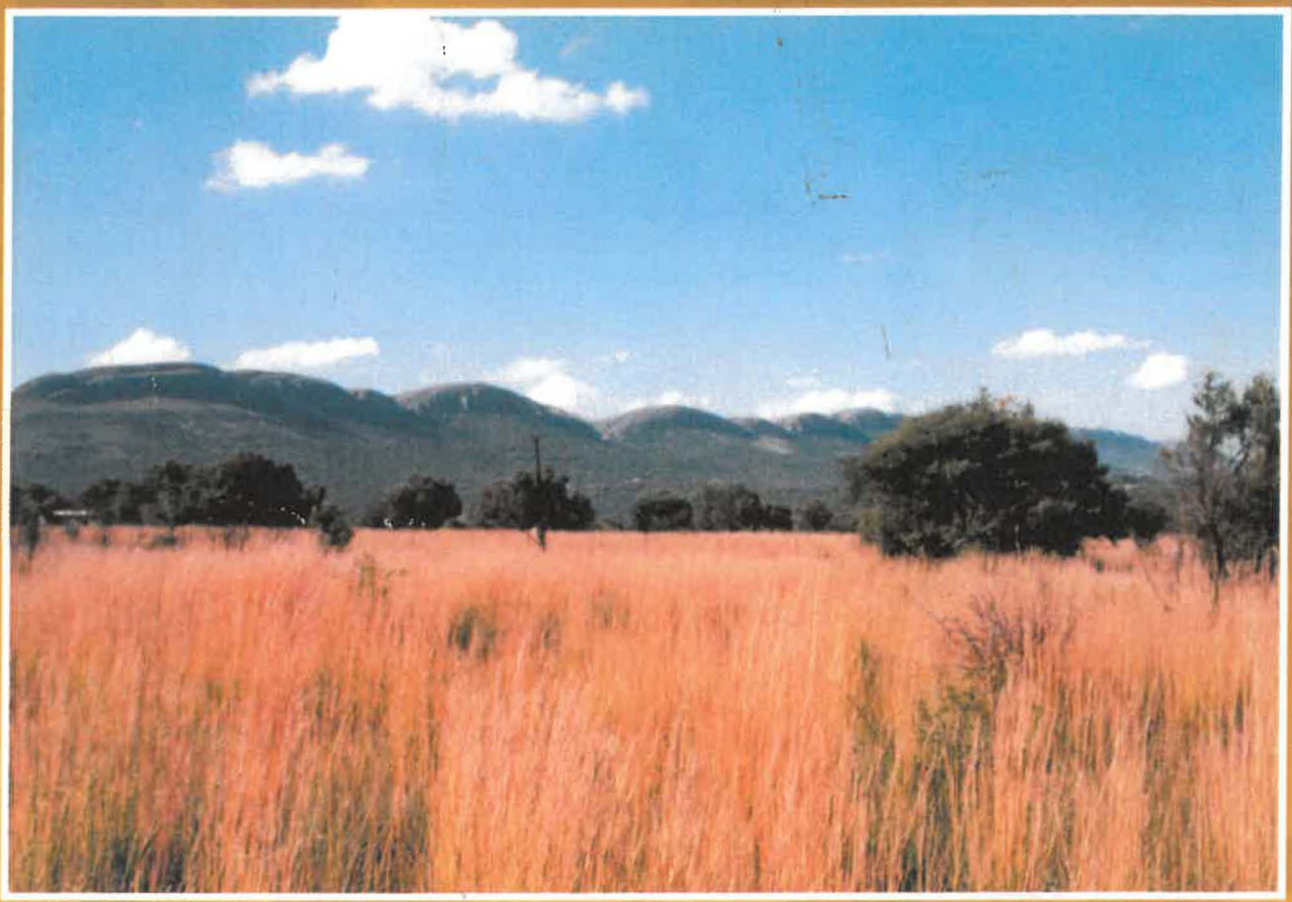
An Explanation of the 1:500 000 General Hydrogeological Map

Johannesburg 2526



By H.C. Barnard

October 2000

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DEPARTMENT OF WATER AFFAIRS AND FORESTRY

Dedication

This brochure is dedicated in honour of

Mr. Bill Orpen
(1936 – 2000)

Part of the Mapping Management Team
since 1994 and the driving force behind
the Hydrogeological Mapping programme.
He will be fondly remembered by his colleagues,
family and friends alike.

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 scarce 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 data bases 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 basic hydrogeological properties. These General 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 OF 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 days, but refuse him water and death is likely to come within hours. The availability of water to even the remotest area is thus vital to maintain this indispensable force for human existence. An estimated 3% of fluid fresh water available on Earth occurs on the surface and 98% occurs underground (Johnson Division, 1975). To tap and develop this vast amount of underground stored water, a keen knowledge of a region's environment, and above all, its diversified geology, is of the utmost importance in order to comprehend how and where groundwater occurs.

The Johannesburg Hydrogeological Map and the accompanying explanatory brochure introduces the current state of groundwater knowledge and the basic geohydrological characteristics of the map area. It needs to be explained that within the map's confines, dissimilar and divergent conditions occur which, to various degrees may impact on groundwater. Under these circumstances, various groundwater distinctives and characteristics can be expected, all of which have been referred to in the brochure.

The primary aim of a General Hydrogeological Map is to produce a synoptic overview of the geohydrological character of an area. The main map thus features borehole yield, aquifer types, groundwater quality and groundwater use, which are superimposed against a somewhat subdued lithology background. The brochure discusses these topics in more detail, as well as issues such as geological controls on groundwater yield and quality, borehole siting, groundwater management, groundwater levels, suggestions for future studies, etc. It is hoped that the product will be found useful by both the groundwater scientist and the interested layman alike. The map and brochure will hopefully also be informative to planners, and that it will play a role in general groundwater education and groundwater awareness-building.

Groundwater has always been an important source of water supply to many people and localities in the map area, especially in the rural environments. Water consumers in many areas rely totally on groundwater for domestic and stock watering purposes and also for urban and irrigation purposes at a number of locations. It is hoped that this map and brochure will serve as a base map for future specialized groundwater maps and groundwater studies as suggested in the brochure.

Acknowledgements

Representatives of the following sectors are thanked for their generous assistance and contribution of groundwater data used in the compilation of the Johannesburg 2526 Hydrogeological Map and its associated Explanation Brochure.

- Directorate Geohydrology, Department of Water Affairs and Forestry (former employer and colleagues of the author)
- Municipalities
- Consultants for the former self-governing territories of KwaNdebele and Bophuthatswana
- Mines
- Agriculture (farmers and plot owners)

The compilation of this brochure is a joint effort between the DWAFs Directorate Geohydrology who funded the project and VSA GeoConsultants as more recent employer of the map author.

The author would also like to thank Phil Hobbs for editing this brochure and for his many other constructive contributions to the final product.

Another special word of thanks is extended to Ewa Baran of the DWAFs Directorate Geohydrology for her expert preparation of the figures presented in this brochure.

The author also wishes to thank the following DWAF personnel who served on the Mapping Management Team and provided guidance:

- Paul Seward — Project Manager
- Elanda Botes — Project Administrator
- Schalk Meyer — Geohydrology Manager
- Helène Mullin — GIS Manager
- Freda Jonck — Cartography Manager

Final thanks go to the following DWAF personnel who served on the Editorial Board and provided critical comment:

- E. (Eberhard) Braune — Director: Geohydrology
- W.R.G. (Bill) Orpen — Deputy Director: Geohydrology
- Z.M. (Dziem) Dziembowski — Deputy Director: Geohydrology (retired)
- F. (Frans) Coetsee — Cartographer & Linguist

Design and layout:

- Homestead Graphic Art Studio

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Abbreviations

amsl	above mean sea level
CCWR	Computing Centre for Water Research (University of Natal, Pietermaritzburg)
DWAF	Department of Water Affairs and Forestry
EC	Electrical conductivity
ERPM	East Rand Proprietary Mines
IWQS	Institute for Water Quality Studies
LSI	Langelier saturation index
n.s.	not specified
SABS	South African Bureau of Standards
SAR	Sodium adsorption ratio
Sect.	Section
SGWCA	Subterranean Government Water Control Area
UNESCO	United Nations Education, Scientific and Cultural Organization

Symbols and Units

>	greater than
<	less than
10^6	million
km	kilometre
km^2	square kilometre
l/s	litre per second
m	metre
m^3	cubic metre
Ma	million years
mm	millimetre
mg/*l*	milligram per litre
mS/m	milliSiemens per metre

1 Introduction

The Johannesburg 2526 hydrogeological map at a scale of 1:500 000 forms part of the general hydrogeological map series of South Africa that will eventually comprise of 23 map sheets. It also represents the first general synthesis of the groundwater resources of the area bordered by latitudes 25° and 27° south and longitudes 26° and 30° east. This area contains the largest industrial development in southern Africa. It also supports a wide spectrum of mining activity that includes gold, platinum and coal mines. These circumstances are accompanied by a large population which ranges from densely concentrated in areas of formal and informal residential development to sparsely distributed in rural areas.

The large (and increasing) population necessarily places a heavy burden on the capacity of existing water resources to meet the growing demand for potable water. This burden is increased by the substantial water demands of industry and mining, the cooling of power stations and the demands of agriculture for food production. It is not within the scope of this brochure to quantify these demands. Their magnitude and nature, however, has a direct impact on the quantity and quality of surface water in the greater part of the region and beyond. The gravity of the situation is obvious if it is considered that the demand (current and projected) on surface water resources has precipitated the Lesotho Highlands Water Project.

Under these circumstances, extensive use is made of groundwater as an additional, and in some instances alternative, source of potable water. This situation is partly attributed to the large-scale occurrence in the map area of dolomitic formations that arguably represent the most productive water-bearing rock type in the country. It is therefore easy to recognize the strain that is increasingly being placed on the quantity and quality of the groundwater resources in the map area. These factors together suggest that the Johannesburg hydrogeological map may be one of the more important maps in the series.

The main aim of the map and its accompanying explanation brochure is to serve as a general reference framework for the sensible planning of groundwater resource development and the management of groundwater resource utilization in the area defined by the map. A further benefit is the educational value this material will hopefully have for its readership. A considerable volume of available groundwater data was consulted in the compilation of this map. Its presentation in map and written form should provide the reader with a fair impression of the amount of groundwater information that is available for the area.

The reader is cautioned to the fact that the main map and its various accompanying inset maps portray information at a relatively small scale, namely 1:500 000 (main map) and either 1:1 500 000 or 1:2 000 000 (inset maps). **This combination of maps can therefore never be used to determine specific local conditions such as might be required for the siting of individual water supply boreholes.** Nevertheless, the map and its accompanying explanation brochure do provide general guidelines regarding groundwater occurrence and quality as well as information on hydrogeological conditions that can be expected to occur in an area of interest to the reader.

2 Physical environment

2.1 General

The Johannesburg hydrogeological map sheet covers an area of some 76 000 km^2. This expanse undoubtedly contains the largest industrial development, supports the widest spectrum of business and mining activity and hosts the highest population figure in southern Africa.

2.2 Climate

The mean annual precipitation varies from 600 to 800 mm over the greatest part of the area, with the northern and western portions receiving from 400 to 600 mm per year on average. The precipitation generally occurs in the form of convectional thunderstorms that deliver up to 90 % of the annual rainfall during the warm to hot summer months between October and March of successive years. The winters are typically dry and cold with frost, the very occasional snow fall being experienced especially on the Highveld. The mean annual evaporation increases across the map area from approximately 1 400 mm in the southeast to some 2 000 mm in the west (Figure 1).

2.3 Topography

Five main terrain morphological units are recognized in the area by Kruger (1983). These are described in Table 1, which also serves as a reference framework and an explanation for Figure 2.

Table 1. Description of the main terrain morphological units (after Kruger, 1983)

BROAD DIVISION	MAP SYMBOL	DESCRIPTION	DRAINAGE DENSITY* (km/km^2)	% OF AREA WITH SLOPES < 5 %
Plains with low relief	1 2 3	Plains Plains with pans Slightly undulating plains	Low – medium (0 – 2)	
Plains with moderate relief	8 9 10 11	Slightly irregular and undulating plains Moderately undulating plains Moderately undulating plains and pans Strongly undulating plains	Low – medium (0 – 2)	> 80 %
Lowlands, hills and mountains with moderate to high relief	13	Lowlands with parallel hills	Low – medium (0 – 2)	50 – 80 %
Open hills, lowlands and mountains with moderate to high relief	18 20	Hills and lowlands Undulating hills and lowlands	Medium (0.5 – 2)	20 – 50 %
Closed hills and mountains with moderate to high relief	23 24 27	Hills Parallel hills Low mountains	Medium (0.5 – 2)	< 20 %

* Total length of drainage channels per square kilometre.

Figure 1. Mean annual evaporation

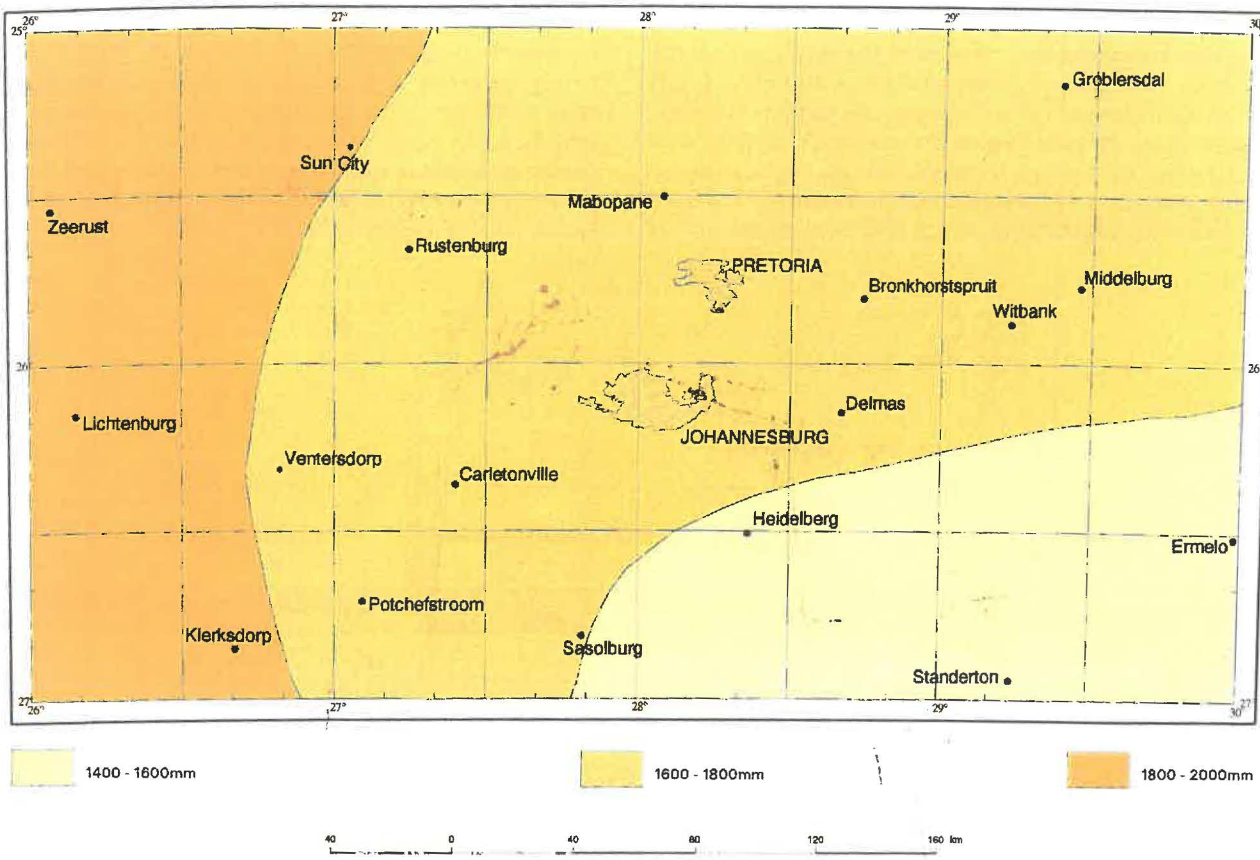
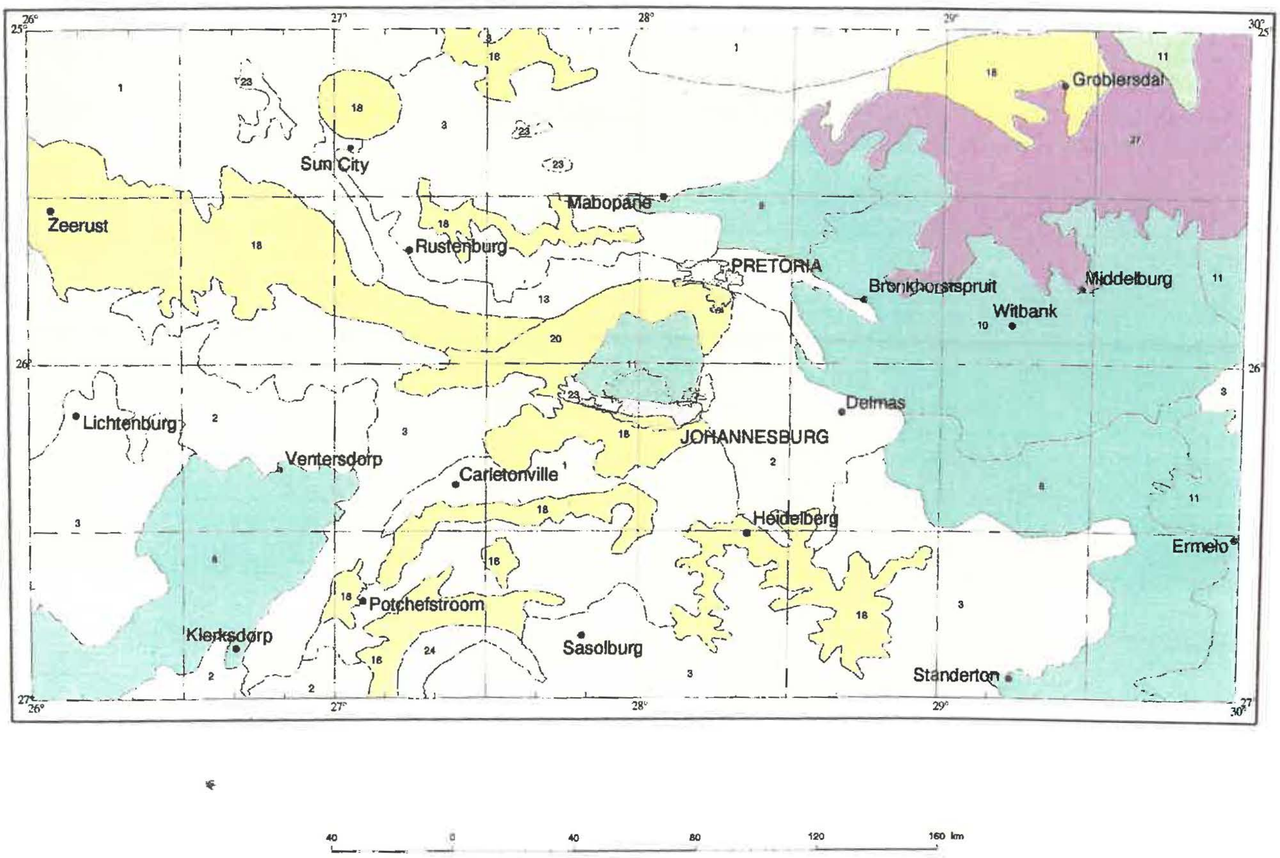


Figure 2. Terrain morphology (after Kruger, 1983)



2.4 Surface water

Three main drainage systems occur in the area. These are the Limpopo River system (Primary Drainage Region A) which drains approximately 30 % of the area, the Olifants River system (Primary Drainage Region B) draining 25 % of the area and the Vaal River system (Primary Drainage Region C) draining the remaining 45 % of the area. The tributaries that drain the headwaters of the Limpopo and Olifants River flow mainly northwards. Those of the Vaal River system drain in a predominantly southerly to southwesterly direction. The surface water divide separating the two northward draining systems from the southward draining system coincides very approximately with latitude 26° south. These characteristics are shown in Figure 3 together with the positions of the major dams located in the area as listed in Table 2.

Table 2. Major dams in the map area

NAME OF DAM	NUMBER IN FIGURE 3	DRAINAGE BASIN	RIVER	STORAGE CAPACITY ($x10^6$ m^3)
Marico-Bosveld	1	A3	Groot Marico	27.0
Kromellenboog	2	A3	Groot Marico	9.3
Lindley's Poort	3	A2	Elands	14.3
Koster	4	A2	Elands	12.8
Vaalkop	5	A2	Elands	56.0
Bospoort	6	A2	Hex	18.2
Olifantsnek	7	A2	Hex	13.6
Buffelspoort	8	A2	Crocodile	10.3
Roodekopjes	9	A2	Crocodile	103.0
Hartbeespoort	10	A2	Crocodile	186.0
Klipvoor	11	A2	Moretele	42.1
Bon Accord	12	A2	Apies	4.4
Roodeplaat	13	A2	Pienaars	41.2
Rietvlei	14	A2	Kafferspruit	12.3
Rust de Winter	15	B3	Elands	26.9
Bronkhorstspruit	16	B2	Bronkhorstspruit	58.0
Trichardtsfontein	17	B1	Rietspruit	15.3
Witbank	18	B1	Olifants	104.0
Doringpoort	19	B1	Olifants	9.2
Loskop	20	B3	Olifants	362.0
Rooikraal	21	B3	Bloed	2.1
Willem Brummer	22	C1	Klein-Kafferspruit	1.2
Grootdraai	23	C1	Vaal	356.0
Vaal	24	C1	Vaal	2 603.0
Klipdrift	25	C2	Loopspruit	13.6
Klerkskraal	26	C2	Mooiriver	8.3
Boskop	27	C2	Mooiriver	20.6
Rietspruit	28	C2	Rietspruit	7.2
Klerksdorp	29	C2	Skoonspruit	5.6

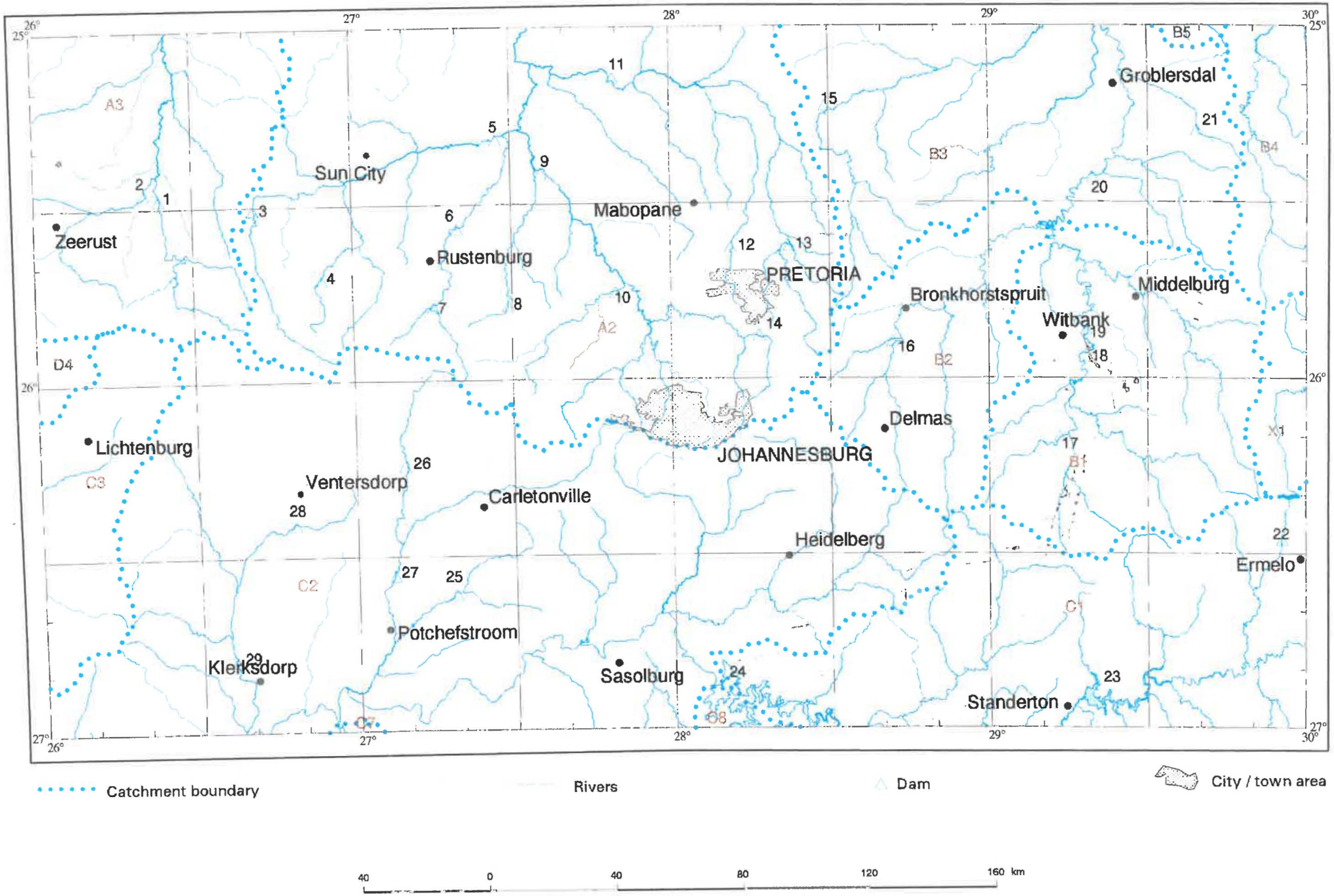


Figure 3. Drainage regions, major dams and rivers

3 Geology

3.1 Major units and rock types

The geology of the map area represents the entire record of the geological history of South Africa. As indicated in Figure 4 and Table 3, most of the major stratigraphic units occur in the area. These are identified, from oldest (top of list) to youngest as follows:

- Basement Complex
- Dominion Group
- Witwatersrand Supergroup
- Ventersdorp Supergroup
- Transvaal Supergroup
- Bushveld Complex
- Waterberg Group
- Karoo Supergroup
- Quaternary deposits

Much of the following discussion is based on and derives from geological information that is freely available in published form. Reference to these sources is provided in the text and fully documented in the References. The lithostratigraphic column presented in Table 3 indicates the extent to which the major units listed above are subdivided as well as the rock types associated with each of these subdivisions. The hydrogeological characterization presented in Section 5 is based on these subdivisions and their associated geological characteristics. More detailed information regarding the geology of the area can be obtained from the 1:250 000 scale published geological maps (refer Section 4.2) and their respective explanation brochures.

