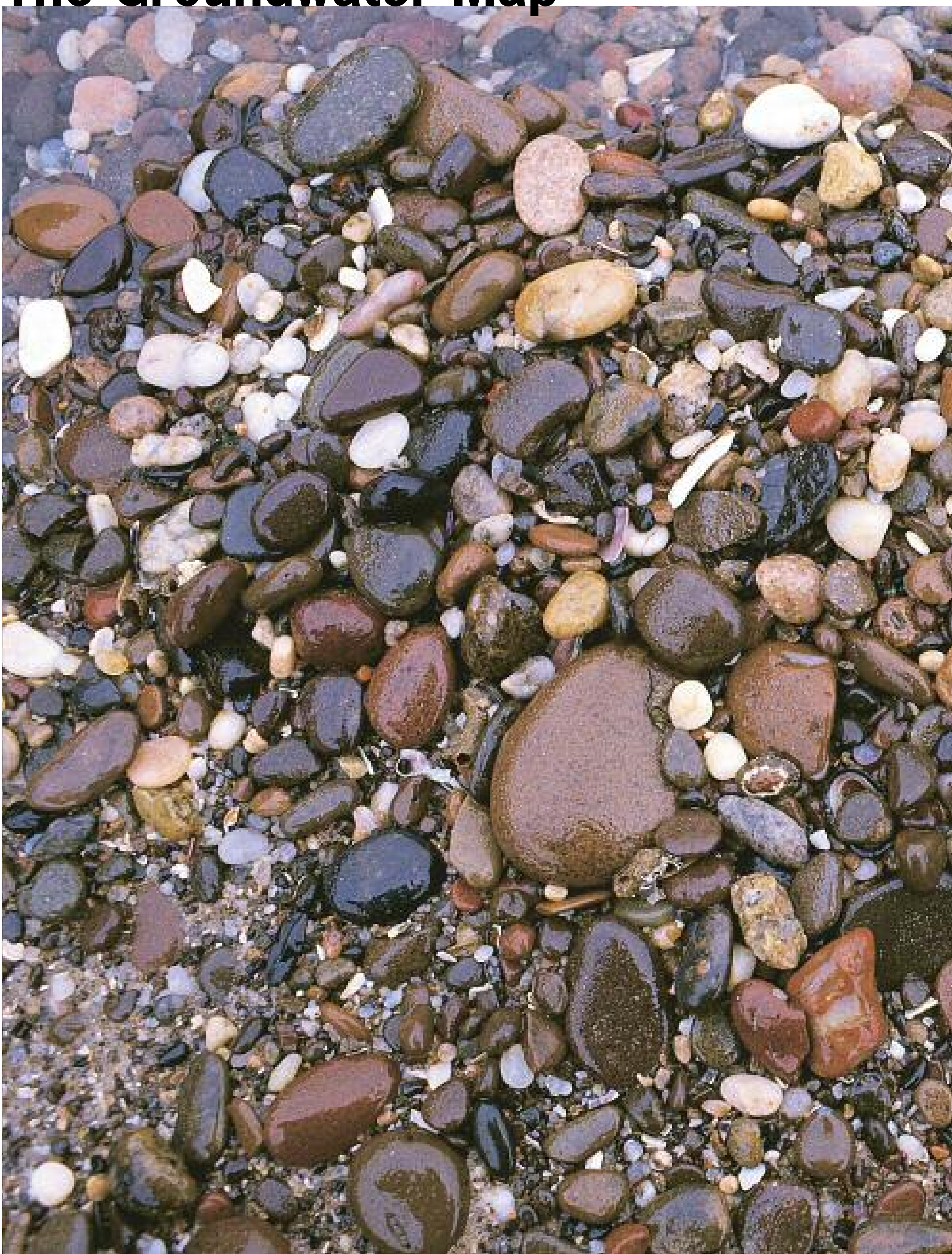
# The Groundwater Map



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# Data and use of the Map

This chapter describes the technical way in which the data used for the Map were collected, created, interpreted and finally prepared. A basic distinction is made between data serving as topographical background information, and the thematic data layers which were constructed, calculated or derived from various sources. The problems in the creation of the topographical base data were mainly due to incomplete, inaccurate or non-documented data sets. The creation of the thematic data themes, relied on the geological, hydrogeological and hydrological data of variable quality captured over the past decades and necessitated a huge effort to search, collect, correct and validate the data. Nevertheless, this process of preparing coherent and good quality data for the Hydrogeological Map has resulted in the most up to date, accurate and complete data sets on ground- and surface water in digital form yet in the MAWRD.

