Jack Nkhoma & Roland Bäumle

Groundwater Resources for Southern Province

A Manual with Explanations for the Use of the Hydrogeological Maps

Republic of Zambia
Ministry of Energy
and Water Development

Federal Institute
for Geosciences
and Natural Resources

Hannover 2007


Kafue
Neganega
Lusitu
Minor Rivers

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1. Groundwater Information System

The newly established groundwater information system consists of [2]:

1. The groundwater database
2. The Geographic Information System (GIS)

Groundwater Database

The groundwater database was established using the commercial software package GeODin®. The software is based on a MSAccess database but provides user-friendly data input masks as shown for instance in the figure below.

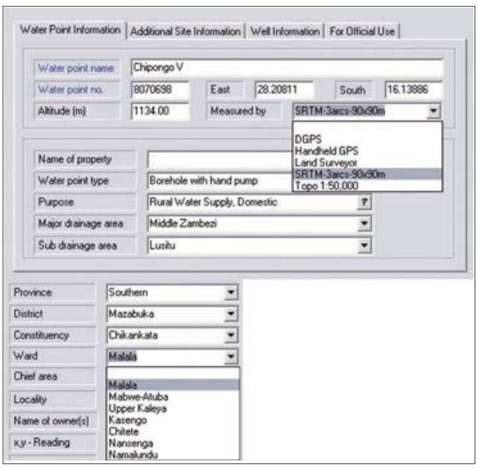


Figure 1: First data input mask for entering a new water point into the GeODin groundwater database (top). Detail on the bottom shows, as an example, how available wards within Chikankata Constituency can be selected from a dropdown list.

The individual input masks were modified to meet the specific needs and requirements of the DWA. The individual fields often work with dropdown lists to facilitate a quick data entry and to prevent spelling mistakes.

The software also offers various possibilities to query, export, display and visualize groundwater related data entered (e.g. selected data tables, borehole completion reports, lithological borehole logs, etc). An example for a borehole design with geological description is given in Figure 2.

Table 1: Type of information held in the GeODin database.

General information	
Location	Water Point name and number Geographic coordinates Elevation Location with regard to drainage catchment Location with regard to administrative/political unit
Drilling	Drilling/completion dates Drilling contractor Water point funding
Status	Type and purpose of water point Usage
Hydraulics	
Aquifer	Borehole and aquifer depth and thickness Aquifer type Static water levels (single values or time-series)
Hydraulic (Pump-) testing	Hydraulic test summary Hydraulic test data Hydraulic characteristics (yield, permeability)
Borehole profile	
Geology	Lithological and stratigraphical log
Design	Position of casing, screens, etc.
Groundwater quality	
Chemistry	Water analyses results Comparisons to drinking water standards Water quality classification

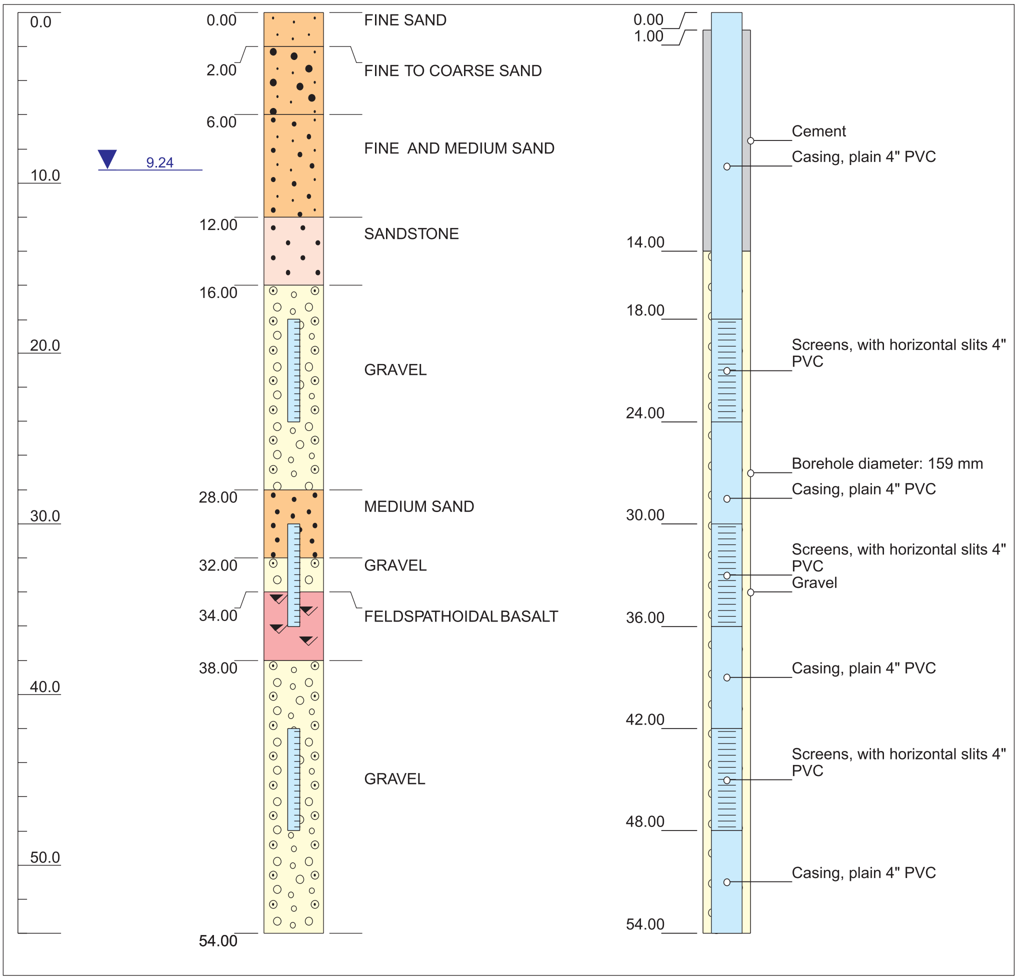


Figure 2: Example of a borehole description exported from the GeODin database for the borehole in Sekute Village, Water-Point No. 8050257 in Kazungula District.

