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The Groundwater Resources of Southern Province, Zambia (Phase 1)

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- Technical Report -

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The Groundwater Resources of Southern Province, Zambia (Phase 1)

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- Technical Report -

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ABBREVIATIONS

CMMU	Water Point Inventory Community Management & Monitoring Unit
CSO	Central Statistical Office
DEM	Digital Elevation Model
DTF	Development Trust Fund
DWA	Department of Water Affairs
EC	Electrical Conductivity
ET	(Actual) Evapotranspiration
EU/EC	European Union/Community
FAO	Food and Agricultural Organization of the United Nations
GIS	Geographic Information System
GPS	Geographic Positioning System
GReSP	Groundwater Resources for Southern Province
GWP	Groundwater Potential
ITCZ	Inter-Tropical Convergence Zone
JICA	Japanese International Cooperation Agency
K	Hydraulic Conductivity
KfW	Kreditanstalt für Wiederaufbau (German Development Bank)
m asl	Meters above Sea Level
meq	Milliequivalent
MET	Meteorological Department Zambia
MEWD	Ministry of Energy and Water Development
MLGH	Ministry of Local Government and Housing
MOH	Ministry of Health
NCSR	National Council for Scientific Research
NWASCO	National Water Supply and Sanitation Council
P	Precipitation
PET	Potential Evapotranspiration
Q	(River) Discharge or Aquifer Yield
q	Specific Capacity of a Well
R	Groundwater Recharge
R%	Groundwater Recharge Rate (in % of Rainfall)
SABS	South African Water Quality Guidelines
SAR	Sodium Adsorption Ratio
SP	Southern Province
SRTM	Shuttle Radar Topography Mission
SWP	Surface Water Potential
SWSC	Southern Water and Sewerage Company
T	Hydraulic Transmissivity
TDS	Total Dissolved Solids
UNESCO	United Nations Educational, Scientific and Cultural Organization
WHO	World Health Organisation
WP-No.	Water Point No.
WRMP	Water Resource Master Plan
ZDWS	Zambian Drinking Water Standards
ZVAC	Zambia Vulnerability Assessment Committee

FOREWORD

The Groundwater Resources for Southern Province Project was proposed and implemented by the Government of Zambia (GRZ) through the Department of Water Affairs (DWA) with support from the Federal Republic of Germany through the Federal Institute for Geosciences and Natural Resources (BGR). The project started in May 2005. The present Phase I covered a 30-month period ending October 2007. The project was implemented in order to fulfil the urgent need for groundwater resource assessment in the Southern Province. It was aimed at strengthening the capacities of the water sector in Zambia with special emphasis on groundwater by compiling a database and hydrogeological maps. The information generated is useful for regulation of groundwater development, use and management in the Province. Furthermore the project was intended to be a model for groundwater assessment in other provinces in the country.

The project was implemented in line with the National Water Policy which promotes integrated water resource management and resultant programmes such as the Water Resources Action Programme. It is also relevant to the Fifth National Development Plan and the 2030 Vision for Zambia and the Millennium Development Goals, all of which recognise the fact that the provision of safe drinking water is critical to economic growth and poverty eradication. The outputs of the project which include trained manpower, a groundwater database and hydrogeological maps will be useful to provincial and national planning and regulation authorities, especially in view of the Water Resources Management Bill which, among other provisions, seeks to provide for the regulation of groundwater. Regulation of groundwater is not provided for by the current Water Act.

It is however notable that some challenges were met during the implementation of the project, namely, regional groundwater flow was not adequately covered due to insufficient number of boreholes, the north-western part of the Province was not mapped and uncertainty of existing groundwater data. Therefore care was taken in interpreting such data. With this in mind it is recommended that updating of the database and maps used in this project should be a continuous process in order to provide meaningful solutions.

A tool for groundwater resource management in Southern Province and Zambia has been placed in the hands of water resource managers, academics, politicians, water users and other interest groups but what remains is the challenge to put it to use and help to achieve the national goal of economic growth and poverty eradication through sustainable development and management of groundwater in the country.

I wish to commend the GReSP Project Team, DWA management and BGR for tasks of implementing the project and producing the project documentation including this brochure which highlights the various issues addressed by the Groundwater Resources for Southern Province Project.

A Hussen

DIRECTOR OF WATER AFFAIRS

LUSAKA

EXECUTIVE SUMMARY

According to the National Water Master Plan the south-western parts of Zambia extending from Mongu in Western Province to the Southern Province form the most drought-prone regions within Zambia. The tropical continental highland climate is characterised by a clear distinction between the cool and hot dry season lasting from May to October and the wet season between November and April. Rainfall totals are the lowest in the country with mean annual rainfall ranging from 650 mm to 800 mm. Furthermore, the distribution of rainfall during individual rainfall events and rainy seasons is very unpredictable. Due to these climatic conditions rain-fed agriculture is highly undependable.

The Southern Province has a share in two of Zambia's major water courses, the Zambezi River including the Kariba reservoir at its southern and eastern boundaries and the Kafue River to its northern margins. But since distances and differences in elevation are large it is not economically feasible to distribute the surface water sources to the central areas of the Province. The discharge of most tributary rivers ceases during the prolonged dry periods. During this time, the large majority of the population of the Southern Province depends on water supply from small dams or groundwater. Groundwater constitutes the only reliable and safe water source available throughout the year, especially during periods of drought. Groundwater is stored underground, often available at much closer proximity compared to surface water sources; it is naturally protected against evaporation and immediate pollution and is often of such quality that no treatment is needed prior to its consumption.

Despite of its importance, the use of groundwater is currently not regulated. Groundwater management regulations are incorporated in the proposed Water Resources Management Bill which is yet to be enacted. Accurate and updated information on both surface and groundwater resources is required to regulate its use and to establish an integrated and sustainable management of the Nation's water resources. For underground water, this includes a comprehensive assessment of the groundwater resources and their current use, an improved understanding of the groundwater systems and their interactions with surface water as well as a continuous and extended monitoring of groundwater levels and quality.

The Project "Groundwater Resources for Southern Province " was launched in May 2005 with the objectives to facilitate an effective groundwater resource planning and management in the Province and to strengthen the capacities in the Zambian water sector. The Project is carried out in the framework of the technical co-operation between the Governments of Zambia and the Federal Republic of Germany and implemented by the Department of Water Affairs (DWA), Ministry of Energy and Water Development, Zambia and the Federal Institute for Geosciences and Natural Resources, Germany.

As an integral part of this Project a professional groundwater information system at the DWA was developed consisting of a groundwater database and a Geographic Information System (GIS). The database stores information on over 3,000 water points including hand dug wells, boreholes, springs and unsuccessful groundwater exploration drill sites. The database includes the information of all major hydrogeological investigations carried out since the mid- 1970s and combines general information (e.g. location, type and purpose of water point) with comprehensive and detailed technical information on groundwater hydraulics, borehole design, geology and groundwater quality.

As part of this study three hydrogeological maps at scale 1:250,000 and another, more detailed map at scale 1:100,000 were developed. The design and legend of the maps follow international guidelines and can be adopted as a standard for groundwater maps of other regions. For future studies and exploration drillings, other thematic maps can readily be prepared at various scales.

This publication reviews the state of knowledge and provides references for further reading on the geography, climate, geology, hydrology and groundwater in the Southern Province. It accompanies the four hydrogeological maps together with a manual that provides detailed explanations for the use of the maps.

The groundwater related information assembled was assessed and interpreted in this study in order to identify groundwater systems and their potential.

About two thirds of the Province is made up of hard rocks that are more or less fractured, and the rest is covered by unconsolidated deposits that host potential porous aquifers. Most of the rock formations have been characterised as heterogeneous, i.e. their potential to host and produce groundwater is extremely variable. That seems to be one of the reasons why about one out of five boreholes drilled was unsuccessful during larger exploration campaigns in the past. Careful planning using the groundwater information system and possibly the use of advanced geophysical methods could considerably improve success rates during exploration.

The comprehensive statistical analysis of available hydrogeological data showed that the potential of groundwater in the Province is overall limited. In some areas, namely regions within the Karoo sandstones and basalts, the alluvial deposits of the Kafue Flats and the calc-silicate rocks in the Mazabuka/Magoye area, groundwater conditions are more favourable. The groundwater quality is overall good although concerns must be raised over microbiological contamination near major settlements due to poor sanitary conditions. In general, potential groundwater production from aquifers is insufficient for larger development such as irrigation schemes. Despite these limitations extractable groundwater volumes are sufficient to assure long-term water supply to rural areas and smaller settlements if used sustainably.

The study has shown that groundwater in the Southern Province is a valuable but overall limited and vulnerable resource. The hydrogeological maps and this publication summarise the information on groundwater in the Southern Province. It is envisaged that the developed groundwater information system and the groundwater maps will support efforts on exploring, managing and protecting the groundwater resources. It is of hope that the information gathered will be of great use to officials at the ministries on national and district level as well as to technicians of the commercial utilities, consultants and to the water sector as a whole. Finally the wish is expressed that the groundwater information system established for Southern Province can soon be extended to cover other Provinces and catchments.

1. INTRODUCTION

1.1. PROJECT FRAMEWORK

The Government of the Republic of Zambia has identified the urgent need for the integrated management of the national water resources, which include both surface water and groundwater.

Integrated Water Resources Management has accurately been defined by the Global Water Partnership Technical Advisory Committee (www.gwpforum.org/) as "*a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.*"

To ensure the sustainable development and use of the country's water resources, the increasing demand for groundwater in agriculture, commercial and domestic use needs to be regulated. The basis is a countrywide assessment of the available quantities and qualities of groundwater. In Zambia to date the use of groundwater is not regulated, in contrast to surface water. This poses a risk to the sustainable development, management and use of the resource.

Like elsewhere in the country the knowledge base on the availability and quality of groundwater is scanty in the Southern Province (SP) (Figure 1-1). This lack of knowledge together with a shortage of qualified staff at planning institutions has been identified as major shortcomings to an effective management of this vulnerable resource. The increasing demand of groundwater for agricultural, commercial and domestic use is creating tension amongst stakeholders. Against this background, the Phase I of the project **Groundwater Resources for Southern Province – GReSP –** was launched in May 2005 with an initial duration of 30 months.

The Project is a joint technical cooperation between the Department of Water Affairs (DWA) at the Ministry of Energy and Water Development (MEWD) and the Federal Institute for Geosciences and Natural Resources (BGR). It is funded by the German Federal Ministry for Economic Cooperation and Development under the German – Zambian Technical Cooperation Program. The Project is in line with the on-going restructuring of the Zambian Water Sector and the development of the new Water Resources Management Bill that will form the legal framework for a sustainable and regulated water use.

The project team comprises experts in the fields of hydrogeology, water quality, GIS/database applications and groundwater resource management from the DWA and the BGR. The Project main office is based at Lusaka. A local office was established at the provincial DWA-headquarters in Choma.

Figure 1-1 Project Area: The Southern Province

1.2. OBJECTIVES AND TASKS

One of the main **objectives** of the Project is to facilitate an effective groundwater resource planning and management in the SP and to fulfil the urgent need for groundwater resource assessment in the SP by compiling a database and hydrogeological maps. The project assembles and generates important and valuable information that will facilitate the regulation of groundwater development, use and management in the Province. The exemplary detailed studies of the identified sub-catchments can form prototypes in the management of groundwater resources in other areas of the country.

Furthermore, the Project aims at strengthening the capacities of the water sector in Zambia with special emphasis to the field of groundwater resources mapping, exploration, groundwater protection and data provision. This contributes to the building up of an efficient institutional framework to handle hydrogeological problems with emphasis on groundwater resource planning and management.

Another objective is to advise regulation and planning authorities on future monitoring and regulation of groundwater resources.

The overall goal of the Project is a better water supply for the Zambian people, thereby contributing to a reduction of poverty in the long term.

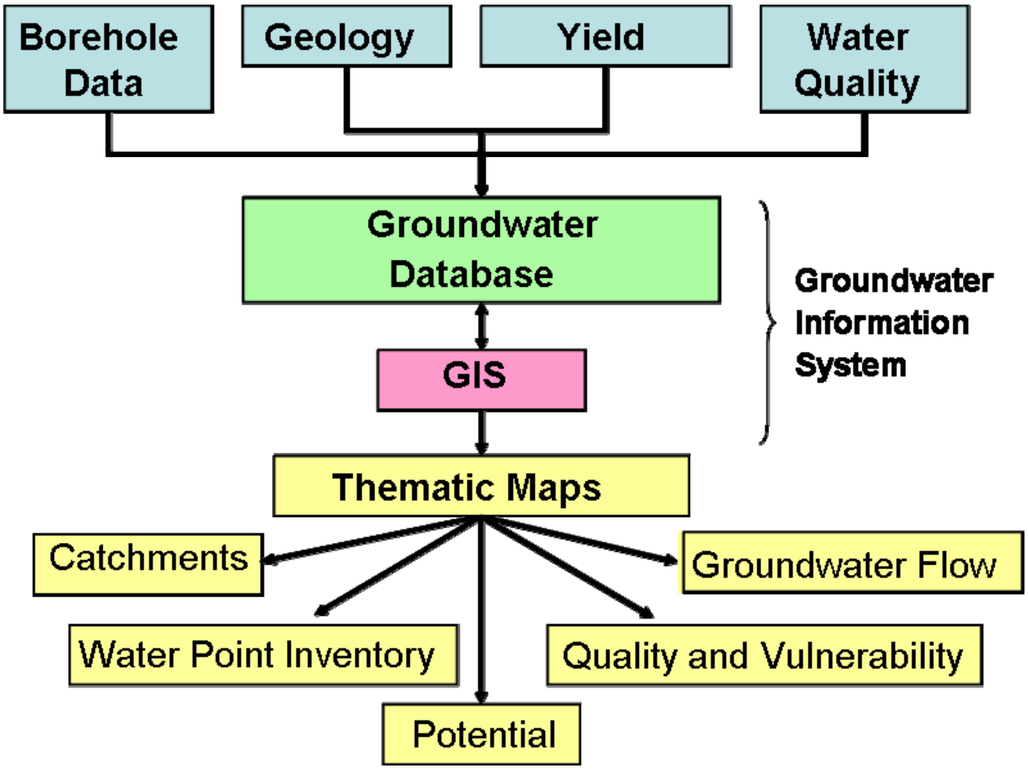


Figure 1-2 Flowchart showing the concept of developing a groundwater information system

The main **task** within this Phase was the development of a **groundwater information system** (Figure 1-2) for the SP comprising a groundwater database and individual GIS map layers.

Individual steps in the development of the information system included:

- developing the new groundwater database structure,
- collecting, assessing, analysing and continuously updating all available groundwater data (analogue and digital) for the compilation of the database,
- digitising all relevant topographical, hydrological, meteorological and hydrogeological data and maps in the SP,
- carrying out a reconnaissance sampling campaign in order to assess groundwater chemistry,
- identifying individual aquifer systems and to assess their potential, groundwater quality and vulnerability,
- training scientists, engineers and technicians in hydrological field investigations, groundwater monitoring and resource management,
- regularly informing all stakeholders on the project activities and achievements, and
- producing and distributing hydrogeological maps and explanatory reports that could be used for management purposes.

1.3. THE SIGNIFICANCE OF GROUNDWATER IN THE PROVINCE

The SP is drought prone and therefore an area of particular concern. The climate is sub-tropical with a clear distinction between the cool and hot dry season lasting from May to October and the wet season between November and April. Rainfall totals and intra-seasonal distribution vary greatly from year to year. The South of Zambia receives the lowest rainfall in the country with mean annual rainfall ranging from 650 mm to 800 mm.

Due to these climatic conditions rain-fed agriculture is highly undependable. The SP covers an area of approximately 85,500 km^2 and is bordered by the Zambezi River to the south, the Kariba reservoir to the southeast and the Kafue River to the north. But despite those large freshwater sources at its margins the Province heavily depends on groundwater since runoff from the tributaries to the major rivers regularly ceases during the dry season.

The population of the SP is estimated at 1.4 Mio inhabitants of which the majority, probably close to three quarters of the total population, live in rural areas (CSO 2003, NWASCO/DTF 2006). Drinking water for the district centres and some smaller towns is provided by the Southern Water and Sewerage Company (SWSC). The district centres tap surface water sources (Zambezi River, Kariba reservoir and smaller dams) whereas some smaller towns, such as Gwembe, Nega-Nega and Chisekesi are supplied to 100% from boreholes. For the large majority of the population that inhabits the vast and often remote rural areas groundwater constitutes the only reliable and safe water source available throughout the year.

2. PHYSIOGRAPHY

2.1. TOPOGRAPHY

A **Digital Elevation Model (DEM)** was compiled for the SP using data of the Shuttle Radar Topography Mission (SRTM) distributed by the US Geological Service. The resolution of the SRTM grid is 3 arcsec or approximately 90 by 90 meters. The original grid was smoothed using a low-pass filter five consecutive times in order to eliminate some irregularities and blanks (i.e. grid cells with no data) within the raw data. The developed DEM extends from 14.5°S and 18.5°S in N-S direction and from 24.5°E and 30°E in W-E direction.

The DEM is visualised as a shaded relief and a block diagram in Figure 2-1. Figure 2-2 shows elevation zones at 200 m intervals. Within the Province the altitude rises from approximately 400m in the Zambezi valley to almost 1400 m on the central plateau. The highest area with an altitude exceeding 1500 m asl is formed by the Mabwetuba Hills in the south-eastern corner of the Mazabuka District, approximately 60 km in ENE direction of Gwembe.

The following three dominant topographic features can be distinguished:

1. The Choma-Kalomo Block
2. The Zambezi graben incl. the escarpment
3. The Kafue Flats

The **Choma-Kalomo Block** is part of the Central African Plateau and formed by ancient (Precambrian) basement rock. The elevation of the undulating surface ranges from 1200 to 1350 m asl with a maximum of 1379 m asl near Mbabala, situated approximately 10 km west of Choma.

The elevation sharply drops along the **escarpment** from about 1000 m to heights of ca. 600 m asl in the Zambezi valley. The drop in altitude over this region varies between 20 and 150 m per km. The rugged terrain is intersected by numerous smaller river valleys. The bottom of the **semi-graben system** is now filled by the Kariba reservoir. The lowest point within the Province is located at the confluence of the Kafue and Zambezi rivers at 370 m asl.

The **Kafue Flats** form a vast floodplain with an altitude between 970 and 1000 m asl. The flats cover an area of up to 60 km wide and 250 km long. The average gradient is as low as 10 cm per km.

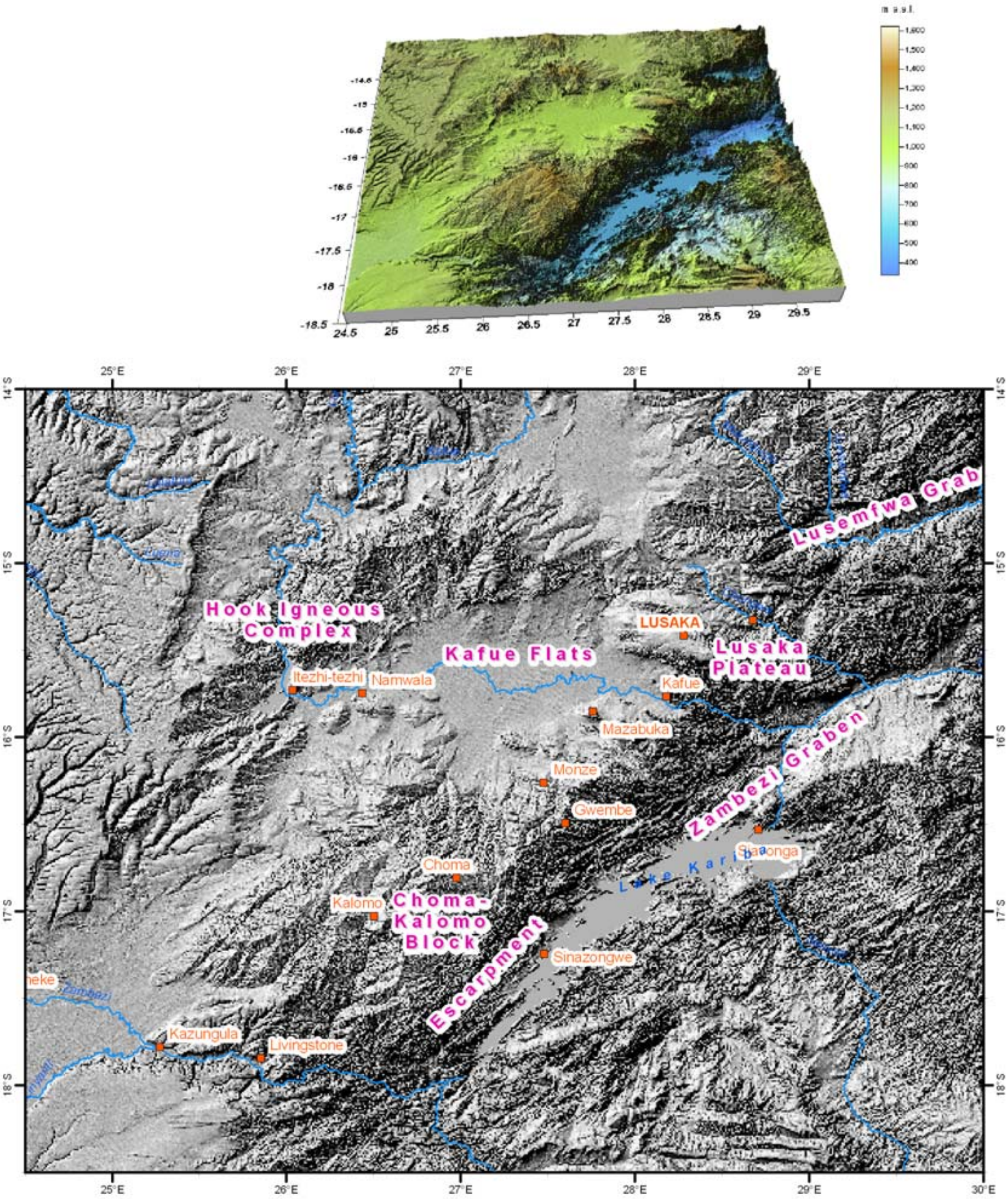


Figure 2-1 Shaded relief and block diagram generated from the DEM

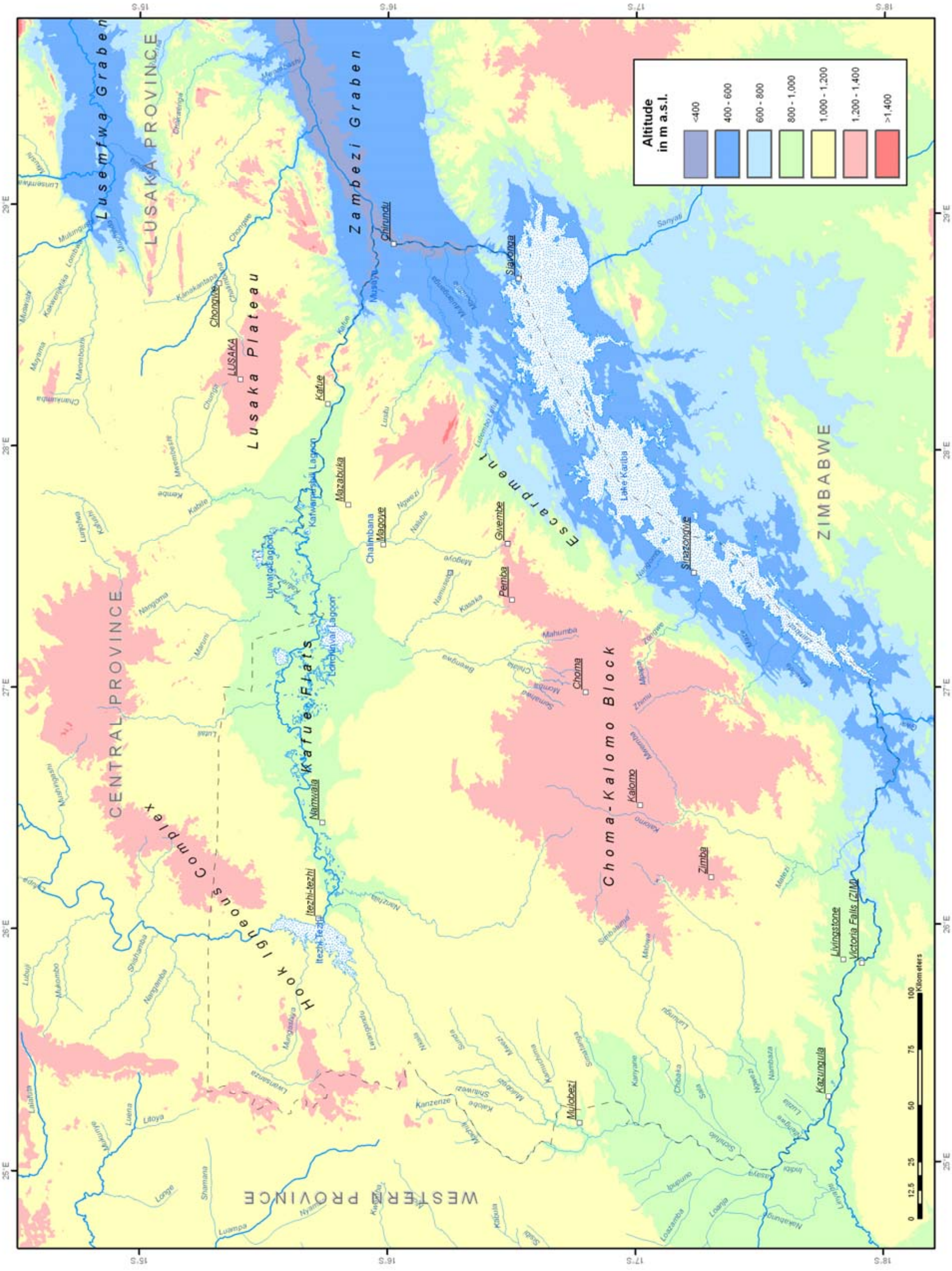


Figure 2-2 Digital Elevation Model (DEM) with elevation zones at 200 m- intervals

2.2. VEGETATION

Large parts of the SP are classified as miombo woodland, which is a type of woodland dominated by semi-evergreen trees 15 to 21 m high with a well-developed grass layer. Most miombo is secondary re-growth as a result of extensive cultivation in the past. In the west, miombo woodlands have invaded into the Kalahari forming miombo/Kalahari woodlands. Along the escarpment zone and within the Zambezi Valley as well as at the western border of the SP mopane woodland is the predominant vegetation type. This is a one-storeyed woodland with an open canopy 6 to 18 m high. Besides mopane, scattered elements of munga woodland dominated by various species of acacia, dry forests, grassland and open woodland occur. Along the drainage lines edaphic grassland is predominant. The grassland can be divided into dambo grassland, riverine grassland, and floodplain grassland. These vegetations are associated with the streams and rivers, floodplains of the larger rivers, seasonally flooded freshwater swamps and some alkaline swamps (Chenje 2000, Forest Department 1976).

Figure 2-3 Mopane woodland with patches of miombo woodland near Siavonga in the Zambezi Valley north of the Lake Kariba during the rainy season (March).

2.3. SOILS

2.3.1. Soil Units

Soil data are available in the Zambian soil map (NCSR & Surveyor General 1986) at scale 1:3 Million. Generally acrisol, luvisol, lithosol and arenosol are dominating in the SP (Figure 2-4). Gleysol, vertisol and fluvisol form less common soil units. A brief description of the most common soil units is given in Table 2-1.

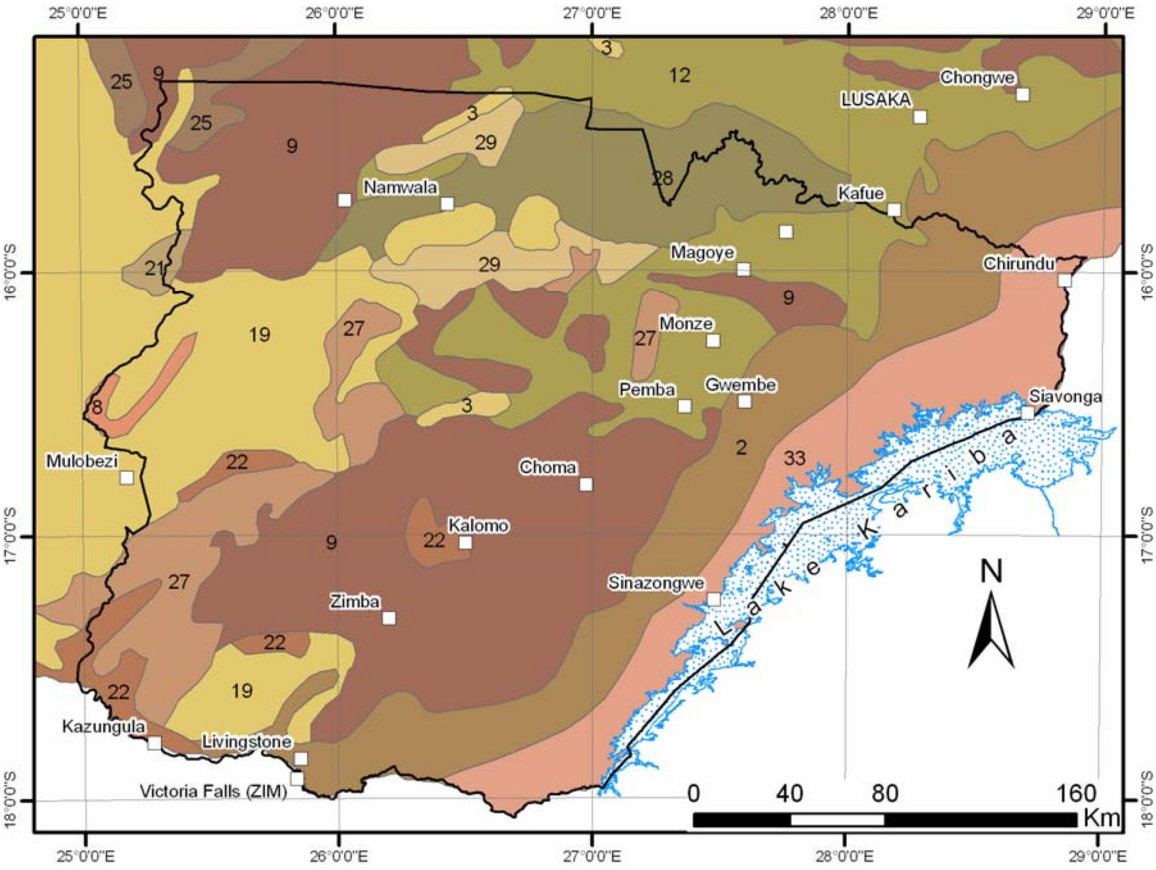


Figure 2-4 Soils of the SP and adjacent areas in Zambia. Explanations are given in the text. Modified after Soil Map of Zambia (NCSR & Surveyor General 1986).

In general, a good correlation between soil units and the geological main subdivision can be observed (Table 2-2). Common soils on metamorphic and magmatic rocks from the Hook Igneous and Basement Complex are lithosols, acrisols, luvisols and ferralsols. On the Muva Supergroup and on granitic rocks of the Choma-Kalomo Batholith, gleysols are usually developed. The rocks of the Katanga Supergroup are mainly covered by luvisols, acrisols and nitisols. Gleysols and fluvisols are occasionally associated with these rocks.

Table 2-1 Brief description of most common soil units found in the SP (simplified after FAO 2006)

Soil unit	**Description**
Acrisol	Soils that have a higher clay content (with generally low base saturation) in the subsoil than in the topsoil as a result of pedogenetic processes (especially clay migration).
Arenosol	Sandy soils with little or no soil development, including both soils developed in residual sands after in situ weathering of usually quartz-rich sediments or rock, and soils developed in recently deposited sands such as dunes in arid environments or beaches.
Cambisol	Soils in an early stage of development with at least an incipient subsurface soil formation.
Ferralsol	Ferralsols represent the classical, deeply weathered, red or yellow soils of the humid tropics. These soils have diffuse horizon boundaries, a clay assemblage dominated by low-activity clays (mainly kaolinite) and a high content of sesquioxides such as iron oxides.
Fluvisol	Genetically young soils lacking well developed zoning found in alluvial (river or lacustrine) deposits.
Gleysol	Wetland soils that are saturated with groundwater for long enough periods to develop a gley horizon with characteristic colour pattern.
Lithosol	Very shallow soils typical for land with strongly dissected topography over continuous rock and soils that are extremely gravelly and/or stony. In the new classification system lithosols are grouped under leptosols.
Luvisol	Soils that have a higher clay content in the subsoil than in the topsoil as a result of pedogenetic processes (especially clay migration). Unlike acrisols, they have high-activity clays throughout the subsoil horizon and base saturation at certain depths.
Nitisol	Deep, well-drained, red, tropical soils with diffuse horizon boundaries and a subsurface horizon with more than 30 percent clay and moderate to strong angular blocky structure elements.
Vertisol	Churning, heavy clay soils with a high proportion of swelling clays. These soils form deep wide cracks from the surface downward when they dry out.

The Karoo rocks in the Zambezi Valley are overlain by luvisols and cambisols. The Cenozoic rocks are mainly covered by arenosols and less commonly by vertisols and gleysols. The latter are found in some specific areas southwest of the Hook Igneous Complex.

Table 2-2 Soils of the SP and associated geology as well as the usual vegetation (in brackets). The soil code corresponds to the labels in Figure 2-4. Soil units according FAO/UNESCO classification (1974-1988).

Soil Code	Soil unit	Description	Associated geology	Area [%]
2	Lithosol, Ferric Acrisol, Ferric Luvisol	Shallow and gravelly soils derived from acid rocks, occurring in rolling to hilly areas, including escarpment (Miombo)	Magmatic and metamorphic rocks of the escarpment zone in the Zambezi Valley	13.66
3	Lithosol	Shallow soils derived from acid rocks occurring on hilly ranges (Miombo)	Magmatic and metamorphic rocks of the Hook Igneous and Basement Complex	0.54
8	Othic/xanthic Ferralsol, Ferric Acrisol	Association of strongly (60% map unit 7) and moderately (40% map unit 9) leached reddish to brownish clayey to loamy soils, derived from acid rocks (Miombo)	Isolated magmatic/metamorphic rocks in the Barotse Basin	0.43
9	Ferric Acrisol, Ferric Luvisol	Moderately leached reddish to brownish clayey to loamy soils, derived from acid rocks (Miombo)	Common soils on magmatic and metamorphic rocks of the Hook Igneous and Basement Complex	24.86
12	Chromic Luvisol, Orthic Acrisol, Eutric Nitosol	Moderately leached red to reddish clayey soils, derived from basic rocks, often in admixture with acid rocks (Munga)	Common soils of the Katanga Supergroup	15.58
19	Albic Arenosol, Ferralic Arenosol	Non or weakly podzolic sandy soils on Kalahari sands (Kalahari and Cryptosepalum)	Kalahari Group	19.47
21	Cambic Arenosol, Dystric Gleysol	Senanga-West floodplain soils (Miombo and termitary associated vegetation)	Cenozoic rocks	0.33
22	Dystric Gleysol	Hydromorphic sand plain soils or very poorly drained soils in large dambos (Grassland)	Muva Supergropup, Choma-Kalomo Batholith and Cenozoic rocks	1.99
25	Ferric Acrisol, Dystric Gleysol, Cambic Arenosol, Xanthic Ferralsol	Association of moderately to strongly leached reddish to yellowish loamy to clayey soils (40% map unit 8) (Miombo) and poorly drained soils in large depressions or valleys (60% map unit 29) (Termitary associated vegetation)	unspecific	1.59
27	Chromic/pellic Vertisol	Swamp soils (Mopane)	Mainly Cenozoic rocks	4.72
28	Pellic/chromic Vertisol	Kafue Flats clay soils (Grassland)	Alluvium, colluvium and laterite of the Kafue Flats	5.67
29	Dystric Gleysol, Humic Gleysol, Dystric Fluvisol	Floodplain soils (Termitary associated and grassland vegetation)	Katanga Supergroup and Cenozoic rocks	2.10
33	Orthic/chromic Luvisol, Eutric Cambisol	Gwembe valley soils (Mopane, Munga, Balkiaea)	Karoo Supergroup in the Zambezi Valley and adjacent escarpment zone	9.01

2.3.2. Soil Thickness

The groundwater database includes 378 boreholes containing information on soil thickness and lithology. The spatial distribution of these boreholes is highly irregular and has cluster centres around Livingstone and Zimba, Gwembe and Pemba, and between Magoye and Siavonga. High borehole densities also exist in the area of Siavonga and Sinazwonge. In the Kafue Flats boreholes are more regular distributed but for large parts of the area no information is available.

This clustered nature of the spatial distribution of information on soil thickness is problematic for interpolation. Furthermore, the quality of the input data regarding the soil thickness may not always be very accurate as the soil thickness in the borehole logs is often considered secondary.

The interpolated distribution of the soil thickness in Figure 2-5 should therefore be regarded as a first, rather rough approximation as its quality is highly depending on the spatial distribution and quality of measurement data. The thickness values range from 0 to 5.5 m around a mean value of 2 m. The distribution is positively skewed (Pearson's first skewness coefficient of 0.4). More details regarding the analysis of the soil depth distribution are given in **Annex 1**.

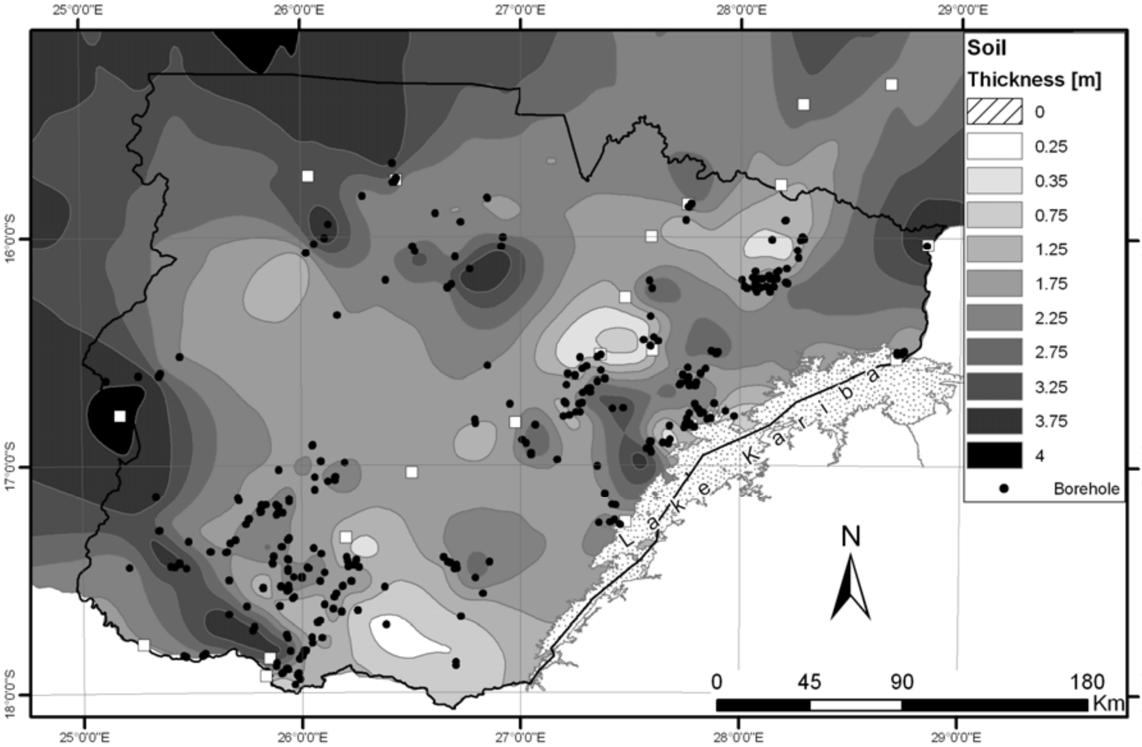


Figure 2-5: Estimation of the soil thickness distribution in the SP and location of the considered boreholes (dots) and major towns (white squares).

3. CLIMATE

Like for most of Zambia the climate in the Southern can be described as humid subtropical, with dry winters and hot summers, corresponding to Class **Cwa** according to the Köppen-Geiger classification. The Zambezi valley experiences a hot, semi-arid Steppe climate with higher temperatures and lesser rainfall (Class **Bhs**). The weather conditions of the Zambian highlands have also accurately been described as a **tropical continental highland climate** (Nieuwolt 1971). Due to the combined effect of low latitude (16 - 18°S), continental position and high elevation above sea level, the climate shows the combination of a clear division into a dry and a rainy season, the predominance of the diurnal cycle over the seasonal, and large daily ranges of temperature.

Commonly three seasons are distinguished (e.g. Monley 1986):

1. Rainy season – a warm wet season from November to April
2. Cold season – a mild to cool, dry season from April to August
3. Hot season – a hot and dry season from September to November.

3.1. TEMPERATURE AND OTHER CLIMATIC PARAMETERS

The Meteorological Department of Zambia operates four meteorological stations in the SP, namely at Choma, Kafue Polder, Livingstone and Magoye. Additionally there are, or temporarily existed, up to 50 voluntary stations (YEC 1995b). The mean annual temperatures are subtropical with values ranging from 19.3 to 22.1°C (Table 3-1). The mean monthly temperatures during the months of October/November are hot (22.5-26°C). The cold season is mild with mean monthly temperatures between 13.5 and 16.5°C. Daily minimum temperatures during this season often fall below 10°C. Due to the continental position of the Province and the predominately high altitude, the temperature shows a large daily range. Due to its lower altitude, the Zambezi graben experiences the highest temperatures during the hot season, and the mildest conditions during the cold season within the Province.

Table 3-1 Climatic parameters (annual means) at stations in SP and for Zambia (Source: (YEC 1995b, after data from MET)

Station	Latitude S	Longitude E	Altitude m asl	Temperature °C	Sunshine hrs/day	Rel. Humidity %	Wind Speed m/sec
Choma	16.850	26.067	1267	19.3	8.2	59.9	1.6
Kafue Polder	15.767	27.917	978	21.6	8.4	59.3	2.1
L/stone	17.867	25.883	987	22.1	8.6	59.0	1.9
Magoye	16.133	27.633	1018	21.3	n/a	n/a	1.5
ZAMBIA				21.0	7.8	64.2	1.6

The Province receives above-average sunshine compared to the national average. Sunshine duration measured at stations in the Province and countrywide average at 8.4 and 7.8 hours per day, respectively.

Average relative humidity in the Province is noticeably lower compared to the whole of Zambia as a direct consequence of lesser rainfall.

3.2. RAINFALL

3.2.1. Secular Rainfall and Droughts

Mean seasonal rainfall from October to May at the four meteorological stations varies between 700 and 800 mm (Table 3-2). The number of **rainfall days** at the four stations varies noticeably between 67 and 83 days per year. Compared to Zambian means, the Province receives 200 to 300 mm less rainfall with 14 to 30 fewer rainfall days per year.

The **regional rainfall distribution** depicted in Figure 3-1 shows that the seasonal rainfall gradually decreases from ca. 800 mm in the north to below 650 mm in the south-western parts of the Province. The isohyetal map is based on stations with long-term data exceeding 25 years of records including stations from central and western Zambia and neighbouring countries. Measured precipitation at Livingstone (697 mm) and the meteorological station "Kariba" in Zimbabwe (766 mm) indicate that rainfall in the Zambezi valley is somewhat lower than rainfall on the plateau formed by the Choma Kalomo block. **The average total rainfall for the Province calculated from the isohyetal map amounts to 757 mm**.

Table 3-2 Long-term annual rainfall and evaporation at stations in SP and for Zambia (Sources: MET, YEC 1995b)

Station	Rain-fall	Rainfall days	Pan Evaporation 100%/75%	Actual Evaporation [1]	PET [2]	Net Evaporation [3]	Runoff Coefficient [4]
	°mm	Day	mm	mm	mm	mm	%
Choma	796	83	1902/1427	667	1522	-726	17
Kafue Polder	767	68	2122/1592	677	1776	-1009	12
L/stone	697	76	2166/1625	637	1745	-1048	9
Magoye	720	67	1991/1493	674	1634	-914	6
ZAMBIA	1001	97	2061/1546	816	1574	-573	18

[1] calculated using Turc (1961)equation

[2] calculated using (revised) Penman (1948) equation

[3] Net evaporation = Rainfall –Potential Evaporation

[4] Runoff Coefficient = 1 – (Actual Evaporation/Rainfall)

The smooth isohyetal contours shown in Figure 3-1 however conceal the high variability of rainfall. **Rainfall in the Province is irregular and unreliable.** Figure 3-2 shows the **secular variation** in rainfall at Choma since 1950. The high variability of rainfall can be illustrated by the statistical parameters of the depicted time-series:

Number of records	56 years
Mean rainfall	796 mm/a
Standard Deviation	206 mm/a
Highest ever observed rainfall	1191 mm/a
Lowest ever observed rainfall	396 mm/a
Coefficient of Variation	26%

The graph suggests a particular dry spell at Choma during the years 1990 to1995. The driest individual rainy seasons occurred during 1972/73 (417mm), 1976/77 (420mm), 1991/92 (356mm) and 1994/95 (411mm). This corresponds well with regional occurrences of **droughts** which were reported for the periods 1946/47, 1965/66 1972/73, 1982/83, 1986-88, 1991/92 and 1994/95 and could be linked to major *El Niño* events (Robins et al. 2006). Preston-Whyte and Tyson (1988) observed an oscillatory pattern in rainfall series over Southern Africa during the period of meteorological record. According to this study, a wet spell with positive anomalies over the sub-continent was observed during the periods 1953/54 – 1961/62 and 1971/72 – 1980/81 whereas the periods 1962/63 - 1970/71 and the 1980's were dry. According to a drought analysis (method of Herbst et al. 1966) carried out by YEC (1995b) the south-western parts of Zambia extending from Mongu in Western Province to Livingstone form the most drought-prone regions within Zambia.