It must be clearly stated, that the data collected for the Hydrogeological Map of Namibia Project (HYMNAM) was first and foremost geared at establishing a national, country-wide map at a scale of 1:1 000 000, with 10 millimetres on the Map equal to 10 kilometres in reality. This focus on a country-wide overview map and the time frame of only two years has meant that the information on the Map is inadequate to allow zooming in and enlarging. More detailed, high-resolution data on geology, boreholes and groundwater might be available for certain regions of the country in the databases of GSN, DWA and NamWater, but cannot be derived from the HYMNAM data sets.

In addition, it must be spelled out clearly that site-specific projects such as the correct siting of boreholes or dump sites require sound, site-specific professional investigations. The information presented on the Map at 1:1 000 000 scale, is by far too general and can only be used as orientation for the site-specific follow-up studies. The results of the detailed investigations should be used to improve the HYMNAM data sets in the future.

**Topographical base data**

When the Hydrogeological Map of Namibia Project (HYMNAM) was initiated, it was assumed that the topographic base data for the Map were readily available in the country. In fact, it soon became apparent, that the accessibility of digital data of good quality and reliability was, and still is, one of the major challenges in Namibia. Another challenge faced throughout the data-capturing period was that existing data sets were of a poor quality or occurred in strange electronic formats lacking any documentation. This made it very difficult to collect the data and transform it into a consistent and correct coverage.

The first step was to implement a geographical reference system to be used throughout the Map project. Taking into account the reference systems for existing data, the following projection was chosen:

| | |
|---|---|
| Type | Albers Equal Area |
| Units | Metres |
| Spheroid | Bessel 1841 |
| 1st standard parallel | -26 00 00 |
| 2nd standard parallel | -20 00 00 |
| Central meridian | 18 30 00 |
| Latitude of origin | -22 00 00 |
| False easting (metres) | 0 |
| False northing (metres) | 0 |

As the HYMNAM Project and the Hydrogeological Map depended greatly on a reliable topographical database, the creation of this was considered the first important step to ensure that all new thematic data fit together geographically and logically. The data sets representing the topographical background displayed on the Map were collected or prepared as shown in the next table.

Numerous corrections were applied to the drainage pattern because it is both a topographic and a water-related feature. The most accurate and complete data set available was the Map created by the Ministry of Environment and Tourism (MET) based on the Digital Chart of the World, which is publicly available and compiled from various data sources. Error corrections and completions were necessary at certain places. For this, topographical maps at scale

**Data sets representing the topographical background**

| Data Set | Source, Preparation |
|---|---|
| National border | Provided by the GSN; coast line and the rivers forming the northern and southern boundary were re-digitised based on the Topo sheets 1:250 000 as well as satellite images |
| Regional boundaries | Provided by the Roads Authority (S Thekie, J van Rensburg) |
| Nature conservation areas | Provided by MET (H Kolberg) |
| Towns | Provided by the Roads Authority (S Thekie, J van Rensburg) |
| Roads | Provided by the Roads Authority (S Thekie, U Truemper) |
| Railways | Provided by GSN |
| Powerlines | Provided by NamPower (U von Seydlitz) |
| Mines | Provided by GSN |
| Pipelines and canals | Provided by MET/NNEP and NamWater |
| Rivers | Basic data provided by MET; corrections applied by DWA based on Topo sheets 1:250 000 and satellite images |
| Oshanas, Swamps, Lakes/Reservoirs, Pans | DCW database; corrections applied by DWA based on Topo sheets 1:250 000 and satellite images |
| Catchment areas | Digitised from maps of DWA |
| Dams | Digitised on the base of information from NamWater |
| Springs | Digitised based on information from the national groundwater database; information gathered from existing maps, reports and field visits |

1:250 000, drainage data sets of published and draft geological maps at scale 1:250 000, and finally, a set of LANDSAT Thematic Mapper satellite images were used to rectify and update the drainage pattern. The result is the most reliable data set on drainage in Namibia, applicable to the national scale of 1:1 000 000, yet errors may be still considerable, as high as 3 mm on the Map or 3 km in reality.

