An Explanation of the 1:500 000 General Hydrogeological Map

Bloemfontein 2924

By P.S. Meyer

June 2003

DEPARTMENT : WATER AFFAIRS AND FORESTRY
REPUBLIC OF SOUTH AFRICA

An Explanation of the 1:500 000 General Hydrogeological Map

Bloemfontein 2924

By P.S. Meyer

June 2003

Cover photograph: The Orange River at Aliwal North. The Orange River, which hosts the two largest storage reservoirs in South Africa, winds through the entire map area, and is a major water supply source to the region and even further afield. The river receives much of its baseflow from groundwater which issues from numerous springs in the Lesotho highlands. (Photograph: P.S.Meyer).

An Explanation of the 1:500 000 General Hydrogeological Map

Bloemfontein 2924

By P.S. Meyer

June 2003

Obtainable from Directorate: Geohydrology
Department: Water Affairs and Forestry
Private Bag x313
Pretoria, 0001
Republic of South Africa

Fax: +27 12 328 6397

E-mail: wb3@dwaf.gov.za

Website: http://www.dwaf.gov.za/geohydrology

ISBN 0-621-3349-4

DEPARTMENT: WATER AFFAIRS AND FORESTRY
REPUBLIC OF SOUTH AFRICA

Foreword

Groundwater in South Africa as a whole is under-utilised, although some local over-exploitation does occur. Groundwater schemes can be implemented quickly and cheaply, and are particularly effective in conjunctive use and dispersed scenarios. With increasing pressure on scare surface water resources, and with the priority of supplying potable water to disadvantaged rural and urban communities, it is clear that groundwater will play an increasingly important role in South Africa's economic and social prosperity.

A major obstacle to the realisation of this prosperity is that insufficient information about groundwater is reaching the planners, decision-makers, users and other affected parties. In an attempt to rectify this situation, groundwater information locked away in experts' minds and computer databases is being made available on maps. The first step in this programme at the regional level is the preparation of "General Hydrogeological Maps" at the scale of 1:500 000.

The main purpose of General Hydrogeological Maps, of which the accompanying map sheet is an example, is to display in an easily understood format what is known about the basic hydrogeological properties. These General Hydrogeological Maps represent a synthesis of the most up-to-date data and geohydrologists' knowledge. Thus these maps are also very useful in identifying areas where additional data should be collected and further investigations need to be conducted.

Groundwater maps – the best available information for the best possible planning, development and management of a strategic resource – will ultimately benefit all South Africans.

EBERHARD BRAUNE
DIRECTOR: GEOHYDROLOGY
DEPARTMENT: WATER AFFAIRS AND FORESTRY
PRETORIA

Preface

With the exception of air, water can, with little doubt, be defined as Man's most precious resource. It is said that to deny Man food, his body can sustain life for weeks, but refuse him water, and death is likely to come within days. The availability of water to even the remotest area is thus vital to maintain this indispensable element for human existence. An estimated 3% of fresh water available on earth occurs on the surface and 97% occurs underground (Johnson Division, 1975). To tap and develop this vast amount of underground stored water, a keen knowledge of a region's environment, its diversified geology and the composite hydrogeological intricacies at play, is of the utmost importance in order to comprehend how and where groundwater occurs.

The primary aim of a General Hydrogeological Map is to produce a synoptic overview of the hydrogeological character of an area. The Bloemfontein Hydrogeological Map and the accompanying explanatory brochure introduce the current state of groundwater knowledge and the basic hydrogeological characteristics of the map area.

The main map features borehole yield, aquifer types, groundwater quality and groundwater use, which are superimposed on a slightly subdued lithological background. The brochure discusses these topics in more detail, as well as issues such as recharge, pollution, borehole siting and groundwater utilisation. A few case reports have been included to highlight problems and issues as experienced in the field.

Groundwater has always been an important source of water supply to many people and localities in the map area. Water consumers in many areas rely totally on groundwater for domestic, stock watering and irrigation purposes. It is hoped that the map and brochure will be found useful:

- to all groundwater users,
- for general planning, especially in the light of the Reconstruction and Development Programme,
- to provide insight around groundwater management initiatives, and
- as tools for groundwater education and groundwater awareness building.

Acknowledgements

The following concerns and individuals are thanked for their assistance and provision of data in the compilation of the Bloemfontein Hydrogeological Map and the Explanatory Brochure:

Various Municipalities, notably the **Municipality of De Aar**

Council for Geoscience, Bellville, notably **Dr. Jurie Viljoen**

Council for Geoscience, Pretoria, notably **Dr. Mike Johnson** and **Dr. Peter Zawada**

Personnel of Geohydrology, DWAF, Free State Region, Bloemfontein

The Department of Agriculture, Petrusburg, notably **R.J. Myburgh**

Geo-Hydro Technologies, Bloemfontein, notably **D.C. Rudolph**

Z.M. Dziembowski – Consultant

Homestead Graphic Art Studio – Design and layout

The following personnel of the DWAF:

Eberhard Braune – Member of the Editorial Board
Paul Seward – Member of the Editorial Board
Jan Girman – Project Manager
Freda Jonck – Cartography Manager
Elanda Botes – Project Administrator
Thiruveni Chetty – GIS Support

Table of contents

Table of contents

List of figures

List of tables

List of plates

Abbreviations

Ave	average
DWAF	Department: Water Affairs and Forestry
EC	Electrical Conductivity
et al	et alii (and others)
GIS	Geographic Information System
IGS	Institute for Groundwater Studies
mamsl	metre above mean sea level
mbgl	metre below ground level
NGDB	National Groundwater Data Base
NWQDB	National Water Quality Data Base
RSA	Republic of South Africa
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WRC	Water Research Commission

Symbols and units

>	greater than
<	less than
%	percent
10^6	million
°C	degrees Celsius
a	annum
ha	hectare
km^2	square kilometre
l/s	litre per second
m	metre
m^3	cubic metre
m^3/a	cubic metre per annum
m/d	metre per day
mg/l	milligram per litre
mm	millimeter
mS/m	milli-Siemens per metre
s	second

1 Introduction

1.1 Map compilation

Extensive use was made of Arc/Info for cartographic compilation, data display and manipulation. Available borehole data from the National Groundwater Data Base (NGDB) was used and supplemented by field visits to areas of sparse data coverage. GIS was used to provide a lithology map on which borehole yields were introduced as colour points, coded according to yield ranges. This map furnished a link between groundwater yield potential and regional geology. Statistical analyses of the coded colour points, employing the author's knowledge of the map area to interpret the data and extrapolate data evidence to areas of sparse information, allowed for the delineation of yield boundaries which were largely drawn by hand. Additional changes and boundary alterations were done within the GIS. The same methodology was used for the compilation of the 1:1 500 000 scale groundwater quality map using data from the National Water Quality Data Base (NWQDB). The quality parameter that is expressed is the electrical conductivity (EC) of the groundwater. The EC intervals shown are taken from the Department of Water Affairs and Forestry (DWAF) guideline limits for human and stock water consumption.

Due to a shortcoming in the NGDB, which does not distinguish between dry boreholes and boreholes with no data, dry boreholes had to be excluded from the boreholes analyses. This is unfortunate as information on dry boreholes can be helpful to determine an area's yield potential.

The following data limitations marred the borehole analyses:

- Poor data quality
- Unscientifically sited boreholes, which often mask the true overall yield potential of a rock unit, and
- Large areas of sparse data distribution.

The lithostratigraphy of the region, taken from the Council for Geoscience published maps, was regrouped and, where necessary, simplified to lithological types. These types are displayed as greyish ornaments on the aquifer map. The geological units are provided with black codes which, for reasons of country-wide uniformity, do not always coincide with the codes of the published geological maps, but are internal Departmental adaptations. The geological units and codes are explained in a chronostratigraphical column.

1.2 Legend explanation

The hydrogeological map utilises an adapted international hydrogeological legend (Anon/UNESCO, 1983). The main alterations to the UNESCO legend were:

- the removal of the division between local, discontinuous or extensive aquifers, and using only local and
- the inclusion of intergranular and fractured as an additional mode of groundwater occurrence since this was considered to be more appropriate to South African conditions.

The borehole yield ranges has been left by UNESCO for the local map authors to define. Consideration of the local conditions resulted in the yield ranges shown in Table 1.

The terminology adopted by the European hydrogeological map authors was used. This refers to the yield ranges of groundwater and further subdivides according to mode of occurrence. For this map region "fractured" was used for the faulted and jointed mode occurrence, also referred to as the fracture regime, and "intergranular and fractured" for the decomposed and fractured/jointed mode of occurrence, also referred to as the intergranular and fractured regime. These divisions are depicted using the colour scheme in Table 1.

To increase the readability of the map the lithology and the geology have been changed as follows:

- lithological occurrences too small to carry a GIS polygon and a stratigraphy code were omitted, and
- lithology boundaries have in places been smoothed out and the boundaries will not always correspond exactly to these of the geological maps.

Schematic cross-sections have been drawn to illustrate the regional hydrogeology in terms of geology and to evince target areas for groundwater development.

The 1:2 000 000 scale inset maps, illustrating distribution of borehole data, elevation above sea level and mean precipitation are entirely computer generated.

1.3 Borehole yield distribution and lithological boundaries

From the 1:500 000 map it can be seen that yield and lithology boundaries do not always coincide. Yield boundaries were determined from the best match to the available data, which may not always be conclusive. It may be speculated that topography, local recharge and the occurrence of superficial material such as calcrete could be major factors in the overall pattern of borehole yield distributions.

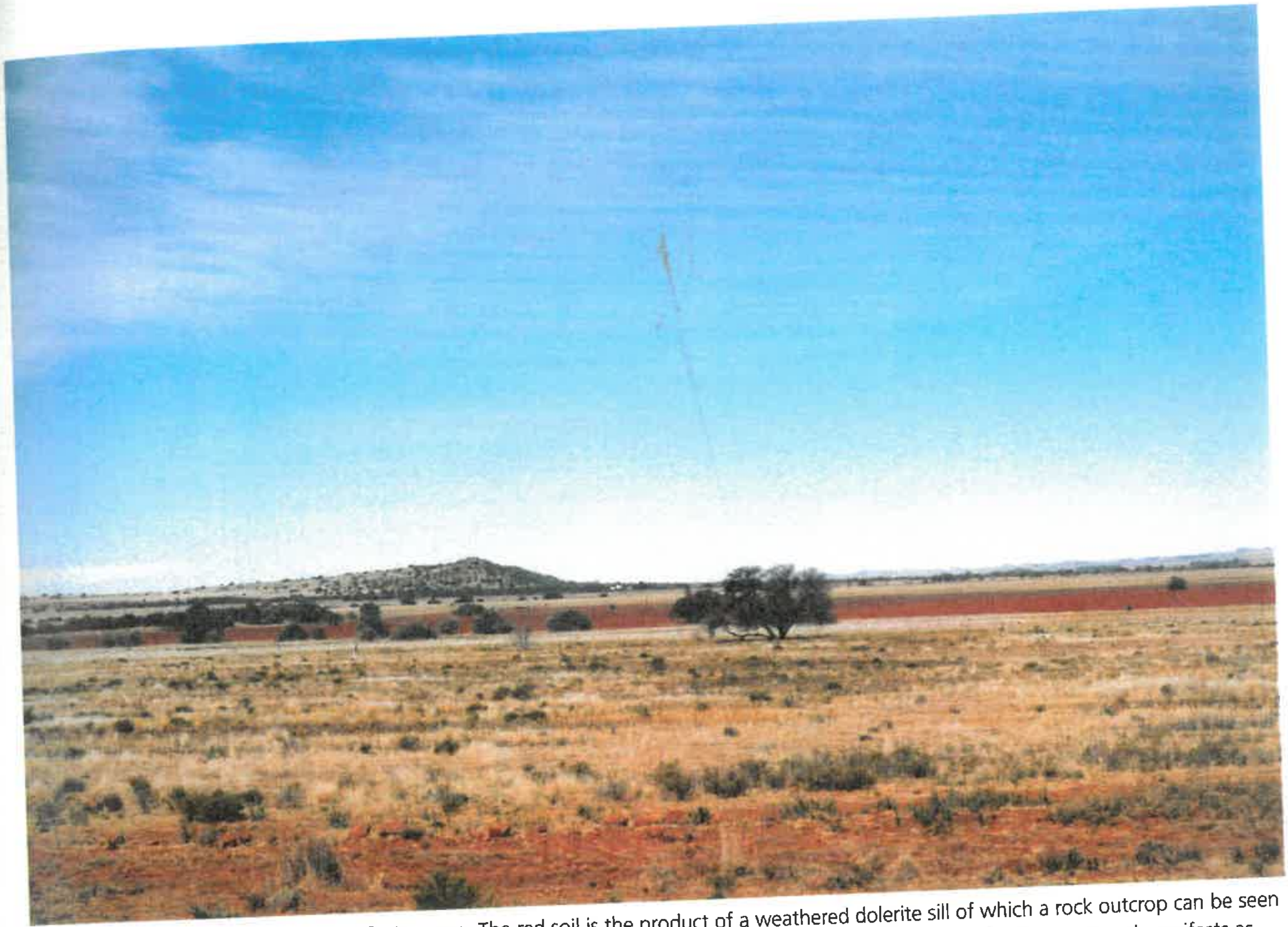


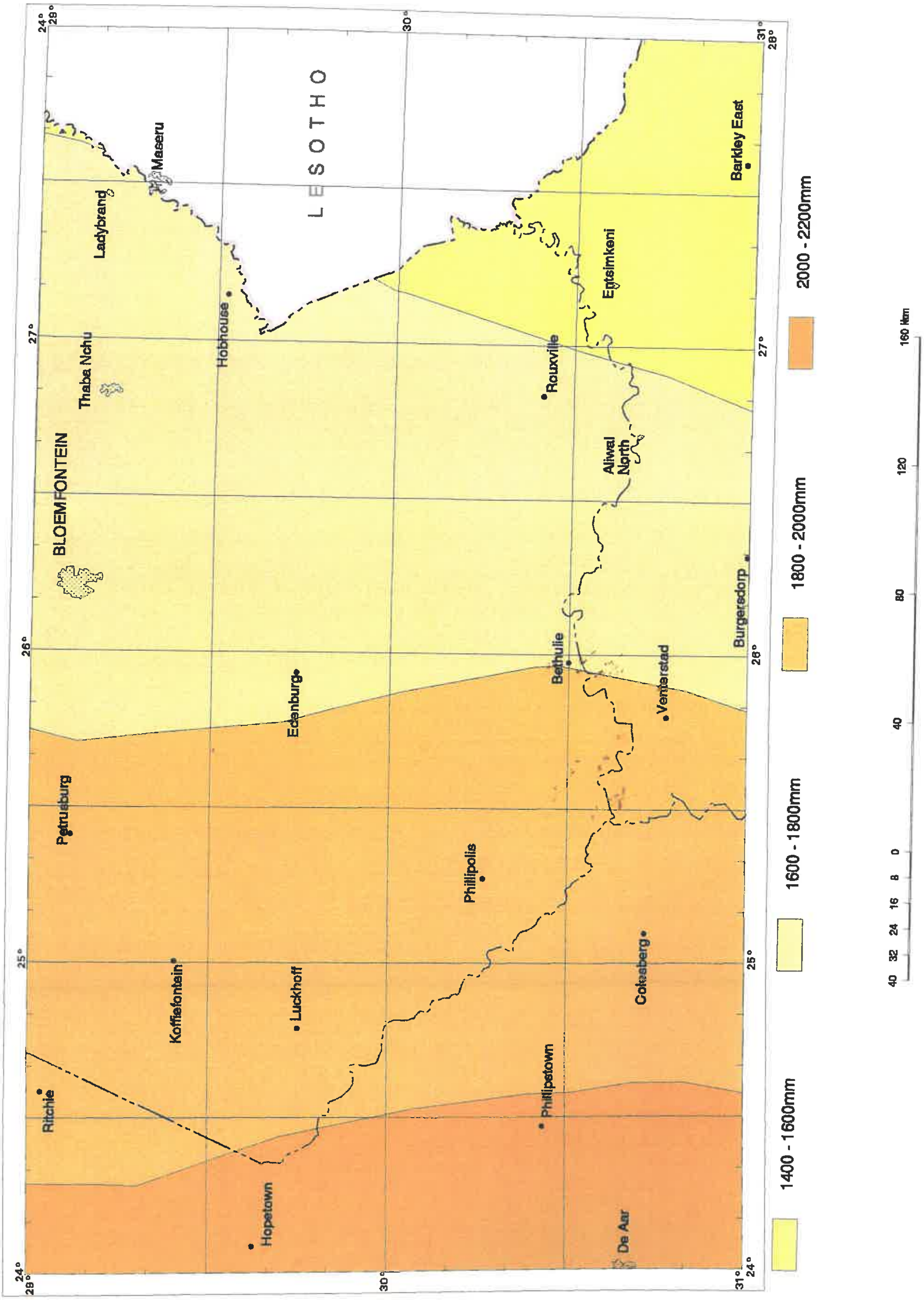
Plate 1. A typical south-western Free State scene. The red soil is the product of a weathered dolerite sill of which a rock outcrop can be seen in the background. Weathered dolerite plays an important role in groundwater occurrence in almost the entire map area and manifests as both fractured and intergranular, and fractured modes of groundwater occurrence. (Photograph: P.S. Meyer).

Table1. Hydrogeological classification of groundwater

AQUIFER TYPE	FRACTURED	INTERGRANULAR & FRACTURED
DESCRIPTION	Fractured and jointed bedrock resulting from intrusive contact zones and mechanical weathering of which the product is rock disintegration. Characteristic weathering residue: calcrete. Groundwater occurs mainly in fractures and joints and on bedding planes.	Mode of weathering: rock decay resulting in de-composition especially of igneous rocks and to a lesser extend also in sedimentary rocks. (Plate 1). Characteristic weathering residue: ferricrete. Groundwater occurs in intergranular interstices in the saturated zone and in jointed and fractured bedrock.

YIELD (*l*/s)	SHADES OF GREEN	SHADES OF BROWN & YELLOW
>5.0	Dark green (b5)	Brown (d5)
2.0 – 5.0	Green (b4)	Light brown (d4)
0.5 – 2.0	Light green (b3)	Pale brown (d3)
0.1 – 0.5	Pale green (b2)	Yellow (d2)
0.0 – 0.1	Not applicable	Yellow tinge (d1)

Figure 1. Mean annual pan evaporation



2 Physical environment

2.1 General

The map covers an area of approximately 75 000 km² within the RSA boundaries. Mixed farming is the main agricultural activity, although the cultivation of wheat, maize and potatoes, under irrigation from groundwater sources, is practised on about 2 000 ha in the Petrusburg district and on a much smalller scale in the Koffiefontein, Luckhoff and De Aar districts.

Mining activities are limited to diamond mining at Koffiefontein and Jagersfontein, and harvesting of salt from salt pans in the western portion of the map area in the Herbert, Fauresmith, Jacobsdal and Hopetown districts.

2.2 Climate

The greater portion of the map area has a semi-arid climate of hot summers and mild to cold winters. Air temperatures are subject to large diurnal and seasonal variations. The climate of the far eastern mountainous areas is slightly more temperate and these areas experience milder summer temperatures. Precipitation generally occurs in the form of thunderstorms from October to March, the peak rainy season being February – March. Unsettled winter weather is occasionally accompanied by snow, especially in the eastern regions of the map area. Mean annual precipitation varies between about 300 mm at De Aar in the west and about 600 mm at Wepener in the east. The Witteberg range receives >800 mm/a. The pan evaporation for De Aar and Wepener varies between the 2 000–2 200 and the 1 600–1 800 mm/a ranges respectively (Table 2).

Table 2. Climatic data

LOCALITY	PRECIPITATION RANGE (mm)	AVERAGE MAXIMUM TEMPERATURE (°C)		AVERAGE MINIMUM TEMPERATURE (°C)		EVAPORATION RANGE (mm/a)
		January	July	January	July	
De Aar	200–300	32.3	16.9	15.8	0.6	2 000–2 200
Koffiefontein	300–400	–	–	–	–	1 800–2 000
Bloemfontein	400–600	30.9	17.4	15.3	-1.9	1 600–1 800
Thaba Nchu	400–600	–	–	–	–	1 600–1 800
Aliwal North	400–600	31.1	17.0	14.5	-0.8	1 600–1 800
Wepener	400–600	30.4	17.2	15.2	-1.2	1 600–1 800
Barkly East	600–800	26.0	13.7	11.3	0.2	1 400–1 600

– = data not available
Source: S.A. Weather Service

The Orange River, named in honour of the Dutch Royal House of Orange, winds through the entire map area from east of Zastron on the Lesotho border to north-west of Hopetown in the west. The Koisan called the river the Gariep, the early white settlers named it the Groot River while in Lesotho it is known as the Senqu River. The river originates high in the Lesotho Highlands some 3 300 m above sea-level where the average annual precipitation can exceed 1 800 mm. The total length of the river from its source to the river mouth at Alexander Bay on the west coast, where the average annual rainfall drops below 50 mm, is 2 300 km. The annual evaporation near the river mouth exceeds 2 000 mm.

The Orange River basin is by far the largest river basin in South Africa with a total catchment area in the order of 1 000 000 km² of which almost 600 000 km² is inside South Africa, with the remainder in Lesotho, Botswana and Namibia. According to various sources the average natural run-off from the basin is more than 12 000 million m³/a, which represents the average river flow if there were no developments of any nature in the catchment. The basin is however heavily developed and the current average annual run-off at the river's mouth is less than half of the natural run-off.

The two largest storage reservoirs in South Africa, namely the Gariep Dam and the Vanderkloof Dam are located on the Orange River and both of them feature on the map. The capacity of the Gariep Dam is in excess of 5 600 million m³, and the capacity of the Vanderkloof Dam exceeds 3 100 million m³. The most important contributing tributaries of the Orange River are the Vaal River, Caledon River, Kraai River, and Fish River (Namibia).

Table 3. Description of the main terrain morphological units (Kruger, 1983)

BROAD DIVISION	MAP SYMBOL	DESCRIPTION	DRAINAGE DENSITY* (km/km²)	% OF AREA WITH SLOPES < 5%
Plains with low relief	1 2 4	Plains Plains and pans Slightly undulating plains and pans	Low – medium (0–2)	>80
Plains with medium relief	5 6 8	Slightly irregular plains Slightly irregular plains and pans Slightly irregular and undulating plains	Low – medium (0–2)	>80
Lowlands, hills	12 14 16	Lowlands with hills Irregular, undulating lowlands with hills Lowlands with mountains	Low – medium (0–2)	50–80
Open hills, lowlands and mountains with moderate to high relief	18 21	Hills and lowlands Mountains and lowlands	Low – medium (0–2)	<20
Closed hills and mountains with moderate to high relief	23 27 29	Hills Low mountains High mountains	Low – medium (0–2)	<20

* Total length of drainage channels per square kilometre

2.3 Physiography and surface hydrology

Altitudes vary from 3 000 mamsl in the Drakensberg on the Lesotho border north-east of Barkly East to about 1 100 mamsl along the Orange River north-west of Hopetown.

