As such, it is protected by a licence agreement, and access to and use of the database is conditional.

For further information regarding availability and format of data-sets and maps in Namibia, the reader is referred to Mr H Strub, MAWRD, Windhoek.

H.9 CAPACITY AND COMMITMENT FOR THE PROJECT

H.9.1 Existing Capacity

The Geohydrology Division of the DWA have limited capacity at a national level for their own mapping programme and information system. From all the interviews held, the major and predominantly identified deficiency related to data collection, management and map production was related to lack of staff as well as lack of suitably qualified staff (specifically trained hydrogeologists), which is attributed to poor remuneration.

The manpower resources available to the Geohydrology Division totals five key staff members. Whilst these staff are highly qualified and experienced, they are mostly involved in general MAWRD and Divisional duties with lack of available time for other work outside of their main areas of responsibilities.

H.9.2 Commitments on Contribution to Regional Mapping Project

The commitments made by individuals and institutions towards the SADC project are summarised below:

- MAWRD – 1 member of staff on senior hydrogeologist level with GIS experience for a 25% time commitment for the duration of the project. This is considered to be a feasible commitment. No funds are available within the Geohydrology Division of the DWA's budget for the SADC map and atlas project;
- NamWater – at least 1 member of staff, suitably qualified at senior hydrogeologist level would be available to work on the SADC Project on a consultancy basis at US$30 / hour for the duration of the project;
- Namibia Geological Survey – 2 members of staff on senior geologist level with GIS and map production skill for a 25% time commitment for the duration of the project. This is considered to be a feasible commitment provided top management of the Geological Survey approve;
- Geo Business Solutions – 10 members of staff with GIS and cartography skill are available to work on the SADC Project on a full time consultancy basis for the duration of the project, at rates varying from Nam$20 to Nam$250 / hour;
- Raison – 2 members of staff with GIS expertise available on a part-time consultancy basis to the project. This commitment requires firming up with an indication of time available as well as consulting rates and will depend on the obvious commitment of Raison to other projects.

The needs and expectations with respect to the SADC project are summarised in Table 9 below.

Table 9: Overview of SADC Map and Atlas Project – Map and Information Expectations

Institution	**MAWRD**	**NamWater**	**Geo Business Solutions**	**Namibia Geological Survey**
Scale	1 : 5 000 000	1 : 5 000 000	1 : 1 000 000 (digital data) The map can be at any scale	SADC region on 1 map
Legend	IAH / UNESCO	UNESCO	-	-
Commitment	Manpower	Manpower	Manpower	Manpower
Comments	Consultants with local experience required The groundwater atlas should include an explanatory booklet	-	-	Consultants with local experience required

H.10 POLICY ISSUES AND CONCERNS

According to the majority of the people / institutions interviewed, the following policy issues need to be urgently addressed before the SADC atlas is applied regionally:

- Aspects of data ownership / custodianship, data distribution, data copyright and data access need to be formalised;
- It was suggested that a SADC Groundwater Data Co-ordination Centre / Committee be established;
- The expectation amongst all the respondents was that the database formed for the SADC Map and Atlas Project must be freely available and easily accessible;
- It was strongly expressed that private institutions must not be able to financially gain by re-selling the SADC Map and Atlas data;

- The project steering committee should have a good skills base with respect to scientific and technical expertise in hydrogeology and map production;
- There will be countries where groundwater data are not freely available, eg being captured by private individuals (or does not belong to a government institution). Provision must thus be made in the budget to purchase this information;
- Available funding should be spent on filling in the gaps in groundwater data or map quality of identified countries that are lacking. This will ensure quick splicing of available maps.

From experience gained during the Namibia mapping project, as well as general observations on the SADC project, the following points are considered relevant:

- There is already an extensive available database of, e.g. roads, rivers DTM, national and provincial boundaries etc from varying international departments and NGOs eg USGS, FAO (Food and Agricultural Organisation of the UN), UK Military Survey (Defence Geographic Centre) etc. The implication being that a good base-map could already be produced of the whole SADC region, by adding some 'intelligence' with respect to groundwater and geology;
- The SADC Map Project should be two-fold: 1) produce the most accurate GIS data platform for the SADC region possible, and 2) use this GIS database to produce groundwater map/s on any scale thereafter;
- The final product should not be 'paper map' orientated, rather it should be seen as a dynamic database that is updated regularly. Any map / atlas product can be produced from this database thereafter;
- It was suggested that there should be a discussion in the atlas / map brochure regarding regional aquifers that cross national boundaries eg Kalahari Basin and Karst Aquifer (fed by the Okavango system). Individual smaller regional aquifer maps should be included in the atlas / brochure, since different aquifer types (eg primary vs secondary aquifers) have different data sets and require different items / features to be displayed on the maps. This would ensure that sufficient detail could be shown for strategically important groundwater resources that would otherwise not be shown on a SADC Region scale.

H.11 REFERENCES

Christelis, G & W Struckmeier (eds). 2001. Groundwater in Namibia, an explanation to the Hydrogeological Map. John Meinert, Windhoek.

Van der Merwe, B. 2001. Implementation of Integrated Water Resource Management in Windhoek, Namibia; Water Association Namibia.