The second data set to receive attention was the country border. To show the total territory of Namibia in the correct topographic position, a new country border data set including the Caprivi Strip had to be developed. The country border was checked using existing maps at scale 1:250 000, a number of geodetic points along the border to Angola, Botswana and Zambia as well as the LANDSAT TM satellite images.

Few changes were necessary for the good-quality data sets such as the roads and towns that had been recently surveyed by the Roads Authority. For other data sets, no further information was available to improve the accuracy nor was it possible to rectify in the time available, nor within the budgetary constraints of the project.

**Preparation of the thematic data layers**

Landsat Thematic Mapper

**In the Caprivi Strip, the old country border (red line) had to be substantially corrected (yellow line) using satellite imagery; the deviation exceeded 10 km**

The thematic data layers displayed on the Map were compiled and derived using data from various sources, analogue as well as digital. In addition, the knowledge and expertise of experts working in the fields of groundwater and /or geology in Namibia were mobilised to extract the pertinent information from the existing data. The table below shows the thematic data layers together with the sources of information used for their construction:

The most important source of data, for the compila-

| Data Set | Source |
|---|---|
| Lithology | Derived from the geological map 1:1000000, from satellite images, borehole completion reports as well as from knowledge of local consultants |
| Geological faults | Provided by GSN |
| Aquifer productivity | Derived from information in the national groundwater database of DWA, borehole completion reports and from knowledge of local consultants |
| Groundwater divides | Derived from information in the national groundwater database |
| Groundwater flow directions | Derived from information in the national groundwater database |
| Depth to groundwater table from surface | Derived from information in the national groundwater database and borehole completion reports |
| Surface water divides | Derived from the data layers of the rivers and the digital terrain model provided by the USGS (GTOPO30) |
| Areas of saline groundwater | Derived from information in the national groundwater database, the CSIR hydrochemical maps as well as from knowledge of local consultants |
| Areas with poor groundwater quality | Derived from information in the national groundwater database, the CSIR hydrochemical maps as well as from knowledge of local consultants |
| Areas of artesian and sub-artesian water | Digitised from documentation of DWA and knowledge of local consultants |
| Groundwater control areas | Digitised from maps of DWA |
| Groundwater irrigation schemes | Digitised based on information from the Division: Agricultural Engineering of the MAWRD |
| Groundwater supply schemes | Digitised based on information from NamWater |

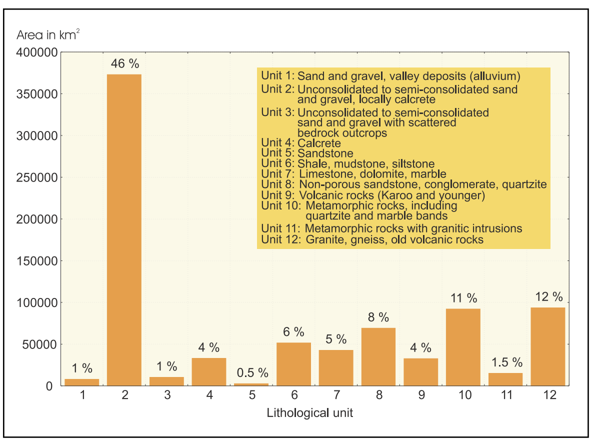
tion of the thematic data layers related to groundwater, was the groundwater database operated by DWA. The second main thematic layer displaying the lithological units is largely based on the existing geological map of the Geological Survey of Namibia at a scale of 1:1 000 000.