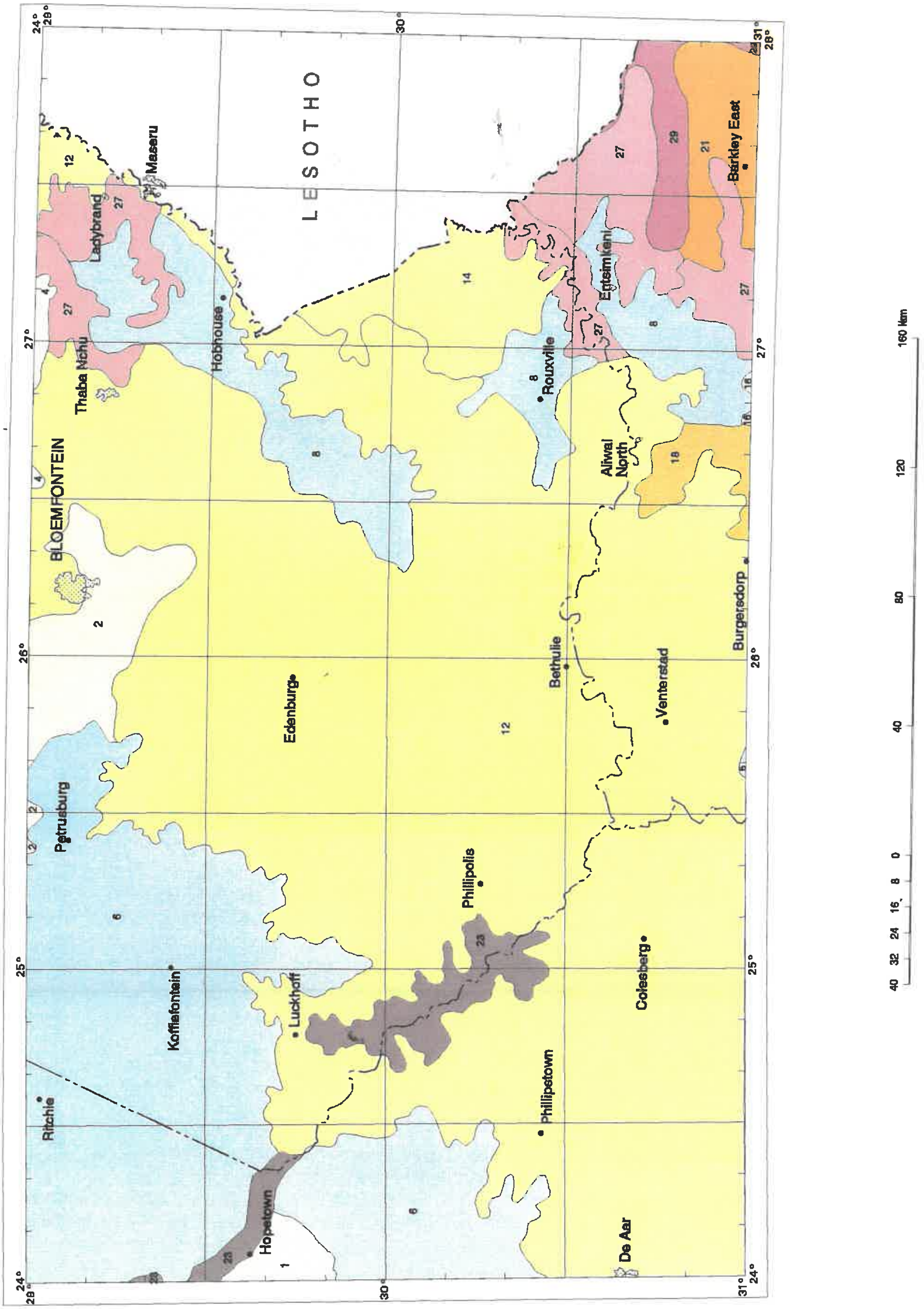
Five main terrain morphological units are recognised in the map area by Kruger (1983) and are described in Table 3 and depicted in Figure 2. Two main drainage systems occur in the map area, namely the Orange River system (primary drainage region D) and its main tributaries such as the Kraai and Caledon Rivers, which drain approximately 67% of the area, and the Vaal River system (primary draining region C), represented by the north-west flowing Modder and Riet Rivers, draining the remaining 33% of the area.

The major dams in the map area, their location in terms of primary drainage region and their storage capacity, are listed in Table 4.

Table 4. Major dams (>3.0 x $10^6 m^3$)

NAME OF DAM	DRAINAGE BASIN	STORAGE CAPACITY ($x10^6 m^3$)
Langzeekoegat Dam	C 51	3.29
Roodepoort Dam	C 51	3.60
Mockes Dam	C 52	6.00
Rustfontein Dam	C 52	72.21
Moutloatsi Setlogela Dam	C 52	14.00
Armenia Dam	D 23	14.16
Knellpoort Dam	D 23	136.15
Newberry Dam	D 23	6.60
Welbedacht Dam	D 23	14.00
Rolandseck Dam	D 24	5.40
Smithfield Dam	D 24	4.55
Montagu Dam	D 24	4.12
Vanderkloof Dam	D 31	3 187.10
Bethulie Dam	D 34	4.60
Gariep Dam	D 35	5 673.80

Figure 2. Terrain morphology (after Kruger, 1983)



3 Geology

3.1 General

The area is mainly underlain by sedimentary rocks of the Karoo Supergroup which have been intruded by numerous dolerite bodies. Pre-Karoo rocks cover only small areas along the northwestern boundaries of the map area (Figure 3). The lithostratigraphic information is given in Table 5. Much of the information on the geology was derived from Zawada, 1992; Bruce *et al*,1983; Le Roux 1993 and Theron, 1963.

3.2 Pre-Karoo Supergroup rocks

3.2.1 Swazian rocks

Two small outcrops of granite were recorded south-east and west of Ritchie. These granite occurrences are too small to feature on the map. The granite is described as light coloured, medium- to coarse-grained with visible biotite flakes, equigranular with quartz, plagioclase, orthoclase and chlorite as the major minerals.

On geophysical evidence (a gravity anomaly of unique magnitude) seven boreholes were drilled in the area around Trompsburg in the mid-1940's. An igneous mass, intrusive into marble, probably of Transvaal Supergroup age and overlain unconformably by Karoo Supergroup sediments, was revealed at a depth of between 1 068 and 1 148 m below surface. Named unofficially the Trompsburg Pluton, this feature has a more or less circular sub-outcrop, the radius being approximately 24 km (Ortlepp, 1969). The study of borehole cores disclosed a similarity between the rocks of the Trompsburg Pluton and those of the Bushveld Igneous Complex (Buchmann, 1960). Borehole TG 1, situated approximately 16 km NW of Trompsburg, was drilled into the pluton. At a depth of 1 432 m, warm artesian water with a flow-rate of 2.4 *l*/s and a temperature of 37°C was intersected. The borehole yield and water temperature subsequently dropped to 0.25 *l*/s and 32.2°C respectively in 1971 (Kent, 1971). The borehole is currently in use for stock watering.

3.2.2 Ventersdorp Supergroup

Three formations of the Ventersdorp Supergroup, namely the Makwassie Formation (of the Platberg Group) and the Bothaville and Allanridge Formations occur patchily in the north-western portion of the map area. The occurrences of the Makwassie and Bothaville Formations are too small to feature on the map.

The largest outcrop of the Makwassie Formation occurs south-west of Ritchie and consists mainly of porphyritic lava and eutaxitic ignimbrite. The Bothaville Formation is subdivided into two units in the map area. The basal sedimentary unit is composed of medium- to coarse grained, cream- to dark-coloured poorly sorted quarzite with occasional thin conglomerate interbeds. The basal sedimentary unit is about 40 m thick and is overlain by the 10 m thick pyroclastic unit, which consists of tuff and volcanic breccia. The Allanridge Formation (R-Val) consists of andesitic lava, the amygdales having been filled with calcite. This unit's basal part is characterised by a 5 m thick horizon of round and oval shaped pillow lavas.

3.3 Karoo Supergroup

The entire sequence of the Karoo Supergroup is depicted on the map.

3.3.1 Dwyka Group

The Dwyka Group (C-Pd) occurs in the far north-western portion of the map area and forms the basal unit of the Karoo Supergroup. A thickness varying from a few metres to 120 m can be expected. On and adjacent to basement highs the Dwyka Group is absent, resulting in the overlying Ecca Group sediments resting directly on pre-Karoo rocks. The variation in the thickness of the Dwyka Group is ascribed to the undulating nature of the underlying basement topography.

The Dwyka Group comprises bluish-grey, unbedded, unsorted tilite (diamictite) with erratics up to 4 m in diameter, set in a sandy to argillaceous matrix (Plate 2). Boulder shale constitutes much of the Dwyka Group and comprises an argillaceous matrix with scattered pebbles and boulders. Limestone lenses of up to 1 m in thickness are often found in the boulder shale.

Figure 3. Principal geological units

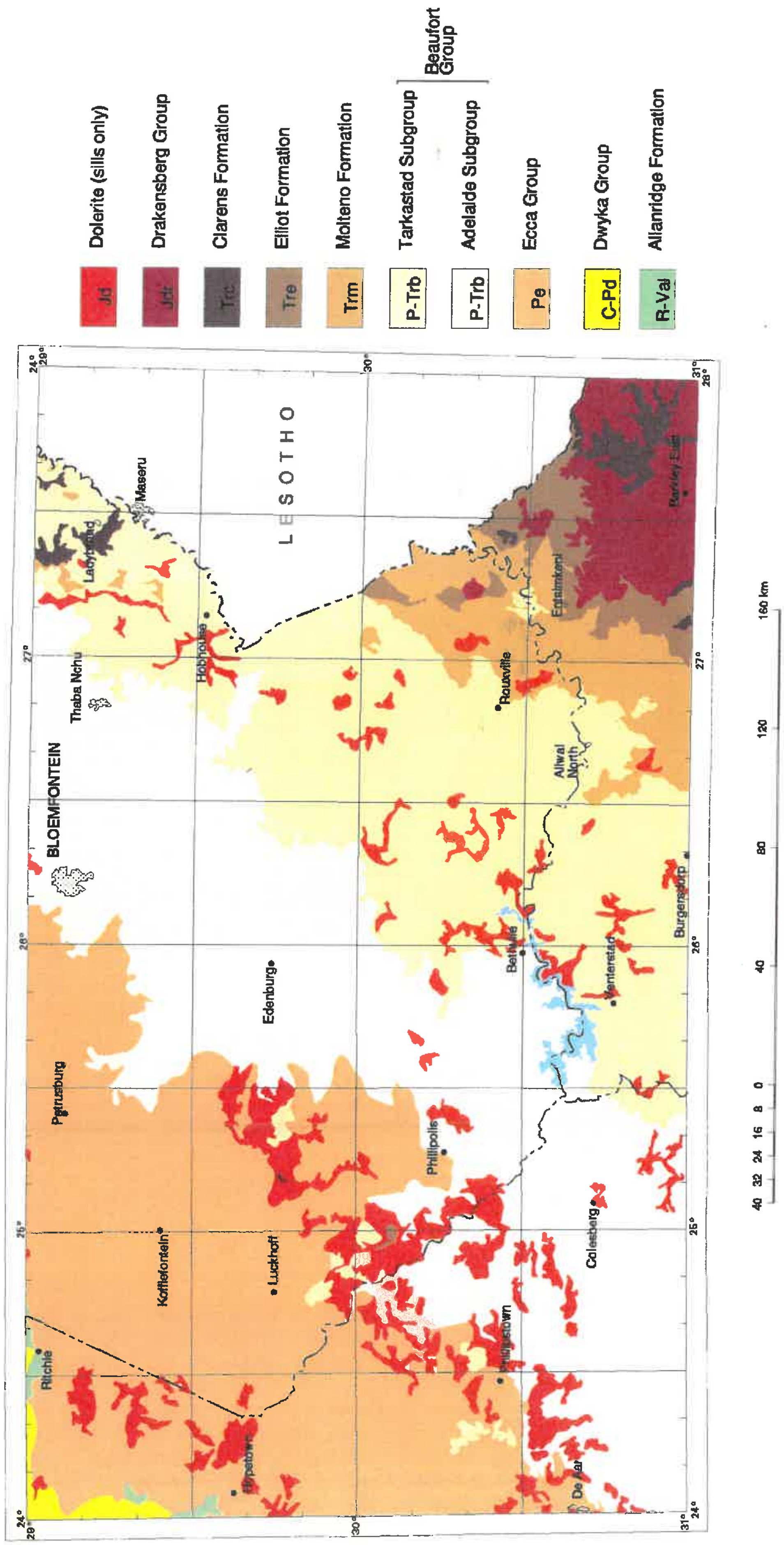


Table 5. Lithostratigraphic legend

Ma	ERATHEM	SYSTEM	GEOLOGICAL UNIT	LITHOLOGY	STRATIGRAPHY			
					Formation	Subgroup	Group/Suite	Supergroup
	Mesozoic	Jurassic	Jdr	Basalt			Drakensberg	KAROO
205			Jd	Dolerite			Karoo Dolerite	
		Triassic	Trc	Sandstone	Clarence			
			Tre	Mudstone & sandstone interbeds	Elliot			
			Trm	Mudstone & sandstone	Molteno			
250	Palaeozoic	Permian/ Triassic	P-Trb (t)	Sandstone & mudstone		Tarkastad	Beaufort	
			P-Trb (a)	Shale/ mudstone & subordinate sandstone		Adelaide		
			Pe	Shale	Tierberg White Hill Prince Albert		Ecca	
		Carboniferous/ Permian	C-Pd	Tillite, shale lenses			Dwyka	
2 650	Randian/ Vaalian		R-Val	Andesite	Allanridge			VENTERSDORP

3.3.2 Ecca Group

The Prince Albert, White Hill and Tierberg Formations together make up the Ecca Group (Pe) which attains a thickness of between 340 and 360 m.

The Prince Albert Formation maintains a relatively constant thickness of between 34 and 46 m. It consists of black carbonaceous shale and dark bluish-green to grey massive micaceous shale with silty lenses. An iron-rich concretion horizon is followed by grey to olive-green micaceous shale/mudstone. The thickness of the White Hill Formation varies between 10 and 18 m but regional thinning northwards has been recorded. The unit consists mainly of thinly laminated carbonaceous shale that weathers to a white colour. Thin, ferruginous bands due to the decomposition of pyrite, have been noted. The uppermost Tierberg Formation attains a thickness of approximately 300 m in the map area. This unit consists of mudstone, light-green to greenish-grey shale with concretional horizons. Shale with interbedded siltstone and fine-grained sandstone comprises the upper portion of this unit.

3.3.3 Beaufort Group

The Beaufort Group (P-Trb) comprises the Adelaide and Tarkastad Subgroups. Neither of these Subgroups are divided into formations in the map area.

The Adelaide Subgroup (portrayed as a predominantly argillaceous unit on the map) attains a maximum thickness of 400 m. It consists of a 10 to 15 m thick marker sandstone at the base, followed by siltstone and grey to reddish mudstone with subordinate lenses of sandstone. The topmost part of the unit consist of bluish to greenish-grey shales and red to purple mudstone.

The Tarkastad Subgroup (portrayed as an argillaceous and arenaceous unit on the map) consists of cream- to khaki-coloured, medium-grained, feldspathic sandstones with interbeds of red, purple and green mudstones. The sandstone horizons are thicker and more prominent than those of the underlying Adelaide Subgroup. The sandstone layers are particularly well developed at the bottom and towards the top of the unit. A thickness of 900 m for this unit was established from a borehole drilled near Aliwal North.

3.3.4 Molteno Formation

The Molteno Formation (Trm), portrayed on the map as an argillaceous and arenaceous unit, consists of greyish-green and red to purple mudstone with bands of fine- to coarse-grained sandstone. Lenses of grit, scattered large pebbles, cobblers and boulders up to 6 kg in weight, occur in certain sandstone beds. The Molteno Formation attains a maximum thickness of 250 m in the south-eastern portion of the map area.

3.3.5 Elliot Formation

The Elliot Formation (Tre) is made up predominantly of maroon or green mudstone and three sandstone interbeds. The mudstone has no bedding and weathers easily. The medium-grained, feldspathic sandstone bands are well-bedded.

3.3.6 Clarens Formation

The Clarens Formation (Trc), indicated as an arenaceous unit on the map, constituted of prominent cream-coloured, fine-grained, massive aeolian sandstone which abruptly overlies the brilliantly coloured Elliot Formation conformably. Concretions of impure, clayey calcareous material and of pyrite occur occasionally. The unit attains a maximum thickness of 200 m.

3.3.7 Drakensberg Group

Overlying the Clarens Formation in sharp contacts, the Drakensberg Group (Jdr) is made up of basaltic lava which can roughly be divided into a compact type and a more porous amygdaloidal type (Plate 4). The latter is generally encountered at the contacts of different lava-flows and the former in the body of such flows. Relatively minor occurrences of pyroclastic rocks, such as tuff, agglomerate and breccia have also been mapped. Scattered sandstone beds near the base of the unit point to the deposition of aeolian sand after the initial outpouring of the lava. The Drakensberg Group attains a thickness of about 900 m in the map area.

3.4 Intrusives

The sedimentary rocks of the Karoo Supergroup have been invaded by numerous dolerite intrusions of Jurassic age. Dolerite dykes (Plate3), generally up to 10 m wide and several kilometres long and dolerite sills, often undulating and in some cases dipping to form ring structures, occur in the map area. The maximum occurrence of sills is attained in the Beaufort Group. Scattered volcanic pipes, diatremes and relict volcanoes are present especially in the Molteno, Elliot and Clarens Formations. A few kimberlite dykes have also been noted.

Volcanism, of which the Drakenberg plateau is a remnant, was particularly violent during Jurassic times around 200 to 190 million years ago and was a manifestation of Gondwana breakup. It was initiated at least 20 million years prior to fragmentation and volcanoclastics are even present in the Permo-Triassic Ecca and Beaufort Groups. In adjacent regions of Mozambique, such as the lower Zambesi valley, volcanism persisted intermittently into Cretaceous time, long after the main outpourings accompanying continental separation, had ceased.

An initial explosive episode is evident by volcanic vents, diatremes and tuffs. The explosive phase was followed by the extrusion of a monotonous succession of mainly basaltic lava flows, of which the preserved thickness in the Drakensberg is 1400 m. The early lava flows were in places covered with sand on which dinosaur tracks are preserved. (Abstract from Tankard *et al*, 1982).

3.5 Alluvium

Alluvium occurs patchily in broad valleys along streams and rivers, and is made up of a variety of loose material. A typical alluvium profile in the De Aar area, for instance, is likely to consist of clayey sand, sandy silt, limestone, sand, pebbles and small boulders. A typical alluvium profile in the DeWetsdorp area, for instance, is likely to consist of clay with thin interbeds of silt and sand. Alluvium thicknesses generally vary between 1 and 10 m and occasionally up to 15 m.

Plate 2. Dwyka Group diamictite (tillite). The tillite is often massive and impervious and generally offers poor groundwater potential. Weathering in the form of rock disintegration is often promoted along joints and fractures which is likely to enhance groundwater potential in places. (Photograph: P.S.Meyer).

Plate 3. A dolerite dyke contact zone east of Colesberg. Jointing and fracturing is often enhanced in the vicinity of intrusive contact zones. These contact zones are common targets for groundwater development in the map area. (Photograph: P.S. Meyer).

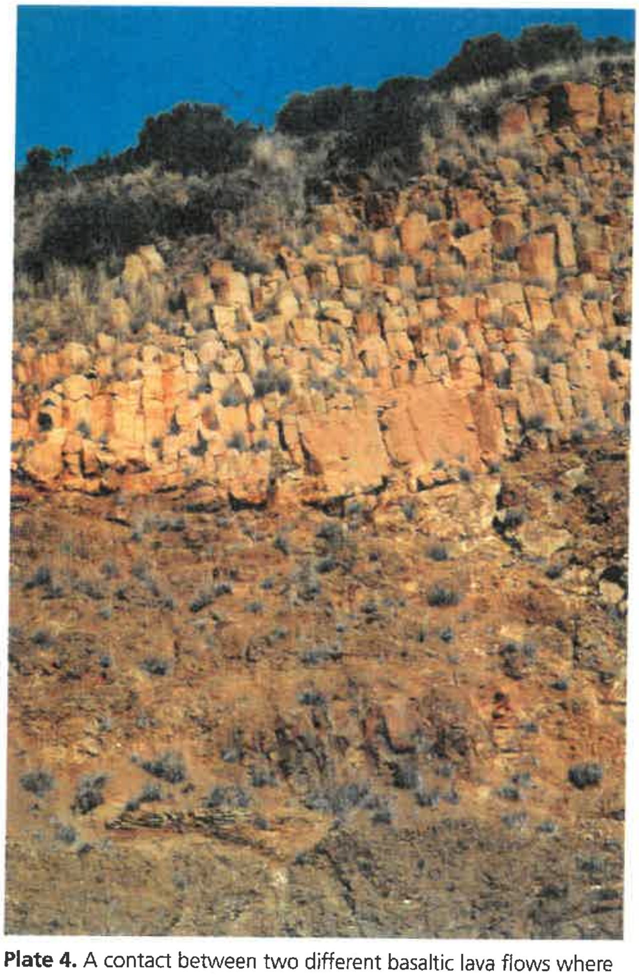


Plate 4. A contact between two different basaltic lava flows where an even-textured lava overlies an amygdaloidal lava. The amygdaloidal type of basaltic lava is more prone to decomposition and is a likely target for groundwater development. (Photograph: P.S. Meyer).

4 The groundwater domain

4.1 Hydrogeology of the different geological units

Two aquifer types occur in the map area, namely the fractured and intergranular, and fractured regimes.

In the fractured aquifer type, groundwater is contained mainly in fractures, joints, fissures including the important jointed transitional zone between the decomposed and solid rock components and on bedding planes (Table 1).

The boundaries between the two modes of groundwater occurrence were largely derived from the Saturated Interstices map (WRC / DWAF, 1995).

4.1.1 Fractured regime

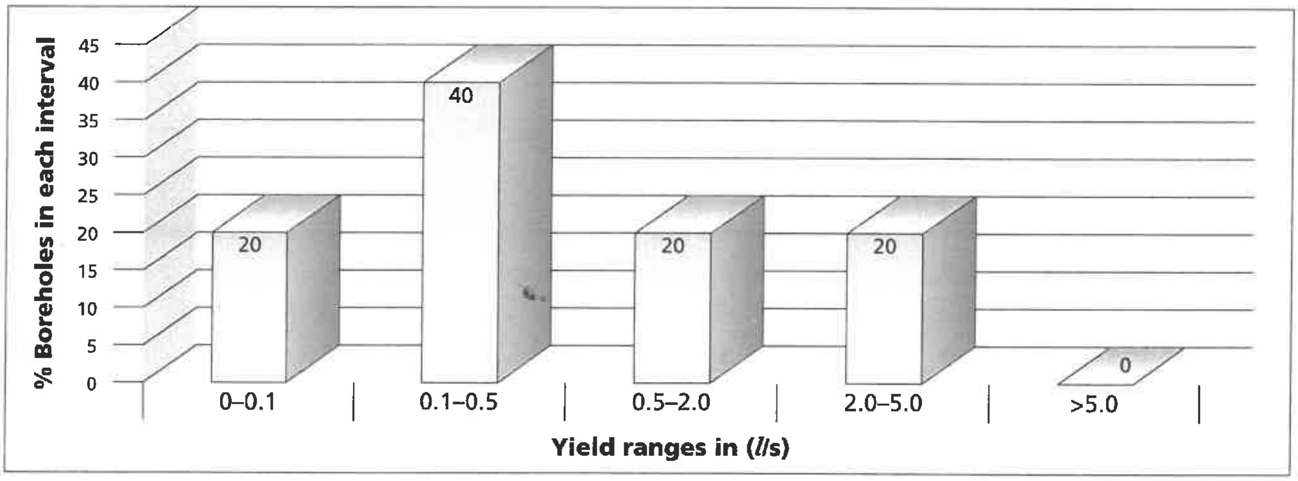
The fractured regime is represented by the Dwyka Group, Ecca Group and portions of the Tarkastad Subgroup of the Beaufort Group south of the Orange River.

4.1.1.1 Dwyka Group

The Dwyka Group (Figure 5) is concentrated in the north-eastern corner of the map area. The occurrence of groundwater in the diamictite (tillite) of this unit is associated with zones of occasional jointing and, less frequently, fracturing. Weathering in the form of rock disintegration is often promoted along joints and fractures (Plate 2) which are likely to enhance the groundwater potential. Occasional sandstone lenses in the tillite can also be employed for generally limited groundwater development. The massive, and as a whole, impervious Dwyka Group rocks generally offer poor groundwater potential as the median yield range of 0.1 *l*/s to 0.5 *l*/s indicates (Figure 4).

Due to the limited areal distribution of the Dwyka Group in the map area, no groundwater quality data are available. If the EC-values of the Dwyka Group rocks on the adjacent Prieska map can be extrapolated to this map area, then EC-values ranging between 30 and 600 mS/m, with an average value of 200 mS/m, can be expected.