The database contains information on more than 3,100 water points including boreholes, hand-dug wells, unsuccessful drillings and springs. The data compilation combines general information (e.g. location, type and purpose of water point) with comprehensive and detailed technical information on groundwater hydraulics, borehole design, as well as geology and groundwater quality (Table 1).

GIS

The GIS includes individual digital map layers containing topographic, geological, hydrological and groundwater related information. The map layers are seamless, i.e. not bounded by the margins of the original map sheets. The GIS layers can be combined for the compilation of various thematic maps or applied to further geo-related applications and analysis.

Water Point Number

For reasons of structuring the database a water point numbering system had to be introduced. Each water point number is unique, i.e. can only be allocated to one point. The number is composed of seven digits with the first digit representing the Province ("8" for the Southern Province), the second and third given out according to the District and the remaining four digits specifying the individual water points.

Table 2: Composition of water point number.

Digit No.	**Value**
1	"**8**" for Southern Province
2 and 3	"**01**" for Choma District "**02**" for Gwembe District "**03**" for Itezhi Tezhi District "**04**" for Kalomo District "**05**" for Kazungula District "**06**" for Livingstone District "**07**" for Mazabuka District "**08**" for Monze District "**09**" for Namwala District "**10**" for Siavonga District "**11**" for Sinazongwe District
4 to 7	Indexed numbers ranging from **1** to **9999**

To water points located in Choma District, for example, numbers ranging from 8010001 to 8019999 will be given out. Accordingly, numbers ranging from 8070001 to 8079999 and from 8110001 to 8119999 represent water points in Mazabuka and Sinazongwe Districts.

2. The Hydrogeological Maps

2.1. Coverage

The hydrogeological maps developed for the Southern Province include three sheets at scales 1:250,000 and one sheet at scale 1:100,000 (Figure 3). The maps are designed to display groundwater features at catchment and sub-catchment scale. The contents of the maps comprise:

- Topography including roads, villages, towns, health centres and schools;
- Hydrography including rivers and wetlands;
- Surface elevation;
- Surface catchment and sub-catchment boundaries;
- Water points such as boreholes and wells, including unsuccessful drilling sites, and thermal springs;
- Lithology and geological structures (faults, etc);
- Boundaries and potential of groundwater systems, so-called aquifers;
- Groundwater elevation contours and direction of groundwater flow;
- Rainfall distribution (Inset map).

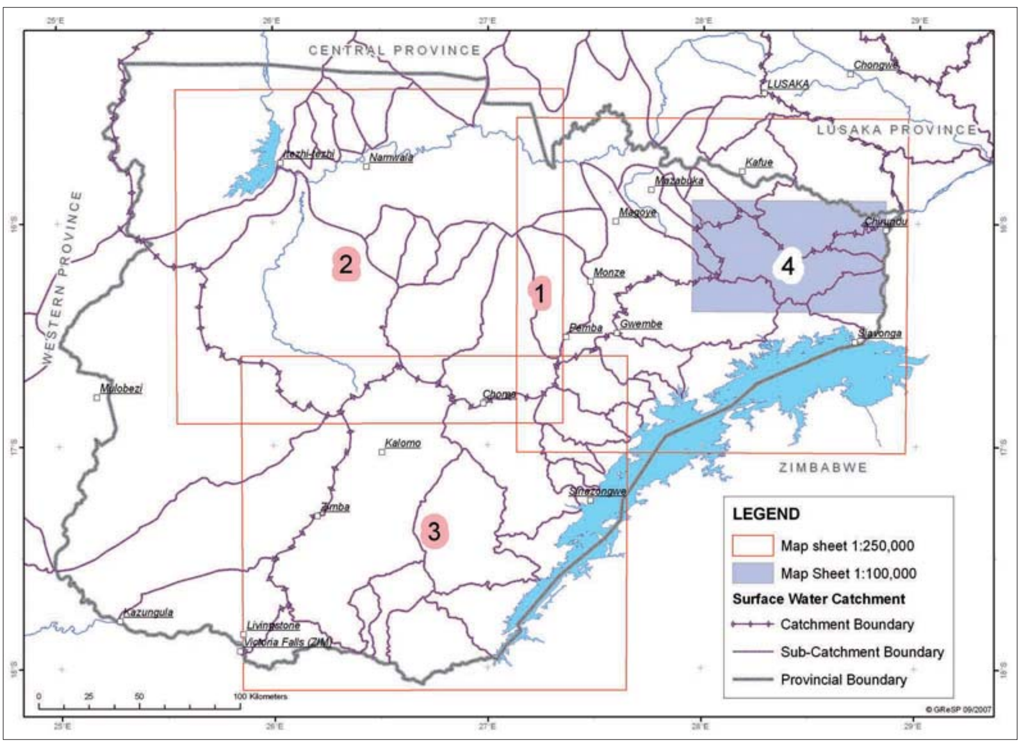


Figure 3: Available hydrogeological map sheets:
1. Northern Kariba Lake and Kafue Gorge
2. Kafue Flats and Southern Tributaries
3. Southern Kariba Lake and Kalomo
4. Lusitu River

2.2. Map elements

Each map sheet consists of the following elements (Fig. 4):

- A cover page with the map title and institutional logos, etc.;
- The body of the main map;
- A map legend;
- A frame consisting of neatline(s) and grid;
- A scale and scale bar;
- Inset map(s);
- Marginal text.