The oldest rock types, namely those of the Basement Complex, are represented by various Archaean granite bodies that differ slightly in their composition (granitic, granodioritic, gneissose or migmatitic) but which are of similar age. The Basement Complex is followed by the Dominion Group, exposures of which occur in the area west of Klerksdorp and are represented by such rock types as quartzite, conglomerate, shale, interbedded lava, andesite and rhyolite.

The Witwatersrand Supergroup is the next youngest unit, and is exposed near Klerksdorp, along the Witwatersrand, in the area around Heidelberg and along the northern and western flanks of the Vredefort dome. It is represented by two assemblages of rock types, the older assemblage comprising of quartzite, reddish and ferruginous magnetic shales, gritty quartzite and conglomerate beds, and the younger assemblage of arenaceous and rudaceous rocks. The Witwatersrand Supergroup is probably best known for its association with the rich gold deposits of the Central Rand, the East Rand, the West Rand and those in the Klerksdorp area that also extend southward to Welkom and Virginia in the Free State Province. The Ventersdorp Supergroup follows the Witwatersrand Supergroup. It is exposed in the southwestern quarter of the map area, in areas around Vredefort, in the Klipriviersberg south of Johannesburg and in the Suikerbosrand west of Heidelberg. It comprises mainly of andesitic lava and tuff, quartz porphyry, conglomerate, sandstone and calcareous shale.

The volcanic and sedimentary rock types of the Transvaal Supergroup overlie the Ventersdorp Supergroup. The volcanic rocks include lava, tuff, andesite, basalt and rhyolite. The sedimentary rocks include quartzite, shale, conglomerate and dolomite. Diabase intrusions, mainly in the form of sills, occur near the top of this unit (Visser, 1989).

The Bushveld Complex is the largest known layered igneous complex. The western and eastern lobes of this complex occur in the north-central part of the map. The rock types that form the Complex are granodiorite, gabbro, norite, anorthosite and granite. This unit is followed by sedimentary rocks (sandstone, grit and quartzitic sandstone with interbedded conglomerate and shale) representing the Waterberg Group.

The next youngest rock types occurring in the map area are the alkaline intrusive rocks (foyaite and syenite) of the Pilanesberg Complex, the carbonatite associated with the Ystervarkkop Carbonatite Complex and the dykes and sills associated with the Pilanesberg dyke system. The latter comprise mainly of diabase, gabbro and diorite with syenite and foyaite forming the composite dykes. Diabase sill and dyke intrusions are also well known in the Waterberg Group in the Middelburg basin (Visser, 1989).

The mainly sedimentary rocks that cover the southeastern portion of the area represent a segment of the northern margin of the basin filled with sediments belonging to the Karoo Supergroup. These sediments include tillite, mudstone, sandstone and shale. They are extensively intruded by dolerite in the form of sills and dykes. The Karoo Supergroup is probably best known for its coal seams that underpin the coal mining industry and, of relevance to this brochure, particularly those extending east and southeast of Witbank and, to a lesser extent, those exploited at Sasolburg and Vereeniging in the south.

The Quaternary represents the youngest period in geological history, and is represented in the map area by river terrace gravels and alluvial sands that occur along the major rivers (Visser, 1989) and by surface limestone (calcrete).

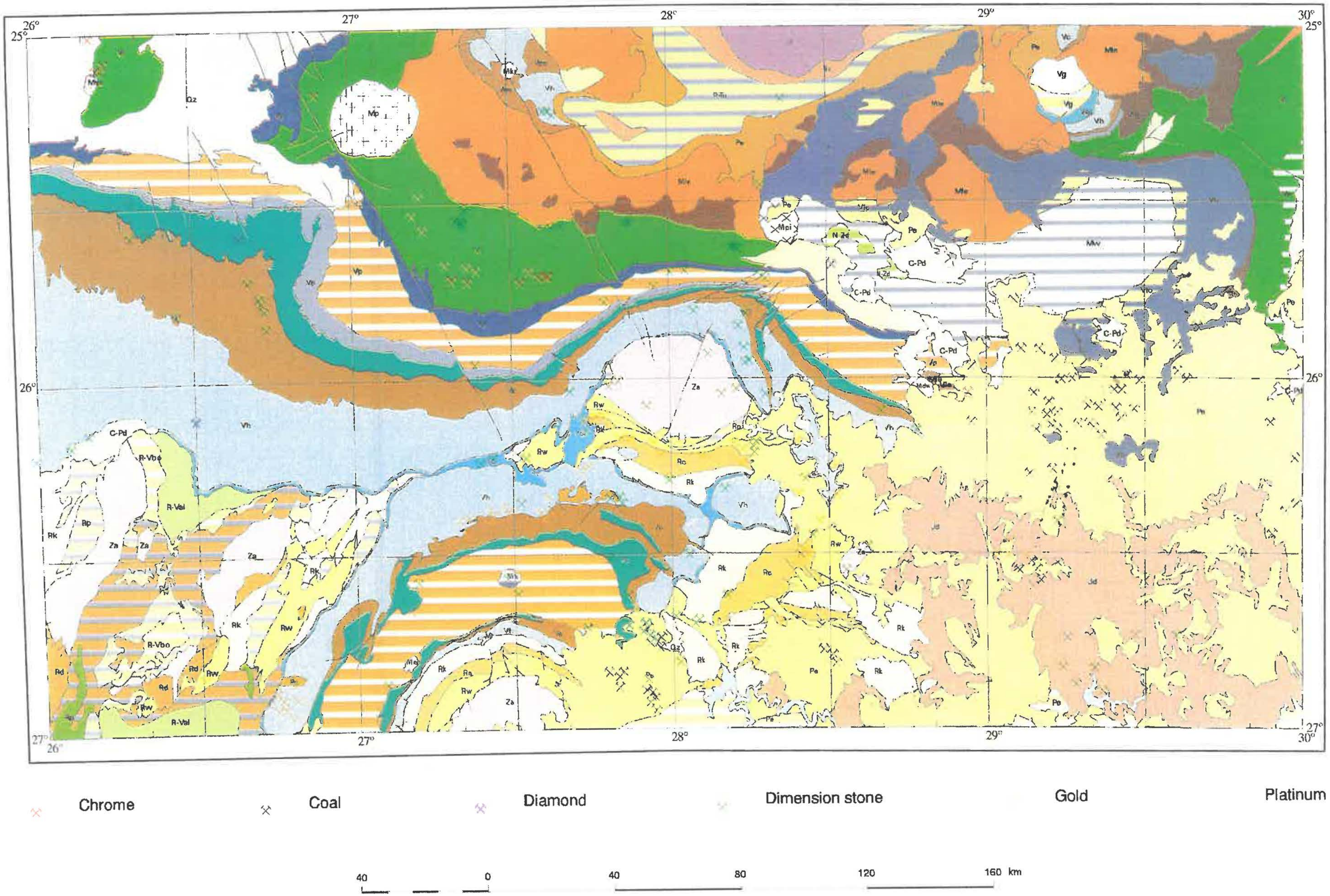


Figure 4. Simplified geological map

Table 3. Lithostratigraphic legend

Ma	Erathem	Hydrogeological Unit		Lithology	Stratigraphy: Formation	Stratigraphy: Group; Suite; Complex	Stratigraphy: Complexes; Supergroup
65	Cenozoic		Qz	Alluvium, sand, calcrete			
	Mesozoic		Jl	Basalt	Letaba Formation	Lebombo Group	
			Jd	Dolerite	Intrusive rock		
			Trc	Sandstone	Clarens Formation		
230			P-Tri	Mudstone, sandstone	Irrigasie Formation	Beaufort Group	KAROO SUPERGROUP
	Paleozoic		Pe	Shale	Volksrust Formation	Ecca Group	
				Sandstone, shale, coal	Vryheid Formation		
570			C-Pd	Tillite, mudstone, sandstone		Dwyka Group	
1180	Namibian						
	Mokolian		Mpi	Foyaite, syenite, carbonatite		Pienaars River Complex	ALKALINE COMPLEXES
			Mp	Foyaite, syenite		Pilanesberg Complex	
			Mf	Harzburgite, norite, gabbro		Rietfontein Complex	BASIC COMPLEXES
			Mro	Andesitic lava		Roodekraal Complex	
			Mkr	Carbonatite		Kruidfontein Complex	CARBONATE COMPLEXES
			Mys	Pyroclastic rocks, carbonatite		Ystervarkkop Complex	
			Mw	Sandstone, conglomerate	Wilge River Formation	Waterberg Complex	BASIC COMPLEXES
			Mdw	Pyroxenite		Dwarsfontein Complex	
			Mx	Harzburgite, norite, gabbro		Losberg Complex	
2070			Mle	Granite		Lebowa Granite Suite	
	Vaalian		Vr	Gabbro, norite, anorthosite		Rustenburg Layered Suite	BUSHVELD COMPLEX
			Vrg	Granodiorite		Rashoop Granophyre Suite	
			Vlo	Sandstone, conglomerate, rhyolite	Loskop Formation		
			Vb	Porphyritic rhyolite		Rooiberg Group	TRANSVAAL SUPERGROUP
			N-Zd	Diabase	Intrusive rock		

Table 3. Lithostratigraphic legend (continued)

Ma	Erathem	Hydrogeological Unit	Lithology	Stratigraphy: Formation	Stratigraphy: Group; Suite; Complex	Stratigraphy: Complexes; Supergroup
	Vaalian	Vp	Andesite, basalt	Dullstroom Formation	Pretoria Group	TRANSVAAL SUPERGROUP
		Vp	Shale, quartzite	Rayton Formation		
		Vp	Quartzite	Magaliesberg Formation		
		Vp	Shale	Silverton Formation		
		Vp	Quartzite	Daspoort Formation		
		Vp	Andesite	Hekpoort Formation		
		Vp/Vco	Shale, quartzite	Timeball Hill/ Rooisloot Formation (Crocodile River Fragment)		
		Vh	Dolomite, chert		Chuniespoort Group	
2560		Vbl	Quartzite, conglomerate	Black Reef Formation		
	Randian	Vg	Slate, quartzite, shale	Bloemfontein Formation	Groblersdal Group	
		Vg	Acid lava, tuff, gneiss	Dennilton Formation		
		R-Val	Andesite	Allanridge Formation		VENTERSDORP SUPERGROUP
		R-Vbo	Conglomerate, sandstone	Bothaville Formation		
		Rp	Andesite	Rietgat Formation	Platberg Group	
		Rp	Quartz phorphyry	Makwassie Formation		
		Rp	Conglomerate, calcareous shale	Kameeldoorns Formation		
		Rk	Andesite, tuff		Klipriviersberg Group	
		Rc	Arenaceous, rudaceous rocks		Central Rand Group	WITWATERS-RAND SUPERGROUP
		Rw	Quartzite, reddish and ferruginous magnetic shales		West Rand Group	
3090		Rd	Quartzite, conglomerate, shale, interbedded lava		Dominion Group	
	Swazian	Za	Granite, gneiss	Halfway House Granite (Zha); Inlandsee Leukogranofels (Zie); unnamed Swazian Rocks (Zz)		BASEMENT COMPLEX

3.2 Geological structures

Apart from lithology (rock type), the occurrence of groundwater is also dictated to a substantial degree by the presence of various geological structures. The more important of these are represented by fault, fissure and fracture zones, and by intrusions in the form of dykes and sills. The distribution of the larger dolerite sills are indicated on both the main map and in Figure 4, where their occurrence within the Karoo sediments covering the southeastern quadrant of the area is shown. The positions of dyke structures are indicated only in regard to the compartmentalization effect they have on the karst aquifers (Figure 10c).

The positions of the major fault structures are indicated on the main map and in condensed form in Figure 4, clearly indicating their linear nature often cutting across two or more geological units. The northern half of the map area would appear to support a greater number of these features than does the southern portion. Their orientation is divided into one of two principal strike directions, namely either northwest-southeast or northeast-southwest. Although faults typically represent prime target zones for water supply boreholes, their success in this regard is not guaranteed.

Plate 1. Regional fault zone in the Wilge River Formation exposed in a road cutting. Note the vertical bedding in the mainly quartzitic rocks. (Photo: M van der Neut)

4 Hydrogeology

4.1 Classification system and criteria

The hydrogeological map utilizes an adaptation of the international legend for hydrogeological maps (UNESCO, 1983). The adaptation recognizes and accommodates aspects and features peculiar to South African hydrogeological conditions. Groundwater occurrence, the dominant theme of the main map, is illustrated on the basis of internationally recognized classes that define the nature of the water-bearing rock formations. Each class is subdivided into groups that represent the varying capacity of a class to yield groundwater to a borehole. A class is identified by a colour and each group by a different tone (intensity) of that colour.

4.1.1 Groundwater occurrence

The 1:500 000 map series recognizes that the water-bearing properties of rock formations are associated with four main types of water-bearing interstices defined as:

- Class A = Intergranular
- Class B = Fractured
- Class C = Karst
- Class D = Intergranular and fractured

Intergranular describes aquifers associated either with loose and unconsolidated formations such as sands and gravels, or with rock that has weathered to the extent where its primary structure is that of a loose or only partly consolidated material. Under these circumstances, water is stored in and transmitted through the intergranular voids that render the material porous and permeable.

Fractured describes aquifers associated with generally hard and compact rock formations in which fractures, fissures and/or joints occur that are capable of both storing and transmitting water in useful quantities.

Karst describes aquifers associated with carbonate rock such as limestone and dolomite and in which groundwater is predominantly stored in and transmitted through cavities and/or fractures. The Sterkfontein caves near Krugersdorp are an example of the cavities that can develop in these rocks.

Intergranular and fractured describes aquifers that represent a combination of the Class A and Class B types of aquifer. This combination suggests that water should be stored in and transmitted through both aquifers, and is also able to pass vertically with relative ease between the two aquifer types. In practice, however, this situation also allows for circumstances where the intergranular interstices serve primarily a storage function, the water being transmitted mainly through the fracture-type interstices. This is a common feature of many South African aquifers, and occurs when the often substantial quantities of water stored in the intergranular voids of weathered rock can only be economically abstracted via fractures penetrated by boreholes drilled into the underlying fractured aquifer.

The aquifer descriptions therefore classify the voids in the rock in which the groundwater is stored and through which it is transmitted and, as such, represent the nature of the water-bearing rock formations. The detail associated with defining sites for the drilling of a successful water borehole, together with the limited geographic extent for which such detail is known, renders the portrayal of such areas at a scale of 1:500 000 virtually impossible.

It should also be recognized that it is possible for more than one type of aquifer to be represented in the same area. For example, a surface layer of sand that is saturated with water and represents an intergranular aquifer, may rest on fractured and jointed bedrock representing a fractured aquifer if the fractures and joints serve to store and transmit water. The capacity of these two aquifers to yield water to a borehole might differ substantially from one another. Under these circumstances, only the aquifer that supports the higher yield and better quality groundwater is shown on the map.

A rule adopted for the map series was to classify the aquifers as intergranular and fractured when the water level occurs in the weathered (intergranular) zone, and as fractured only when the water level occurs below this zone. Available soil, land type and hydrogeological information together with a map of igneous rock weathering (Weinert, 1974) assisted in differentiating between these two types of aquifer.

The subdivision of each aquifer class into groups defining the varying capacity of an aquifer class to yield groundwater to a borehole recognizes the variation in borehole yield associated with any aquifer. The groups therefore essentially represent various ranges of borehole yield. The definition of these ranges is not an issue that can be assessed universally and applied unilaterally through an international publication such as that by UNESCO (1983). The consideration and recognition of South African conditions has resulted in the selection of the ranges presented in Table 4. The colour associated with each yield range by aquifer type indicated in Table 4 is also reflected on the main map legend.

Table 5 presents statistical information relevant to the borehole yield data used for the evaluation of this groundwater parameter in regard to each geological unit. The 5 091 records represent 96.6 % of the 5 272 records sourced during the study. The information also indicates that no borehole yield data were sourced in regard to nine of the 34 geological units (and groupings of units) that occur in the map area. In two of these instances, namely the Alkaline Complexes and the Letaba Formation, the general findings of previous relevant studies are presented. In all instances where data is presented, a cross-reference to the appropriate section in the report is also provided.

Table 4. Classification of groundwater occurrence and borehole yields

YIELD RANGE	AQUIFER TYPE			
	INTERGRANULAR	FRACTURED	KARST	INTERGRANULAR & FRACTURED
< 0.1 *l*/s	Blue tinge (A1)	Green tinge (B1)	Olive tinge (C1)	Yellow tinge (D1)
0.1 – 0.5 *l*/s	Pale blue (A2)	Pale green (B2)	Pale olive (C2)	Pale brown (D2)
0.5 – 2.0 *l*/s	Light blue (A3)	Light green (B3)	Light olive (C3)	Light brown (D3)
2.0 – 5.0 *l*/s	Blue (A4)	Green (B4)	Olive (C4)	Brown (D4)
> 5.0 *l*/s	Dark blue (A5)	Dark green (B5)	Dark olive (C5)	Dark brown (D5)

Table 5. Borehole yield statistics for each geological unit

GEOLOGICAL UNIT	BOREHOLE YIELD STATISTICS						
	No. of Records	< 0.1 *l*/s	0.1–0.5 *l*/s	0.5–2.0 *l*/s	2.0–5.0 *l*/s	> 5.0 *l*/s	Maximum Yield
INTERGRANULAR AQUIFERS (CLASS A)							
Crocodile River alluvium (Sect. 5.2)	44	0.0 %	0.0 %	0.0 %	0.0 %	100.0 %	31.6 *l*/s
FRACTURED AQUIFERS (CLASS B)							
West Rand Group (Sect. 5.3.1)	234	1.3 %	18.8 %	44.4 %	13.2 %	22.2 %	30.0 *l*/s
Central Rand Group (Sect. 5.3.2)	109	4.6 %	19.3 %	56.8 %	11.9 %	7.3 %	25.0 *l*/s
Kameeldoorns Formation (Sect. 5.3.3)	79	1.3 %	13.9 %	49.4 %	10.1 %	25.3 %	18.0 *l*/s
Bothaville Formation (Sect. 5.3.4)	58	3.4 %	20.7 %	29.3 %	34.5 %	12.1 %	24.0 *l*/s
Black Reef Formation (Sect. 5.3.5)	63	6.3 %	15.8 %	50.7 %	20.6 %	6.3 %	6.3 *l*/s
Magaliesberg Formation (Sect. 5.3.7)	50	8.0 %	30.0 %	38.0 %	20.0 %	4.0 %	9.3 *l*/s
Wilge River Formation (Sect. 5.3.9)	40	2.4 %	41.5 %	36.6 %	7.3 %	12.2 %	7.8 *l*/s
KARST AQUIFERS (CLASS C)							
Chuniespoort Group (Sect. 5.4)	1 230	3.2 %	7.2 %	23.6 %	15.1 %	50.5 %	126.0 *l*/s
INTERGRANULAR and FRACTURED AQUIFERS (CLASS D)							
Basement Complex (Sect. 5.5.1)	240	0.8 %	8.3 %	28.8 %	35.0 %	27.0 %	36.0 *l*/s
Klipriviersberg Group (Sect. 5.5.3)	164	4.8 %	37.2 %	39.0 %	12.8 %	6.0 %	20.0 *l*/s
Rietgat Formation (Sect. 5.5.5)	74	1.0 %	21.6 %	32.4 %	36.5 %	9.5 %	15.0 *l*/s
Allanridge Formation (Sect. 5.5.6)	62	3.2 %	43.5 %	35.5 %	9.6 %	8.1 %	12.0 *l*/s
Timeball Hill/Rooisloot Formation(s) (Sect. 5.5.8)	333	2.7 %	23.1 %	42.3 %	20.4 %	11.4 %	20.0 *l*/s
Silverton Formation (Sect. 5.5.9)	202	1.5 %	18.3 %	40.6 %	17.8 %	21.8 %	20.0 *l*/s
Hekpoort Formation (Sect. 5.5.10)	72	0.5 %	22.2 %	33.3 %	37.5 %	6.9 %	7.0 *l*/s
Rooiberg Group (Sect. 5.5.12)	44	4.5 %	38.6 %	43.2 %	6.8 %	6.8 %	7.0 *l*/s
Loskop Formation (Sect. 5.5.13)	36	4.1 %	26.0 %	44.0 %	20.0 %	6.8 %	6.4 *l*/s
Rashoop Granophyre Suite (Sect. 5.5.14)	39	2.6 %	51.3 %	38.5 %	7.7 %	0.0 %	5.2 *l*/s
Rustenburg Layered Suite (Sect. 5.5.15)	217	6.9 %	35.5 %	38.7 %	12.4 %	6.5 %	10.0 *l*/s
Lebowa Granite Suite (Sect. 5.5.16)	354	2.5 %	40.4 %	39.3 %	13.8 %	4.0 %	14.6 *l*/s
Alkaline Complexes (Sect. 5.5.17)	10	8 no. (80 %) < 0.5 *l*/s : 2 no. > 0.5 *l*/s					5.0 *l*/s
Dwyka Group (Sect. 5.5.18)	34	2.9 %	29.4 %	44.1 %	23.5 %	0.0 %	4.4 *l*/s
Vryheid Formation (Sect. 5.5.19)	506	17.6 %	34.6 %	31.2 %	10.3 %	6.3 %	12.6 *l*/s
Ecca Group (undifferentiated) (Sect. 5.5.20)	185	8.0 %	41.6 %	33.0 %	14.0 %	3.2 %	9.2 *l*/s
Irrigasie Formation (Sect. 5.5.21)	26	3.8 %	45.6 %	35.2 %	8.8 %	6.9 %	28.0 *l*/s
Clarens Formation (Sect. 5.5.22)	110	1.8 %	46.4 %	45.5 %	4.5 %	1.8 %	8.0 *l*/s
Letaba Formation (Sect. 5.5.23)	476	314 no. (66 %) ≤ 10 *l*/s : 162 no. > 10 *l*/s					30.0 *l*/s

Dominant Yield Class

4.1.2 Groundwater quality

The chemical composition of groundwater derives from the interaction between infiltrating rainwater, soils, rock types and evapotranspiration. Some of this interaction takes place in the unsaturated zone where soil type and evapotranspiration influence the chemical composition of the infiltrating rainwater. Once this water has reached the saturated zone, its character is further influenced by the physical and geochemical properties of the rock type encountered along the groundwater flow path. The chemical elements that most commonly occur in groundwater and which pose a possible health problem are nitrate and fluoride.