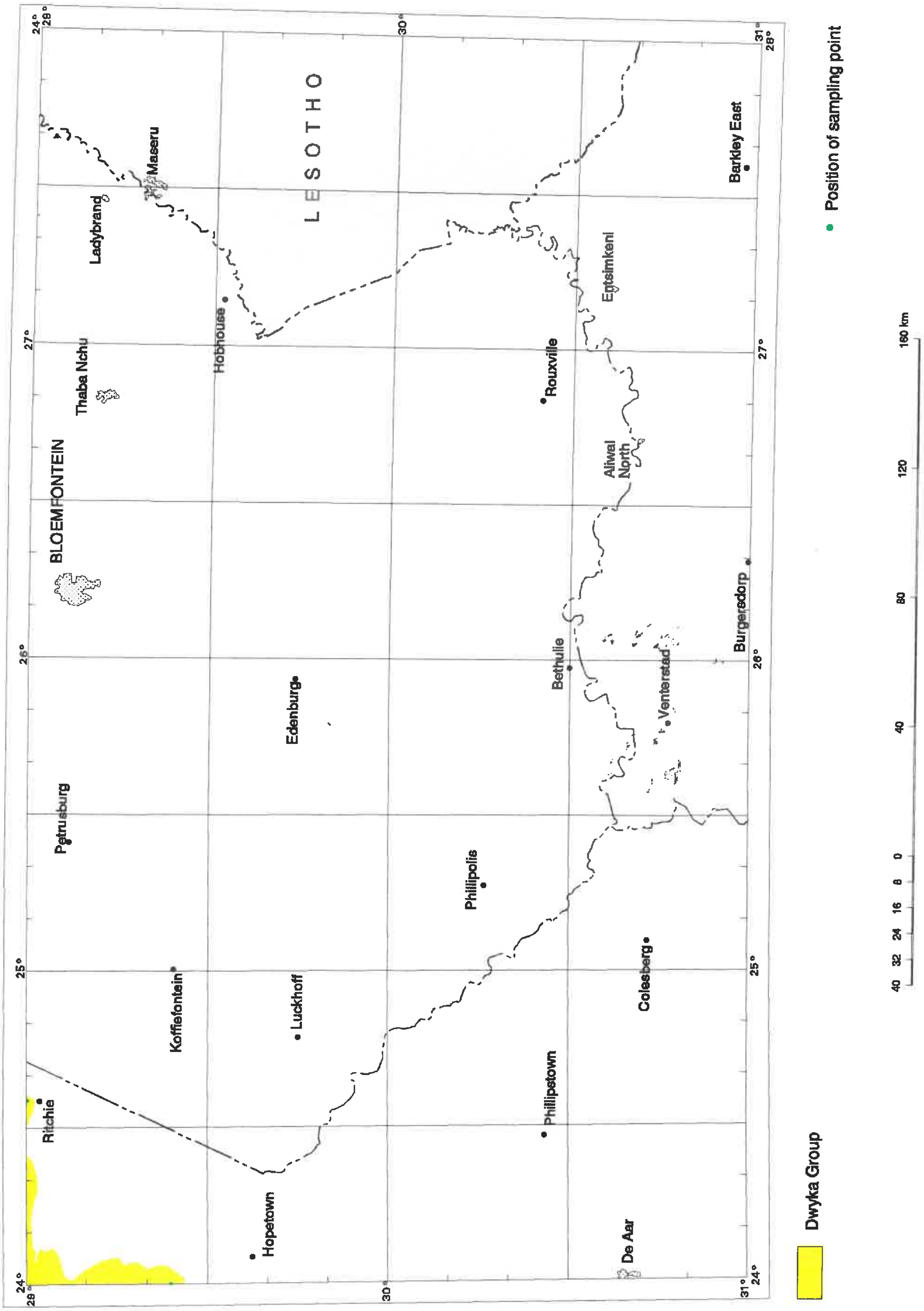
Figure 4. Yield frequencies of boreholes in the Dwyka Group (15 records analysed)



4.1.1.2 Ecca Group

Groundwater occurrence in the predominantly argillaceous beds of the Ecca Group (Figure 8) is associated with dolerite contact zones, joints (often the result of mechanical weathering) and bedding planes. It seems that the presence of calcretes with high effective porosity, when thick enough to impact on recharge, has a positive influence on groundwater occurrence, as the high yielding boreholes in the Petrusburg surrounds demonstrate (Plate 6).

Figure 5. Areal location of the Dwyka Group and associated chemical groundwater sampling points



A borehole yield analysis (Figure 7) indicates that the overall median yield range for this unit falls in the 0.5 *l*/s to 2.0 *l*/s category, while 13% of boreholes yield < 0.1 *l*/s and 11% of boreholes yield >5 *l*/s.

ECs of groundwater vary widely between 10 and 12 000 mS/m with a mean value of 118 mS/m (Table 6). Excessively high EC values probably occur within the spheres of influence of salt pans. Nitrate concentrations exceeding the maximum allowable limit of 10 mg/*l* occur at various localities (see satellite "Groundwater quality" map on the Hydrogeological map sheet) and can mainly be ascribed to agricultural practices. Groundwater from the Ecca Group rocks generally has a sodium – chloride character (Figure 6). It should be mentioned that the Stiff diagrams throughout the brochure were drawn from the "mean values" in the "Chemistry of groundwater" tables. Despite the occurrence of occasional ionic imbalances, the use of "mean values" versus "representative analyses" as used in some brochures of the map series, was considered more advantageous.

Figure 6. Stiff diagram of the groundwater chemistry in Table 6 (Ecca Group)

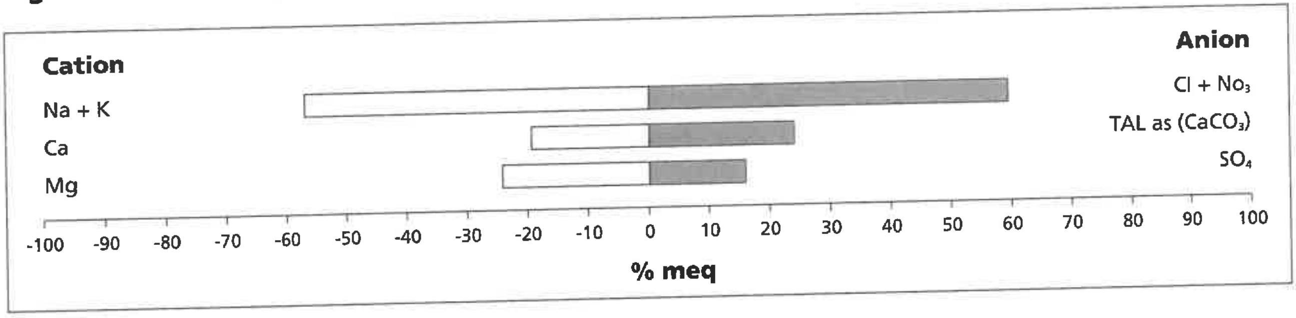


Table 6. Chemistry of groundwater from the Ecca Group (Statistics derived from 408 analyses)

DETERMINANT	MINIMUM VALUE	MAXIMUM VALUE	MEAN VALUE	A	B
pH	4.24	9.59	7.92	6–9	5.5–9.5
Electrical Conductivity (mS/m)	9.50	12 650.00	118.68	70.0	300.0
Total Dissolved Salts (mg/*l*)	120.00	149 372.00	1 138.23	1 200.0	2 000.0
Sodium (mg/*l* Na) mg 11	5.10	56 343.50	228.89	100.0	400.0
Potassium (mg/*l* K) mg11	0.32	229.15	4.69	200.0	400.0
Calcium (mg/*l* Ca) mg11	1.40	351.50	62.78	150.0	200.0
Magnesium (mg/*l* Mg) mg11	1.10	399.00	51.44	70.0	100.0
Chloride (mg/*l* Cl) mg11	3.10	76 331.50	318.65	250.0	600.0
Total Alkalinity (mg/*l* $CaCo_3$)	35.30	506.60	217.70	300.0	650.0
Sulphate (mg/*l* SO_4) mg11	6.00	14 373.90	118.72	200.0	600.0
Nitrate (mg/*l* N) mg11	0.05	347.86	9.65	6.0	10.0
Fluoride (mg/*l* F) mg11	0.11	14.82	0.76	1.0	1.5

A = Drinking Water Quality Criteria: Maximum Recommended Limit

B = Drinking Water Quality Criteria: Maximum Allowable Limit

Figure 7. Yield frequencies of boreholes in the Ecca Group (541 records analysed)

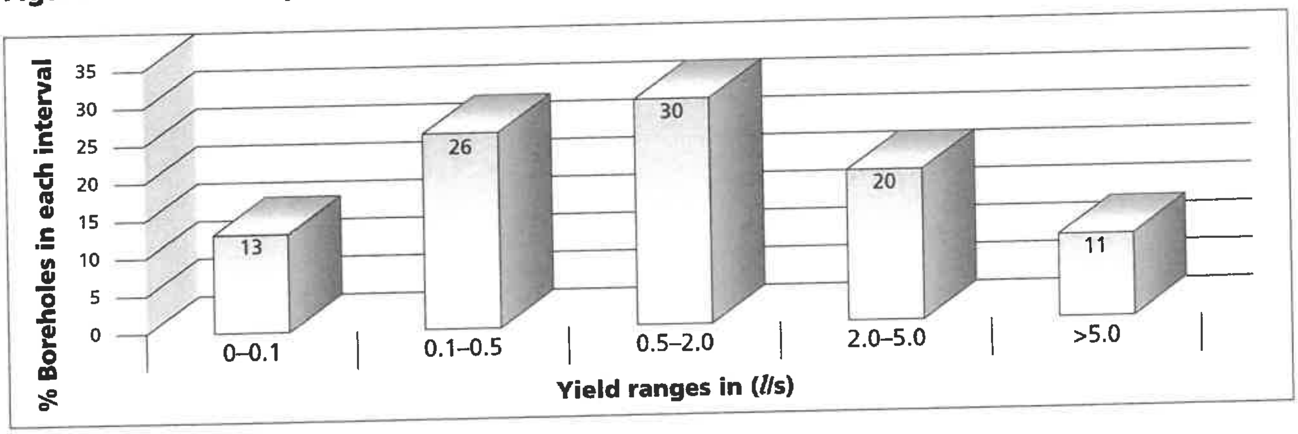
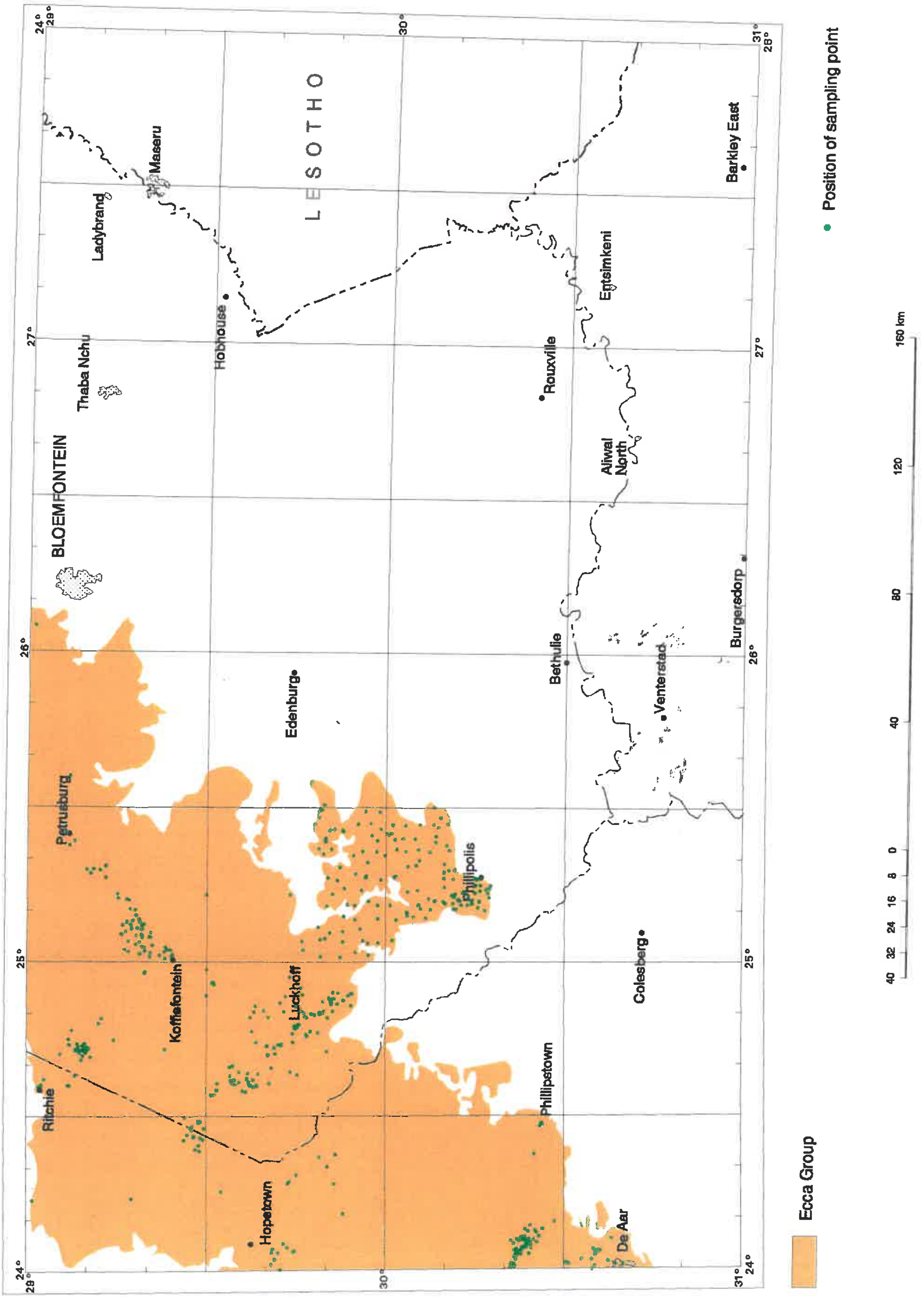


Figure 8. **Areal location of the Ecca Group and associated chemical groundwater sampling points**



That groundwater can give rise to costly problems in the civil engineering construction was emphasised in the Orange-Fish Tunnel Project south of Venterstad, by the flooding of the Shaft 2 tunnel heading, on August 28, 1969. An abnormal, and for the Karoo rocks a most unusual, fissure zone was intersected during blasting. The calculated inflow was 3 090 m^3/h under a hydrostatic head of 87 m.

Sandstone, siltstone and mudstone of the Tarkastad Subgroup (Beaufort Group) have been intersected in the tunnel. These rocks have been intruded by an interconnected network of post-Karoo dolerites. Although only meagre groundwater yields were struck at depth on most dolerite dyke contact zones with sedimentary rocks, one prominent east-west trending dyke contact zone yielded 75 *l*/s at tunnel level. Approximately 1 800 m east of the tunnel route a thermal spring with a temperature of 30°C was located, indicating deep groundwater circulation associated with one of the dykes.

It was deduced, following various hydrogeological investigations, that the tunnel was flooded when an east-west trending fissure zone was intersected. The fissure zone can be compared with a diastrophic joint system, extending to abnormal depths and which was not associated with any dolerite intrusion. With an estimated minimum lateral width of 365 m, this zone consists of numerous open, highly permeable joints, varying in width from hair-line to 7.6 cm at the flooding point.

An arcuate belt of gravity highs (for particularly the Bouguer anomaly) extending from the Doringberg fault near Prieska to the post-Karoo age faults in Lesotho, suggest the possible existence of a major fault system of pre-Karoo age, which has been reactivated during post-dolerite times. It is postulated that the abnormal fissure zone at Shaft 2, the thermal springs in the area south of Venterstad, together with the thermal springs at Aliwal North (all depicted on the hydrogeological map) are associated with this deep-seated zone of crustal disturbance.

It should be mentioned that a total volume of 33.4 x $10^6 m^3$ of groundwater (including the flooding event, draw-down tests and dewatering of the tunnel), was drained over a 15 month period, which resulted in only a fairly limited lowering of groundwater levels, as detected in observation boreholes.

Chemical analyses of groundwater samples, collected from various geohydrological environments indicated that different types, and thus different bodies of water are present. The quality of the groundwater varied from slightly saline, chloride to alkaline, soda-carbonate. Carbon-14 and tritium age-determinations of selected samples indicated the age of the groundwater to vary from zero to approximately 4 000 years. (Derived from Olivier, 1970)

4.1.1.3 Beaufort Group (Tarkastad Subgroup – fractured regime)

The Tarkastad Subgroup fractured regime of the Beaufort Group (Figure 10) mainly occurs south of the Orange River, roughly between Venterstad and Aliwal North. It is depicted on the map as a lithological unit with approximately equal proportions of argillaceous and arenaceous rocks. Groundwater occurs in dolerite contact zones with country rocks, occasional joints and fractures, and on bedding planes. Weathering, mostly the mechanical mode of weathering (rock disintegration) in the argillaceous horizons and in intrusive dolerite bodies, contributes to groundwater potential. The arenaceous horizons are however less prone to weathering, but are more disposed to jointing and fracturing from which it derives its groundwater properties.

A borehole yield analysis (Figure 9) shows that the overall median yield range for this unit falls in the 0.5 *l*/s to 2.0 *l*/s yield order and that 17% of boreholes yield >5 *l*/s. The somewhat promising yield representation in Figure 9 might be misleading considering the relatively small number of only 35 boreholes on which the analysis has been based.

ECs of groundwater vary between 50 and 221 mS/m with a mean value of 78 mS/m (Table 7). The groundwater tends to be alkaline with roughly equal proportions for the sodium, calcium, magnesium and chloride determinants (Figure 11).

Figure 9. Yield frequencies of boreholes in the Beaufort Group (Tarkastad Subgroup – fractured mode of groundwater occurrence) (35 records analysed)

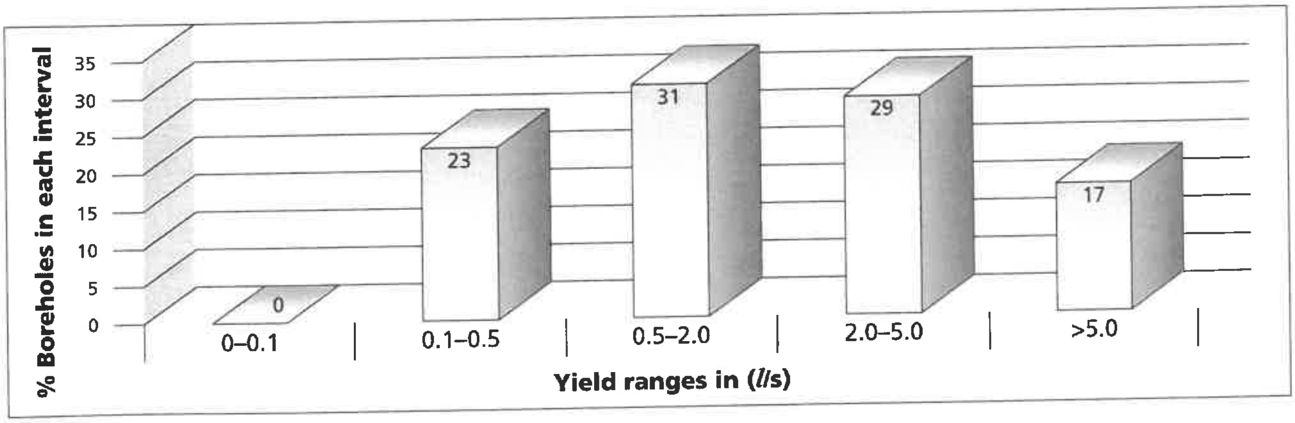


Figure 10. Areal location of the Beaufort Group (fractured regime) and associated chemical groundwater sampling points

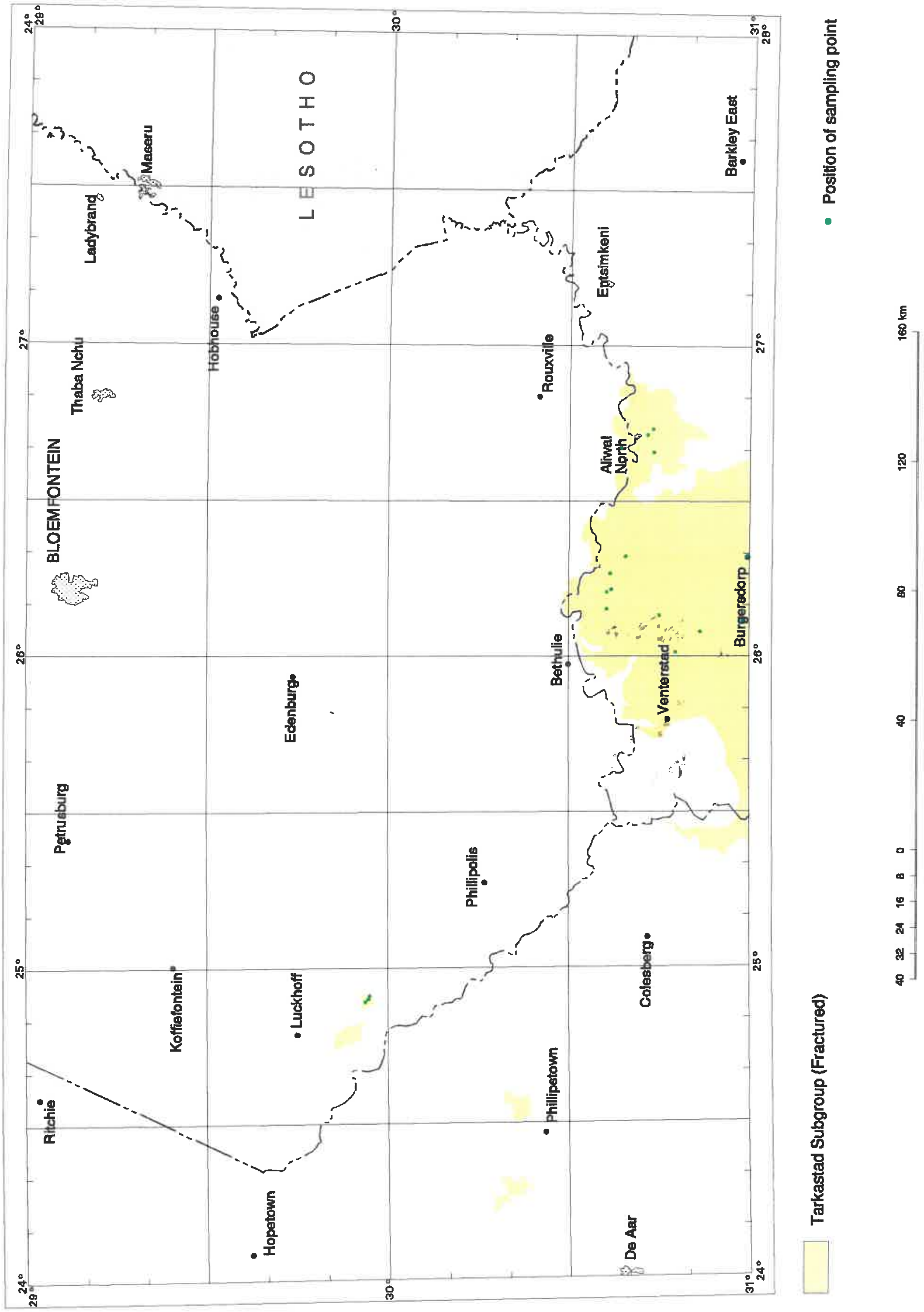


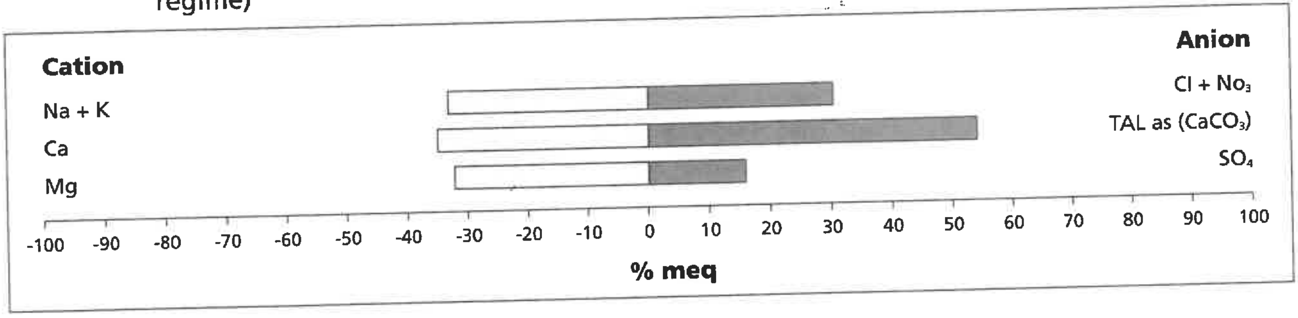
Table 7. Chemistry of groundwater from the Beaufort Group – Tarkastad Subgroup fractured regime (Statistics derived from 15 analyses)

DETERMINANT	MINIMUM VALUE	MAXIMUM VALUE	MEAN VALUE	A	B
pH	7.52	8.44	7.88	6–9	5.5–9.5
Electrical Conductivity (mS/m)	50.60	221.00	78.87	70.0	300.0
Total Dissolved Salts (mg/*l*)	368.00	714.00	522.00	1 200.0	2 000.0
Sodium (mg/*l* Na) mg 11	18.10	153.50	56.65	100.0	400.0
Potassium (mg/*l* K) mg11	0.75	14.44	3.76	200.0	400.0
Calcium (mg/*l* Ca) mg11	18.90	79.40	52.51	150.0	200.0
Magnesium (mg/*l* Mg) mg11	4.30	43.30	28.40	70.0	100.0
Chloride (mg/*l* Cl) mg11	11.80	140.60	40.40	250.0	600.0
Total Alkalinity (mg/*l* $CaCo_3$)	13.20	394.50	126.12	300.0	650.0
Sulphate (mg/*l* SO_4) mg11	10.30	78.10	31.40	200.0	600.0
Nitrate (mg/*l* N) mg11	0.24	7.90	2.86	6.0	10.0
Fluoride (mg/*l* F) mg11	0.31	2.48	0.79	1.0	1.5

A = Drinking Water Quality Criteria: Maximum Recommended Limit

B = Drinking Water Quality Criteria: Maximum Allowable Limit

Figure 11. Stiff diagram of the groundwater chemistry in Table 7 (Beaufort Group – fractured regime)



4.1.2 Intergranular and fractured regime

The intergranular and fractured mode of groundwater occurrence is represented by an obscured granite occurrence (see paragraph 3.1.1), the pre-Karoo Allanridge Formation, the Adelaide and Tarkastad Subgroups of the Beaufort Group, the Molteno, Elliot and Clarens Formations, the widespread dolerites and the Drakensberg Group.