Main map (body)

The "map body" shows the main theme of the map for the selected map area. The main theme of the hydrogeological map is, of course, groundwater. Other examples of thematic maps are maps showing climate, vegetation, natural resources, population density, economic activity, etc.

Legend

The "map legend" or "map key" explains the map symbols used on the map and what objects or features (e.g. town, river, district, etc.) they represent. Map symbols are made of cartographic elements like points, lines and polygons.

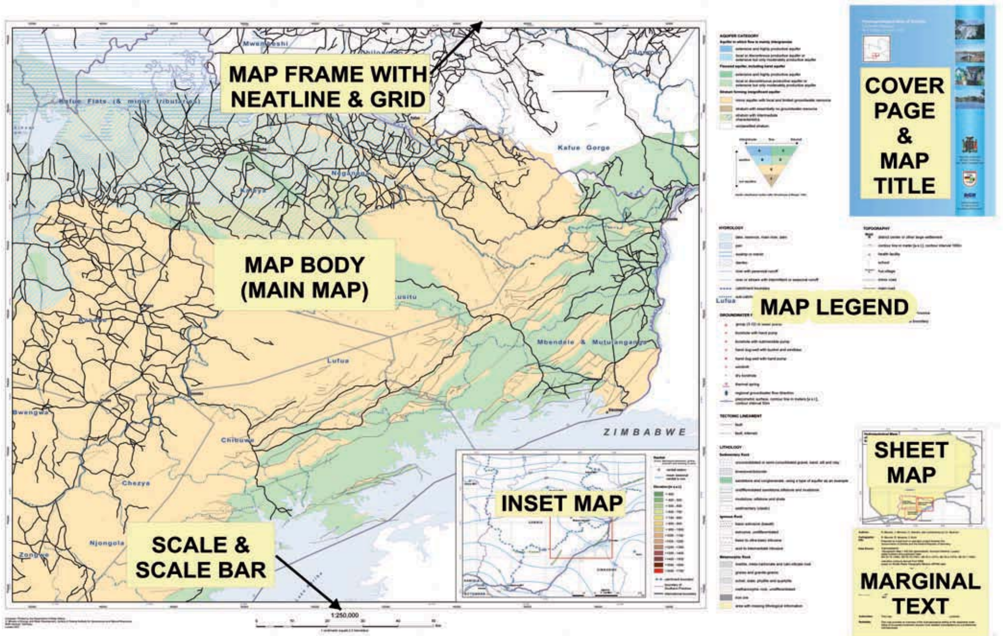


Figure 4: Main components of the hydrogeological maps.

Scale and scale bar

The "map scale" indicates the relationship between a certain distance on the map and the actual distance on the ground. A "large" scale map refers to one which shows greater detail. A graphic scale such as a scale bar can be used to determine distances on the ground along with a ruler. A word statement gives a written description of the map distance. For the maps at scale 1:250,000 and 1:100,000 this statement is "One centimetre equals 2.5 kilometres" and "one centimetre equals one kilometre", respectively. An example of the scale, scale bar and the corresponding word statement is given below:

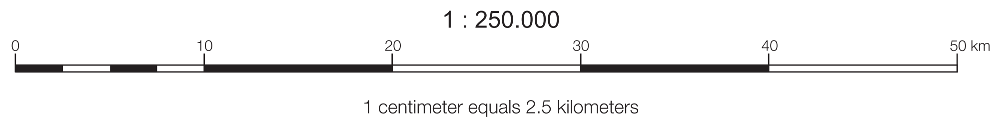


Figure 5: Scale and scale bar.

Neatlines and grid

Neatlines are used to frame the map and to indicate exactly where the area of a map begins and ends. The numbers next to the neatlines represent "world" coordinates of the geographic coordinate system and "metric" coordinates (easting and southing) corresponding to the projected coordinate system. The system of latitudes and longitudes form the "geographical graticule" whereas the network of lines connecting the metric coordinates is referred to as the map "grid".

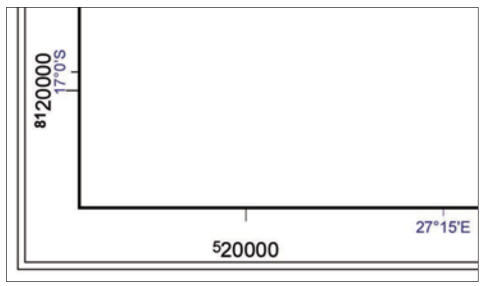


Figure 6: Neatline, graticule and grid.

For the examples indicated below the geographic coordinates indicate an area 27 degrees 15 minutes east of the prime meridian (0 degree) which, by definition, passes through Greenwich (near London) and 17 degrees south of the Equator.