### Lithology layer

The preparation of the thematic data set on the lithological layer took place in several steps. As a starting point, the units on the 1:1 000 000 Geological Map were arranged according to the rock types (lithology), because the type of rock determines the groundwater flow in it. Being of minor importance, the age and stratigraphical position were not taken into consideration. A legend describing the different rock types was created. This differentiation was gradually refined and finalised, using detailed documentation and the expertise of local geologists. Finally, the 164 units outlined on the geological map were reduced to the 12 units contained in the lithological data layer.

The area covered by each of these large lithological units is shown in the bar graph. Almost half of the country (48 %) is covered by unconsolidated deposits such as gravel, sand and silt, while 24 % are sedimentary hard rocks (limestone, dolomite, sandstone, mudstone, shale), 12 % metamorphosed sedimentary rocks, 4 % young volcanic rocks, and 12 % basement rocks, bringing the percentage of hard rock areas in which groundwater exploration is difficult, to 52 %.

### Aquifer productivity

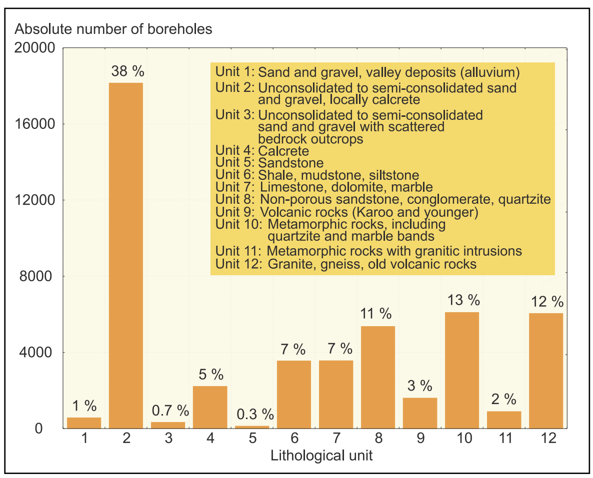



**Area covered by the lithology units used on the Map**

The current groundwater database stores information on positions, construction details, depth to water level and yields from about 48 000 boreholes. Problems encountered included missing values and wrong entries, due to the historical development of the database. It started as an application in a UNIX environment, was converted into a dBase file and finally into a MS-ACCESS database. This caused many errors due to lost tables, mixed up data sets and destroyed relationships between various tables. Now, DWA together with NamWater is developing a new database application (GROWAS) which will be ready by the end of 2001.

Nevertheless, the content of the database proved very useful and the influence of errors was minimised by the large volume of information available and the small scale of the Map, scale 1:1 000 000. The number of boreholes, and thus the reliability of information is shown on the inset map "Density of borehole information" on the main Map. This is reflected here in the graph showing the number of boreholes recorded in the database, per lithological unit of the Map.

The two graphs clearly indicate the correlation between




**Boreholes drilled in the lithological units**

the size of the area covered by the various lithological units and the number of boreholes drilled. Surprisingly, no unit stands out as a prominent aquifer with a high number of boreholes. Instead, the distribution of population and the demand for groundwater are decisive criteria for the number of boreholes in various parts of the country. Therefore, it is necessary to analyse the distribution of borehole yields to be able to delineate aquifers, aquitards and aquicludes.

The wealth of borehole completion reports was used to confirm and amend the information extracted from the database. These hardcopy documents are filled once a borehole is drilled. There are about 21 000 borehole completion reports in the files of DWA and NamWater. These reports comprise information about the borehole design, the initial yield during pumping tests and the lithological units encountered. In the compilation of the Map, only reports providing solid and complete information were used. A limited number of representative boreholes with a detailed lithological description and complete data sets on depth, yield and groundwater quality, were selected as reference boreholes and are displayed on the Map (see Annex 4 "Comparison of selected guideline values for drinking water quality").

Reports from previous groundwater projects available in NamWater and DWA were scrutinised and checked to obtain complete and consistent data. Useful ones were selected and the information regarding groundwater potential, quality and use, as well as other important hydrogeological details were extracted for the Map. This information was used to confirm or adjust the information derived from the database and the completion reports.