4.1.2.1 Swazian age granite

Two minute occurrences of Swazian age granite (much too small to exhibit on the map), indicated on the 2924 Koffiefontein geologicaol map in the vicinity of Richie, could not be located and no groundwater information could be obtained from this alleged granite occurrence.

4.1.2.2 Allanridge Formation

Limited occurrences of the Allanridge Formation (Figure 12) of the Ventersdorp Supergroup appear along the north-western edge of the map area. Groundwater in the predominately andesitic lava of this unit can be developed by targeting jointed diabase dykes and their contacts and fractures in occasional fault zones. Groundwater can also occur in basins of decomposition and in the transitional jointed zone between the decomposed and solid lava.

A borehole yield analysis (Figure 13) indicates a 0.5 to 2.0 *l*/s median yield range for this unit. ECs of groundwater in the 70 to 300 mS/m quality range can be expected.

Figure 12. Areal location of the Allanridge Formation

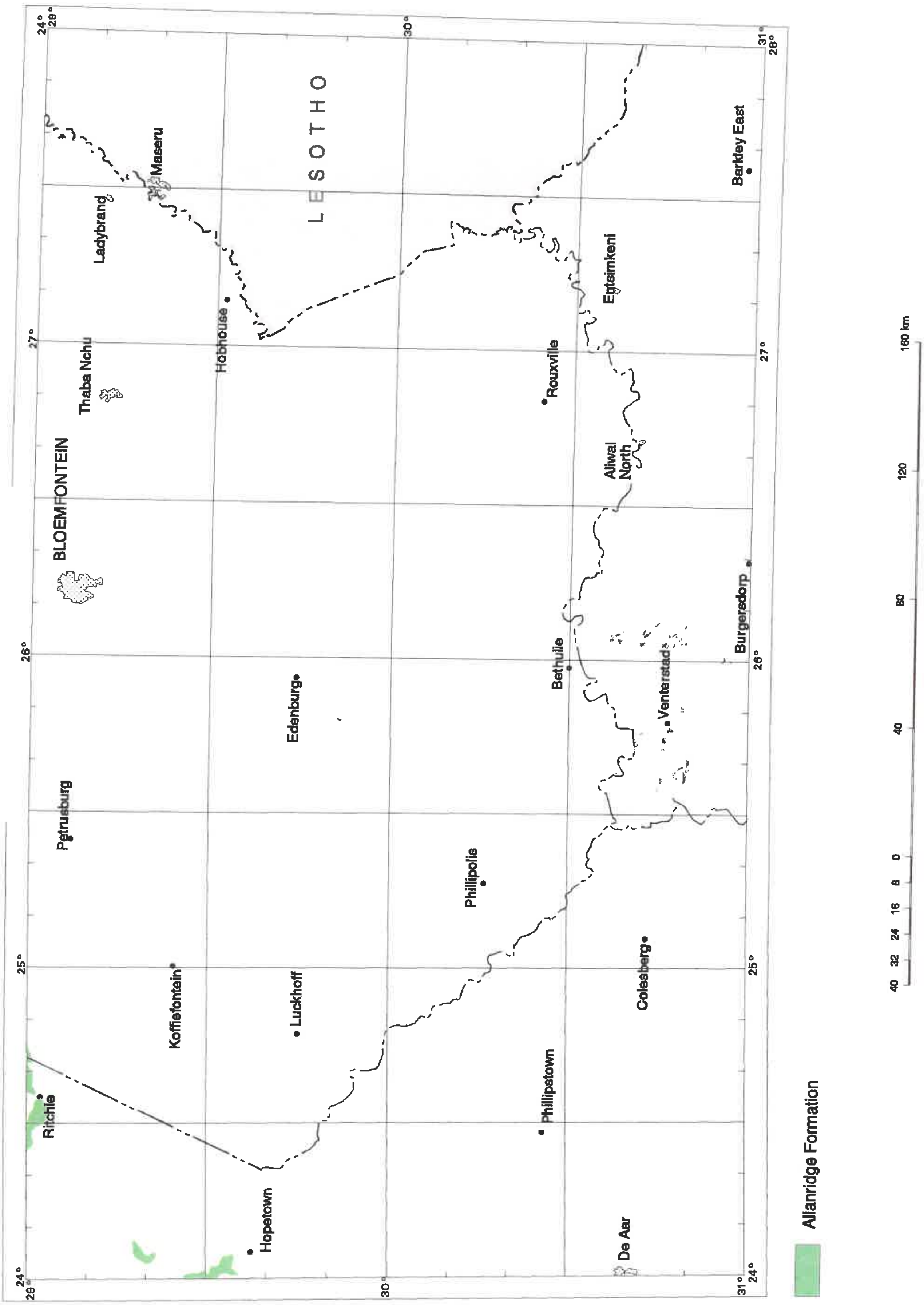
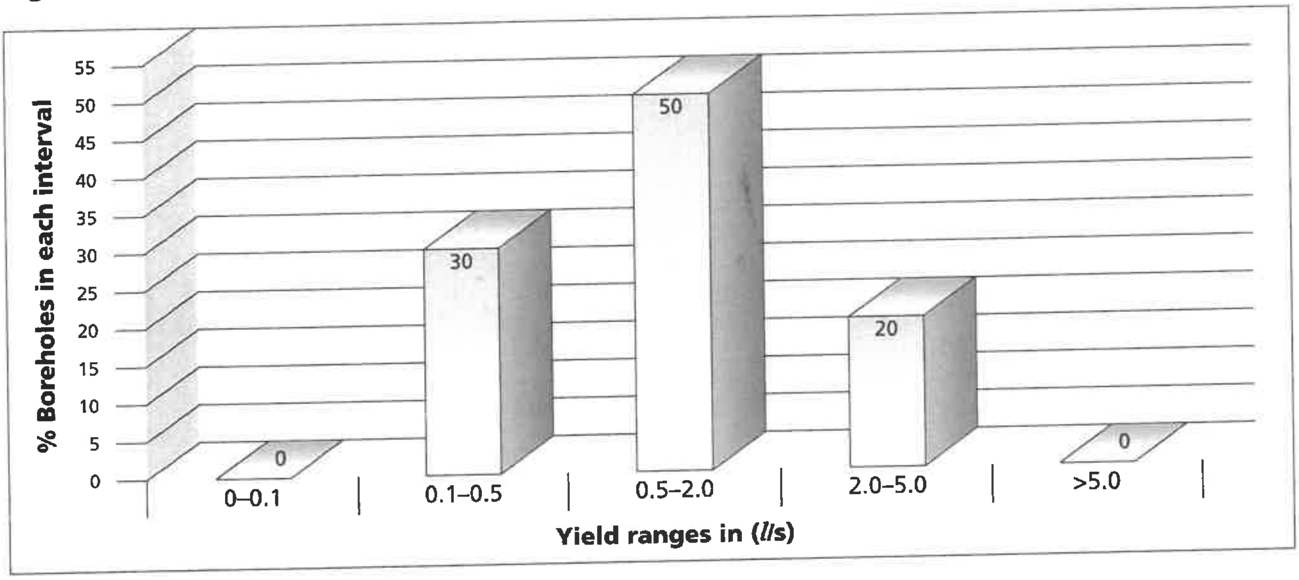


Figure 13. Yield frequencies of boreholes in the Allanridge Formation (10 records analysed)



4.1.2.3 Beaufort Group (Intergranular and fractured regime)

4.1.2.3.1 Adelaide Subgroup

The Adelaide Subgroup (Figure 14) is a predominantly argillaceous unit. The rocks of this unit have been extensively intruded by dolerite sills, notably in the area between De Aar and Jagersfontein, and to a lesser extent by dolerite dykes.

Groundwater occurs in joints and fractures of dolerite contact zones with country rocks, in decomposed dolerite and as well as in the semi-weathered, jointed transitional zone between decomposed and solid dolerite. Groundwater can also be developed from weathered and jointed sedimentary rocks and on bedding planes.

A borehole analysis (Figure 16) disclosed that the overall median yield range of 0.5 to 2.0 *l*/s applies to this unit. ECs vary between 20 and 795 mS/m with an average value of 85 mS/m (Table 8). The groundwater tends to be alkaline with roughly equal proportions for the sodium, calcium, magnesium and chloride determinants (Figure 15).

4.1.2.3.2 Tarkastad Subgroup

The Tarkastad Subgroup (Figure 19) consists of sandstone with interbeds of mudstone which have been intruded by dolerite sills and dykes.

Groundwater occurs in joints of dolerite contact zones with country rocks, in joints and occasional fractures in sedimentary rocks and on bedding planes. Weathering, often in the form of rock decay, especially in dolerite bodies, plays a positive role in groundwater occurrence.

A borehole yield analysis (Figure 18) indicates that the overall median yield range for this unit falls in the 0.5 to 2.0 *l*/s category. ECs vary between 13 and 130 mS/m with a mean value of about 58 mS/m (Table 9). Total alkalinity and sodium occassionally exceed maximum recommended limits, while fluoride and nitrate are the only anions to exceed maximum allowable limits in some instances (Table 9). Groundwater in this unit is inclined to have a bicarbonate nature with roughly equal proportions for the sodium, calcium and magnesium determinants (Figure 17).

> A large ring-like dolerite structure, about 15 km in diameter, occurs south-east of Reddersburg. The ring-complex has intruded shale of the Adelaide Subgroup of the Beaufort Group, and the structure has in turn been intruded by a number of marginally younger dolerite dykes. A strong spring emerges on the north-western edge of the ring-structure on the farm Mostershoek. The strong spring yields between 20 *l*/s during dry periods and up to 40 *l*/s during wet periods. The dolerite in the vicinity of the spring is well-decomposed, has high permeability, and a recharge value of about 8% of annual precipitation has been calculated for this feature.
>
> Sill/ring-structures are fairly common in the map area. A morpho-tectonic analysis shows the general "saucer-shape" of a sill/ring complex, which comprises a flat-lying inner sill always corresponding to low grounds, a peripheral inclined sheet forming the ring, and an outer sill corresponding to high grounds, and a ring feeder dyke branching into the inclined sheet. Sill and ring complexes, intruded at different stratigraphic levels, and commonly stacked above one another in different ways, result in various tectonic and morphological patterns. Satellite imagery and magnetic fabric demonstrate the concept of "ring-within-a-ring" and "ring stacking" very well (Chevallier *et al*, 2000; Woodford and Chevallier, 2002).
>
> Karoo dolerite rings and sills have proven to be structures conducive to the formation of deep-seated fractured-rock aquifers. Yields of up to 70 *l*/s were intersected at intersections of feeder dykes and sills at depths mostly in excess of 200 m. The increase in yield with depth could also indicate that even higher yielding fractures may exist at greater depth (Chevallier *et al*, 2000).

Figure 14. Areal location of the Beaufort Group (Adelaide Subgroup – intergranular/ fractured regime) and associated chemical groundwater sampling points

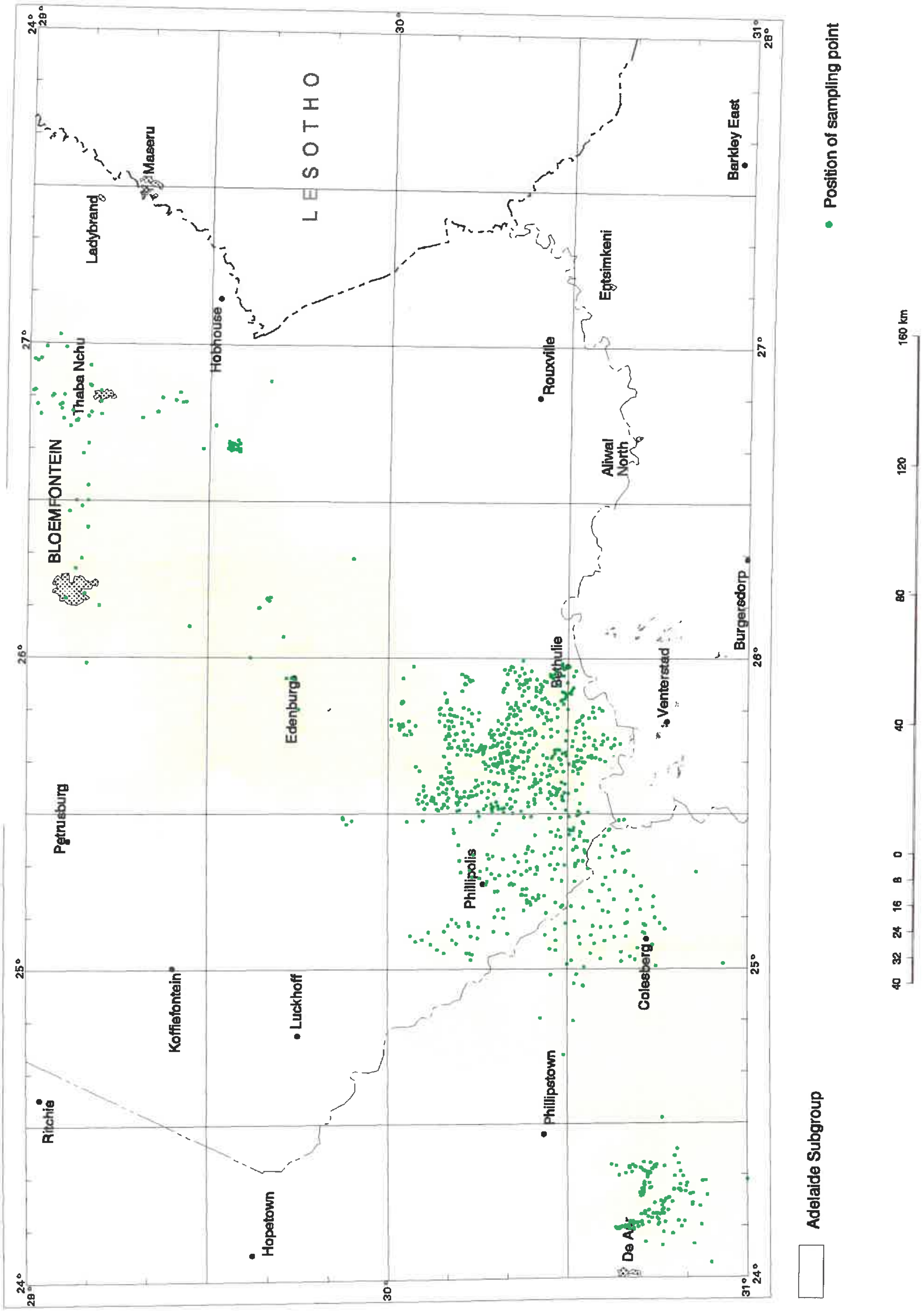


Table 8. Chemistry of groundwater from the Beaufort Group (Adelaide Subgroup – intergranular and fractured regime) (Statistics derived from 435 analyses)

DETERMINANT	MINIMUM VALUE	MAXIMUM VALUE	MEAN VALUE	A	B
pH	6.70	9.4	7.78	6–9	5.5–9.5
Electrical Conductivity (mS/m)	19.10	794.30	85.16	70.0	300.0
Total Dissolved Salts (mg/*l*)	226.00	6 805.00	782.99	1 200.0	2 000.0
Sodium (mg/*l* Na) mg 11	11.60	1 746.20	93.58	100.0	400.0
Potassium (mg/*l* K) mg11	0.30	39.61	2.13	200.0	400.0
Calcium (mg/*l* Ca) mg11	2.00	909.80	72.78	150.0	200.0
Magnesium (mg/*l* Mg) mg11	1.70	476.50	45.81	70.0	100.0
Chloride (mg/*l* Cl) mg11	3.30	123.48	11.60	250.0	600.0
Total Alkalinity (mg/*l* $CaCo_3$)	35.80	597.10	235.06	300.0	650.0
Sulphate (mg/*l* SO_4) mg11	4.70	1993.0	111.98	200.0	600.0
Nitrate (mg/*l* N) mg11	0.04	98.36	4.78	6.0	10.0
Fluoride (mg/*l* F) mg11	0.13	7.60	0.76	1.0	1.5

A = Drinking Water Quality Criteria: Maximum Recommended Limit
B = Drinking Water Quality Criteria: Maximum Allowable Limit

Figure 15. Stiff diagram of the groundwater chemistry in Table 8 (Beaufort Group – intergranular and fractured regime – Adelaide Subgroup)

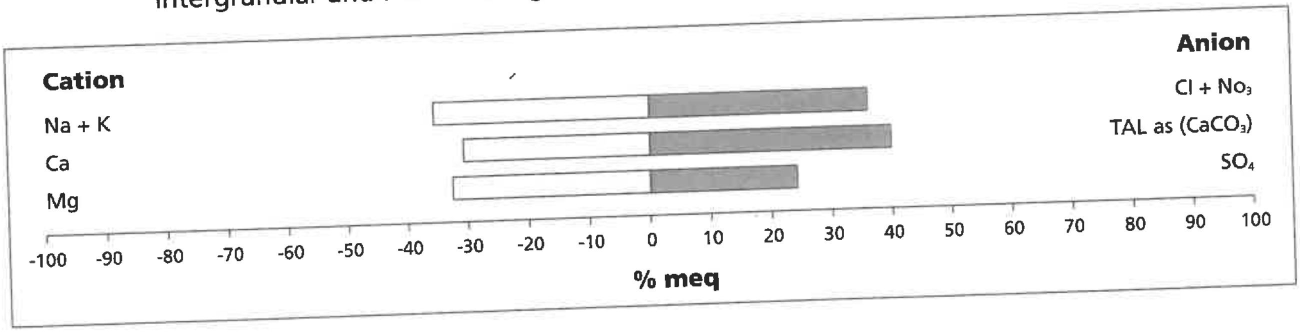


Figure 16. Yield frequencies of boreholes in the Beaufort Group (Adelaide Subgroup – intergranular and fractured regime) (2 720 records analysed)

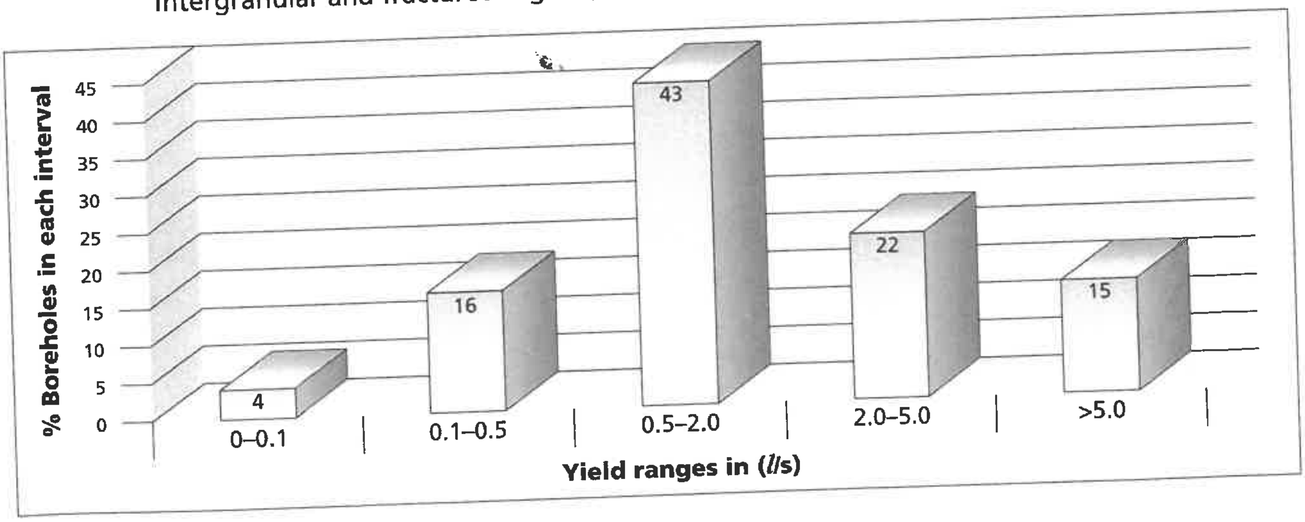


Table 9. Chemistry of groundwater from the Beaufort Group (Tarkastad Subgroup – intergranular and fractured regime) (Statistics derived from 17 analyses)

DETERMINANT	MINIMUM VALUE	MAXIMUM VALUE	MEAN VALUE	A	B
pH	7.00	8.77	7.80	6–9	5.5–9.5
Electrical Conductivity (mS/m)	13.00	130.44	58.92	70.0	300.0
Total Dissolved Salts (mg/*l*)	270.00	732.00	445.00	1 200.0	2 000.0
Sodium (mg/*l* Na) mg 11	16.00	115.20	53.39	100.0	400.0
Potassium (mg/*l* K) mg11	0.43	5.62	1.61	200.0	400.0
Calcium (mg/*l* Ca) mg11	5.40	112.00	46.41	150.0	200.0
Magnesium (mg/*l* Mg) mg11	1.80	49.60	20.90	70.0	100.0
Chloride (mg/*l* Cl) mg11	3.70	50.00	20.59	250.0	600.0
Total Alkalinity (mg/*l* $CaCo_3$)	67.24	363.50	206.05	300.0	650.0
Sulphate (mg/*l* SO_4) mg11	9.20	155.70	34.85	200.0	600.0
Nitrate (mg/*l* N) mg11	0.09	10.69	1.75	6.0	10.0
Fluoride (mg/*l* F) mg11	0.20	2.28	0.79	1.0	1.5

A = Drinking Water Quality Criteria: Maximum Recommended Limit B = Drinking Water Quality Criteria: Maximum Allowable Limit