Current viewpoints regard nitrate concentrations higher than 10 mg/*l* (as N) a health threat to children younger than two years, and consider that concentrations exceeding 20 mg/*l* N render water unsuitable for drinking without treatment. Water containing fluoride levels of more than 1.5 mg/*l* is considered detrimental to teeth and bone structure if consumed over long periods of time (DWAF, 1996). High fluoride concentrations characterize the groundwater occurring in the Springbok Flats basin, the surrounding Lebowa granites of the Bushveld Complex and the Pilanesberg Alkaline Complex. McCaffrey (1995) suggests that the high fluoride concentrations in the Springbok Flats basin are due to the final dissolution of fluorite-bearing minerals contained in the granitic rocks and their weathered product which was carried into and filled the basin during arid erosional episodes.

The chemical composition of groundwater occurring in the various rock formations is characterized and compared on the basis of 1 529 complete chemical analyses of groundwater samples obtained from as many sources. These samples span a collection period of 28 years (1970 to 1997). Based on the geographic position of its source relative to the surface geology at that position, each sample was assigned to a geologic unit. A statistical analysis of the sample population generated for each geologic unit defines the mean chemical composition, mean Electrical Conductivity and mean pH values as well as the standard deviation and coefficient of variation associated with each element or parameter analyzed. The mean chemical composition of the groundwater and statistics defined for each geological unit is presented in Table 6, which also references the individual tables bearing the more detailed statistical information defined for each sample population.

In addition to the chemical element and parameter concentrations and statistics referred to, values for the Sodium Adsorption Ratio (SAR) and the Langelier Saturation Index (LSI) are also reported for each set of data. The SAR value provides an indication (mainly to agriculturalists) of the chemical suitability of water for irrigation use. This is assessed on the basis of two "hazard" factors, namely the EC which defines the salinity hazard of the water, and the SAR value which defines the sodium hazard. The SAR calculation relates the concentration of sodium in the water to the combined concentration of calcium and magnesium. The greater the value associated with either or both of the two "hazard" factors, the less suitable the water for irrigation use. These factors are not the only ones that determine the suitability of water for irrigation use. Other factors of equal if not greater importance include the crop type to be irrigated, the soil type in which the crop is planted and the volume of water applied per irrigation cycle. Ignoring any of these other factors, however, then water with a very high salinity value (> 225 mS/m) and a very high SAR value will be the least suitable for irrigation.

The LSI, which is a measure of the calcium carbonate ($CaCO_3$) solubility, provides an indication of the scaling potential (hardness) of water. Positive LSI values (> 0) indicate that the water is supersaturated in regard to $CaCO_3$ and scaling or incrustation may be expected. Negative values indicate that the water is undersaturated with respect to $CaCO_3$ and scaling is therefore unlikely to occur.

The Durov diagram used to display the groundwater quality data in graphical form represents a trilinear graph that distinguishes the cation from the anion component of water chemistry in two separate triangular fields, yet integrates the composite chemistry in a centralized field. A distinguishing feature of this diagram is the presentation of information pertaining to two other chemical parameters that do not form part of the triangular or centralized fields. In this instance, the parameters EC and pH are shown. A further refinement of the standard Durov diagram is the portrayal of a "halo" in the central field describing the distribution of the composite groundwater chemistry about the mean.

Table 7 presents information on water quality guidelines for domestic, stock and irrigation use on the basis of the electrical conductivity (salinity) of the water. This table should be read together with the "Groundwater Quality" inset map and also provides the quantitative reference framework against which the suitability of this chemical parameter for a specific use is described in this document.

Table 6. Mean chemical composition of water obtainable from each geological unit

GEOLOGICAL UNIT	No. of Sources	AVERAGE CHEMICAL ELEMENT / PARAMETER VALUE														WATER TYPE
		pH	EC mS/l	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Cl mg/l	SO_4 mg/l	T.Alk mg/l	N mg/l	F mg/l	SAR	LSI	
SABS 241–1984 maximum allowable limit for drinking water →			300	n.s.	n.s.	100	400	n.s.	600	600	n.s.	10	1.5	n.s.	n.s.	
INTERGRANULAR AQUIFERS (CLASS A)																
Crocodile River alluvium (Table 9)	32	7.6	85.9	591.8	62.2	43.3	62.0		85.6	52.8	232.0			1.5	-0.2	Mg-CO_3
FRACTURED AQUIFERS (CLASS B)																
West Rand Group (Table 11)	81	7.2	37.3	254	27.0	18.9	18.7	1.8	**24.7**	16.1	117.0	4.5	0.3	0.6	-1.2	Mg-CO_3
Central Rand Group (Table 12)	18	7.3	29.3	207	17.6	13.7	20.0	**2.6**	17.9	33.5	85.0	**2.0**	0.3	**1.2**	-1.6	Mg-CO_3
Kameeldoorns Formation (Table 13)	30	7.5	48.0	360	45.0	27.0	17.0	2.0	13.7	**54.0**	162.0	4.8	0.3	0.5	-0.6	Ca-CO_3
Bothaville Formation (Table 14)	42	7.4	30.4	200	23.0	11.0	18.0	3.4	20.0	**10.0**	88.0	6.0	0.2	0.9	-1.3	Ca-CO_3
Black Reef Formation (Table 15)	52	7.0	34.3	238	28.0	18.0	14.0	1.7	15.0	**36.0**	98.0	2.8	0.2	0.5	-1.8	Mg-CO_3
Daspoort Formation (Table 16)	10	7.1	26.0	195	19.7	16.6	5.4	1.3	8.9	4.9	112.0	1.8	0.2	0.3	-1.7	Mg-HCO_3
Magaliesberg Formation (Table 17)	13	6.9	48.0	381	56.0	22.0	18.9	2.7	17.0	**54.0**	165.0	**11.3**	0.2	0.5	-1.5	Ca-HCO_3
Rayton Formation (Table 18)	45	7.4	**60.0**	300	36.0	22.0	19.7	1.7	20.5	11.7	150.0	5.7	0.6	0.7	-0.8	CaMg-HCO_3
Wilge River Formation (Table 19)	18	7.4	25.5	180	20.0	12.0	13.0	2.5	**10.4**	6.2	93.0	**3.1**	0.8	0.6	-1.3	CaMg-HCO_3
KARST AQUIFERS (CLASS C)																
Chuniespoort Group (Table 21)	223	7.6	62.9	443	52.7	35.4	24.1	2.3	**37.7**	**70.5**	177.3	**5.6**	0.3	0.5	-0.4	CaMg-HCO_3
INTERGRANULAR and FRACTURED AQUIFERS (CLASS D)																
Basement Complex (Table 22)	62	7.5	38.0	263	29.0	16.0	23.0	2.4	**18.5**	18.4	122.0	6.5	0.3	0.9	-1.0	Ca-HCO_3
Dominion Group (Table 23)	9	7.5	131.0	928	53.0	24.0	**206.0**	2.9	116.0	**296.0**	186.0	4.5	0.3	**4.3**	-0.6	Na-SO_4
Klipriviersberg Group (Table 24)	66	7.6	60.0	405	49.0	30.0	27.0	1.8	36.0	**70.0**	151.0	6.3	0.2	0.8	-0.5	CaMg-HCO_3
Rietgat Formation (Table 25)	24	7.8	66.0	502	41.0	25.0	**70.0**	2.3	**30.5**	**29.0**	255.0	6.8	0.3	**3.9**	-0.3	Na-HCO_3
Allanridge Formation (Table 26)	30	7.7	57.0	380	55.0	25.0	22.0	2.2	47.0	7.8	172.0	11.0	0.2	0.6	-0.3	Ca-HCO_3
Timeball Hill/Rooisloot Formation(s) (Table 27)	81	7.2	34.0	278	29.0	19.0	15.0	1.6	**15.0**	**26.0**	125.0	**2.9**	0.3	0.6	-1.5	Mg-HCO_3
Silverton Formation (Table 28)	43	7.6	58.0	428	44.0	32.0	30.0	2.8	**39.0**	**56.0**	181.0	3.9	0.3	0.9	-0.6	Mg-HCO_3
Hekpoort Formation (Table 29)	41	7.5	52.0	398	44.0	26.0	30.0	2.0	23.5	**79.0**	156.0	3.5	0.3	**1.2**	-0.8	Ca-HCO_3
Rooiberg Group (Table 30)	16	7.1	34.0	216	26.0	14.0	13.0	8.0	23.5	**26.0**	81.5	**5.9**	0.4	0.6	-1.9	Ca-HCO_3
Loskop Formation (Table 31)	3	7.6	24.8	219	20.0	9.0	15.0	2.7	6.7	12.7	126.0	0.7	0.1	0.6	-1.0	Ca-HCO_3
Rashoop Granophyre Suite (Table 32)	41	7.3	31.0	226	22.0	15.0	17.0	2.6	21.0	**13.7**	108.0	2.2	0.8	0.9	-1.6	Mg-HCO_3
Rustenburg Layered Suite (Table 33)	73	7.7	105.0	760	99.0	56.0	45.0	**2.7**	94.0	184.0	219.0	10.6	0.3	1.1	-0.1	Ca-HCO_3
Lebowa Granite Suite (Table 34)	46	7.6	60.0	418	60.0	32.0	40.0	3.7	63.4	**71.0**	168.0	6.6	1.7	1.4	-0.6	Ca-HCO_3
Alkaline Complexes (Table 35)	22	7.7	95.0	631	66.0	33.0	91.0	3.2	82.4	82.7	273.0	**7.1**	**6.8**	**7.5**	-0.2	Ca-HCO_3
Dwyka Group (Table 36)	46	7.6	53.0	363	43.0	26.0	26.0	3.4	51.0	12.0	159.0	7.8	0.2	0.9	-0.6	CaMg-HCO_3
Vryheid Formation (Table 37)	125	7.5	57.0	400	38.0	24.0	43.0	3.6	**44.0**	**47.0**	162.0	**3.9**	0.4	**1.8**	-0.8	Mg-HCO_3
Ecca Group (undifferentiated) (Table 38)	26	7.6	38.0	258	29.0	18.0	17.0	**2.4**	**21.0**	**21.0**	118.0	**6.0**	0.2	0.5	-0.9	CaMg-HCO_3
Irrigasie Formation (Table 39)	19	7.7	167.0	1224	96.0	89.0	161.0	4.8	202.0	**288.0**	298.0	**19.3**	0.5	3.3	0.03	Mg-SO_4
Clarens Formation (Table 40)	22	7.9	65.0	463	61.0	33.0	26.0	1.8	30.0	26.0	224.0	12.9	0.3	0.6	0.2	Ca-HCO_3
Letaba Formation (Table 41)	170	7.8	116.0	674	85.0	49.0	53.0	2.5	76.0	**102.0**	233.0	22.5	**0.4**	1.4	0.01	Ca-HCO_3

Coefficient of variation lies between 100 and 200 %	**Coefficient of variation exceeds 200 %**

Table 7. Water quality guidelines (after DWAF, 1993)

ELECTRICAL CONDUCTIVITY (mS/m)	PURPOSE AND SUITABILITY		
	Domestic	**Stock**	**Irrigation**
< 70	Suitable	Suitable	Suitable
70 – 150	Suitable – slightly salty taste	Suitable	Suitable – salt sensitive crops may show a 10 % decrease in yield. Wetting of foliage should be avoided.
150 – 300	Tolerable – a marked salty taste	Suitable	Suitable for moderately salt tolerant crops although a 10 % decrease in yield can be expected. Wetting of foliage should be avoided.
300 – 450	Unacceptable – tolerable for short-term consumption	Suitable – some loss in productivity	Tolerable for moderately salt tolerant crops although a 20 % decrease in yield can be expected. Wetting of foliage should be avoided.
> 450	Totally unacceptable	Tolerable – may be refused by animals not accustomed to the water	Generally unacceptable

4.2 Mapping methodology

Sources of information and data used for the compilation of the map included (a) borehole and water quality data contained in the DWAFs National Groundwater Data Base and National Water Quality Data Base, (b) borehole data collected by consultants for the former self-governing KwaNdebele and Bophuthatswana territories, (c) various geohydrological reports and (d) field visits and borehole surveys. An inset map at a scale of 1:2 000 000 appearing on the main map indicates the distribution density of borehole-based information.

An evaluation of the borehole yield and groundwater quality data was applied to a selection of stations associated with coordinate accuracies of 100 m or better. These stations form part of the 5 272 yield values and 3 785 complete chemical analyses reported in Table 8.

The geological framework of the main map is provided by the 1:250 000 scale geological maps 2526 Rustenburg, 2528 Pretoria, 2626 West Rand and 2628 East Rand published by the Council for Geoscience. These maps show the geographic occurrence and surface distribution of different rock types (lithologies) that occur in the region. The different lithologies also represent differences in space (ie. their position relative to one another with depth below the ground surface or, in more simple terms, their stratification) and differences in time (ie. their geological age according to the time at which they were formed). These aspects are recognized in the terms lithostratigraphy and chronostratigraphy respectively.

Since the classification of aquifers considers amongst other factors the lithology of rock formations, it is possible to group similar lithostratigraphic units together as representing a single hydrogeological unit. These groupings are represented on the main map by the various lithology symbols. The unifying lithostratigraphic units are identified by the alphabetic codes printed on the map and referenced in the chronostratigraphic column. Additional information in regard to these units and their associated rock types is presented in Table 3.

The mapping of groundwater occurrence based on borehole yield data and hydrogeological classification was achieved by superimposing a grid over the lithology-based hydrogeological units. The dimensions of each grid block were set at one-sixtieth of a degree. This is equivalent to one minute or roughly 1 700 m by 1 700 m. Each grid block was colour coded according to the borehole yield range (refer Table 4 and the legend shown on the main map) represented by the median borehole yield occurring in that particular grid block. Regional patterns and trends were identified based on visual inspection and, where supported by sufficient evidence and reasoning based on experience, extrapolated into areas of data scarcity. Groundwater quality concerns represented by the elements nitrate and fluoride (refer Section 4.1.2) are shown where these exceed recognized safe concentration limits.

A similar approach was followed in the compilation of the 1:1 500 000 scale inset map representing the general quality of groundwater in the region in terms of its EC value. All available EC values were contoured in accordance with the various limits recognized in the South African Bureau of Standards (SABS 241-1984) specification for water for domestic supplies. Regional patterns and trends were identified and extrapolated into areas of data scarcity on the same basis as has been described for the main map.

The conceptual hydrogeological cross-section (profile) presented on the main map illustrates the relationship between groundwater occurrence and geology. It also illustrates the target environment favourable for the development of groundwater resources. The other two inset maps, both appearing at a scale of 1:2 000 000 on the main map, illustrate the surface elevation above sea level and the mean annual precipitation as derived from data provided by the Chief Directorate: Surveys and Mapping (Department of Land Affairs) and the Computing Centre for Water Research (CCWR) at the University of Natal (Pietermaritzburg) respectively.

Extensive use was made throughout of the ArcInfo® Geographic Information System (GIS) for cartographic, data manipulation and data display purposes.

Table 8. Number of hydrogeological and hydrochemical records sourced

NATIONAL GROUNDWATER DATA BASE		NATIONAL WATER QUALITY DATA BASE		
Borehole Records	Borehole Yield Values	Electrical Conductivity Values	Nitrate and Fluoride Values	Complete Chemical Analyses
33 197	5 272	7 442	3 785	3 785

5 Hydrogeological characterization

5.1 Introduction

The subdivisions of the major geological units identified in Section 3.1 are described in hydrogeological terms on the basis of their geographic distribution, groundwater occurrence and borehole yield, groundwater quality and hydrochemical classification. The hydrogeological characterization is supported by statistical analyses of borehole yield and groundwater quality data for each geological unit. These are presented in tabulated form and also displayed as Borehole Yield Distribution and Durov diagrams.

The nature and form of hydrogeological attributes such as groundwater occurrence and drainage patterns is similar in many of the geological units. For instance, secondary permeability developed along faults, joints, dyke contacts, bedding planes and lithological contacts accounts for and permits groundwater storage and movement, recharge and withdrawal in many of the geological units. Further, the groundwater drainage pattern in the map area generally mimics that of surface water as a function of the topography, and groundwater divides therefore commonly coincide with surface watersheds. The surface that defines the groundwater level consequently exhibits a muted resemblance to the land surface. Notable deviations from these typical attributes are discussed in regard to each individual geological unit where such deviations are manifested.

5.2 Intergranular aquifers

The alluvial sediments that adjoin the Crocodile River in the area downstream of the Roodekopjes and Vaalkop dams represent the only primary aquifer in the map area for which borehole yield and groundwater quality data are available. The nature and occurrence of these sediments is reported by Hobbs (1982a) to be substantial (up to 30 m thick) but irregular in their development. The high yield potential of boreholes that draw water from this aquifer is seen in the observation that they seldom deliver less than 5.0 *l*/s (Table 5). The water is used mainly for crop irrigation, and augments that drawn by farmers from the river itself. The rate of groundwater abstracted for this purpose from 13 operational boreholes amounted to some 2.7 million cubic metres (Hobbs, 1982a) in 1982. It was estimated that if half of the remaining 60 potential irrigation boreholes existing at the time were brought into production, then groundwater exploitation would increase to 7.2 million cubic metres per year. The rapid expansion of groundwater abstraction from this resource in the late 1970's and early 1980's prompted the Department of Water Affairs and Forestry to implement control over this development by proclaiming the area a Subterranean Government Water Control Area. This was effected in terms of Proclamation No. 18 of 1983.

The chemistry of the alluvial groundwater as presented in Table 9 indicates that this water is generally suitable for all use since none of the elements/parameters report a value that exceeds the maximum allowable limit for drinking water (Table 6). The low coefficients of variation reported in Table 9 point to the small measure of variability associated with the quality of this groundwater. This characteristic directly reflects the general homogeneity associated with the quality of this groundwater. It also indirectly reflects the relative homogeneity associated with the yield of boreholes tapping this aquifer as is suggested by the singular borehole yield statistic grouping (Table 5).

Table 9. Chemistry of groundwater from the Crocodile River alluvial aquifer

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 32 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	6.7	7.6	8.0	0.3	3.9 %
Electrical Conductivity (mS/m)	40.6	85.9	125.8	20.0	23.3 %
Total Dissolved Salts (mg/*l*)	253.0	591.8	825.0	146.0	24.7 %
Calcium (mg/*l* Ca)	18.3	62.2	120.0	22.0	35.4 %
Magnesium (mg/*l* Mg)	16.9	43.3	79.4	16.0	37.0 %
Sodium (mg/*l* Na)	25.0	62.0	102.2	21.0	33.9 %
Chloride (mg/*l* Cl)	21.5	85.6	204.0	35.0	40.9 %
Sulphate (mg/*l* SO_4)	2.6	52.8	144.7	33.0	62.5 %
Total Alkalinity (mg/*l* $CaCO_3$)	78.0	232.0	342.0	69.0	29.7 %
Langelier Saturation Index (LSI)	-1.9	-0.2	0.5	0.6	
Sodium Adsorption Ratio (SAR)	0.5	1.5	3.0	0.6	40.0 %

A distinguishing feature of the alluvial aquifer is its hydraulic connection with the Crocodile River (Hobbs, 1982b). This is demonstrated both by the sympathetic positive response of groundwater levels in boreholes to a rise in river stage (Figure 5) and by the similar quality of alluvial groundwater to that of river water (Table 10).

Table 10. Comparison of Crocodile River water and alluvial groundwater chemistry

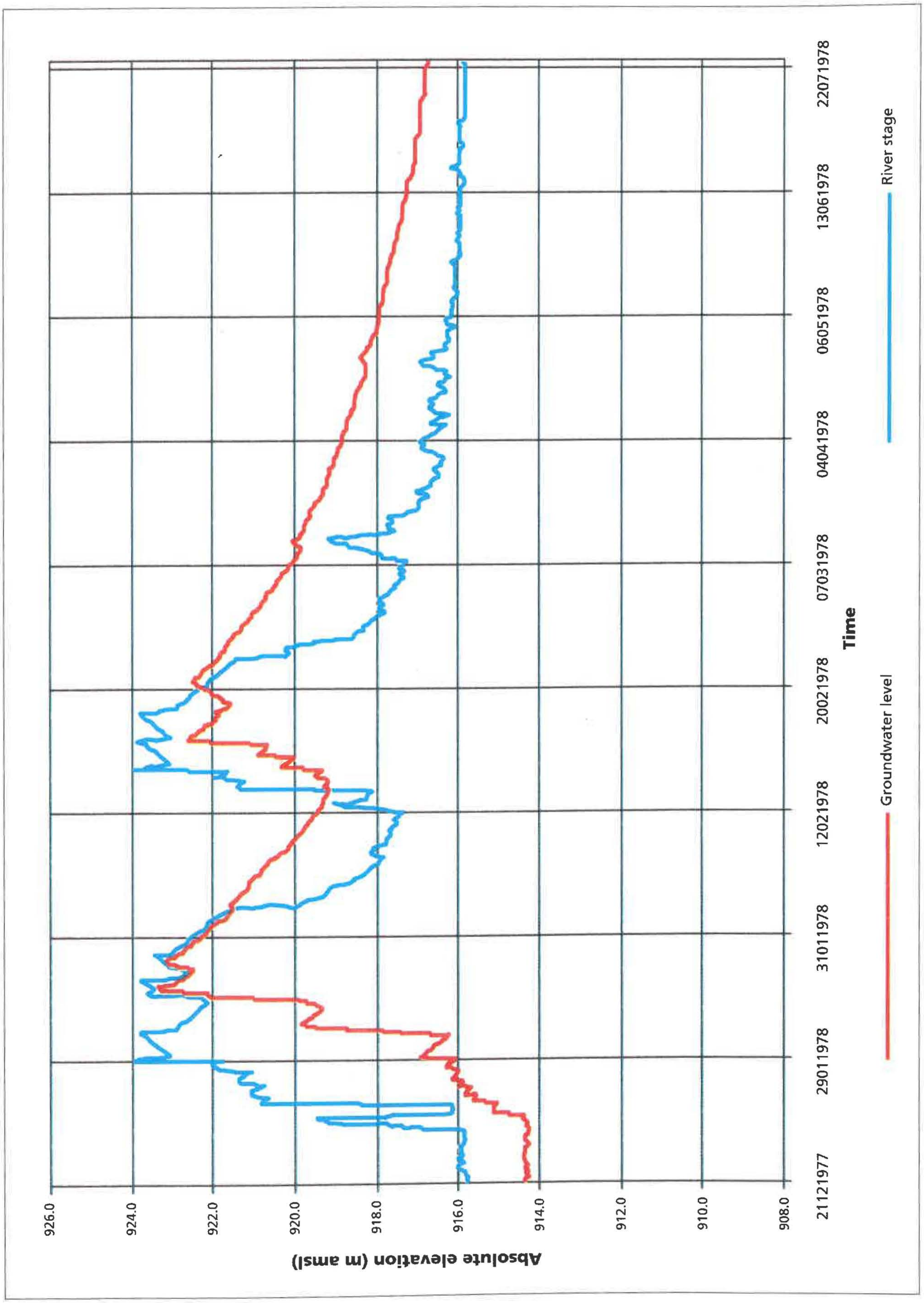
ELEMENT / PARAMETER	TYPICAL CHEMICAL COMPOSITION	
	Crocodile River Water (after Hobbs, 1982b)	**Alluvial Groundwater** (from Table 9)
pH	7.3	7.6
Electrical Conductivity (mS/m)	71.5	85.9
Total Dissolved Salts (mg/*l*)	524.4	591.8
Calcium (mg/*l* Ca)	47.5	62.2
Magnesium (mg/*l* Mg)	30.0	43.3
Sodium (mg/*l* Na)	74.5	62.0
Chloride (mg/*l* Cl)	72.2	85.6
Sulphate (mg/*l* SO_4)	81.6	52.8
Total Alkalinity (mg/*l* $CaCO_3$)	173.0	232.0
Langelier Saturation Index (LSI)	-0.4	-0.2
Sodium Adsorption Ratio (SAR)	3.0	1.5
Water Type	$Na\text{-}HCO_3$	$Mg\text{-}HCO_3$

5.3 Fractured aquifers

Consolidated hard rock covers approximately 99 % of the map area. This rock mass was formed over a period of some 3 000 million years, experiencing episodes of intrusion in an early stage and later enduring several phases of deformation. The deformation processes and subsequent continental uplift, weathering and erosion all aided in the development of the present groundwater environment. Competent rocks comprising mainly arenaceous material underwent brittle failure, the numerous resulting fracture structures enhancing the development of secondary porosity in these formations. The relative flexibility of less competent rocks, on the other hand, inhibited such development in associated formations.