Using this information, the second important layer, the aquifer productivity data set, was created step by step. Firstly, the yield figures stored in the groundwater database were analysed and spatially interpolated. The following categories were chosen, after discussion with local experts:

These yield figures and the aquifer type derived from a

| Yield in $m^3/h$ | Human activities possible |
|---|---|
| < 0.5 | Only emergency water supply or very small livestock |
| 0.5 – 3 | Small settlements with small stock units |
| 3 – 15 | Farming/settlements with a certain amount of large stock units |
| > 15 | Farming/settlements with large stock units, municipal water supplies and irrigation |

generalisation of the lithological layer, whether porous, unconsolidated deposits or fractured hard rocks, made it possible to map the country according to the International Legend for Hydrogeological Maps, recommended by the International Association of Hydrogeologists (IAH) and UNESCO (Struckmeier & Margat 1995). This legend uses a colour scheme that subdivides the rock bodies into aquifers and non-aquifers (aquitards and aquicludes). The latter are shown in two shades of brown, while the aquifers are further split into porous or fractured. This distinction is useful, because they have fundamentally different flow characteristics and thus groundwater investigation and exploitation also differs. Porous aquifers are shown in blue and fractured aquifers in green. Two shades of these colours are used to reflect the productivity. Dark blue and dark green represent aquifers with high potential (yields generally above 15 $m^3/h$), while light blue or green indicate aquifers with moderate potential (yields generally between 3 and 15 $m^3/h$).

The results of this data analysis exercise were discussed with the local groundwater consultants. They provided input based on their experience and specialist knowledge of certain areas of the country. Their input was all the more valuable, because few records exist about unsuccessful boreholes and thus the aquifer potential concluded from the database and other records was seriously overestimated in some areas. This could be corrected by those with local experience.

The other groundwater related data sets were established in much the same way. Firstly, the data available in the database were analysed and the results printed on the Map. Then, local groundwater consultants were solicited to rectify and adjust those results. This multiple-step exercise, combining information of different sources, evaluating it, discussing it and refining it, finally created the best picture of the hydrogeological situation in the country. Involving local hydrogeologists in this project also guaranteed that the experience and intuitive expert knowledge of individuals, not captured in any database nor documented, was harnessed for the Map.

# Inset maps

There are five inset maps and three geological cross sections on the Map. These provide complementary information that, to retain clarity and legibility, could not be presented on the main Map.

In the inset map "Rainfall and main catchments in South-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ern Africa", at a scale of 1:10 000 000, the major rivers and their catchment basins are shown together with the rainfall distribution in southern Africa, south of 12° latitude. It clearly demonstrates that Namibia shares most of the surface water catchments with neighbouring countries and lies in an area of very low rainfall. The data for this inset map originated from the data set of the "SADC Water Resource Database" and from Arnestrand & Hansen, 1993; published in Pallett 1997, amended and revised on the basis of up to date Namibian sources.

The insert map "Altitude of ground surface", at a scale of 1:6 000 000, shows altitude intervals in metres above mean sea level. These contour lines were interpolated from the digital terrain model GTOPO30 provided by the US Geological Survey. This terrain model was developed using several data sources. The lateral grid size is about 900 m. The accuracy of the height information depends heavily on the data source used for a specific area and can be as low as ±80 m. Obvious errors in the data set have been corrected on the basis of topographic maps at scale 1:250 000.

The inset map "Groundwater quality", at a scale of 1:6 000 000, shows the TDS (total dissolved solids) values in boreholes throughout the country. The classification is according to the Namibian Guidelines (Annex 4), which classifies water according to quality criteria as Groups A (excellent quality water), B (good quality water), C (low risk water) and D (high risk water, unsuitable for human consumption).

The insert map "Density of borehole information", at a scale of 1:6 000 000, was created by calculating the numbers of boreholes existing in the database per topographical map sheet at 1:50 000. The information shown on this map together with the figures provide a good indication about the reliability of information, i.e. where in the country enough knowledge about the hydrogeological situation is available, and where information is lacking.