Figure 17. Stiff diagram of the groundwater chemistry in Table 9 (Beaufort Group – intergranular and fractured regime – Tarkastad Subgroup)

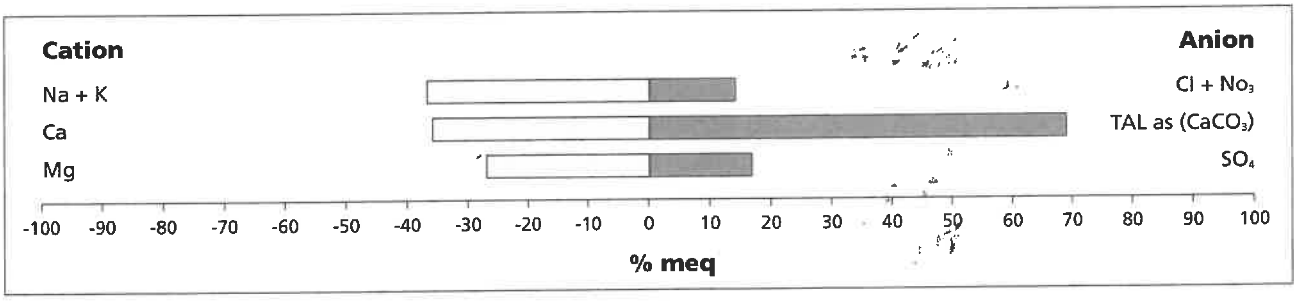


Figure 18. Yield frequencies of boreholes in the Beaufort Group (Tarkastad Subgroup – intergranular and fractured regime) (289 records analysed)

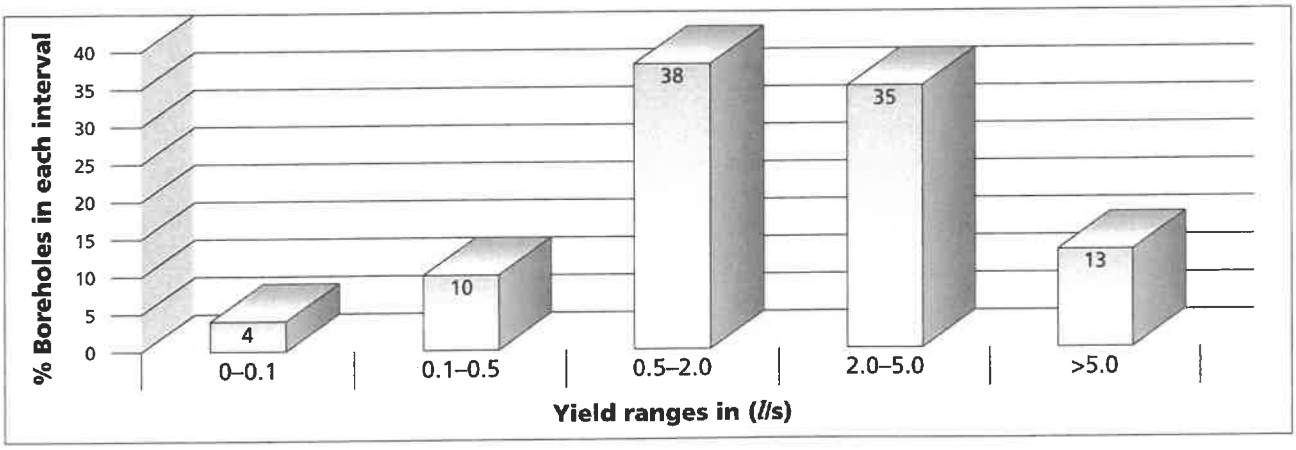
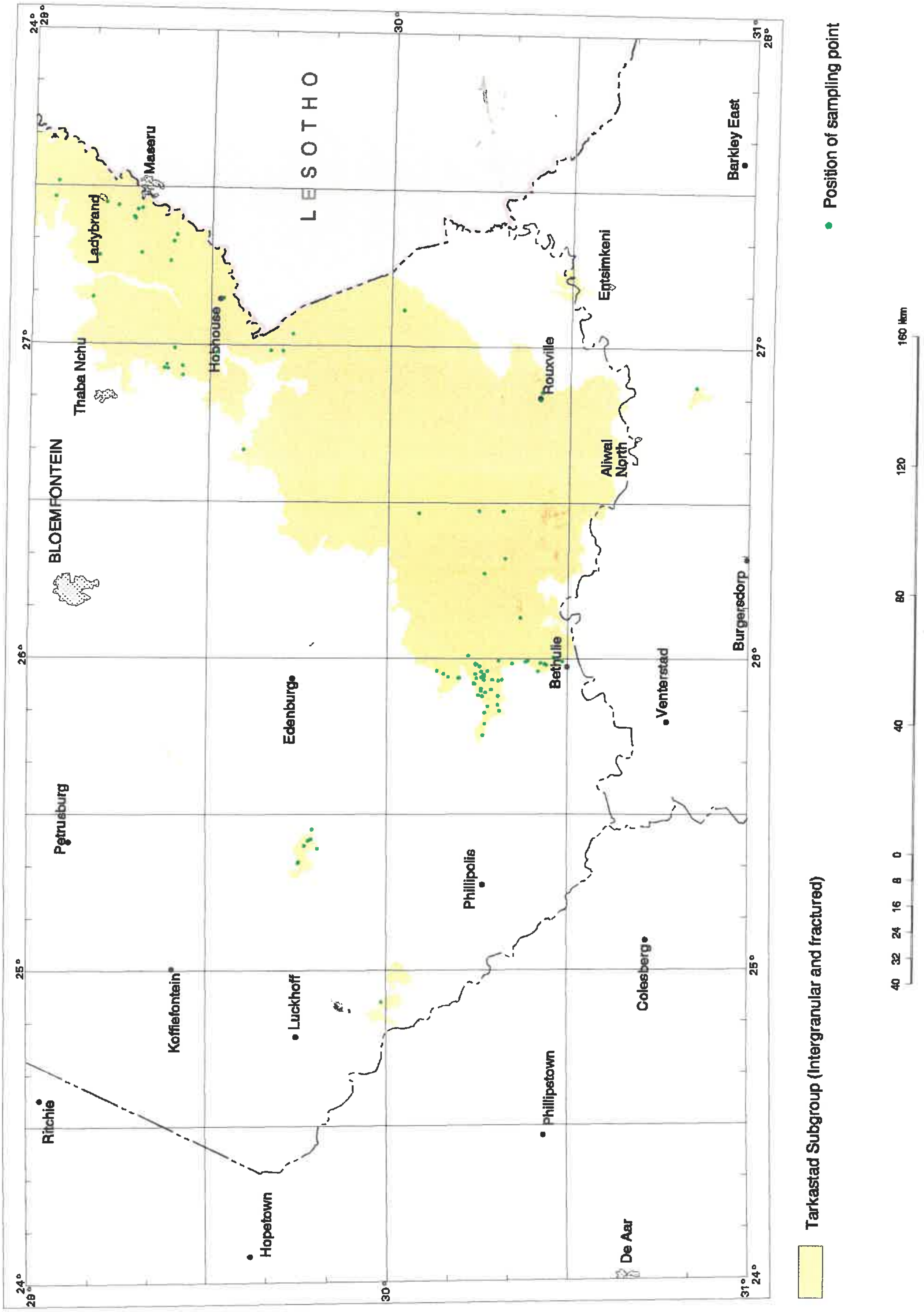


Figure 19. Areal location of the Beaufort Group (Tarkastad Subgroup – intergranular and fractured regime) and associated chemical groundwater sampling points



4.1.2.4 The Molteno, Elliot and Clarens Formations

The Molteno Formation, composed of mudstone and sandstone, the Elliot Formation, compiled of mudstone and subordinate sandstone, and the Clarens Formation (Figure 23) which is essentially a sandstone unit, collectively cover the far eastern portion of the map area along the Lesotho border. These Formations have all been intruded by a variety of dolerite bodies, but intrusions into them are apparently less prevalent compared with the rest of the map area. Groundwater can be developed from joints and fractures in intrusion contact zones with sedimentary rocks, in joints, and on bedding planes in sedimentary rocks as well as in decomposed rocks, particularly in dolerite bodies. The following factors often render these Formations less productive in terms of groundwater potential:

- Some of the units, especially the Clarens Formation, frequently occur as isolated, protruding remnants, thus literally constituting "high and dry" conditions.
- The landscape in the outcrop area of these Formations is often dissected resulting in higher run-off and less recharge
- The relative scarcity of dolerite intrusions in some localities mean fewer propitious drilling targets.

Assumptions regarding groundwater chemistry in these Formations are bound to be distorted and rendered almost meaningless in view of only two chemical analyses available for each of the Molteno and Elliot Formations (Tables 10 and 11) which obviously portray extreme and unrepresentative chemical values. The groundwater of both the Molteno and Elliot Formations seems to be of a sodium-chloride nature (Figure 20 and 22). Almost no groundwater chemistry data is available for the Clarens Formation. However, one EC field measurement is available which has a value of 35 mS/m.

Table 10. Chemistry of groundwater from the Molteno Formation (Statistics derived from 2 analyses)

DETERMINANT	MINIMUM VALUE	MAXIMUM VALUE	MEAN VALUE	A	B
pH	7.47	8.77	8.12	6–9	5.5–9.5
Electrical Conductivity (mS/m)	42.40	97.70	70.05	70.0	300.0
Total Dissolved Salts (mg/*l*)	395.00	4 034.00	2 214.50	1 200.0	2 000.0
Sodium (mg/*l* Na) mg 11	105.80	916.40	511.00	100.0	400.0
Potassium (mg/*l* K) mg11	5.05	24.69	14.87	200.0	400.0
Calcium (mg/*l* Ca) mg11	7.90	194.30	101.10	150.0	200.0
Magnesium (mg/*l* Mg) mg11	6.30	240.20	123.25	70.0	100.0
Chloride (mg/*l* Cl) mg11	8.80	2 030.70	1 019.75	250.0	600.0
Total Alkalinity (mg/*l* $CaCo_3$)	71.77	129.50	104.98	300.0	650.0
Sulphate (mg/*l* SO_4) mg11	9.20	195.10	102.15	200.0	600.0
Nitrate (mg/*l* N) mg11	0.09	0.38	0.24	6.0	10.0
Fluoride (mg/*l* F) mg11	0.84	2.19	1.52	1.0	1.5

A = Drinking Water Quality Criteria: Maximum Recommended Limit

B = Drinking Water Quality Criteria: Maximum Allowable Limit

Figure 20. Stiff diagram of the groundwater chemistry in Table 10 (Molteno Formation)

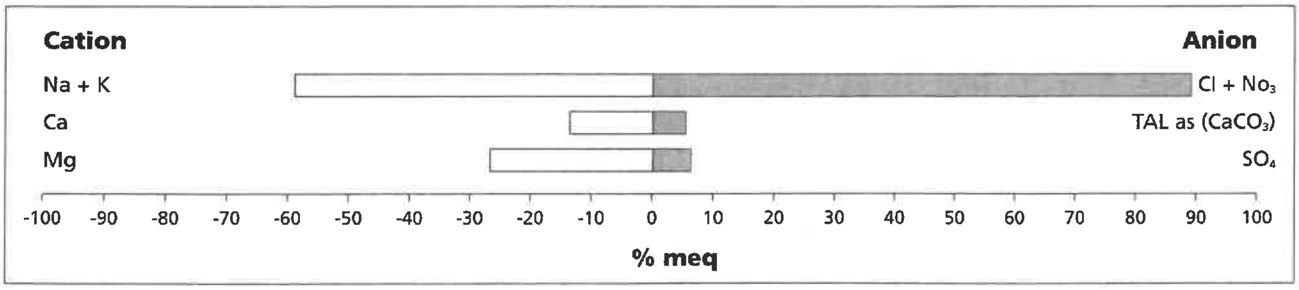


Figure 21. Yield frequencies of boreholes in the Molteno Formation (187 records analysed)

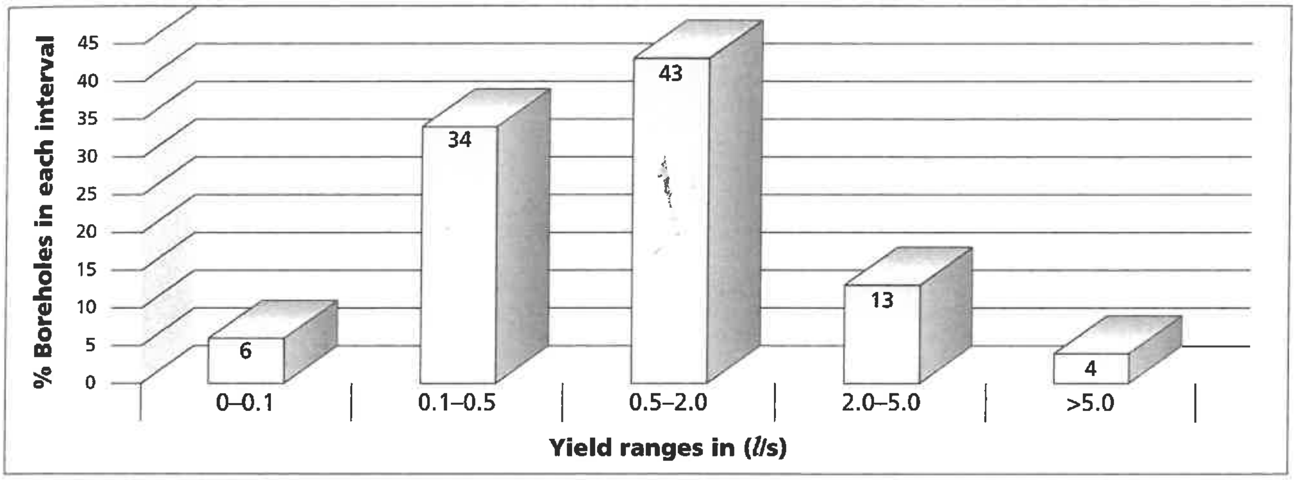


Table 11. Chemistry of groundwater from the Elliot Formation (Statistics derived from 2 analyses)

DETERMINANT	MINIMUM VALUE	MAXIMUM VALUE	MEAN VALUE	A	B
pH	6.20	7.61	7.15	6–9	5.5–9.5
Electrical Conductivity (mS/m)	5.60	667.00	188.40	70.0	300.0
Total Dissolved Salts (mg/l)	472.00	4 034.00	2 253.00	1 200.0	2 000.0
Sodium (mg/l Na) mg 11	57.70	916.40	487.05	100.0	400.0
Potassium (mg/l K) mg11	7.22	24.69	15.96	200.0	400.0
Calcium (mg/l Ca) mg11	53.60	194.30	123.95	150.0	200.0
Magnesium (mg/l Mg) mg11	19.30	240.20	129.75	70.0	100.0
Chloride (mg/l Cl) mg11	37.70	2 030.70	1 034.20	250.0	600.0
Total Alkalinity (mg/l $CaCo_3$)	73.80	152.80	113.30	300.0	650.0
Sulphate (mg/l SO_4) mg11	44.20	195.10	119.65	200.0	600.0
Nitrate (mg/l N) mg11	0.06	0.99	0.39	6.0	10.0
Fluoride (mg/l F) mg11	0.46	2.19	1.33	1.0	1.5

A = Drinking Water Quality Criteria: Maximum Recommended Limit

B = Drinking Water Quality Criteria: Maximum Allowable Limit

Figure 22. Stiff diagram of the groundwater chemistry in Table 11 (Elliot Formation)

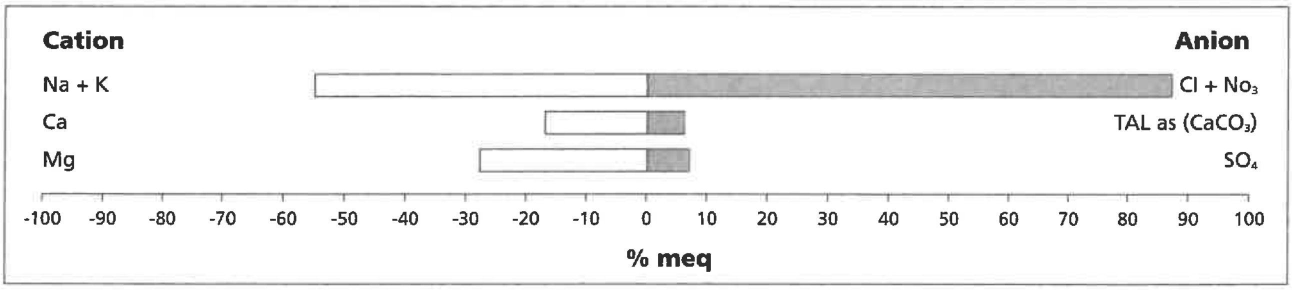


Figure 23. Areal location of the Molteno, Elliot and Clarens Formations and associated chemical groundwater sampling points

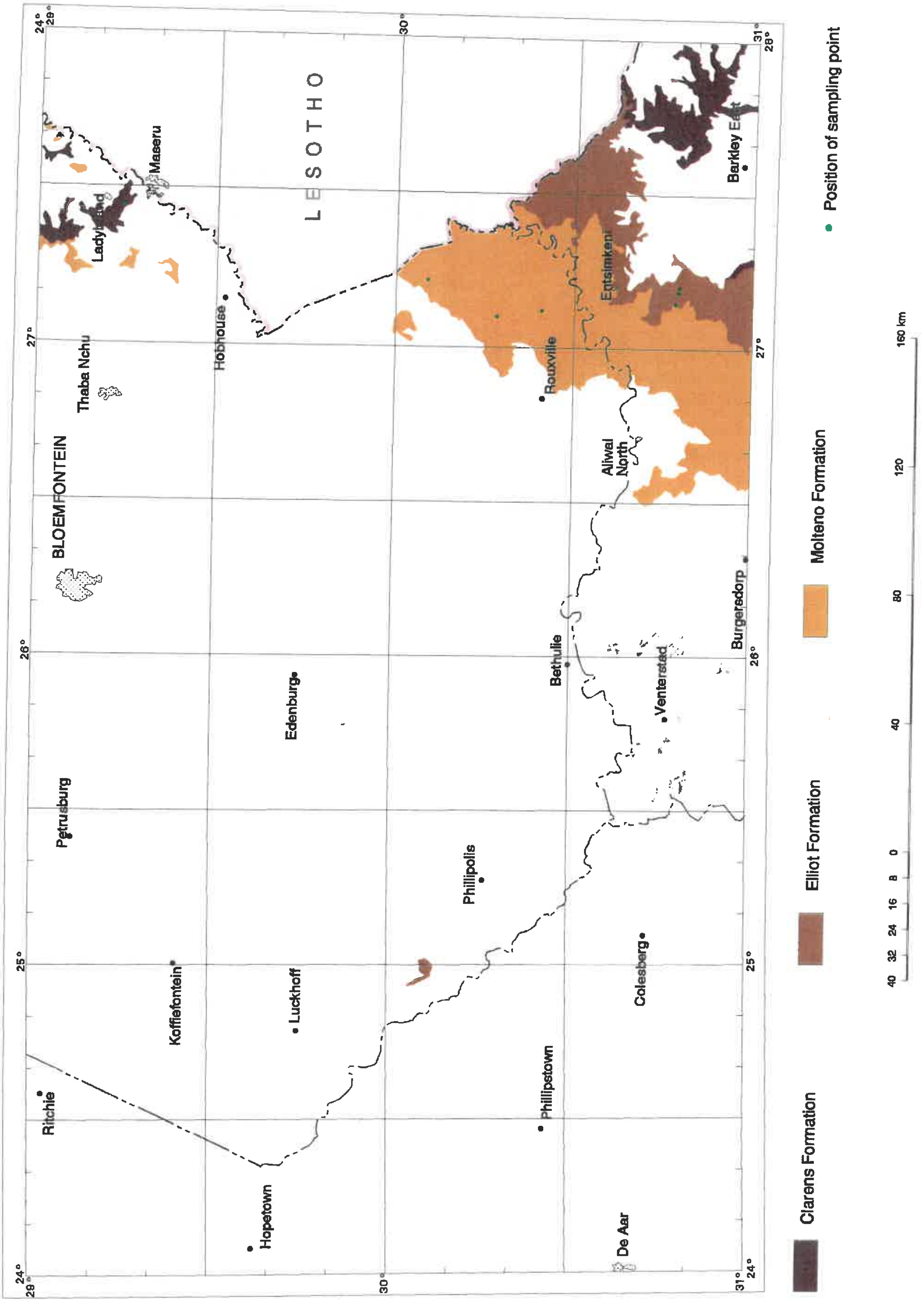


Figure 24. Yield frequencies of boreholes in the Elliot Formation (65 records analysed)

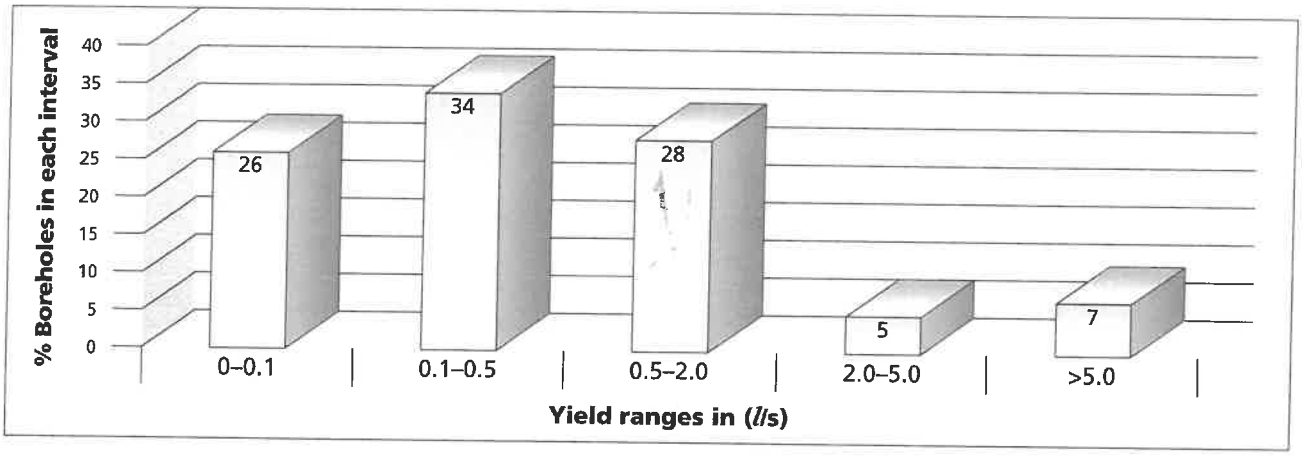
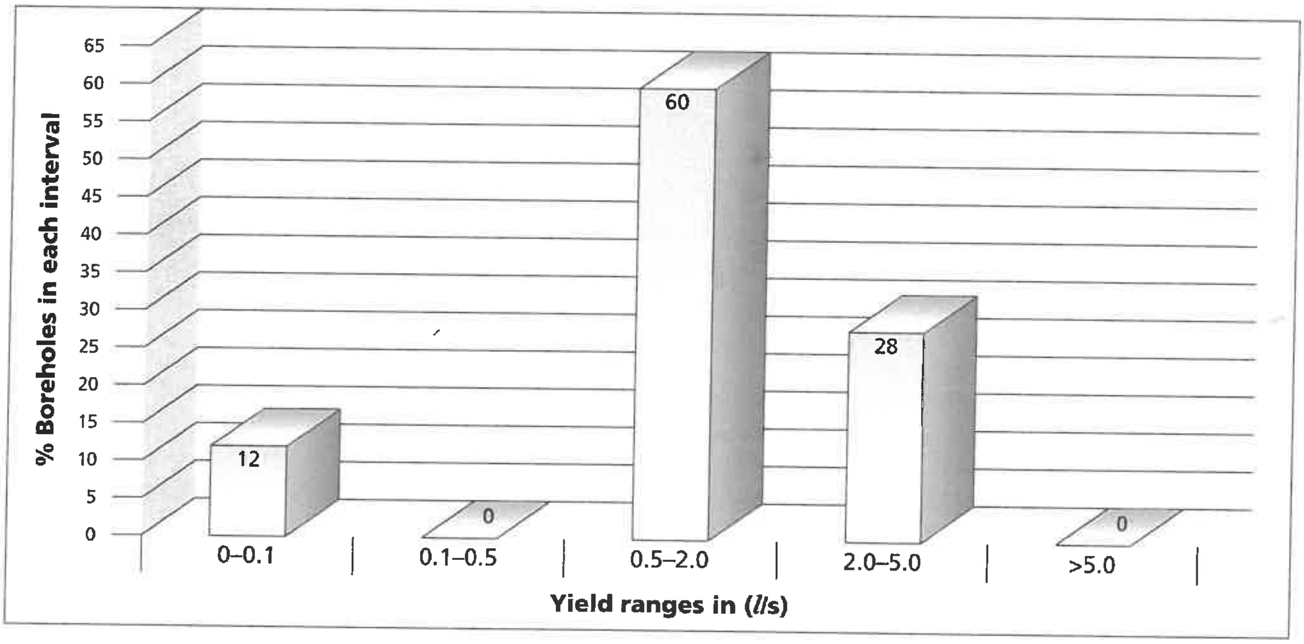


Figure 25. Yield frequencies of boreholes in the Clarens Formation (25 records analysed)



4.1.2.5 Karoo Dolerite Suite (Jd)

Dolerite intrusions, both in dyke (not portrayed in Figure 26) and sill form occur throughout the map area (Figure 26) and are particularly abundant in some portions of the Ecca and Beaufort Groups. Dolerite sills often transgress from one sedimentary horizon to other horizons, and are often irregular in shape. Both sills and dykes display various dips. Irregularity of dolerite bodies complicates appraised interception depths. Dolerite bodies are nevertheless of paramount importance in terms of groundwater potential. Apart from groundwater occurrences in jointed and fractured contact zones between sedimentary rocks and dolerite (provided contact zones are not too deep), groundwater can also be found in decomposed dolerite and in the transitional zone between decomposed and solid dolerite.