The map projection applied is based on the Transverse Mercator system using the 27 degrees East line as the central meridian. By definition, a value of 500,000 meters ("false easting") and of 10,000,000 meters ("false nothing") is given to the central meridian and the Equator, respectively, in order to avoid negative values. Easting and southing indicate the position of a location in relation to the central meridian and the Equator. In the examples given, the coordinates define an area approximately 20,000 m (520,000 minus 500,000 metres) east of the central meridian and 1,880,000 m (10,000,000 minus 8,120,000 metres) south of the Equator.

Marginal Text

The additional text section includes the author's and cartographer's names, map projection details, disclaimers, source of data, etc.

2.3. Inset maps

There are two inset maps included in the respective 1:250,000 map sheets, one located beneath the legend and one inside the body of the main map.

The inset underneath the legend (sheet map) shows the position and rectangular extent of the three hydrogeological maps available for Southern Province in relation with the entire Zambia and neighbouring countries. A similar inset map is included in the 1:100,000 map sheet of the Lusitu catchment.

The second inset titled "Rainfall and Topography" represents a separate thematic map showing the topography, dominant topographic features such as the Kafue Flats and the Escarpment as well as meteorological stations and the general rainfall pattern (Fig. 7). The altitude given in metres above sea level is displayed as classified colour bands at 100 mm intervals. The rainfall isolines known as "isohyets" or "isohyetal lines" show the distribution of mean seasonal rainfall in millimetres for the southeastern parts of Zambia. Seasonal rainfall refers to rainfall totals from September to April. The extent of the hydrogeological map sheet (body of main map) within the frame of the inset map is shown as a rectangle bordered in red colour.

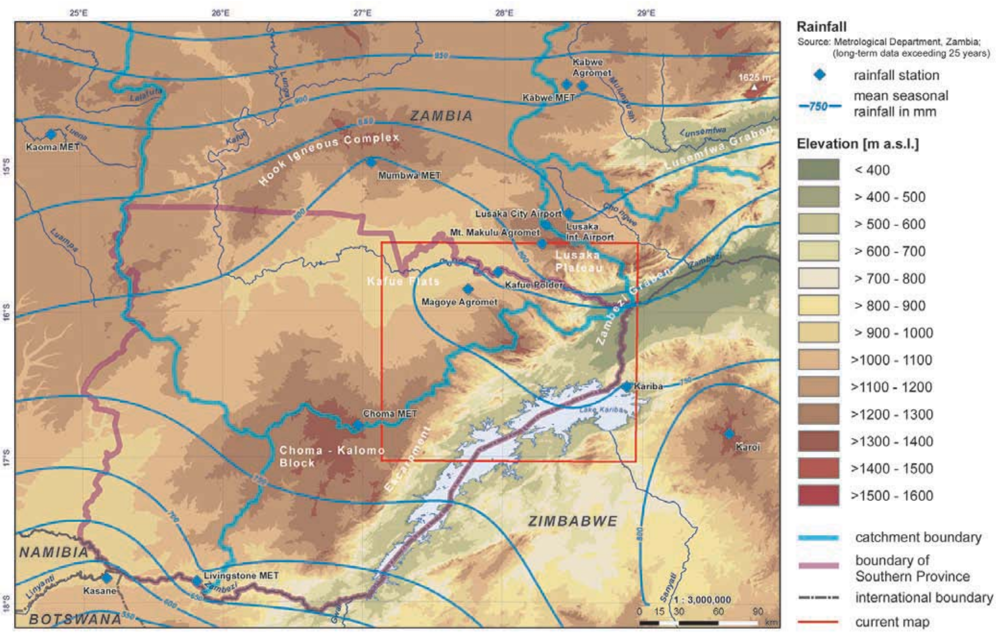


Figure 7: Inset map included in the hydrogeological maps 1:250,000 showing topography and overall rainfall pattern.

2.4. Content of Main Map

2.4.1. Hydrology

The hydrology displays surface water bodies and boundaries. Surface water features include lakes, dams, wetlands as well as rivers and river catchments.

Rivers

The map symbology distinguishes perennial rivers from intermittent or seasonal rivers.

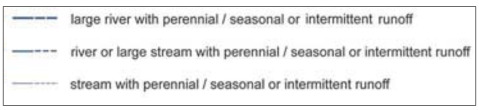


Figure 8: Map symbols for water courses.

A river or stream that flows all year round is called perennial.

A seasonal river or stream flows only during the rainy season and dries out during the dry season.

A river or stream is called intermittent if run-off is subject to interruption depending on the amount and duration of rainfall. The flow of intermittent rivers lasts over longer periods compared to ephemeral rivers, which are mostly dry and subject to water flow for only short periods (hours to a few days) after heavy rainfalls.

Wetlands

Wetlands cover more than 20% of Zambia's total area [1]. Three different symbol classes for wetlands are used in the hydrogeological maps. The symbols represent swamps or marshes, pans, and dambos.

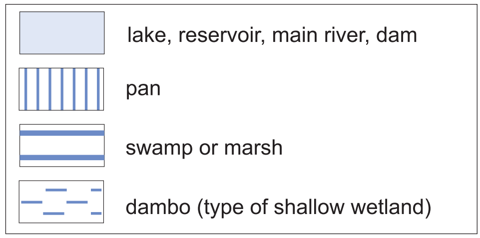


Figure 9: Map symbols for various types of wetlands.