Apart from the strong temporal variations of rainfall, a large regional variability is common during individual rainfall seasons. During the seasons 2001/02 and 2002/03, for instance, the rainfall at Livingstone only reached 50% and 33% of the precipitation at Kafue Polder during the same period, respectively, whereas two years later, during the 2005/06 rainy season, Livingstone received more rainfall than the station situated at the Kafue River (see Figure 3-3).

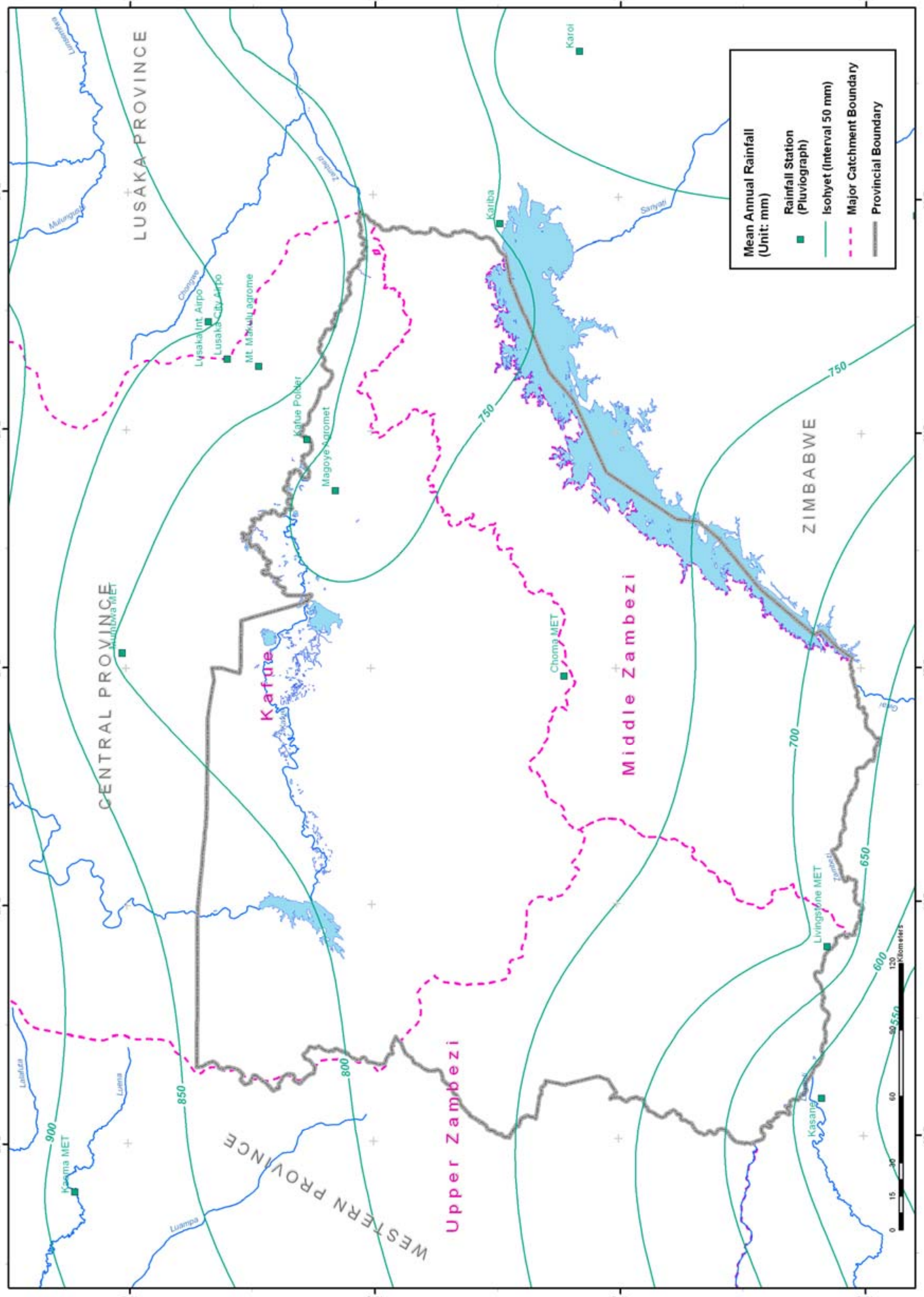


Figure 3-1 Isohyetal map of annual rainfall (Data sources include Metrological Department Zambia, Department of Meteorological Services, Botswana and report by Beilfuss & dos Santos 2001)

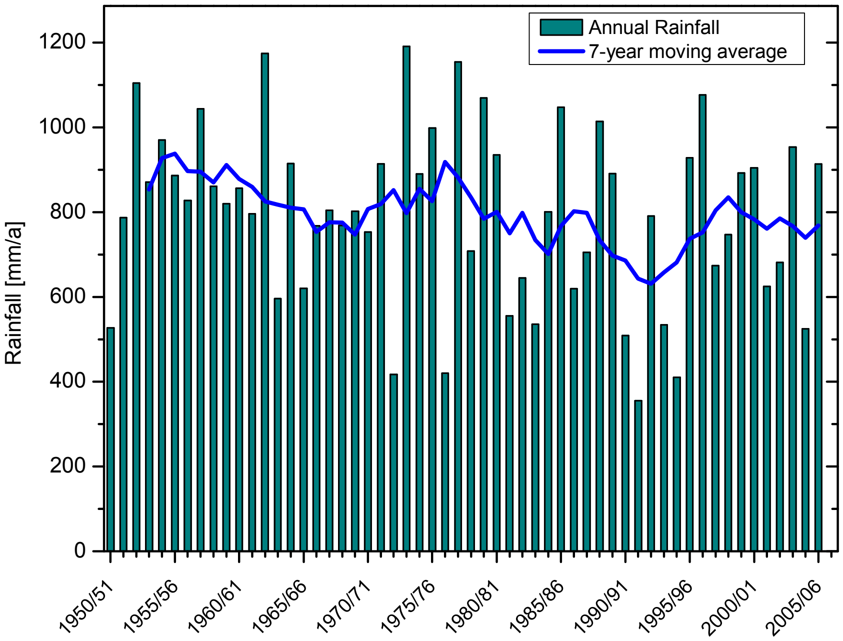


Figure 3-2 Long-term (secular) rainfall (since 1950) at Choma showing a large temporal variation (Source: MET)

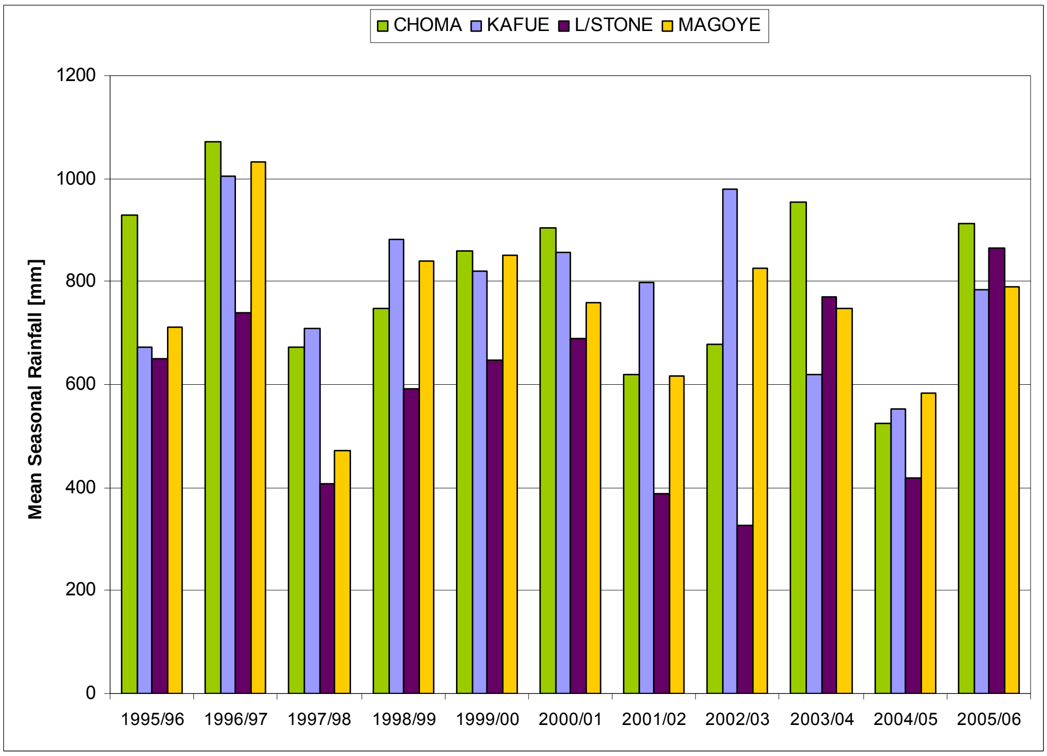


Figure 3-3 Seasonal rainfall (1995 – 2006) at rainfall stations in SP (Source: MET). The diagram shows the high variability of rainfall between individual rainy seasons (temporal variation) as well as between individual stations (regional variation).

3.2.2. Monthly Rainfall

The annual variation of **monthly rainfall** is controlled by the clear distinction between the wet season during summer and the dry winter. The wet and dry season are separated from each other by a short pre-rainy season (September – November) and post-rainy period (April-May).

The rainy season in Zambia can be linked to the southward shift of the so-called Inter-Tropical Convergence Zone (ITCZ). During the winter months the ITCZ is situated over the Sahel region at about 15°N. The ITCZ shifts southwards following the movement of the sun. During January the position of the ITCZ over eastern Africa is at 17°S (e.g. Preston-Whyte & Tyson 1988). The trade winds of both hemispheres converge into the low pressure area over the ITCZ. The ITCZ is an area of pronounced convective activity and therefore associated with heavy tropical rain.

During the pre-rainy and post-rainy seasons rainfall is associated with northeasterly winds which bring rather moist air masses to the region. High surface temperatures cause the formation of heat lows with a number of individual convectional thunderstorms that typically occur during the afternoon. The main rainy season from December to February rainfall is associated with the Congo Air Boundary (a branch of the ITCZ). This period is characterised by a broad zone of converging air masses, a predominance of westerly winds and extensive rainfall without a clear diurnal cycle. Most of the rainfall is hence associated with westerly winds (Nieuwoldt 1971).

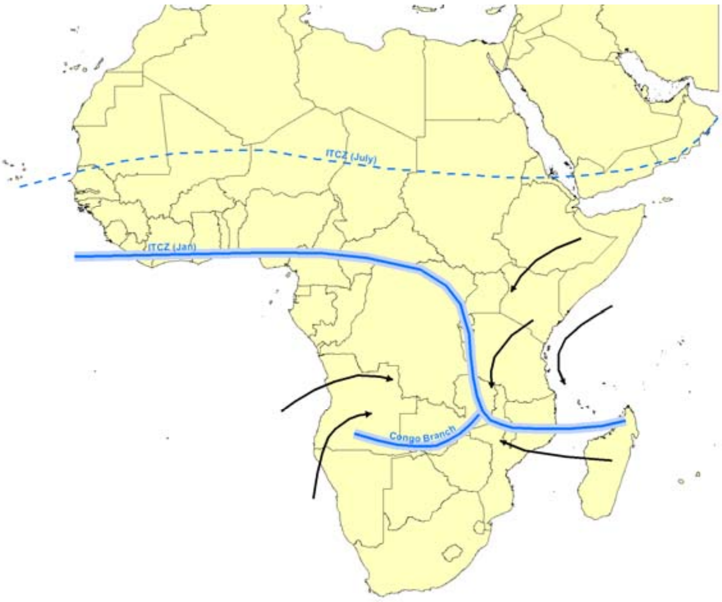


Figure 3-4 Approximate position of the ITCZ during the Southern Hemisphere winter (dashed line) and summer (thick line) and predominant wind directions during summer (arrows) (simplified after Nieuwoldt 1971 and Preston-Whyte & Tyson 1988)

The monthly means for Choma are shown in Figure 3-6. Over 90% of the seasonal rainfall is concentrated over the months from November to March. The highest individual monthly rainfall is encountered during the months of December, January or February. The three months have over 70% of the total rainfall. The winter months from June to August are practically without rain.

The description of the high short-term variability of the climate is beyond the scope of this report. It should however be noted that apart from the high spatial and temporal variability the rainfall pattern is also characterised by high intensities. The highest ever recorded 1-day rainfall at the four meteorological stations until 1994 for instance varies between 978 mm and 1267 mm (YEC 1995b). Figure 3-5 shows the frequency distribution of daily rainfall at Choma during the 2005/06 rainy season.

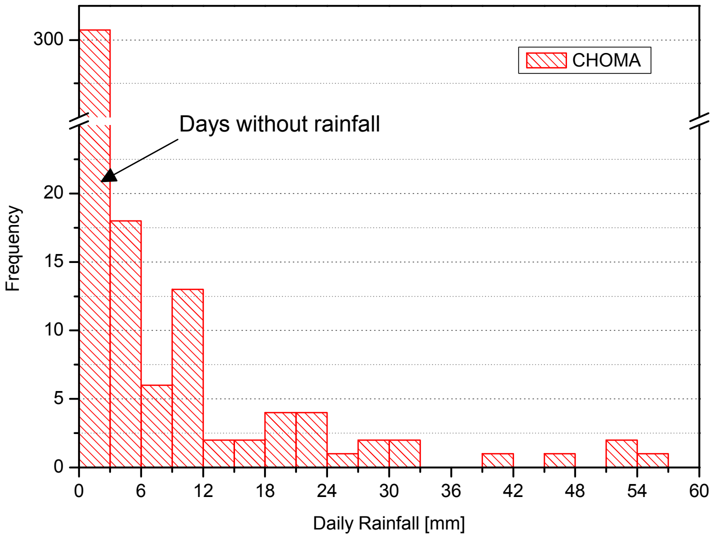


Figure 3-5 Frequency of daily rainfall at Choma during the 2005/06 rainy season

3.3. EVAPORATION

Long-term **Class-A pan evaporation** at the four meteorological stations in the SP varies between 1902 mm and 2166 mm (Table 3-2). The highest value is measured at Livingstone. The Class-A pan evaporation at the station Kariba in Zimbabwe amounts to 1882mm (Beilfuss & dos Santos 2001).

Evaporation from open water bodies such as lakes is often estimated by multiplying the pan evaporation by 0.75. Values corrected in such way range from 1427 mm to 1625 mm. Refer to Chapter 4.2 for a discussion of evaporative losses from the Kariba and Itezhi Tezhi reservoirs.

Potential evapotranspiration (PET) is commonly determined using the Penman equation (1948). YEC (1995b) obtained values for PET with a slightly revised version of the Penman approach ranging from 1522 – 1776 mm for stations situated in the Province. A similar estimate for PET of 1784mm is given by Beilfuss & dos Santos (2001) for the Kafue Flats. They applied the same approach using data from the Namwala meteorological station. The values determined for PET are in the same order of magnitude but about 100 mm lower than the corrected pan evaporation.

Actual Evaporation from vegetated land surfaces (quantity of water that is actually removed due to the combined effect of evaporation and plant transpiration) is much lower than PET since surfaces and soils will gradually dry out between individual rainfall periods and markedly during the dry season. Annual actual evaporation estimated calculated from the empirical Turc (1961) equation varies between 637mm and 677mm (YEC 1995**b**).

Net evaporation is defined as the difference between mean rainfall and potential evaporation and may be used as a measure for aridity. Due to high temperatures and the pronounced dry season, the net evaporation in the region takes always large negative values. The net evaporation is largest on the plateau (Choma: -726mm) and lowest in the Zambezi valley (Livingstone: -1048mm).

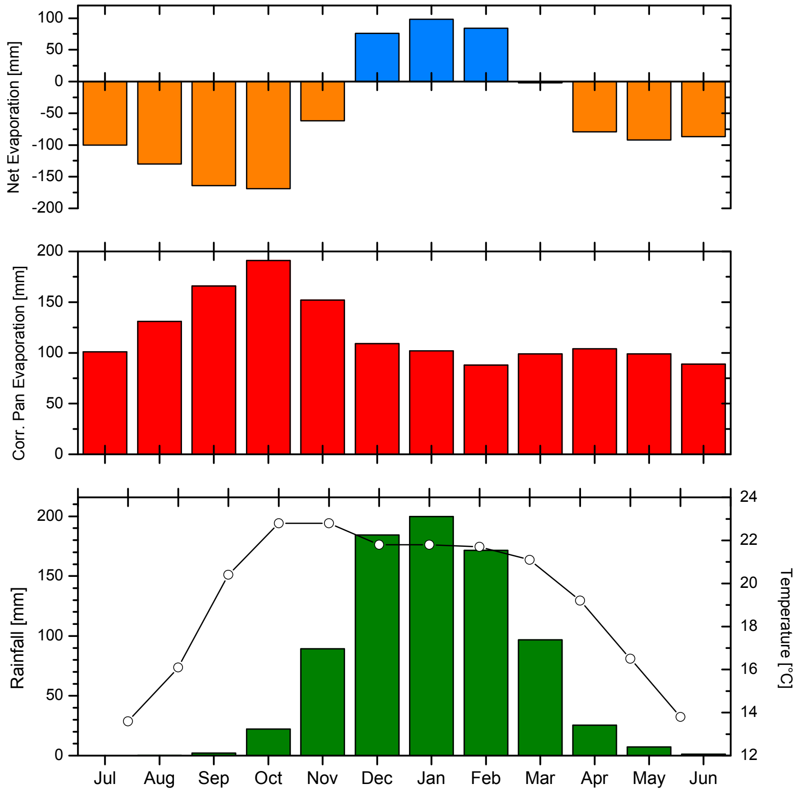


Figure 3-6 Seasonal variation of monthly mean temperature, rainfall and evaporation at Choma (Source: MET)

The seasonal variation of monthly rainfall, temperature, evaporation and net evaporation at Choma is depicted in Figure 3-6. It can be summarized as follows:

1. The highest (potential) evaporation (155 - 190mm/month) is encountered during the hot season. Low potential evaporation (90 - 100mm/month) occurs during the rainy months due to high humidity and during winter due to low temperatures.
2. Actual evaporation can be assumed to peak during the rainy and post-rainy season when surfaces are wet and soils often become saturated with water.
3. Net evaporation is negative (i.e. PET exceeds rainfall) for all months except for December to February.

4. HYDROLOGY

4.1. RIVER SYSTEMS AND RUNOFF

The SP is part of two major river systems, notably the Zambezi and the Kafue rivers. These two major rivers form together with the two Kafue tributaries Nanzhila and Kaleya the only perennial watercourses within the SP. All other tributaries are characterized by seasonal or intermittent runoff during the rainy season.

The SP is bordered by the Kasaya River, a minor tributary of the Zambezi, to the west, the Zambezi to the south, Lake Kariba to the southeast and the Lower Kafue River to the north.

4.1.1. Zambezi River

The Zambezi Catchment is commonly divided into three major parts (e.g. Beilfuss & dos Santos, 2001):

1. The Upper Zambezi Catchment from its headwaters to the Victoria Falls,
2. the Middle Zambezi Catchment covering the area from the Falls to the Cahora Bassa Dam in Mozambique,
3. the Lower Zambezi Catchment extending from the Cahora Bassa gorge to the Zambezi delta at the coast of the Indian Ocean.

The Zambezi headwaters originate from the highlands in Northwestern Zambia and Angola on the south side of the equatorial divide. From there, the general flow direction is southwards where the river enters a broad plateau including the vast Barotse floodplains. West of the town of Sesheke, the Zambezi sharply turns to the East. On its eastward course, the river geologically exits the area covered by Kalahari sands and cuts its riverbed into the basaltic rocks of the Upper Karoo Group near the border between the Western and SPs. After plunging down the Victoria Falls, and cascading down the Batoka and Devils gorges for a distance of approximately 120 km, the Zambezi flows into the vast Kariba Dam reservoir. The area comprising the smaller rivers draining the Sinazongwe, Gwembe and Siavonga Districts in SP as well as the Gwai (or ”Gwayi”), Sengwa, and Sanyati rivers that originate from the Zimbabwean highlands is known as the **Gwembe Valley** (Mpamba 2007, Beilfuss & dos Santos 2001).

The SP shares approximately 625 km or 21.5% of the total length (ca. 2900 km) of the Zambezi. Figure 4-1 depicts the change in the catchment area of the Zambezi from its headwaters at the Angolan/Zambian border to the confluence of the Luangwa River. Within the borders of the SP, there are two noticeable steps in the area curve caused by the contributions of the Chobe/Linyanti river system at approximately km 1200, whose catchment is largely located outside Zambian territories, and the Kafue River at km 1780.

Annual Discharge

The average outflow of the Zambezi at the Kariba dam amounts to approximately 1300 m^3/s (Table 4-1). Under typical drought conditions the outflow at Kariba Dam reduces to 750 m^3/s or 58% of the average discharge. The lowest ever recorded outflow between 1953 and 1992 was 455 m^3/s.

Figure 4-2 shows that the smaller Zambezi tributaries of the SP contribute comparatively little to the overall runoff of the Zambezi. Between the confluence of the Linyanti and the Kariba Dam the average discharge increases by only ca. 140 m^3/s. This increase can be largely attributed to the Zimbabwean rivers in the Gwembe Valley of which the larger ones are perennial. The mean annual discharge from these rivers is given as 232 m^3/s by Beilfuss & dos Santos (2001). The main tributary in this section on Zambian territory is the Kalomo River. Tributary flow in the Gwembe valley is highly variable and begins with the onsets of rains during November and usually peaks in January or February. The flow decreases quickly and typically ceases by early in the dry season. During drought conditions tributary flow levels evaporation losses from Kariba Lake, and consequently the Zambezi just manages to maintain its flow volume during its passage through the Gwembe Valley.

The specific discharge of the Zambezi River, defined as the ratio of average discharge to the catchments area, amounts to about 200 $m^3/d/km^2$ throughout the SP (Figure 4-3). This corresponds to only one third of the value for the Zambezi headwaters upstream of the Kabombo River confluence in the Western Province.

Monthly Discharge

The hydrograph of mean monthly discharge is shown in Figure 4-4. At Victoria Falls the mean monthly discharge increases sharply from January to April. The mean date of arrival of the peak is April 19, with a standard variation of 19 days (Beilfuss & dos Santos 2001). According to the Water Resources Master Plan (YEC 1995a) the maximum monthly discharge is 2,762 m^3/s. The average minimum discharge of 337 m^3/s occurs during October.

The hydrograph of monthly discharge at Lake Kariba is flattened out due to the storage capacity of the reservoir and possibly the regulated operation of the dam's turbines and spillway. The maximum monthly discharge still occurs during April but is sharply reduced compared to the river upstream. The maximum and minimum monthly outflow from the dam is 1,927 m^3/s and 883 m^3/s, respectively. The ratio between maximum and minimum discharge is 2.2, compared to 8.2 at Victoria Falls.

Unlike the Zambezi and Kafue rivers, the tributaries in the Gwembe Valley lack extensive storage reservoirs such as large dams and swamps. Runoff from the incised valleys therefore occurs as floods in response to major rainfall events. The cumulative discharge from the Gwai (54,610 km^2), Sengwa (25,000 km^2) and Sanyati Rivers (43,500 km^2) peaks during February and totals more than 900 m^3/s. Due to the lack of storage in the catchment the peak discharge occurs two months earlier than in the Zambezi.

Table 4-1 Observed and statistical discharge at selected gauging stations for SP for the period between 1953 - 1992 (after YEC 1995a&b)

Gauging Station	**Catchment**	**Q**	**Q_D**	**Q_{Max}**	**Q_{95}**	**Q_{185}**	**Q_{275}**	**Q_{355}**	**Q_{Min}**
Victoria Falls	Upper Zambezi	1187	744	3225	1766	777	449	316	298
Kariba Lake (Outflow)	Middle Zambezi	1299	756	6668	1083	904	729	482	455
Kafue Hook Bridge	Middle Kafue	308	161	1113	469	173	95	55	49
Itezhi Tezhi Dam (Outflow)	Middle Kafue	278	162	832	325	188	147	109	85
Kafue Gorge (Outflow)	Lower Kafue	296	163	574	402	253	177	123	100

Explanations:

Q	30-years average discharge (1963-1992) in m^3/s
Q_D	Probable average discharge of drought with a 10-year return period
Q_{Max}	Maximum discharge recorded
Q_{95}	High discharge, exceeded on 95 days a year
Q_{185}	Median discharge, exceeded on 185 days a year
Q_{275}	Low discharge, exceeded on 275 days a year
Q_{355}	Drought discharge, exceeded on 355 days a year
Q_{Min}	Minimum discharge recorded

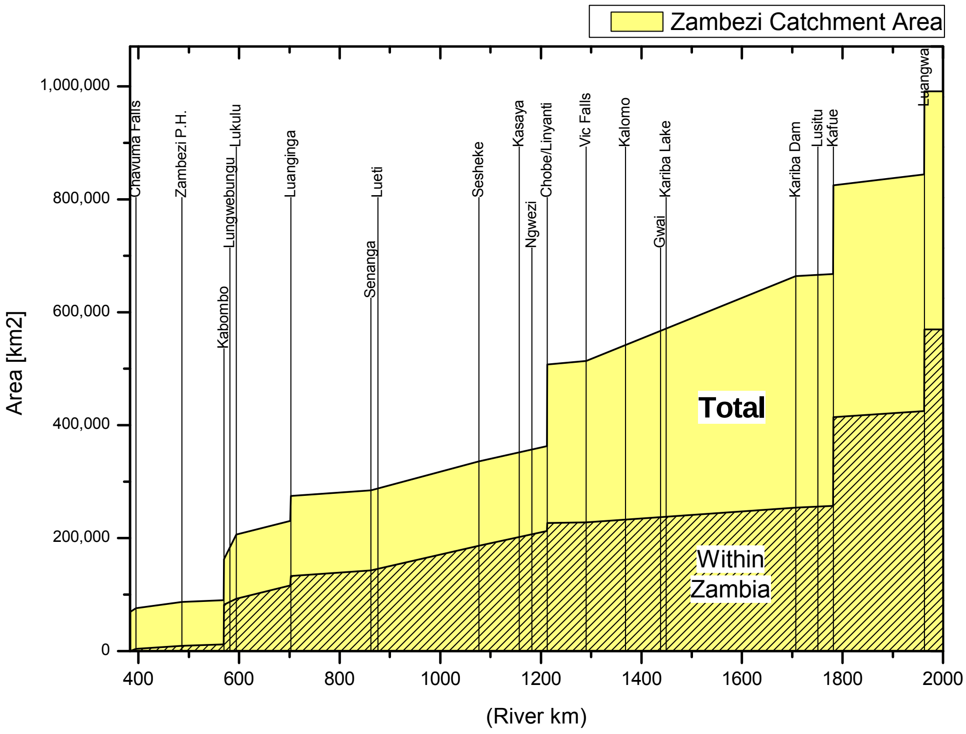


Figure 4-1 Area of Zambezi Catchment from its headwaters to the Luangwa confluence. Note that the SP is located in the section between the Kasaya and Kafue rivers.

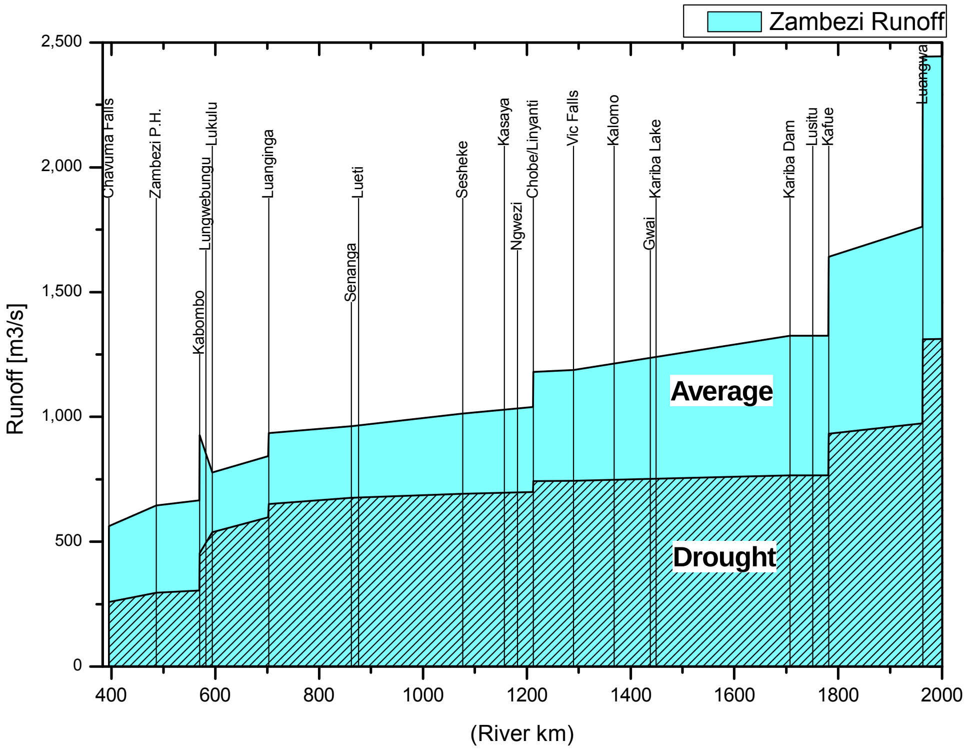


Figure 4-2 Annual runoff of the Zambezi River between Zambian border in Western Province and Luangwa confluence. Blue area shows average runoff over the 30-year period between 1963-1992. Hatched area shows probable drought discharge with a return period of 10 years. [Data source: YEC, 1995a]

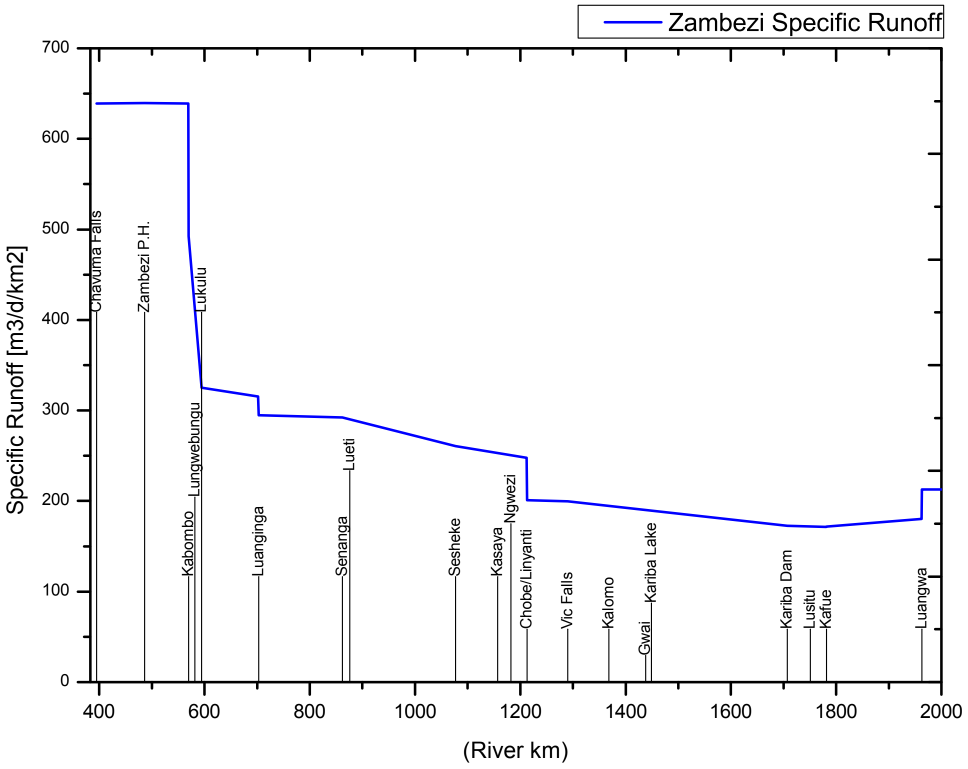


Figure 4-3 Specific Runoff (or runoff per area) of the Zambezi between the Zambian border in Western Province and the Luangwa confluence [Data Source: YEC, 1995a].

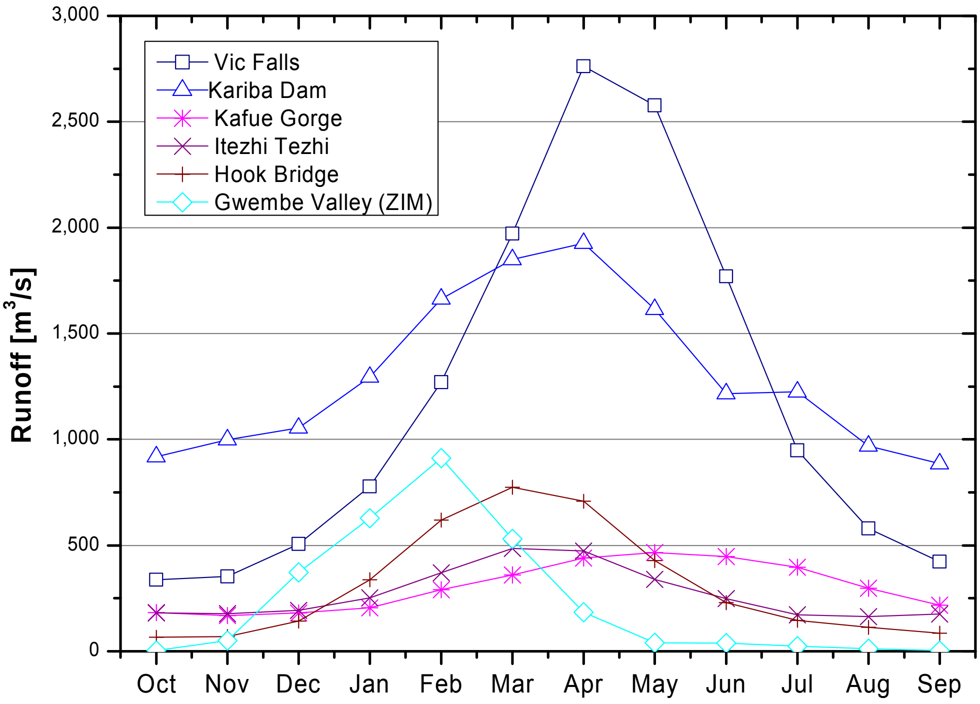


Figure 4-4 Average monthly discharge at selected gauging stations in the Kafue and Zambezi catchments [Data Source: Beilfuss & dos Santos 2001, YEC, 1995a]

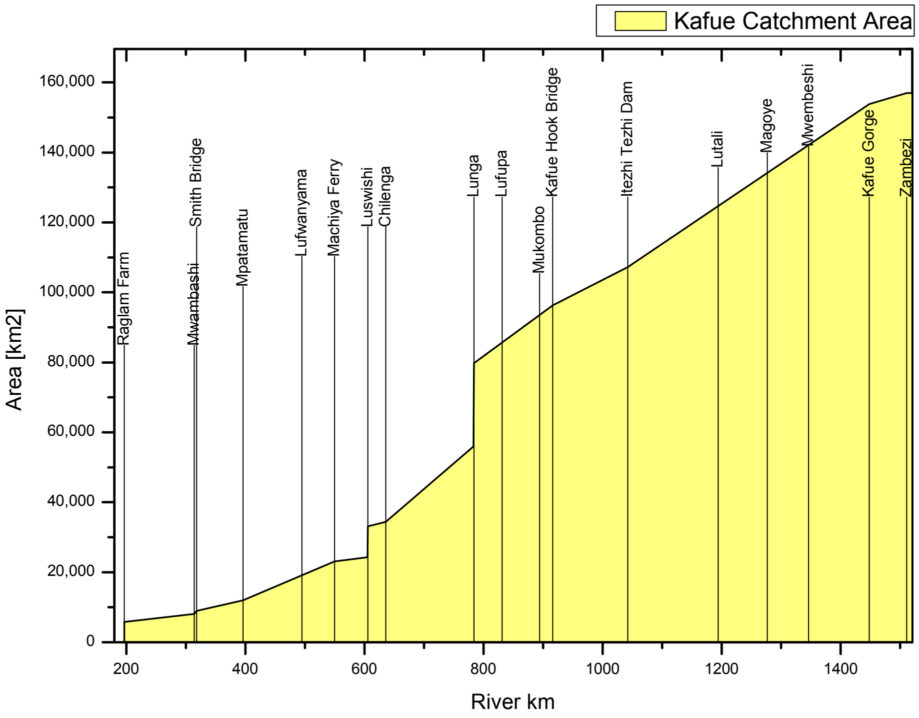


Figure 4-5 Area of Kafue Catchment along its course. The Kafue River enters the SP just downstream of Kafue Hook bridge [Source of data: YEC, 1995a].

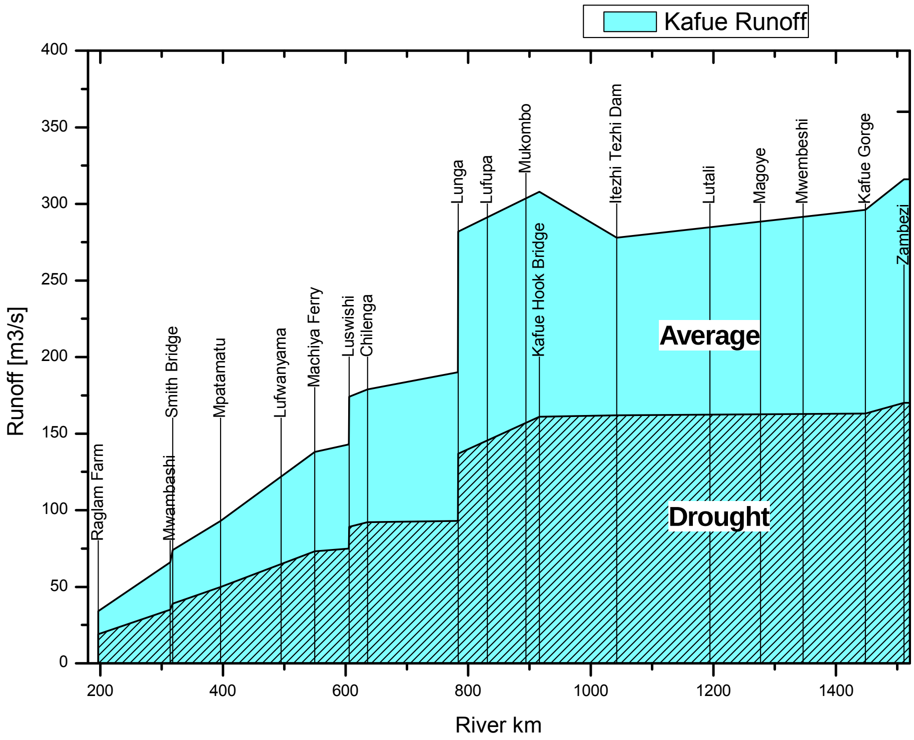


Figure 4-6 Annual runoff of the Kafue River. Blue area shows average runoff over the 30-year period between 1963-1992. Hatched area shows probable drought discharge with a return period of 10 years. [Source of data: YEC, 1995a]

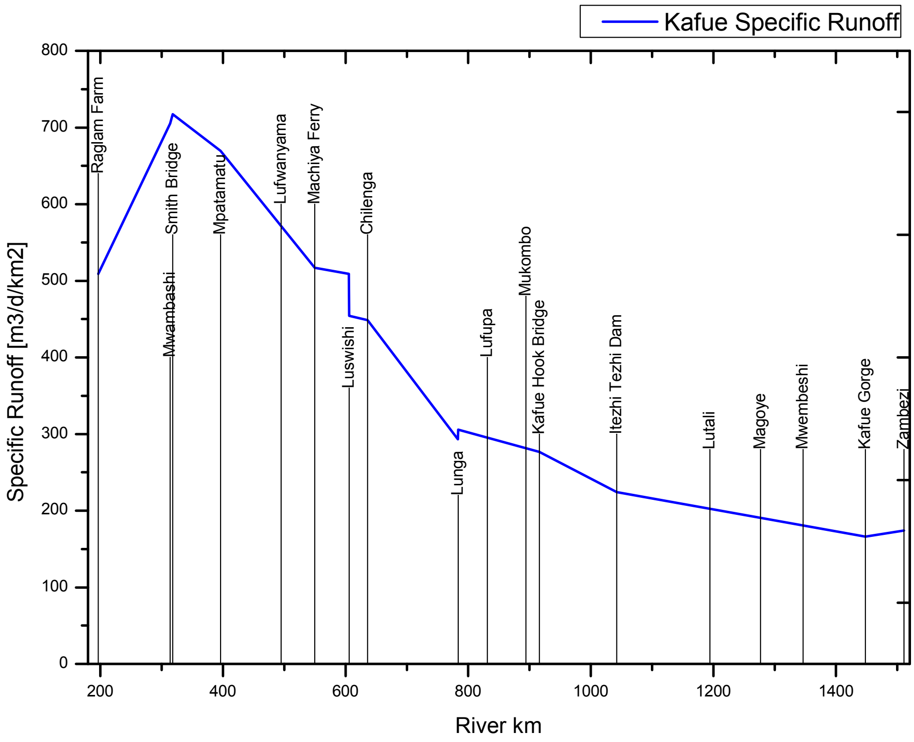


Figure 4-7 Specific runoff (or runoff per area) of the Kafue River [Source of data: YEC, 1995a].

4.1.2. Kafue River

The Kafue River forms the largest basin within the Middle Zambezi river system. Its watershed is entirely located on Zambian territory. The Kafue Catchment can be divided into the three following sections:

1. The Upper Kafue Catchment including the Kafue headwaters upstream of Lubungu and the large Lunga sub-catchment,
2. the Middle Kafue Catchment covering the area from the Lunga confluence to the Itezhi Tezhi Dam,
3. the Lower Kafue Catchment covering the Kafue Flats and the Kafue Gorge downstream of Itezhi Tezhi down to the river confluence with the Zambezi.

The Kafue originates from the plateau in the Copperbelt Province, an area with average rainfall well above 1100 mm. In most of the Upper and Middle sections the river follows generally a southerly or westerly direction. The river enters the SP in its middle section approximately 57 km downstream of the Kafue Hook Bridge which is located along the Mongu Road. At the Itezhi Tezhi reservoir outlet the river sharply turns in an eastward direction to enter the Kafue Flats, a floodplain with an area up to 60 km wide and 250 km long. From Itezhi Tezhi to the Kafue Gorge the altitude drops from 995 m to 970 m asl over a river section of 400 km resulting in an average flow gradient of only 6 cm per km.

Figure 4-5 shows the overall gradual increase of the catchment area along of the course of the Kafue River from its source to its confluence. A sharp increase in the total catchment area is only encountered at the confluences of the Luswishi and the Lunga Rivers in the Upper Catchment.

Annual Discharge

Similar to the Zambezi the hydrological regime of the Kafue River is very complex. On its downward course it passes two large floodplains, the Lukanga Swamps (2600 km^2) and the Kafue Flats (15,000 km^2), and two large reservoirs created by the Itezhi Tezhi and the Kariba Gorge dams. In this it differs strongly from the Luangwa catchment, which is similar in size but differs significantly in geomorphology and lacks large floodplains and dams.

After the confluence of the Lunga River, i.e. after about half of the river's total length, the average annual discharge of roughly 300 m^3/s increases only slightly (Figure 4-6). Between Kafue Hook Bridge and the Itezhi Tezhi Dam the average annual discharge drops even by about 30 m^3/s due to evaporative losses from the dam. During drought conditions, the discharge downstream of Itezhi Tezhi is maintained at approximately 160 m^3/s. Individual discharge rates at the gauging stations relevant for SP are given in Table 4-1.

The specific runoff declines sharply from the Kafue headwaters to the Lunga confluence, and thereafter more moderately towards the Zambezi confluence (Figure 4-7). In the SP, the specific discharge ranges from 170 to 280 m^3/d/km^2. These values are in the same order of magnitude as those for the Zambezi in the SP.

As a summary, most of the discharge of the Kafue River system is generated in the Upper Catchment. In the Middle and in particular the Lower Kafue Catchment, inflow from tributaries roughly equals evaporative losses from the dams and floodplains.

Monthly Discharge

The average monthly discharge at gauging stations at Hook Bridge, Itezhi Tezhi Dam and Kafue Gorge are depicted in Figure 4-4. It should be noted that flow below Itezhi Tezhi is largely regulated through the regulation gate at the dam. A comparison of the three hydrographs show the combined impact of the Itezhi Tezhi dam and the Kafue Flats on the flow regime of the Lower Kafue River, which can be characterized by:

(1) a delay of the arrival of the peak flow from March at Hook Bridge to May at Kafue Gorge,

(2) a significant decrease in maximum monthly discharge from 774 m^3/s at Hook Bridge to 485 m^3/s at Itezhi Tezhi and 448 m^3/s at Kafue Gorge,

(3) a sharp decrease of the ratio between maximum and minimum monthly discharge from 11.7 at Hook Bridge to 3.0 at Itezhi Tezhi and to 2.8 at Kafue Gorge.