A borehole analysis (Figure 28) shows that the overall median yield range of 0.5 to 2.0 *l*/s is applicable to this unit. This assumption may however be misleading, as yields obtained on dolerite/sedimentary contact zones might in some instances have been included in the analysis data. The application of the 0.1 to 0.5 *l*/s median yield range would seem to be a safer supposition.

ECs of groundwater from the dolerite sills vary between 17 and 553 mS/m with a mean value of 92 mS/m (Table 12). Although mean values for different determinants, with the exception of nitrate, do not exceed maximum recommended limits, maximum values for sodium, calcium, magnesium, chloride and sulphate do exceed maximum allowable limits (Table 12). Groundwater from the dolerites tends to be alkaline with roughly equal portions for the sodium, chloride, calcium and magnesium determinants (Figure 27).

Figure 26. Areal location of the Karoo Dolerite Suite (major sills) and associated chemical groundwater sampling points

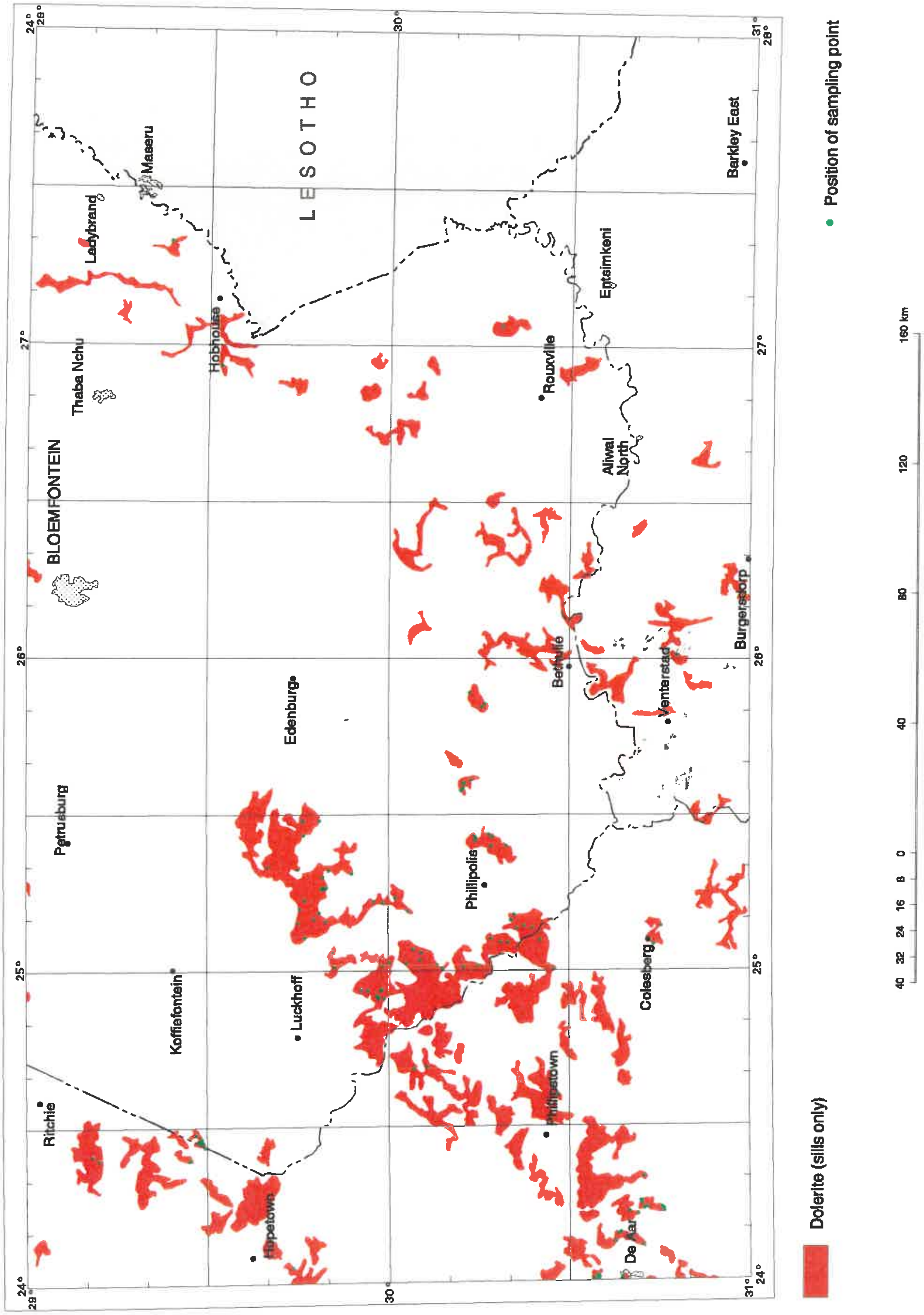


Table 12. Chemistry of groundwater from the Karoo Dolerite Suite (Statistics derived from 78 analyses)

DETERMINANT	MINIMUM VALUE	MAXIMUM VALUE	MEAN VALUE	A	B
pH	7.08	8.48	7.79	6–9	5.5–9.5
Electrical Conductivity (mS/m)	16.90	553.6	92.65	70.0	300.0
Total Dissolved Salts (mg/l)	140.00	3 508.00	748.55	1 200.0	2 000.0
Sodium (mg/l Na) mg 11	5.40	826.20	8 239.00	100.0	400.0
Potassium (mg/l K) mg11	0.41	36.95	3.04	200.0	400.0
Calcium (mg/l Ca) mg11	9.50	255.50	65.60	150.0	200.0
Magnesium (mg/l Mg) mg11	1.50	165.00	48.92	70.0	100.0
Chloride (mg/l Cl) mg11	3.70	1 108.50	113.61	250.0	600.0
Total Alkalinity (mg/l $CaCo_3$)	125.60	400.30	251.60	300.0	650.0
Sulphate (mg/l SO_4) mg11	6.50	782.00	94.04	200.0	600.0
Nitrate (mg/l N) mg11	0.05	48.79	5.36	6.0	10.0
Fluoride (mg/l F) mg11	0.14	4.21	0.71	1.0	1.5

A = Drinking Water Quality Criteria: Maximum Recommended Limit

B = Drinking Water Quality Criteria: Maximum Allowable Limit

Figure 27. Stiff diagram of the groundwater chemistry in Table 12 (Karoo Dolerite Suite)

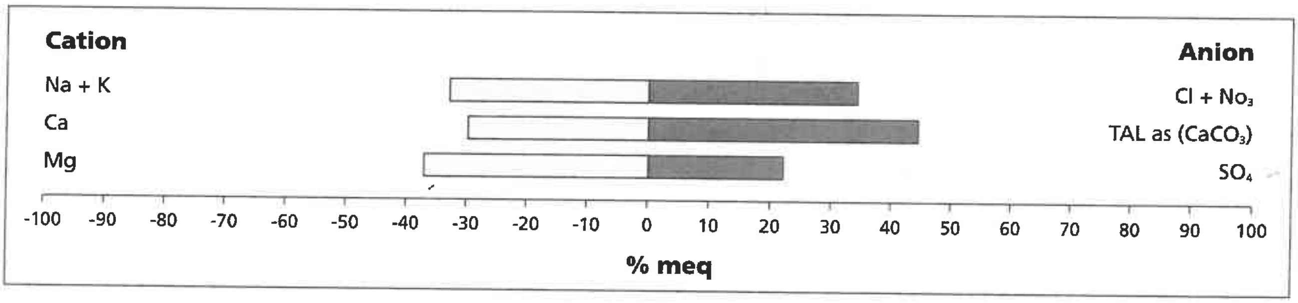
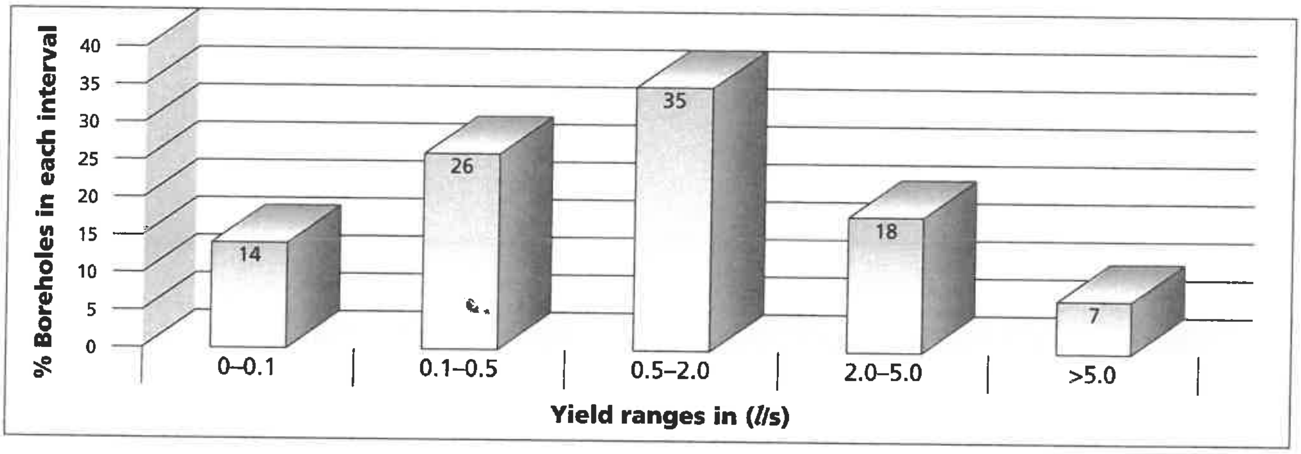


Figure 28. Yield frequencies of boreholes in the Karoo Dolerite Suite (258 records analysed)



4.1.2.6 Drakensberg Group (Jdr)

The Drakensberg Group (Figure 31) is restricted to the south-eastern corner of the map area. This unit occupies mountainous, topographically dissected terrain, a characteristic that inevitably impacts on the region's groundwater occurrence in terms of generally deeper groundwater-levels for this unit.

The area is underlain by basaltic lava and minor occurrences of tuff, agglomerate and breccia. The lava can roughly be divided into a compact, even-textured type which almost resembles dolerite and a more porous amygdaloidal type. The amygdaloidal type of lava seems to be more prone to decomposition than the even-textured type. The basalts are on appearance generally well decomposed.

Groundwater can be obtained in decomposed lava and in the transitional jointed zone between decomposed and solid lava. Contacts between different lava flows as well as fractured dolerite dyke contacts with lava can also be targeted for groundwater development. Due to the relatively deep regional groundwater-level, a fair percentage of decomposed material will probably feature above groundwater-level, rendering it non-utilisable for groundwater exploitation. Numerous, low-yielding springs emerge, especially on contacts between decomposed and solid rocks.

A borehole yield analysis (Figure 30) shows that the overall median yield range of 0.1 to 0.5 *l*/s is applicable to this unit,

Table 13. Chemistry of groundwater from the Drakensberg Group (Statistics derived from 1 analysis)

DETERMINANT	MINIMUM VALUE	MAXIMUM VALUE	MEAN VALUE	A	B
pH			7.85	6–9	5.5–9.5
Electrical Conductivity (mS/m)	67.10	121.00	94.05	70.0	300.0
Total Dissolved Salts (mg/*l*)	436.10	786.50	611.30	1 200.0	2 000.0
Sodium (mg/*l* Na) mg 11			131.10	100.0	400.0
Potassium (mg/*l* K) mg11			2.45	200.0	400.0
Calcium (mg/*l* Ca) mg11			54.00	150.0	200.0
Magnesium (mg/*l* Mg) mg11			48.90	70.0	100.0
Chloride (mg/*l* Cl) mg11			111.40	250.0	600.0
Total Alkalinity (mg/*l* $CaCo_3$)			26.20	300.0	650.0
Sulphate (mg/*l* SO_4) mg11			157.80	200.0	600.0
Nitrate (mg/*l* N) mg11			1.85	6.0	10.0
Fluoride (mg/*l* F) mg11			1.19	1.0	1.5

A = Drinking Water Quality Criteria: Maximum Recommended Limit
B = Drinking Water Quality Criteria: Maximum Allowable Limit

Figure 29. Stiff diagram of the groundwater chemistry in Table 13 (Drakensberg Group)

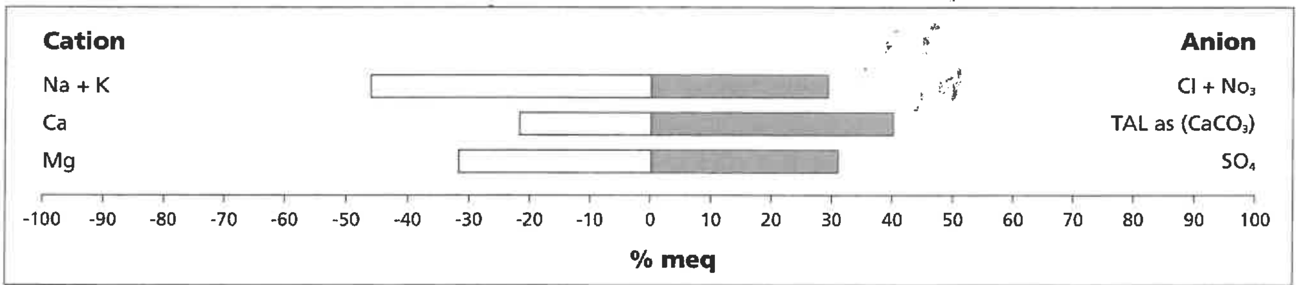
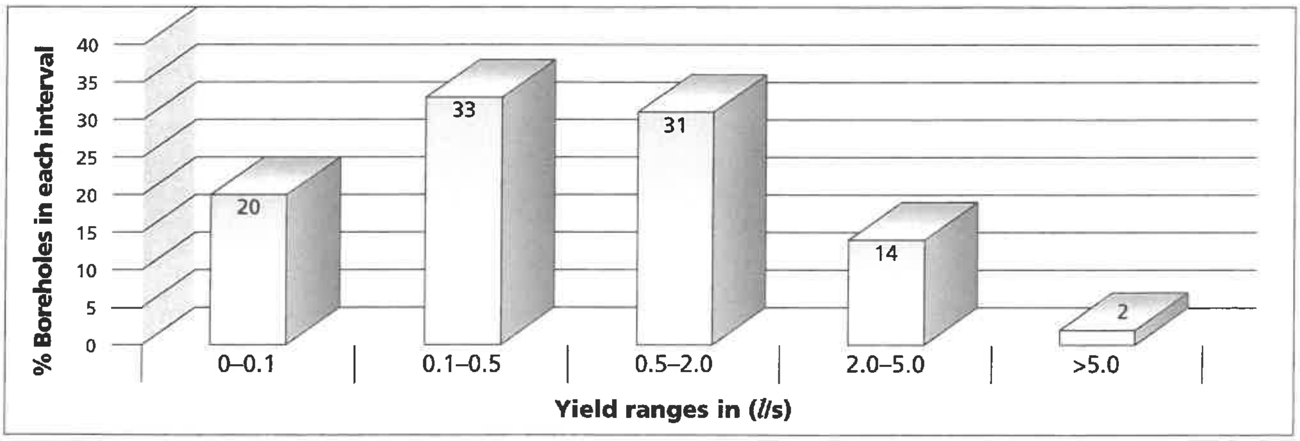


Figure 30. Yield frequencies of boreholes in the Drakensberg Group (105 records analysed)



and that 20% of boreholes yield < 0.1 *l*/s, all pointing to a low-yielding borehole expectancy for the basalts.

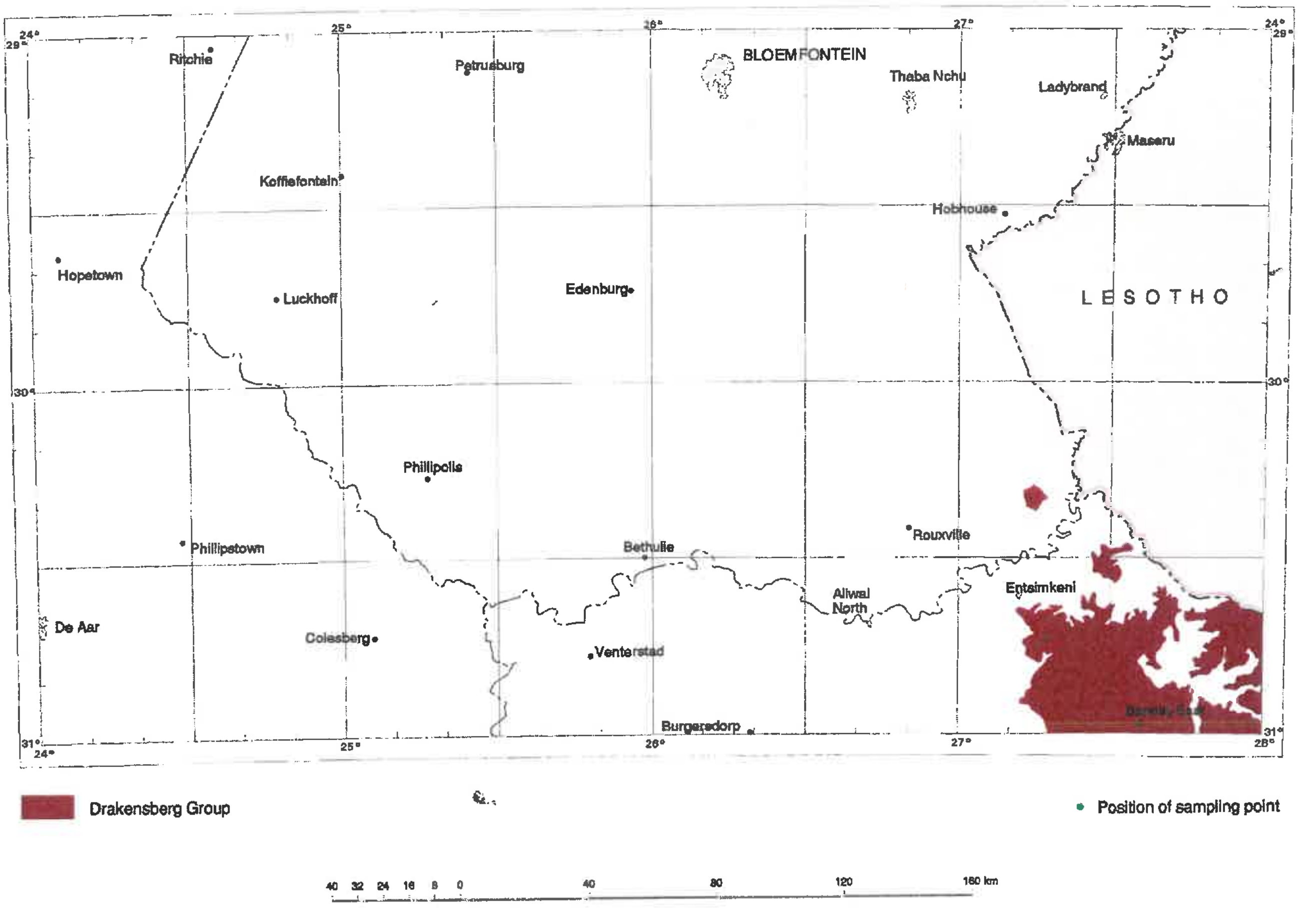
Information on groundwater quality, gleaned from a mere two EC data points and only one chemical analysis suggests that ECs may vary between a potable 60 and 120 mS/m, averaging 94 mS/m and only the sodium cation occasionally exceeding the maximum recommended limit (Table 13). Groundwater from the Drakensberg Group seems to be of a bicarbonate-sodium-chloride nature (Figure 29). The available information is however too scanty to substantiate this claim.

4.1.3 Intergranular regime

4.1.3.1 Alluvium

No meaningful intergranular (alluvial) aquifers have been reported within the map area. However, isolated two-layered aquifers, constituting intergranular (alluvial) aquifers overlying intergranular and fractured aquifers have been described (par. 4.2.2). It can readily be accepted that alluvium can also act as a groundwater recharge medium.

Figure 31. Areal location of the major Drakensberg Group and associated chemical groundwater sampling points



4.2 Selected case reports

To highlight some of the problems and findings pertaining to groundwater within the map area, the essence of the following selected case reports are included.

4.2.1 Jagersfontein (Basic data derived from Kok, 1982)

The Jagersfontein area is predominantly underlain by shale of the Adelaide Subgroup of the Beaufort Group, which has been intruded by dolerite of Jurassic age and a number of kimberlite pipes of Cretaceous age, some of which are diamond bearing. One such pipe is located on the townlands and has been mined for diamonds since 1871.

The town was dependent for many years on boreholes for its water supply, but due to diminishing borehole yields this source of water became unreliable and a supplementary source was needed to alleviate shortages. Following the discontinuation of mining activities by De Beers Ltd Consolidated Mines in 1971, that Company gave permission to the town council of Jagersfontein in 1980 to utilise groundwater from the diamond mine for municipal use. Groundwater from the abandoned mine (Plate 5) is currently the only source of water supply to the town of Jagersfontein and it is also an important supplementary source of water to neighbouring Fauresmith.

Pumping takes place from a depth of 220 m below surface, using the main rock shaft (Figure 32). After dewatering during mining prior to 1971, the water-level in the abandoned mine rose to approximately 183 m from 1971 to 1980, allowing for a potential groundwater-level drawdown of 37 m at a calculated abstraction rate of 17.5 *l*/s.

From the available information the following conclusions can be made:

- Abstraction figures and water-level data for the period August 1980 to March 1982 indicate that the groundwater-level fluctuated between 183.12 and 184.30 m during that period when a total of about 500 000 m^3 was abstracted.
- The low fluctuation amplitudes of the groundwater-level during this nineteen month period, and the fact that the aquifer succeeded in maintaining that degree of abstraction for the past 20 years, points to the existence of a remarkably sustainable groundwater source.