In geography, a marsh is a type of wetland which is subject to frequent or continuous inundation. A marsh is different from a swamp, in that it has a smaller proportion of open water surface, and is generally shallower than a swamp.

A pan is a depression without drainage outlet where water pools seasonally.

Dambos have been defined as "seasonally waterlogged, predominantly grass covered, depressions bordering headwater drainage lines" [4]. The term for this complex type of shallow wetland is used in central, southern and eastern Africa, particularly in Zambia and Zimbabwe.

Figure 10: Dambo surrounded by woodland.

The treeless grass covered depression is seasonally waterlogged by seepage from surrounding high ground assisted by rainfall and has shallow water tables (<1 m) for most part of the year [1]. The vegetation of dambos is characterised by grasses, rushes, sedges and the lack of trees, contrasting with surrounding woodland such as miombo woodland.

Catchments

A catchment or drainage basin is the land area that is drained by a river or river system.

Catchment boundaries in the map refer to the catchments of the two major river systems, namely the Kafue and Zambezi rivers. Catchment boundary lines separate the Kafue Catchment which is part of the Middle Zambezi from the Upper Zambezi Catchment (drainage area upstream the Victoria Falls) and the remaining areas of the Middle Zambezi Catchment.

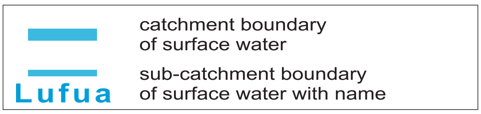


Figure 11: Map symbols for catchment boundaries.

Sub- Catchment boundaries delineate the river drainage areas of smaller tributaries to the Kafue and Zambezi rivers.

2.4.2. Geology

Lithology

The lithology describes the rock type and its composition. The maps distinguish between about a dozen different types of lithology. Sedimentary, igneous and metamorphic rocks together form the three major groups of rock.

Sedimentary rock is formed by the deposition and compaction of mineral grains or materials from living organisms, or by chemical precipitation. Sedimentary rocks include among others limestone, dolomite, conglomerate, sandstone and shale.

Igneous rock is a rock solidified from cooled magma. They are called extrusive if formed at the earth's surface or intrusive if the magma cools and solidifies underneath the surface. Typical examples for extrusive and intrusive igneous rocks are basalt and granite.

Metamorphic rock is a rock derived from preexisting rock, of either sedimentary or igneous origin that was transformed in response to marked changes in temperature and pressure usually at considerable depth under the Earth's surface. Metamorphic rocks include marble, gneiss and schist.

Three examples for ornaments used to display lithological characteristics in the maps are shown below:

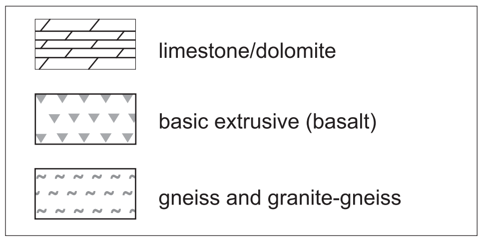


Figure 12: Map symbols for various types of lithology.

Tectonic lineaments

A fault is a fracture or a zone of fractures along which there has been displacement of the sides relative to each other. In rocks with little primary porosity (voids) faults may constitute major pathways for underground water flow.

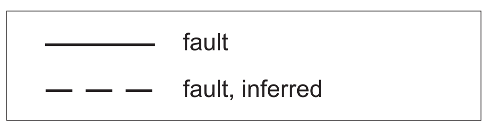


Figure 13: Map symbols for faults.

Inferred faults are faults that cannot be detected on the surface. Instead, their position was derived from geological interpretation.

2.4.3. Groundwater Features

Water Point Information

Individual map symbols are used to differentiate between the various water point types (Fig. 14). Boreholes are thus distinguished from shallow hand dug wells. The symbols also denote the type of installation such as handpump, submersible pump, bucket and windlass or windmill. Boreholes that were reported to be dry are also displayed on the maps. Finally, the maps show natural occurrences of hot (thermal) springs.

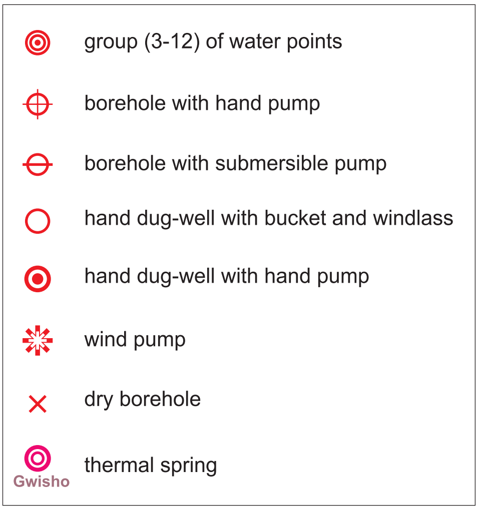


Figure 14: Map symbols allocated to the various water point types.

On the 1:100,000 scale map the water points are labelled with the water point number (see Chapter 1). Furthermore, water points with highly mineralised water carry the following symbol:

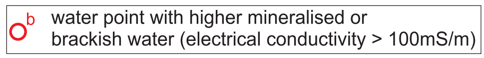


Figure 15: Map symbol for water points with higher mineralised water.