Plate 2. Discharge of 16 *l*/s produced by a borehole tapping alluvial sediments building the primary aquifer of the Crocodile River valley floodplain. Tree line marks the river channel. (Photo: PJ Hobbs)

Figure 5. Response of alluvial aquifer groundwater level to changes in Crocodile River stage height (after Hobbs, 1982b)



5.3.1 West Rand Group (Witwatersrand Supergroup)

The distribution of the West Rand Group is shown in Figure 6a together with the positions of groundwater sample sources. The Group consists of quartzite, reddish and ferruginous magnetic shales and gritty quartzite and conglomerate horizons. Rapidly alternating argillaceous and arenaceous sediments are interspersed with diabase sills and dykes. The less resistant shales and diabase usually occupy the floors of valleys and depressions. The more resistant quartzites give rise to a series of parallel ridges in the Klerksdorp area and south of Ventersdorp. Differences in surface elevation are nowhere very pronounced, limiting the amount of surface run-off from this formation. De Villiers (1961) reports that the interspersed diabase sills yield strong water on the upper and lower contacts with their host rock and when they are weathered deeply enough. Generally higher yields are also associated with more deeply weathered shale formations. Especially favourable circumstances occur in low-lying areas where lithological contacts and bedding planes are weathered. The Sugar Bush Fault south of Heidelberg is also associated with higher yields.

The groundwater yield potential is classed as moderate on the basis that 65 % of the boreholes on record produce less than 2 *l*/s (Figure 6b). The groundwater level generally occurs between a depth of 10 and 25 m below surface. The deeper water levels (approaching 25 m) in the area around the Vredefort dome are attributed to the hilly nature of the area. The low relief of much of the remaining area around Klerksdorp and south of Ventersdorp most probably accounts for the general absence of well-defined springs in this area. Groundwater is more commonly discharged via seeps that occur along the floors and slopes of the principal valleys. Infiltration and recharge is generally promoted by the permeability of the sandy soils that occur in the area. Barnard (1997) indicates that groundwater recharge to the west of Randfontein can amount to 6.5 % of the average annual rainfall.

The chemical data (Table 11 and Figure 6c) indicate that groundwater quality in terms of salinity, with an average EC value of some 37 mS/m, is generally suitable for all use.

The greatest coefficients of variation are associated with chloride and sulphate which suggests the influence of contamination, probably by mining activities, in some of the samples. The maximum SAR value assigns a low sodium hazard to this water, indicating that the salinity hazard is of marginally greater significance in classifying this water for irrigation use.

Table 11. Chemistry of groundwater from the West Rand Group

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 81 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	5.3	7.2	8.4	0.6	8 %
Electrical Conductivity (mS/m)	2.6	37.3	256.0	35.0	94 %
Total Dissolved Salts (mg/*l*)	21.3	254.0	1492.0	210.0	83 %
Calcium (mg/*l* Ca)	1.0	27.0	243.0	30.0	111 %
Magnesium (mg/*l* Mg)	1.0	18.9	132.0	18.0	95 %
Sodium (mg/*l* Na)	1.0	18.7	126.0	21.0	112 %
Potassium (mg/*l* K)	0.1	1.8	8.4	1.7	94 %
Chloride (mg/*l* Cl)	1.0	24.7	570.0	71.0	287 %
Sulphate (mg/*l* SO_4)	1.0	16.1	202.0	30.8	191 %
Total Alkalinity (mg/*l* $CaCO_3$)	8.0	117.0	346.0	73.0	62 %
Nitrate (mg/*l* N)	0.1	4.5	30.2	5.5	122 %
Fluoride (mg/*l* F)	0.1	0.3	1.7	0.2	67 %
Langelier Saturation Index (LSI)	-5.0	-1.2	0.8	1.4	
Sodium Adsorption Ratio (SAR)	0.1	0.6	4.8	0.6	100 %

Figure 6a. Geographical distribution of the West Rand and Central Rand Groups and associated groundwater sampling points

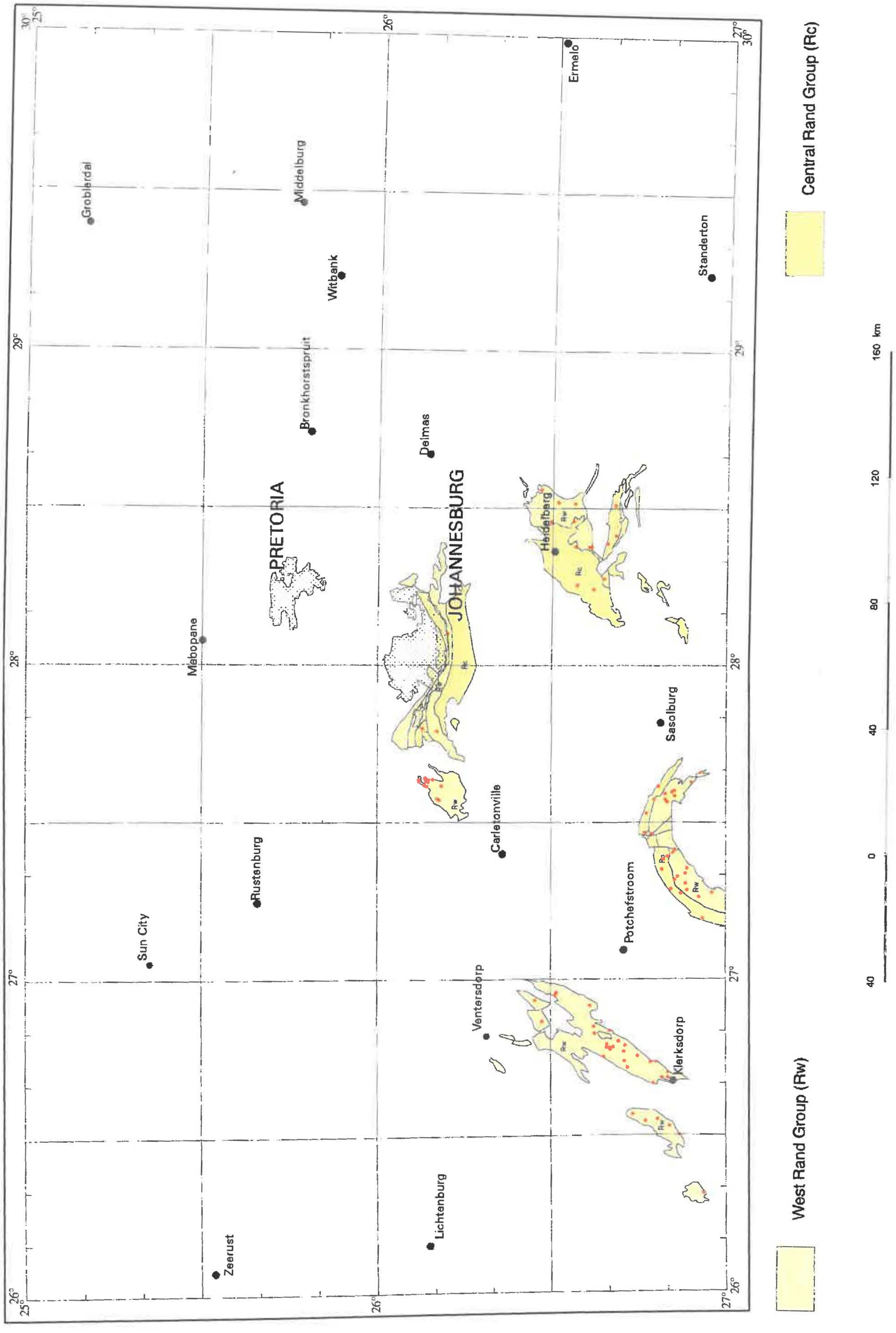


Figure 6b. Borehole yield distribution for the West Rand and Central Rand Groups

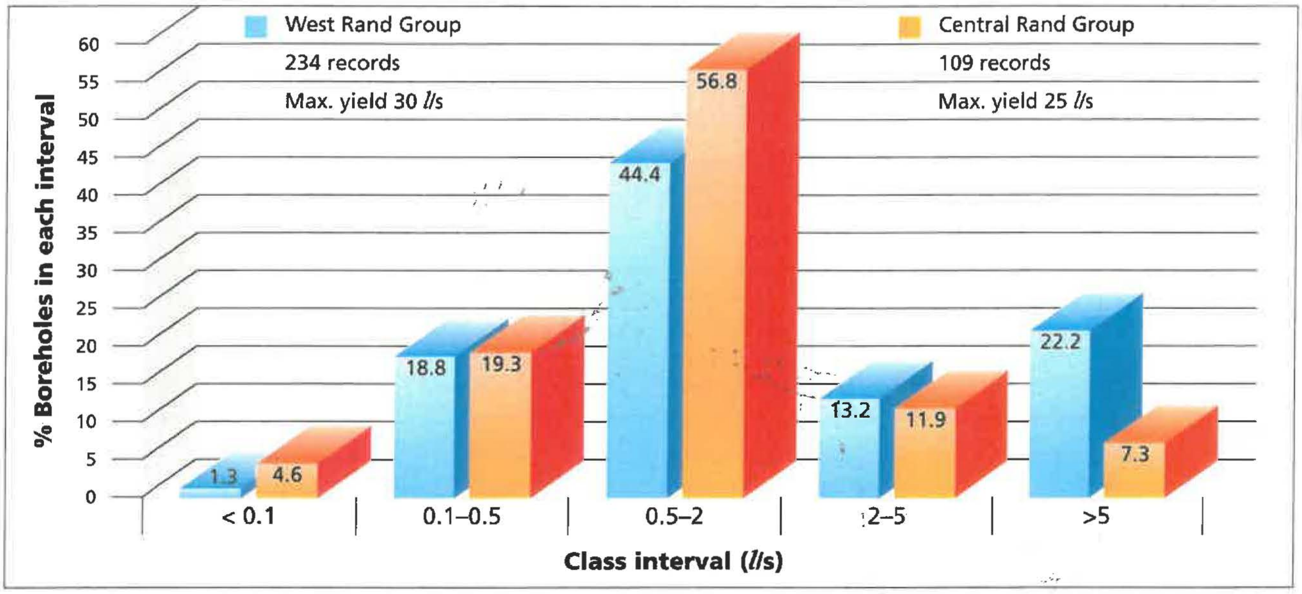
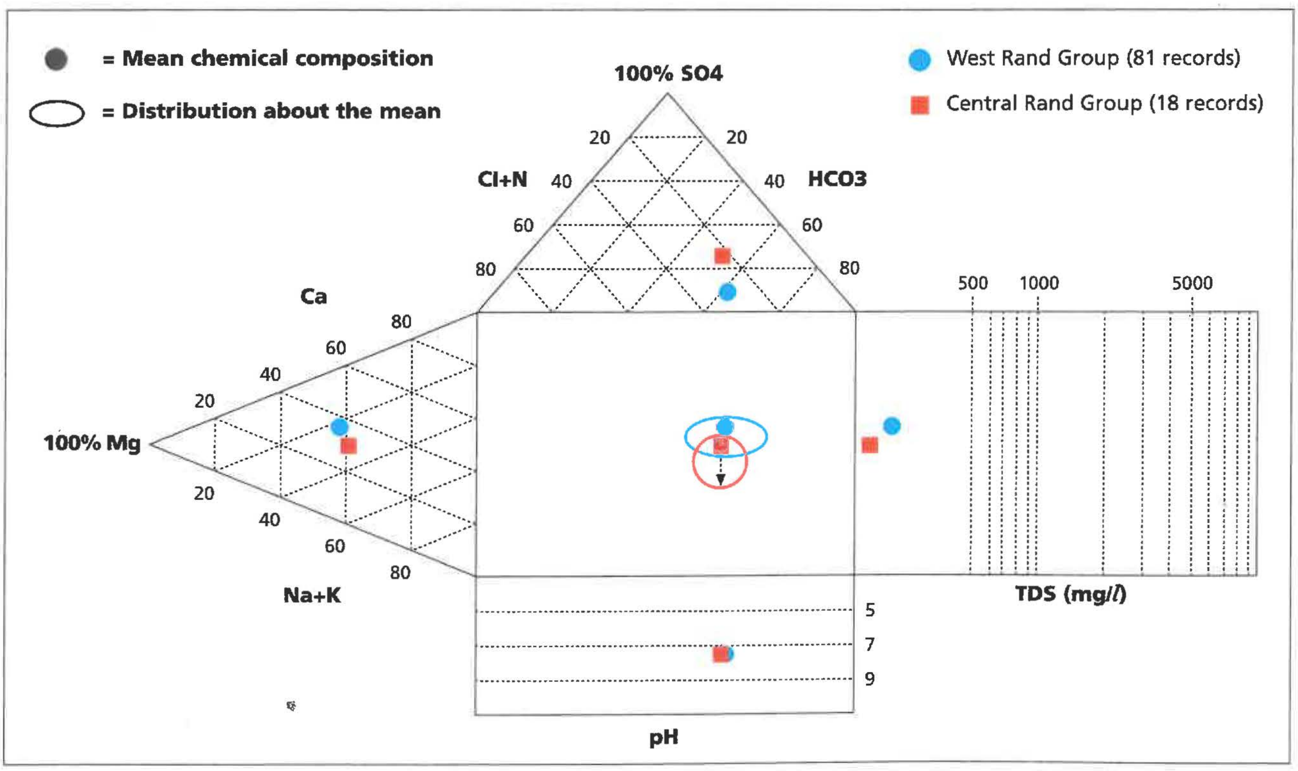


Figure 6c. Chemistry of groundwater from the West Rand and Central Rand Groups



5.3.2 **Central Rand Group** (Witwatersrand Supergroup)

The distribution of the Central Rand Group rocks is also shown in Figure 6a together with the positions of groundwater sample sources. It is indicated in Table 3 (Section 3.1) that this Group is composed of arenaceous and rudaceous rocks. Weathering of these rocks generally produces sandy soils which might promote recharge locally. Unfortunately very little is known about the water-bearing properties of the Central Rand Group rocks to the south of Johannesburg.

The groundwater yield potential is classed as moderate on the basis that 80 % of the boreholes sourced for yield information produce less than 2 *l*/s (Figure 6b). Generally higher borehole yields to the south of Heidelberg are associated with the Sugar Bush Fault. The depth to groundwater level in this unit, similar to that described for the West Rand Group, occurs between 10 and 25 m below surface. No noteworthy springs are known to occur in the outcrop area of the Central Rand Group.

The chemical data (Table 12 and Figure 6c) indicate that groundwater quality in terms of salinity, with an average EC value of some 29 mS/m, is generally suitable for all use. The greatest coefficients of variation are associated with potassium and sulphate, the latter again suggesting the influence in some of the samples of contamination probably by mining activities. The maximum SAR value and the substantial coefficient of variation associated with this parameter assigns a medium sodium hazard to this water, indicating it to be of generally greater significance than salinity in classifying this water for irrigation use.

Table 12. Chemistry of groundwater from the Central Rand Group

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 18 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	6.1	7.3	10.0	1.0	14 %
Electrical Conductivity (mS/m)	3.9	29.3	115.6	31.5	108 %
Total Dissolved Salts (mg/*l*)	14.0	207.0	611.0	227.0	110 %
Calcium (mg/*l* Ca)	1.0	17.6	100.0	24.0	136 %
Magnesium (mg/*l* Mg)	1.0	13.7	65.0	17.0	124 %
Sodium (mg/*l* Na)	2.0	20.0	84.0	27.6	138 %
Potassium (mg/*l* K)	0.1	2.6	33.8	7.9	304 %
Chloride (mg/*l* Cl)	1.0	17.9	113.0	29.0	162 %
Sulphate (mg/*l* SO_4)	1.0	33.5	253.0	61.0	182 %
Total Alkalinity (mg/*l* $CaCO_3$)	3.0	85.0	278.0	78.5	92 %
Nitrate (mg/*l* N)	0.1	2.0	14.7	3.5	175 %
Fluoride (mg/*l* F)	0.1	0.3	0.8	0.2	67 %
Langelier Saturation Index (LSI)	-5.0	-1.6	0.7	1.3	
Sodium Adsorption Ratio (SAR)	0.1	1.2	10.8	2.5	208 %

5.3.3 **Kameeldoorns Formation** (Ventersdorp Supergroup)

The distribution of the Kameeldoorns Formation is shown in Figure 7a together with the positions of groundwater sample sources. The Formation is composed of breccia, a coarse basal conglomerate, greywacke, calcareous shale and pure limestone. It would appear that the highest yielding boreholes are associated with chert layers or a silicified breccia such as are found at Hartbeesfontein. Backström *et al* (1952) identify this as secondary chert representing rocks that were changed by silicification. De Villiers (1961) states that groundwater is encountered in fractures developed by weathering to sufficient depth within the saturated zone in the chert and sandstone.

The groundwater yield potential is classed as good on the basis that 35 % of the boreholes on record produce more than 2 *l*/s (Figure 7b). The depth to the groundwater level generally occurs between 5 and 20 m below surface. A spring of unknown yield occurring on the contact between the chert breccia and the underlying tuff sediments at Hartbeesfontein has stopped flowing, due probably to the abstraction of groundwater for supply to the town and nearby mine. The discharge (also unknown) of another spring located to the north of Hartbeesfontein (see Main Map) has diminished most probably due to groundwater abstraction by farmers. Weathering of the Kameeldoorns Formation produces a sandy soil full of pebbles derived from the conglomerate horizon, or otherwise from the overlying Bothaville Formation. These circumstances are conducive to rainwater infiltration and represent favourable groundwater recharge conditions. Unfortunately no recharge studies for this Formation have been undertaken and no information in this regard could be sourced.

The chemical data (Table 13 and Figure 7c) indicate that groundwater quality in terms of salinity, with an average EC value of 48 mS/m, is generally suitable for all use. The greatest coefficient of variation is associated with sulphate. Since no mining activities occur in the vicinity of this Formation, the origin of the sulphate is most probably natural such as occurs in association with gypsum. The maximum SAR value assigns a low sodium hazard to this water which, together with the EC statistics, indicate that salinity is of marginally greater significance in classifying this water for irrigation use.

Figure 7a. Geographical distribution of the Kameeldoorns and Bothaville Formations and associated groundwater sampling points

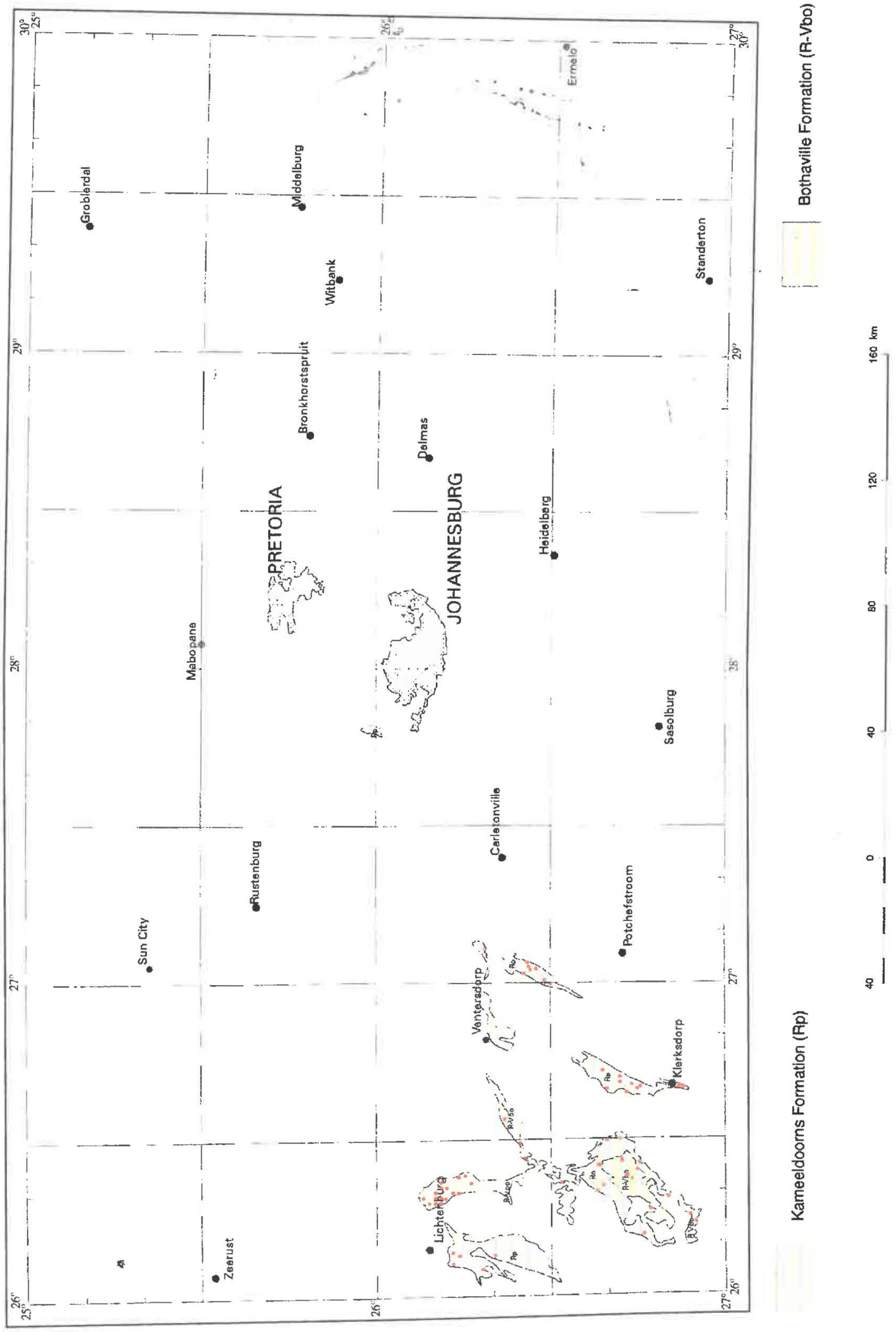
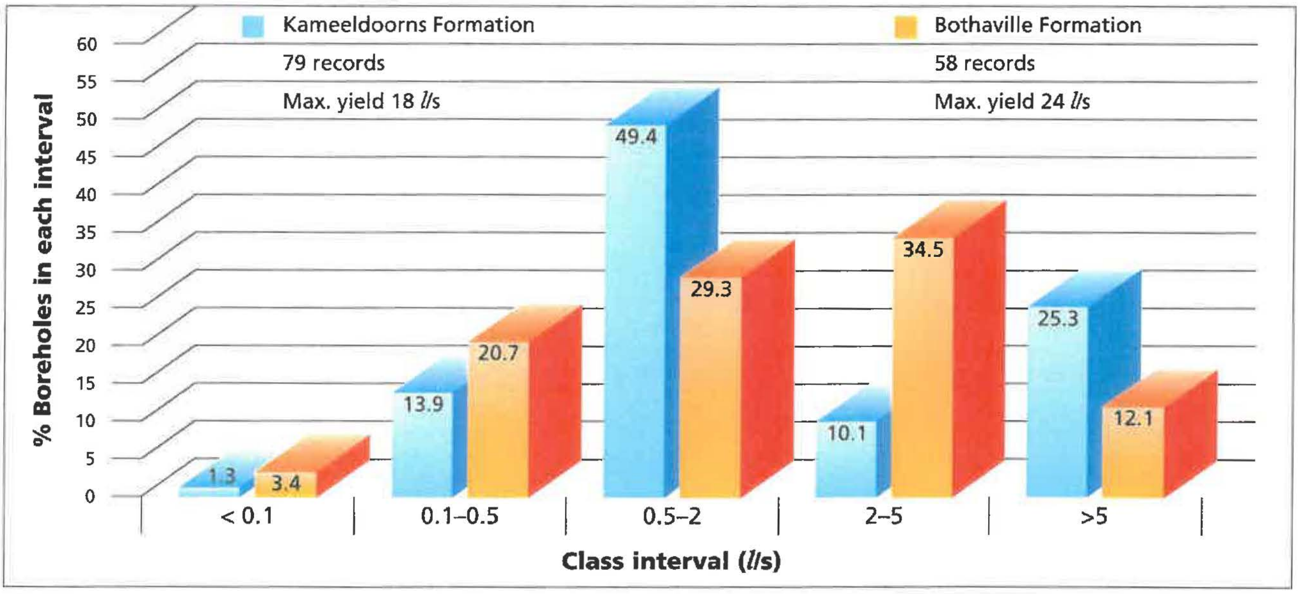