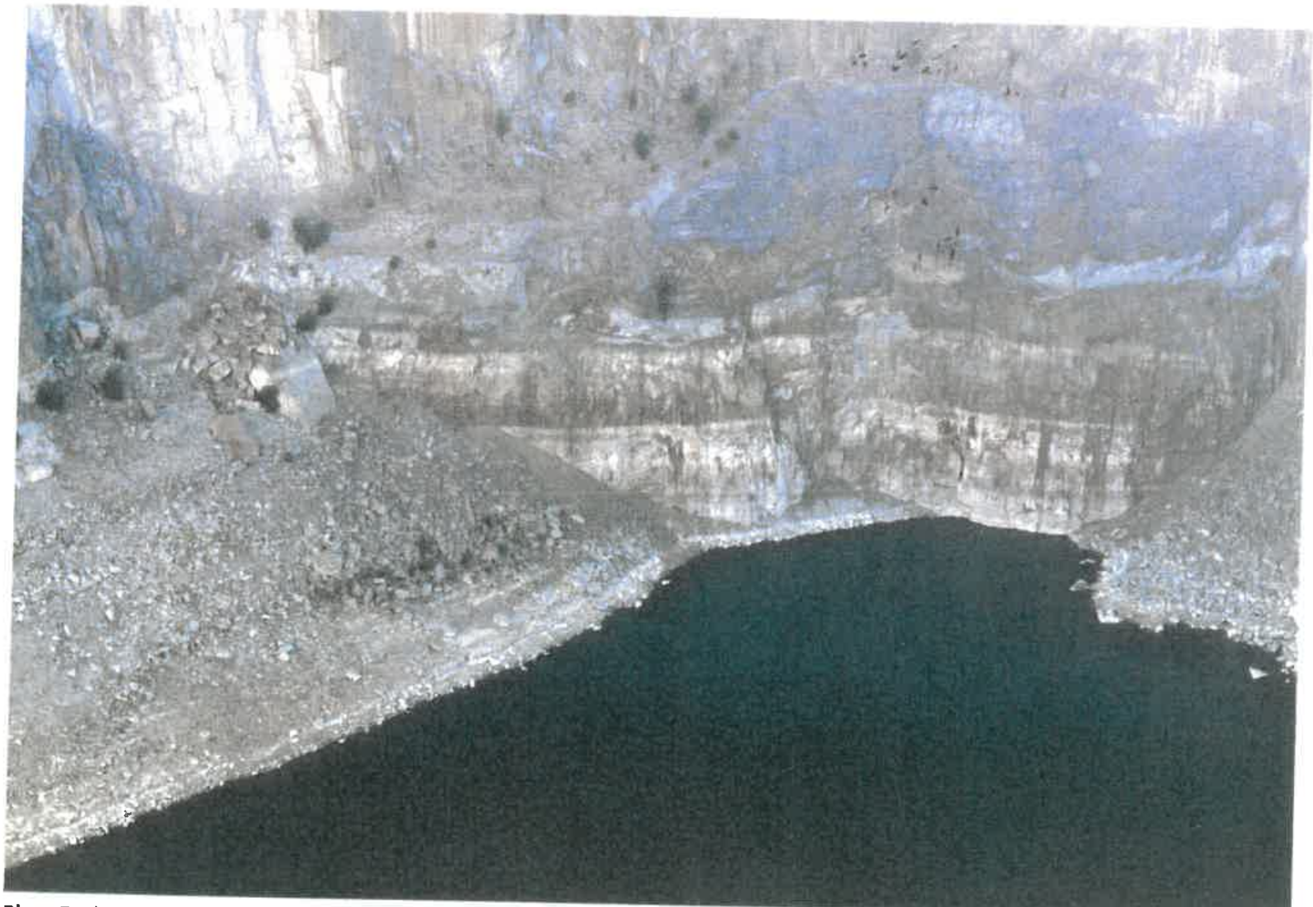


Plate 5. The abandoned Jagersfontein diamond mine which is currently the source of water supply to Jagersfontein and Fauresmith. Groundwater was probably intercepted in unweathered fractured intrusive dolerite contact zones to depths of up to 700 m below surface. (Photograph: P.S.Meyer).

- Groundwater probably occurs on unweathered fractured contact zones between the various dolerite and shale horizons at depths varying from about 300 to 700 m below surface (Figure 32).
- The deep water interception (encountered during shaft sinking) is in contradiction to the general assumption and belief that meaningful groundwater is unlikely to occur below the weathered zone of 18 m below surface in the map area (paragraphs 4.2.2 and 4.2.3). A chemical analysis indicates that the water from the shaft is of sodium – sulphate nature, and according to a Piper trilinear diagram the water has not been recharged recently but falls on the border between dynamic and stagnant water.

4.2.2 De Aar (Largely derived from Vegter, 1992)

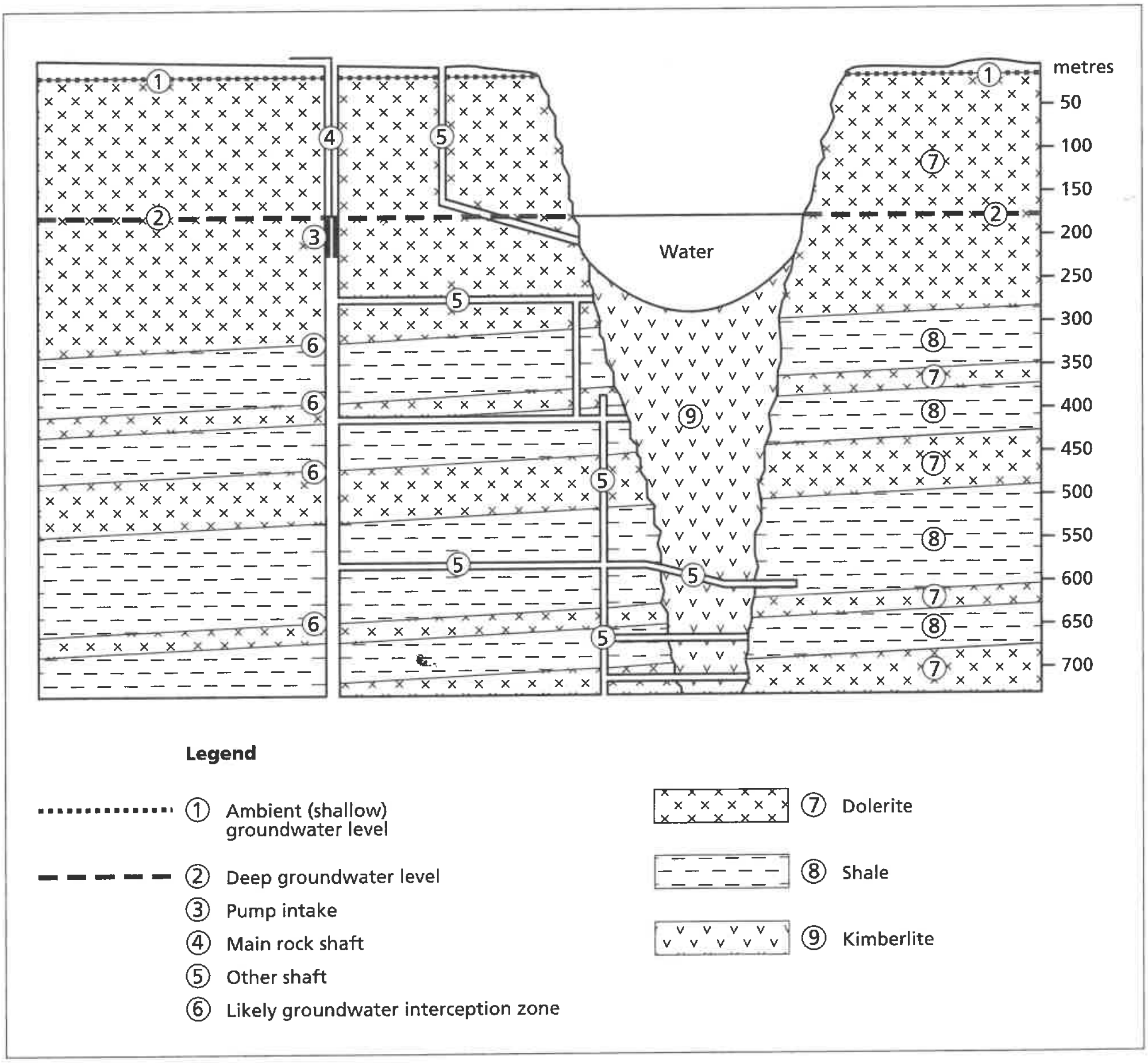
Since its establishment in 1902, De Aar has relied solely on groundwater sources for its water supply. From January to December 2000 a total of 2.12 x 10^6 m^3 was abstracted from the following well-fields: Paardevlei, Caroluspoort and Burgerville, all located east of longitude 24° E and spread between 7 and 30 km distance from De Aar. The fourth well-field, known as the Southwest well-field, is situated approximately 11 km south-west of De Aar and does not feature on the map. The well-fields east of longitude 24° E provided about 78% of the town's water requirements in 2000.

The surroundings of De Aar lie at an elevation of between 1 200 and 1 500 m above mean sea-level. It has a semi-arid climate with an average rainfall of about 300 mm (Table 2).

Evaporation exceeds 2 000 mm/a.

The area is geologically underlain by shale and subordinate siltstone of the Ecca Group west and north-west of the town,

Figure 32. Geohydrological profile of the Jagersfontein Mine (After DeBeers Ltd. 1969 – modified)



and mudstone, siltstone and sandstone of the Beaufort Group east and south-east of the town. The sedimentary rocks have been intruded by undulating dolerite sheets on two horizons and by dolerite dykes. The dolerite is of Jurassic age. Some kimberlite dykes of Cretaceous age have also been reported. Deposits of alluvium occur along river courses.

Three aquifer types can be distinguished:

- The basal section of alluvial deposits which is usually coarse-grained.
- Weathered and fractured Ecca and Beaufort strata and dolerite with optimal fracturing in the vicinity of intrusive contacts
- A two-layered aquifer, constituting an intergranular (alluvial) aquifer overlying an intergranular and fractured aquifer.

The sedimentary rocks and dolerite owe their water-bearing properties to jointing and fracturing which is generally limited to the top 20 to 30 m below surface. Weathering processes play an essential role in opening up joints and fractures and in converting the rocks into more porous media. Jointing and fracturing is enhanced in the vicinity of intrusive contacts.

Statistical analyses of exploratory drilling and other investigation results have provided the following information:

- The probability of striking water is highest between depths of 5 and 15 m.
- Individual strike yields are mostly less than 1.0 l/s.
- Strike yields and fracture permeability decrease with depth.
- Boreholes owe high yields to having struck a number of water-bearing fractures, rather than a single high yielding one.
- Groundwater levels in the valleys are mostly less than 5 m below surface.
- There is no material difference in strike yields in the upper and lower contact zones of dipping dolerite intrusions.
- Water is struck more readily in the sedimentary portions of both upper and lower intrusive contact zones than in the dolerite portions.
- Apart from vertical to inclined fracturing associated with dolerite dykes and dipping dolerite sills, there are some indications that horizontal fracturing along bedding planes may also be an important water-bearing feature.
- The most prolific aquifers are composite aquifers, consisting of an intergranular (porous and permeable sand and gravel) and an underlying weathered (fractured rock) component. Yields in excess of 5 l/s have been obtained from the two-layered aquifers.
- Geophysical exploration methods have not been particularly useful in groundwater exploration..
- Recharge from rainfall infiltration ranges between 4.3% and 7% for different terrains and geological settings.
- Estimates of assured yield vary between a minimum of 7.2 mm/a to a maximum of 9.5 mm/a.
- Of approximately 600 chemical analyses, 65% have a total dissolved solids content of less than 1 000 mg/l, and 83% have TDS-values of less than 1 500 mg/l.
- There is a tendency for groundwater quality to deteriorate with pumping.
- Values for transmissivity and storage coefficients for alluvium, fractured hard rock and composite aquifers respectively, range as follows:

	ALLUVIUM	FRACTURED HARD ROCK	TWO-LAYERED AQUIFERS
Transmissivity (m^2/d)	212 – 347	7 – 1 320	83 – 3 797
Coefficient of storage S	0.062 – 0.11	2×10^{-6} – 0.02	3.6×10^{-5} – 0.074

4.2.3 Colesberg (Basic information derived from Boehmer, 1972)

Colesberg has for many years been dependant on groundwater for its water supply, and needed supplementary sources towards the end of the 1960's. Extensive groundwater investigations, including drilling were undertaken in 1970 on a variety of geological settings in search for additional groundwater sources (Figure 33).

The Colesberg area is predominantly underlain by shale of the Adelaide Subgroup of the Beaufort Group, which has been intruded by numerous dolerite dykes and undulating dolerite sills.

Two boreholes, G26194 and G26196, were drilled into sedimentary rocks to depths of 41 and 39 m respectively. G26194 yielded 22 l/s and G26196 yielded 0.01 l/s. Water in G26194 was intercepted at 25.6 m, presumably in a joint feature. The yield in G26194 subsequently decreased gradually and the borehole is currently not in municipal use.

Eight boreholes were drilled on different dyke contacts with sedimentary rocks. Two of these boreholes, G24025 and G24028 yielded 5 l/s each. These two boreholes were drilled to depths of 61 and 21 m respectively, and water was intercepted between 11 and 18 m. The yields of both these boreholes decreased over time and they are currently in use only as emergency sources of water supply. The remaining six boreholes positioned on dyke contact zones were drilled to depths of between 21 and 34 m, and interception depths of between 5 and 21 m were recorded, with yields varying between 0.1 and 0.5 l/s. The last six mentioned boreholes were never put to municipal use and have since been abandoned.

One borehole, G26195 was drilled into a narrow dolerite dyke to a depth of 12 m, when solid dolerite was presumably encountered. This borehole yielded 0.25 l/s.

Borehole G26198 was drilled to a depth of 21 m in sedimentary rocks, which are covered by alluvium of an unknown thickness. A yield of 0.7 l/s was struck at 10.5 m.

Two dry boreholes, G26197(a) and G26197(b) were drilled down to the lower contact zones of dolerite sills with sedimentary rocks to depths of 18 and 30 m respectively.

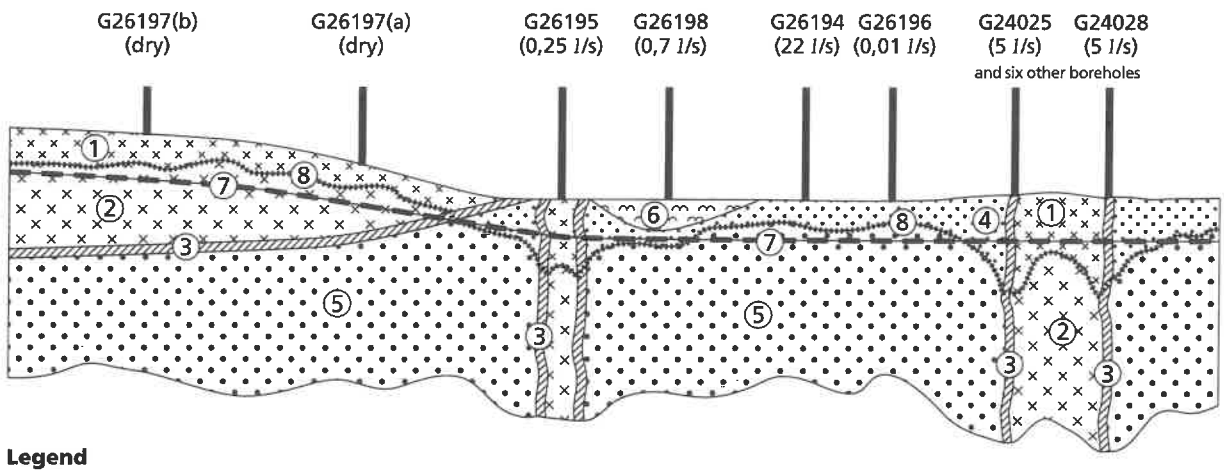
According to the investigation results, fracture porosity occurs mainly along the narrow contact zones between dolerite intrusions and sedimentary rocks. These zones are generally only productive in the upper decomposed zone of about 18 m below surface.

Where deeper, unweathered contacts were encountered, no significant groundwater yields were obtained.

The reported decrease in borehole yields following periods of abstraction can probably be attributed to the limited storage capacity of the narrow fractured contact zones, which in turn control yield sustainability.

An estimated groundwater recharge factor of about 5% of annual precipitation is accepted for large areas of the Karoo Supergroup rocks in the map area. To provide groundwater to a town the size of Colesberg, which is situated in an almost semi-desert environment, would require several, preferably unconnected, independent, meticulously managed borehole fields. This is particularly true in view of the limited groundwater storage capacity of the rocks in the Colesberg area, as well as the relatively low annual rainfall and subsequent meagre groundwater recharge. The use of groundwater was abandoned some years ago and water is currently obtained from the Orange River.

Figure 33. Groundwater occurrence in the Colesberg area: A schematic profile (Not to scale)



4.2.4 Thaba Nchu (Basic data derived from Gombar, 1973)

Thaba Nchu is, in terms of geology, situated on shale, mudstone and subordinate sandstone of the Adelaide Subgroup of the Beaufort Group. A number of dolerite dykes and irregular dolerite sills have intruded the sedimentary rocks.

Groundwater has for many years been the only, albeit inadequate source of water supply to the town. Between 30 and 40 boreholes have in the course of time been drilled, which were either unsuccessful, or have gradually dried up in the wake of abstraction. In the early 1970's three production boreholes could effectively supply only about 40% of the town's water requirements and water restrictions were the order of the day.

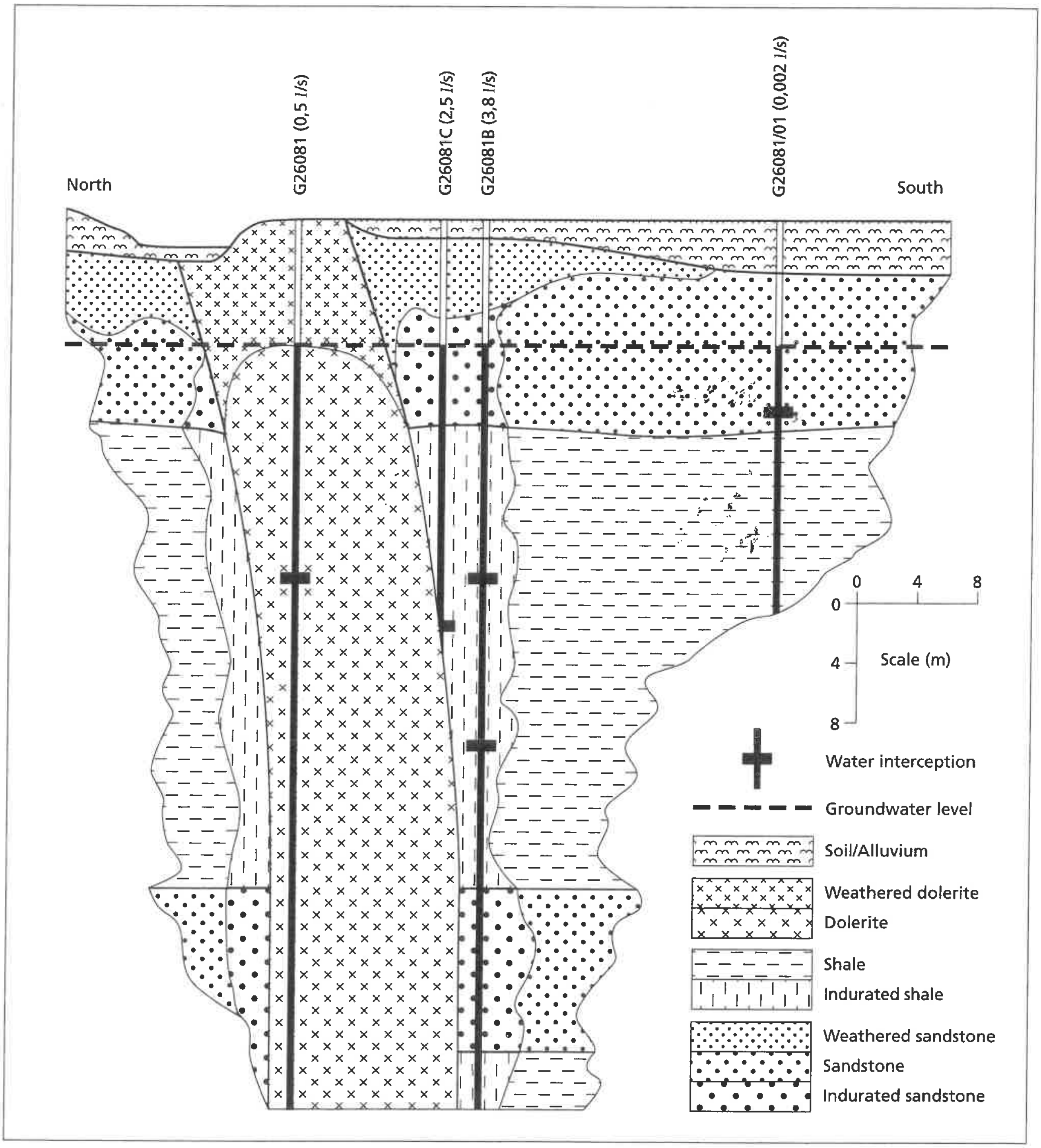
In 1973 a borehole-siting programme, employing geological and geophysical methods of tracing water-bearing zones, was undertaken. A total of 31 exploratory boreholes were subsequently drilled of which at least seven boreholes were positioned on dolerite contact zones with sedimentary rocks. Two of these boreholes were sited on partly decomposed sills penetrating intrusion contact zones. These two boreholes yielded 5.6 and 7.2 *l*/s respectively. As far as can be ascertained, five boreholes were drilled into dyke contact zones, some of which are depicted in Figure 28. The yields of boreholes drilled into dyke contact zones varied from 0.55 and 3.80 *l*/s. One borehole, G26081 was drilled into a dolerite dyke (Figure 34) and yielded 0.5 *l*/s. The remainder of the boreholes were apparently drilled into sedimentary rocks at various distances from dolerite intrusions. Yields of these boreholes varied between 1.25 *l*/s and zero.

Thaba Nchu's groundwater history during the past twenty years is somewhat blurred. The fact that the town has switched from groundwater utilisation to surface water supply can probably be blamed on groundwater supply failure in the face of bulk abstraction. The supply failure in turn, is indicative of yield unsustainability due to lack of groundwater storativity.

Information gained from an investigation in an area around Thaba Nchu (Joubert, 1953) suggest the following:

- Both dyke and sill dolerite intrusions occur
- Dolerite dykes criss-cross the area in all directions, vary between vertical to near vertical, generally have widths of between 0.3 and 9 m and form linear features, often over several kilometres long.
- Two types of dolerite sills can be distinguished, namely horizontal bodies which have intruded more or less conformably into bedding-planes, and irregular, large transgressive bodies often displaying high-angles.
- Best drilling results can be obtained by drilling in and along dolerite bodies which traverse valleys where regular recharge can be anticipated.

Figure 34. Results of drilling on and along a dolerite dyke at Thaba Nchu (Hypothetical where information is wanting)



4.2.5 The Petrusburg Aquifer (Basic information derived from Rudolph and de Lange, 2000)

The Petrusburg Aquifer, located approximately 80 km west of Bloemfontein, covers an area of about 72 000 ha. Based on rather indistinct catchment divides, the Aquifer is divided into three units, known as the Immigrant, Tafelkop and Helderwater units.

Geologically the area around Petrusburg is underlain by shale, mudstone and subordinate sandstone of the Ecca Group. Dolerite sills and dykes occur widely.This explains why dolerite was encountered in 14 out of 18 boreholes recently drilled for exploratory purposes (Table 14). Deposits of calcrete (Plate 6), widely distributed and reputedly reaching a thickness of up to 30 m, have been reported. The deposits of calcrete apparently do not form a blanket covering of the area, as calcrete did not feature in 11 out of 18 boreholes drilled during the above-mentioned exploratory drilling programme (Table 14). High-yielding boreholes of up to 29 *l*/s have been recorded in the Petrusburg Aquifer. Percentage of boreholes with yields of more than 5 *l*/s varies between 38% in the Immigrant unit, 25% in the Tafelkom unit and 23% in the Helderberg unit (Table 15). In 1999 more than 4.7 x 10^6 m^3 of groundwater was abstracted from the Immigrant unit, 5.8 x 10^6 m^3 from the Tafelkop unit and 3.6 x 10^6 m^3 from the Helderwater unit. The average groundwater storage capacity of the calcrete is about 2%, which is four times higher than the 0.5 % for the Karoo rocks in general (Viviers, 1995).