Water from these points has an electrical conductivity (EC) exceeding 100 mS/m at 25°C and may be brackish (EC > 150 mS/m) or saline (EC > 1500 mS/m).

Figure 16: The two most common water point types: Handpump of type India Mark II (left) and hand dug well with bucket and windlass (right).

Groundwater Potential

In the hydrogeological maps, the groundwater systems were grouped in six classes (or "categories") according to their potential. Rocks that are water saturated and sufficiently permeable to transmit groundwater are called "aquifers".

The applied distinction of aquifer classes was adopted from the method proposed by Struckmeyer and Margat [5]. The classification combines information on aquifer potential (productivity and lateral extent) and the type of groundwater flow regime (intergranular or fissured).

The scheme of areal colours was developed to represent hydrogeological characteristics in the maps. The colouring scheme is illustrated in Figure 17 as a triangle in which the potential is decreasing from top to bottom. Dark blue and dark green colours represent aquifers with high potential. Light blue and light green colours represent aquifers with moderate potential. Formations with limited potential are coloured in light brown while strata with essentially no groundwater are in dark brown.

For groundwater systems with high or moderate potential the colouring scheme also considers the dominant type of groundwater flow within the rock. Blue colours are used for systems in which flow is mainly intergranular while green colours represent systems formed by hard rock, including karst rock, in which flow occurs in fissures, fractures or dissolution cavities (see box "Groundwater Flow Regimes" for more details).

An attempt was made to give practical examples for the possible use of the groundwater resources for each category (Table 3, last column). Aquifers with a high potential (categories A and C) for example may permit withdrawals of regional importance such as supply to major towns or large-scale irrigation. Aquifers with limited potential (category E) should suffice for the supply of water to rural villages with a handpump.

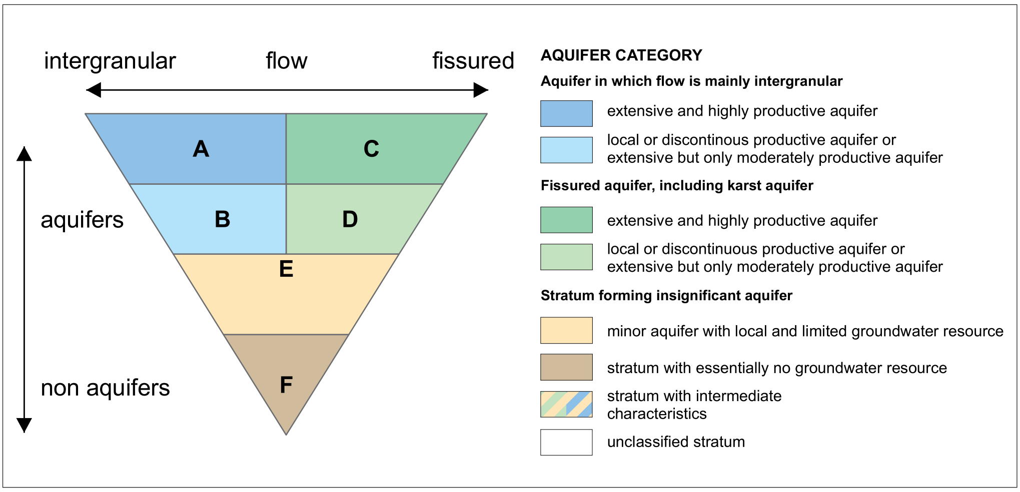


Figure 17: Aquifer classification system (after Struckmeyer & Margat, 1995).

Table 3: Hydraulic characterisation of the aquifer categories (modified after Krásny, 1993, Struckmeyer & Margat, 1995). See box "Hydraulic Characteristics of Aquifers" for an explanation of the listed parameters.

Aquifer Category	Specific Capacity [L/s/m]	Transmissivity [m^2/d]	Permeability [m/d]	Very approx. expected yield [L/s]	Groundwater Potential
A ,C	> 1	> 75	> 3	> 10	High: Withdrawals of regional importance (supply to towns, irrigation)
B, D	0.1 – 1	5 – 75	0.2 – 3	1 – 10	Moderate: Withdrawals for local water supply (smaller communities, small-scale irrigation etc.)
E	0.001 – 0.1	0.05 – 5	0.002 – 0.2	0.01 – 1	Limited: Smaller withdrawals for local water supply (supply through handpump, private consumption)
F	< 0.001	< 0.05	< 0.002	< 0.01	Essentially none: Sources for local water supply are difficult to ensure

Hydraulic Characteristics of Aquifers

Groundwater systems are usually characterised according to their hydraulic properties, including:

The *hydraulic conductivity* K, given in units m/d, is defined by Darcy's Law and can be considered a measure (or a "coefficient") of the permeability of rock with regard to water.