Prior to the dam construction, water levels in the flats used to rise during November and December and, according to Beilfuss & dos Santos (2001), an area of up to 5650 km^2 was inundated for several months each year. Monthly average water levels and secular variation of water levels in the Kafue Flats have been published in the National Water Resources Master Plan (YEC 1995b, page C-37ff). Water levels usually peak in March and are lowest during November. Annual fluctuations in water levels (monthly averages) are in the order of 4 to 5 m, but maximum fluctuation reaches about 7 m.

4.2. DAMS AND RESERVOIRS

Three large dams for hydropower generation are located in the SP, the Kariba dam in the Middle Zambezi Catchment as well as the Itezhi Tezhi and Kafue Gorge dams in the Lower Kafue Catchment. The basic facts on the dams are summarized in this section.

The size of the surface and catchment areas of the three dam reservoirs are summarized in Table 4-2. The reservoir levels since the start of operations of the three dams are depicted in Figure 4-8.

Table 4-2 Surface and catchment area as well as storage capacity of the three major reservoirs in SP (Total capacity after Beilfuss & dos Santos 2001)

Reservoir	Catchment	Start of operation	Surface Area [km^2]	Catchment Area [km^2]	Total Capacity [Mm^3]
Kariba	Middle Zambezi	1958	5350	663,880	160,000
Kafue Gorge	Lower Kafue	1972	800*)	152,710	885
Itezhi Tezhi	Lower Kafue	1976	313	106,511	5,700

*) Depending on degree of flooding values from 600 to 1600 km^2 are reported

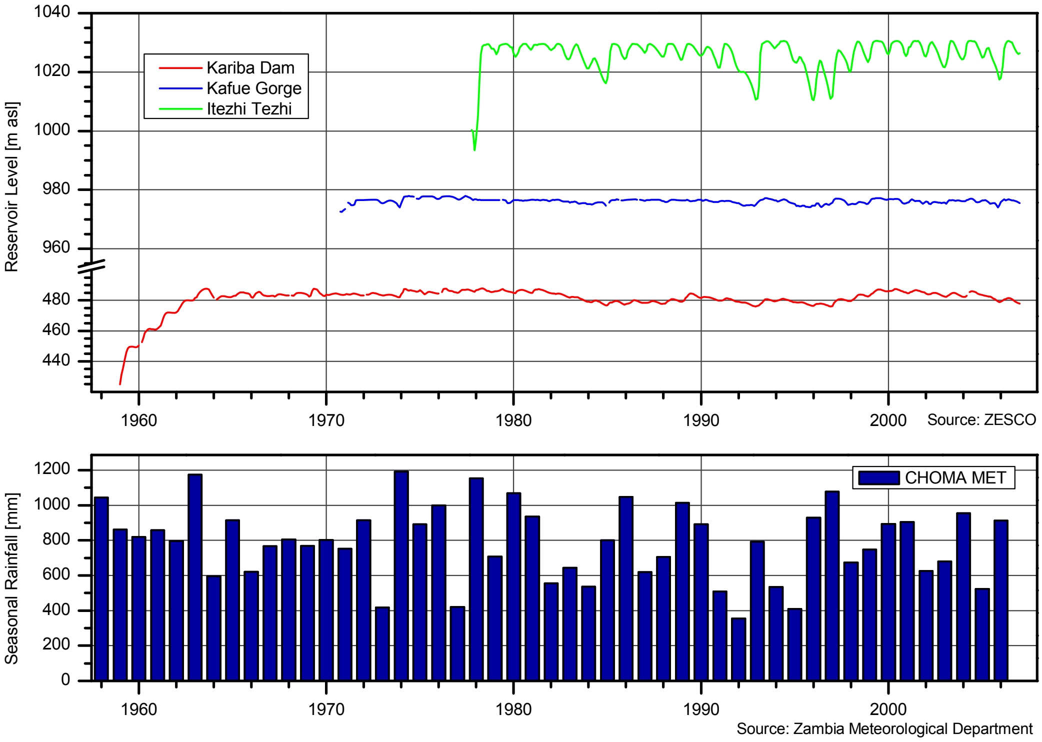


Figure 4-8 Reservoir levels since 1959 in comparison with seasonal rainfall at Choma MET.

Kariba Dam and Reservoir

With a surface area of about 5,350 km^2 and a total capacity of 160 km^3, the Kariba dam is the third largest reservoir in Africa after the Owen Falls (Victoria/Nile) and the Nasser reservoir (Nile). The 131 m high and 633 m long dam wall was built into an intrusion of granitic gneiss near Siavonga into which the Zambezi has incised a deep gorge. The reservoir is up to 30 km wide and 280 km long.

The dam was closed in 1958 and operates to regulate the Zambezi flow regime and for hydropower generation. The significant reduction of monthly peak flow (see Chapter 4.1.1) has caused a dramatic decrease in the inundated area of floodplains below the Kariba Gorge including the Mana Pools National Park.

Beilfuss & dos Santos (2001) estimated evaporation from the reservoir at 1694 mm using tank evaporation data available at Kariba Meteorological Station. Net evaporation (evaporation – rainfall) is given as 955 mm. Net losses hence can be estimated at ca. 13% of the inflow (1340 m^3/s after YEC 1995b) into the dam.

Kafue Gorge Dam and Reservoir

The Kafue dam was completed at Kafue gorge in 1972 and hosts a hydropower station. The crest of the 50 m high wall is at 981.5 m asl and creates a total reservoir capacity of 885 Mm^3. At full retention level the inundated area extends up to Nyimba gauging station (close to Lonchinvar National Park), an area that corresponds to almost 50% of the Kafue Flats. An area from 600 to 1600 km^2 that previously was only seasonally inundated is now permanently flooded. This comparatively large surface area of the reservoir results in an unfavourable surface to volume ratio.

Beilfuss & dos Santos (2001) estimated evaporation from the Kafue Flats using the Penman equation and climatological data from Namwala Meteorological Station. They obtained 1784 mm/a as evaporation and 1045 mm/a as net-evaporation from the Flats. Assuming that these values also apply to evaporation from the reservoir surface (estimated at 800 km^2) net losses from the dam would be ca. 10% of the inflow of 272 m^3/s (YEC 1995b) into the dam.

Itezhi Tezhi Dam and Reservoir

Itezhi Tezhi dam commenced operation during 1976/1977. The dam wall has a length of 1800 m and a crest height of 65 m. The reservoir has a capacity of 5,700 Mm^3 and covers an area of about 313 km^2.

The purpose of the dam is to optimize inflow into the Kafue Gorge reservoir for an effective hydropower production and to minimize evaporation losses from the Kafue Gorge reservoir. Releases from the dam are typically kept at approximately 170 m^3/a except during main flood events. As a result, the extent of flooding in the western parts of the Kafue Flats has been significantly reduced.

Beilfuss & dos Santos estimate the reservoir evaporation and net-evaporation at 1620 mm/a and 780 mm/a, respectively. Net evaporative losses from the reservoir total approximately 3% of the inflow (255 m^3/s after YEC 1995b).

It is worth mentioning that estimates evaporation and net losses from the dam reservoirs given by Beilfuss & dos Santos and by YEC in the Water Resources Master Plan vary strongly. YEC (1995b: p. C-40) calculated the net-evaporation from the reservoir water balance. They obtained rates of 445 – 546 mm/a for Kariba Dam, 570 mm/a for Kafue Gorge reservoir and 460 mm/a for Itezhi Tezhi Dam. It yet appears that tributary flows into the reservoirs have been neglected in this study. This could explain the considerably lower estimates for net-evaporation from the reservoirs.

4.3. CATCHMENTS

Figure 4-9 represents a map showing the major catchments and individual river catchment for the SP and adjacent areas. The map is based on the DEM described in Chapter 2.1 and the river system digitized from the topographic maps at scale 1:250,000 (Surveyor General 1971 - 1992).

The major catchments Middle Zambezi and Kafue are subdivided into the following **sub-catchments**:

Middle Zambezi (excluding Kafue):	Kalomo & minor tributaries Lake Kariba Lusitu & minor tributaries
Kafue:	Upper Kafue (incl. Lunga Catchment) Middle Kafue (incl. Itezhi Tezhi) Lower Kafue

The sub-catchment boundaries largely match with the basins and “blocks” delineated as part of the WRMP (YEC 1995a). The surface water resource potential given in the WRMP can hence easily be linked to the sub-catchments.

Detailed data on the individual catchments can be found in Table 4-3 and Table 4-4. The tables link the catchments to the basin and block numbers defined by the WRMP for easy reference.

Each sub-catchment has been further subdivided into individual river catchments. Within the SP the Kasaya (15,401 km^2), Kalomo (6,309 km^2) and Ngwezi (5,358 km^2) rivers form the largest individual catchments in the Zambezi basin. The largest river catchments in the Lower Kafue are the Nanzhila catchment (7,134 km^2) followed by the Bwengwa (2,510 km^2), Magoye (2,281 km^2) and Munyeke (2,271 km^2) catchments.

The Kafue Catchment covers 46% of the total area of the Province (85,150 km^2) whereas 51% of the total area is part of catchments that drain directly into the Zambezi River. The remaining 3% are covered by Kariba Lake.

The SP shares one quarter of the total Kafue Catchment (23% of the Middle Kafue Catchment and 66% of the Lower Kafue Catchment). Upstream of the Kafue confluence approximately 17% of the Zambezi catchment area within Zambian territory is part of the SP. The Zambian portion of the Middle Zambezi south of the Kafue confluence is entirely located in the SP.

Table 4-3 Sub-catchments of the Zambezi Basin

Sub-catchment	**River Catchment**	**Basin No. (WRMP)**	**Block No. (WRMP)**	**Area in Zambia [km^2]**	**Area in SP [km^2]**	**Area in SP [%]**	**Total Catchment Area [km^2]**
Central Plains (Barotse)	Upper Zambezi with tributaries	AZ-2 to AZ-14	BZ-1 to BZ-5	187,766	46	0	
	Loanja	AZ-15	BZ-6	4,235	0	0	
	Kasaya	AZ-15	BZ-6	15,401	9,945	64.6	
	Ngwezi	AZ-15	BZ-6	5,358	5,358	100	
	Cuando/Linyanti	AZ-16	n/a	14,046	0	0	
	Minor Rivers	AZ-17	BZ-6	2,166	2,166	100	
UPPER ZAMBEZI				**228,973**	**17,515**	**7.7%**	**513,780**
Kalomo & Minor Tributaries	Kalomo	AZ-18	BZ-7	6,309	6,309	100	
	Namaluba	AZ-18	BZ-7	266	266	100	
	Ngwemanzi	AZ-18	BZ-7	719	719	100	
	Other (Minor) Rivers	AZ-18	BZ-7	1,939	1,939	100	
Lake Kariba	Upper Kariba	AZ-18	BZ-7	998	998	100	
	Zhimu	AZ-18	BZ-7	2,517	2,517	100	
	Maze	AZ-18	BZ-7	613	613	100	
	Zongwe	AZ-18	BZ-7	2,445	2,445	100	
	Sikalamba	AZ-18	BZ-7	224	224	100	
	Lowe/Nangombe	AZ-18	BZ-7	323	323	100	
	Njongola	AZ-18	BZ-7	717	717	100	
	Chezya	AZ-18	BZ-7	852	852	100	
	Chibuwe	AZ-18	BZ-7	781	781	100	
	Lufua	AZ-18	BZ-7	2,407	2,407	100	
	Other (Minor) Rivers	AZ-18	BZ-7	2,264	2,264	100	
Lusitu & Minor Rivers	Mbendele & Mutulanganga	AZ-19	BZ-8	792	792	100	
	Lusitu	AZ-19	BZ-8	1,831	1,831	100	
	Other (Minor) Rivers	AZ-19	BZ-8	319	319	100	
MIDDLE ZAMBEZI (upstream Kafue confluence)				**26,315**	**26,315**	**100**	**154,190**
ZAMBEZI (TOTAL)				**255,288**	**43,831**	**17.2**	**667,970**

Table 4-4 Sub-catchments of the Kafue Basin

Sub-catchment	River Catchment	Basin No. (WRMP)	Block No. (WRMP)	Area in Zambia [km^2]	Area in SP [km^2]	Area in SP [%]	Total Catchment Area [km^2]
Upper Kafue	Upper Kafue with tributaries	AK-1 to AK-9	BK-1 to BK-6	55,158	0	0	
	Lunga	AK-10 & AK-11	BK-7	24,519	0	0	
UPPER KAFUE				**79,677**	**0**	**0**	**79,677**
Middle Kafue (incl. Itezhi Tezhi)	Lufupa	AK-12	BK-8	10,453	0	0	
	Mukombo & Mushingashi	AK-12	BK-8	5,650	0	0	
	Itezhi Tezhi	AK-13	BK-9	10,731	6,249	58.2	
MIDDLE KAFUE				**26,834**	**6,249**	**23.3**	**26,834**
Lower Kafue	Nkala	AK-14	BK-10	1,302	1,296	99.5	
	Nanzhila	AK-14	BK-10	7,134	7,134	100	
	Mbuma	AK-14	BK-10	291	291	100	
	Baunza	AK-14	BK-10	321	321	100	
	Banga	AK-14	BK-10	432	432	100	
	Lukomezi	AK-14	BK-10	1,115	779	69.9	
	Lutali	AK-14	BK-10	4,345	572	13.2	
	Nangoma	AK-14	BK-10	1,749	0	0	
	Chibenge	AK-14	BK-10	469	0	0	
	Ulwafuli & Namakaka	AK-14	BK-10	554	554	100	
	Kwichila	AK-14	BK-10	470	470	100	
	Chitongo	AK-14	BK-10	490	490	100	
	Munyeke	AK-14	BK-10	2,271	2,271	100	
	Bwengwa	AK-14	BK-10	2,510	2,510	100	
	Kasane	AK-14	BK-10	1,500	1,500	100	
	Magoye	AK-14	BK-10	2,281	2,281	100	
	Kaleya	AK-14	BK-10	876	876	100	
	Mazabuka	AK-14	BK-10	225	225	100	
	Nakanega	AK-14	BK-10	428	428	100	
	Mwembeshi	AK-14	BK-10	4,503	0	0	
	Chilongolo	AK-14	BK-10	735	0	0	
	Kafue Flats (& minor tributaries)	AK-14	BK-10	11,646	8,297	71.2	
	Other (Minor) Rivers	AK-14	BK-10	551	551	100	
	Kafue Gorge	AK-15	BK-11	3,262	1,341	41.1	
LOWER KAFUE				**49,461**	**32,619**	**65.9**	**49,461**
KAFUE (TOTAL)				**155,972**	**38,868**	**24.9**	**155,972**

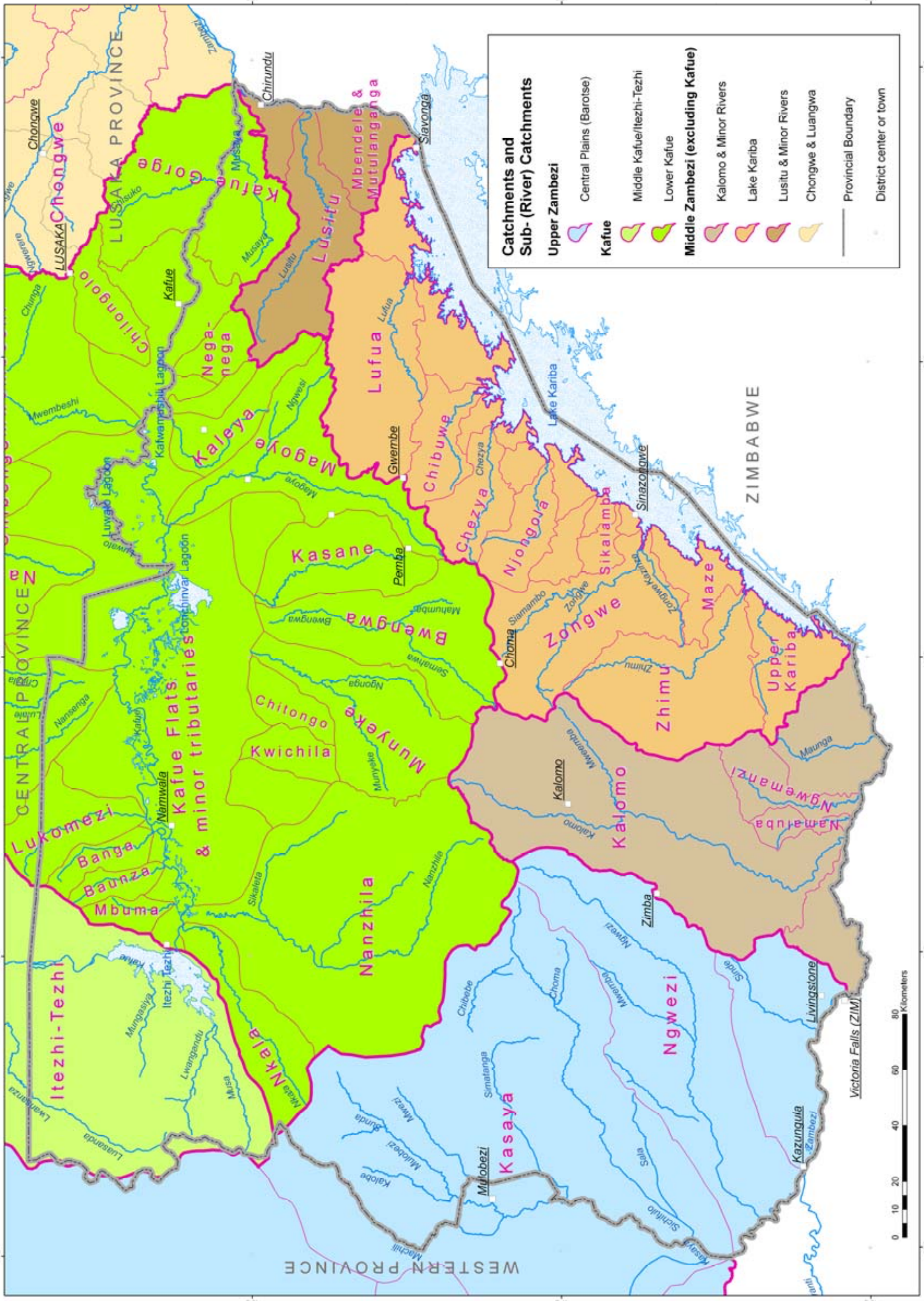


Figure 4-9 Major river systems and catchments

4.4. SURFACE WATER POTENTIAL

In the Water Resources Master Plan - WRMP (YEC 1995a), the surface water potential *SWP* for a basin was defined as the difference between precipitation *P* and losses through evapotranspiration *ET* and groundwater recharge *R*, i.e.:

$SWP = P - ET - R$

Assuming that the change in storage of water in the basin over time is zero, the SWP can be estimated using the following equation:

$SWP = A_{\%} \cdot (Q_{out} - Q_{in})$, *where*

Q_{out}	Average river outflow from the catchment
Q_{in}	Average inflow into the catchment,
$A_{\%}$	Percentage of catchment area inside of Zambia

The SWP was calculated for so-called “blocks” which combine sub-basins depending on the availability of gauging stations. The relevant blocks for SP are named BZ-6 to BZ-8 in the Zambezi Catchment and BK-9 to BK-11 in the Kafue Catchment (refer to Table 4-3 and Table 4-4 for details).

The calculated SWP for SP and its catchments is given in Table 4-5. The table comprises values for 30-years average runoff as well as values for drought conditions. The totals given in the WRMP could not be entirely confirmed. For instance, the WRMP did not include the catchment block BK-11 in the calculations for the SWP of the SP. For the Itezhi Tezhi block (BK-9) the surface water potential is negative during average runoff years, which is caused by a decrease in discharge between Kafue Hook Bridge and Itezhi Tezhi outflow. This suggests that a considerable amount of water is lost by evaporation or goes into storage and that the proposed method is not applicable to this block. Other, smaller discrepancies to the WRMP can be explained by slight differences in the size of the catchment areas.

The overall surface water potential totals 1,770 Mm^3/a during average runoff conditions and 558 Mm^3/a during drought conditions. For comparison, in the WRMP the potential is given as 1,934 Mm^3/a and 436 Mm^3/a for average and drought conditions, respectively.

The SP has the lowest SWP in Zambia followed by the Lusaka and Copperbelt Provinces. It is also characterized by a relatively low potential per capita (YEC 1995a).

Table 4-5 Surface Water Potential for catchments in SP

Block	**Catchment**	**Sub-catchment**	**Area [km^2]**			**A$_{\%}$**	**SWP [Mm^3/a]**	
			Total	In ZAM	In SP		Average	Drought
BZ-6	Upper Zambezi	e.g. Kasaya, Ngwezi	177,727	41,207	17,515	0.23	1265	388
BZ-7	Middle Zambezi	Kalomo, Kariba Lake	150,100	23,373	23,373	0.16	550	59
BZ-8	Middle Zambezi	Lusitu & minor tributaries	4,090	2,942	2,942	0.72	590	204
BK-9	Kafue	Middle Kafue – Itezhi Tezhi	10,731	10,731	6,249	1.0	(-946)	32
BK-10	Kafue	Lower Kafue – Kafue Flats	46,199	46,199	31,278	1.0	568	32
BK-11	Kafue	Lower Kafue – Kafue Gorge	3,262	3,262	1,341	1.0	631	221
Southern Province			**--**		**82,700**	**--**	**1,770**	**558**

Notes: Runoff data and total catchment areas after YEC 1995b; Average SWP: calculated using average runoff over the 30-year period between 1963-1992; Drought SWP: calculated using probable drought discharge with a return period of 10 years.

5. GEOLOGY

Data concerning the geology of the SP are available on maps of various scales and publication dates. Most of the geological information on SP is provided on maps scaled at 1:100,000. The northern area is partly available at a scale of 1:250,000 only. The area in the south-east along the Kariba Lake is mapped at a scale of 1:125,000 focusing on mapping the coal resources of that region. The remaining areas only are available at scale 1:1 Mio. (Figure 5-1).

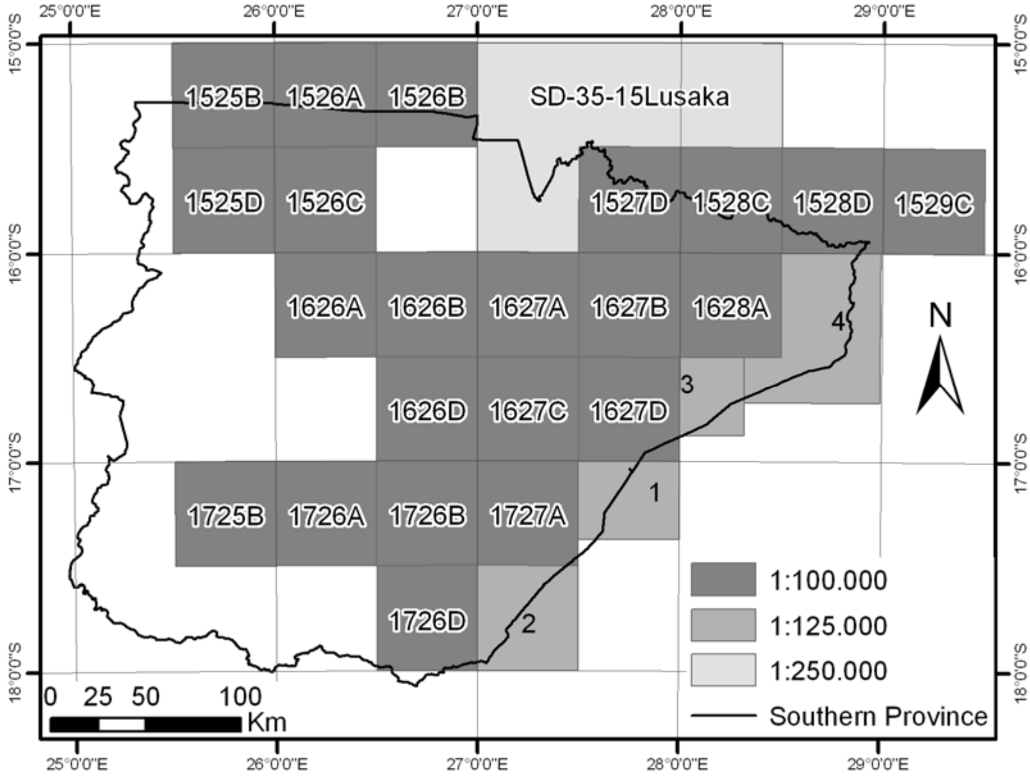


Figure 5-1 Coverage of available geological map sheets of the SP. Remaining areas within Zambia are available at scale 1:1 Mio. Numbers 1 – 4 represent sheets at scale of 1:125,000.

The considered geological map sheets at **1:100.000** scale are:

1525B (Seifert 2000), 1525D (Griffith 1998), 1526A (Abell 1976), 1526B (Abell 1970), 1526C (Griffith 1998), 1527D and 1528C (Smith 1963), 1528D (Cairney 1966), 1529C (Barr 1997), 1626A (Loughlin 1998), 1626B (Tavener-Smith 1961), 1626D (Johns 1995), 1627A (Brown 1966b), 1627B (Newton 1969) 1627C and 1627D (Newton 1963), 1628A (Brown 1966a), 1725B (Liyungu 1998), 1726A and 1726B (Zigmund 1995), 1726D and 1727A (Matheson 1968).

At scale **1:125,000** the following sheets were used:

The Karoo System and Coal Resources of the Gwembe District, SW Section, Sheets 1 and 2 (Tavener-Smith 1960), and NE section Sheets 1 and 2 (Gair 1959).

The remaining gaps were filled by using the geological maps at scale 1:250,000, Sheet No. SD-35-15 (GSD 1984) and the geological map of Zambia, scale 1:1 Mio. (GSD 1981).

The hydrological maps produced during this project are based on a seamless geological and lithological map. The seamless map layers were generated by digitising and merging the individual geological maps listed above. It was beyond the scope of this project to sample geological field data. Besides a few simplifications, the geological information was obtained from existing geological maps. Geological units stretching across map sheet borders with different names or attributes have been merged together by consulting technical literature and keeping the name of the most prominent unit. In a few cases, however, the geological description between adjacent units by the respective mapping geologists differed in such a manner that merging of these units was not suitable.

5.1. STRATIGRAPHIC SUCCESSION

Zambia is located within the amalgamation between the Congo- and Kalahari Plate. In Zambia, the sutures between these old Cratons are represented by the Lufilian Arc, the Irumide Belt and the Zambezi and Mozambique Belts respectively (Figure 5-2). The main tectonic structure is the Trans-African Shear Zone, which is at least 3,000 km long and transects southern Africa (Windley 1995) from Namibia to Tanzania. This main tectonic feature is represented in the SP by the Mwembeshi Shear Zone (MSZ) that strikes NE-SW through the northern part of the SP.

The Geological units are subdivided using the following classification: Supergroup, Group and Formation. The Supergroups according to their age and the main geological regions are:

1. Basement Complex incl. the Choma-Kalomo Batholith
2. Muva
3. Katanga
4. Hook Igneous Complex
5. Cape (not exposed in the SP)
6. Karoo
7. Cenozoic (recent) rocks.

The geology of the SP consists of rocks of various ages. The oldest rocks belong to the mid-Proterozoic and the youngest are of Cenozoic age.

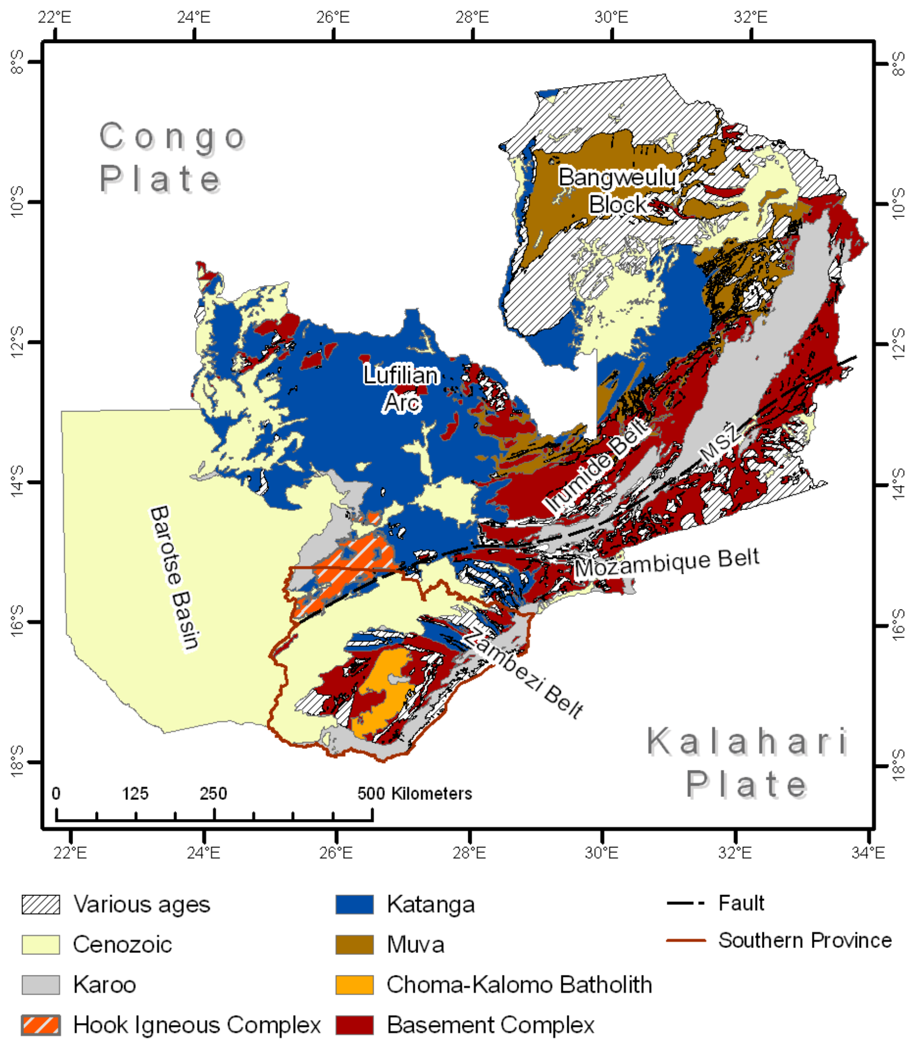


Figure 5-2 Geology and main tectonic setting of Zambia (after GSD 1981, Yemane et al. 2002). MSZ: Mwembeshi Shear Zone.

Large parts of the SP are occupied by rocks of the Precambrian. These are the Basement Complex with the Choma-Kalomo Batholith, the Muva Supergroup and the Katanga Supergroup. Early Phanerozoic rocks are represented by the Hook Igneous Complex. The Karoo Supergroup is of Palaeozoic and Mesozoic age and the youngest deposits are Cenozoic sediments.

Between these units several unconformities like stratigraphic and structural hiatus are developed (Figure 5-3). The rocks of the SP include several orogenies and rift phases, which are today recorded in the geological sequence. This sequence has undergone a series of complex tectono-thermal events reflecting today a rough picture of the geological development from the last 1.3 Ga of the Central African Continent.

The main tectonic events are as follows (Drysdall et al. 1972, Porada & Berhorst 2000):

1. the **Irumide Orogeny** between 1,350 and 1,000 Ma followed by a

2. Rifting stage that is possibly related to the break-up of the Rodinia Supercontinent between 880 and 804 Ma and the development of the Lufilian Belt.
3. Between 850 and 840 Ma the rift structure propagated northwest-wards with ongoing subsidence (Lower Roan).
4. Establishment of a carbonate platform and lagoon-basin (Lower to Upper Roan) followed by the
5. Rapid opening and subsidence of the Kundelungu Basin between 760 and 740 Ma.

The rifting stage turned within a compressional environment into subduction at ca. 600 Ma, which led to continental collision around 530 Ma (John 2001). This event is usually known as the **Lufilian Orogeny**, which is part of the continent-wide Pan-African Orogeny that cumulated to the Gondwana Supercontinent. The overriding plate contained the “Katanga High” area north of the Hook Complex, the Hook Granites as well as the central and southern Zambezi Belt. The overridden plate included most of the Lufilian Belt and the northern Zambezi Belt.

This orogeny was followed by the Karoo Rifting associated with the break-up of Gondwana between mid-Paleozoic to early Jurassic time.

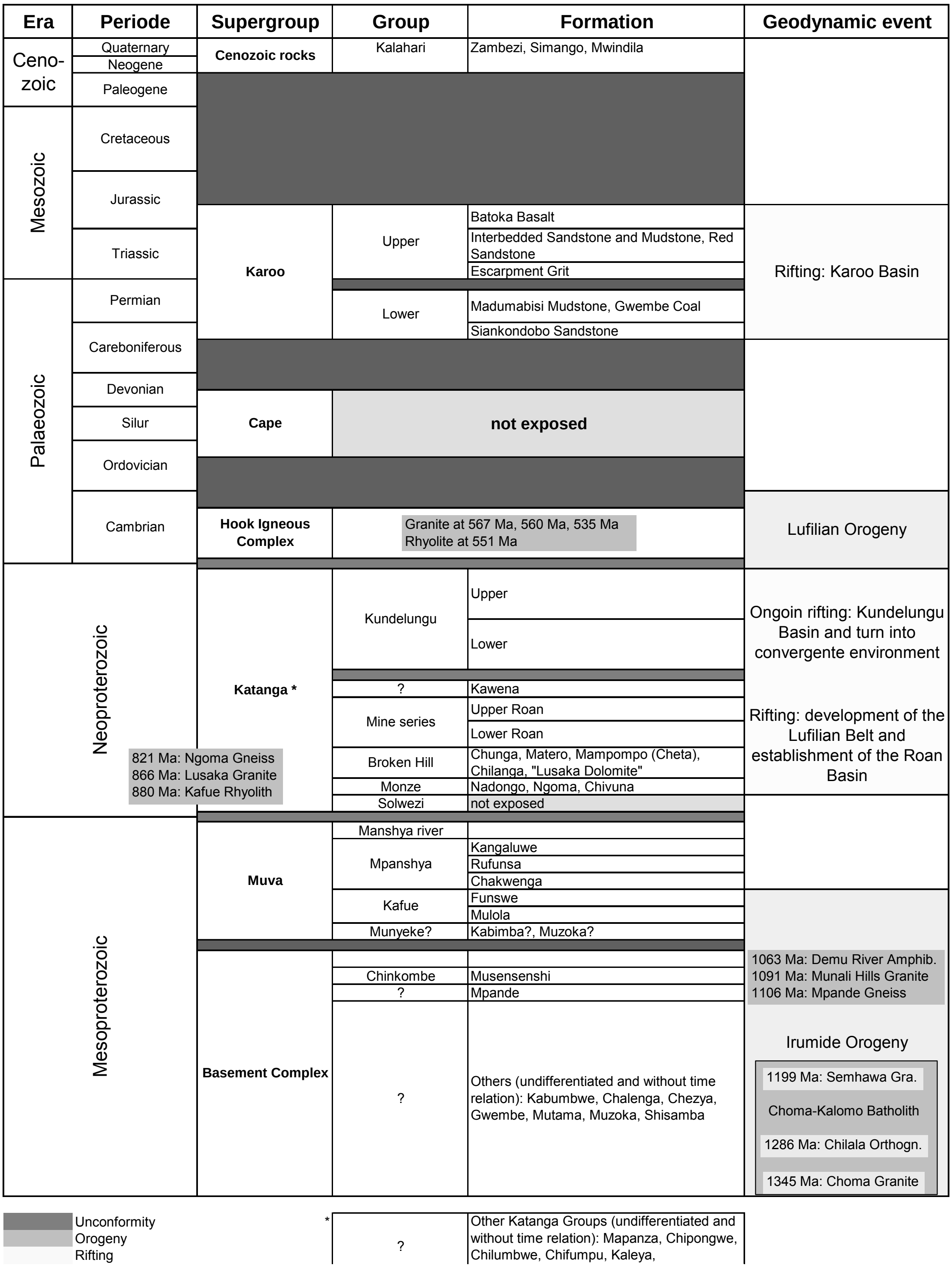
The final episode of rifting is related to the development of the East African Rift system in late Cretaceous and Paleogene time (Nyambe et al. 2002, Nyambe 1999a).

Basement Complex

In the SP basement rocks are predominantly exposed around the Choma-Kalomo Batholith within the Choma-Kalomo Block (Figure 5-4). Besides this, smaller exposures are within the Zambezi Belt. The rocks comprise gneiss, granite-gneiss, granites but also amphibolites, quartzite, marble and calc-silicate rocks. The ages are Mesoproterozoic. For the Choma-Kalomo Block several age measurements are available (Figure 5-5):

Demu River Amphibolite	1,062 ± 14.9Ma (Hanson et al. 1988)
Semahwa Granite	1,198 ± 6 Ma (Hanson et al. 1988)
Chilala Orthogneiss	1,285 ± 64 Ma (Hanson et al. 1988)

The Siasikabole Granite, the Main Granite (Choma Granite) and the Zongwe Orthogneiss are intruded in a narrow time interval at ca. 1,345 Ma. The Choma-Kalomo Block may represent the southwest continuation of the Irumide Belt across the Zambezi Belt (De Waele et al. 2001).



Era	Periode	Supergroup	Group	Formation	Geodynamic event
Ceno-zoic	Quaternary	Cenozoic rocks	Kalahari	Zambezi, Simango, Mwindila	
	Neogene				
	Paleogene	▨	▨	▨	
Mesozoic	Cretaceous	▨	▨	▨	
	Jurassic	▨	▨	▨	
	Triassic	Karoo	Upper	Batoka Basalt	Rifting: Karoo Basin
				Interbedded Sandstone and Mudstone, Red Sandstone	
				Escarpment Grit	
			▨	▨	
Palaeozoic	Permian		Lower	Madumabisi Mudstone, Gwembe Coal	
				Siankondobo Sandstone	
	Careboniferous	▨	▨	▨	
	Devonian				
	Silur	Cape	not exposed		
	Ordovician	▨	▨	▨	
	Cambrian	Hook Igneous Complex	Granite at 567 Ma, 560 Ma, 535 Ma Rhyolite at 551 Ma		Lufilian Orogeny
		▨	▨	▨	
Neoproterozoic		Katanga *	Kundelungu	Upper	Ongoin rifting: Kundelungu Basin and turn into convergente environment
				Lower	
			▨	▨	
			?	Kawena	Rifting: development of the Lufilian Belt and establishment of the Roan Basin
			Mine series	Upper Roan	
				Lower Roan	
	821 Ma: Ngoma Gneiss 866 Ma: Lusaka Granite 880 Ma: Kafue Rhyolith		Broken Hill	Chunga, Matero, Mampompo (Cheta), Chilanga, "Lusaka Dolomite"	
			Monze	Nadongo, Ngoma, Chivuna	
			Solwezi	not exposed	
		▨	▨	▨	
Mesoproterozoic		Muva	Manshya river		
			Mpanshya	Kangaluwe	
				Rufunsa	
				Chakwenga	
			Kafue	Funswe	
				Mulola	
			Munyeke?	Kabimba?, Muzoka?	
		▨	▨	▨	
		Basement Complex			1063 Ma: Demu River Amphib. 1091 Ma: Munali Hills Granite 1106 Ma: Mpande Gneiss
			Chinkombe	Musensenshi	
			?	Mpande	
			?	Others (undifferentiated and without time relation): Kabumbwe, Chalenga, Chezya, Gwembe, Mutama, Muzoka, Shisamba	Irumide Orogeny 1199 Ma: Semhawa Gra. Choma-Kalomo Batholith 1286 Ma: Chilala Orthogn. 1345 Ma: Choma Granite

▨ Unconformity
▒ Orogeny
░ Rifting

*		
	?	Other Katanga Groups (undifferentiated and without time relation): Mapanza, Chipongwe, Chilumbwe, Chifumpu, Kaleya,

Figure 5-3 Major lithological subdivision and tectono-thermal events in the SP. Note: the time relations of the groups and formations are rough approximations and not drawn to scale.

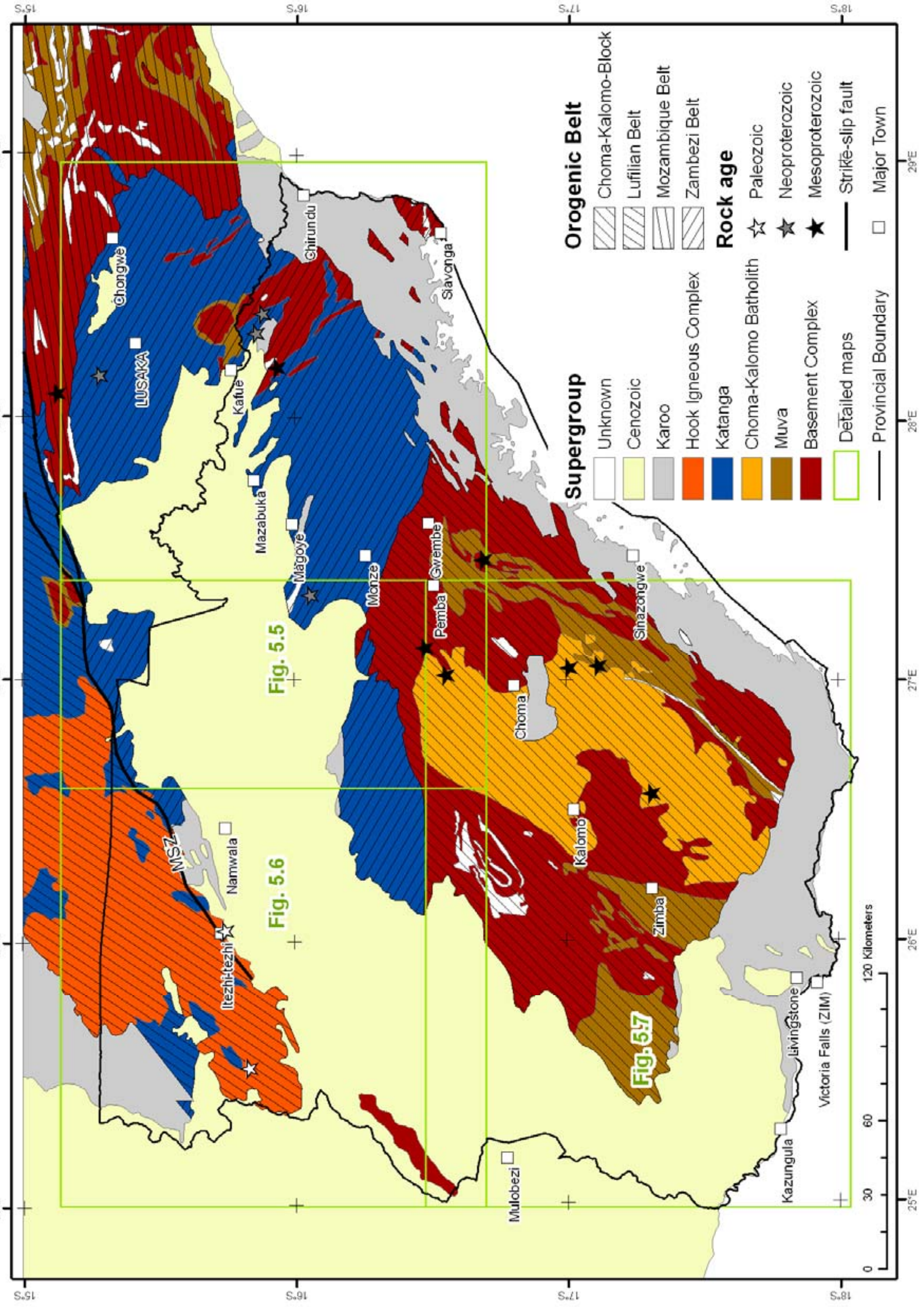


Figure 5-4 Geological map of the SP and adjacent areas showing the Supergroup distribution and regional tectonic setting. The signature of the orogenic belts indicating their main strike directions. MSZ: Mwembeshi Shear Zone. The outlined detailed maps are shown in Figure 5-5, Figure 5-6 and Figure 5-7.

In the Zambezi Belt the ages for the Mpande Gneiss (1,105 ± 3.5 Ma (Hanson 1999)) and the Munali Hills Granite (1,090 ± 1.3 Ma (Katongo et al. 2004)) are known. The Munali Hills Granite unit is gneissic up to amphibolite facies and is a small intrusion into the Mpande Gneiss. Both Granitoids were emplaced in a convergent-margin setting (Katongo et al. 2004). The Mpande-Gneiss located in this region has attained its gneissic fabric during the Lufilian Orogeny (Katanga time). Also the gneisses and granites from the Choma-Kalomo Block were partly reworked by the Lufilian Orogeny.

Muva Supergroup

The Muva Supergroup is mainly a metasedimentary succession and is sometimes referred to as “Upper Basement” (Porada & Berhorst 2000). The supergroup consists predominantly of schist, quartzites, gneisses, amphibolites and marble. Together with the Basement Complex the rocks of the Muva Supergroup are exposed in the Choma-Kalomo Block, with the Mpande Gneiss extending into the Zambezi Belt as well as the Mozambique Belt. The age is throughout Mesoproterozoic.