Table 13. Chemistry of groundwater from the Kameeldoorns Formation

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 30 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	5.6	7.5	8.3	0.5	7 %
Electrical Conductivity (mS/m)	2.0	48.0	158.0	37.0	77 %
Total Dissolved Salts (mg/*l*)	21.0	360.0	1284.0	293.0	81 %
Calcium (mg/*l* Ca)	2.0	45.0	181.0	42.0	93 %
Magnesium (mg/*l* Mg)	1.0	27.0	123.0	27.0	100 %
Sodium (mg/*l* Na)	2.0	17.0	63.0	12.0	71 %
Potassium (mg/*l* K)	0.3	2.0	5.9	1.4	70 %
Chloride (mg/*l* Cl)	1.0	13.7	117.0	20.9	153 %
Sulphate (mg/*l* SO_4)	2.0	54.0	680.0	153.0	283 %
Total Alkalinity (mg/*l* $CaCO_3$)	10.0	162.0	329.0	76.0	47 %
Nitrate (mg/*l* N)	0.1	4.8	24.0	5.2	108 %
Fluoride (mg/*l* F)	0.1	0.3	1.1	0.2	67 %
Langelier Saturation Index (LSI)	-4.6	-0.6	0.8	1.0	
Sodium Adsorption Ratio (SAR)	0.1	0.5	1.2	0.3	60 %

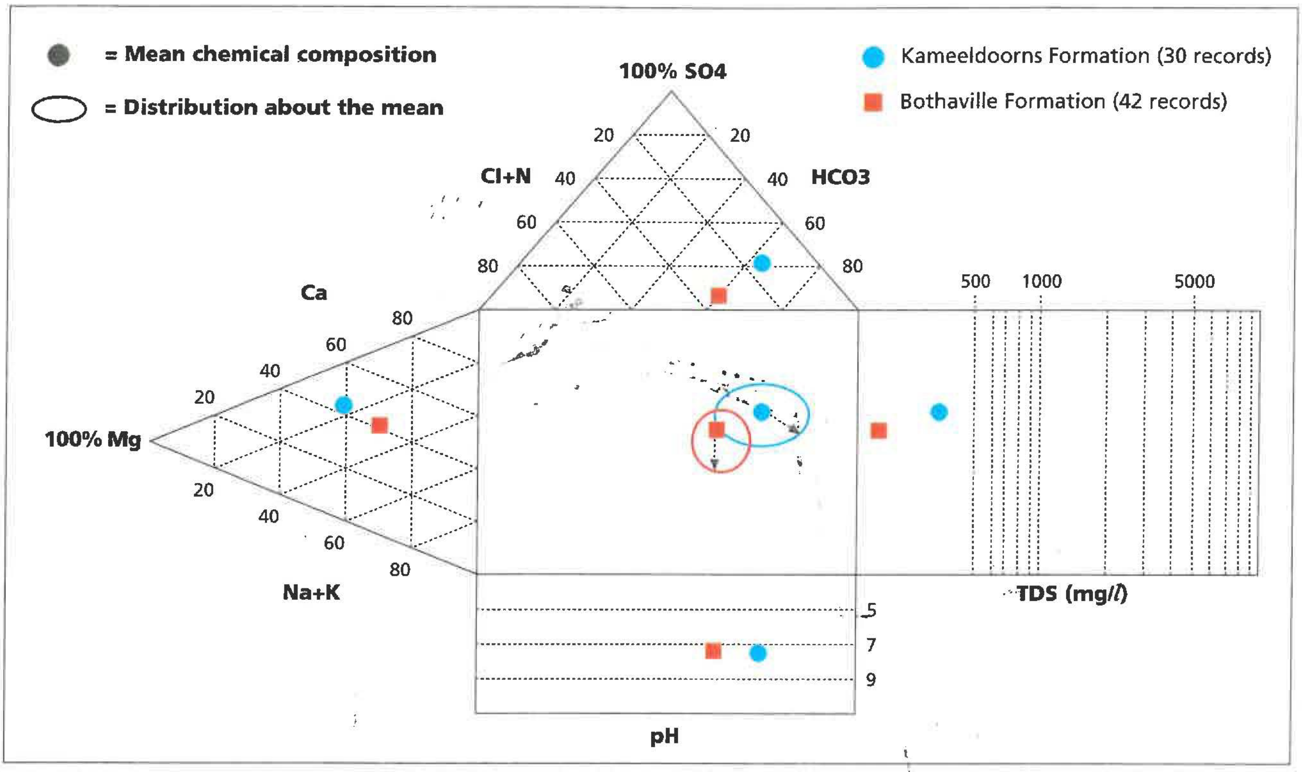
Figure 7b. Borehole yield distribution for the Kameeldoorns and Bothaville Formations



5.3.4 Bothaville Formation (Ventersdorp Supergroup)

The distribution of the Bothaville Formation is also shown in Figure 7a together with the positions of groundwater sample sources. The Formation is composed of conglomerate, sandstone and shale. The nature of groundwater occurrence is similar to that described for the Kameeldoorns Formation (Section 5.3.3), namely in fractures developed by weathering to sufficient depth within the saturated zone in the sandstone (De Villiers, 1961). The groundwater yield potential is classed as good on the basis that 47 % of the boreholes for which yield data are available, produce more than 2 *l*/s (Figure 7b). The depth to the groundwater level generally occurs between 5 and 15 m below surface. A borehole survey undertaken in the area identified a relatively strong spring, situated to the south of Hartbeesfontein (see Main Map), associated with this unit. A comparison of the catchment areas of this spring with its flow rate suggests that the percentage of rainfall recharge is

Figure 7c. Chemistry of groundwater from the Kameeldoorns and Bothaville Formations



relatively high. This is partly attributed to high infiltration through the loose and pebbly nature of the soil cover derived from weathering of the conglomerate horizons.

The chemical data (Table 14 and Figure 7c) indicate that groundwater quality in terms of salinity, with an average EC value of 30 mS/m, is generally suitable for all use. The coefficients of variation are generally less than 100 %, with sulphate the most notable exception. The maximum SAR value assigns a low sodium hazard to this water which, together with the EC statistics, indicate that the SAR and salinity values are of similar significance in classifying this water for irrigation use.

Table 14. Chemistry of groundwater from the Bothaville Formation

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 42 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	4.0	7.4	8.2	0.6	8 %
Electrical Conductivity (mS/m)	11.0	30.4	104.0	21.5	71 %
Total Dissolved Salts (mg/*l*)	48.7	200.0	718.0	155.0	78 %
Calcium (mg/*l* Ca)	6.0	23.0	103.0	22.0	96 %
Magnesium (mg/*l* Mg)	1.0	11.0	48.0	9.8	89 %
Sodium (mg/*l* Na)	3.0	18.0	86.0	16.7	93 %
Potassium (mg/*l* K)	0.6	3.4	14.1	2.2	65 %
Chloride (mg/*l* Cl)	2.0	20.0	104.0	23.0	115 %
Sulphate (mg/*l* SO_4)	1.0	10.0	140.0	28.0	280 %
Total Alkalinity (mg/*l* $CaCO_3$)	9.0	88.0	267.0	66.0	75 %
Nitrate (mg/*l* N)	0.6	6.0	21.9	4.6	77 %
Fluoride (mg/*l* F)	0.1	0.2	1.2	0.2	100 %
Langelier Saturation Index (LSI)	-3.2	-1.3	0.6	1.0	
Sodium Adsorption Ratio (SAR)	0.1	0.9	7.3	1.1	122 %

5.3.5 Black Reef Formation (Transvaal Supergroup)

The Black Reef Formation is comparatively thin, averaging only 30 m in thickness in the map area. It is composed of quartzite, lenticular beds of grit and conglomerate as well as shale at the top. Its geographical distribution is shown in Figure 8a together with the positions of groundwater sample sources.

The best exposures are located along the Ventersdorp-Randfontein anticline that occupies the region to the west of Carletonville. Very little information on the occurrence of groundwater in this formation is available. This might be attributed to the low groundwater yield potential suggested by the observation that 73 % of the boreholes on record produce less than 2 *l*/s (Figure 8b).

The groundwater level depth in the Black Reef Formation is determined largely by the direction of groundwater movement between this lithology and the adjoining dolomite of the Chuniespoort Group. In instances where the direction of groundwater movement is toward the dolomite, the groundwater gradient is generally much steeper through the quartzitic rocks than in the dolomitic formations.

This characteristic has been demonstrated by Hobbs (1988) in the area southwest of Pretoria, where the Black Reef Formation separates the Basement Complex granite of the Halfway House Granite dome from the dolomite of the Chuniespoort Group. The steeper gradient is attributed to the poorer transmissive properties of the quartzite compared to those of the dolomite. In those instances where the direction of groundwater movement from adjoining units is toward the quartzite, the poorer transmissive properties of the latter cause it to act as a barrier to groundwater flow, producing generally shallow groundwater levels in this Formation.

Consideration of the groundwater chemistry data for this Formation must recognize that the limited thickness of this geological unit to some extent compromises the representativeness of the data. The groundwater chemistry may, for example, represent a mixture of the groundwater contained in this Formation and in the adjoining geological units. Nevertheless, the chemical data (Table 15 and Figure 8c) indicate that groundwater quality in terms of salinity, with an average EC value of some 34 mS/m, is generally suitable for all use. Sulphate reveals the greatest and most notable coefficient of variation, suggesting an association of some of the samples with mining activities. The maximum SAR value assigns a low sodium hazard to this water which, together with the EC statistics, indicate that the SAR and salinity values are of similar significance in classifying this water for irrigation use.

Table 15. Chemistry of groundwater from the Black Reef Formation

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 52 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	4.8	7.0	8.3	0.8	11 %
Electrical Conductivity (mS/m)	2.1	34.3	139.0	34.1	99 %
Total Dissolved Salts (mg/*l*)	21.0	238.0	1034.0	236.0	99 %
Calcium (mg/*l* Ca)	1.0	28.0	109.0	29.0	104 %
Magnesium (mg/*l* Mg)	1.0	18.0	103.0	20.5	114 %
Sodium (mg/*l* Na)	1.0	14.0	93.0	20.0	143 %
Potassium (mg/*l* K)	0.2	1.7	11.7	2.3	135 %
Chloride (mg/*l* Cl)	1.0	15.0	90.0	24.0	160 %
Sulphate (mg/*l* SO_4)	1.0	36.0	557.0	100.0	278 %
Total Alkalinity (mg/*l* $CaCO_3$)	6.0	98.0	521.0	99.0	100 %
Nitrate (mg/*l* N)	0.1	2.8	20.1	3.8	136 %
Fluoride (mg/*l* F)	0.1	0.2	0.7	0.2	100 %
Langelier Saturation Index (LSI)	-5.1	-1.8	0.6	1.8	
Sodium Adsorption Ratio (SAR)	0.1	0.5	2.1	0.5	100 %

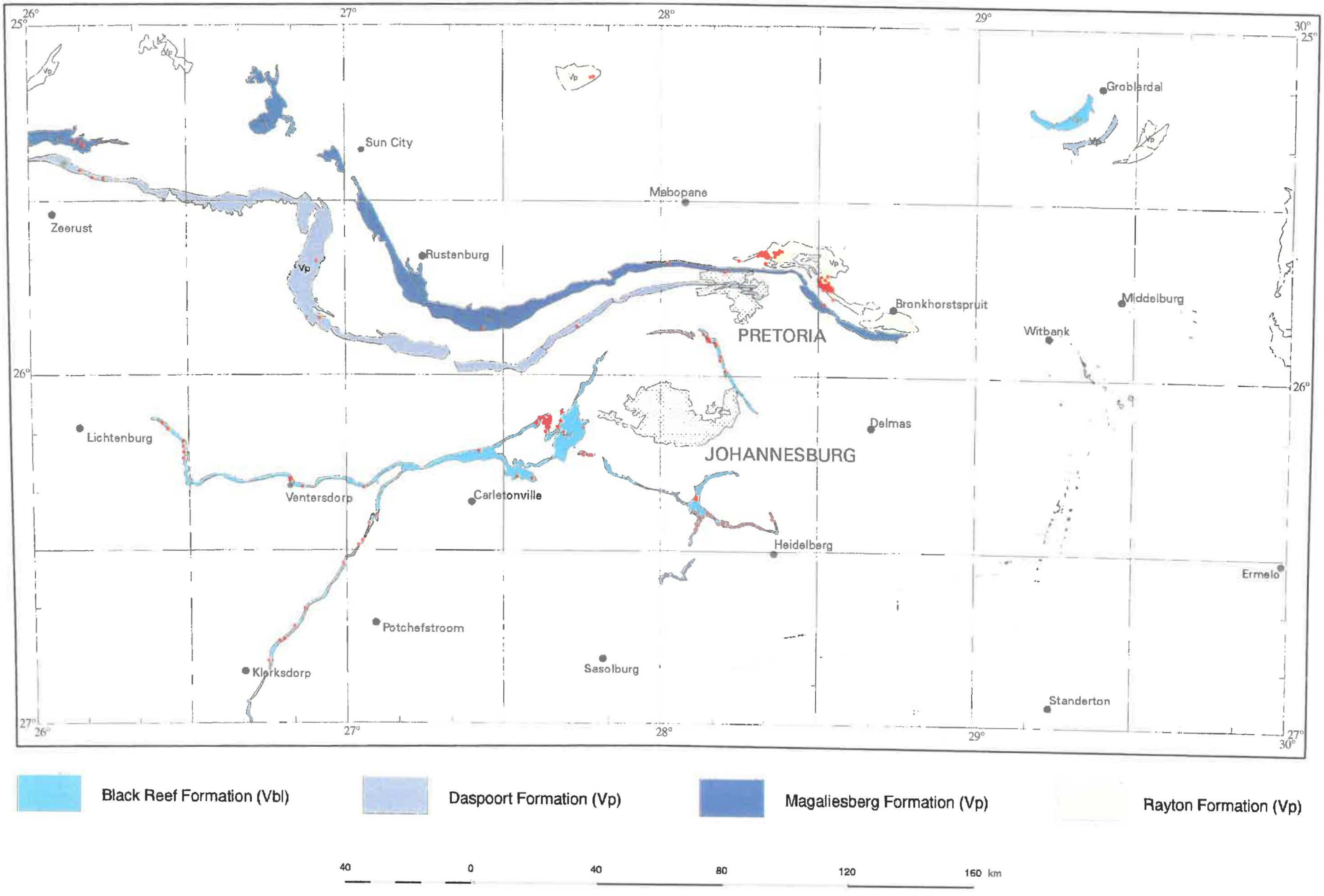


Figure 8a. Geographical distribution of the Black Reef, Daspoort, Magaliesberg and Rayton Formations and associated groundwater sampling points

Figure 8b. Borehole yield distribution for the Black Reef and Magaliesberg Formations

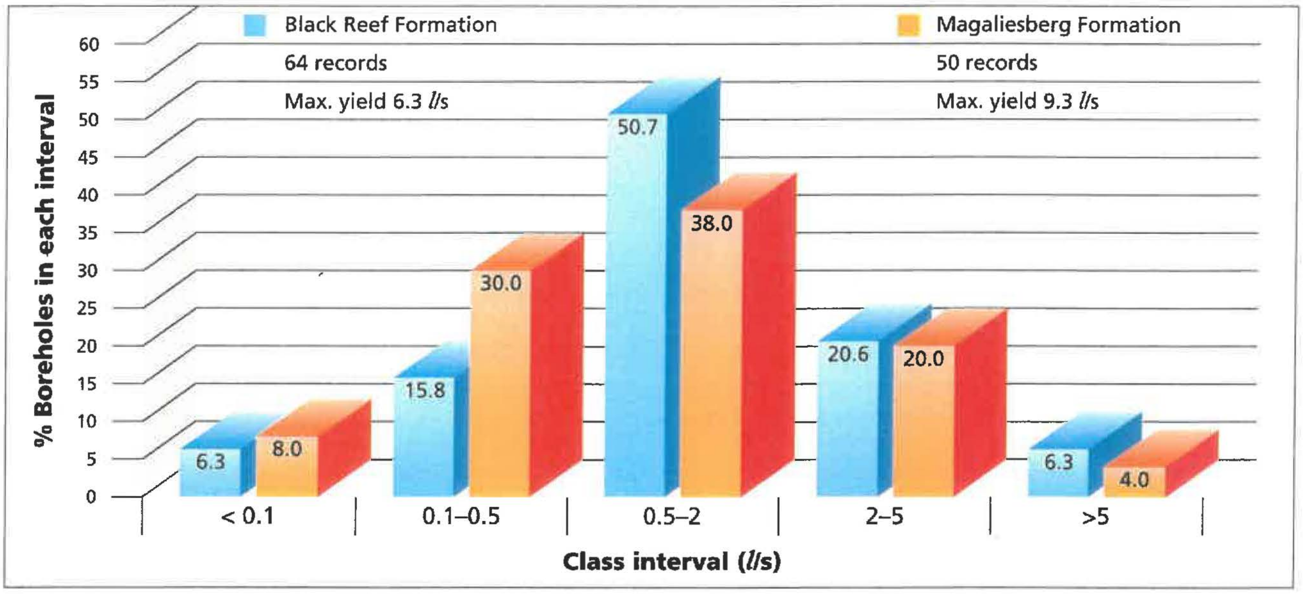
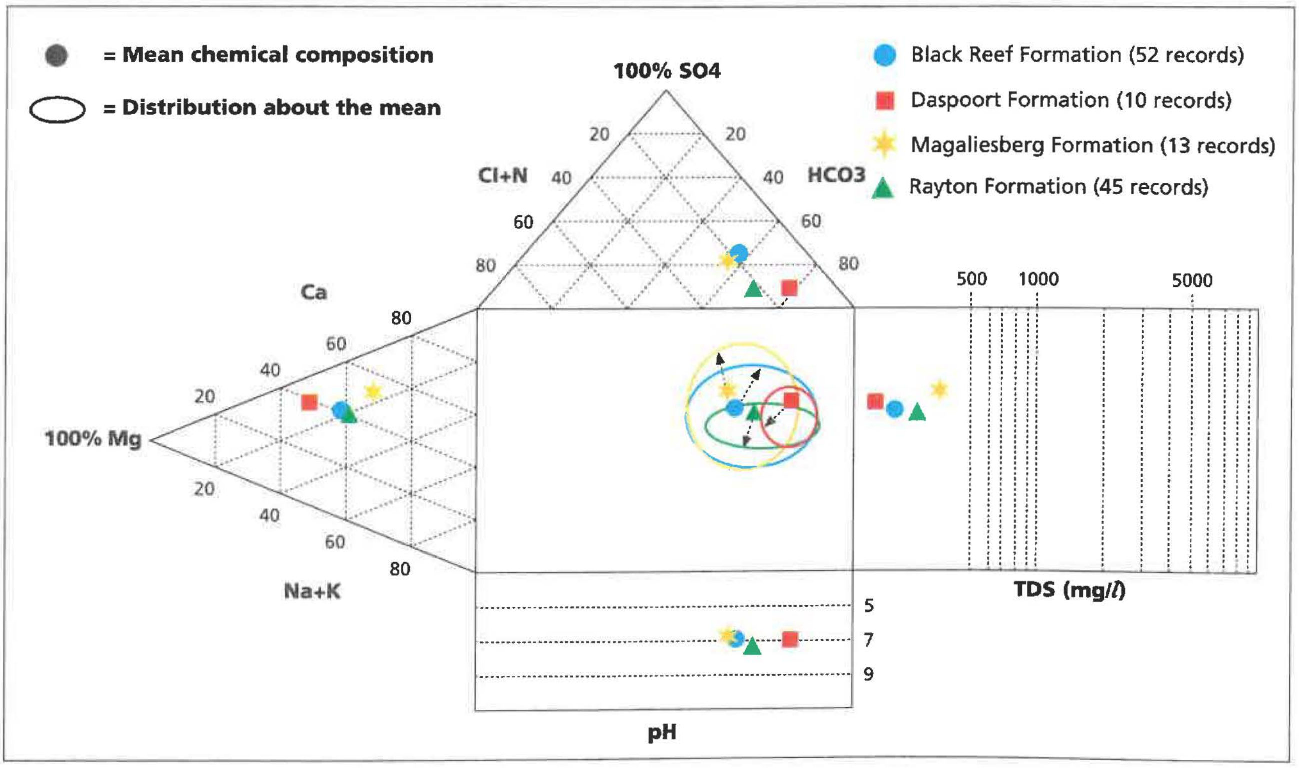


Figure 8c. Chemistry of groundwater from the Black Reef, Daspoort, Magaliesberg and Rayton Formations



5.3.6 Daspoort Formation (Transvaal Supergroup)

The distribution of this lithology (an orthoquartzite with thinly interbedded shale and siltstone) is also shown in Figure 8a together with the positions of groundwater sample sources. Groundwater occurrence is associated with faults and related shear zones, with the upper and lower contact zones of intrusive diabase sills with overlying and/or underlying shale and quartzite horizons, and with occasional joints in fresh diabase. The depth to groundwater level generally occurs between 10 and 30 m below surface. The poor storage capacity of the quartzitic rock often restricts its ability to accept infiltrating rainwater, causing groundwater to daylight on surface after heavy rains.

Numerous landowners obtain household water supplies from dug drainage trenches especially where this unit is covered by a layer of surface sand two or more metres in thickness. It would therefore appear that although recharge of the Daspoort Formation, which drains into the underlying Hekpoort Formation, is relatively high, its utilization value is limited due to its poor storage capacity. An artesian borehole associated with the Daspoort Formation is shown on the Main Map to the north of Zeerust.

The chemical data (Table 16 and Figure 8c) indicate that groundwater quality in terms of salinity, with a mean EC value of 26 mS/m, is generally suitable for all use. The coefficients of variation are commonly less than 100 %, with chloride the singular exception. The SAR and EC statistics indicate that these parameters are of similar significance in classifying this water as generally suitable for irrigation use.

Table 16. Chemistry of groundwater from the Daspoort Formation

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 10 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	5.8	7.1	8.1	0.9	13 %
Electrical Conductivity (mS/m)	3.8	26.0	64.0	20.8	80 %
Total Dissolved Salts (mg/l)	29.0	195.0	442.0	152.0	78 %
Calcium (mg/l Ca)	2.0	19.7	59.0	19.3	98 %
Magnesium (mg/l Mg)	1.0	16.6	39.0	14.5	87 %
Sodium (mg/l Na)	2.0	5.4	15.0	3.5	65 %
Potassium (mg/lK)	0.3	1.3	3.2	0.9	69 %
Chloride (mg/l Cl)	2.0	8.9	59.0	16.7	188 %
Sulphate (mg/l SO_4)	1.0	4.9	13.0	3.9	80 %
Total Alkalinity (mg/l $CaCO_3$)	15.0	112.0	275.0	90.7	81 %
Nitrate (mg/l N)	0.4	1.8	5.8	1.8	100 %
Fluoride (mg/l F)	0.1	0.2	0.5	0.2	100 %
Langelier Saturation Index (LSI)	-4.3	-1.7	0.3	1.7	
Sodium Adsorption Ratio (SAR)	0.1	0.3	0.6	0.2	67 %

5.3.7 Magaliesberg Formation (Transvaal Supergroup)

The distribution of this lithology, also an orthoquartzite, is shown in Figure 8a together with the positions of groundwater sample sources. This unit increases in thickness from the approximately 15 m it has in the area north of Zeerust, to a value of around 300 m in the area around Pretoria, gradually building the Magaliesberg mountain range in the process.

Kok (1993a) indicates that groundwater occurrence is most often associated with fractures and with the contact zones of diabase sills located at the foot of the northern slopes of the Magaliesberg. Groundwater also occurs in faults and associated shear zones. The groundwater yield potential is classed as low on the basis that 76 % of the available borehole yield records support a value of less than 2 l/s (Figure 8b). The depth to groundwater level generally occurs between 10 and 40 m below surface. Numerous springs emanate from this unit. Bredenkamp *et al* (1995) computed the base flow of a mountainous catchment near Rustenburg to have a variance of 12 to 20 % of the mean annual rainfall.

The chemical data (Table 17 and Figure 8c) indicate groundwater quality in terms of salinity, with a mean EC value of 48 mS/m, to be generally suitable for all use. The greatest coefficients of variation are associated with sulphate and with nitrate. The latter observation suggests that caution should be exercised when considering this water for human consumption. The SAR and EC statistics indicate that these parameters are of similar significance in classifying this water as generally suitable for irrigation use.