The inset map "Vulnerability of groundwater resources", at 1:6 000 000 scale, outlines the vulnerability of groundwater resources to pollution. The risk of groundwater pollution from the surface mainly depends on the depth to the water table, the type of the underlying aquifer (porous or fractured), the flow in the aquifers, and the amount of rainfall in the recharge area. The vulnerability map therefore integrates depth to groundwater, aquifer type, predominant flow and recharge from rainfall, takes these variables into account in a simple rating system, and shows where proper protection of aquifers from pollution is essential.

The Map includes three cross-sections of important multi-layered aquifer systems in the country. The upper two intersect the Stampriet Artesian Basin and the bottom one intersects the karstified Otavi Mountain Land area and the adjacent areas to the north-west and south-east. These cross-sections emphasise the vertical dimension and highlight the fact that groundwater flow systems are 3-dimensional in reality. This is difficult to portray in the 2-dimensions available for a map. Sound interpretation of a hydrogeological map requires a constant awareness of the third dimension.

## Use of the Map

The purpose of the Map is to provide the public as well as decision makers in the government and the private sector, with accurate information on the occurrence, utilisation and vulnerability of groundwater resources in the country. Ideally, it must provide answers to questions asking "where", "what" and "how much". Due to the small scale of 1:1 000 000 of the Map, it provides an overview for planning of new groundwater-related projects. For instance, it can assist in rough planning of environmentally sound new settlements, industrial sites, and water abstraction schemes. It can also be used as a strategic document for national development plans. It helps identify areas in which groundwater knowledge is as yet insufficient, and where further investigative studies should be undertaken. For a hydrogeological specialist it delivers basic information about work to be carried out for a groundwater exploration project (e.g. siting methods), and gives an indication about expected success rates for drilling new boreholes in certain areas. It definitely cannot be used to exactly locate new boreholes, since the scale is much too small and the resolution and accuracy of the information used to compile the Map is insufficient.

The International Legend allows the Map to be read in two different ways, from a distance and close up. From a distance of several metres, the overview of the Map area can be grasped and the distribution of aquifers, aquitards and aquicludes easily seen. For those wanting more detailed information, e.g. on the use of groundwater, there is, on closer scrutiny, a wealth of symbols indicating water supply and irrigation schemes, springs, boreholes and water control areas.

In particular, emphasis is placed on showing data characterising the groundwater flow systems. Springs are natural outflow areas and may sustain important wetlands. The way groundwater supplies these springs is shown, where sufficiently known, by arrows indicating the flow direction. In most of the country, particularly in the western mountainous areas, the boundaries of large, regional groundwater flow systems coincide with the boundaries of surface water catchments, and the groundwater divides are not shown. Where they are known to differ from the catchment boundaries, groundwater divides are shown as a line of purple circles. They can be used to delineate the groundwater flow systems within uniform hydrogeological units.

A wealth of man-made features that affect the natural groundwater systems is shown in red on the Map. All sites where groundwater is abstracted in appreciable quantities, such as water supply and irrigation schemes using groundwater are depicted. In the vicinity of these abstraction points, groundwater levels may be lowered locally or regionally. Inter-basin transfers from one catchment or groundwater basin to another are represented on the Map, because this information is important for water balance calculations. For instance, in the north and in the Windhoek area, appreciable amounts of water are imported into these groundwater basins via canals and pipelines.

Information on water quality is only considered if the groundwater is unfit for human consumption because of high concentrations of total dissolved solids, i.e. exceeding 2 600 mg/L. More detailed information on chemical parameters can be found on the set of groundwater quality maps published in 1982 (Huyser et al. 1982).

The inset maps, at even smaller scales, serve only as a rough overview of the theme displayed, but provide additional background information to understand and complement the features shown on the main Map. For example, the Map showing the borehole density in the country reflects the reliability of the productivity data in certain areas. Obviously, in areas with a low borehole density, the productivity information is based on fewer records and is thus less accurate.

Finally, the Map user is referred to the information provided in this book "Groundwater in Namibia – an explanation to the Hydrogeological Map". It contains a wealth of useful complementary information on the natural environment, rocks and groundwater, and includes aspects of groundwater use and protection pertinent to Namibia.

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**FURTHER READING**


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