Katanga Supergroup

The Katanga Supergroup is of Neoproterozoic age. The Kafue Rhyoliths 879 ± 19 Ma (Hanson et al. 1994), the Lusaka Granite 865 Ma (Barr et al. 1978) and Ngoma Gneiss 820 ± 7 Ma (Hanson et al. 1988b) intruded at this time into the Basement. Their emplacement took place during the earliest extensional stage of continental rifting in the Lufilian-Zambezi Belt (Katango et al. 2004). Porada & Berhorst (2000) dated these felsic intrusive rocks to pre-Katanga time. The Lusaka Granite is unconformably overlain by and with erosional contacts to metasediments of the Katanga Supergroup. The Ngoma Gneiss is in intrusive (?) and tectonic contact with Katanga or pre-Katanga metasediments. The emplacement of the Ngoma-Gneiss is related to extensional fractures in a transtensional regime during rifting.

The area south of the Mwembeshi Shear Zone, which separates by definition the Lufilian Belt from the Zambezi Belt, is occupied by the Chunga-, Cheta- and Lusaka-Formations (Figure 5-5). The Chunga-Formation consists mainly of schists with a few lenses of impure limestone, which had undergone metamorphism up to amphibolite facies. The Cheta-Formation includes low grade meta-carbonates with intercalation of quartz-muscovite-chlorite schists, carbonaceous schists, slates and phyllites and amphibolites near the base. The rocks of the Lusaka-Formation are also called “Lusaka Dolomite”. In fact, these rocks are metamorphic and should therefore be called marbles (Porada & Berhorst 2000, Nkhuwa 1996). These three formations are thrusted over each other. At the bottom, the Chunga-Formation shows the highest metamorphism. It includes sediments of the Katanga Supergroup and sheared basement. The overthrusted Chunga- and Lusaka-Formations are transported to the north and are strongly folded. During progressive contraction, backfolding and backthrusting to the south took place.

The central to southern Zambezi Belt of Zambia is formed by metasedimentary rocks of various composition: marble and calc-silicate rocks alternating with regions of amphibolite-facies, kyanite, staurolith and locally sillimanite and garnet bearing schists and gneisses. The Kafue Rhyolith and the Nazingwe-Formation are the earliest Katanga deposits within a rifting environment and are metamorphosed up to amphibolite facies. Both formations rest unconformably upon the Mpande-Gneiss and are overlain by the Kafue Group. The Kafue Group is stratigraphically below the Kafue Rhyolite and Nazingwe Formation and is therefore pre-Katanga in age. The contacts between these formations are primarily tectonic (Porada & Berhorst 2000).

The opening of the Roan Basin was related to crustal rifting, possibly propagating to the northwest from the Zambezi Aulacogen and was accompanied by magmatism. The Roan Group is interpreted as a carbonate platform after marine transgression. The carbonate platform is considered to have formed a barrier with an adjacent lagoon behind, in which anoxic conditions were established for later Cu-Co mineralization. A clastic margin, mudflats and possibly sabkahs existed towards the hinterland. The platform relicts of the Roan-Rift-Basin can be traced from the Copperbelt to the south and across the MSZ into the northern part of the Zambezi Belt. The Katanga sediments occur in allochtonous sheets that were thrusted northeast-wards onto the hinterland of the basin. The metamorphism is largely greenschist-facies and locally up to amphibolite-facies.

The Kundelungu Group is separated by a tectonic breccia from the Roan Formation but this breccia is not exposed in the SP. The Lower Kundelungu Formation is represented by meta-sedimentary rocks, mainly quartzite, schist and some calc-silicate rocks. The Upper Kundelungu is poorly exposed in the most northern part of the SP and consists of quartzite and slate; In general, the Katanga Supergroup is mainly represented in the eastern and northern part of the SP and includes a wide range of metamorphic rocks.

Hook Igneous Complex

U-Pb age determination on zircons by Hanson et al. (1993) shows that all igneous rocks of the Hook Massif were intruded into the sedimentary rocks of the Kundelungu Group. Two separate phases of syn-tectonic granite yield ages of 559 ± 18 Ma and 566 ± 5 Ma. Later movement of the MSZ was accompanied by intrusion of rhyolite at 551 ± 19 Ma and the post-tectonic granitic intrusions took place at 533 ± 3Ma. These ages shows that the deposition of the Kundelungu group is pre-570 Ma (Editor's note in: Griffith 1998).

The Hook Igneous Complex is restricted to the northwestern part of the SP and consists mainly of granitoids accompanied by metamorphic rocks like gneiss and migmatite. The granitoids are mainly granites, but syenite, diorite granodiorite and tonalite, monzonite, adamellite and, as minor intrusive rock, gabbros are also represented. A small outcrop of rhyolite representing the extrusive character of this magmatism occurs along the Mwembeshi Shear Zone.

Karoo Supergroup

The Karoo Supergroup deposits are related to rifting accompanied by the establishment of large scale graben-systems. The rifting is related to the break-up of Gondwana and starts at carboniferous time and continues to early Jurassic. The

Barotse Basin is the largest Karoo basin which extends in north-south direction in western Zambia and the adjacent countries. Two graben systems extend east of the Barotse Basin, striking east-northeast to west-southwest covering a large part of the SP: the Kafue Graben and the Zambezi Graben (Unrug 1987). The sedimentary sequence of the Karoo Supergroup lies unconformably over older rocks. The Lower Karoo starts with the Siankondobo Sandstone-Formation, followed by the Gwembe Coal-Formation. The Madumabisa Mudstone-Formation finishes the Lower Karroo and with the beginning of the Upper Karoo in early Triassic the Escarpment Grit-Formation starts off. The following Interbeded Sandstone and Mudstone Formation and Red Sandstone-Formation are topped by the early Jurassic Batoka Basalt Formation. The thickness of these largely tholeiitic basalts are between 30 and 390 m and can be separated into 23 flow events (Unrug 1987). The basalts in Zambia are present in the southern part of the Barotse Basin and as a minor occurrence within the Kafue Graben and Zambezi valley. The Karoo sediments in the mid-Zambezi rift valley are deposited in a basin of a half-graben type and are approximately 4.5 km thick (Nyambe 1999b).

Cenozoic Deposits

The Cenozoic deposits are represented by unconsolidated or semi-consolidated clastic sediments of Paleogene, Neogene and Quaternary age. The deposits can be separated into two groups:

(1) Alluvium, colluvium deposits from the Kafue and Zambezi rivers that include floodplain material in a variety of grain size distributions, alluvial flat deposits and terrace deposits of the Lake Kariba.

(2) The Neogene and Quaternary Kalahari Group which covers large areas of the western and south-western part of the SP.

The Kalahari group forms large parts of central southern Africa and is related to an End-Cretaceous to early Neogene crustal flexuring along the Okavango-Kalahari-Zimbabwe Axis causing erosion of the land surface and subsequent sedimentation in a basin covering 2.5 Mio. km^2 (Moore & Larkin 2001, Thomas & Shaw 1990). Today this basin forms a plateau with a mean altitude of 1000m above sea level with limited relief.

The Kalahari Group within the SP consists predominantly of unconsolidated or semi-consolidated sand that were deposited mostly by aeolian processes (fossil dunes). Gravel, silt and clay are minor deposits.

5.2. LITHOLOGY

The **north-eastern area** of the SP (Figure 5-5) is dominated by metamorphic rocks of the Katanga Supergroup and the Basement rocks of the Zambezi Belt and by sedimentary rocks of the Karoo Supergroup striking along the Zambezi rift valley. Loose rocks of the Kafue graben system, which adjoin the Katanga rocks to the northwest, cover large parts of the northern sector of the SP. The Basement in this part of the SP is restricted by the Mpande Gneiss with variable structure and texture, and the foliated Munali Hills Granite. The Katanga Supergroup consists of a broad band of different metamorphic rocks. A rather small area is occupied by the meta-rhyolites of the Kafue rhyolites. The Nega Formation contains mainly pure schist whereas the Nteme schist is partly pegmatised and includes also amphibolite rocks and marble bands. The Muzuma Formation is a fine banded calc-silicate rock and contains schist with bands of marble. The Mapanza Formation is in contrast mainly a calc-silicate rock with subordinated schist and marble bands. The Ngoma Formation contains apart from gneiss and granite-gneiss also minor bands of schist and quartzite. The Gwembe and Chezya gneiss is the transition to the Choma-Kalomo Block and beside gneiss contains gneiss-schist intercalation and quartzite rocks. The Karoo Supergroup in the northeastern part of the SP contains mainly sandstone with interbedded mudstone from the Upper Karoo Group (Escarpment Grit Formation, Interbedded Sandstone and Mudstone Formation, Red Sandstone Formation). Only a few outcrops near Gwembe expose the Gwembe Coal Formation. The uppermost Karoo, the Batoka Basalt crops out near Chirundu. The Cenozoic rocks in the northwest of the Katanga rocks are un- or semi-consolidated alluvial and residual deposits containing gravel, sand, silt and clay.

The **north-western area** of the SP (Figure 5-6) is mostly occupied by clastic sediments of the Kalahari Group and other Cenozoic deposits. At the uppermost north, the Hook Igneous Complex, the Kundelungu Group and the Karoo Supergroup are exposed. The Kalahari Group is represented by un- or semi-consolidated sand whereas the remaining Cenozoic deposits also include gravel, silt and clay. The Kundelungu rocks are meta-sedimentary rocks like quartzite, slate, schist, conglomerate, phyllite and calc-silicate rocks. The Hook Igneous Complex contains metamorphic rocks (gneiss and migmatite) and a huge variety of granitoidic rocks mainly formed by felsic to intermediate intrusives but also to a minor extent by mafic intrusives and felsic extrusives. The rocks of the Karoo Supergroup in this part of the SP are from the upper part of the stratigraphic sequence but basalts are not exposed. Consequently, the lithology is restricted to the clastic deposits within the Karoo sequence (sandstone, mudstones and escarpment grit).

The **south-western part** of the SP (Figure 5-7) is dominated by rocks of the Choma-Kalomo Block and major outcrops of the Batoka Basalt Formation and sediments of the Karoo Supergroup. The Choma-Kalomo Block comprises felsic and intermediate intrusive rocks (Choma granite) and metamorphic rocks surrounding the Choma granite. The granitoidic suite includes granite, diorite, granodiorite and tonalite, granite-gneiss, norite, adamellite and syenite. The surrounding metamorphic rocks of the Basement Complex and the Muva Supergroup are quartzite, gneiss, amphibolite, dolerite, marble (locally siliceous), migmatite and schist.

The Karoo rocks in the **south-eastern area** of the SP are again clastic sediments of the Interbedded Sandstone and Mudstone Formation as well as sandstones of the Red Sandstone Formation. The Batoka Basalt at the southern border has basaltic to andesite composition with agglomeratic intercalations partly towards the top of the sequence.

In summary, the lithology in the SP is dominated by (1) clastic unconsolidated sediments of Cenozoic age (35.5%) and (2) metamorphic rocks of mostly Precambrian age which cover 32.7% of the surface. Intrusive and extrusive rocks (19.3%) as well as consolidated clastic sediments of Phanerozoic age (12%) are less represented. Chemical sediments with less than one percent of the surface area are considered negligible (Table 5-1).

Table 5-1 Rock types and their surface distribution within the SP

Rock type	Surface Distribution [%]
Gravel, sand, silt and clay	35.50
Gneiss and granite-gneiss	15.06
Intrusives	14.80
Schist, slate, phyllite and quartzite	10.69
Undifferentiated sand-,silt- and mudstone	9.29
Basalt	4.50
Marble, meta-carbonates and calc-silicate rocks	3.58
Metamorphic rocks, undifferentiated	3.36
Mudstone, siltstone and shale	1.61
Sandstone and conglomerates	1.19
Unknown lithology	0.42
Limestone/Dolomite	0.05

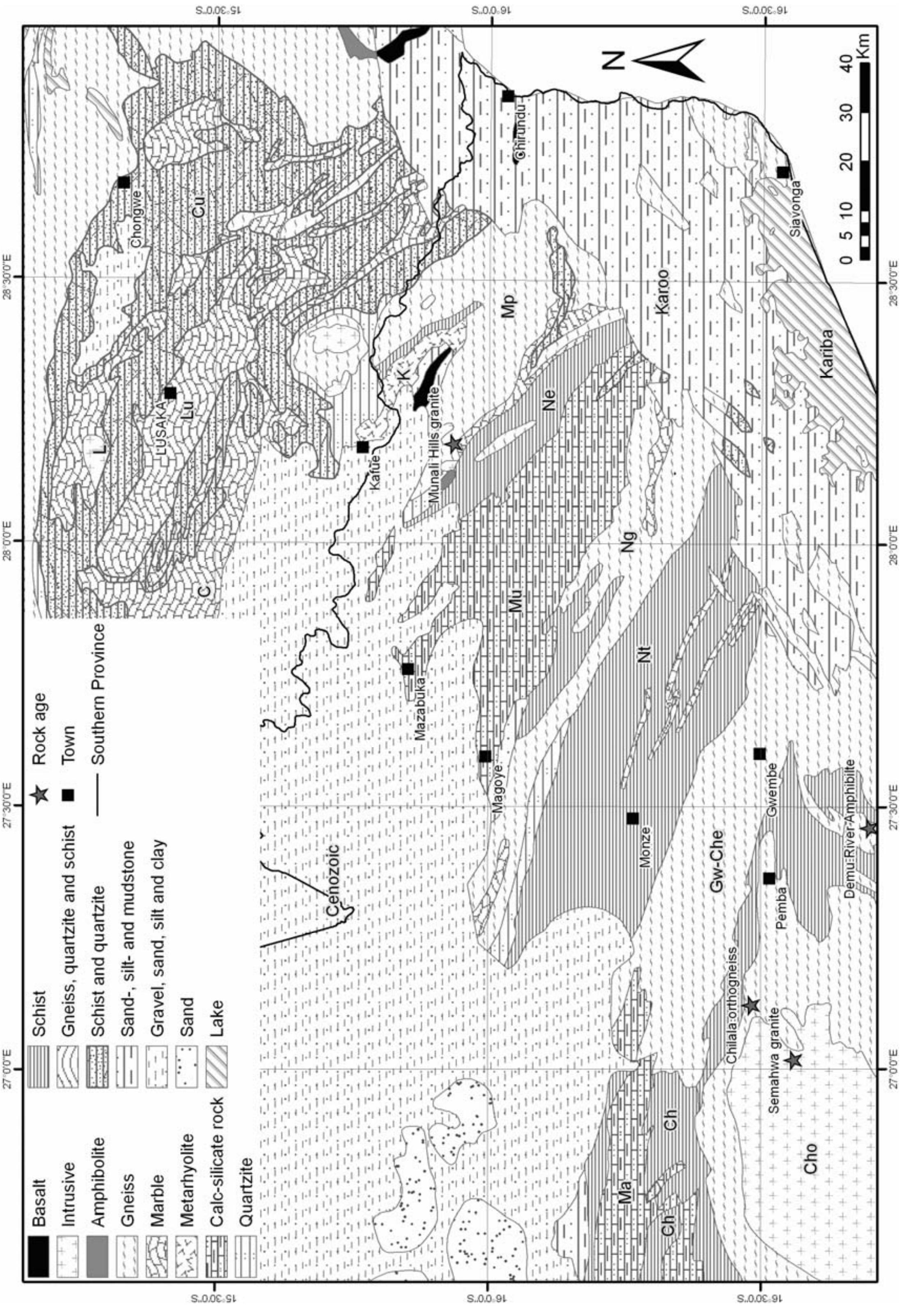


Figure 5-5 Lithological map of the NE region of SP (after GSD 1981) showing the main geological groups and formations. C: Cheta, Ch: Chilumbwe Schist, Cho: Choma Granite, Cu: Chunga, Gw-Che: Gwembe and Chezya Gneiss, K: Kafue rhyolite, L: Lusaka Granite, Lu: Lusaka-Dolomite, Ma: Mapanza, Mu: Muzuma, Ne: Nega, Ng: Ngoma, Nt: Nteme. For rock ages refer to text.

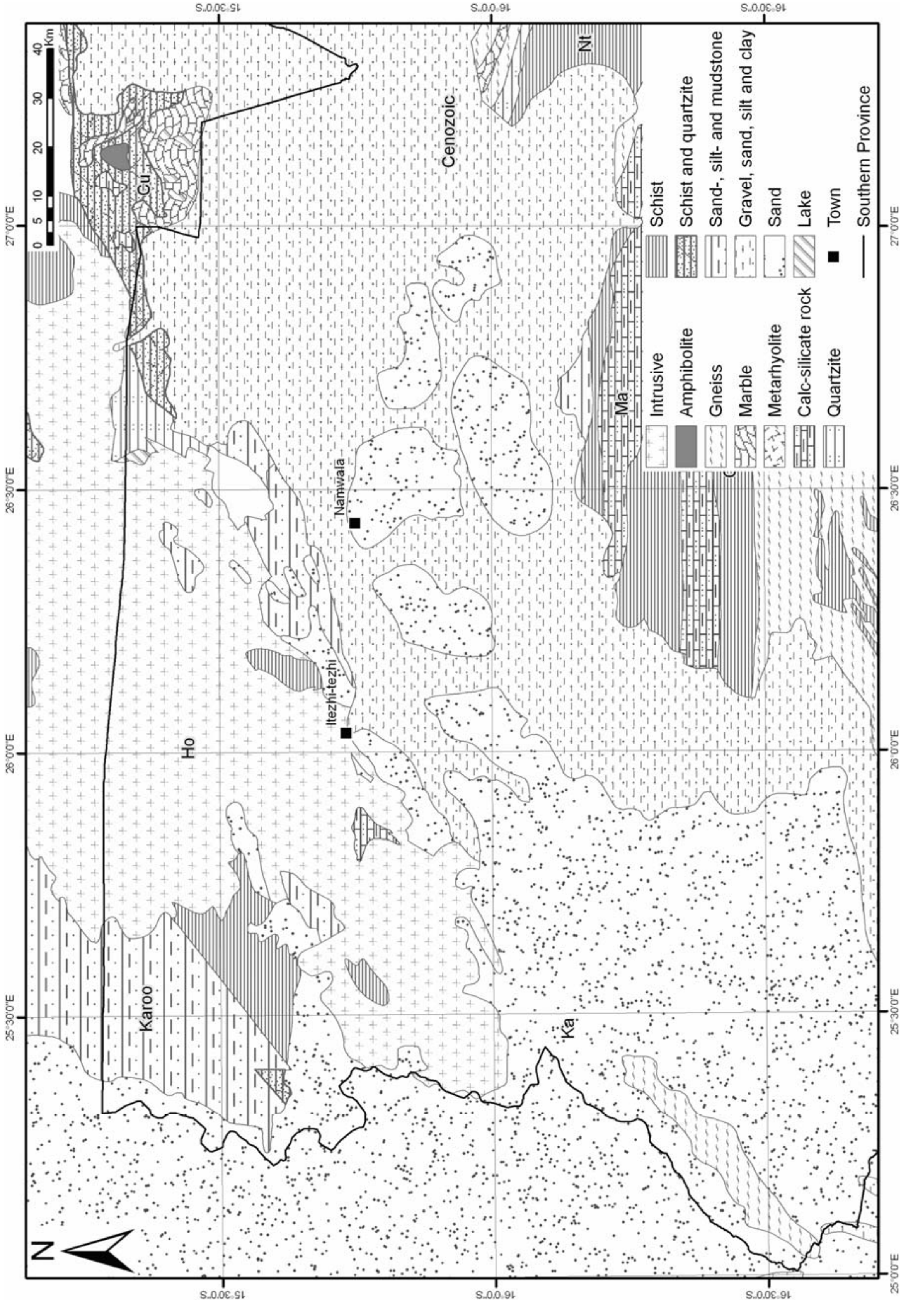


Figure 5-6 Lithological map of the NW region of SP (after GSD 1981) showing the main geological groups and formations. Ho: Hook Igneous Complex, Ka: Kalahari Group, Ma: Mapanza Formation, Nt: Nteme Formation.

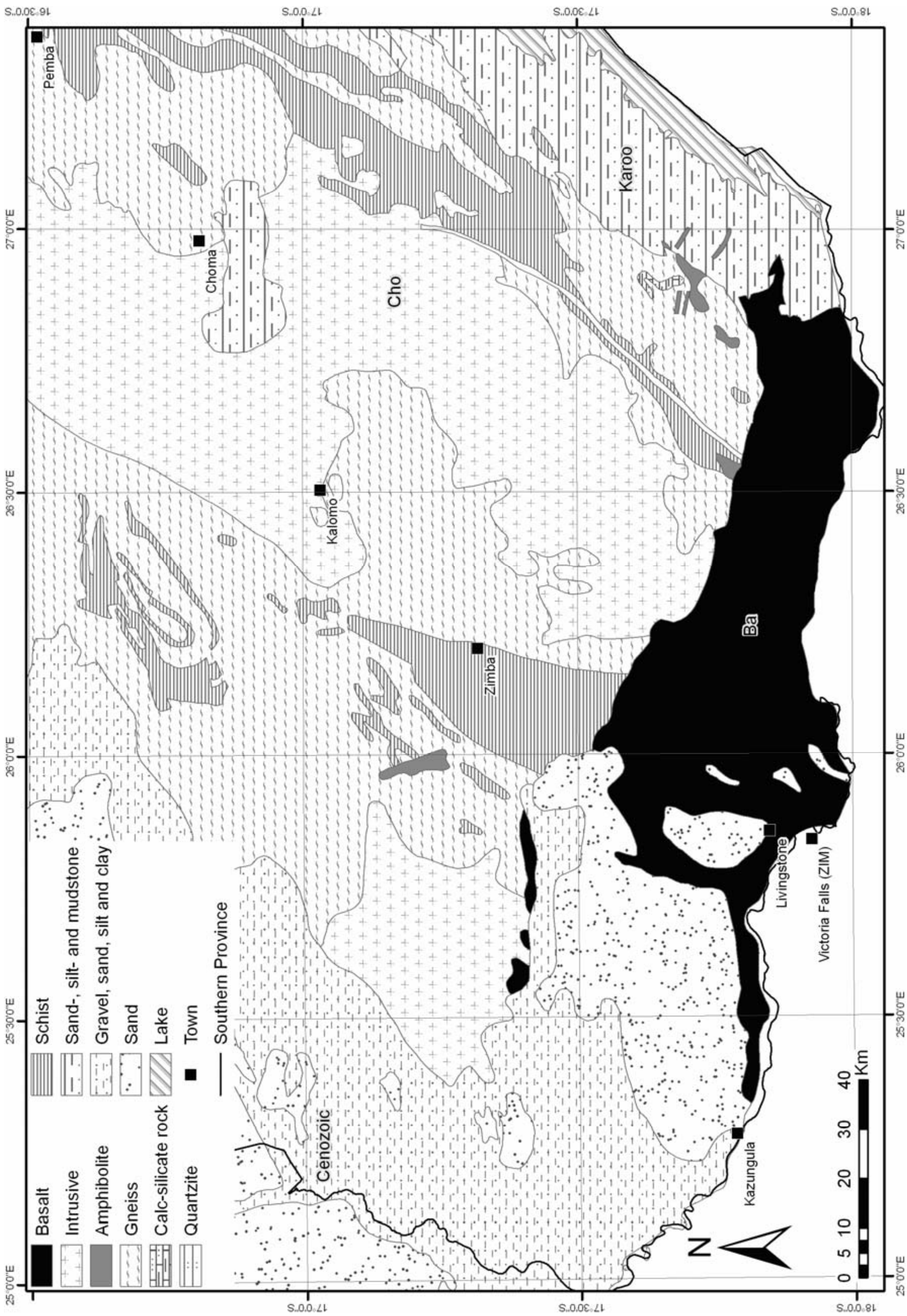


Figure 5-7 Lithological map of the SW region of SP (after GSD 1981) showing the main geological groups and formations. Ba: Batoka Basalt, Cho: Choma Granite.

5.3. TECTONICS

Due to the broad range of geological units and their related history the tectonic structures within the SP are highly complex. The series of tectonic events of various ages have created a distinct set of structures. For example, the structures within the Choma-Kalomo Block are interpreted into three events represented by three deformation, three foliation and accordingly three lineation directions (Johns 1995). Younger tectonic events have also left their structural imprints on the surface of the SP. The Lufilian Orogeny and the Karoo rifting are well distinguishable in terms of their geological structures.

The general structure trends of the older supergroups (pre-Lufilian and Lufilian) are indicated by the signature in Figure 5-4. The general structure of the Choma-Kalomo Block is trending northeast-southwest while the Zambezi Belt is perpendicular orientated. The Mozambique Belt is generally oblique orientated to the Zambezi Belt. The structure of the Karoo rifting is largely northeast-southwest orientated and slightly oblique to the Mwembeshi Shear Zone, which is part of the major tectonic structure in southern Africa (Trans-African Shear Zone). In the large area which is covered by the Cenozoic sediments geological structures are missing or are at least hardly accessible for mapping.

With respect to the aim of the GReSP study, only tectonic structures which are supposed to be important in relation to groundwater flow are considered in the following. Folds, lineation features and deformations of high metamorphic rocks are not considered because detailed information about related rocks is not available over the entire area. The focus is on the tectonic elements, which are available on the geological maps. These are mainly:

- faults
- normal faults
- transcurrent faults
- dykes and
- secondary intrusive mineralization like pegmatites and aplites, porphyry rocks and quartz veins

5.3.1. Fault Systems

The overall fault statistics show the dominance of the northeast-southwest trending faults and a less developed north-northeast to south-southwest trending fault direction. Apart from this a minor perpendicular directed maxima exists (Figure 5-8). This might be explained by the relatively high proportion of the area covered by the Choma-Kalomo Block and the dominance of the youngest structures developed during the Karoo rifting with both trending approximately the same direction.

Table 5-2 Descriptive statistics of the fault system length in the SP with special consideration of the Hook Igneous Complex and the Zambezi Belt. Lengths are given in meters.

Region	No. of elements	Mean	Stand. Error	Median	Stand. Deviation	Skew.	Range	Min.	Max.
Choma-Kalomo Block	1,849	4,126	118	2,720	5,087	4.63	74,927	71	74,998
Zambezi Belt	250	3,994	263	2,907	4,157	2.46	32,032	71	32,102
Hook Igneous Complex	431	2,871	196	1,517	4,073	3.63	30,420	99	30,519

The length distribution of the faults is significantly skewed (coefficient of skewness: 4.6) and resembles a log-normal distribution, which is in fact a typical distribution for such measures. The length has a broad range of roughly 75 km with values ranging from 71 m to 174,998 m. It reflects the variety of the fault pattern (Table 5-2). The long faults are linked on the one hand to the Mwembeshi Shear Zone and on the other hand to the graben structure of the Karoo rift system.

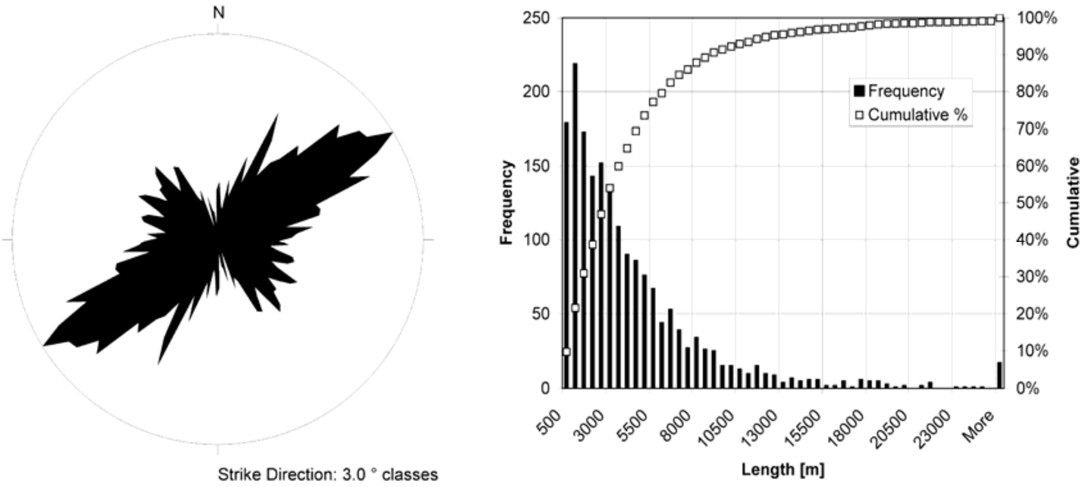


Figure 5-8 Left: Rose diagram of the fault system in the **SP**; n = 1849, largest pedal = 75 values (4% of all values). Right: Length distribution of the fault system. Class width 500m.

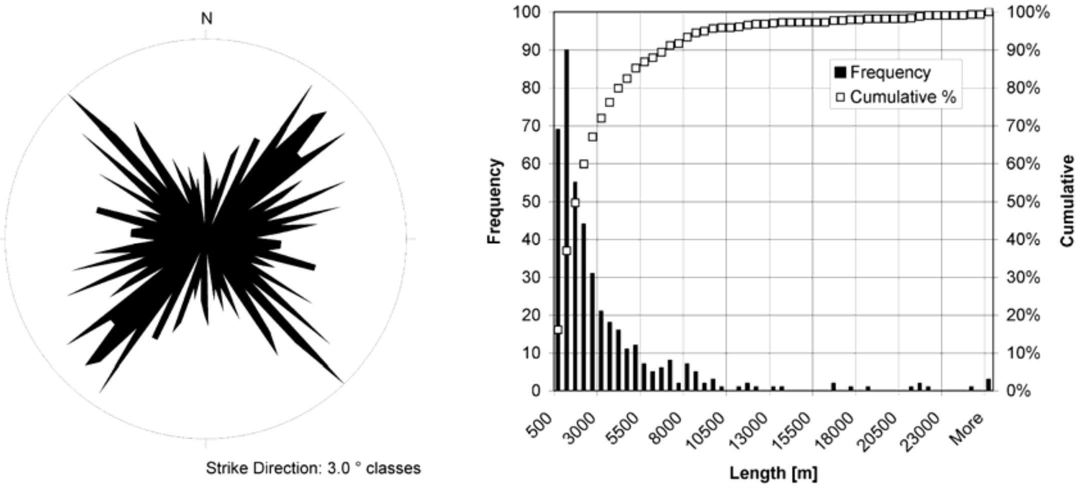


Figure 5-9 Left: Rose diagram of the fault system in the **Zambezi Belt**; n = 431, largest pedal = 16 values (3% of all values). Right: Length distribution of the fault system. Class width 500m.

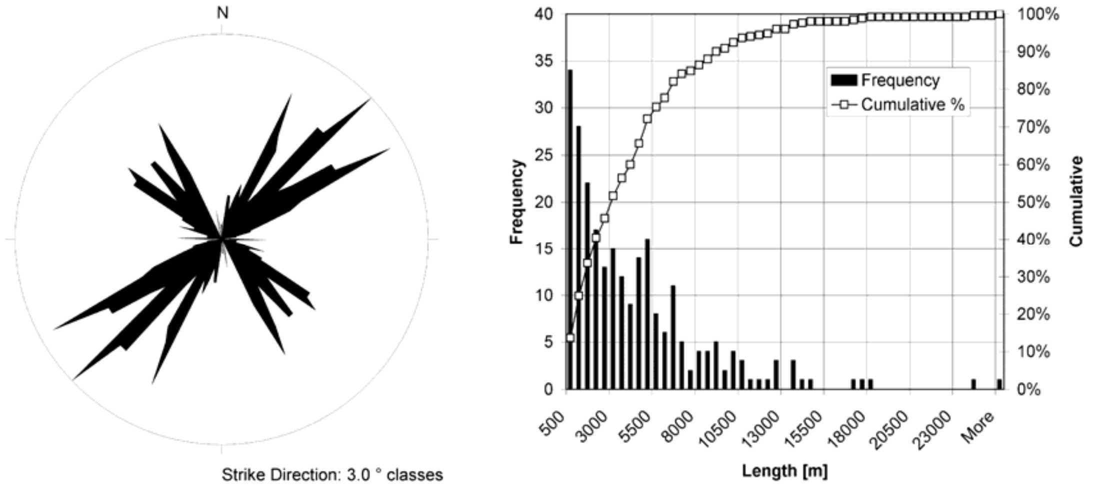


Figure 5-10 Left: Rose diagram of the fault system of the **Hook Igneous Complex**; n = 250, largest pedal = 14 values (5% of all values). Right: Length distribution of the fault system. Class width 500m.

The fault system of the Zambezi Belt and the Hook Igneous Complex noticeably deviate from the overall fault trend distribution of the SP (Figure 5-9 and Figure 5-10). In their regional setting the northwest-southeast trending faults are more clearly developed. The fault length in both regions is also log-normal distributed but the average fault length is shorter and the maximum length is less than 50% compared to the values obtained for the whole Province. In the Zambezi Belt regions the different fault generations are well distinguishable. The older (?) northwest trending structures are superimposed by younger (?) northeast trending structures, which may mainly be related to the Karoo rifting.

Detailed structural analysis of lineaments and tectonic features by means of Landsat images were performed in cooperation between the "*Institut Egid Bordeaux*" and the BGR for the northern part of the Choma-Kalomo Block and the adjacent Katanga rocks. This analysis includes statistics of river lineaments and tectonic lineaments distinguishing between faults and other tectonic and geological features applying the scan-line technique. The results of this work are detailed and cannot be summarized in this report but the interested reader is referred to the technical report (Forest 2006).

5.3.2. Dyke Systems

Dykes and similar structures in crystalline rocks form discontinuities, which may affect the large scale hydraulic behaviour of their host rocks. Such structures may have a drainage effect for large areas with preference flow effects along their strike.

In the SP the main regions hosting such discontinuities are the Choma-Kalomo Block, the Zambezi Belt and the Hook Igneous Complex. Their distinguished tectonic regime is represented in the structural setting of their secondary rocks like aplites, minor acid and basic intrusives, dykes, pegmatite intrusions, and quartz veins.

The largest number of discontinuities is developed within the Choma-Kalomo Block with a total number of 934 elements. Their spatial trend is highly uniform, trending mainly in accordance to the main structural strike direction, in northeast-southwest direction (Figure 5-11). Once more the length distribution is log-normal with 90% of the features being shorter than 3,000 m. The mean length is 1,413 m (Table 5-3).

The spatial trend of the discontinuities in the Zambezi Belt is dominantly into west-northwest to east-southeast direction with a minor maximum trending approximately perpendicular (Figure 5-12). The length distribution is relatively uniform with a poorly shaped log-normal distribution. Around 50% of all values are within the 250 to 500 m" class.

Table 5-3 Descriptive statistics of the dyke system length in the SP with special consideration of the Choma-Kalomo Block, the Zambezi Belt and the Hook Igneous Complex. Lengths are given in meters.

Region	**No. of elements**	**Mean**	**Stand. Error**	**Median**	**Stand. Deviation**	**Skew.**	**Range**	**Min.**	**Max.**
Choma-Kalomo Block	943	1,413	46	983	1,412	2.89	14,295	175	14,470
Zambezi Belt	391	864	124	331	2,446	8.50	33,955	147	34,102
Hook Igneous Complex	120	538	32	385	353	2.22	2,373	159	2,532

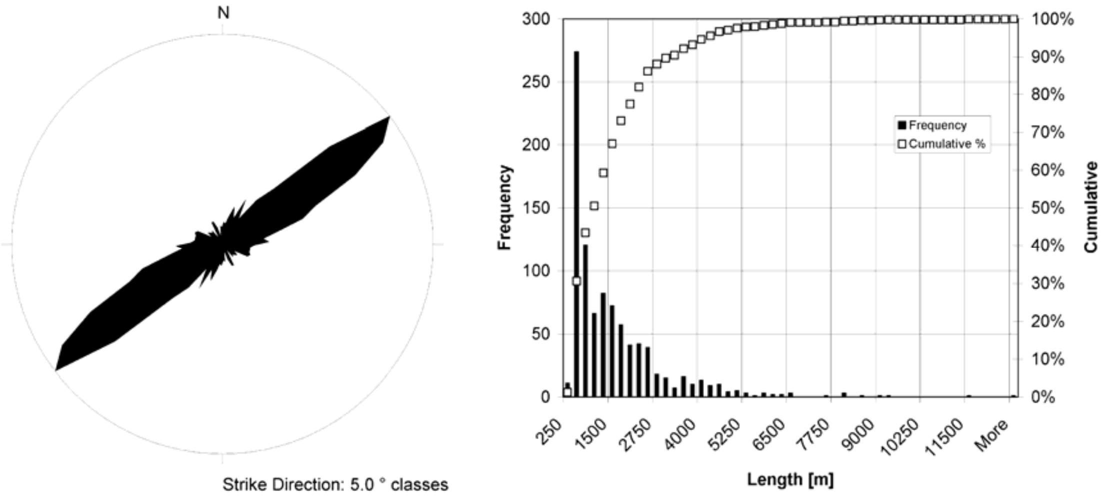


Figure 5-11 Left: Rose diagram of the dyke system of the **Choma-Kalomo Block**; n = 934, largest pedal = 113 values (12% of all values). Right: Length distribution of the dyke system. Class width 250 m

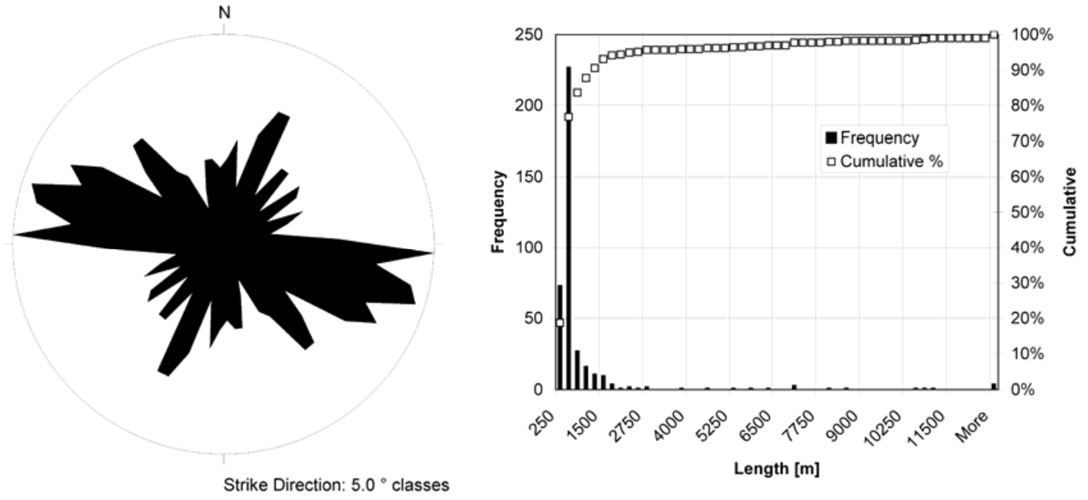


Figure 5-12 Left: Rose diagram of the dyke system of the **Zambezi Belt**; n = 391, largest pedal = 22 values (5% of all values). Right: Length distribution of the dyke system. Class width 250m.

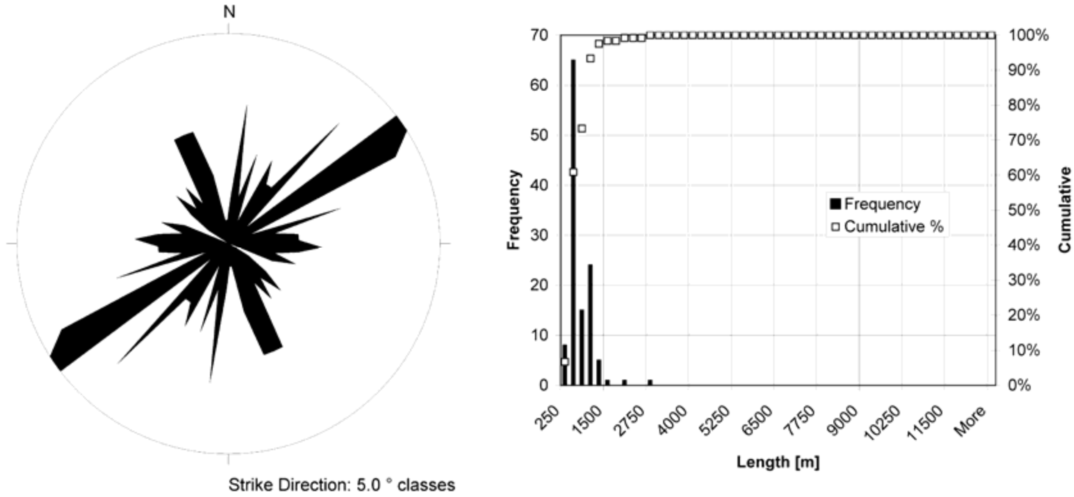


Figure 5-13 Left: Rose diagram of the dyke system of the **Hook Igneous Complex**; n = 120, largest pedal = 9 values (7% of all values). Right: Length distribution of the dyke system. Class width 250m.

The variability of the strike direction within the Hook Igneous Complex is comparatively large (Figure 5-13). Besides the main northeast-southwest direction several minor directions exist. In general, the discontinuities within the host rock have strike directions similar to the faults. However, the average length of these discontinuities is considerably shorter compared to those of the faults.

In summary, the structural properties of the SP related to groundwater have two main aspects. The first is the fault system, which differs slightly in its strike directions within the different subregions. From a tectonically point of view the dominating structures related to the Karoo rifting are expected to have relatively high hydraulic potential due to their general extensional character.

The second structural aspect is related to the discontinuities in respect to the mineral composition and rock genesis. These dykes and secondary intrusions have generally differing strike directions and shorter spatial extensions than the faults. Their hydraulic properties may be different compared to those of the host rock.

6. WATER USE, SUPPLY AND SANITATION

6.1. WATER USE AND IRRIGATION

There are approximately 890 dams in SP (personal comm. DWA Hydrology Section). The majority of these hydraulic structures are earth dams apart from a few concrete dams constructed solely for township water supply in the major towns along the line of rail. Weirs were constructed for stream flow measurements. One of the major dams in the Province is the Itezhi Tezhi dam constructed to impound water for regulating release for hydropower generation at Kafue Gorge power station (900 Megawatts). Downstream Itezhi Tezhi reservoir is a vast flood plain called the Kafue Flats (250 km long and 50 km wide). The flats include wide wetlands and fertile alluvial plains which are a source of livelihood among villagers, small scale farmers and commercial irrigation plantations and farms. For the villagers the flood plains are grazing grounds for cattle and hunting ground for small animals. The Kafue Flats harbours the Lochinvar and Blue Lagoon National parks. The Kafue Lechwe is adapted to the area and the area is also a sanctuary of a big variety of birds. The grassland offers thatching grass and clay for constructing rural domestic structures.

The Kariba dam on the Zambezi River was constructed between 1954 and 1961. Lake Kariba is one of the biggest man-made lakes in the world with about 185 cubic kilometres of water. It is 220 km long and 40 km wide with an area of about 5,350 square kilometres. The construction is used for hydropower generation (600 MW from North Bank power station and 675 MW from south Bank power station). Lake water also sustains irrigation, wildlife, domestic animals and a vibrant ecology of plant and animal life in the area.

One of the water sources for domestic use is from the dry river beds of seasonal streams. In the wet season and few months (April to August) after the rainy season the water in most of seasonal streams is used for irrigation, gardening and livestock watering. The irrigation methods practised in rural areas by small-scale farmers are generally not capital-expensive but often inefficient .They include buckets, watering cans and hosepipes etc to grow, among others, vegetables, maize, rice, bananas, citrus trees and sugarcane. Recent innovations like the use of a treadle pump have improved the efficiency of watering. Water harvesting farming through the use of micro-basins to capture water is one of the methods used by some small-scale farmers to improve water management efficiency.

Figure 6-1 Women fetching water from loose sediments of dry riverbed

Around ten hectares along Lake Kariba are used for flood recession cropping (Aquastat 2007). In this type of farming crops utilize the shallow water table and the water retained in the soil. The area which is seasonally flooded is used to grow crops at the end of the rainy season when the flooding subsides.

There are on a commercial basis some small irrigation schemes that were developed by government. These are Buleya Malima in Sinazongwe (62 ha of furrow irrigation), Nkandabwe (12 ha) and Chiyabi and Siatwinda (12 ha) in the Gwembe valley.

Figure 6-2 Maize field on the fluvial deposits of the Zongwe River

On the plateau there is a huge irrigation scheme in Mazabuka town called the *Nakambala Sugar Estate*. This parastatal scheme was initiated by the Government to grow specific crops for throughput to the industries. Nakambala Sugar Estate was developed by *Tate and Lyle* but it is now managed by *Illovo Sugar Group Company* of South Africa. Over 720,000 cubic meters of water per day is drawn from Kafue River for irrigating 13,413 ha of the sugarcane plantation (Chabwela & Mumba 1996).

Groundwater is currently of little importance with respect to irrigation of crops in the SP.

6.2. WATER SUPPLY

According to the 2000 census the population count for the SP was 1.21 million (CSO 2003). Assuming an average population growth rate of 2.3%, the population of the Province has reached around 1.4 million today. The majority of the population lives in rural areas whereas only ca. 250,000 (17%) people live in peri-urban (12%) and low-cost (5%) areas (NWASCO/DTF 2006). No figure is available of the population living in medium and high-cost urban areas. 50% of the peri-urban areas are not legalized. The average household size in peri-urban areas and low cost areas is around 5.6 persons per household. In total, 53 peri-urban areas and 32 low cost areas are located within the SP.