Table 17. Chemistry of groundwater from the Magaliesberg Formation

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 13 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	5.6	6.9	8.5	2.1	30 %
Electrical Conductivity (mS/m)	1.6	48.0	120.0	38.0	79 %
Total Dissolved Salts (mg/*l*)	13.0	381.0	1107.0	318.0	83 %
Calcium (mg/*l* Ca)	1.0	56.0	252.0	66.0	118 %
Magnesium (mg/*l* Mg)	1.0	22.0	51.0	16.9	77 %
Sodium (mg/*l* Na)	1.0	18.9	97.0	24.0	127 %
Potassium (mg/*l* K)	0.1	2.7	10.2	2.6	96 %
Chloride (mg/*l* Cl)	1.0	17.0	90.0	26.0	153 %
Sulphate (mg/*l* SO_4)	1.0	54.0	536.0	140.0	259 %
Total Alkalinity (mg/*l* $CaCO_3$)	3.0	165.0	319.0	111.0	67 %
Nitrate (mg/*l* N)	0.1	11.3	83.4	23.0	204 %
Fluoride (mg/*l* F)	0.1	0.2	0.3	0.1	50 %
Langelier Saturation Index (LSI)	-9.4	-1.5	1.0	2.9	
Sodium Adsorption Ratio (SAR)	0.1	0.5	2.3	0.6	120 %

5.3.8 Rayton Formation (Transvaal Supergroup)

This unit comprises of four quartzite horizons alternating with four thin beds of shale and intruded by diabase sheets. Its distribution is shown in Figure 8a together with the positions of groundwater sample sources. A borehole survey undertaken by Nealer (1982) at Rayton found that borehole yields range between 0.1 and 2.5 *l*/s with only a few yields in excess of 5 *l*/s being recorded. This survey also established that the depth to groundwater level occurs between surface and 20 m depth.

The groundwater quality data (Table 18 and Figure 8c) indicate that particularly EC, chloride, sulphate, nitrate, fluoride and SAR are associated with substantial coefficients of variation. The presence of nitrate and fluoride in this list suggests that caution should be exercised when considering this water for human consumption. The SAR and EC statistics indicate that caution might also need to be exercised when considering this water for irrigation purposes.

Table 18. Chemistry of groundwater from the Rayton Formation

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 45 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	6.5	7.4	8.4	0.4	5 %
Electrical Conductivity (mS/m)	5.1	60.0	889.0	128.0	21 3%
Total Dissolved Salts (mg/*l*)	33.0	300.0	854.0	193.0	64 %
Calcium (mg/*l* Ca)	4.0	36.0	109.0	26.0	72 %
Magnesium (mg/*l* Mg)	1.0	22.0	76.0	19.0	86 %
Sodium (mg/*l* Na)	2.0	19.7	149.0	23.5	119 %
Potassium (mg/*l* K)	0.2	1.7	6.3	1.5	88 %
Chloride (mg/*l* Cl)	1.0	20.5	175.0	38.0	185 %
Sulphate (mg/*l* SO_4)	1.0	11.7	119.0	23.0	197 %
Total Alkalinity (mg/*l* $CaCO_3$)	13.0	150.0	310.0	78.0	52 %
Nitrate (mg/*l* N)	0.1	5.7	54.0	9.8	172 %
Fluoride (mg/*l* F)	0.1	0.6	3.7	0.9	150 %
Langelier Saturation Index (LSI)	-3.4	-0.8	0.9	0.9	
Sodium Adsorption Ratio (SAR)	0.1	0.7	8.3	1.2	171 %

5.3.9 Wilge River Formation (Waterberg Group)

The distribution of this Formation is shown in Figure 9a together with the positions of groundwater sample sources. It is composed mainly of reddish-brown to purple sandstone, grit and quartzitic sandstone with intercalations of conglomerate and shale. These rock types are to a large extent intruded by diabase sills and dykes that play a major role in the occurrence of groundwater. Groundwater occurrence is also commonly associated with fault and fracture zones and with bedding planes. The groundwater potential generally is classed as low to moderate on the basis that 80 % of the boreholes consulted yield less than 2 *l*/s (Figure 9b). The depth to groundwater level commonly occurs between 10 and 40 m below surface.

The chemical data (Table 19 and Figure 9c) indicate that the quality of the groundwater in terms of salinity is generally excellent and suitable for all use (average EC value of 26 mS/m). A number of elements/parameters, particularly chloride, sulphate, nitrate and fluoride, indicate substantial coefficients of variation. The presence of nitrate and fluoride in this list suggests that caution should be exercised when considering this water for human consumption. The SAR and EC statistics indicate that these parameters are of similar significance in classifying this water as generally suitable for irrigation use.

Table 19. Chemistry of groundwater from the Wilge River Formation

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 18 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	6.8	7.4	8.0	0.3	4 %
Electrical Conductivity (mS/m)	7.8	25.5	90.8	21.0	82 %
Total Dissolved Salts (mg/*l*)	57.8	180.0	512.0	132.0	73 %
Calcium (mg/*l* Ca)	4.0	20.0	70.0	19.5	98 %
Magnesium (mg/*l* Mg)	2.0	12.0	67.0	15.7	131 %
Sodium (mg/*l* Na)	3.0	13.0	42.0	9.8	75 %
Potassium (mg/*l* K)	0.9	2.5	5.2	1.0	40 %
Chloride (mg/*l* Cl)	1.0	10.4	115.0	25.5	245 %
Sulphate (mg/*l* SO_4)	1.0	6.2	44.0	10.1	163 %
Total Alkalinity (mg/*l* $CaCO_3$)	31.0	93.0	270.0	63.0	68 %
Nitrate (mg/*l* N)	0.1	3.1	30.8	6.9	223 %
Fluoride (mg/*l* F)	0.1	0.8	4.1	1.3	163 %
Langelier Saturation Index (LSI)	-2.7	-1.3	0.2	0.9	
Sodium Adsorption Ratio (SAR)	0.2	0.6	1.5	0.4	67 %

Plate 3. Landscape west of Pretoria. View looking northwest showing northerly dipping dolomite (Eccles Formation) in the foreground and quartzite (Magaliesberg Formation) on the horizon. (Photo: S Laubscher)

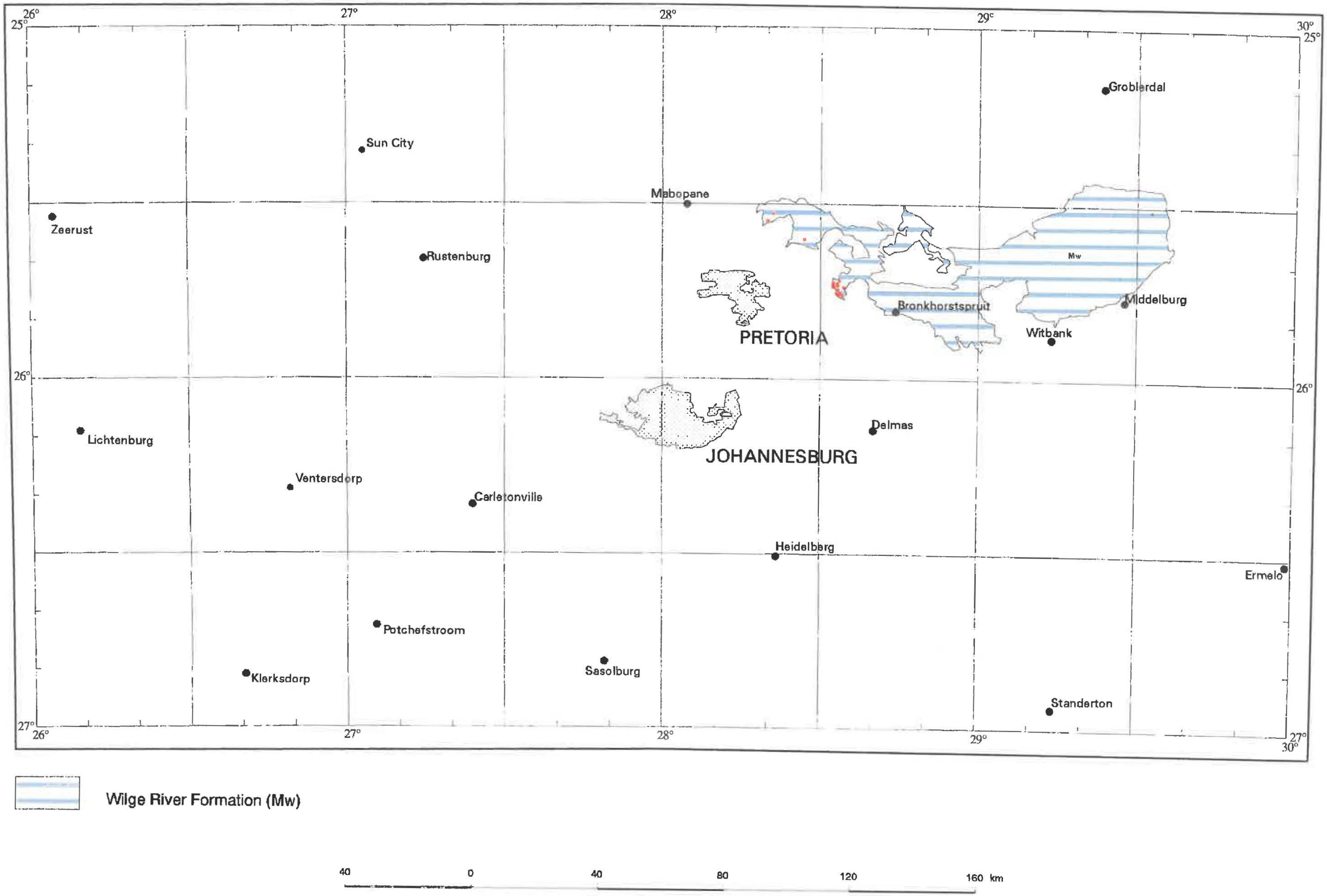


Figure 9a. Geographical distribution of the Wilge River Formation and associated groundwater sampling points

Figure 9b. Borehole yield distribution for the Wilge River Formation

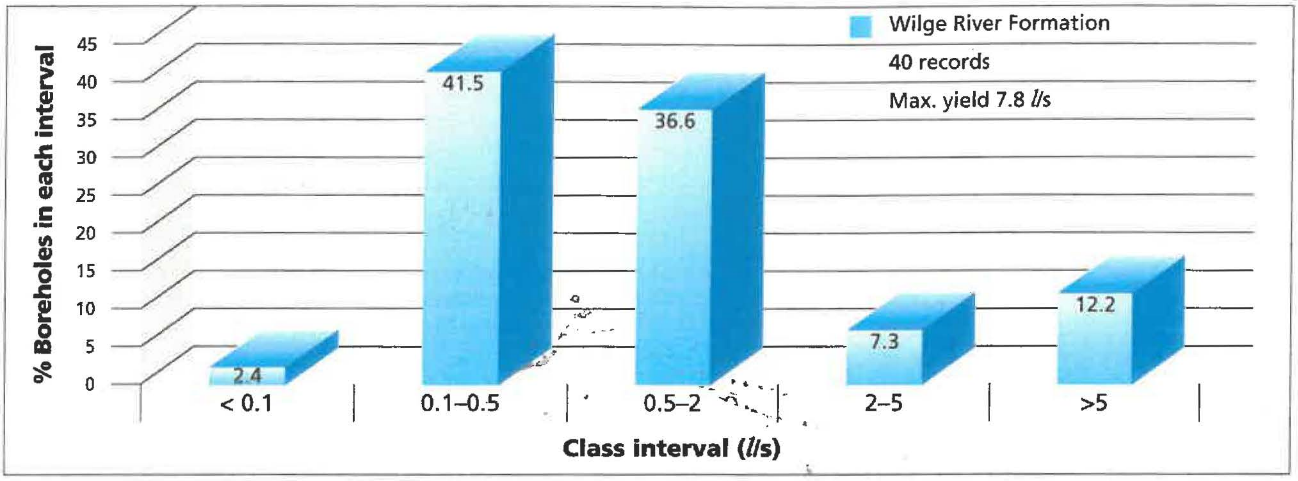
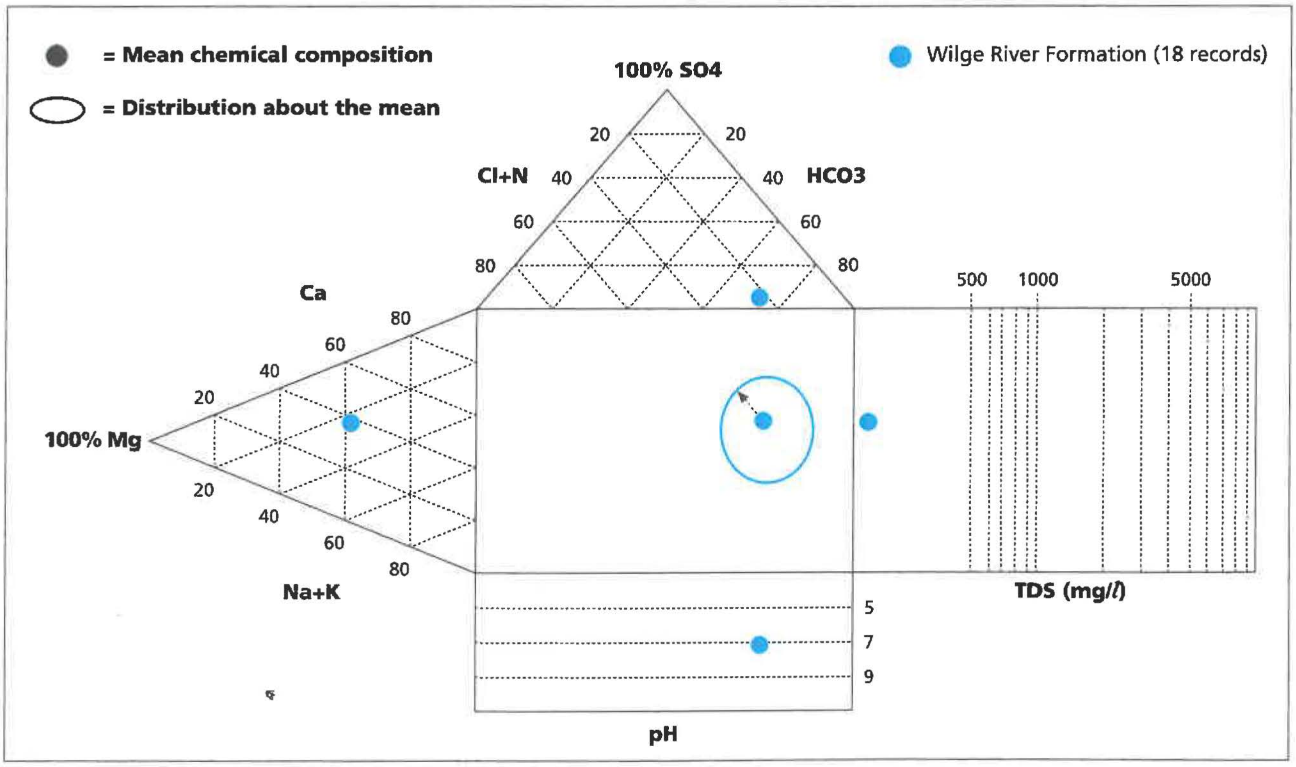


Figure 9c. Chemistry of groundwater from the Wilge River Formation



5.4 Karst aquifers

These are represented in the study area by the Chuniespoort Group, which is composed mainly of chemically derived sediments such as carbonate. These sediments alternate between chert-rich (chert-bearing) and chert-poor dolomite the distributions of which, as far as these distinctions have been mapped, are indicated in Figure 10a. The geographical distribution of the Chuniespoort Group is shown in Figure 10b together with the positions of groundwater sample sources. The "outliers" of dolomite located northeast of Sun City in the so-called Crocodile River fragment and south of Groblersdal in the Marble Hall-Moos River fragment represent remnants of the Transvaal Supergroup enclosed by the younger Bushveld Complex.

The dolomites of the Chuniespoort Group represent the most important aquifer in South Africa. This is due to the generally high to very high storage capacity (storativity) and often highly permeable characteristics of this rock type. It is therefore common cause that numerous large-scale and widespread groundwater investigations have been carried out on this groundwater system in the past. Reference in this regard the work by Barnard (1997), Bredenkamp *et al* (1986), Bredenkamp (1995), Enslin and Kriel (1967), Fleisher (1978a, 1978b, 1980, 1981), Hobbs (1988), Kafri *et al* (1985), Kok (1985), Kotze *et al* (1994), Kuhn (1986, 1989), Leskiewicz (1984a, 1984b, 1986, 1989) and Polivka (1987).

As infiltrating rainwater containing weak carbonic acid (H_2CO_3) percolates through dolomite along planes of weakness such as faults, fractures and joints associated with intense deformation, it dissolves the dolomite according to the following chemical reaction:

$3CaCO_3.2MgCO_3 + 5H_2CO_3 \rightarrow 3Ca(HCO_3)_2 + 2Mg(HCO_3)_2$
dolomite + carbonic acid → calcium-bicarbonate + magnesium-bicarbonate

The soluble bicarbonates produced by the dissolution process are transported away in solution, in extreme instances resulting in the development of open cavities and caves. Residual products such as silica, iron and manganese oxides and hydroxides (wad) are left behind as permeable deposits filling the cavities. The chemical weathering described by this process is referred to as karstification and is clearly demonstrated in the form of the Sterkfontein Caves near Krugersdorp. Perhaps the most significant result of karstification, however, is its association with the development of sinkholes. There is strong evidence that the weathering/leaching of dolomite and the resulting development of highly permeable zones of large storage capacity is controlled by lithostratigraphy. The aquifer therefore typically comprises an extensive cover of residual solution debris underlain by karstified dolomite forming a heterogeneous aquifer.

Sediments of the younger Karoo Supergroup commonly fill ancient sinkhole features in the dolomite. Although the karstified dolomite acts as the main aquifer, Bredenkamp *et al* (1986) report that fractures extending to considerable depths in non-karstified dolomite also often support high yields. Studies by Enslin and Kriel (1967) in the Carletonville area indicated that the storage capacity (storativity) of dolomite in this vicinity decreases with increasing depth below surface. A decline from an estimated 9.1 % at a depth of 61 m below surface to 1.3 % at a depth of 146 m is reported. According to Bredenkamp *et al* (1995), however, the storativity of dolomitic aquifers generally varies between 1 and 5 %.

The continuity of the dolomite aquifer is interrupted by geological structures in the form of vertical and sub-vertical

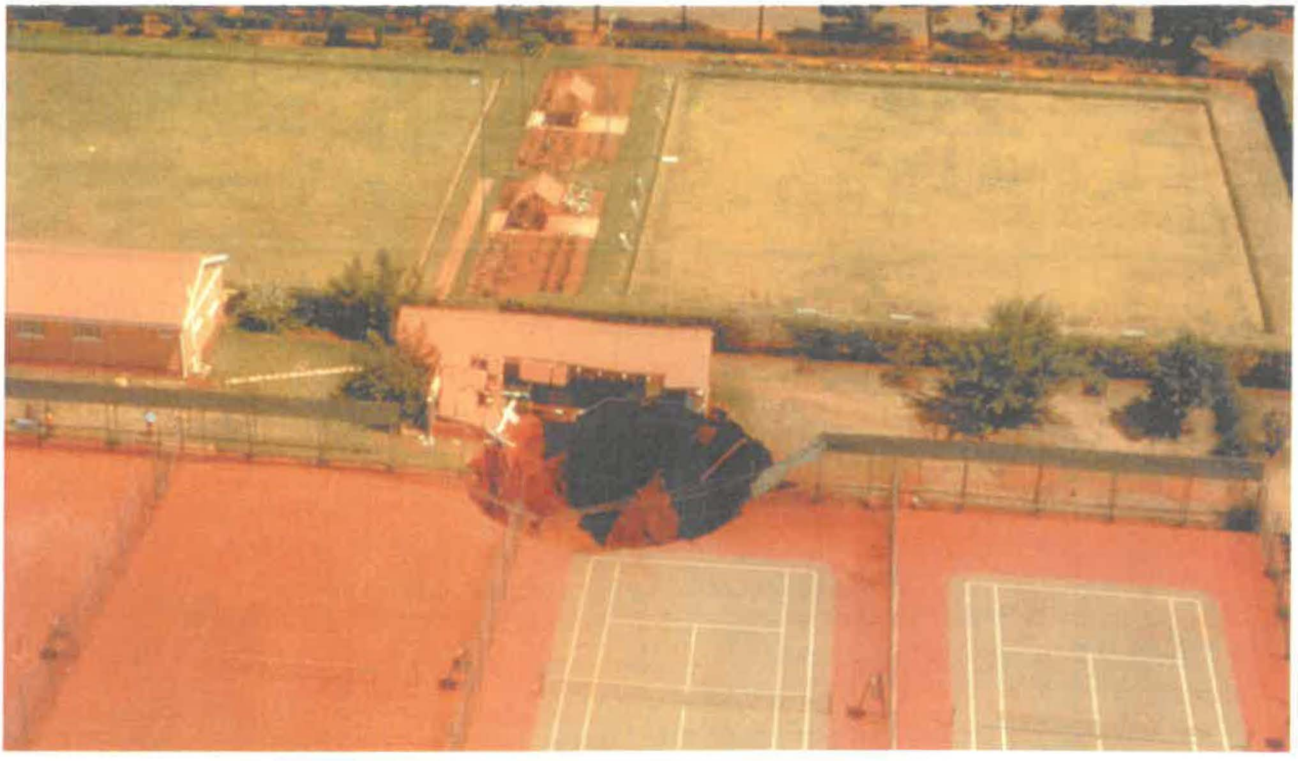


Plate 4 Catastrophic damage to surface structures caused by a sinkhole. (Photo: Council for Geoscience)

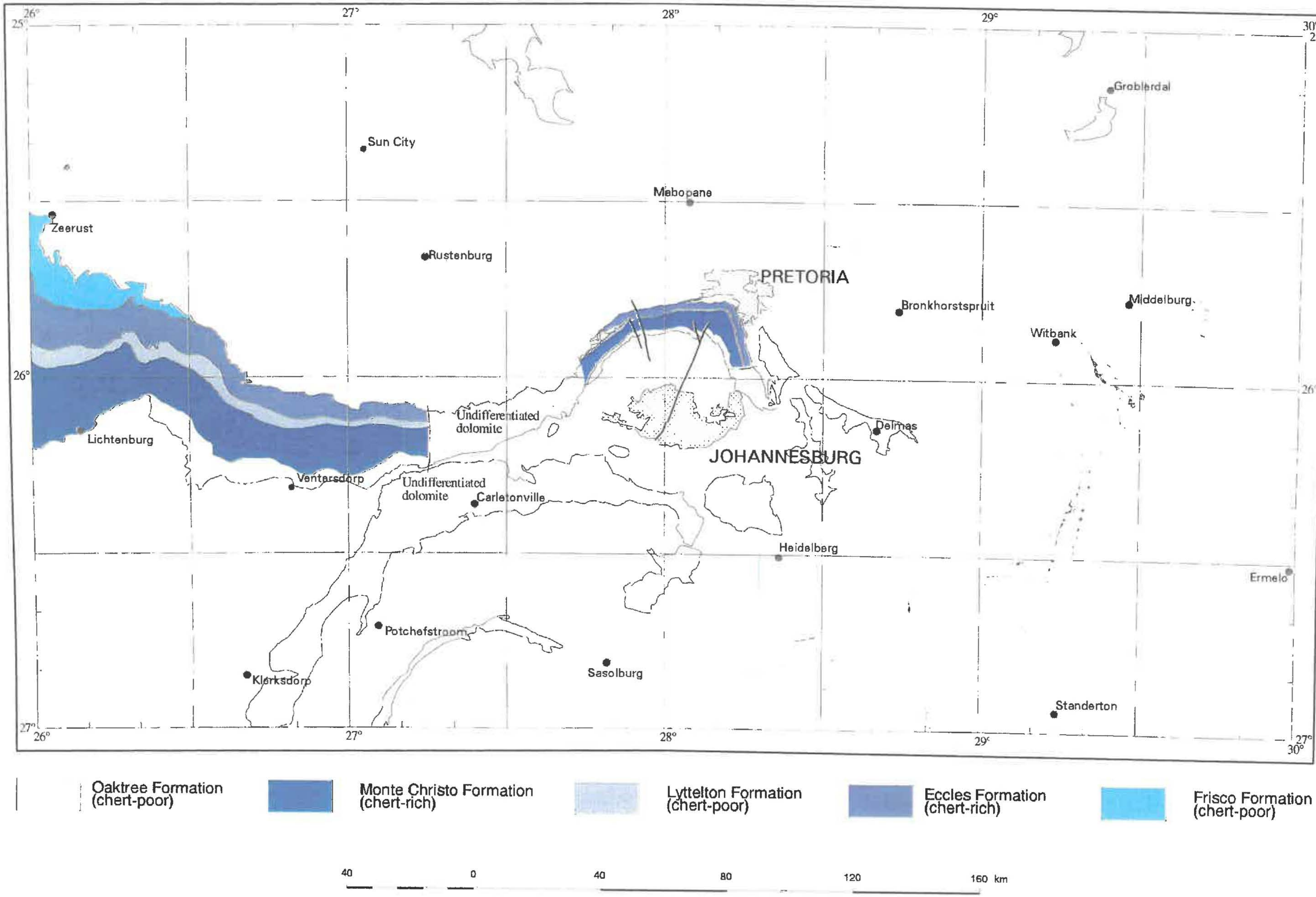


Figure 10a. Geographical distribution of the individual lithostratigraphic units of the Chuniespoort Group