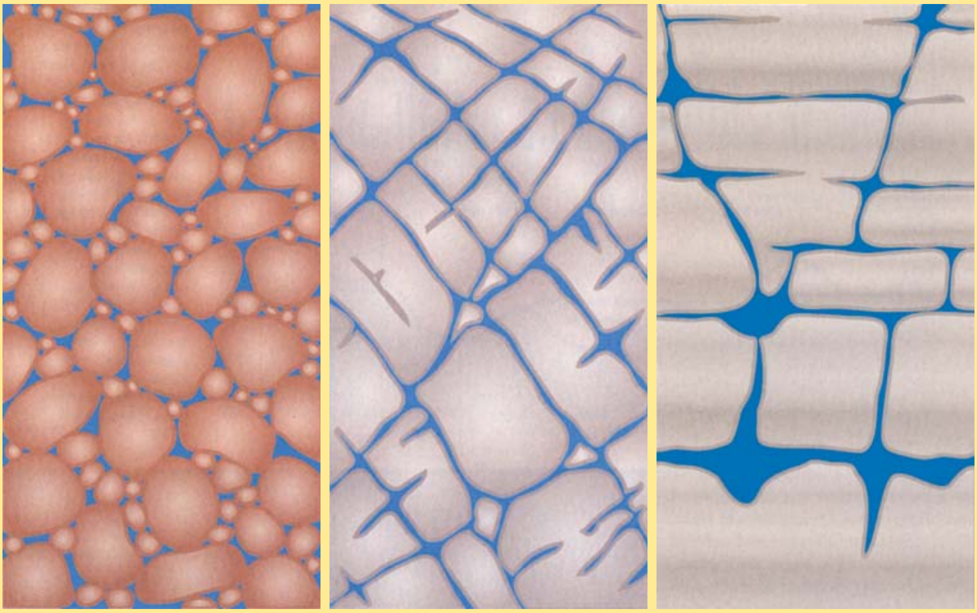
The *transmissivity* T, given in units of m^2/d, which can be considered a measure of the amount of water that can be transmitted through a rock formation.

The *specific capacity q*, given in units L/s/m, which is obtained by dividing the discharge of a pumped well by the stabilised drawdown at the specific pumping rate that was observed during the pumping test.

The *yield* Q, given in L/s, which in this context refers to the likely or characteristic yield that a well can produce from a rock formation.

Suggested further reading: Fetter C W (2001): Applied Hydrogeology.- 4th ed. 598 pp; Prentice Hall; Upper Saddle River, New Jersey.

Groundwater Flow Regimes



There are three major types of groundwater flow regimes:

(1) Intergranular flow occurs through the voids (pore space) between individual mineral grains (left picture). This type of flow is typical for rock consisting of unconsolidated deposits (e.g. loose gravel, sand or silt).

(2) In hard rock, groundwater can be transmitted through fissures or fractures. The void space created by fissures is called "secondary" porosity in contrast to the "primary" porosity referring to the original (unfractured) pore space when the rock was formed. If the primary porosity is small groundwater flow is virtually restricted to fissures.

(3) Secondary porosity can also be created by leeching of minerals. As rock dissolves along fractures or bedding planes large cavities and even caves can develop (right picture). This leads to the development of "Karst" formations in which groundwater can drain quickly. Karst is usually developed in carbonate rocks such as limestone and dolomite. Groundwater is often abundant in these formations, but can almost as easily be polluted as surface streams.

Groundwater Flow

The movement of groundwater in the rock is displayed on the maps by means of arrows and groundwater contour lines. The arrows indicate the regional direction of groundwater flow. The groundwater contours give the elevation of the groundwater table in meters above sea level.

The groundwater table is the surface that separates the zone that is saturated with water from the unsaturated zone above. The depth of groundwater at a specific point can be estimated by subtracting the altitude of the ground surface from the elevation of the groundwater table.

Figure 19 below explains the occurrence, movement and circulation of water in the hydrosphere with emphasis on groundwater. When rain falls on the ground surface, a portion infiltrates into the ground by gravity