Accurate information is required to improve the understanding of the water situation in the country. Zambia's water resources use of 2004 cannot be accurately determined since comprehensive water use data is generally not adequate due to poor data records kept by different users as well as the inadequate regulatory capacity to monitor the various water uses. This is true for both groundwater (which is not regulated) and surface water.

Groundwater management regulations exist in the New Water Resources Management Bill which is yet to be enacted. The current Water Act empowers Government through the Water Development Board to control water allocations but the Board has little capacity to enforce the existing law.

The last comprehensive water use survey was carried out by the Water Resources Master Plan Study 1993 – 1996 which requires updating. The major water use categories are domestic water supply, industrial water supply and agricultural water supply.

More recent data concerning water supply (and sanitation) were taken from the AQUATIS database (NWASCO/DTF 2006). The database provides information on water supply and sanitation of peri-urban and low-cost areas throughout Zambia for the period 2004/2005. According to this study peri-urban areas are *"initially unplanned informal or formal settlement within the area of jurisdiction of a local authority"*. Low-cost areas are "*planned residential areas where houses or yards are usually connected to the water distribution network and the sewer line. […] In most cases, the water supply and sanitation infrastructure is in a poor state and often not functioning".*

Since rural areas are not covered by the AQUATIS database, information on water supply in rural areas had to be derived from the groundwater database.

Urban and Peri-urban Water Supply

The Southern Water and Sewerage Company (SWASCO) is the Commercial Utility in charge to provide drinking water to the urban and peri-urban population. In 2004/2005 the water supply coverage by SWASCO was 63% which is considered unacceptably low according to NWASCO's benchmark for service coverage in low density town areas (<70%) as well as in densely populated towns (<80%) (NWASCO 2005). Peri-urban and low-cost areas are covered by only 41% according to the AQUATIS database.

The total annual water production by SWASCO is roughly 20 million cubic meters which corresponds to a production of approximately 290 litres per day and person served. Township water supply depends on both surface and groundwater as can be seen from Table 6-1 below.

Table 6-1 Water supply to major towns and settlements in SP

Town	**Longitude**	**Latitude**	**Supply Source**	**No. of supply wells**	**Supply Rate [m^3/a]**
Livingstone	25.86546	-17.84210	Surface (Zambezi)	0	10,800,000
Kazungula	25.27648	-17.78571	Surface (Zambezi)	0	155,520
Zimba	26.20284	-17.31831	Surface (Dam)	0	162,840
Kalomo	26.50509	-17.03192	Surface (Dam)	0	410,400
Choma	26.97870	-16.81222	Surface (Dam)/Groundwater	2	2,303,750
Sinazongwe	27.48078	-17.24899	Surface (Kariba)/Groundwater	n/a	142,840
Mbabala	26.99214	-16.71400	Groundwater	1	24,080
Namwala	26.43613	-15.74950	Surface (Kafue)/Groundwater *)	3	584,640
Batoka	27.25195	-16.76892	Groundwater	2	24,660
Pemba	27.39889	-16.53367	Groundwater	3	10,920
Chisekesi	27.47833	-16.48861	Groundwater	1	37,330
Gwembe	27.60142	-16.49797	Surface/Groundwater	2	129,240
Munyumbwe	27.77692	-16.64714	Groundwater	1	136,670
Monze	27.47775	-16.26657	Surface (Dam)	0	1,292,340
Mazabuka	27.76081	-15.85355	Surface (Kafue)/Groundwater	2	1,651,080
Nega-Nega	28.03864	-15.83544	Groundwater	1	72,000
Siavonga	28.71046	-16.53454	Surface (Kariba)	0	1,065,190
Chirundu	28.85045	-16.03086	Surface (Zambezi)	1	145,520
Itezhi-tezhi	26.00693	-15.77449	Surface (Dam)	0	n/a
Magoye	27.59532	-15.99572	Groundwater	n/a	n/a

*) Groundwater is the main source and surface water is standby

Source: Township water supply, SWASCO, 2006

The main source of drinking water in urban and peri-urban areas is from individual connections in the households, followed by communal tabs and handpumps. In Monze, water kiosks have been established that are operated by a vendor selling on behalf of the service provider (Figure 6-3). Water kiosks are now considered the most economic and effective way to provide drinking water to peri-urban and low-cost areas (NWASCO/DTF, 2005).

According to the AQUATIS database, the main problems when it comes to water supply are:

1. Water quantity (not enough water available)

2. Distance between dwellings and source of water
3. The time of waiting until water can be fetched

In 6% of the peri-urban and 22% of the low-cost areas water is continuously available (24 hrs/7 days). 43% of the peri-urban and 31% of the low-cost areas have regular intermittent water supply and 19% and 47% have erratic water availability in the peri-urban and the low-cost areas, respectively.

Table 6-2 Average tariff (in Zambian Kwacha) to pay per 20-litre container of water in 2005 after NWASCO/DTF 2006.

Area	Well	Hand pump	Private connection	Water Kiosk
Peri-urban	500	50	170	24
Low-cost	-	100	100	-

Figure 6-3 Water Kiosk at Monze (Photo: NWASCO)

53% of the population in the peri-urban areas and 7% in the low-cost areas are paying for water.

Rural Water Supply

In rural areas water for domestic use is still to a large extent tapped from surface water sources such as rivers, lakes and smaller dams. During the dry season, however, groundwater is the only reliable source of water in most areas. The survey undertaken in June 2007 by the Zambia Vulnerability Assessment Committee (ZVAC) revealed that over 50% of households in all the surveyed districts[1)] of SP (except Siavonga and Sinazongwe) relied on groundwater for drinking water supply. Reliance on groundwater is highest in Gwembe District (73%) and lowest in Siavonga District (23%) (ZVAC 2007).

The water supply covered by groundwater is mostly provided by boreholes with hand-pumps (ca. 60% of all water points in the groundwater points). Common depths of boreholes are in the range of 50 to 70 meters. Borehole installations seem to gradually replace the hand-dug wells that are usually equipped with a bucket and windlass or sometimes with a handpump. Hand-dug wells are shallow with depths ranging from a few meters to seldom above 20 meters.

6.3. SANITATION

The percentage of households in SP with access to "improved sanitation" in 2003 was 40% whereas the national coverage was 65% according to the Millennium Development Goals Zambia Status Report (MoF 2005). The United Nations (UN) definition of "improved sanitation" used here assumes that facilities such as septic tank systems, pour flush latrines, simple pit or ventilated improved pit latrines are likely to be adequate, provided that they are not public.

Using the same definition, the survey data of the Zambia Vulnerability Assessment Committee shows that the average percentage of households having access to sanitation in SP is 48% compared to 71% in Zambia (ZVAC 2007). Over 50% of households in Zambia use traditional pit latrines while about 30% have no sanitary facility at all (Figure 6-4).

Districts in SP with less than 50% of households having improved sanitation are Kazungula, Gwembe, Namwala and Sinazongwe. The lowest access to improved sanitation is in Kazungula (25%) while the highest is in Choma (62%).

Traditional latrines match the UN definition of simple pit latrines. Although this type of facility is regarded an improved sanitation according to the UN definition, it is worth noting that it may turn out to be a source of groundwater contamination depending on the hydrogeological conditions of the area. In areas of shallow groundwater tables and high permeable host rocks such as karstified formations, faecal contaminants may rapidly be transported from the facility into the groundwater system and then reach water supply points in the vicinity. This is likely to occur especially during heavy rain and storm events. Examples of such an area in SP are parts of Mazabuka.

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[1] Livingstone was the only district not considered in the survey.

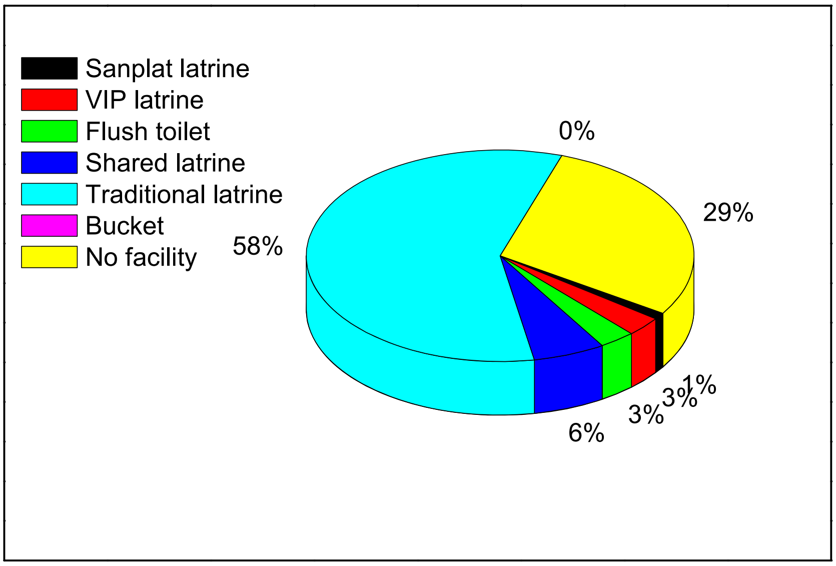


Figure 6-4 Percent distribution of households in Zambia by type of excreta disposal facility (ZVAC 2007)

The survey revealed that the level of hygiene awareness and practice in the Province is very low and this together with poor sanitation greatly contributes to high incidences of waterborne diseases such as diarrhoea as further demonstrated by the survey whereby 60% of households that reported diarrhoea cases did not wash their hands with soap after using the latrine or toilet. This survey covered largely rural areas but also included peri-urban and urban areas in the sample.

The AQUATIS survey reported by NWASCO/DTF (2006) which considered peri-urban and low cost areas separate from rural areas puts the percentage of households having no access to any sanitation facilities at 48% (peri-urban) and 18% (low cost) areas. The most important sanitation facilities in peri-urban areas are (in order of importance):

1. Bush (i.e. no facilities)
2. Pit latrine
3. “Kavela” (plastic bags, etc.)

In low cost areas the sanitation facilities are (in order of importance):

1. Sewer system
2. Pit latrine
3. Bush

Sharing of sanitation facilities is common in 9% of the peri-urban areas and in 19% of the low-cost areas. Reported problems associated with sanitation are mainly smell and collapses of the facilities (Table 6-3).

Table 6-3 Main sanitation problems reported by people in order of importance after NWASCO/DTF 2006

Peri-urban	Low-cost area
1. Collapses frequently	1. Smell
2. Smell	2. Lack of privacy
3. Quickly filling	3. Collapses frequently

7. GROUNDWATER INFORMATION SYSTEM

As an integral part of this Project a professional groundwater information system was developed at the DWA. The information system consists of:

1. The groundwater database (GeODin)
2. The Geographic Information System (ArcGIS)

The software purchased in order to establish the information system is listed in **Annex 2**.

7.1. GROUNDWATER DATABASE

The groundwater database was established using the commercial software package GeODin® (www.geodin.com). The software is based on a MSAccess database but provides user-friendly data input masks as shown for instance in Figure 7-1. 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.

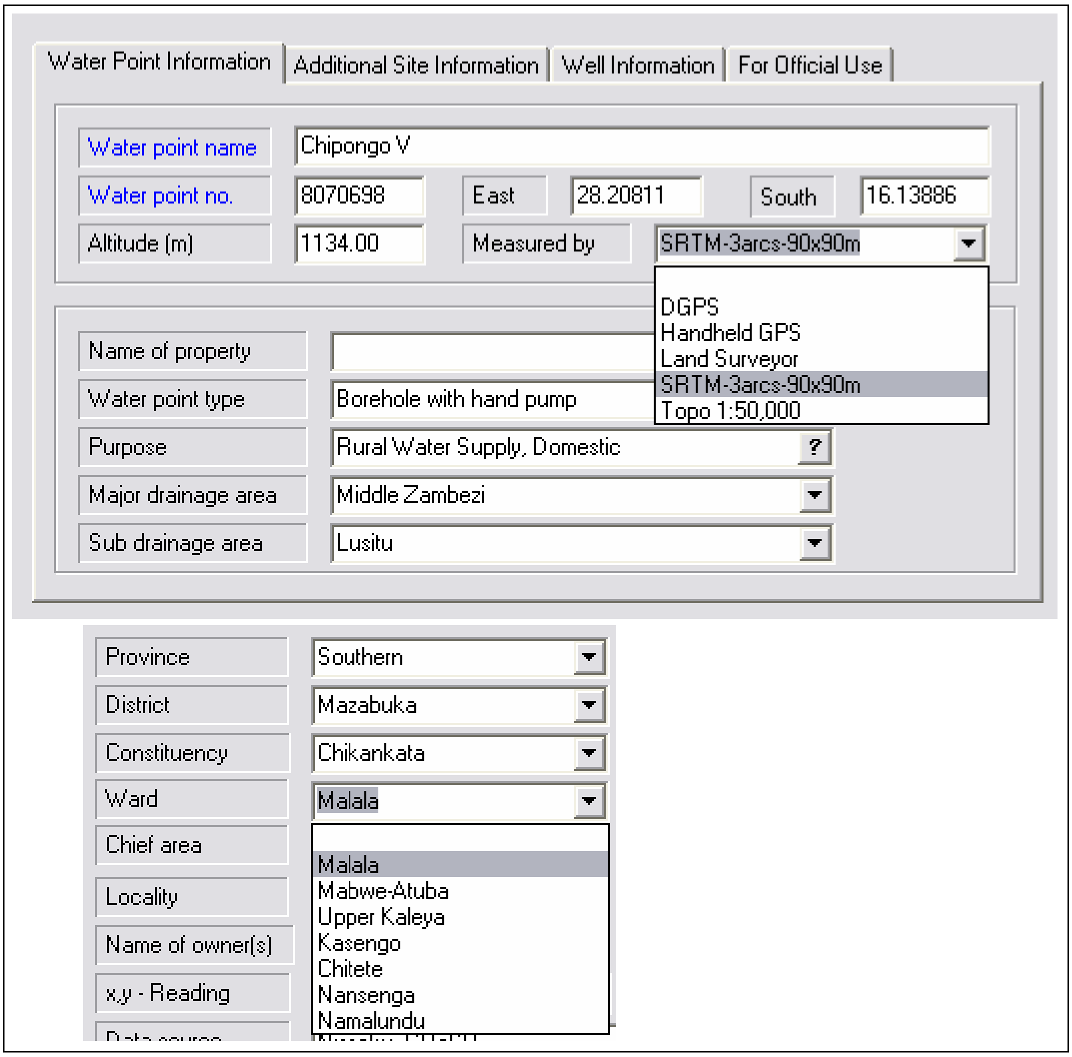
The software also offers various possibilities to query, export, display and visualize groundwater related data entered (e.g. selected data tables, borehole completion reports, lithological borehole logs, etc). Examples for a borehole design with geological description and for a hydraulic test are given in Figure 7-2 and Figure 7-3, respectively.

DATA SOURCES

The data entered into the database were assembled from the following sources:

1. Results of the groundwater resources inventory commissioned by the UNESCO/NORAD Water Research Project and the National Council for Scientific Research (Chenov 1978);
2. Borehole completion and construction reports from projects commissioned by the MEWD and the Japan International Cooperation Agency (JICA) between 1986 and 2003 (Sanyu 1987, DWA 1987, Pacific Consultants Int. Tokyo 1990, Nissaku Co. Ltd 1999, Mitsui & Co. Ltd. & Nissaku Co. Ltd. 2003);
3. Water Point questionnaires collected by the Water Point Inventory Community Managament & Monitoring Unit (CMMU) between the early and mid 1990's under supervision of the two line ministries in the water sector, namely the MEWD and MLGH;
4. Results of the water supply and sanitation project commissioned by the MLGH & the German Development Bank (KfW) (GKW Consult 1996 & 2003);
5. Data of drilling of rural water supply boreholes funded by UNICEF between 2002 and 2005;
6. Borehole completion reports at the DWA, in particular of drilling works in the Gwembe Valley between 2001 and 2005 that were funded by the Seventh-day Adventist Church (Mpamba 2007);

7. Data, in particular GPS readings and groundwater quality data, collected or updated by this project.



Water point name	Chipongo V
Water point no.	8070698
East	28.20811
South	16.13886
Altitude (m)	1134.00
Measured by	SRTM-3arcs-90x90m
Name of property	
Water point type	Borehole with hand pump
Purpose	Rural Water Supply, Domestic
Major drainage area	Middle Zambezi
Sub drainage area	Lusitu
Province	Southern
District	Mazabuka
Constituency	Chikankata
Ward	Malala
Chief area	
Locality	
Name of owner(s)	
x,y - Reading	

Figure 7-1 First data input mask for entering a new water point into the GeODin groundwater database (top). Detail on bottom shows, as an example, how available wards within Chikankata Constituency can be selected from dropdown list.

Type of Data

The database combines general information (e.g. location, type and purpose of water point) with comprehensive and detailed technical information on groundwater hydraulics, borehole design, geology and groundwater quality (Table 7-1).

Quality of Data

All data were scrutinized and checked for plausibility. In this process, the correct spelling of names was checked and names harmonised, coordinates verified on the map or in the field, and measurement data corrected wherever possible and necessary. Throughout the project duration, the database was continuously updated.

The quality and amount of data for water points from the individual sources varied considerably. For many boreholes such as for the CMMU dataset only general information was available such as the type of the water point and the coordinates. More recent drilling reports provided by Nissaku 1999, Mitsui & Nissaku 2003 and GKW Consult 1996 & 2003 in contrast contain a detailed description of geology encountered and borehole design, hydraulic test data and results and some chemical analyses.

Water points of which the coordinates were found to be erroneous or missing were removed from the database. The coordinates of boreholes given in the report by Chenov (1978) were often imprecise and could not be verified in many cases. Many of these old boreholes are believed to be abandoned today and consequently, were omitted from the database.

Table 7-1 Type of information held in the GeODin database

General information	
Location	Borehole name and no. 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 chemistry Comparisons to drinking water standards Water type and quality

The quality of most of the existing chemical analyses from existing sources is considered poor. The results are often implausible, with electrical balances exceeding the 5%-error criterion. This was the main reason to carry out a reconnaissance groundwater sampling campaign (Chapter 8.7.1).

By August 2007, the database contained:

- 3,116 water points
- 1,620 (drilled) boreholes, of which the large majority is installed with a handpump
- 1,150 hand-dug (shallow) wells
- 13 thermal springs
- 159 reported unsuccessful (dry) boreholes
- ca. 700 water points with hydraulic information
- ca. 220 complete sets of hydraulic test data
- ca. 520 boreholes with lithological description
- ca. 300 water points with comprehensive hydrochemical data

A full set of the water points captured in the database at this stage is given in **Annex 3**.

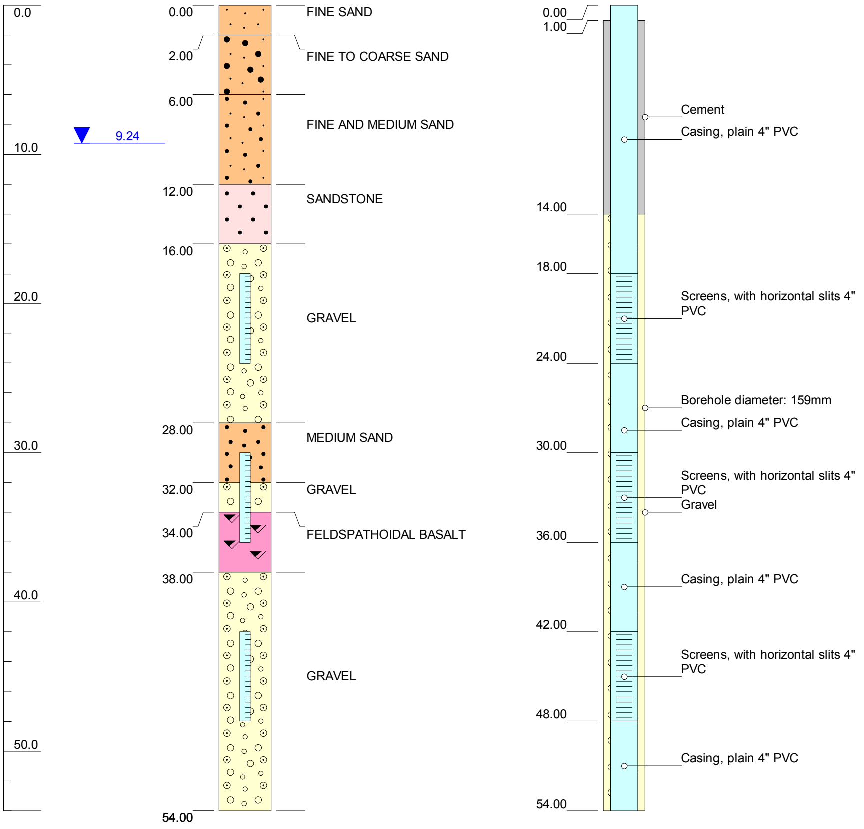
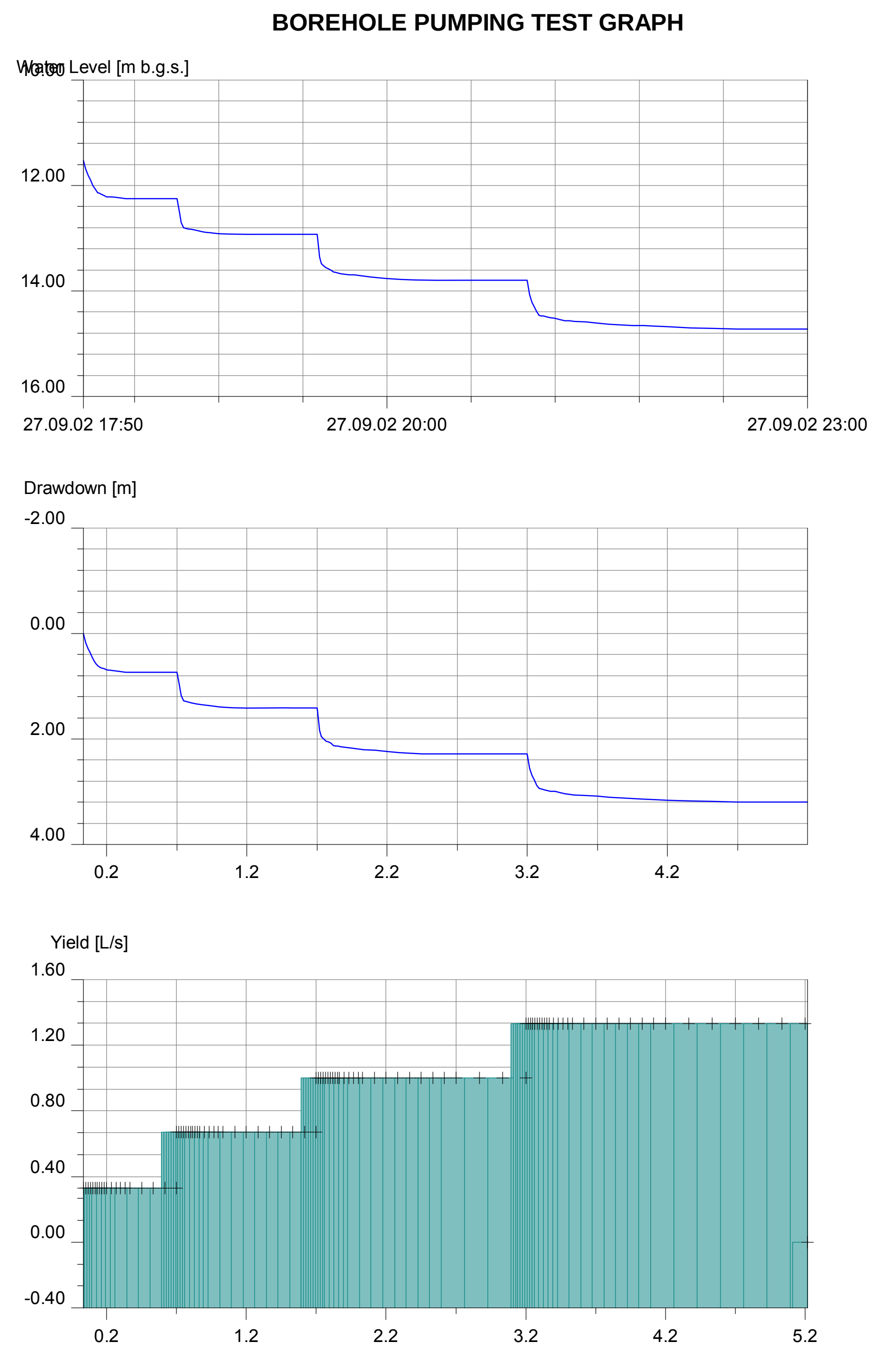


Figure 7-2 Example of a borehole description exported from the GeODin database for the borehole in Sijuwa Village, Water-Point No. 8110419 in Sinazongwe District



Water point name:	**Chitebe Settlement**		
Water point no.:	**8050246**	Ward: Moomba (KazungulaDistrict)	
Driller:		Drill unit:	
Drilling completion:	25.02.2002	Main Aquifer:	Sandstone and meta-sandstone
Test method:	STEP (WELL) TEST	Water quality:	fresh
RWL before test:	11.52 m from ground surface	Recopmmended Yield:1.3 L/s	

Figure 7-3 Example of a step test diagram exported from the GeODin database for the borehole at Chitebe Settlement, Water-Point No. 8050246 in Kazungula District

Water Point No.

For reasons of structuring the database a water point numbering system was introduced. Each water point number (WP-No) is unique, i.e. can only be allocated to one point. The WP-No is composed by seven digits with the first digit representing the Province (“8” for SP), the second and third given out according to the District and the remaining four digits specifying the individual water points (Table 7-2). If required the numbering method can be converted in a system that represents catchment rather than administrative boundaries.

Table 7-2 Composition of water point number

Province	District	Water Point	Resulting WP-No
Southern = **8**	Choma = **01** Gwembe = **02** Itezhi Tezhi = **03** Kalomo = **04** Kazungula = **05** Livingstone = **06** Mazabuka = **07** Monze = **08** Namwala = **09** Siavonga = **10** Sinazongwe = **11**	Indexed numbers ranging from **1** to **9999**	e.g. For Choma: no.’s ranging from 8010001 to 8019999 are available. For Mazabuka: 8070001 – 8079999. For Sinazongwe: 8110001 – 8119999.

7.2. GEOGRAPHIC INFORMATION SYSTEM - GIS

The GIS for the SP was established at the DWA using the ESRI Software package ArcGIS® V. 9.x.

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 georelated applications and analysis. The available mapped information is described below:

Topography

The digitized version of the **topographic maps 1:250,000** series were originally produced by the Zambia Survey Department in association with the Provincial Center for Geographic Information Systems (PCGIS) under support to the Decentralised Rural Development (SDRD). The original digital map layers were revised and the area covered extended beyond the provincial boundaries. The aerial coverage now includes the eight map sheets Namwala, Lusaka, Rufunsa, Choma, Monze, Kariba, Livingstone and Sinazongwe. The information includes administrative boundaries, hydrology, transport, landuse, national parks, towns and villages.

Furthermore, approximately 80 sheets of the Zambian **topographic maps 1:50,000** series were digitized during this Project phase. The main focus at this large scale was on the river systems.

The available topographic information also includes the **DEM** described at length in Chapter 2.1. Map layers include for example elevation contours at 50m- intervals.

Geology

Geological information includes layers showing the distribution of geological formations and lithology on the surface, and of major fault and dyke systems. The map layers are available at scales from 1:100,000 to 1:1 Mio. To achieve this, 22 map sheets at scale 1:100,000, four map sheets at scale 1:125,000 and one map sheet at scale 1:250,000 were digitised and combined to seamless layers (see Chapter 5 and Figure 5-1).

Hydrology

The hydrological information made available in map layers comprise:

- Catchment and sub-catchment maps for the Lower Kafue and Middle Zambezi Rivers (Chapter 4)
- Isohyetal maps of the precipitation

Groundwater

The information on groundwater included in the GIS is further described and discussed in Chapter 8. In summary, the GIS comprises groundwater related information such as:

- Water point inventory maps based on, and linked to, the groundwater database showing boreholes, wells and other water points together with detailed technical information for each point as given in Table 7-1
- Groundwater contours and flow direction
- Spatial distribution of average depth from the ground surface to the groundwater table
- Location and type of thermal springs (Chapter 8.5)
- Spatial distribution of main aquifers and their hydraulic characteristics and potential
- Groundwater chemistry
- Spatial distribution of groundwater vulnerability

8. GROUNDWATER RESOURCES

8.1. AQUIFER CLASSIFICATION SYSTEM

8.1.1. Aquifer Parameters

The aquifer classification developed for the hydrogeological mapping of the SP aims at distinguishing groundwater systems according to their productivity and potential. The classification is based on characteristic hydraulic properties of the rocks hosting groundwater. Parameters describing such properties are transmissivity, hydraulic conductivity, specific capacity and aquifer yield.

Transmissivity T

The transmissivity *T* is a measure of the "*amount of water that can be transmitted through a unit width by the full saturated thickness of the aquifer under a hydraulic gradient of 1"* (Fetter 2001). It is typically given in units of m^2/d or m^2/s. The transmissivity is determined by evaluating hydraulic tests such as pumping or slug tests. Correct evaluations of hydraulic tests require knowledge of the hydraulic conditions surrounding the well. Wrong assumptions in this regard often lead to inaccurate results.

The transmissivity equals the product of the hydraulic conductivity *K* and the saturated thickness of the aquifer *b*, i.e.:

$$T = K \cdot b$$

Hydraulic Conductivity K

The hydraulic conductivity *K* is defined by *Darcy's Law* and can be considered a measure (or a "coefficient") of the permeability of rock towards the flow of groundwater. Typical units are m/s or m/d. *K* is a function of the *intrinsic permeability*, which is representative of the properties of the porous medium alone (e.g. size of pore space openings), and the properties of the fluid, i.e. the viscosity and density of groundwater. In the field, *K* is usually determined by dividing *T* obtained from a pumping test analysis by the saturated thickness.

Specific Capacity q

The yield of a well *Q* divided by the drawdown *s* is called specific capacity *q, i.e.:*

$$q = \frac{Q}{s}$$

Typical units of *q* are $Ls^{-1}m^{-1}$ or $m^3d^{-1}m^{-1}$ (e.g. Fetter 2001). The specific capacity is calculated from the measured drawdown and yield during a pumping test at steady-state conditions. The major advantage of using the specific capacity as a parameter for aquifer characterisation is that *q* can be determined quickly and straightforwardly and without further knowledge of the type of flow towards the well (radial, linear, vertical, etc.) and of the aquifer type (porous, fractured, etc.). It can therefore be considered a less ambiguous parameter for aquifer productivity compared to *T*. It also contains information on how efficiently (against which drawdown) a certain discharge can be produced from an aquifer. This information is not available if only the well yield *Q* is reported.

The major difficulty in this approach is that the well is assumed to be 100% efficient, i.e. that there are no well losses due to turbulent flow and that the drawdown in the well equals the drawdown in the adjacent rock formation. If well losses are significant the value of *q* calculated from the observed drawdown in the pumped well will significantly undervalue the actual productivity and hence, potential of the aquifer.

Well and aquifer yield, Q

In this report, the aquifer yield refers to the likely or characteristic yield that a well can produce from a rock formation. The yield of a well is most accurately evaluated by a “well performance” or “step-drawdown” test. The information on well yields given in the original drilling reports, however, is often ambiguous and of various accuracy. The yields have been determined by blow, constant-discharge or step-drawdown tests. The latter were conducted using three to a maximum of five distinct pumping rates. Blow tests can at best provide an estimate of the actual borehole yield. If only a constant discharge test has been carried out, the determined yield is frequently set equal to the actual pumping rate. The reported yield therefore may often represent the capacity of the pump available at site rather than well characteristics. In summary, reported values of well yield may not represent actual aquifer properties and should therefore be treated with caution.

Safe and sustainable yield

The aquifer yield as defined in this report should not be set equal to the “safe” or “sustainable” yield of groundwater system. One of the first but somewhat vague definition of “safe yield” of an aquifer was proposed by Todd (1959) as “*the amount of water which can be withdrawn from it [the aquifer] annually without producing an undesired result*”.

Traditionally, the safe yield has been defined as the attainment of a long-term balance between the amount of groundwater abstracted from a catchment and the amount of water recharging the aquifer. Thus, the safe yield has been determined as the amount of groundwater that is annually replenished by groundwater recharge. Overexploitation then takes place in the situation in which, for some years, average aquifer abstraction rate is greater than the average recharge rate.

It has recently been pointed out that the concept of the safe yield is interpreted too simplistically since it does not look at the need to maintain aquifer discharge or water levels (Sophocleous 1997, Bredehoeft 1997 & 2002, Foster et al. 2006). The concept only considers the inflow into a catchment while neglecting the discharge from the aquifer into streams, springs and aquifers situated downstream. Sustainable management of an aquifer must therefore take account of the economic and environmental impacts of lowering the groundwater tables and of depletion or drying-up of springs and streams. As climatic conditions vary, it must also be recognised that the sustainable yield varies over time.

The "sustainable yield" or the "permissible abstraction" from a catchment should be defined as the abstraction rate at which the regional drawdown and the discharge of springs or streams will stabilise at a level (below the current levels) that is acceptable with respect to both environmental and economical concerns.

8.1.2. Empirical Relationship between Transmissivity and Specific Capacity

Various authors (e.g. in Fetter 2001, Huntley et al. 1992) have established an empirical relationship between the transmissivity T and the specific capacity q of the form:

$$T = C \cdot q^{a},$$

where C and a are constants that are empirically determined from available data sets of T and q

The groundwater database contains 436 pairs of T and q. The best-fit regression line for the data set is:

$$T = 82.5 \cdot q^{1.1293},$$

where the units for T and q are m^2/d and $Ls^{-1}m^{-1}$, respectively.

The squared correlation coefficient R^2 is 0.86 (Figure 8-1). It is suggested that the empirical relationship is used as a rough estimate of T when full aquifer test analysis for a well is not available.

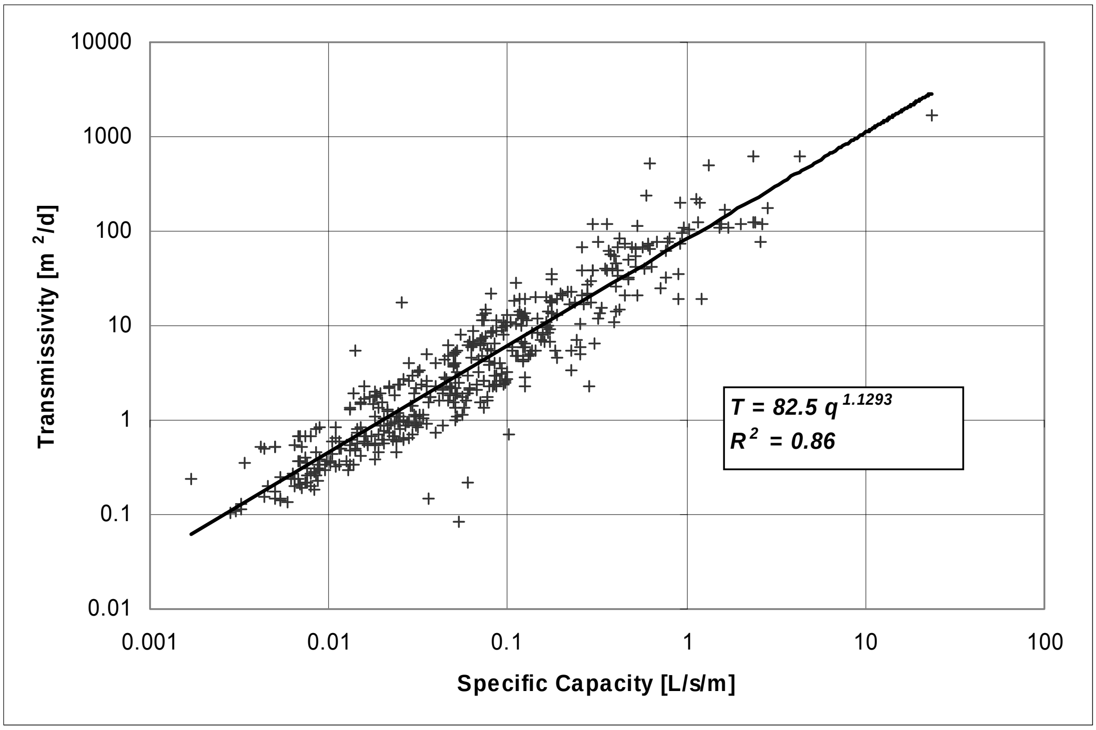


Figure 8-1 Empirical relationship between transmissivity T and specific capacity q for boreholes in the SP (sample size n = 436). Pleas note the double-logarithmic scale used in the graph.

8.1.3. Aquifer Categories

The applied distinction of aquifer categories follows the method proposed in 1995 by Struckmeyer & Margat. The classification distinguishes six categories according to the aquifer potential (productivity and lateral extension) and type of groundwater flow (intergranular or fissured). A description of each category (A to F) is given in Figure 8-2. The depicted triangle also shows the colors allocated to each category in the hydrogeological map.

Roughly, the categories differentiate aquifers with “high”, “moderate”, “limited” and “essentially no” potential. An attempt was made to give practical examples for the possible use of the groundwater resources for each category (Table 8-1, 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) could suffice for the supply of water to rural villages with a handpump.

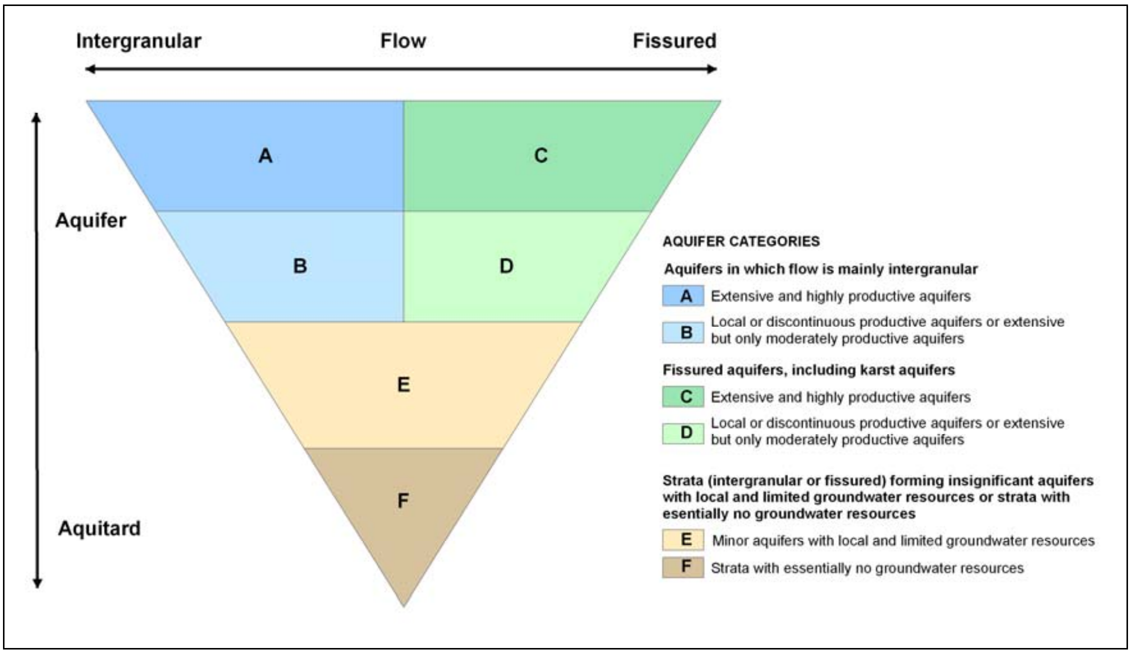


Figure 8-2 Aquifer classification system (modified after Struckmeyer & Margat, 1995)

Table 8-1 also provides characteristic values for specific capacity, transmissivity, permeability and approximate expected yield for each category. **However, it has to be remembered that hydraulic parameters may vary widely, even in areas with relatively uniform lithology, but particularly in areas where groundwater flow is controlled by zones of intense fracturing and faulting.**

Table 8-1 Hydraulic characterisation of the aquifer categories (modified after Krásny, 1993, Struckmeyer & Margat, 1995)

Aquifer category	**Specific capacity** *[L/s/m]*	**Trans-missivity** *[m²/d]*	**Permea-bility** *[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

Note that the pairs of specific capacity and transmissivity that form the thresholds between aquifer categories follow more or less the empirical relationship of the form $T = f(q)$ developed in Chapter 8.1.2. Further note that in Table 8-1, T divided by the respective value of K is approximately 25 m which represents the presumed average aquifer thickness.

8.2. MAJOR AQUIFER SYSTEMS

8.2.1. Aquifer Lithology

The approach applied to identify major aquifer systems in the SP was to differentiate between major lithological groups and their regional distribution. The hydraulic properties of each group were then statistically analysed. An aquifer category was thereafter determined for each lithological group based on the regional hydraulic properties. In a second step smaller areas that form localised groundwater occurrences with different or exceptional hydraulic behaviour compared to the surroundings were delineated based on the experience and information of local groundwater experts at the DWA.

The ten aquifer systems with distinct lithological groups and regional occurrence are given in Table 2-2. Unconsolidated alluvial and Kalahari sediments covering the Kafue Flats and the western parts of the Province form the largest system with 35% of the total area. Other important systems in terms of surface area coverage are constituted by Precambrian gneisses and undifferentiated basement rocks (20% of total area), acid to intermediate igneous (granitoidic) rocks of the Choma-Kalomo Block and the Hook Igneous Complex (15%), and the Karoo sandstone in the eastern portion of the Province (11%).

Table 8-2 Main aquifer systems and their lithology and occurrence

No	System	Litho-stratigraphical description	Main regional occurrence	[%] of total area of SP
1	Acid to intermediate igneous rock	Granitic rocks typically associated with the Choma-Kalomo Block and the Hook Igneous Complex, but also found within the Katanga Supergroup.	Throughout the SP, predominant unit in the Choma-Kalomo area	15
2	Basalt	Basalt rock of mainly Upper Karoo Age	In the South between Kazungula. Livingstone and Zimba	4.5
3	Gneiss & undifferentiated metamorphic rock	Predominantly gneiss and granitic gneiss within the Basement, Katanga & Muva Supergroups	North-eastern areas of SP, between Monze, Gwembe, Pemba and Choma and near Siavonga	20
4	Schist, shale & slate	Various schists of Precambrian age	Throughout the SP	7.8
5	Quartzite	Quartzitic rocks of predominately Precambrian age	Throughout the SP	<1
6	Carbonate & calc-silicate rock	Mainly calc-silicate rocks and marbles or dolomitic rocks of the Katanga Supergroup	Mazabuka District and area east of Mapanza	4.0
7	Mudstone	Karoo mudstones (mainly Madumabisa Mudstone Formation)	Escarpment zone of Siavonga, Gwembe and Sinazongwe Districts	1.6
8	Pre-Kalahari sand- and siltstone	Mostly Upper Karoo sand- and siltstones (Red Sandstone and Interbedded Sandstone and Mudstone Formations)	Escarpment zone of Siavonga, Gwembe and Sinazongwe Districts	11
9	Kalahari sandstone	Consolidated or semi-consolidated sandstone of the Kalahari Group	Western areas of SP including Kazungula. Itezhi Tezhi and Namwala Districts	<1
10	Unconsolidated clastic sediments	Interbedded gravel, sand, silt and clay formed by alluvial deposits and unconsolidated Kalahari sediments	Kafue Flats and western areas of SP	35

8.2.2. Hydraulic Test Statistics

The hydraulic test statistics for the ten identified aquifer systems are based on evaluation of specific capacity, transmissivity and recommended yield of boreholes. The hydraulic conductivity is not included in the analysis since it was in almost all cases obtained from dividing *T* by the estimated (and often tentative) saturated thickness. The database contains:

- 601 values of specific capacity
- 431 values of transmissivity
- 881 values of recommended yield

Note that a yield of zero was allocated to unsuccessful ("dry") boreholes, which explains the considerably higher number of values for *Q*. It has to be born in mind that low-yielding boreholes were often sealed and not pump-tested. Consequently, no values of *q* or *T* could be determined for these very low yielding wells. It must hence be assumed that the statistical analysis of hydraulic data is biased towards better yielding wells.

Table 8-3 contains the main descriptive statistical parameters for hydraulic aquifer characteristics. The number of available wells (sample size *n*) for the individual systems varies widely, being highest for acid igneous rocks, schists, and Karoo sand- and mudstones and relatively low for carbonate rocks, quartzite and Kalahari sandstone.