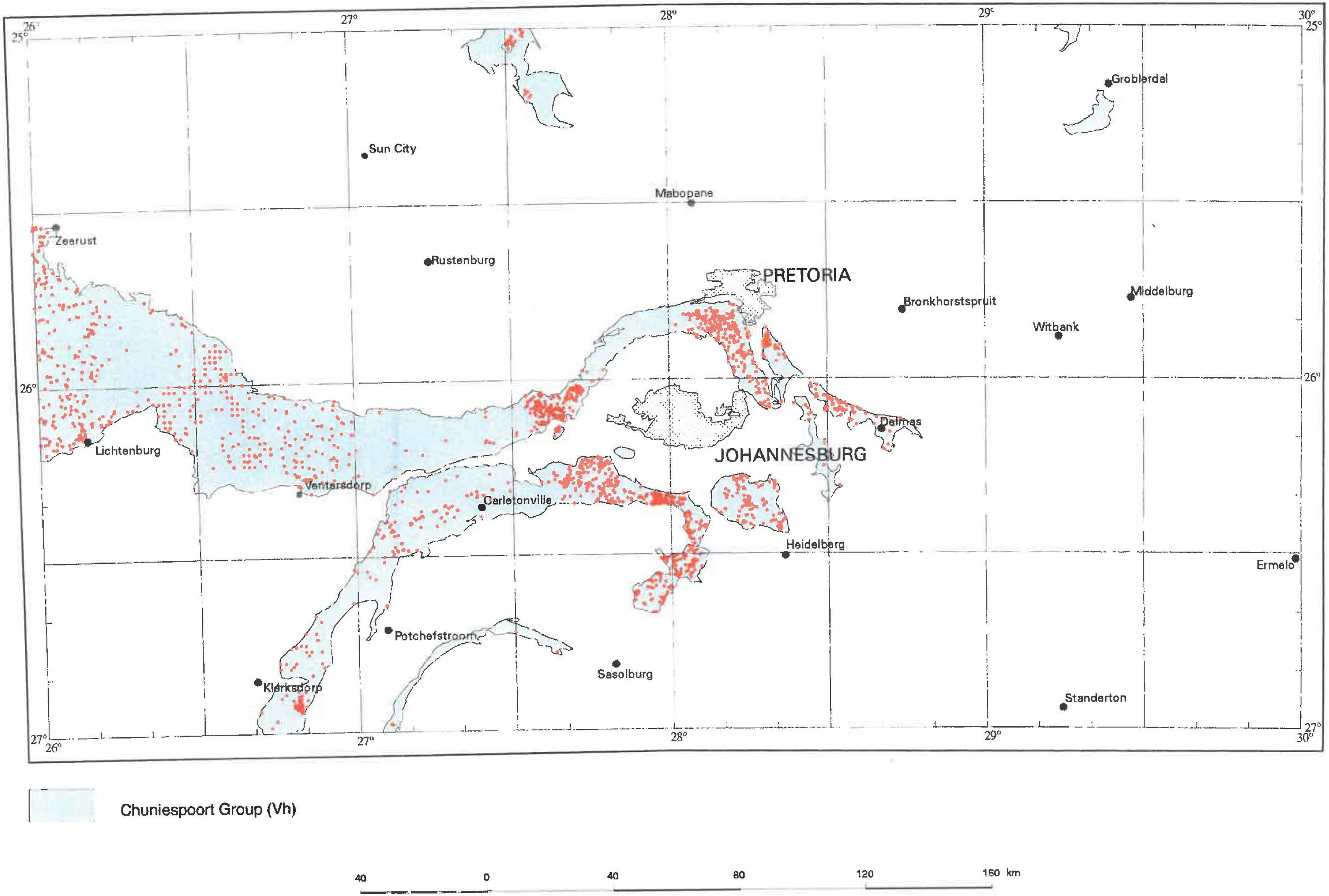


Figure 10b. Geographical distribution of the Chuniespoort Group and associated groundwater sampling points

intrusive dykes. These low permeability or impermeable rocks serve as barriers to the movement of groundwater through the dolomite, resulting in the formation of compartments. The distribution of these features is indicated in Figure 10c.

The low density of surface drainage networks in dolomitic areas suggests high recharge and significant underground flow. This flow often supports high-yielding springs located at the lowest surface elevation of a compartment in proximity to an impermeable boundary such as a dyke or lithological contact. Figure 10c presents a more detailed picture of compartmentalization in relation to associated dyke and spring features. Groundwater is often lost from one compartment to another via overflow or leakage through dyke features in low lying areas where these are weathered in the near-surface.

Ground stability is an important consideration in establishing large-scale water abstraction schemes in dolomite. The rate and extent of water level drawdown is one of the critical factors in the development of ground subsidence and sinkholes. The risk of development of these features is greatest in areas where the groundwater level occurs closer to surface (less than 30 m) and where it fluctuates more than 6 m in response to pumping.

An indication of the magnitude of groundwater abstraction from the dolomitic formations in the map area is provided in Table 20. The spring flow values listed in this table amount to a total of 120.5 million cubic metres. The total of the other listed abstractions amounts to 314.7 million cubic metres.

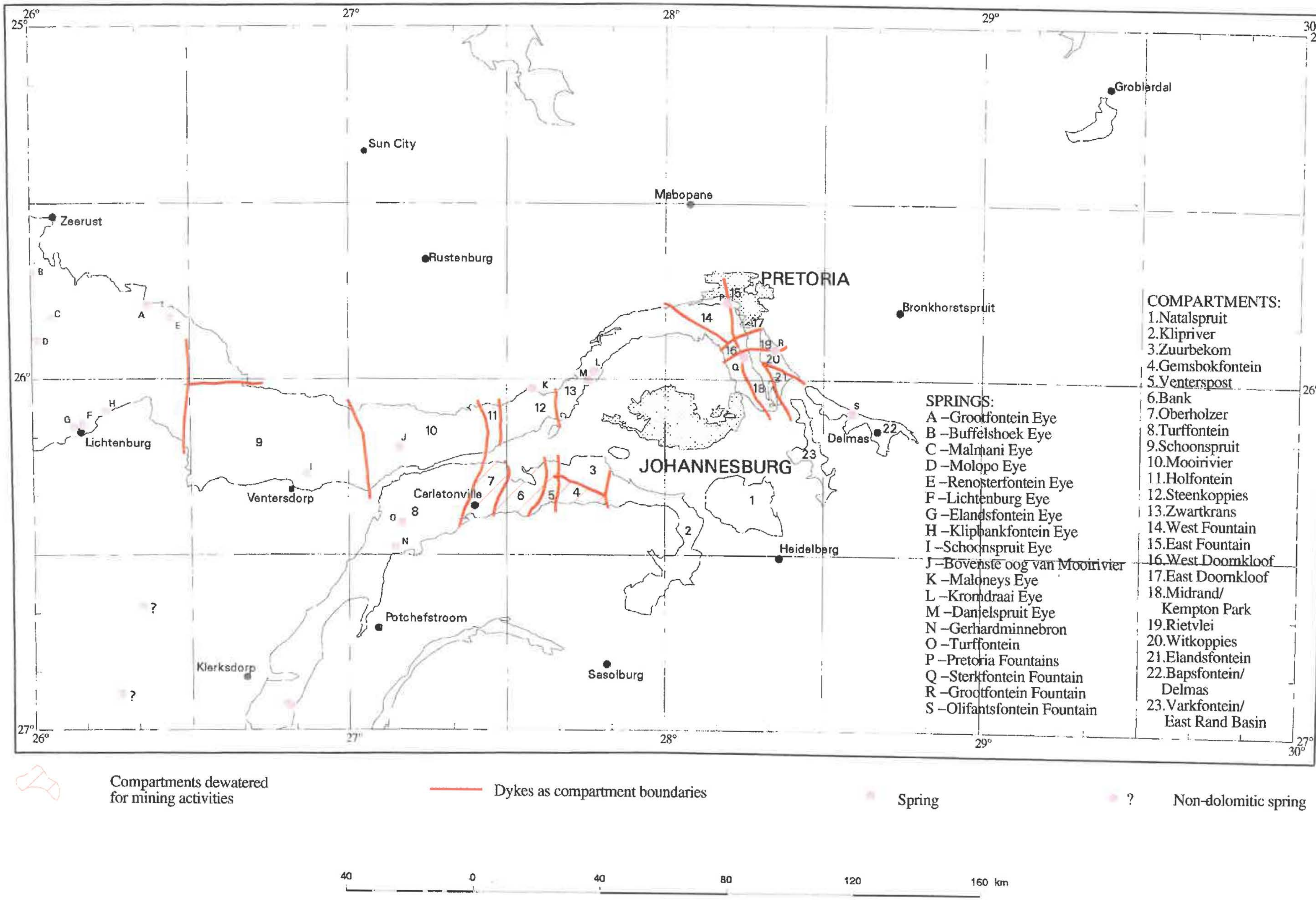
The groundwater yield potential is classed as excellent on the basis that 50 % of the boreholes on record produce more than 5 *l*/s (Figure 10d), with a maximum of 126 *l*/s. Unlike most other formations, the groundwater level in dolomitic aquifers does not necessarily follow the topography. More often than not, it occurs as a nearly horizontal surface indicative of a low hydraulic gradient and very permeable formation. This characteristic partly explains the occurrence of extremely deep groundwater rest levels in areas of raised topography. Depths exceeding 100 m below surface are not uncommon. The very deep water levels in the dolomite compartments east of Carletonville are, however, the result of dewatering (Figure 10c) by gold mines exploiting the reefs of the underlying Witwatersrand Supergroup.

An indication of the regional rainfall recharge characteristics of dolomitic aquifers as derived by Bredenkamp *et al* (1995) is shown in Figure 10f, which indicates a maximum

Table 20. Summary of average annual groundwater abstraction and spring flow from the various compartments of the Chuniespoort Group

COMPARTMENT	NO.	SPRING FLOW	IRRIGATION	DOMESTIC	MINING	MUNICIPAL/ INDUSTRIAL	SOURCE REFERENCE
Natalspruit	1		20.4				Kafri *et al* (1985)
Klipriver	2		23.0	1.3		1.0	Kafri *et al* (1985)
Zuurbekom	3				7.6	10.0	Fleisher (1981)
Gemsbokfontein	4		1.5		43.2		Leskiewicz (1984a)
Venterspost	5				27.0		Fleisher (1981)
Bank	6				36.0		Fleisher (1978b)
Oberholzer	7				19.0		Fleisher (1981)
Turffontein	8	40.8					Fleisher (1981)
Schoonspruit	9	24.0	27.4	2.5			Kotze *et al* (1994)
Mooirivier	10	16.0	3.0				Orpen (1977)
Holfontein	11		6.0				Bredenkamp *et al* (1986)
Steenkoppies	12	7.0	19.0	1.9			Barnard (1997)
Zwartkrans	13	9.1	18.0				Bredenkamp *et al* (1986)
West Fountain	14	5.6		0.5		3.6	Hobbs (1988b)
East Fountain	15	4.1					Hobbs (1988b)
West Doornkloof	16			0.1			Hobbs (1988b)
East Doornkloof	17			0.1			Hobbs (1988b)
Midrand/Kempton Park	18	2.4	1.6				Kuhn (1989)
Rietvlei	19	0.4					Kok (1985)
Witkoppies	20	2.8					Leskiewicz (1986)
Elandsfontein	21	1.3	4.0				Leskiewicz (1986)
Bapsfontein/Delmas	22	7.0	5.0	1.0		3.0	Leskiewicz (1984b)
Varkfontien/East Rand Basin	23		2.5	1.0	24.5		Leskiewicz (1984b)
		Spring flow and groundwater abstraction rates reported as million cubic metres per annum					

Figure 10c. Distribution of individual dolomite compartments and related major springs



recharge value of almost 9 % for a mean annual precipitation of nearly 800 mm. A higher recharge value of 13.9 % has, however, been calculated for the dolomite compartments west of Krugersdorp (Bredenkamp *et al*, 1986).

The large number (223) of chemical analyses consulted for assessment of dolomitic groundwater quality (Table 21 and Figure 10e) form part of a much larger population numbering 2 520. Although the average EC value of 63 mS/m and mean pH value of 7.6 indicate that the quality of the groundwater is generally acceptable for any use, a number of elements/ parameters, in particular chloride, sulphate and nitrate, show coefficients of variation greater than 200 %. These circumstances suggest the presence of contamination in some of the groundwaters, indicating that caution should be exercised when considering dolomitic groundwater for human consumption. This emphasizes concerns regarding the vulnerability of this important water resource to contamination and, therefore, its loss as a potential source of potable water.

Table 21. Chemistry of groundwater from the Chuniespoort Group

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 223 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	5.8	7.6	9.5	0.4	5 %
Electrical Conductivity (mS/m)	4.4	62.9	397.0	56.0	89 %
Total Dissolved Salts (mg/*l*)	43.1	443.6	3402.0	403.0	91 %
Calcium (mg/*l* Ca)	1.0	52.7	436.0	54.0	102 %
Magnesium (mg/*l* Mg)	1.0	35.4	223.0	31.0	88 %
Sodium (mg/*l* Na)	1.0	24.1	299.0	39.0	162 %
Potassium (mg/*l* K)	0.1	2.3	39.0	4.2	183 %
Chloride (mg/*l* Cl)	1.0	37.7	900.0	83.0	220 %
Sulphate (mg/*l* SO_4)	1.0	70.5	2172.0	233.0	330 %
Total Alkalinity (mg/*l* $CaCO_3$)	8.0	177.3	664.0	94.0	53 %
Nitrate (mg/*l* N)	0.1	5.6	122.0	12.1	216 %
Fluoride (mg/*l* F)	0.1	0.3	2.8	0.4	133 %
Langelier Saturation Index (LSI)	-4.7	-0.4	3.0	1.0	
Sodium Adsorption Ratio (SAR)	0.03	0.5	2.9	0.5	100 %

Plate 5. Dolomite landscape south of Pretoria. Preferential weathering of the dolomite along joint and fault zones gives rise to the rough terrain. The thinner, more prominent, layers visible in the rock outcrop represent chert horizons within the dolomite. (Photo: M van der Neut)

Plate 6. Stream draining the Malmani Eye near Ottoshoop in the western part of the map area. (Photo: L Botha)

Figure 10d. Borehole yield distribution for the Chuniespoort Group

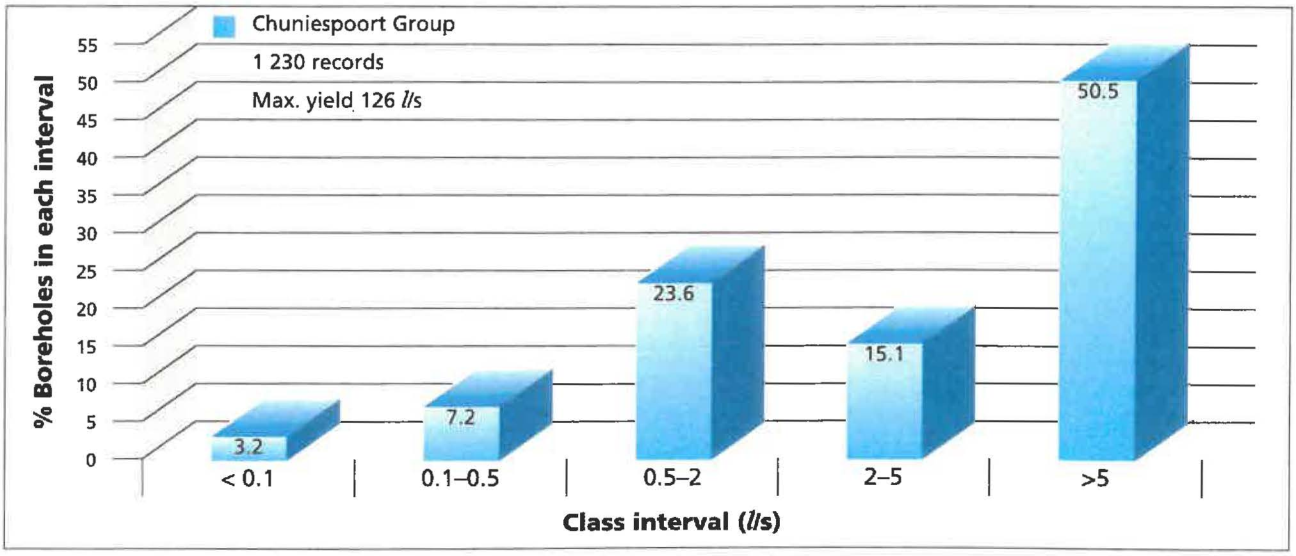


Figure 10e. Chemistry of groundwater from the Chuniespoort Group

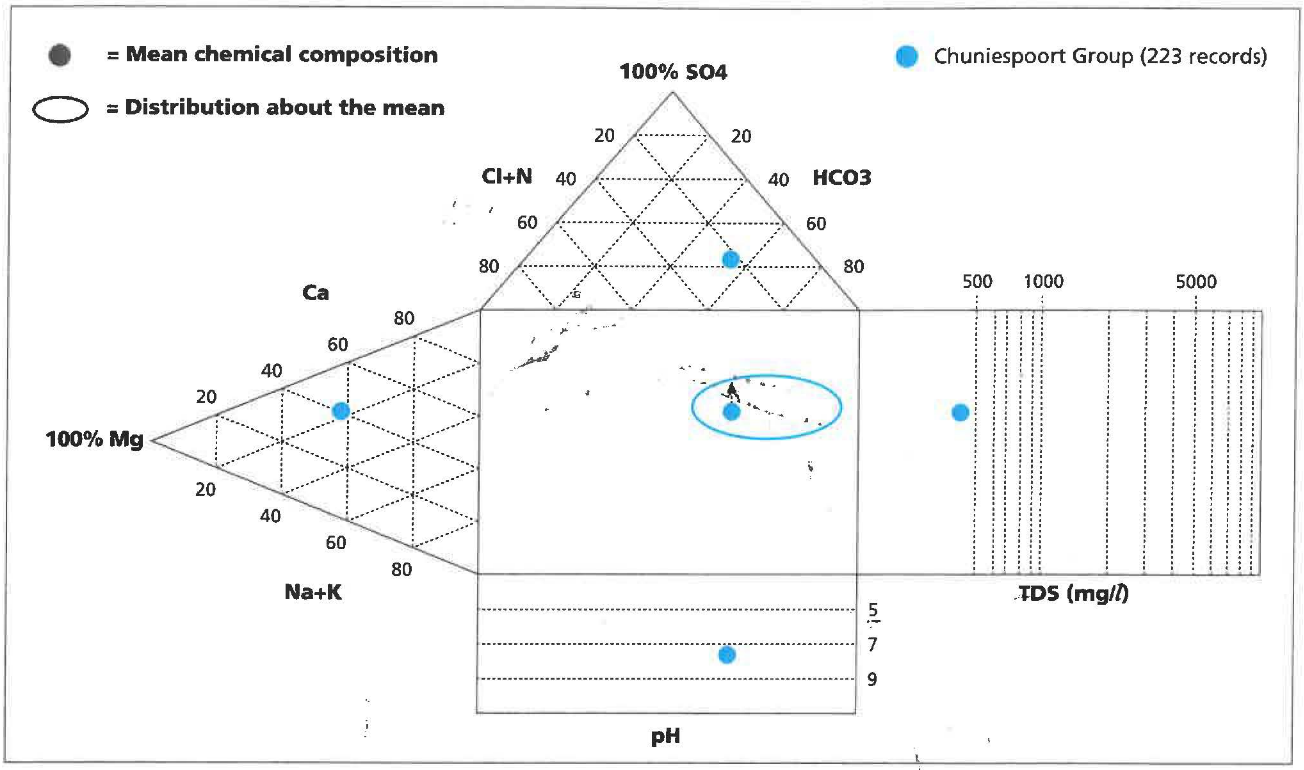
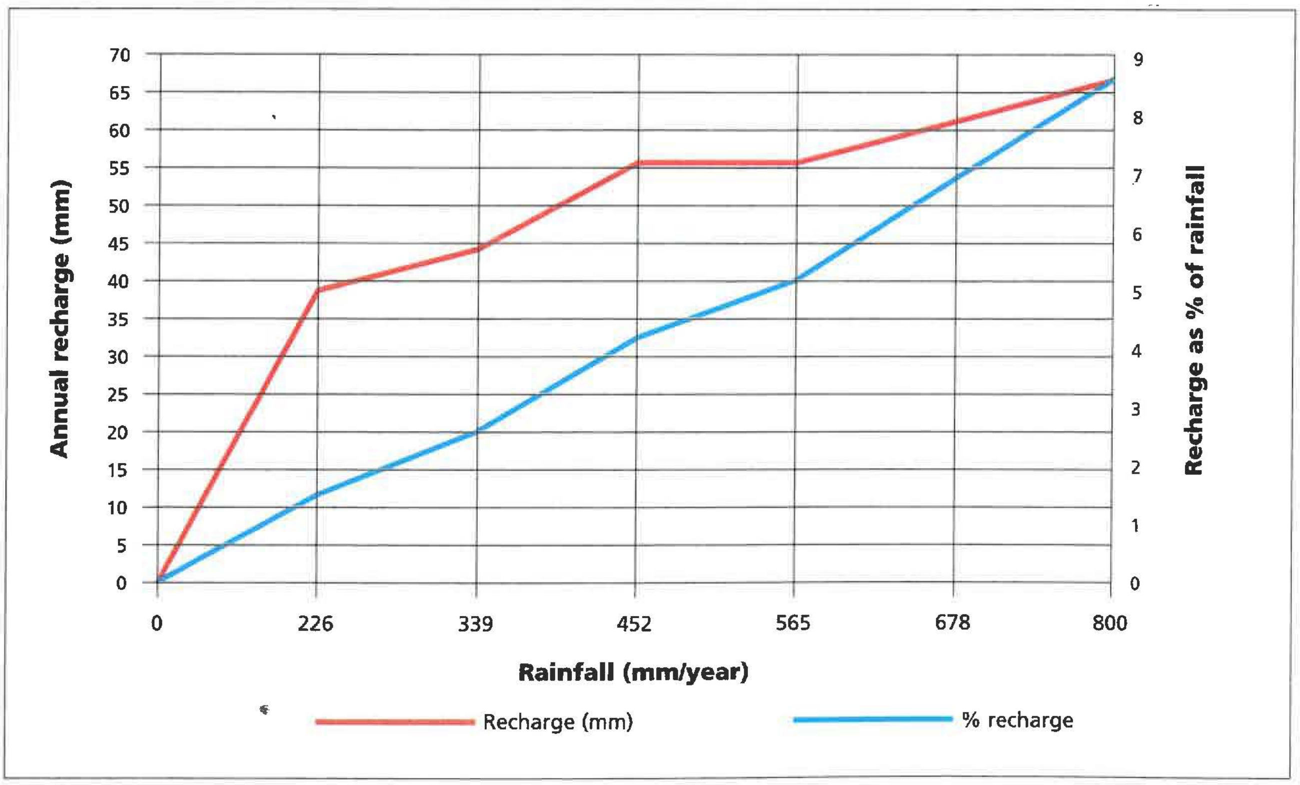


Figure 10f. Regional rainfall recharge for dolomite (after Bredenkamp *et al*, 1995)



5.5 Intergranular and fractured aquifers

5.5.1 Basement Complex

The distribution of this Complex is shown in Figure 11a together with the positions of groundwater sample sources. Groundwater occurrence in these mainly granitic rocks is generally associated with zones of weathering, brecciation and jointing. De Villiers (1961) reports basins of weathering of up to 60 m deep in the vicinity of Klerksdorp. Groundwater is often encountered in both the saturated weathered material below the regional groundwater rest level and in the transition zone between weathered and fresh granite. The basins of weathering normally coincide with the drainage pattern. The majority of fault and joint zones are steeply dipping structures that tend to narrow and even pinch out at depth with a corresponding decrease in permeability. The porosity is usually less than 1 %, while fresh rock may be regarded as impermeable.