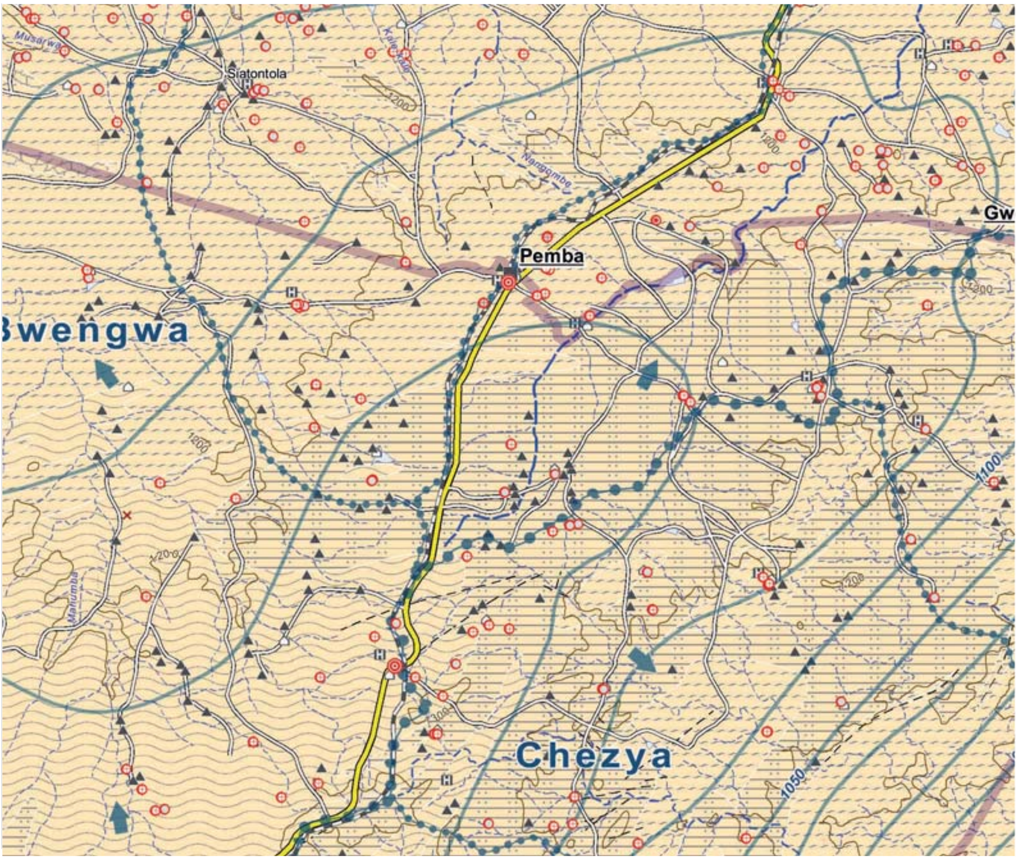


Figure 18: Excerpt of the hydrogeological map showing groundwater contours (blue lines) and regional flow direction (blue arrows).

where it moves both vertically and laterally depending on the slope. Infiltrating water first passes through the unsaturated zone before it reaches the groundwater table. Groundwater fills the interconnected open spaces (pores) between mineral grains and fractures. Groundwater generally flows from high (in terms of elevation) areas to low areas. Along topographic sinks it recharges rivers as base flow as well as lakes and oceans. Springs and seeps occur where the ground surface intersects the groundwater table or where groundwater is under pressure and can reach the surface through fracture zones. In Southern Province the groundwater flow is overall directed towards the two major river systems, the Kafue and Zambezi, and towards Kariba Lake.

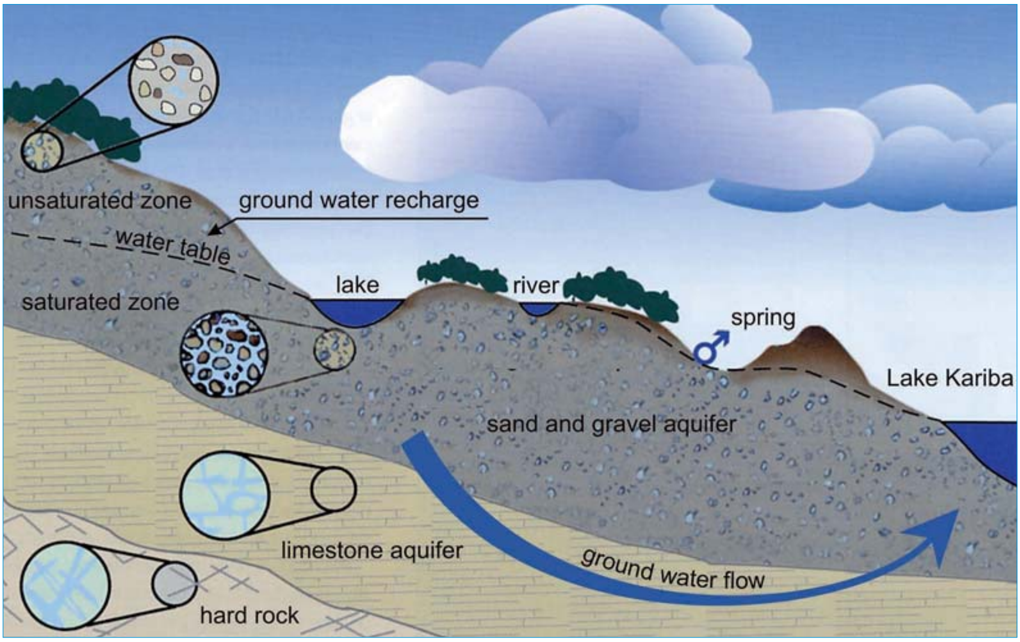


Figure 19: Schematic illustration of groundwater flow in the Southern Province.

3. References

[1] Akayombokwa I. & and N. Mukanda (1998): Wetland classification for agricultural development in Eastern and Southern Africa: the Zambian case.- Zambia country paper in: Food and Agriculture Organization of the United Nations (FAO): Wetland Characterization and classification for sustainable agricultural development; Sub-Regional Office for East and Southern Africa (SAFR) Harare. www.fao.org/DOCREP/003/X6611E/x6611e02f.htm#P2557_115570.

[2] DWA/BGR - Department of Water Affairs & Federal Institute for Geosciences and Natural Resources (2007): The Groundwater Resources of Southern Province, Zambia (Phase 1).- by Bäumle R., Neukum Ch., Nkhoma J., & O. Silembo; Vol. 1 - Technical Report & Annex; 132 pages; Lusaka.

[3] FUGRO Consult GmbH (2007): GeODin V. 5.0; www.geodin.com; Berlin, Germany.

[4] Mackel, R. (1985): "Dambos and related landforms in Africa; an example for the ecological approach to tropical geomorphology". Z. Geomorphol. N.F. Supplementary Band 52: 1–23.

[5] Struckmeyer W F & J Margat (1995) Hydrogeological maps – A guide and a standard legend.- International Association of Hydrogeologists; 177 pp.; Hannover, Heise.

Kafue Flats (& minor tribut
Lonchinvar Lagoon
Mazabuka
Mazal
Kaleya
Magoye
Minor Rivers
Magoye
Monze
Kasane
Lufua
Gwembe
Pemba
ngwa

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