Table 8-3 Descriptive statistics of aquifer characteristics

NO	SYSTEM	Param.	n	Mean	Median	Stdev	CV [%]	Min	P25	P75	Max	CATEG-ORIES
1	Acid igneous rock	q	97	0.30	0.034	2.37	778%	0.0045	0.015	0.073	23.33	
		T	87	23.1	1.4	179.1	775%	0.15	0.56	2.6	1670	E
		Q	157	0.56	0.31	0.71	126%	0	0.11	0.8	5	
2	Basalt	q	68	0.21	0.080	0.39	188%	0.0050	0.027	0.177	2.36	
		T	65	30.5	5.5	100.1	328%	0.21	2.12	15.7	618	E - D
		Q	89	0.70	0.60	0.67	95%	0	0.2	1.2	3.6	
3	Gneiss & undiff. metamorphic rock	q	47	0.16	0.044	0.28	171%	0.0017	0.017	0.175	1.32	
		T	20	40.1	4.2	111.5	278%	0.09	0.52	21.0	500	E
		Q	73	1.09	0.40	1.90	174%	0	0.1	1	9	
4	Schist, shale & slate	q	108	0.21	0.050	0.44	211%	0.0032	0.017	0.160	2.42	
		T	67	21.6	2.9	40.3	187%	0.11	0.88	14.0	197	E
		Q	116	1.19	0.80	1.41	119%	0	0.31	1.4	7	
5	Quartzite	q	34	0.20	0.028	0.55	272%	0.0053	0.009	0.075	2.67	
		T	30	10.2	1.2	25.3	249%	0.14	0.44	5.3	120	E
		Q	37	1.08	0.70	1.01	94%	0.1	0.3	1.7	5	
6	Carbonate & calc-silicate rock	q	20	0.44	0.059	1.33	301%	0.0034	0.021	0.218	6.00	
		T	12	22.8	2.0	43.1	189%	0.19	0.50	14.0	121	E - D
		Q	36	1.19	0.32	2.09	176%	0	0	1.2	10	
7	Mudstone (Karoo)	q	74	0.19	0.049	0.39	207%	0.0027	0.021	0.163	2.86	
		T	32	34.1	3.0	69.3	203%	0.13	0.62	11.3	238	E
		Q	147	1.59	0.90	2.13	134%	0	0.4	2	12	
8	Pre-Kalahari sand- and siltstone	q	67	0.50	0.167	1.00	198%	0.0070	0.058	0.418	5.71	
		T	46	39.3	15.8	94.6	240%	0.18	2.33	38.7	628	D - E
		Q	137	2.23	1.50	2.51	112%	0	0.6	3	15	
9	Kalahari sandstone	q	25	0.19	0.087	0.23	121%	0.0067	0.044	0.229	0.92	
		T	25	15.7	5.8	22.1	141%	0.27	2.28	13.8	74	E - D
		Q	25	0.81	0.80	0.41	51%	0.2	0.5	1.1	1.5	
10	Unconsolidated clastic sediments	q	61	0.26	0.074	0.80	311%	0.0028	0.027	0.235	6.15	
		T	46	13.5	5.1	23.8	177%	0.11	1.09	14.8	120	E - B
		Q	64	1.49	0.92	1.93	129%	0	0.4	1.6	10	

Explanations: **n**: sample size; **Stdev**: Standard deviation; **Min**: smallest value observed; **Max**: Highest value observed; **CV**: Coefficient of variation defined as the ratio of the standard deviation to the mean; **Median**: also called 50th percentile, represents the value that divides the higher half of all values from the lower half; **P25**: 25th percentile or "first quartile", the value below which 25% of all observed values fall; **P75**: 75th percentile or "third quartile", the value below which 75% of all observed values fall.

As a major finding, the examined hydraulic parameters vary over a wide range for all aquifer systems. This is reflected in the large values for standard deviation and coefficient of variation. The latter typically varies between 100% and 300%. These large values are an expression of the heterogeneity of the rock formations, including the intergranular deposits, encountered in the SP.

The frequency distribution of specific capacity depicted in Figure 8-3 is strongly positive skewed, i.e. the median is much smaller than the arithmetic mean. In fact, the frequency distribution can be fitted reasonably well to a probability curve of the log-normal type. As a consequence, the arithmetic mean does not prove a suitable parameter to describe representative aquifer properties. It is therefore recommended to use the median together with the 25th and 75th percentile instead. A smart way to plot these parameters is by using a box chart (Figure 8-4). The box is bounded at the top and bottom by the 75th and 25th percentile, respectively. The horizontal centre line represents the median. In addition, the arithmetic mean and the smallest and largest value observed are shown as points along the vertical line. The larger the extent of the box the higher is the scattering in the hydraulic data between the two percentiles, and the more pronounced is the heterogeneity within the aquifer system. In Figure 8-4, for instance the largest box (i.e. largest variation) is observed for the Pre-Kalahari sandstones (System no. 8). For planning purposes it may be justified to assume that the hydraulic properties (such as yield) of newly drilled boreholes can be expected to be within the range of the 25th to the 75th percentile.

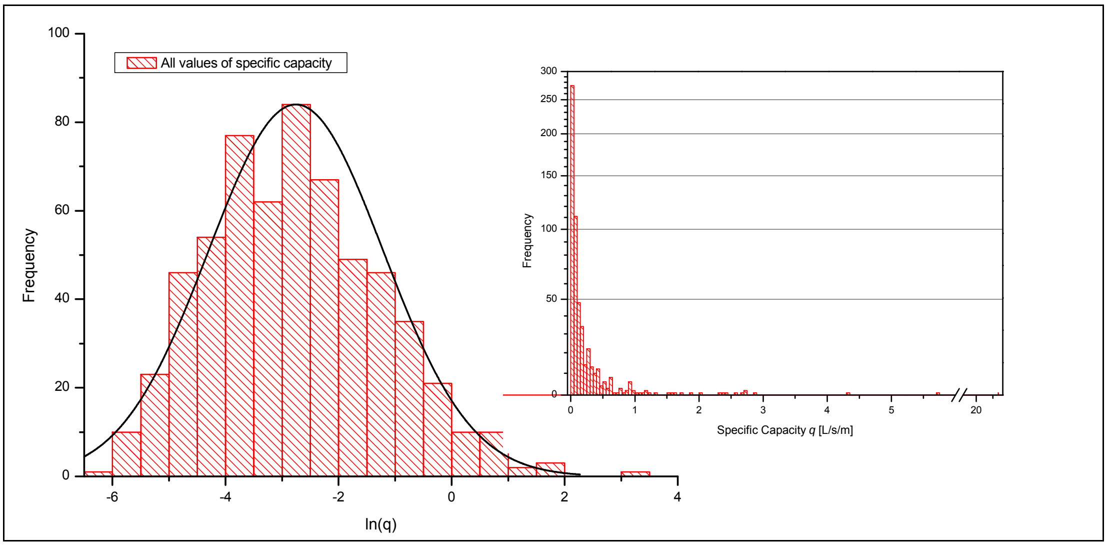


Figure 8-3 Frequency distribution of all measured values of aquifer specific capacity *q* fitted to a log-normal probability distribution. Note that in the graph to the left values of logarithm of *q* are plotted.

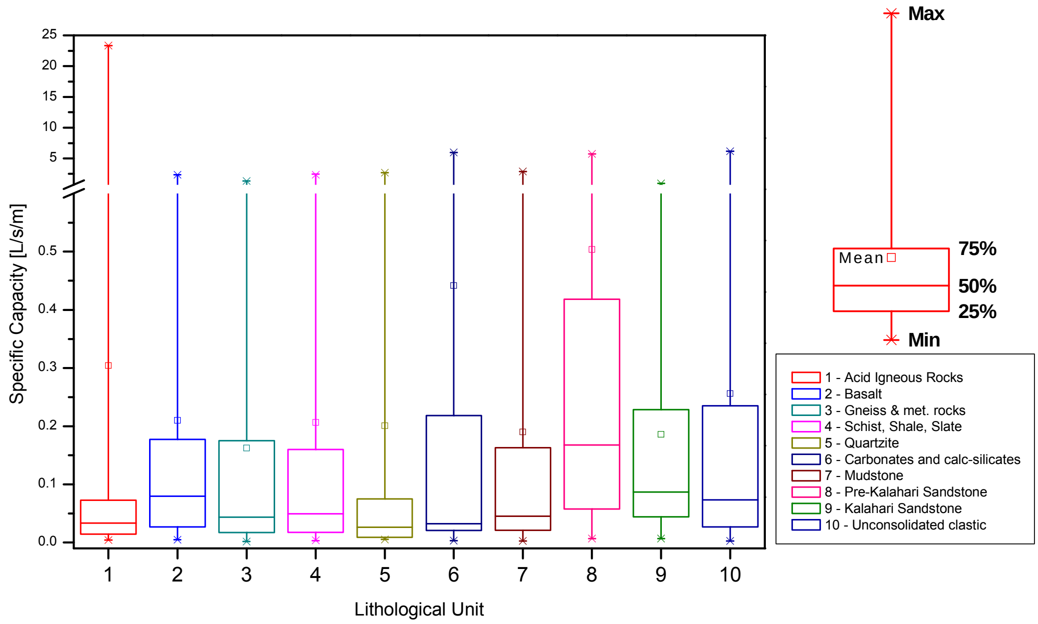


Figure 8-4 Box charts of specific capacity *q* for individual aquifer systems. Values of minimum, maximum, mean, median and the 75^{th} and 25^{th} prercentile are given in Table 8-3.

Table 8-4 summarises the results of an examination of how frequently dry and exceptionally high productive wells were encountered in the various aquifer systems. A comparatively low rate of success is reported for gneiss and undifferentiated basement rock (23% of dry boreholes), acid to intermediate igneous rocks (21% dry) and basalt (19% dry). Somewhat unexpectedly, more than 30% of the documented boreholes drilled in carbonate and calc-silicate rocks were also dry (Table 8-4). This finding, however, may not be representative as a result of the relative small sample size of only 36 boreholes.

Very few unsuccessful boreholes are reported for the systems formed by unconsolidated sediments, Kalahari sandstone, quartzite as well as schists. It is believed that this finding is representative for at least the first two of the above mentioned systems.

As a final result from the data in Table 8-4 it can be concluded that wells with exceptional high yields (q>1 L/s/m) are rarely found regardless the aquifer lithology.

Table 8-4 Statistics of boreholes with exceptional low and high yields

No	SYSTEM	No. of boreholes	No. (%) of "dry" boreholes	No. of high productive wells	
				q > 1.0 L/s/m	q > 10L/s/m
1	Acid to intermediate igneous rock	157	33 (21%)	2	1
2	Basalt	89	17 (19%)	3	0
3	Gneiss & undifferentiated metamorphic rock	73	17 (23%)	1	0
4	Schist, shale & slate	116	3 (0.3%)	5	0
5	Quartzite	37	0 (0%)	2	0
6	Carbonate & calc-silicate rock	36	11 (31%)	2	0
7	Mudstone	147	5 (3.0%)	2	0
8	Pre-Kalahari sand- and siltstone	137	9 (6.6%)	7	0
9	Kalahari sandstone	25	0 (0%)	0	0
10	Unconsolidated clastic sediments	64	1 (0.0%)	2	0

8.2.3. Aquifer Potential

Due to the observed heterogeneity of all identified aquifer systems it proves a difficult task to quantify their regional potential. Almost two thirds of the aquifer systems of the SP are formed by hard rock in which groundwater flow is associated with the occurrence and type of fracture and fault systems. The intergranular systems within alluvium and Kalahari deposits are often characterised by interbedded layers of clay, silt, sand and gravel as a consequence of their complex depositional environment and history. In result, they also host non-uniform, often discontinuous or layered aquifers.

Groundwater Potential Characterisation based on Statistical Analysis

From a stochastical point of view the ten aquifer systems do not significantly[2] differ from each other due to the observed high variance of hydraulic parameters. An exception is system no. 8, the Pre-Kalahari sandstones, for which significantly higher values of specific capacity, transmissivity and yields are generally reported. Despite the somewhat discouraging results of the stochastical analysis, it was the impression that the statistical data nevertheless show some trends regarding the potential of individual aquifers that could possibly be confirmed in the future when more reliable field data on aquifer hydraulics is available. The observed trends agree with the experiences made by hydrogeologists and drillers at the DWA.

In this first tentative approach the following system was rated an aquifer with, at least in parts, **moderate potential** corresponding to **category D** (refer to Table 8-1 and Table 8-3):

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[2] Assuming that the distribution of hydraulic values in each system ("sample") follow a log-normal relationship, values of the logarithm of specific capacity, *ln(q)* were calculated for the stochastical analysis. The arithmetic means of the converted values of each sample were then tested using a two-sample t-test at the 95% significance level. A two sample t-test can be employed to test whether or not two population means are equal.

1. The Pre-Kalahari sand- and siltstones, with medians (with 25th and 75th percentile given in brackets) for specific capacity of 0.17 L/s/m (0.06 - 0.42), transmissivity of 16 m^2/d (2 – 39) and yield of 1.5 L/s (0.6 – 3).

The following three systems were rated aquifers with **limited to moderate potential** or **categories E to B/D**:

1. The Karoo basalt, with values for specific capacity of 0.08 L/s/m (0.03 - 0.18), transmissivity of 6 m^2/d (2 – 16) and yield of 0.6 L/s (0.2 – 1.2).
2. The unconsolidated clastic sediments, with values for specific capacity of 0.07 L/s/m (0.03 - 0.24), transmissivity of 5 m^2/d (1 – 15) and yield of 0.9 L/s(0.4 – 1.6).
3. The Kalahari sandstones, with values for specific capacity of 0.09 L/s/m (0.04 - 0.23), transmissivity of 6 m^2/d (2 – 14) and yield of 0.8 L/s (0.5 – 1.1).

The carbonate rocks of the SP, in particular in the Mazabuka area qualify partially to categories D.

All other aquifer systems including those formed by the widespread granitoidic and granitic rocks are classified as aquifers with **limited potential** or **category E**.

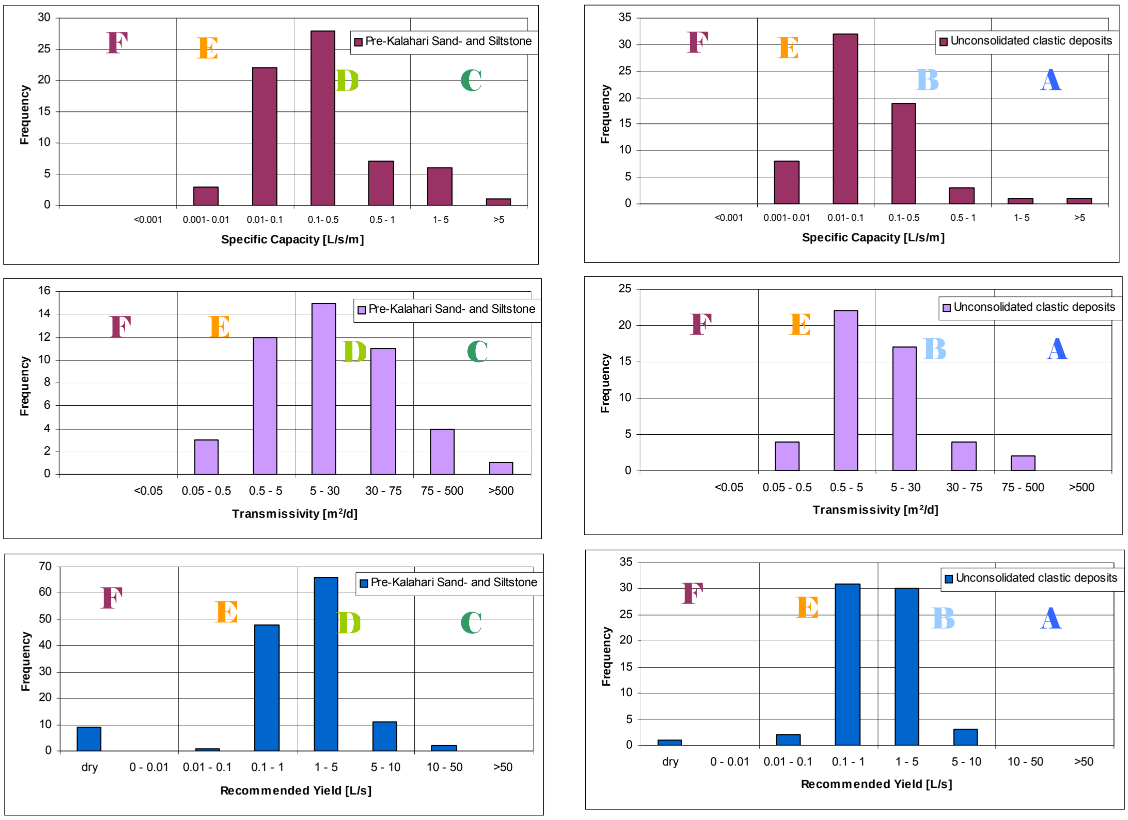

Figure 8-5 Frequency of observed values for specific capacity *q* (top), transmissivity *T* and yield *Q* (bottom) for the systems Pre-Kalahari sand- and siltstone (left) and unconsolidated clastic deposits (right). Capital letters represent aquifer categories according to the applied classification system (see Figure 8-2).

A detailed frequency distribution of the three investigated hydraulic parameters for the Pre-Kalahari sandstones and unconsolidated rocks is shown in Figure 8-5. A full set of this type of diagrams are presented in **Annex 4**. The values are grouped to fit the limits of major aquifer categories. It can clearly be seen that the observed values within each system extend over at least three different categories. This once more is an indication of the large heterogeneity of the aquifers. Nevertheless, the peak for the Pre-Kalahari sandstones falls within category D, and between categories E and B in the example of the unconsolidated rock corresponding to the overall classification presented above.

The regional distribution of the aquifer systems and their category is shown in Figure 8-6. In summary, most aquifer systems of the SP, especially those in the central areas formed by granitoidic and basement rocks, have only limited potential and are only suitable for smaller withdrawals (e.g. private consumption or local rural water supply through handpumps). In some areas, especially at the margins of the Province, groundwater systems with moderate potential can be found. These systems usually are formed by unconsolidated deposits, Karoo sandstone or basalt and may be sufficient for withdrawals for local water supply to smaller communities or for small-scale irrigation.

Groundwater Potential Characterisation based on Field Experience

Apart from this regional classification based on lithology and statistics of hydraulic parameters some localised occurrences of groundwater systems are known that often differ from the general pattern. The information is based on experience drawn from areas where the DWA has been carrying out rural water development activities.

The following are areas with low groundwater potential in SP.

1. Kasaya Kazungula – The area is flat with the aquifer belonging to the Kalahari sedimentary rock. The lithology is composed of unconsolidated, semi-consolidated clastic deposits of gravel, sand, silt and clay. It is likely that the aquifer is composed predominantly of clays that are less transmissive. Aquifers within the unconsolidated Kalahari sediments are often productive and extensive but may be lowly yielding in this particular place.
2. Livingstone is overlain by loose sands that overlie the Batoka basalts. Groundwater potential in this area is generally limited where the basalt is massive (e.g. near airport and quarries to the east of Livingstone) although the aquifers are described as locally productive but discontinuous.
3. Kasiya in Livingstone District– The Batoka Basalt in this area is known to be massive with little secondary porosity.
4. Kabuyu (towards Nyawa) – The aquifer type is Kalahari sandstone overlying Karoo Basalt. The Kalahari sandstone is composed of sandstone and siltstone interbedded with layers or lenses of clay-rich sediments.
5. Nzwida School in Chief Nyawa's area – the rocks are characterized by the predominance of low permeable biotite granite.
6. Makoli in Kazungula District is located on the Choma-Kalomo batholith composed of schist, migmatite and biotite granite. The rocks in this area are believed to be massive and to have low secondary porosity.
7. Namwianga School area – see Makoli.
8. Ngolongozya River and Chundwe school areas – see Makoli.
9. Kabanga (towards Mapatizya) – The area bears metamorphic rocks largely composed of granitic gneiss and gneiss. The aquifer is considered poor with local and limited groundwater resources.
10. Namuswa School – Quartzitic schists dominate the surrounding area. The school is, however, is located on an outcrop of granitic rock.
11. Chisuku in Chief Mweemba's area – The clastic sediments of Karoo age (Escarpment Grit) of this area are reported to have little potential.
12. Munzuma Dam – High yielding boreholes are unlikely in this area. The area is predominantly granitic.
13. Mayobo (south of Mapanza) and Chisikili school area – The group of metamorphic rocks in this area belong to the Muva Supergroup. Orthogneiss is predominant and has poor groundwater potential.

14. Nazibula in chief Nyawa’s area – the area associated with metamorphic basement rock with essentially no groundwater resources.
15. Omba School area – see Nazibula.
16. Monze Town – The town sources groundwater from a minor aquifer (area within a radius of ca. 10 km around the town) within the Neoproterozoic (Katanga) metamorphic rocks (quartz-biotite schist).
17. Bweengwa – Generally, the regional lithology is described as unconsolidated or semi-consolidated, interbedded gravel, sand, silt and clay. The aquifers are associated with deep water levels. It seems as if the occurrence of thick clay layers or lenses is typical for this area.
18. The lithology of Pemba after Japi is composed of metamorphic rocks. The aquifer in this area is made of quartz-muscovite schist with very low groundwater potential.
19. Itezhi-Tezhi around township – The township and areas in the immediate North are located on a granitic mound of the acid to intermediate intrusive rocks of the Hook Igneous Complex. Better groundwater yields can be expected in areas to the South along the contact zones between the granitic rock formations and the Upper Karoo sandstone/ siltstone/ mudstone.
20. Kanzwa near Chief Kaingu Palace – see Itezhi-Tezhi Township.
21. Munali – The area formed by acid intermediate igneous rocks (Munali Hills granite) is surrounded by various metamorphic rocks and known to be difficult with respect to groundwater exploration.
22. Kariba store area near Siavonga is situated on metamorphic rocks. Groundwater is restricted to fractured or weathered gneiss.
23. Kabanana (Siavonga) – The geology in this area is characterised by mudstone and sandstone interbedded with mudstone of Karoo age with rather low potential.
24. Gulumunyanga (in Siampande, Nakasika area) – Mudstone and sandstone interbedded with mudstone that are known to have poor groundwater potential are found in this area. Water levels are very deep.

The following are areas with moderate to high groundwater potential in SP.

25. Namwala Council – Aeolian sands together with alluvium are deposited in this area. It is assumed that the valley fill materials around this area have larger contents in sand resulting in higher permeability.
26. Banamwaze – the aquifers of the area are formed by alluvium of the Kafue Flats.
27. Chitongo area (near “Niko turn-off”) – The good aquifers in the area are composed of unconsolidated clastic deposits with higher percentages of sand and gravel.

28. Muchila (near Rural Health Centre) – The marbles, metacarbonate and calc-silicate rocks ("Mapanza Carbonate") of this area are good aquifers depending on the degree of fracturing and karstification.
29. The carbonate rocks southeast of Mazabuka and Magoye – The metamorphic formations of the area belong to the Katanga Supergroup. The Neoproterozoic rocks comprise marble, meta-carbonates and calc-silica-rocks. Groundwater is abundant in parts where the carbonate rocks are karstified or densely fractured.
30. Mwanamainda and Munali hills – The area is located on unconsolidated clastic sediments. The sediments in this area are moderately transmissive.
31. Lubombo near Nega Nega – there is a strip of marbles or calc-silicate rocks traversing Lubombo Township that are known to form local but productive aquifers. The surrounding area is made of alluvium of the Kafue flats.
32. Kaleya compound (Mazabuka) is built on alluvial deposits of the Kafue flats with high groundwater potential
33. Gwembe town and township – The gneiss and granitic gneiss ("Gwembe Gneiss") surrounding the settlement are usually considered of limited groundwater potential. However, some unusually high yielding boreholes (Q > 2 L/s) could be developed in the town area, such as at the hospital. High yielding boreholes are located exactly on major fractures. A similar situation was encountered north of Gwembe near Chisekesi and St. Canisius School where groundwater is probably confined to the regolith above the gneiss or in fractures.
34. Munyumbwe – Similar to the situation at Gwembe the area has generally aquifers with local and limited groundwater resources. Nevertheless, high yields were encountered along fractures of granitic gneiss and gneiss and around contacts between metamorphic rocks of gneissic character and Karoo rocks composed of interbedded sandstone, siltstone and mudstone.
35. Demu – Mesoproterozoic schist and quartzite are dominant rock types in the area. The more productive areas may be linked to quartz intrusions.
36. Choma DWA borehole (stores) and Choma township towards Mochipapa – The reported locally high well yields are associated with zones of weathered granites.
37. Chief Siachitema area and Van Neede, Chance and Shone Foster farms in Sibanyati area west and south west of Choma – Approximately 20 km west of Choma town the geology changes from granitic gneiss and granite to alluvial and colluvial deposits. The igneous and metamorphic rocks in this area are generally minor aquifers with local and limited groundwater resources but reported higher yields may be linked to the weathered contact zone between the superficial deposits and the granitic rocks.
38. Mukwela (Kalomo) and Mrs Muhila – The lithology is composed of acidic igneous intrusives of the Kalomo Batholith. Weathered granite is the likely

aquifer but has generally limited potential. Spots in the area with thicker regolith and areas with major fractures, however, are known to be highly transmissive.

39. Sinde artesian borehole– The point is near the contact of the basic extrusive igneous basalts and the unconsolidated or semi-consolidated sediments composing gravel sand silt and clays of Kalahari origin. The artesian well discharges water throughout the year and is a source of livelihood to the locals who have built a small dam to impound the water. The effluent from the flowing well is used for mainly domestic drinking water, gardening, animal watering and fishing. The recharge area for the well is unknown.
40. Sinazeze/Nkandabwe (Maamba) – High yielding boreholes are likely to be aligned to the geological contact between the Karoo mudstone and basement rocks. Fault zones and areas recharged by streams and rivers are the likely areas where high groundwater potential is envisaged. However, the aquifers in this area are generally localised and have overall limited groundwater capacity.
41. Sinazongwe –the sandstone, siltstone and mudstone of the Karoo formation host moderately productive aquifers.

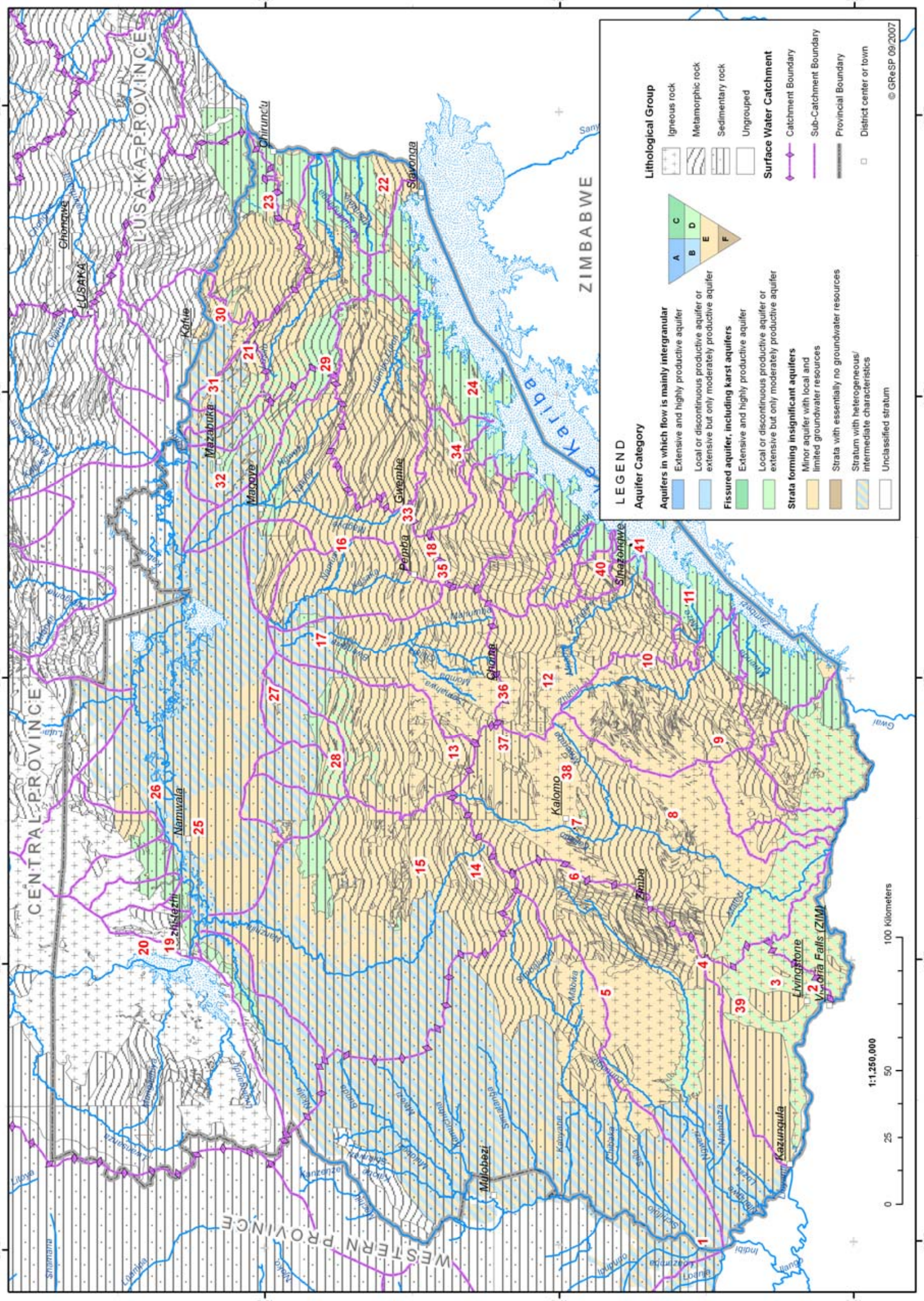

Figure 8-6 Simplified map showing the different aquifers categories and major lithological groups for the SP. The numbers (in red) refer to the specific sites discussed in the text.

8.3. REGIONAL GROUNDWATER FLOW

The database currently holds 1,661 data points containing information on groundwater levels. Throughout the SP the elevation of the groundwater tables ranges from 374 to 1370 m asl. The data has a clustered spatial distribution with the highest density of boreholes within the Monze District. Minor cluster centres are located in the Gwembe and Mazabuka districts (Figure 8-8).

The data includes different types of water points containing mostly boreholes and hand-dug wells. This likely produces problems in data interpolation as the hand-dug wells do perhaps not reach the regional water table but instead tap only minor, locally perched water resources. Another problem for the interpolation of the groundwater levels are seasonal and secular fluctuations of the water table because for most of the data points, only one water level measurement is available. The database comprises values taken between 1978 and 2006. Most values are measured subsequent to drilling and do not reflect seasonal effects.

A stochastical analysis however shows that the spatial variations in groundwater elevation (in m asl) at provincial scale are primarily controlled by surface altitude variations (i.e. topography) and to a much smaller extent by the water level (depth-to-surface) measurements. The close relationship between surface and groundwater table elevations can be explained by the high range in altitude variations (>1000m) across the SP compared to the relatively small variations in groundwater depth (usually <10m). Errors in individual water level measurements and time-dependent groundwater fluctuations have therefore only a minor influence on the regional groundwater elevation contours. This explains why the groundwater levels estimated from the groundwater contouring procedure3) correlate reasonably well with the measured groundwater levels despite the comparatively poor input data (Figure 8-7).

It is important to mention that for larger-scale mapping of groundwater level contours, particular for areas with a less pronounced topography, time-dependant fluctuations of the water table and the distinction between local or perched and regional aquifers must not be ignored.

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[3] The Surfer® contouring software package was used to produce a preliminary contour map which was subsequently modified manually.

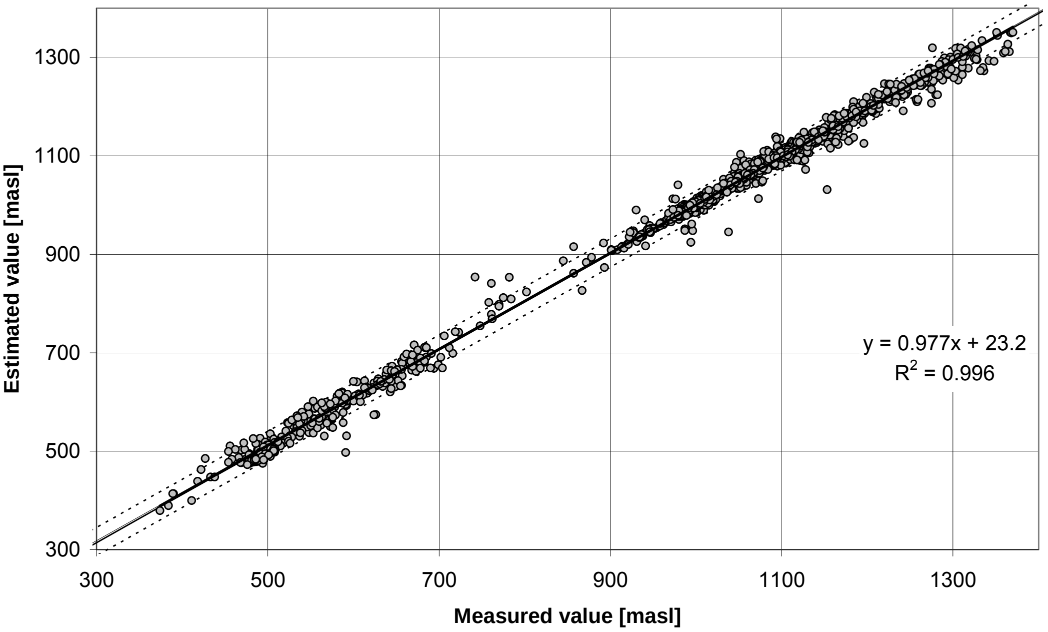

Figure 8-7 Measured vs. estimated groundwater levels in m asl. Estimated values are obtained from regional groundwater contour mapping (i.e. Surfer® grid). Solid line: linear fit, dashed line: upper and lower 95% prediction limit of the linear regression.

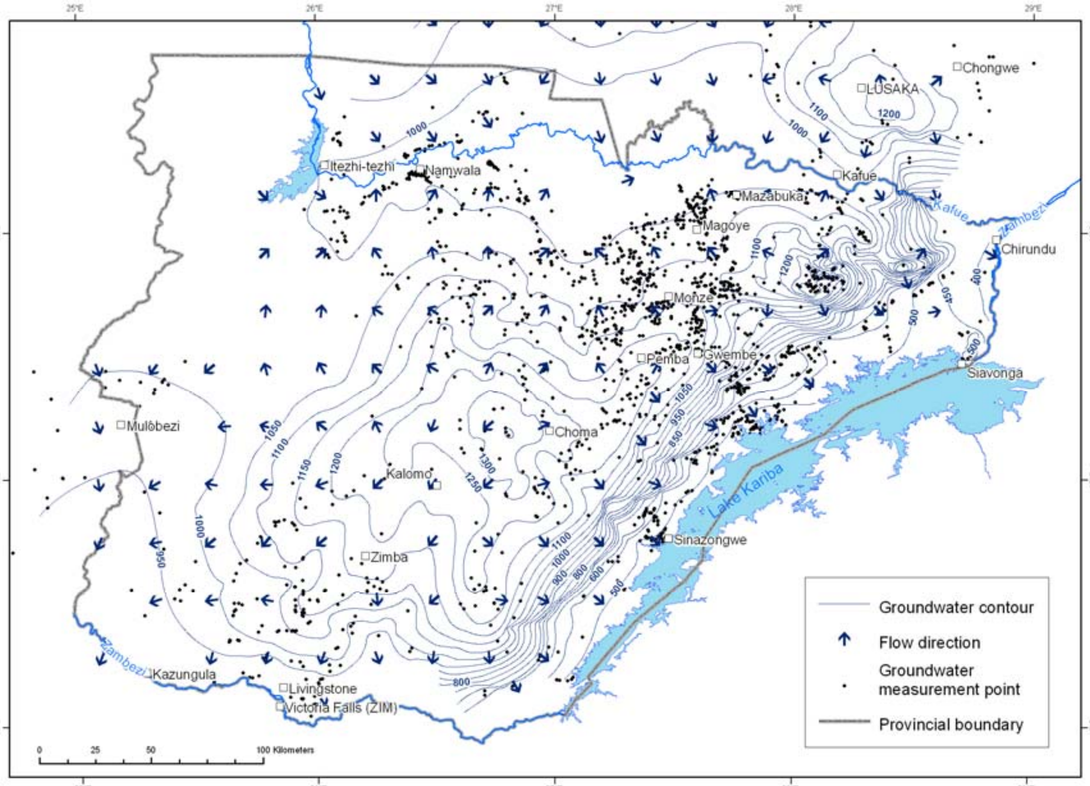

Figure 8-8: Regional groundwater contour map of the SP and the adjacent north-eastern Lusaka area with indication of the groundwater flow directions. Water levels are given in m asl.

The interpolated groundwater contours and the respective groundwater flow directions are overall reasonable. The groundwater is flowing from three distinctive areas with high groundwater levels, namely the Choma-Kalomo Block, the Mabwetuba Hills area (hosting the highest point within the SP) and the Lusaka Plateau, towards the major rivers Zambezi and Kafue and Lake Kariba (Figure 8-8). The groundwater gradient within the alluvial plain of the Kafue River is generally low and is directed towards the river course. In the westernmost part of the SP groundwater levels and flow directions are not predictable due to the lack of data. As a consequence to the similarity between surface slope and groundwater characteristics, rather steep groundwater gradients are estimated for the escarpment zone in the direction of Lake Kariba.

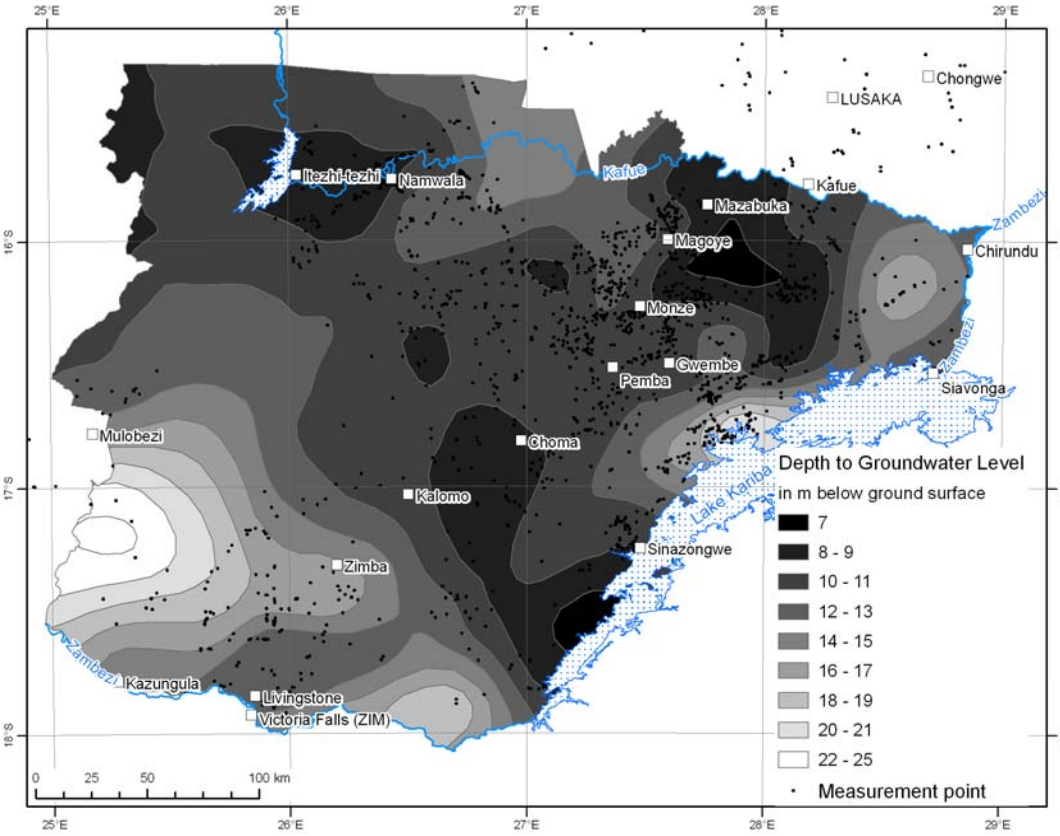

Figure 8-9: Estimated depth to groundwater table in the SP in meters from ground surface interpolated from the indicated measurement points.

The interpolation of the depth to the groundwater table (Figure 8-9) is based on the same database as the map showing groundwater elevation contours. Similar to the previous estimation, it must be considered a rough approximation of the real conditions as the data points available are strongly clustered and rather sparse compared to the size of the SP. In contrast to the prediction of the groundwater elevation contours the error produced due to the occurrence of perched or other local aquifers and temporal variations of the groundwater table could be rather significant in this approximation but cannot be further assessed due to the limited number of data points and measurements. Hence, the spatial distribution of the groundwater table depth should be regarded as a first, rough approximation and must be verified during future studies considering additional time-related measurements.

8.4. GROUNDWATER RECHARGE AND POTENTIAL

Long-term Groundwater recharge over an area can be considered the renewable groundwater storage. Groundwater recharge, *R* for catchments in Zambia was estimated by using the baseflow separation method for major rivers and by assessment of the seasonal changes of groundwater storage as follows (YEC 1995b):

R = Increase in groundwater storage - Baseflow

The assessment of the groundwater fluctuations was based on a comparatively small number of observation points (10–20) and on measurements over only one (?) rainy season. The baseflow separation method has two major short-comings if applied to SP: (1) Large areas that generate baseflow in the Zambezi are located outside Zambia and (2) the estimation of baseflow might be difficult as runoff is regulated through the three major dams in SP.

The estimated change in groundwater storage was subtracted from assumed baseflow to obtain a groundwater recharge rate, *R%* of 9% and a recharge *R,* of 70 mm/a for the Province. For Zambia, *R%* and *R* are 8% and 78 mm/a, respectively, according to the study. A numerical simulation of the groundwater level fluctuations over the Kafue Catchment resulted in a R% of 10%.

Assuming that the long-term change in storage equals zero the *R* in a catchment can be calculated from the water balance as follows

$R = P + (Q_{out} - Q_{in}) - ET$

P	Average precipitation in the catchment
Q_{out}	Average river outflow from the catchment
Q_{in}	Average inflow into the catchment,
ET	Losses through evapotranspiration

R% is than calculated as follows:

$R\% = R / P \cdot 100\%$

The method was applied to the following two areas:

1. The Middle Zambezi Catchment (Blocks BZ-7 & BZ-8)[4]
2. The Lower Kafue Catchment (Blocks BK-10 & BK-11)

The results presented in Table 2-2 depend largely on the accuracy of evapotranspiration. Since this value is based on only few measuring points and the empirical method of Turc (1961) the results can only be regarded a rough approximation. The estimated *R%* are similar to the values given in the WRMP. For

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[4] Block numbers according to WRMP

the Middle Zambezi and the Lower Kafue Catchment *R%* amounts to 6% and 11%, respectively. The result for the Middle Zambezi Catchment, however, has to be looked at with caution because only 17% of the catchment area are within Zambia.

Table 8-5 Groundwater recharge estimates for catchments in SP

Block	**Catchment**	**Sub-catchment**	**Area [km^2]**		
			Total	In ZAM	In SP
BZ-7 & BZ-8	Middle Zambezi	Kalomo, Kariba Lake, Lusitu	154,780	26,315	26,315
BK-10 & BK-11	Kafue	Lower Kafue	49,461	49,461	32,619

Block	**P [mm]**	**ET [1)] [mm]**	**ΔQ [2)] [mm]**	**R [mm]**	**R%**	**R [Mm^3/a]**	**R [Mm^3/a] SP**
BZ-7 & BZ-8	747	673	-28	46	6.1	7,058	4,655
BK-10 & BK-11	783	673	-38	86	11.0	4,242	2,798

Notes: [1)] estimated using Turc (1961) equation, see Chapter 3.3 [2)] Data from YEC 1995b

Estimating the groundwater potential is a much more difficult task than assessing surface water potential (Chapter 4.4). Values of total volumes of groundwater that are sometimes calculated from estimates of aquifer thickness and porosity are misleading since they do not represent volumes that can actually be pumped from aquifers. Actual abstractions are limited by the hydraulics of the groundwater system rather than by stored volumes, and the well design which both control the drawdown in the well and aquifer. In order to be sustainable, groundwater abstractions must furthermore take environmental and economical impacts of lowering the groundwater tables into account in order to prevent the depletion or drying-up of springs and streams (refer to discussion in Chapter 8.1).

A reliable quantification of the groundwater resources of the SP is currently not possible due to the limitations of available data regarding in particular climate (e.g. evapotranspiration), groundwater recharge, groundwater flow dynamics and aquifer geometry (e.g. layering, vertical and lateral extensions). Currently available are the qualitative description and typical range of borehole yields and hydraulic characteristics of the identified aquifer system as described in Chapter 8.2.

Future investigations should perhaps focus on groundwater systems of smaller areas, like sub-catchments, with known conflicts between surface and groundwater users. If additional climatic and hydrological data and information on aquifers and seasonal groundwater level fluctuations are gathered an accurate conceptual hydrogeological model could be developed to simulate and assess the sustainable groundwater abstraction for this area.

8.5. SPRINGS

Unfortunately, springs in the Province have never been mapped systematically and were not included in the topographic maps at scale 1:50,000. A number of springs are known to exist in the Gwembe Valley along the escarpment. The locations of these springs are, however, often remote and difficult to access. They are associated with the various fracture and fault systems within the Karoo rocks, or occur at the contact between the Karoo and the Basement. Although some of the springs are perennial they are rarely used for water supply purposes. This may be related to the fact that springs are considered sacred places.

Zambia's hot and mineralised springs have been systematically investigated between 1971 and 1974 by Legg (1974). According to this reconnaissance survey report several important groups of hot springs can be found in the SP, namely the Bbilili hot springs in Kalomo District, the hot springs north of Choma, the hot springs of Lochinvar National Park and the Longola hot spring near Itezhi Tezhi (Figure 8-10).