Notwithstanding the admittedly limited information gained from the 1998 exploratory drilling programme, the data points to largely poor groundwater strikes on dolerite/sedimentary contact zones. Although dolerite was encountered in 14 out of 18 boreholes drilled, only three interceptions on dolerite/sedimentary contact zones were recorded, with airlift yields of 2.4 *l*/s in G47344, 0.1 *l*/s in G47369 and 10 *l*/s in G47370 (Table 14).

This translates to meaningful (potential bulk supply) interceptions on intrusive contact zones of only 5% of contact zone incidences.

Calcrete has been encountered in only 7 out of 18 boreholes drilled in the 1998 exploratory drilling programme. The thickness of the calcrete in these boreholes varied between 1 and 12 m, groundwater-levels were in all instances deeper than calcrete thickness. No water was thus intercepted in calcrete, and airlift yields varied between 0.1 and 4.8 *l*/s with only one borehole yielding more than 5 *l*/s (the yield of >5 *l*/s is associated with an interception on an intrusive contact zone in G47370 and is not calcrete related). It can therefore be tentatively concluded that calcrete-poor situations equate to comparatively low groundwater potential.

Intrusive contact zones and sedimentary rocks not overlain by substantial deposits of calcrete do not seem to have formed high-yielding aquifers. Reports by groundwater developers would however suggest that substantial deposits of calcrete may be responsible for the high groundwater potential of the Petrusburg surrounds, as depicted on the map.

Plate 6. An outcrop of porous calcrete near Petrusburg. There are strong indications that the thick deposits of calcrete occurring in the area, may, due to their high recharge enhancing properties, be responsible for high yielding boreholes in the Petrusburg area. (Photograph: P.S. Meyer).

Table 14: Information of exploratory boreholes drilled in 1998 in the Petrusburg area

BOREHOLE NUMBER	UNIT	DEPTH (m)	WATER STRIKE (mbgl)	AIRLIFT YIELD (l/s)	GROUND-WATER LEVEL (mbgl)	REMARKS
G 47344	Helderwater	132	75; 113	2.4	20.30	Dolerite, sandstone, shale. Interception on dolerite/shale contact
G 47345	Helderwater	60	–	seepage	7.66	Calcrete, dolerite. Calcrete 6m thick
G 47346	Helderwater	60	21	3.0	9.82	Dolerite, sandstone, shale. Interception in shale.
G 47347	Helderwater	60	–	seepage	9.78	Dolerite, sandstone, shale.
G 47348	Helderwater	120	20; 90	2.9	5.40	Mudstone, shale, sandstone. Interception on sandstone/shale contact.
G 47349	Helderwater	60	21	0.5	4.96	Dolerite mudstone, shale. Calcrete 1m thick. Interceptiion in shale.
G 47350	Tafelkop	120	10	0.8	10.0	Dolerite mudstone, shale, sandstone. Interception on dolerite/ mudstone contact.
G 47351	Tafelkop	30	24	2.4	9.71	Dolerite mudstone, shale. Interception on mudstone/shale contact.
G 47352	Tafelkop	30	24	1.8	9.68	Dolerite mudstone, shale. Interception in shale
G 47353	Tafelkop	24	18	0.2	9.68	Mudstone, dolerite, shale. Interception in mudstone
G 47354	Tafelkop	18	–	–	–	Dolerite; mudstone
G 47368	Tafelkop	42	36	1.8	10.85	Dolerite; mudstone, shale. Interception in shale
G 47369	Tafelkop	42	35	0.1	10.65	Dolerite; mudstone, shale. Interception on dolerite/shale contact
G 47370	Tafelkop	42	28	10.0	10.90	Dolerite; mudstone, shale. Interception on shale/dolerite contact.
G 47371	Immigrant	120	19	4.8	?	Mudstone; shale; sandstone; dolerite. Interception in shale.
G 47372	Immigrant	60	–	seepage	?	Mudstone; shale; sandstone; dolerite.
G 47373	Immigrant	60	–	seepage	19.18	Calcrete; mudstone; shale; sandstone. Calcrete is 3m thick
G 47374	Immigrant	60	–	seepage	20.00	Calcrete; mudstone; sandstone; dolerite. Calcrete is 3m thick.

4.2.6 **Dewetsdorp** (Largely derived from WRC, 1991)

A research project to determine the exploitation potential of Karoo Aquifers was conducted by the Institute for Groundwater Studies (IGS) from 1985 to 1989. The project was funded by the Water Research Commission (WRC).

Following a feasibility study, two localities, namely Dewetsdorp and De Aar complied with a set of research requirements, and were thus selected as suitable research areas. The particulars of the research at Dewetsdorp can be summed up as follows:

- Dewetsdorp lies in the eastern part of the Karoo Basin. The research area has a 21.1 km^2 surface area which consists of a well-defined groundwater shed in the west, south and south-east. The eastern boundary is formed by a topographical ridge between the Kareefontein Spruit and the Modder River Valley. In the north, where Kareefontein Spruit joins the Modder River, there is no boundary and surface water as well as groundwater discharge occurs here.
- The area has an average annual precipitation of 587 mm, and during the study period evapotranspiration varied between approximately 70 mm/month in the winter and about 240 mm/month in the summer. Elevation varies between 1 475 and 1 620 mamsl.
- Geologically the study area lies on the boundary between the Permian Adelaide and the Triassic Tarkastad Sub-

Table 15: Statistics for the Petrusburg Aquifer

Number of boreholes entered into the databank from the Immigrant Unit	144
Number of boreholes entered into the databank from the Tafelkop Unit	153
Number of boreholes entered into the databank from the Helderwater Unit	169
Total number of boreholes entered into the Aquabase Data Bank	466
Number of boreholes for which yields are available in the Immigrant Unit	124
Number of boreholes for which yields are available in the Tafelkop Unit	97
Number of boreholes for which yields are available in the Helderwater Unit	106
Total number of boreholes for which yields are available	327
IMMIGRANT UNIT	
Number of boreholes with yields of 5 *l*/s and more	47 (38%)
Number of boreholes with yields between 2 and 5 *l*/s	42 (34%)
Number of boreholes with yields between 0.5 and 2 *l*/s	17 (14%)
Number of boreholes with yields between 0.1 and 0.5 *l*/s	18 (14%)
Catchment area: 14 840 ha Area under irrigation: 493 ha (3.32% of the catchment area) Groundwater abstraction during 1999 for irrigation: 4.74 x10^{6}m^3 (33.5% of the total abstraction from the Petrusburg Aquifer) Altitudes vary between 1 250 and 1 310 mamsl with an average altitude of 1 267 mamsl.) Borehole depths vary between 20 and 70/m, with an average depth of 30.64 m. Depths to groundwater-level vary between 4.32 and 28.20 m below surface	
TAFELKOP UNIT	
Number of boreholes with yields of 5 *l*/s and more	24 (25%)
Number of boreholes with yields between 2 and 5 *l*/s	50 (52%)
Number of boreholes with yields between 0.5 and 2 *l*/s	16 (16%)
Number of boreholes with yields between 0.1 and 0.5 *l*/s	7 (7%)
Catchment area: 24 900 ha Area under irrigation: 468 ha (1.88% of the catchment area) Groundwater abstraction during 1999 for irrigation: 5.82 x10^{6}m^3 (41.0% of the total abstraction from the Petrusburg Aquifer) Altitudes vary between 1 260 and 1 380 mamsl with an average altitude of 1 293 mamsl.) Borehole depths vary between 13 and 55 m, with an average depth of 31 m. Depths to groundwater-level vary between 3.60 and 29.10 m below surface	
HELDERWATER UNIT	
Number of boreholes with yields of 5 *l*/s and more	24 (23%)
Number of boreholes with yields between 2 and 5 *l*/s	60 (57%)
Number of boreholes with yields between 0.5 and 2 *l*/s	15 (14%)
Number of boreholes with yields between 0.1 and 0.5 *l*/s	7 (6%)
Catchment area: 31 747 ha Area under irrigation: 237 ha (0.75 % of the catchment area) Groundwater abstraction during 1999 for irrigation: 3.62 x10^{6}m^3 (25.5% of the total abstraction from the Petrusburg Aquifer) Altitudes vary between 1 228 and 1 380 mamsl with an average altitude of 1 277 mamsl.) Borehole depths vary between 10 and 42 m, with an average depth of 29 m. Depths to groundwater-level vary between 2.67 and 19.67 m below surface	

groups of the Beaufort Group. The Adelaide Subgroup consists of fine-grained sandstone and greyish-red mudstone of the Balfour Formation. The Tarkastad Subgroup is represented by the Katberg (sandstone) Formation. The Katberg sandstone, due to its resistance to weathering, occupies the higher south-western portion of the research area. Dolerite sills occur on the hills west and north-west of the town and a number of dolerite dykes are also present in the area. Soil cover, varying in thickness between 0 and 6 m, formed an important part of the research. Average percentages for sand, silt and clay in soil profiles of 52%, 11% and 37% respectively, have been ascertained (Table 16).

In order to achieve the stated objective the following research requirements were identified:

1. The quantitative determination of groundwater recharge as a function of rainfall and type and thickness of the soil cover.
2. The determination of hydraulic parameter values and their variability with depth in order to establish to what degree production boreholes can be used in excess of recharge during times of continuous droughts.

In developing a research programme, it was realised that the following topics needed consideration:

- Geology of the aquifer system,
- Hydraulic parameters of the aquifer system,
- Determination of the groundwater balance,
- Modelling of aquifer behaviour, and
- Development of a method for the calculation of the exploitation potential.

A geohydrological investigation, including a hydrocensus and various geophysical surveys, was carried out. As the impact of the soil cover on recharge, among other factors was considered important, 40 boreholes were drilled to gain information on the soil cover, provide hard rock information, provide observation boreholes at sites where pumping and/or packer tests were envisaged, and to fill gaps in the observation network in order to have sufficient points for subsequent modelling.

Some results:

- From the neutron gauge measurements in the unsaturated zone, it can be deduced that noticeable recharge through matrix flow occurs rarely during normal rainy seasons. Only during exceptional rains and at a limited number of places does soil water move through the unsaturated zone.
- From water-level observations it can be concluded that:
  - almost immediate recharge occurs at the foot of hill slopes where the soil is absent or has a coarse texture, and there are indications that recharge occurs along preferred pathways.
  - water-levels respond with a considerable time lag in the more central parts of the aquifer and the rise in water-level in these areas is up to an order of magnitude less than in the higher lying parts.
- From the pumping and packer tests carried out it was calculated that the transmissivity of the Dewetsdorp aquifer varies between approximately 7 and 40 m^2/d with a representative transmissivity value of about 10 to 13 m^2/d. Calculated storage values are generally in the order of 10^{-4} while a value of $3.5 \cdot 10^{-4}$ is regarded as representative. A non-achievement was the inability to determine either the change of the storage with depth, or the "thickness" of a

Table 16. Groundwater research at Dewetsdorp: salient borehole information

Number of boreholes:	
– drilled	40
– of which depths are available	40
– with depths of 100 m and more	6 (ave. depth 100.5 m; ave. yield 0.7 *l*/s)
– with depths between 50 and 99 m	2 (ave. depth 72.0 m; ave. yield 0.25 *l*/s)
– with depths between 30 and 49 m	32 (ave. depth 38.2 m; ave. yield 0.28 *l*/s)
– with depths less than 30 m	0
– of which yield data are available	29
– with yields of 5 l/s and more	0
– with yields between 2 and 5 *l*/s	1 (%)
– with depths between 0.5 and 2 *l*/s	3 (1%)
– with yields between 0.1 and 0.5 *l*/s	13 (4%)
– with yields of less than 0.1 *l*/s	12 (4%)
Number of boreholes in which dolerite was encountered	8 (20% of boreholes)
Number of boreholes in which water interceptions can be associated with dolerite	40
Varying thickness of soil	0 to 6 m
Average percentage of sand in soil profiles	52%
Average percentage of silt in soil profiles	11%
Average percentage of clay in soil profiles	37%

fractured aquifer. If, however water-level and abstraction records were available for a long enough time period the storage could be calculated with the SVF-method (saturated volume fluctuation method).

- From the relatively short-term abstraction and water-level data available it was concluded that conventional pumping tests do not allow even an approximate determination of the storage. This is attributed to the fact that fractured, inhomogeneous and isotropic aquifers cannot be analysed with conventional methods.
- From the chemical analyses it can be concluded that groundwater in Dewetsdorp is of suitable quality for human consumption, except for occasional higher fluoride concentrations.
- Borehole yields were generally poor, as 86% of the 40 researched boreholes drilled yielded 0.5 *l*/s or less (Table 16). Dolerite was encountered in only 8 of the boreholes and only four contact zones with sedimentary rocks yielded water.

4.3 Supplementary notes

4.3.1 Recharge potential

Precipitation is the most important source of recharge in the map area. Precipitation decreases from >600 mm/a at Thaba Nchu, Wepener and Barkly East in the east to less than 300 mm/a at De Aar in the west (Table 2). Despite the relatively high precipitation in the east and the comparatively open exposure of the rocks to direct recharge, the following factors reduce recharge:

- high run-off due to the dissected topography and thus less scope for infiltration
- the prevalence of dense and compact mudstones, which restricts deep infiltration away from joint and fracture systems, and
- the comparative scarcity of intrusion-associated joints and fractures on account of the apparent smaller frequencies of dolerite bodies
- thick clayey soil covers, particularly evident in valleys.

Nonwithstanding lower rainfall, recharge conditions improve towards the western portion of the map due to:

- gentler topography with resulting lower run-off, thus allowing more scope for infiltration
- the occurrence of porous, recharge enhancing calcretes, and
- the incidence of more joints and fractures due to the higher density of dolerite intrusions.

Other, less important and largely localised recharge sources are river recharge and irrigation losses. Estimated recharge from rainfall infiltration for different terrains and various geological settings ranges between 2 and 7%.

4.3.2 Groundwater pollution

Due to the largely rural nature of the area and the lack of heavy industry and mining, groundwater in the map area is generally unpolluted.

Limited saltwater intrusion (strictly speaking not considered pollution) occurs at localities situated within the sphere of influence of salt pans. This is particularly evident in the western portion of the map where isolated high EC values have been registered. The effect of salt pans, being internal drainage systems, seems to be limited.

Concentrations of nitrate levels exceeding the maximum allowable limit of 10 mg/*l* in groundwater occur in areas in the western portion of the map, namely the stretch of land between Petrusburg and Koffiefontein, the region from north-west to south-east of Luckhoff and an area north of to south-east of De Aar. These high nitrate levels can mainly be attributed to the use of fertilisers for agricultural purposes.

Fluoride values, apart from a few localised concentrations west of Luckhoff and north to south-east of De Aar, are generally well below the maximum allowable limit of 1.5 mg/*l*.

Increases of EC and nitrate levels could be anticipated where informal settlements are undergoing rapid growth and where suitable sewage disposal methods are not adopted.

4.3.3 Borehole siting

A scientific approach to borehole siting, executed by trained personnel, is highly recommended.

A careful interpretation of satellite images and aerial photographs, followed by a thorough field reconnaissance of the topography and geology of the area, and the collection and exposition of hydrocensus data, should precede any geophysical investigation. Geophysical methods to apply include the magnetic method to locate and define dolerite bodies, the resistivity method to determine thickness of alluvium and/or weathered material, and the electro-magnetic method to trace zones of fracturing and jointing in rocks.

4.3.4 Groundwater utilisation

Groundwater is the only source of water supply to a number of communities and localities in the map area. In the agricultural field groundwater is widely used for both domestic and stock watering purposes. Groundwater abstraction in excess of 1.0×10^6 m^3 for irrigation occurs in the Petrusburg surrounds and in an area north-west of Bloemfontein. Moderate groundwater use for irrigation occurs patchily in the Luckhoff, Hopetown and De Aar districts and in a few other localities, where abstraction amounts to less than 0.1×10^6 m^3/a per locality and are thus not indicated as areas of large scale abstraction on the map.

Groundwater use by municipalities, both current and historical utilisation, is listed in Table 17. Only four municipalities, namely De Aar, Phillipolis, Jagersfontein/Fauresmith and Reddersburg are currently using groundwater in excess of 100 000 m^3/a.

4.3.5 Groundwater management

Groundwater, in contrast with surface water, has a major disadvantage when it comes to management: it is largely concealed. The depletion of a groundwater source would thus often come as a surprise if the groundwater-level is not monitored. Groundwater monitoring, whether it be water-level, abstraction, or quality monitoring is an essential element of groundwater management. Periodic groundwater monitoring should be practised as a matter of routine, especially in cases of large scale abstraction. It is also important to keep records of measurements in order to render the evaluation and interpretation of the data more meaningful.

The implementation of sound groundwater monitoring practices will strengthen the hand of the DWAF to manage the country's water resources, including groundwater, as provided for in the new National Water Act (No. 36 of 1998).

Table 17. Municipal groundwater use

LOCALITY	A	B	C
Jacobsdal		•	
Petrusburg	•		
Hopetown		•	
Koffiefontein		•	
Luckhoff			•
Petrusville		•	
Philipstown	•		
De Aar	•		
Colesberg			•
Philippolis		•	
Venterstad			•
Bethulie			•
Springforntein		•	
Trompsburg	•		
Fauresmith	•		
Jagersfontein	•		
Edenburg		•	
Redersburg		•	
De Wetsdorp		•	
Thaba Nchu			•
Ladybrand		•	
Barkly East		•	
Zastron			•
Vanstadensrust		•	
Smithfield		•	
Lady Grey		•	
Burgersdorp		•	

A = Groundwater is currently the only source of water supply

B = Groundwater is currently a supplementary and/or an emergency source of water supply

C = Groundwater is currently not used, was utilised in the past

5 Recommendations for further studies

Suggestions for more detailed groundwater related studies include the following:

- Fairly detailed hydrocensus information is available on the Petrusburg Aquifer and it suggests that the occurrence of calcrete could play a major groundwater role. A recent drilling programme revealed that deposits of calcrete seem to occur patchily and do not form a blanket covering in the Petrusburg area. The drilling also disclosed that the groundwater potential is apparently limited in area where the calcrete deposits are thin or absent. A study should be conducted to define the areal and the vertical extent of the calcrete deposits and its impact on the groundwater regime.
- Relatively high yielding areas have been delineated in the Phillipolis, Springfontein and Thaba N'chu surrounds, to mention but a few. Studies should be initiated to determine whether the higher groundwater potential of these areas can be ascribed to the occurrence of significant deposits of calcrete.
- A tendency for groundwater quality to deteriorate with ongoing pumping has been noted in the De Aar well-fields (Vegter, 1992). This phenomenon may be related to the two-layered (intergranular and fractured) nature of the aquifer which is likely to manifest also in other Karoo-rock situations. To identify the different hydrochemical faces and to understand the processes which are involved three-dimensional studies of flow paths and hydrochemistry will be required.
- Investigations of narrow dolerite intrusion contact zones with Karoo sedimentary rocks, an understanding of their often limited groundwater storage capacity, and developing means of enhancing recharge and effective groundwater management, could ultimately result in realising the groundwater potential of these aquifers.
- Dolerite ring structures have proven to be conducive to the formation of deep-seated fractured-rock aquifers. A number of dolerite ring structures are known to occur in the map area, particularly in the southern portion of it. These structures could be profitably investigated.

Being located in Bloemfontein, the Institute for Groundwater Studies (IGS) warrants mentioning. The IGS at the University of the Orange Free State was founded in 1974. To date more than 200 postgraduate students from South Africa and 14 other African countries have qualified in Geohydrology at this institution. The IGS conducts contract research on a wide variety of water related topics. Of special interest is its contribution to the mining and industrial sectors, and to the understanding of the nature and behaviour of South Africa's aquifers. This has led to the development of specialised field equipment, a well-equipped chemical laboratory and a number of computer models for the management and operation of aquifers. Academic courses at the IGS include aquifer mechanics, theory of groundwater flow, geophysical methods of groundwater exploration, groundwater quality and groundwater pollution, development of groundwater resources, and an introduction to groundwater modelling.

References

ANON/UNESCO, 1983
International legend for hydrogeological maps. Revised edition, 1983. Unesco.

BOEHMER W.K., 1973
A determination of the hydrological characteristics of the components of composite dolerite dyke aquifers and a joint system aquifer for the yield determination of boreholes for the Colesberg water supply.
Technical report Gh 1789, Directorate Geohydrology, DWAF.

BRUCE RW, KRUGER G.P. en JOHNSON M.R., 1983
Die Geologie van die Gebied Aliwal Noord. Toeligting: Blad 3026, Geologiese Opname van Suid Afrika.

BUCHMANN J.P., 1960
Exploration of a Geophysical Anomaly at Trompsburg, Orange Free State, South Africa. Transactions of the Geological Society of South Africa. Volume LX111, 1960.

CHEVALLIER L., GOEDHART M. and WOODFORD A.C., 2001
The influences of dolerite sill and ring complexes on the occurrence of groundwater in Karoo fractured aquifers: a morpho– teconic approach. WRC Report No 937/1/01.

DE BEERS LTD., 1969
De Beers Consolidated Mines, Limited, Jagersfontein Mine. Technical report Gh 3252, Directorate Geohydrology, DWAF.

GOMBAR O., 1973
Thaba Nchu – Watervoorsiening (Voorlopige Verslag). Technical report Gh 2889, Directorate Geohydrology, DWAF.

JOHNSON DIVISION JOP INC., 1975
Groundwater and Wells.

JOUBERT C.V., 1953
Ondergrondse water in die Etage Middel-Beaufort. Technical Report Gh 1073, Directorate Geohydrology, DWAF.

KENT L.E., 1971
Warmbronne in die Oranje-Vrystaat – Aanvullende Verslag.
Technical report Gh 1585, Directorate Geohydrology, DWAF.

KOK T.S., 1982
Municipal water supply from Jagersfontein mine. Orange Free State.
Technical report Gh 3232, Directorate Geohydrology, DWAF.

KRUGER G.P.,1983
Terrain morphological map of South Africa. Soil and Irrigation Research Institute, Department of Agriculture, Pretoria.

LE ROUX F.G., 1993
Die Geologie van die Gebied Colesberg. Toeligting: Blad 3024, Geologiese Opname van Suid-Afrika.

OLIVIER H.J., 1970
Notes on the geohydrological and hydrogeological investigations of the flooded Shaft No.2 Orange-Fish Tunnel, Northern Cape. Proc. 13th annual cong. geol. Soc. S. Afr., Cape Town.

ORTLEPP R.J., 1959
A Pre-Karoo Igneous Complex at Trompsburg, Orange Free State, Revealed by Drilling Exploration. Transactions of the Geological Society of South Africa. Vol.L11, 1959, pp33–57.

RUDOLPH D.C. and DE LANGE S.S., 2000
Petrusburg aquifer delineation study. Report no.: RVN 259.2/381.
Prepared for Department of Water Affairs and Forestry.

TANKARD A.J., JACKSON M.B.A., ERIKSSON K.A., HOBDAY D.K., HUNTER D.R. and MINTER W.E.L., 1982
Crustal Evolution of Southern Africa, Springer Verlag, New York.

VEGTER J.R., 1992
De Aar's Ground-water supply; A Digest of the past and an Outlook for the Future. Technical report Gh 3775, Directorate Geohydrology, DWAF.

WATER RESEARCH COMMISSION/DEPARTMENT OF WATER AFFAIRS., 1995
Groundwater Research of the Republic of South Africa, Sheet 2 (Saturated Interstices).

WATER RESEARCH COMMISSION/INSTITUTE FOR GROUND-WATER STUDIES., 1991
Exploitation Potential of Karoo Aquifers. WRC Report No. 170/1/91.

WOODFORD A.C. and CHEVALLIER L., (Editors) 2002
Hydrogeology of the main Karoo Basin: Current knowledge and future research needs. WRC Report No. TT 179/02.

VIVIERS J., 1995
Grondwater en die belangrikheid van doeltreffende bestuur. Notes for a presentation to farmers. Institute for Groundwater Studies, University of the Free State.

ZAWADA P.K., 1992
The Geology of the Koffiefontein Area, Explanation Sheet 2924, Geological Survey of South Africa.

Printed for the Government Printer Pretoria by Formeset Printers Cape.