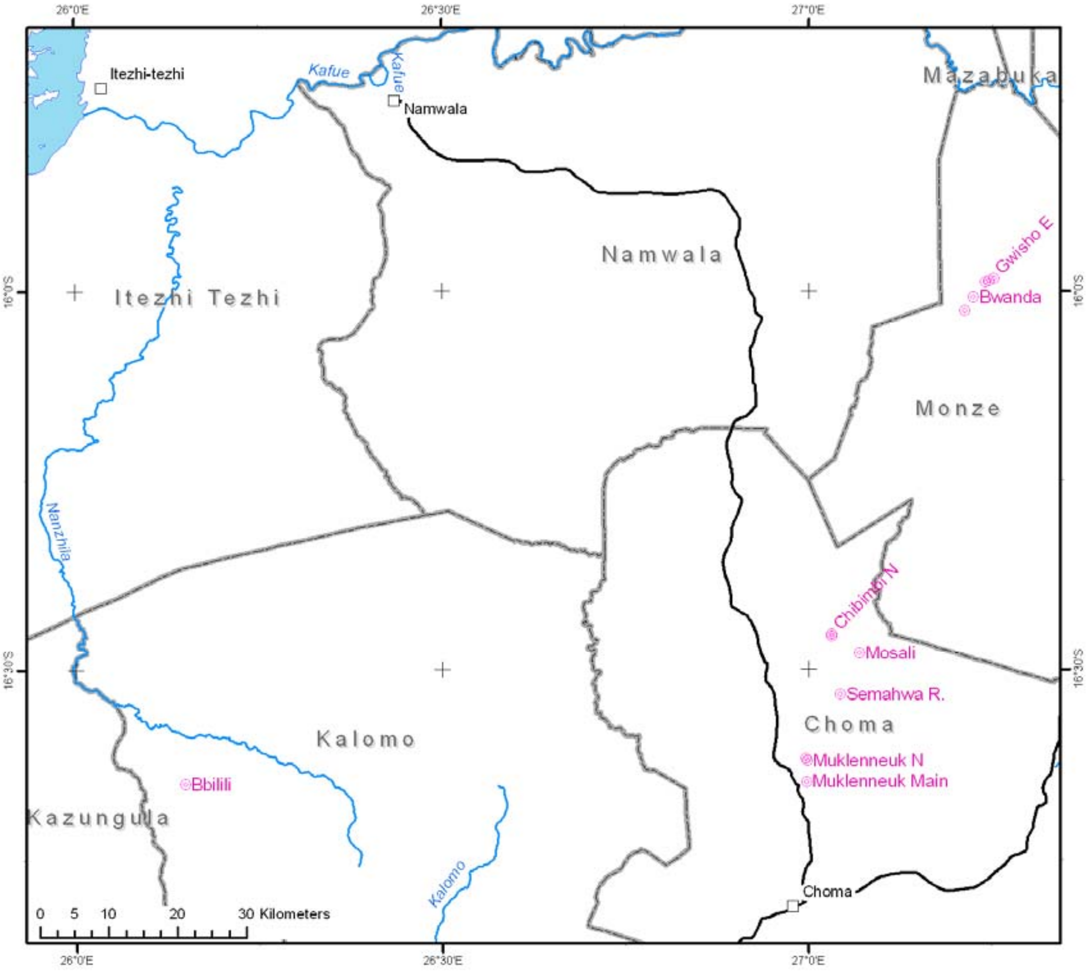

Figure 8-10 Location of hot springs in SP. The precise location of Longola spring is not known (see text)

The hot springs occur on major, probably deep faults within the Choma-Kalomo block or at the contact of Karoo sediments with Precambrian rocks. According to Legg, the spring water is likely of meteoric origin, heated by deep circulation in fault zones, and enriched in minerals by dissolution of minerals from the rock adjacent to the faults during the prolonged passage. High levels of sulphate are usually associated with leaching of Karoo sediments.

The **Bbilili hot springs** are located along the access road to the southern Kafue National Park from Kalomo at an altitude of approximately 1090 m asl. The springs occur at the contact along a fault separating Lower Karoo sediments to the north from rocks of Precambrian (Katanga?) age to the south. The two main springs yield 3 and 5 L/s and the water temperature is 30 and 62°C, respectively. The most abundant dissolved salt is sodium sulphate Na–SO_4 (TDS ca. 1000 mg/l).

The **Choma group of hot springs** include (from south to north) the *Muckleneuk Main* (6.3 L/s, 74°C), the *Muckleneuk North* (0.3 L/s, 44°C) and the *Sportsman's Den* springs (3.3 L/s, 48°C) on the Bruce Miller farm (no. 60a) , the *Semahwa* hot spring (1.3 L/s, 46°C) on the old Semahwa homestead farm no. 81a, the *Mosali* hot spring (0.4 L/s, 52°C) on farm Mosali (no. 37a) as well as the *Chibimbi North* (0.6 L/s, 58°C) and *South* (1.9 L/s, 48°C) springs on farm Chimbimbwe (no. 62a). The altitude of the spring outlets decreases in northward directions from 1218 to 1112 m asl. The springs are associated with north-south and east-south-east trending sets of faults and shear zones within the granitoidic and metamorphosed rocks of the Kalomo Batholith. Chemically, the springs are of the Na–SO_4/(HCO_3) type. The mineralization of these springs is comparatively low (TDS ca. 500 mg/l). At Muckleneuk Main spring, a large fluoride content of 7 mg/l is reported by Legg (1974).

The **Lonchinvar group of hot springs** include the *Bwanda* and *Gwisho* hot springs and the *Namulula* hot spring. The springs are located at 1000 to 1010 m asl. The Bwanda springs are the hottest in the Province with temperatures from 67 to over 90°C. The temperature of the Gwisho springs ranges from 45 to 72°C; the temperature of Namulula spring amounts to 52°C. Spring discharge estimates at Lonchinvar are not available. The water is generally of the Na–SO_4/Cl type, but the spatial and temporal variation in spring water chemistry appears more complex compared to the Bbibili and Choma hot springs. With TDS between 1500 – 2500 mg/l, these springs have the highest mineralization of the springs in the Province. The spring water is particularly rich in sodium (350-750 mg/l) and sulphate (340-1340 mg/l).

The strong **Longola hot spring** (10 L/s) that occurs on an extension of a north-south striking fault between Upper Karoo and rocks of the Hook Igneous Complex was exposed during the excavations of the Itezhi Tezhi dam and is presumably covered by the reservoir today. The springs are associated with a major fault zone consisting of a number of closely-spaced, sub-parallel faults that separate Karoo sediments overlain by alluvium to the north from Precambrian rocks to the south. The water is of the Na–SO_4/Cl type (TDS ca. 1500 mg/l).

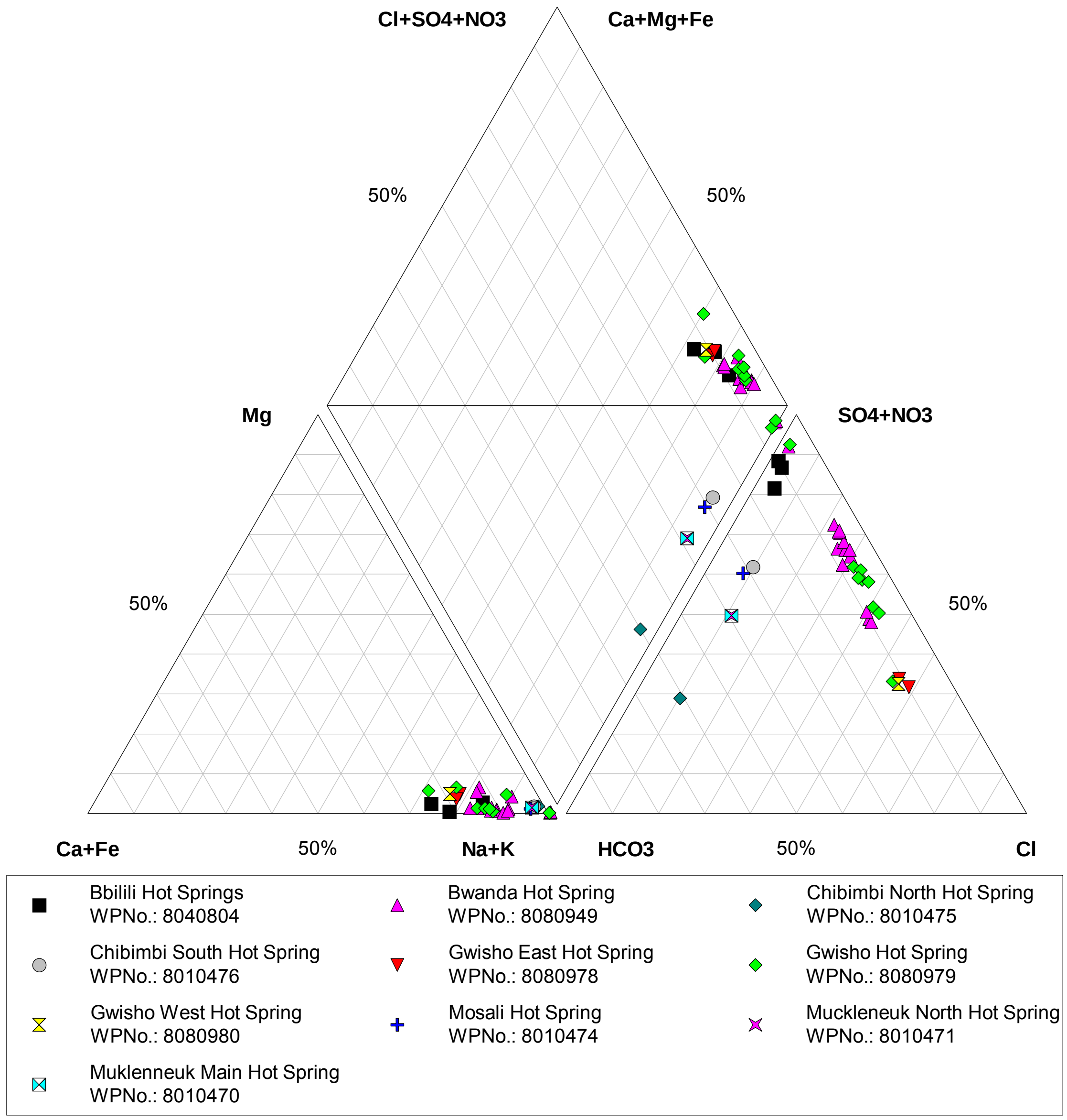

Figure 8-11 Piper diagram showing the major chemical composition of water from hot springs in SP (Data after Legg 1974)

8.6. GROUNDWATER LEVEL MONITORING

Continuous groundwater level monitoring data in the SP is extremely sparse. This is considered a matter of concern. At present groundwater levels are only measured by the DWA at the following three sites (Table 8-6):

Table 8-6 Sites with continuous data of groundwater level measurements in the SP

WP-No.	Name	East	South	Geology	Period	Frequency
8010477	Choma DWA-Stores	26.98153	16.81864	Kalomo Batholith	From 2004	Daily, discontinuous
8020413	Makuyu *)	27.88529	16.59698	Karoo sand- & mudstone	12/06/03 – 04/07/05	Daily, discontinuous
8100183	Lusitu	28.75094	16.19297	Karoo sandstone	From 18/10/2004	Nearly daily

*) at Munyumbwe, World Vision Properties (Mpamba 2007)

At this stage it is difficult to give advice on the establishment of future monitoring sites since such undertaking needs to be integrated into a national monitoring network that is currently under preparation. Considering the importance and size of the identified aquifer systems (Chapter 8.2), it seems necessary to establish monitoring sites within the Karoo sandstone, the Karoo basalt, the alluvial aquifer of the Kafue Flats and the extensive basement rocks. The Kalahari hosts another important aquifer system, which could be monitored at sites in Western Province. In this tentative proposal it is therefore recommended to establish at least four permanent groundwater monitoring sites in the SP (Figure 8-12):

1. In the Kafue Flats north of Mazabuka (Lower Kafue Catchment)
2. In the Karoo sandstone near Lusitu or Munyumbwe (Middle Zambezi Catchment)
3. In the Choma-Kalomo granites (Lower Kafue Catchment, close to catchment boundary)
4. In the Karoo basalt near Livingstone (Upper Zambezi Catchment)

If possible, existing sites (in particular at Lusitu and Choma) should be retained and technically upgraded. The sites should preferably be located near operating meteorological stations so that groundwater level fluctuations can be correlated to rainfall data.

The proposed sites are meant to be part of a national monitoring network. The main objective of such monitoring system should be to observe seasonal and long-term groundwater fluctuations. Daily measurements (with a standard water-level measurement device) would be sufficient for this purpose although modern data loggers should be given preference provided that qualified technical staff is available to read out and process data from the loggers.

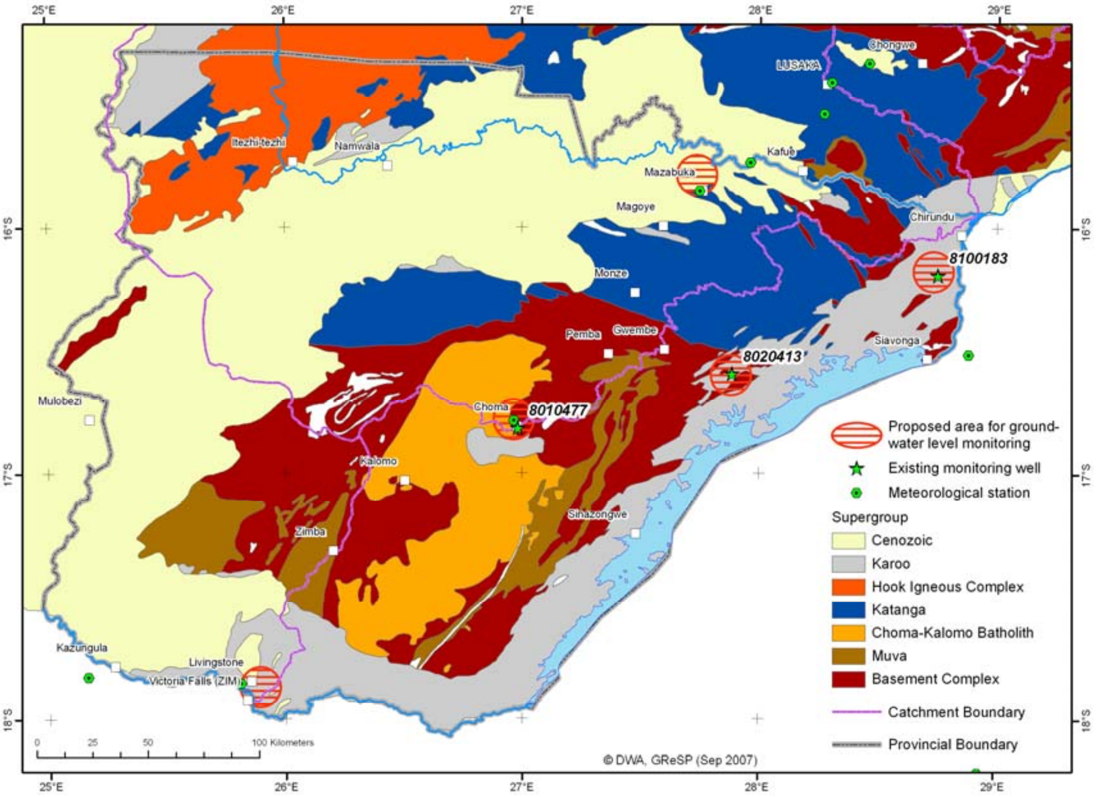

Figure 8-12 Proposed areas for future groundwater level monitoring in the SP

8.7. CHEMICAL GROUNDWATER COMPOSITION AND QUALITY

8.7.1. Groundwater Quality Sampling Campaign

Groundwater quality sampling under GReSP was carried out by sampling of 104 existing boreholes shown in the map in Figure 8-13. The boreholes were chosen on the basis of having supplementary hydrogeological data such as lithology, borehole depth, yield and construction details that could be used in the overall assessment of the groundwater resource. In addition, the spatial distribution was considered so that the whole Province could be covered as far as possible.

Individual tasks of sampling the campaign included the collection and preparation of groundwater samples for analysis at the laboratory and *in-situ* measurements of pH, redox potential, conductivity, dissolved oxygen and water temperature,

The objectives of groundwater quality sampling were to:

1. Orient Water Quality Officer(s) in groundwater quality sampling,
2. Identify groundwater quality risks,
3. Be able to characterize the overall groundwater chemistry

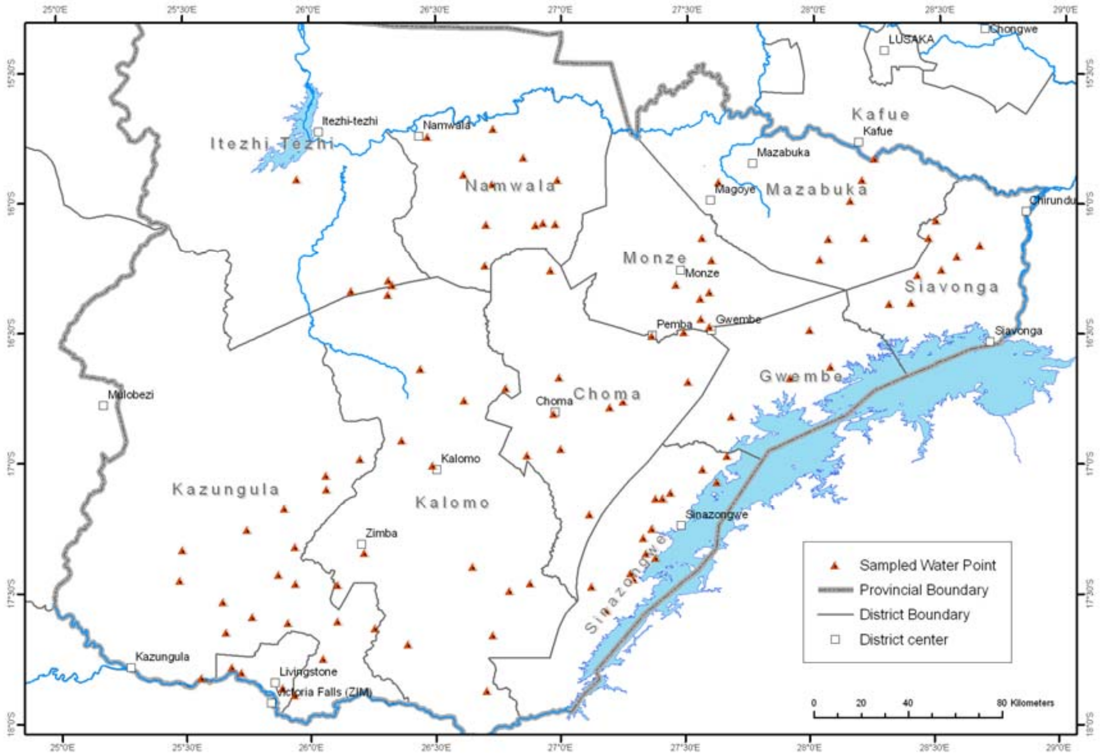

Figure 8-13 Map of boreholes sampled under GReSP

Sampling Methods

A total of five main sampling campaigns were carried out between December 2005 and March 2007 during which a total of 104 samples were collected from SP. Prior to these, three field visits were conducted to the study area and during the visits the Water Quality Officer was oriented in groundwater sampling and in-situ measurement of physico-chemical parameters, namely pH, redox potential, conductivity, dissolved oxygen and water temperature. As part of the orientation, the Officer was shown how to use the field data sheets and the sampling protocol (**Annex 5**).

At the sampling site groundwater was mainly collected by means of a hand pump. The sampling unit (consisting of a flow-through metallic box and other components, see Figure 8-14) was connected to the outlet of the hand pump by means of a hosepipe. The hosepipe was connected in such a way as to maintain an air-tight system in the compartment (inside the metallic box) where the probes for pH/Eh/temperature, conductivity and dissolved oxygen measurements were tightly inserted. The well was pumped prior to the start of measurement for up to 20 minutes. Then water was pumped through the box for an average of 15 minutes per borehole while taking readings at intervals of 3 minutes. Meanwhile an estimate of flow rate was made by collecting pumped out water in a standard container and noting, by a stop watch, the time it took to fill up. Flow rate was then calculated as volume of water (liters) divided by the time (seconds) it took to fill up the standard container.

Figure 8-14 Hydrochemical sampling at Siangwaze Village, WP-No. 8020189, in Gwembe District

The parameters considered in this project include the following:

- *In-situ* parameters: pH, electrical conductivity, dissolved oxygen, water temperature and alkalinity and CO_2 -acidity.
- Physical-chemical parameters measured at the laboratory: pH, electrical conductivity, total alkalinity, total hardness and total dissolved solids.
- Cations: sodium, potassium, calcium, magnesium, manganese and total iron.
- Anions: bicarbonate, sulphate, nitrate and chloride
- Heavy metals: arsenic, lead, zinc, and copper

The Fixed Endpoint titration method was used to determine the other *in-situ* parameters, namely, alkalinity and acidity (CO_2 acidity) in the unfiltered water samples. Alkalinity was determined by titrating with acid (HCl) down to a pH of about 4.5. Acidity was determined by titrating with base (NaOH) up to pH 8.3.

Sample Preservation, Conveyance and Laboratory Analysis

At each site, 2 x 50 ml plastic bottles (with concentrated nitric acid as preservative) and 2 x 500 ml or 250 ml plastic bottles for raw water samples were used to collect groundwater samples. The bottles were put in cool boxes and transported to Choma and later to Lusaka by road. Then one set of samples was flown to South Africa for analysis at the *Institute for Soil, Climate and Water (ARC laboratory)* through a commercial courier service. The other set was kept as a backup in case of loss or doubtful results. The storage time of the samples from collection to analysis ranged from 3 to 65 days as indicated in Table 8-7 below.

Table 8-7 Sampling campaigns in Southern Province carried out by GReSP

Campaign No.	Date of sample collection	Location by District	No. of samples collected	Laboratory analysis by
1	25/01/2006 to 28/02/2006	Mazabuka, Choma, Gwembe	15	ARC
2	17/03/2006 to 11/05/2006	Monze, Siavonga, Namwala, Choma	26	ARC
3	07/06/2006 to 09/07/2006	Kazungula, Livingstone, Kalomo	28	ARC
4	15/08/2006 to 07/09/2006	Sinazongwe, Choma, Gwembe, Kalomo	21	ARC
5	26/09/2006 to 29/09/2006	Kalomo, Choma, Kazungula, Gwembe, Itezhi-Tezhi	14	ARC, BGR (repeat, 10 samples)

Apart from the ARC laboratory in South Africa, the BGR Laboratory in Germany was used at one time to clarify results obtained from the ARC laboratory.

The results of the chemical analyses are presented in **Annex 6**.

8.7.2. Overall Groundwater Chemistry

The assessment of groundwater quality alongside quantity is essential to the sustainable development and management of groundwater resources. Through water chemistry, the chemical composition of groundwater is determined and used to evaluate the quality of a given groundwater resource with respect to the occurrence and flow of water in the subsurface. This in turn helps to explain environmental phenomena such as rock-water interactions. Knowledge of the chemical composition and quality of groundwater is essential to finding solutions to pollution problems.

The following hydro-geochemical characterization in terms of genesis and usability of groundwater in the SP is based on just above 100 groundwater samples, which are considered to be reliable and representative. Samples included in the analysis have an anion-cation balance of five percent (±5%) error or less. Note that water analyses of thermal springs as discussed in Chapter 8.5 were not included in the analysis since their chemistry was not considered representative to a larger area due to their naturally confined occurrence.

Major anion (HCO_3, SO_4, Cl, NO_3) and cation (Na, K, Ca, Mg) composition of the considered samples is typical for continental groundwater with primarily meteoric origin, shown by the accumulation of data in the left quarter (Ca/Mg- HCO_3) of the rhombus in the Piper-Diagram (Figure 8-15). Piper diagrams for selected individual lithological groups are given in Figure 8-16 confirming this result with the exception of the samples taken from mudstones.

Bicarbonate strongly dominates the anion composition of groundwater with equivalent concentration >50%meq (right triangle). Consequently, chloride and sulphate contents are below 40%meq, except for two samples. Samples of this type show only temporary hardness. This indicates the domination of meteoric influence in groundwater of the SP.

Major cation composition of the samples varies strongly between earth alkali (Ca, Mg) and alkali ions (Na, K), with a predominance of calcium. Particularly, the groundwater type from aquifer(s) of the “mudstone”- group has high sodium contents. Groundwater from aquifers allocated to the lithological groups „*shist or slate*“ and „*sandstone or meta-sandstone*“ are within the transition zone between alkali and earth alkali water.

These observations lead to the assumption that ion exchange reactions are responsible for local alkalinisation of groundwater, as indicated by the depicted trend line in the Piper diagram (Figure 8-15). Especially in weathering products of feldspar-rich igneous rocks, such as sandstone and silt/clay offer sodium-loaded mineral surfaces for ion exchange reactions ($Ca^{2+}/Mg^{2+} \leftrightarrow 2Na^{+}$). Aquifers with higher clay mineral content, such as mudstones, have high exchange capacities due to the large surface area of clay minerals. Combined with high residence times, typical for low permeable aquifer types, this leads to a general concentration of solutes and especially increased sodium content, which can be observed in the piper diagrams.

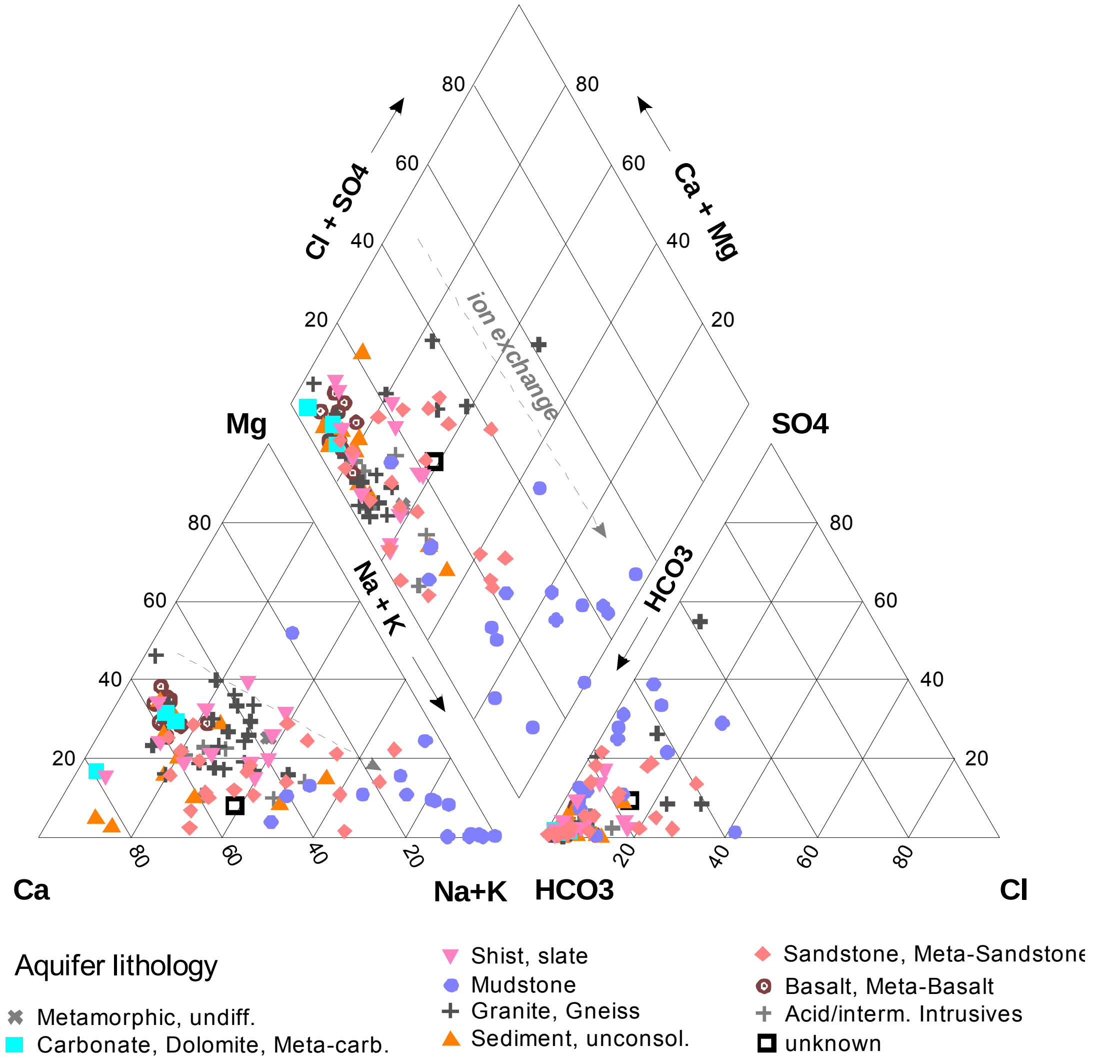

Figure 8-15 Piper diagram showing major composition combining anion triangle (right) and cation triangle to a rhombus (top). Grey arrow indicate trend with increasing impact of ion exchange processes.

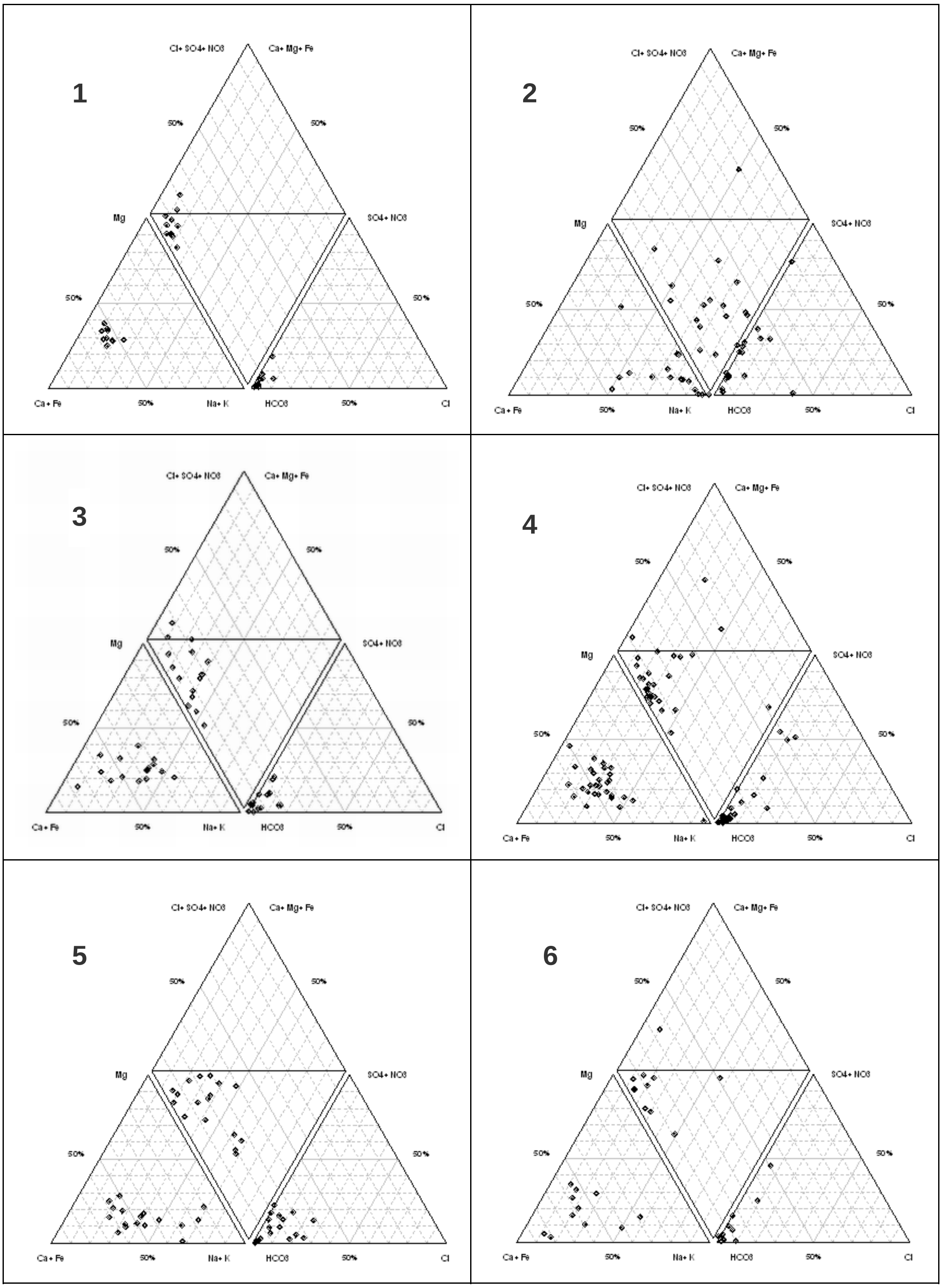

Figure 8-16 Piper diagrams for groundwater samples separated according to aquifer lithology:

1	Basalt and meta-basalt	2	Mudstone
3	Metamorphic rocks (undifferentiated)	4	Granitoidic rocks
5	Sandstone and meta-sandstone	6	Unconsolidated gravel, sand, silt and clay

8.7.3. Groundwater Contamination

The water quality is evaluated against the intended use of water for instance, domestic (including drinking water), industrial and agricultural purposes. In many countries specified guideline values or standards exist for the various types of water usage. In Zambia, only standards for drinking water have been developed. Water for other uses is normally assessed based on international guidelines such as the World Health Organisation (WHO 2006), the European Union (EU) guidelines and national standards such as the South African Water Quality Guidelines (SABS) and the Australian Aquatic Ecosystem Guidelines. In this report the water quality guidelines applied are the Zambian Drinking Water Standards (ZDWS) developed by the Zambia Bureau of Standards (ZBS 1990). Where values are missing, the WHO, EU or the SABS guidelines are used.

The overall groundwater quality in SP with respect to the chemistry is generally good as seen from both the existing and new data collected during the period of implementation of GReSP. Nevertheless about 10% of the boreholes that were reliably analysed were found to be unsuitable for drinking according to the ZDWS. Chemical parameters exceeding the respective national standard include sodium, nitrate, manganese, and heavy metal content.

Some data sets showed some unusual high values for minor constituents, especially for lithium, manganese, lead and zinc. This is possibly due to contamination of the sample or by laboratory errors. Only in obvious cases data correction was possible, still existing data errors which are less obvious could not be excluded.

Groundwater Salinity

Soil salinity is a worldwide problem with increasing relevance especially in developing countries. Beside climatic and hydrologic reasons one major source may be high salinity of irrigation water. Furthermore, high sodium content may lead to a clogging of clay mineral fraction in agricultural soil, leading to a strongly decreased water percolation and field capacity of soil.

High sodium content (>200 mg/l) was found mostly in the Zambezi Valley which represented about 9% of the boreholes analysed. All of these boreholes had high EC values too, that is, above 1000 µS/cm and they are all in the sand-, silt- and mudstone types of lithology (Figure 8-18).

In the Wilcox diagram (Figure 8-17), salinity of groundwater is expressed as conductivity, measured in field and the sodium hazard (sodium adsorption ratio, SAR) derived from the absolute sodium content. It is obvious that most samples are in field S1-C2 and therefore suitable for irrigation purpose. Nevertheless, a few samples have too high salinity and/or sodium content. The Wilcox diagram suggests that sodium and salinity hazard of groundwater sampled from “mudstone” aquifers may be high to very high and, therefore, generally not suitable for irrigation purpose.

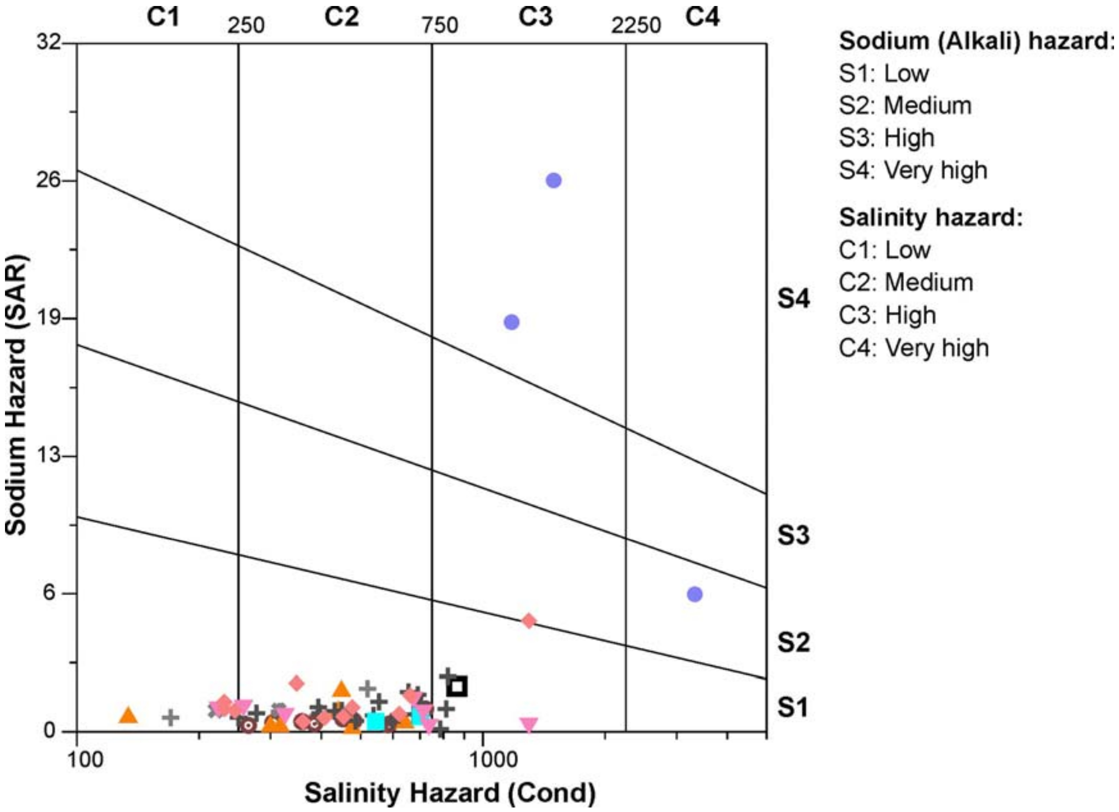

Figure 8-17 Wilcox diagram categorizing sodium and salinity hazard of sampled groundwater when used for irrigation purpose. Symbols represent lithology, see Figure 8-15. Note that not all samples of Figure 8-15 are displayed due to missing measurements of electric conductivity.

Groundwater Toxicity

In this section identified contaminants with toxic or extremely high values are discussed. The WHO drinking water guideline recommendations are added wherever threshold values for toxicity are lower compared to the ZDWS.

Arsenic (As)

About 97% of the considered water quality data pass the valid Zambian threshold for drinking water (50 µg/L), however, 25% of samples fail to comply the WHO guideline (10 µg/L). Moreover, uncertainty is remarkable in several samples where the applied analytical method is not sufficient to check the WHO guideline due to high detection limits such as 20µg/L.

Arsenic is widely distributed throughout the Earth’s crust, and therefore introduced into drinking-water sources primarily through dissolution of or desorption from naturally occurring minerals and ores. There are a number of regions, especially Southeast Asia, South America and mining districts with sulphide mineralization, in where arsenic may be present at elevated concentrations in groundwater. Elevatet levels of arsenic in drinking-water are a significant cause of health effects, predominantly skin and cancer diseases.

Lead (Pb)

Almost 27% of the considered groundwater samples fail the drinking water limit (10 µg/L) for lead recommended from WHO and some (6%) even fail the higher Zambian threshold value (50 µg/L). Please note that the real number of Pb-contaminated samples may be even higher, because for significant number of samples, lead has not been observed or the detection limit is not low enough (e.g. 20 µg/L) to exclude toxic levels. High dissolved lead occurs mainly in groundwater from acid and basic igneous and metamorphic rocks. A natural source may be dissolution of Pb-containing sulphides, possibly occurring in fine-grained and bituminous sediments or zones of hydrothermal mineralization. Furthermore, high lead concentrations may result from anthropogenic waste, such as lead-acid batteries, solder and alloys.

Lead is considered to be a general toxicant that accumulates in the skeleton and is very toxic especially in case of children and pregnancy, because infants adsorb four to five times more lead in comparison to adults. Adverse affects of lead are various, including neurological, behavioural and cognitive effects and cancer diseases.

Fluoride (F)

Fluoride levels are known to be increased in groundwater along the East African Rift (BGS 2001). In SP higher fluoride levels have been found in some thermal springs including Muckleneuk hot spring (Chapter 8.5).

Only few (4%) groundwater samples fail the ZDWS of 1.5 mg/L, with more than 3 mg/L as the highest fluoride content found in the considered groundwater samples. Generally, the fluoride levels are quite low in SP and do not represent a major health problem for drinking water.

Fluoride is considered to be essential especially during growth of skeletal tissues (bones and teeth). Nevertheless, several studies clearly establish that continuous uptake of high fluoride concentrations lead to disturbance of skeleton growth. In many regions with high fluoride exposure, fluoride is a significant cause of morbidity.

Iron and Manganese (Fe, Mn)

Even after excluding doubtful values manganese concentrations in 7% of the samples exceed the Zambian threshold of 0.3 mg/L. Manganese is naturally occurring in many surface and groundwater sources, particularly under anaerobic or low-oxidizing conditions. According to WHO, greatest exposure to manganese is usually from food. Manganese is an essential element for humans and other animals. Adverse effects can result from both deficiency and overexposure. Few epidemiological studies report adverse neurological effects following extended exposure to very high levels in drinking-water.

The iron content of 11% of the samples exceeds the local drinking water threshold (1 mg/L) and reaches values up to four milligram per liter. This is not surprising in groundwater exposed to reducing environment and does not have adverse health effects. Nevertheless, consumers may complain about taste and weak digestion problems or discolouration of laundry, which are usually accompanied with higher iron concentrations. Although most of the boreholes located in the sandstone areas had high iron content, the metal is fairly spread out among other lithological units such as gneiss, granite and schist but in lesser amounts.

Nitrate and Nitrite (NO_3, NO_2)

The Zambian standard for nitrate in drinking water is 50 mg/L. About 4% of all considered samples fail the threshold with maximum concentrations exceeding 100 mg/L. In only one sample (Kalomo-GKW, WP-No, 8040655) the more toxic degradation product nitrite does fail the valid detection limit 0.2 mg/L. The measured nitrate and nitrite concentrations were 244 mg/l and 0.25 mg/l, respectively. The well is reportedly not in use and should not be reconnected for drinking water supply.

The primary health concern regarding nitrate and nitrite is the formation of the so-called “blue-baby syndrome”, affecting mostly infants and children. In their stomach, nitrate is reduced to nitrite, and nitrite is able to oxidize haemoglobin, and therefore restricts oxygen transport around the body.

Nitrate and nitrite are naturally occurring anions that are part of the nitrogen cycle. Nitrate is used mainly in inorganic fertilizers. The nitrate concentration in groundwater and surface water is normally low but can reach higher levels as a result of leaching or runoff from agricultural land or contamination from human or animal wastes as a consequence of the oxidation of ammonia and similar sources. The high nitrate content in the Kalomo-GKW well and two others in Mazabuka Town (WP-No’s 8070707 and 8070710) could be attributed to contamination from one or more of the possible causes mentioned above.

8.7.4. Regional Distribution Patterns

Regionalization of data proved difficult due to lack of information on filter depth in some cases, and the low sample density within the 50,000 km^2 large area (~1 sample/50 km^2) in general. Furthermore, lithology information of samples taken from borehole reports was not always consistent with the geological map 1:100,000. For these reasons, the following results may be indicative of a general pattern but need to be verified in the future using more comprehensive chemical and lithological data.

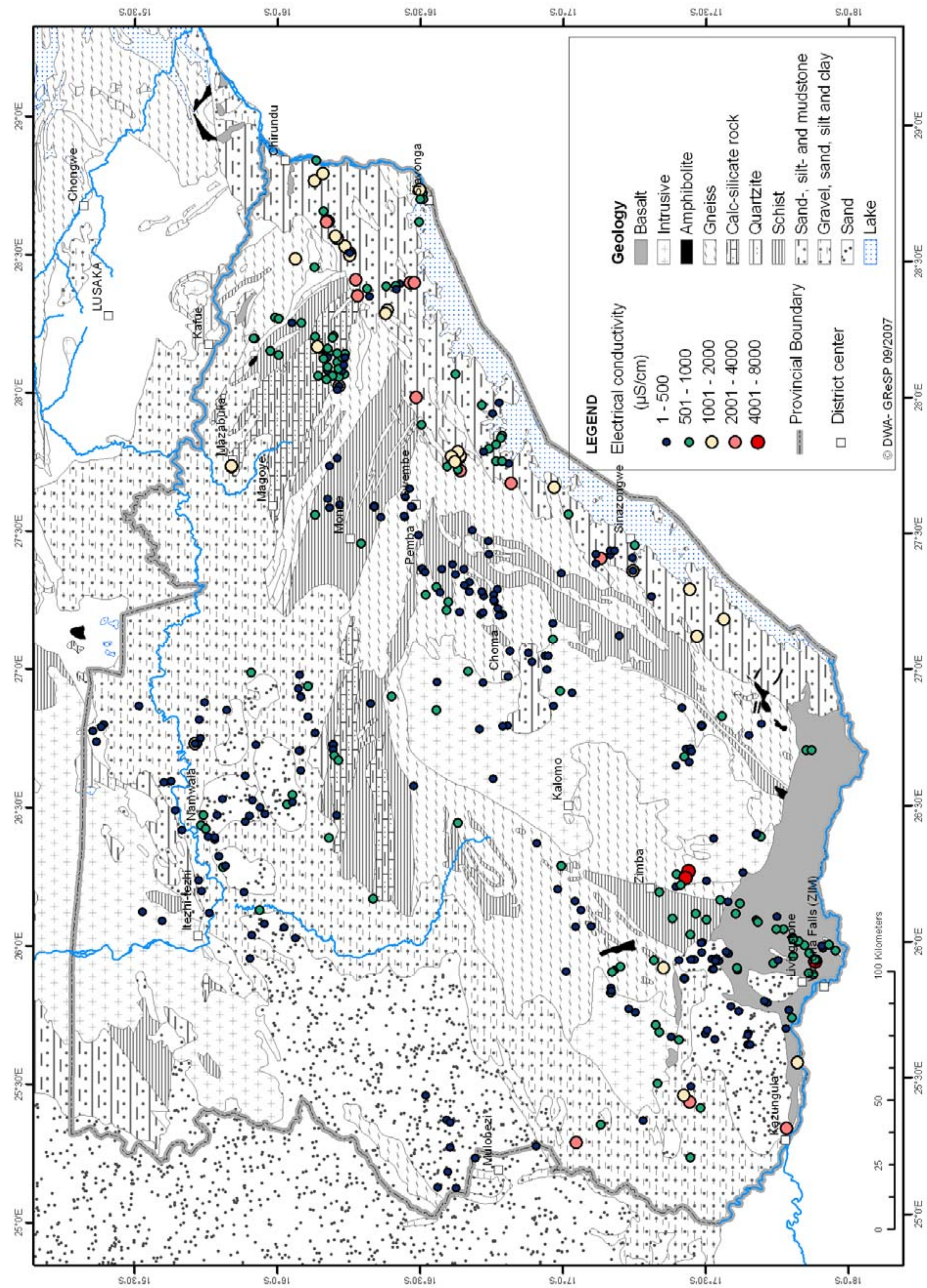

Figure 8-18 Regional distribution of salinity of groundwater expressed in electrical conductivity

Regionalization of chemical parameter based on the considered data set show only general spatial relationships. However, samples of Na-HCO_3 water type observed for the “mudstone” groundwater accumulate in the southeast of SP (escarpment), where fine-grained Karoo-Sediments crop out. A more detailed regionalization is inhibited by the spatial hydrochemical variability of the groundwater. For instance, samples 8110431 and 8110432, located within 200m distance from each other, show a significantly different hydrochemical composition and associated lithology. However, according to the geological map they fall into the same stratigraphic unit.

To achieve an advanced regionalization of chemical groundwater composition and to derive “hydro-genetic” interpretations a higher sample density and more precise well information are needed.

Boreholes in the southern parts of the Province represented by the granitoid and basalt lithological units yielded water with relatively low electric conductivity (EC), that is, less than 1000 µS/cm. The percentage of boreholes producing water with conductivity exceeding 1000 µS/cm is 12%, but most of the samples still fall below the Zambian drinking water standard of 2300 µS/cm. The areas along the Zambezi Valley in Sinazongwe, Gwembe and Siavonga Districts host groundwater with very high EC values ranging from 1100 µS/cm to 3400 µS/cm (Figure 8-18). The associated geology was mostly composed of sandstone, mudstone and partially, gneiss. Groundwater with elevated EC (>1000 µS/cm) was also encountered in the south-western part of the Province that is covered by Kalahari sands.

One sample (Bbondo Clinic) is remarkable due to its high solutes content and is failing the local threshold for EC (>3000 µS/cm) and sulphate (>>400 mg/L). The high sulphate levels could be explained to coal occurrences in the vicinity of the well since coal is often rich in sulphide. Even when no direct adverse health effects are reported with high sulphate content, long-term consumption of this brackish groundwater is not recommended.

8.7.5. Waterborne Diseases

Water-related diseases according to the World Health Organization (WHO 1992) mean *“any significant adverse effects on human health, such as death, disability, illness or disorders, caused directly or indirectly by the condition, or changes in the quantity or quality, of any waters”*. Waterborne diseases arise generally from the contamination of water by pathogenic viruses or bacteria, which are transmitted when water is consumed or used in preparation of food. Waterborne diseases reported in the SP during 2005 are gastro-intestinal diseases like diarrhoea, dysentery, and occasionally cholera. The diseases are mostly caused by contamination of water or food by excreta. Schistosomiasis (bilharzia) is caused by certain types of snails that carry the pathogen and its appearance is linked to surface water as the infection is commonly transmitted during wading or swimming in lakes, ponds or other surface water bodies.

In 2005, suspected **cholera** cases totalled 18 incidences. 11 infections have been reported by hospitals in Livingstone District, three by hospitals in Siavonga District and two each in Choma and Mazabuka District.

According the Ministry of Health Annual Health Statistical Bulletin (MOH 2005a), the SP had the highest number of incidences of suspected **dysentery** of all Zambian provinces. The highest number of incidences (>20 per thousand admissions) in 2005 within the SP was reported from the Gwembe and Sinazongwe districts (MOH, pers. comm.). In the central districts Monze and Choma, particularly high numbers of suspected dysentery cases have reportedly occurred in local hospitals of the towns of Monze and Choma. In total, more than 17,000 cases of dysentery were reported in the SP. Generally, children under five years are most heavily affected by dysentery (Figure 8-19).

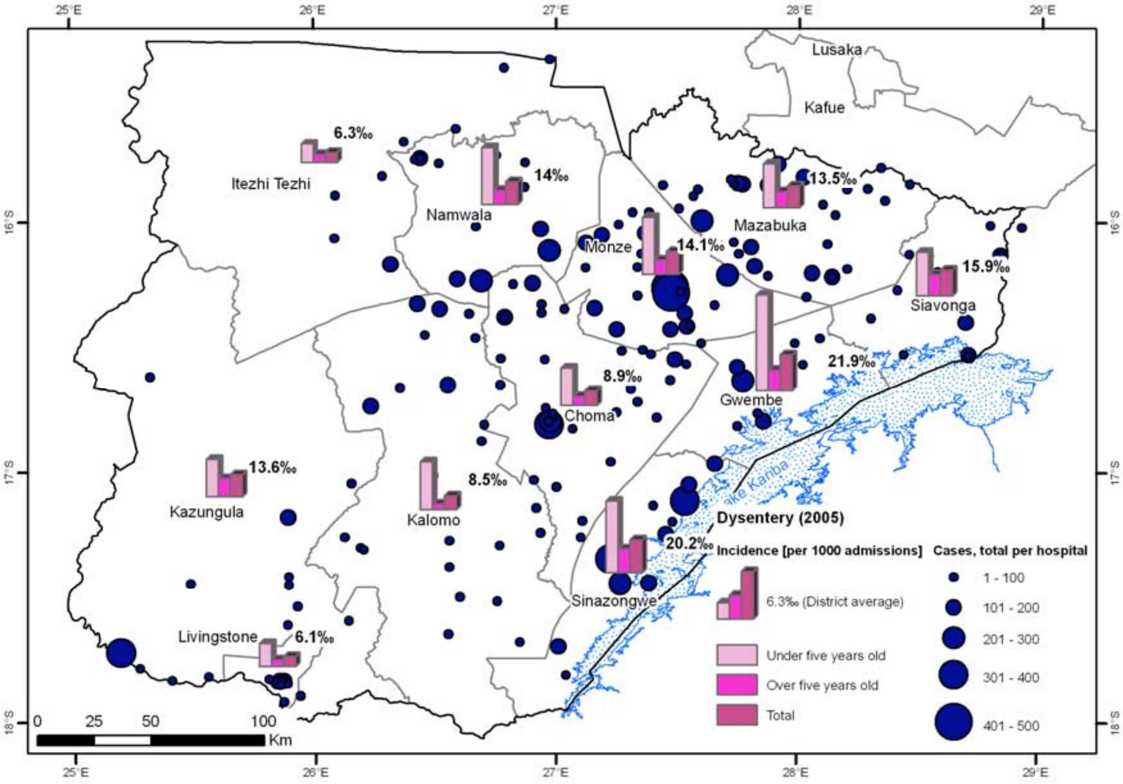

Figure 8-19 Incidence of suspected **dysentery** per thousand admissions in each district and total cases of suspected dysentery reported by hospitals in 2005 (Source: MOH).

The number of **diarrhoea** infections is much higher compared to other waterborne diseases. In 2004, the SP had the highest case fatality rate of diarrhoea (134 per 1000 admissions) compared to other provinces, and the rates were higher in both the under 5-years age group and the age group 5-years and above (MOH 2005b). In 2005, the total number of reported cases in 2005 was 113,000. The highest number of infected persons in the SP was reported by the Namwala urban health centre with 2,563 incidences. High infection rates also occurred in districts which are located along the major rivers Kafue and Zambezi or Lake Kariba. Like for dysentery, children under the age of 5 years were particularly affected. They yield the highest number of infections causing diarrhoea in each district (Figure 8-20).

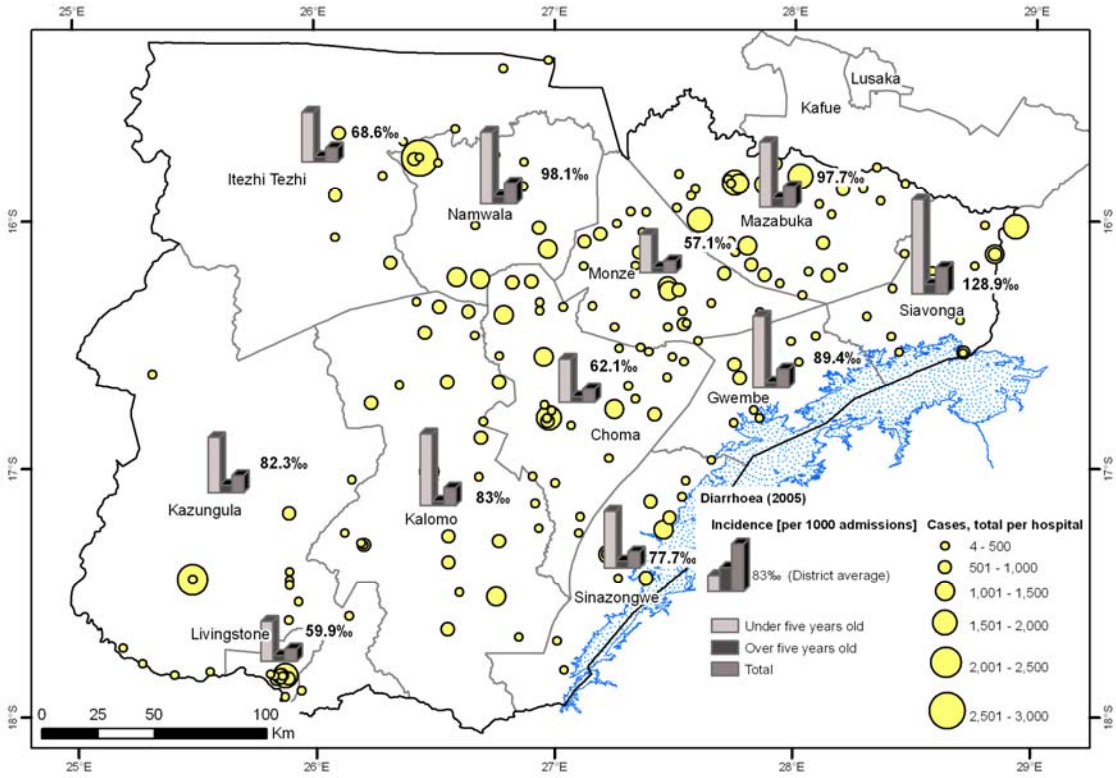

Figure 8-20: Incidence of **diarrhoea** per thousand admissions in each district and total cases of diarrhoea reported by hospitals in 2005 (Source: MOH).

Schistosomiasis is generally less common than dysentery. The highest total number of cases was reported in 2005 for Choma District (1025 of a total of 6025 reported cases). Not unexpectedly, the highest infection rates per capita occurred in the districts along Lake Kariba. For schistosomiasis the incidences among children under 5 years are in all districts lower than for people exceeding this age (Figure 8-21).

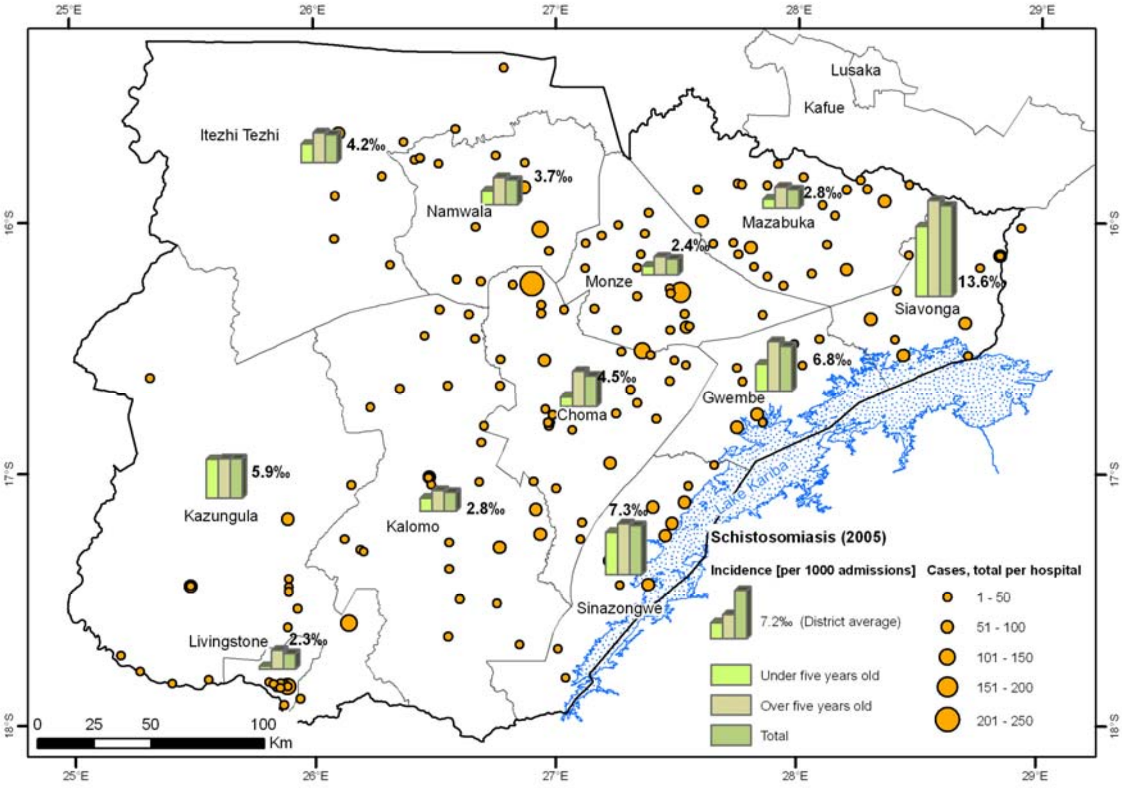

Figure 8-21: Incidence of **schistosomiasis** per thousand admissions in each district and total cases of schistosomiasis reported by hospitals in 2005 (Source: MOH).

Generally waterborne diseases occur most frequently in the rainy season (November to April) when more cases are reported than in the dry season (May to October) due to contamination of drinking water sources by the combined effect of surface runoff and poor sanitation conditions. Particularly cholera has been found to be a menace near water bodies during the rainy season. Such areas are associated with fishing activities which attract a lot of people who settle along the shores of the lakes or rivers. Usually the fishing camps have poor sanitary conditions thereby increasing the risk of outbreaks of waterborne diseases. Examples of cholera prone areas are Lake Kariba catchment and the Kafue Flats. However, when compared to non-blood diarrhoea, cholera rarely occurs. Non-blood diarrhoea is the third commonest disease in the province and it is prevalent throughout the year. According to the recent ZVAC (2007) survey, diarrhoea is mainly caused by poor hygiene practices in households.

A study by Simoonga *et al* (2003) revealed that the transmission of urinary schistosomiasis in Zambia and hence SP can be all year round, but with varying intensities during different seasons and that SP along Zambezi River was among three provinces (besides Western and North-Western) with the highest transmission potential in the country. The study covered areas around Lake Kariba and Kafue Flats.

8.7.6. Water Quality Discussion

It is likely that groundwater sources in SP are not as badly affected by contamination as surface water sources when health statistics and chemical data for the province are regarded. The most waterborne disease-prone areas are situated along surface water bodies e.g., Kafue Flats (Namwala, Mazabuka Districts) and Lake Kariba (Siavonga, Gwembe, Sinazongwe).

Considering the significance of groundwater for supplying drinking water (see Chapter 6.2), the protection of the groundwater resource from contamination in the Province is critical to the sustainable provision of safe and clean water. Improved water sources that facilitate the access to clean and safe water comprise boreholes, protected wells or springs while unsafe sources include rivers or lakes and unprotected wells and springs.

The threat of groundwater contamination due to poor sanitation in the Province is real. For instance the ZVAC Survey in June 2007 revealed that access to improved sanitation is generally poor and that on-site sanitation in form of traditional pit latrines is the commonest means of excreta disposal. On-site sanitation has been shown to contribute to groundwater contamination especially in limestone aquifers, e.g., in Lusaka where septic tanks and pit latrines are common, a number of boreholes and shallow wells have been found to have elevated levels of nitrate beyond the drinking water standard value of 50mg/l (as NO_3). Another example is in Mazabuka Town where two boreholes (see above) located in an area with on-site sanitation, were found to have high nitrate content. This area is also underlain by calc-silicate rocks that are generally very vulnerable to pollution. Areas around the Nakambala Sugar Estate are also expected to have high nitrate in groundwater due to consistent application of inorganic fertilizers in the sugar plantation.

8.8. GROUNDWATER VULNERABILITY

Groundwater vulnerability in this context means "*vulnerability of groundwater to contamination*". The concept of groundwater vulnerability was introduced into hydrogeology by Margat (1968). In the past 40 years several concepts and methods for vulnerability mapping have been developed. Today *intrinsic vulnerability*, which is independent of a specific contaminant or group of contaminants and the contamination scenario, is distinguished from *specific vulnerability* which relates groundwater vulnerability to certain contaminants and contamination scenarios. Furthermore, a distinction is made between *source* and *resource* protection meaning protection of water abstraction points (springs or wells) and protection of the groundwater resource in general, respectively.

In the following, the term vulnerability always refers to intrinsic vulnerability of the groundwater resource.

For vulnerability mapping in the SP the German so-called GLA-Method was applied. The method was proposed by Hoelting et al. (1995). The method is appropriate for all kinds of groundwater systems but has some shortcomings for karst aquifers.

Fortunately, pure karst aquifers are of minor importance within the SP, and the application of the GLA-Method hence appears appropriate.

The GLA-Method estimates the effectiveness of the unsaturated zone to protect the groundwater from adverse effects. The unsaturated zone is herein subdivided into three compartments: soil, subsoil and hard rock. The subsoil is referred to as unconsolidated deposits. In practice, all layers between the surface and the groundwater table that can be distinguished by their individual hydraulic properties are considered. The GLA-Method classification defines the degree of vulnerability in relation to the mean transit time of percolating water in the unsaturated zone. It is worth noting that this relation is only an approximation.

The assessment scheme considers the following parameters:

➢ Soil: effective field capacity	Parameter S
➢ Percolation rate	Parameter W
➢ Rock type	Parameters R_u, R
➢ Structure of hard rocks	Parameter F
➢ Thickness of each stratum	Parameter T
➢ Perched aquifer	Parameter Q
➢ Artesian conditions	Parameter HP

The overall protective effectiveness P_T (this is the “reciprocal” meaning of vulnerability) of the unsaturated zone is calculated by using the relation:

$$\mathrm{P_T} = \left(S * T + \left(R_u * T_u + R_1 * F_1 * T_1 + \ldots R_n * F_n * T_n\right)\right) * W + Q + HP$$

where R_u stands for the unconsolidated rock and $R_1 \ldots R_n$ for the individual hard rock layers within the unsaturated zone. If more than one unconsolidated layer is present all others are incorporated accordingly.

In General, the vulnerability is strongly dependent on the thickness of the unsaturated zone. Unfortunately, the density of boreholes with water level information is rather limited for the SP. Furthermore, the spatial distribution of the boreholes is strongly clustered and information concerning soil cover is rather insufficient for detailed vulnerability mapping. For this reason a reliable and detailed vulnerability estimation based on a conceptual hydrogeological model of the SP’s aquifers is not possible. Hence, a rather approximate assessment of the vulnerability of the groundwater resource based on the GLA-Method is implemented. The resulting map therefore shows a more general estimation of vulnerability and does not substitute more detailed local studies for land use planning.

The vulnerability map of SP is based on the regional model of groundwater levels using the borehole database in order to calculate the thickness of the unsaturated zone (Chapter 8.3). Soil properties were estimated by consulting the Zambia soil map. The thickness of the soil layer (**Parameter T**) was assessed by analysis of borehole data (Chapter 2.3). A conceptual model of the subsoil cover distribution could not be realized due to the poor data density. The thickness of the unsaturated hard rock was calculated by subtracting the thickness of the soil layer from the total depth of the unsaturated zone. It follows that the vulnerability map is only based on the soil cover and the unconsolidated as well as the hard rock lithology according to the geological maps. In this simplified approach neither perched aquifers nor artesian conditions where considered.

The protective function of the soil cover is estimated by its effective field capacity (**Parameter *S***). S (Table 8-8) refers to 1m soil and is therefore multiplied by the soil thickness *T*. The higher the effective field capacity, the more water can be stored and consequently the more effective is the protective function of the soil column.

Table 8-8 Assessment of the Parameter *S* according to the effective field capacity per 1m thick soil column.

ΣeFC [mm] down to 1m depth	Parameter S
>250	750
>200 – 250	500
>140 – 200	125
>90 – 140	125
>50 – 90	50
<50	10

According to YEC (1995a & 1995b) groundwater recharge in Zambia is estimated to vary between 8 and 10% of the annual rainfall. Hence, the assessment of the percolation rate (**Parameter *W***) is based on the interpolated rainfall data (Chapter 3.2) with an average rate of 9%. According to this estimation groundwater recharge lies between 50 and 100 mm/a in the SP. Consequently, a value of 1.75 is applied as parameter *W* to the whole SP (Table 8-9).

Table 8-9 Classification of the Parameter *W* according to the percolation rates (groundwater recharge).

Percolation rate [mm/a]	Parameter W
>400	0.75
>300 – 400	1
>200 – 300	1.25
>100 – 200	1.5
<100	1.75

The consolidated rocks (bed rocks) above the groundwater table are estimated according to their lithological and structural characteristics (**Parameters *R* and *F***). The GLA-Method uses the following assessment scheme (Table 8-10):

Table 8-10 Assessment and classification of consolidated rocks and their structural characteristics.

Rock type	R/R_u
claystone, slate, marlstone, siltstone	20
sandstone, quartzite, volcanic rock, plutonic rock, metamorphic rock	15
porous sandstone, porous volcanic rock	10
conglomerate, breccia, limestone, tuffaceous limestone, dolomitic rock, gypsum rock	5
Unconsolidated rock	25

Structure	F
non-jointed	25
slightly jointed	4
moderately jointed, slightly karstic	1
moderately karstic	0.5
strongly jointed, fractured or strongly karstic	0.3
not known	1

Despite the fact that some formations include significant proportions of limestone or dolomite the structural characteristics for the majority of hard rocks were rated with a value (for *F*) of 4. For the limestone and dolomites no information on karstification is available and therefore a value of 1 was chosen for *F*. For the marbles and calc-silicate rocks of the Katanga Supergroup an intermediate value of 2 was chosen to consider variable degrees of fracturing and karstification due to variable compositions of the bed rock.

Values for lithology (*R*) were applied using Table 8-10. In accordance to the GLA assessment scheme a R_u-value of 25 was allocated to unconsolidated sedimentary deposits. For unconsolidated rocks no structural factor is necessary.

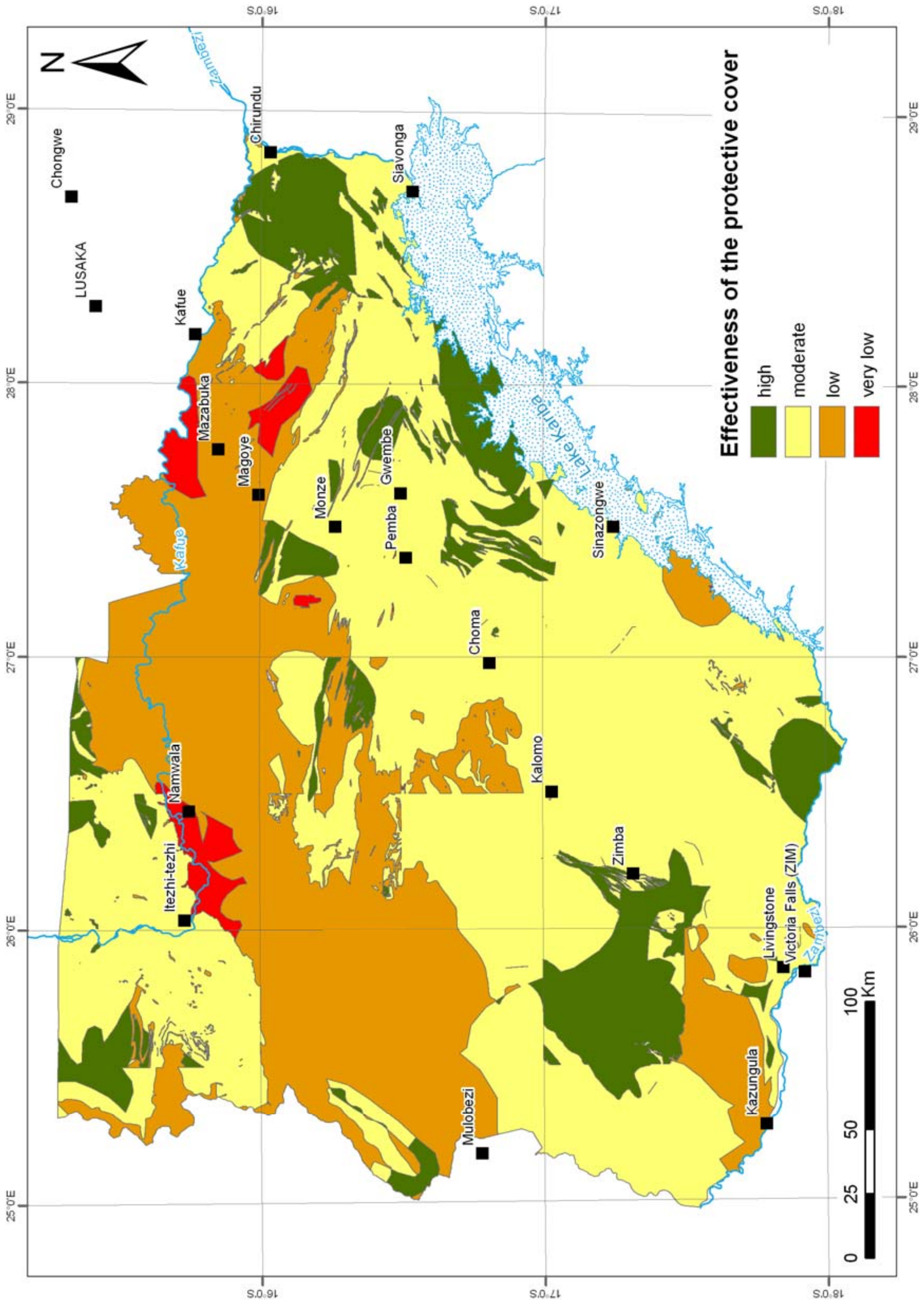

Figure 8-22 Effectiveness of the protective cover (vulnerability map) in the SP.

The distribution pattern of the vulnerability map reflects on the one hand the geological distribution and on the other hand the spatial pattern of the depth to groundwater table. Low protective (high vulnerable) covers according the GLA-Method are formed by semi- to unconsolidated rocks of the Kafue Flats and the Cenozoic rocks partly including the sediments of the Kalahari Group. Very low protective (very high vulnerable) are some alluvial areas along the Kafue River with rather shallow groundwater tables. Most of the granitoids and metamorphic rocks of the Choma-Kalomo Block, the Hook Igneous Complex and the Katanga Supergroup are classified as moderate protective (vulnerable). The calc-silicate rocks of the Katanga Supergroup southeast of Magoye and Mazabuka are an exception. These rocks are classified to be low protective due to their possibly higher degree of fracturing. In summary, high protective (low vulnerable) covers are associated with high depths of groundwater table and granitoids and metamorphic rocks. High protective covers are found west of Zimba, southeast of Pemba and Gwembe, west of Chirundu and to a minor extent within the Hook Igneous Complex (Figure 8-22).

In total, the vulnerability map distinguishes well between the semi- and unconsolidated rocks on the one hand and the magmatic and metamorphic rocks on the other hand. The differences within the groups are mainly due to the varying thickness of the unsaturated zone. This involves the major source of uncertainty as the interpolation of soil thickness and groundwater table gives only a rough approximation of the real and time-dependent distribution pattern.

8.9. HYDROGEOLOGICAL MAPS

The only hydrogeological map available in Zambia prior to this study is at scale 1:1.5 Mio (Mac Donald and Partners 1990). This map provides an appropriate classification of Zambia’s aquifer systems and a very good general idea of overall hydrogeology at national scale. The groundwater information the map is based on, however, is largely taken from Chenov’s report and data (1978) and hence, somewhat outdated.

The hydrogeological maps developed in this Phase are at **scales 1:250,000** (three sheets) and **1:100,000** (one sheet). They are designed to display the hydrogeology at catchment and sub-catchment scale. All information displayed is available in digitised format (ArcGIS feature classes). The maps cover more than 75% of the total Provincial area (Figure 8-23).

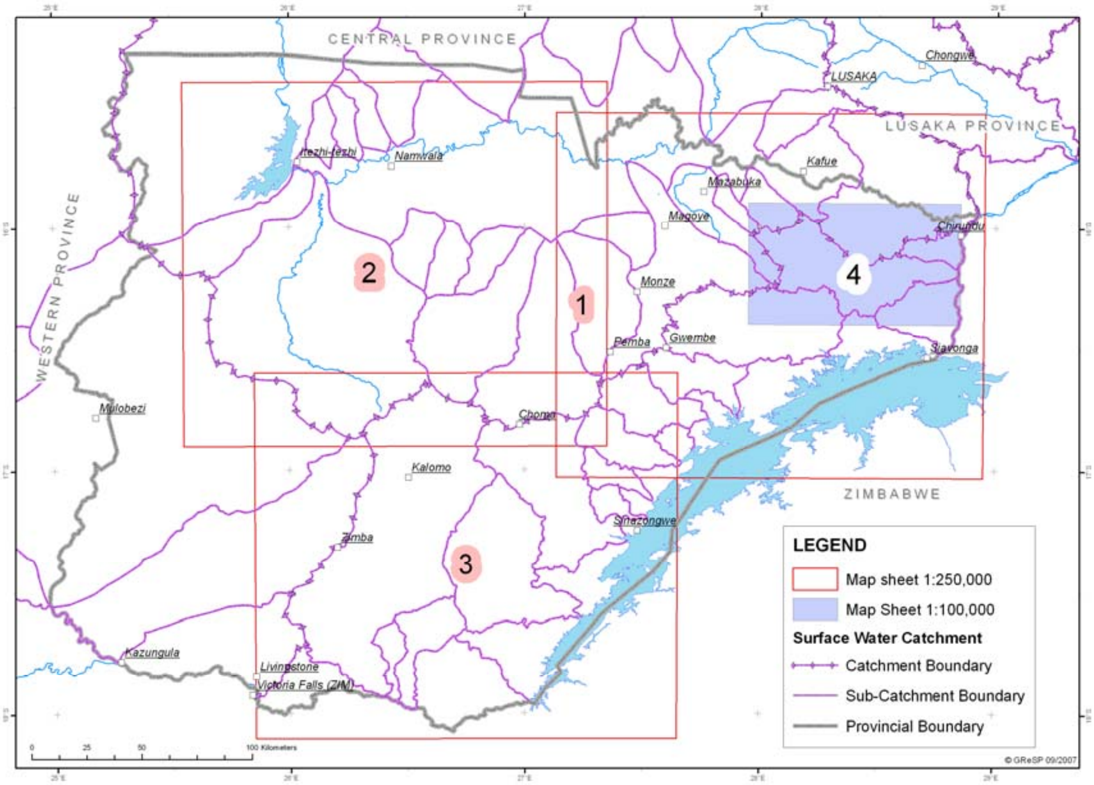

Figure 8-23 Hydrogeological map sheets:
1 Northern Kariba Lake and Kafue Gorge
2 Kafue Flats and Southern Tributaries
3 Southern Kariba Lake and Kalomo
4 Lusitu River

The contents of the maps 1:250,000 comprise (Figure 8-24):

- Topography including roads, villages, towns, rivers and wetlands based on topographical map sheet series 1:250,000
- Health centres and schools
- Surface elevation at 100m intervals based on the DEM
- Boreholes and wells, including unsuccessful drilling sites
- Hot springs
- Surface catchment and sub-catchment boundaries
- Lithology and geological structures (faults, dykes, etc) according to geological map sheets 1:100,000 series, where available.
- Aquifer limits based on 10 major lithological units
- Aquifer potential based on six different categories
- Groundwater elevation contours at 50m intervals and direction of groundwater flow
- Rainfall distribution (map inlay)

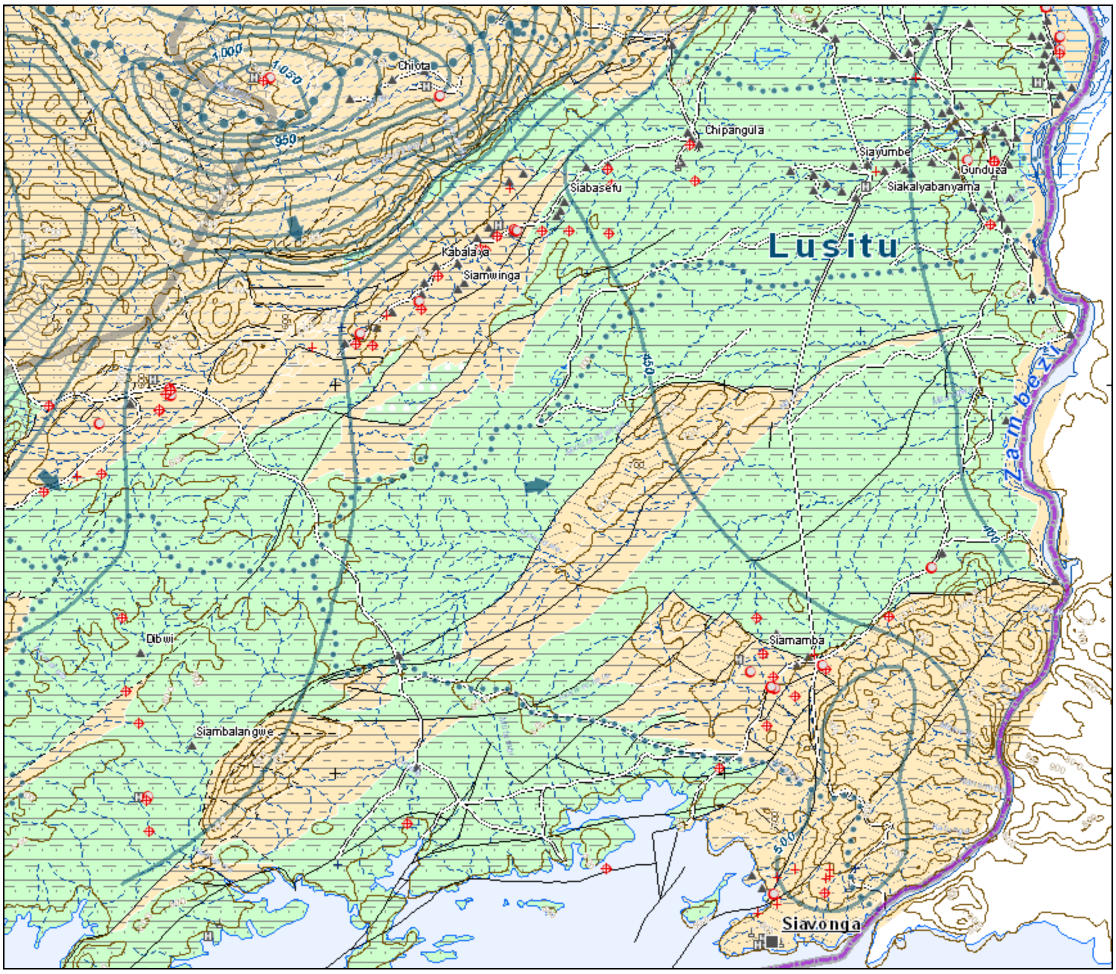

Figure 8-24 Excerpt of the hydrogeological map 1:250,000

The map sheet 1:100,000 is overall similar but includes the database number for each water point. Individual map symbols for boreholes and hand-dug wells could be displayed even if they were clustered. Furthermore, the topography is shown in more detail (50m-elevation contour intervals instead of 100m). The map at this scale is better suitable for tracing individual water points in the field due to its larger scale. The map also distinguishes water points with brackish or saline water.

The brochure accompanying the maps includes thematic maps of the SP (scale approx. 1:2 million showing:

- DEM
- Soil type distribution
- Regional geology
- Regional surface water and groundwater systems
- Groundwater vulnerability
- Groundwater salinity
- Occurrence of water borne diseases

9. CONCLUSIONS AND RECOMMENDATIONS

This report reviews the state of knowledge and provides references for further reading on the geography, climate, geology, hydrology and groundwater in the SP. The report also describes in detail the newly developed groundwater information system including the database and GIS map layers. Groundwater related information was assessed and interpreted in order to categorize individual aquifer systems. Thus, the potential of individual aquifers was determined, as was groundwater quality and hydraulics.

The major results and recommendations derived can be summarised as follows:

Groundwater Database

The database facilitates the effective use of borehole and groundwater information and future groundwater exploration and management. Statistical information on aquifer characteristics of catchments or administrative units can easily be obtained and made available to planners. It is recommended to extend the groundwater information system to national level by using the existing database structure and software.

A new water point system based on district boundaries was introduced in order to administer water points. Such a system could be used by authorities to register all boreholes in a prescribed manner as stipulated by the Draft Water Resources Management Bill. It is advisable to adopt the developed water point numbering system nation-wide, or otherwise to set up an alternative system that could be based on catchment boundaries, soon.

It is furthermore recommended to permanently establish the position of a “Groundwater Information System Manager” and an “Assistant Groundwater Information System Manager” at the DWA. The officers should have profound knowledge in the database software package *GeODin* and basic knowledge in *MSAccess*. The main task of the Information System Managers should be to supervise the maintenance and continuous updating of the database, to administer the water point numbering system and to observe the regular submission and quality of data.

Hydrogeologists, Water Quality Officers and other staff that regularly work with groundwater data should be trained in the use of the basic features of GeODin, such as data entry, browsing and data export.

Field Data Acquisition

The regular submission of drilling records, water levels and abstraction data must be further propagated among stakeholders. Once enacted, the new Water Resources Management Bill should oblige drilling companies and water users to submit groundwater related data automatically, but this process must be monitored carefully.

The Project also identified the need of harmonising the data acquired during groundwater exploration. Even if no hydrogeologist or consultant is available at the drill sites basic training of the drilling foreman or other staff on site should make it possible to collect a minimum set of data including date and location of drilling including a sketch map, GPS co-ordinates, drill depth, borehole and casing diameter, depth of screens installed, static and pumped water levels and pumped yield. Specific training of staff should be provided where necessary.

The existing DWA record sheets for borehole completion and pumping tests are considered sufficient for this purpose if filled in complete and correctly. A data sheet for water sampling purposes has been created for this Project. The data input sheets should be made widely accessible (also through the Internet, if possible) to other Ministries in the sector, drilling companies and NGO's.

Water chemistry data obtained from previous studies has often been incomplete and of limited reliability. A general concern must be raised on the standard and quality of local Zambian laboratories. If funds allow for water quality testing, all major ions (Ca, Mg, Na, K – HCO_3, NO_3, SO_4, Cl) should be included in the chemical analysis as a part of a standard procedure. The advantage of this would be that the reliability of chemical data could be assessed by calculation of the electrical balance.

GIS

The GIS is a valuable tool for plotting and analysing groundwater data spatially. It is recommended that for surface and groundwater managing purposes the topographic map sheet series at scale 1,250,000 are used and that all relevant information from these maps is digitized and made available as seamless map layers (ArcGIS feature classes such as shp-files). The map series comprise 54 sheets nationwide.

The delineation of surface catchments and sub-catchments already accomplished for the SP and some adjacent catchments should be continued for all Zambian river catchments. The delineation should be based on a DEM constructed using SRTM data (resolution of 90mx90m).

Due to the large importance that geological information provides for the assessment of groundwater potential it is recommended to digitize all geological maps available at scale 1:100,000 (ca. 92 sheets available), or where unavailable maps at scale 1:250,000 (ca. 12 sheets available).

Hydrogeological Maps

In this study a standard design and legend were developed for hydrogeological maps series at two different scales, 1:250,000 and 1:100,000. The developed format follows international guidelines. It is desirable to adopt this standard for other regions, and to make amendments only where necessary, e.g. if additional groundwater features need to be included in maps of other areas.

For obvious reasons, the margins of hydrogeological maps should follow catchment rather than administrative boundaries. By doing so, the maps will be in line with the intended catchment-based management of water resources and the development of catchment and sub-catchment management councils.

Groundwater Level Monitoring

A continuous and extended groundwater monitoring of water tables and, in selected areas, groundwater quality is considered crucial for a future groundwater resource assessment and management. Groundwater level observations can be used to identify trends in groundwater recharge, storage and availability. Groundwater quality monitoring can help to recognize the potential degradation of water quality. The establishment of such a monitoring network in SP should be part of a national monitoring concept.

It is recommended to establish a minimum of four wells for water table monitoring in the SP each representing one of the large aquifers within the Karoo sandstone, the Karoo basalt, the alluvial aquifer of the Kafue Flats and the basement rocks. Suggestions for possible locations for monitoring are given in this report. Preference was given to sites near meteorological stations or existing monitoring wells.

Groundwater Potential

The potential of groundwater in the SP is overall limited despite the occurrence of some aquifers with moderate groundwater potential such as within the Karoo sandstone. Aquifers are extremely heterogeneous but wells with exceptional high yields (q>1 L/s/m) are rarely found regardless the aquifer lithology. Groundwater therefore is usually not suitable for larger development or for irrigation schemes. Locally, groundwater may be sufficient to supplement surface water- based irrigation systems along the major rivers and Lake Kariba or to facilitate small-scale irrigation.

Overall, groundwater is suitable for domestic and rural water supply. Groundwater exploration however is not without risks due to the heterogeneous nature of most groundwater systems. About one out of five boreholes drilled during larger exploration campaigns in the past was unsuccessful. About two thirds of all aquifers are hosted by hard rock formations; the remainder is largely formed by interbedded clastic sediments. Since these aquifers are very heterogeneous, the importance of modern siting methods is emphasized. Careful siting using detailed structural analysis and advanced geophysical methods could considerably increase success rates and maximum yields during exploration drilling. Training of personnel in charge of groundwater development in geophysical field measurements and advanced evaluation methods is hence strongly recommended.

Groundwater Quality

From a chemical point of view groundwater meets the national drinking water standards in most areas and is well suitable for water supply.

Some wells, in particular in the Gwembe Valley show high electrical conductivity (EC>1000 µS/cm) indicating increased salinity, and may locally not be suitable for human consumption. Iron contents are also locally high (>1 mg/l) but this causes no health threat.

Values of arsenic, manganese, sulphate and fluoride exceeding Zambian or WHO standards have been found at individual sites but no clear distribution pattern could be recognized due to the limited amount of data. Overall this seems to be a local phenomenon.

Potential contamination of groundwater by nitrate, fertilizers and pesticides may occur in the vicinity of large irrigation schemes, but the investigation of local pollution sources was beyond the scope of this study. Especially the Kafue Flats whose effectiveness of protective cover has been identified as “low” to very “low” due to shallow groundwater tables may be vulnerable to such contamination.

Diarrhoea and dysentery cases (in 2005) were abundant especially in settlements near Lake Kariba, some district centres and generally in Monze District. The wide-spread occurrence of waterborne diseases near settlements hints at faecal contamination due to poor sanitary conditions. Wells in such areas are also likely to show elevated levels of nitrate.

Consequently, continuous groundwater quality observations might be required near major settlements to monitor faecal contaminations and near large agricultural areas to assess contamination by nitrate, fertilizers or pesticides.

ACKNOWLEDGEMENTS

During Phase I the Project received valuable data and information from various institutions and individuals.

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- ☐ Central Statistical Office for population data and administrative boundaries
- ☐ Ministry of Health for information on Rural Health Centres
- ☐ NWASCO for the urban and peri-urban water supply and sanitation information system
- ☐ Southern Water and Sewerage Company for abstraction data
- ☐ JICA and UNICEF for borehole (drilling) data
- ☐ School of Mines, in particular Prof. Nyambe for geological maps and reports
- ☐ Mr. H Mpamba, for data on his recent research in the Gwembe Valley.

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