The groundwater yield potential of the Basement Complex igneous rocks is classed as good on the basis that 62 % of the boreholes on record produce more than 2 *l*/s (Figure 11b). High yielding boreholes located to the north of Ottosdal, in the vicinities of Hartbeesfontein and Coligny and in the area between Klerksdorp and Ventersdorp appear to be associated with deep weathering of the granites. The granitic rocks in the vicinity of Klerksdorp and Ventersdorp are much more weathered than the similar formations of the Vredefort and Johannesburg domes. This feature might lend support to general geological speculation that the domes were formed by upward forces in the earth's crust where the rate of upward movement exceeded that of the combined processes of weathering and erosion. Of greater significance to groundwater resources is the observation that the more weathered granites generally support a larger number of higher-yielding boreholes.

The depth to groundwater rest level is generally between 5 and 30 m below surface. The deeper groundwater rest levels could be ascribed to well distributed fracturing and associated permeability occurring in the fresher bedrock below the weathered material. The low surface relief and the "spongy" nature of the weathered granite gives rise to groundwater seeps or seepages rather than to well-defined springs. Barrier springs occur where impermeable diabase dykes transect the groundwater flow path. One instance is known of an artesian borehole located in this granite. It occurs in the vicinity of Heidelberg (refer Main Map), and is used for domestic water supply. It is considered that recharge of the granitic aquifers from rainfall might be higher than the 1 to 2 % of mean annual precipitation reported by Bredenkamp *et al* (1995) for other granitic terrains. This consideration is based partly on the sandy nature of the soil cover. Unfortunately, no studies in this regard are known.

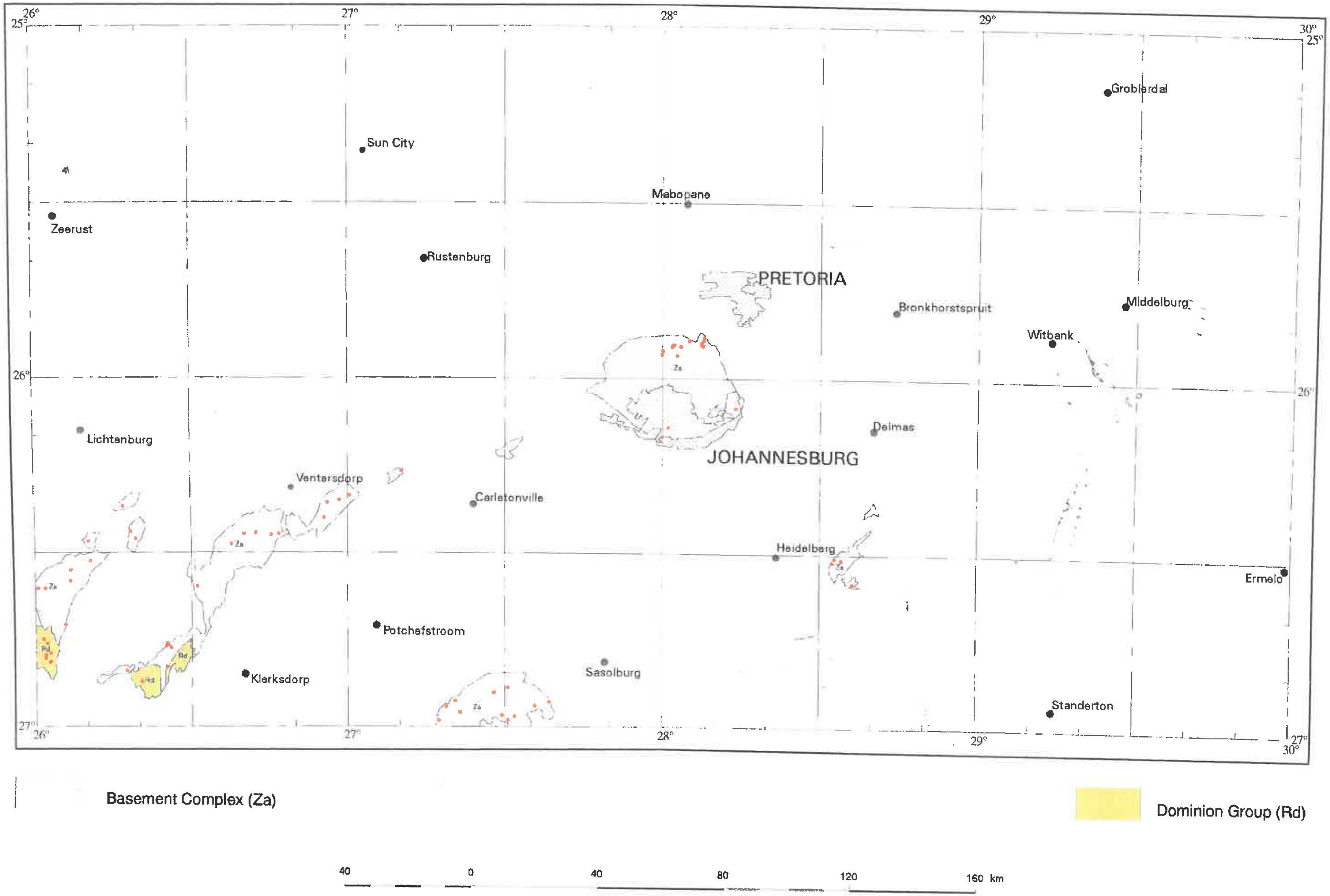
The data presented in Table 22 and Figure 11c indicate that the quality of the groundwater might be regarded as very good with an average EC value of 38 mS/m and a mean pH value of 7.5. Only the elements chloride and sulphate indicate substantial coefficients of variation. Although this is mitigated by the relatively low maximum concentrations recorded for these two elements, potential contamination of this resource remains a threat. Both the sandy nature of the soil cover (which promotes recharge) and the depth of weathering (that promotes groundwater storage) increases the risk of contamination of these groundwater resources.

The SAR and EC statistics indicate that salinity should enjoy greater significance than the SAR value in classifying this water as generally suitable for irrigation use.

Table 22. Chemistry of groundwater from the Basement Complex

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 62 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	6.7	7.5	8.4	0.4	5 %
Electrical Conductivity (mS/m)	8.6	38.0	180.0	27.0	71 %
Total Dissolved Salts (mg/*l*)	67.0	263.0	1170.0	188.0	71 %
Calcium (mg/*l* Ca)	5.0	29.0	155.0	26.0	90 %
Magnesium (mg/*l* Mg)	2.0	16.0	48.0	12.0	75 %
Sodium (mg/*l* Na)	2.0	23.0	172.0	23.3	101 %
Potassium (mg/*l* K)	0.4	2.4	18.1	2.5	104 %
Chloride (mg/*l* Cl)	1.0	18.5	274.0	38.0	205 %
Sulphate (mg/*l* SO_4)	1.0	18.4	202.0	34.0	185 %
Total Alkalinity (mg/*l* $CaCO_3$)	24.0	122.0	284.0	74.0	61 %
Nitrate (mg/*l* N)	0.1	6.5	47.0	7.9	122 %
Fluoride (mg/*l* F)	0.1	0.3	1.7	0.24	80 %
Langelier Saturation Index (LSI)	-2.7	-1.0	0.5	0.9	
Sodium Adsorption Ratio (SAR)	0.1	0.9	3.2	0.5	56 %

Figure 11a. Geographical distribution of the Basement Complex and Dominion Group and associated groundwater sampling points



5.5.3 Klipriviersberg Group (Ventersdorp Supergroup)

The Klipriviersberg Group comprises mainly of andesitic lava and tuff. Its distribution is shown in Figure 12a together with the positions of groundwater sample sources. Groundwater occurs in association with basins of weathering as well as in the transitional zone between weathered and fresh lava. De Villiers (1961) reports that the lava in the vicinity of Klerksdorp decomposes to clay with a low permeability. A highly permeable transition zone of fractured and jointed lava sandwiched between the clay horizon and underlying fresh lava produces significant quantities of groundwater. De Villiers (1961) also reports a correlation between higher yielding boreholes and the steeper marginal zones of weathering basins.

In exceptional instances, groundwater is also encountered between different lava flows located at depth in otherwise fresh and solid rock. In areas where the fresh lava is shallow or is exposed on surface and forms broad rounded hills (eg. north of Parys, south of Johannesburg and northwest of Heidelberg), groundwater occurs in association with the weathered bottoms of broad valleys. South of Heidelberg, groundwater in the lava is contained in fractures and fault planes associated with the Sugar Bush Fault. High yielding boreholes are also correlated with the contact zone between diabase dykes and the lava.

The groundwater yield potential is classed as low on the basis that 81 % of the available borehole yield data support values of less than 2 *l*/s (Figure 12b). The groundwater level generally occurs between 10 and 25 m below surface. No information regarding recharge estimates for this formation could be sourced.

The data presented in Table 24 and Figure 12c indicate that the quality of the groundwater, with mean EC and pH values of 60 mS/m and 7.6 respectively, is generally acceptable for any use. The only element that shows a significant coefficient of variation is sulphate. The SAR and EC statistics indicate that these parameters are of similar significance in classifying this water as generally suitable for irrigation use.

Table 24. Chemistry of groundwater from the Klipriviersberg Group

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 66 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	6.9	7.6	9.7	0.5	7 %
Electrical Conductivity (mS/m)	13.2	60.0	264.0	48.0	80 %
Total Dissolved Salts (mg/*l*)	108.0	405.0	1860.0	320.0	79 %
Calcium (mg/*l* Ca)	4.0	49.0	246.0	43.0	88 %
Magnesium (mg/*l* Mg)	3.0	30.0	162.0	26.0	87 %
Sodium (mg/*l* Na)	4.0	27.0	104.0	22.0	81 %
Potassium (mg/*l* K)	0.1	1.8	11.7	2.3	128 %
Chloride (mg/*l* Cl)	2.0	36.0	316.0	64.0	178 %
Sulphate (mg/*l* SO_4)	1.0	70.0	1038.0	164.0	234 %
Total Alkalinity (mg/*l* $CaCO_3$)	7.0	151.0	574.0	89.0	59 %
Nitrate (mg/*l* N)	0.1	6.3	31.0	6.4	102 %
Fluoride (mg/*l* F)	0.1	0.2	1.1	0.2	100 %
Langelier Saturation Index (LSI)	-4.3	-0.5	1.17	0.8	
Sodium Adsorption Ratio (SAR)	0.1	0.8	6.9	0.8	100 %

5.5.4 Makwassie Formation (Ventersdorp Supergroup)

The Makwassie Formation is composed predominantly of quartz and feldspar porphyries. As shown in Figure 4, this Formation covers only a very small portion of the map area. The quartz porphyry has similar hydrogeological characteristics to that of the Basement Complex granites (Section 5.5.1) with groundwater occurrence being associated with the transitional contact zone between weathered and fresh rock.

Insufficient data are available to assess borehole yields. The few groundwater rest level measurements that are available suggest a depth of between 5 and 15 m below surface. Hydrochemical information is represented by three EC measurements made during a borehole survey undertaken in the outcrop area of the Makwassie Formation. These measurements indicate salinity values of 40 to 60 mS/m.

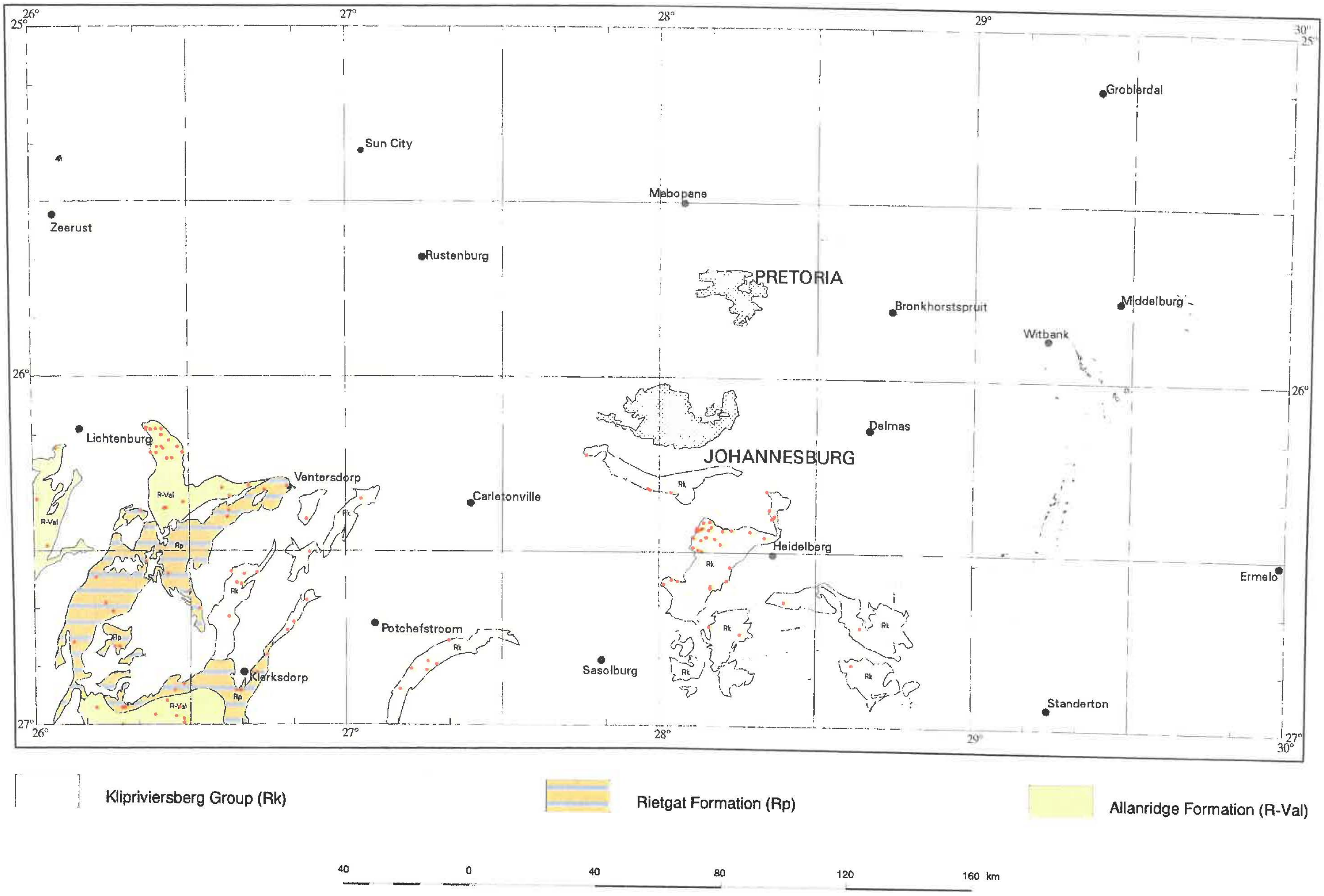


Figure 12a. Geographical distribution of the Klipriviersberg Group and the Rietgat and Allanridge Formations and associated groundwater sampling points

Figure 12b. Borehole yield distribution for the Klipriviersberg Group and the Rietgat and Allanridge Formations

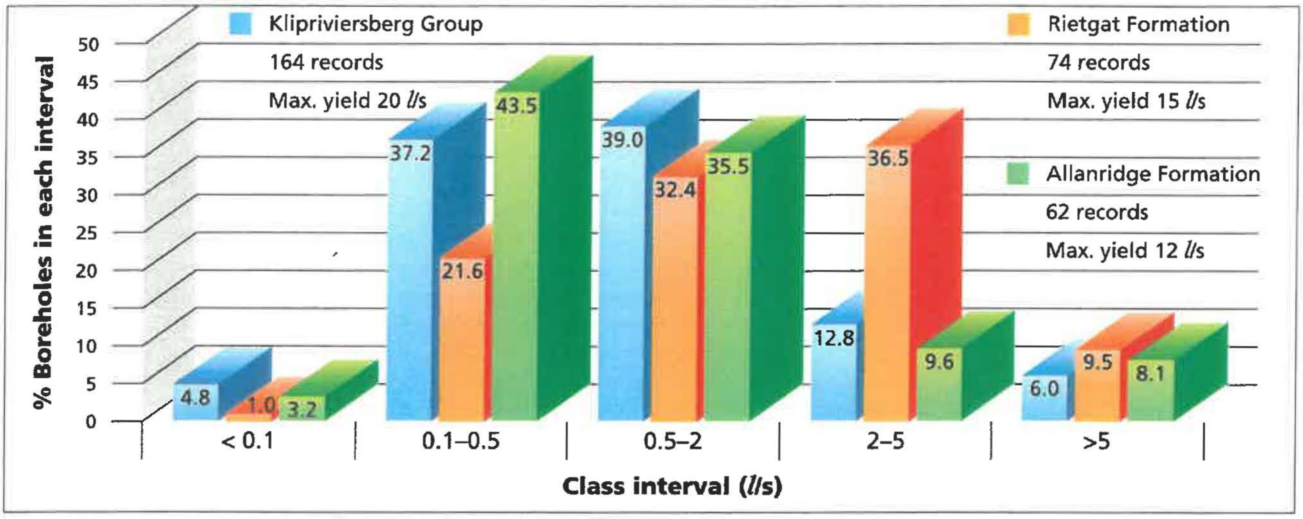
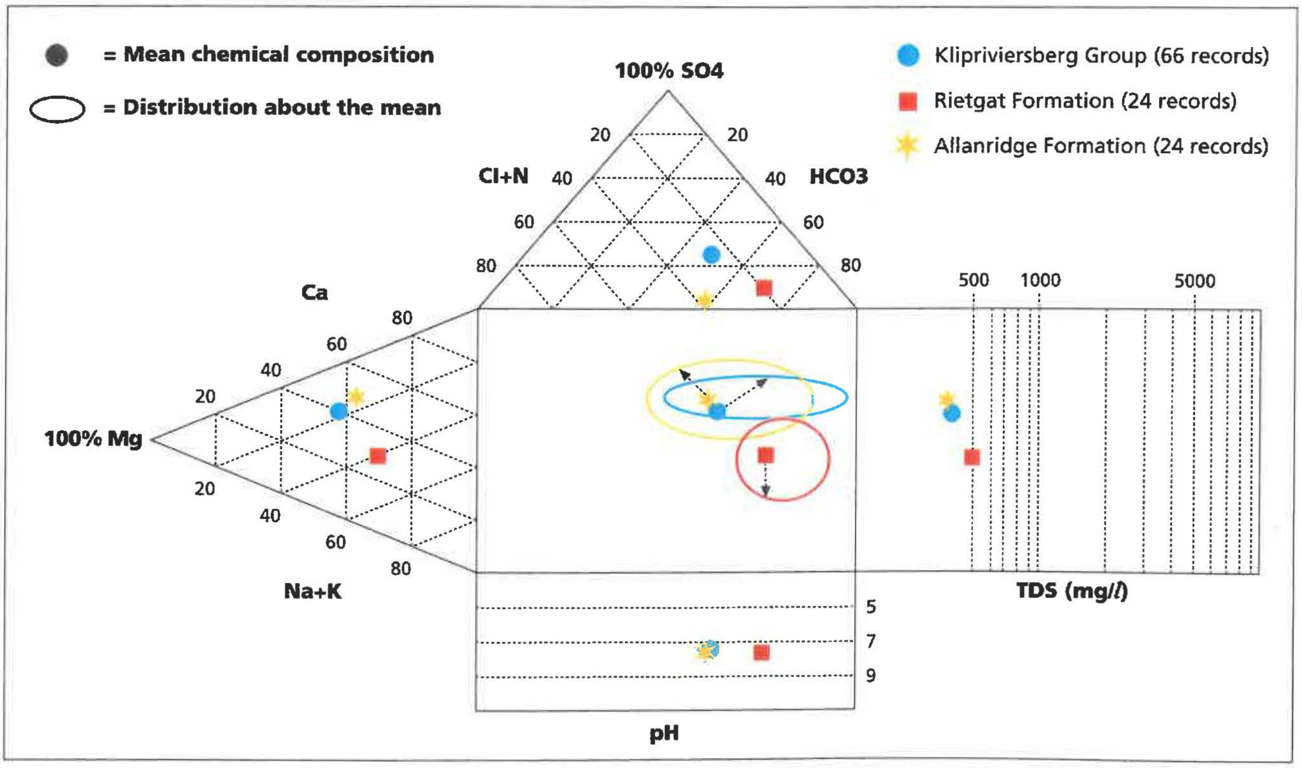


Figure 12c. Chemistry of groundwater from the Klipriviersberg Group and the Rietgat and Allanridge Formations



5.5.5 Rietgat Formation (Ventersdorp Supergroup)

The Rietgat Formation is composed mainly of andesitic lava with interbedded shale, conglomerate and impure limestone. Its distribution is shown in Figure 12a together with the positions of groundwater sample sources. Groundwater occurrence is more frequently associated with zones of weathering, brecciation and jointing as well as lithological and dyke contact zones. The hydrogeological characteristics are similar to those of the Klipriviersberg Group (Section 5.5.3).

Nel *et al* (1939) considered the water-bearing properties of the lava to be controlled largely by their mode of extrusion, hypothesizing that the intermittent outpouring of lava resulted in the superimposition of several sheet flows, each sheet being compact in its centre and amygdaloidal toward its upper and lower margins. These differences resulted in variations in the degree, mode and depth of weathering. Water circulating along unconformable surfaces or joints caused contiguous rocks to decompose, the amygdaloidal phases being affected most in giving rise to spongy material with a high storage capacity.

The classification of the groundwater yield potential as moderate is based on the observation that 45 % of the boreholes on record produce more than 2 *l*/s (Figure 12b). The groundwater rest level occurs between 10 and 30 m below surface.

The data presented in Table 25 and Figure 12c indicate that the quality of the groundwater is generally acceptable with an average EC value of 66 mS/m and a slightly alkaline mean pH value of 7.8. Elements that show a significant coefficient of variation are sodium, chloride and sulphate. The substantial coefficient of variation associated with sodium is also reflected in the SAR statistics, indicating that the sodium hazard must receive greater attention than that of salinity in classifying this water for irrigation use.

Table 25. Chemistry of groundwater from the Rietgat Formation

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 24 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	7.0	7.8	9.2	0.5	6 %
Electrical Conductivity (mS/m)	12.0	66.0	490.0	90.0	136 %
Total Dissolved Salts (mg/*l*)	48.0	502.0	4034.0	750.0	149 %
Calcium (mg/*l* Ca)	2.0	41.0	82.0	20.0	49 %
Magnesium (mg/*l* Mg)	2.0	25.0	64.0	15.0	60 %
Sodium (mg/*l* Na)	4.0	70.0	1280.0	252.0	360 %
Potassium (mg/*l* K)	0.3	2.3	10.3	2.2	96 %
Chloride (mg/*l* Cl)	3.0	30.5	374.0	73.0	239 %
Sulphate (mg/*l* SO_4)	2.0	29.0	305.0	63.0	217 %
Total Alkalinity (mg/*l* $CaCO_3$)	22.0	255.0	1910.0	351.0	138 %
Nitrate (mg/*l* N)	0.3	6.8	20.7	5.7	84 %
Fluoride (mg/*l* F)	0.1	0.3	1.3	0.3	100 %
Langelier Saturation Index (LSI)	-2.5	-0.3	0.8	0.8	
Sodium Adsorption Ratio (SAR)	0.1	3.9	81.7	16.0	410 %

5.5.6 Allanridge Formation (Ventersdorp Supergroup)

The distribution of the Allanridge Formation, which is composed mainly of andesitic lava, is shown in Figure 12a together with the positions of groundwater sample sources. The hydrogeological characteristics are similar to those of both the Klipriviersberg Group (Section 5.5.3) and the Rietgat Formation (Section 5.5.5).

The groundwater yield potential is classed as low on the basis that 80 % of the borehole yield records have values of less than 2 *l*/s (Figure 12b). Groundwater occurrence is most often associated with basins of weathering, and groundwater rest levels typically occur at depths of 10 to 15 m below surface.

The chemical data (Table 26 and Figure 12c) show the general quality of the groundwater to be acceptable for any use. The average EC value of 57 mS/m and slightly alkaline mean pH value of 7.7 both support this observation, as does the notably uniform chemistry revealed by the coefficient of variation values. These values are smaller than 70 % in most cases, and exceed 100 % only for chloride and fluoride. The SAR and EC values indicate that the sodium and salinity hazards are of similar significance when this water is being considered for irrigation purposes.

Table 26. Chemistry of groundwater from the Allanridge Formation

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 30 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	6.2	7.7	8.4	0.4	5 %
Electrical Conductivity (mS/m)	7.4	57.0	115.5	24.0	42 %
Total Dissolved Salts (mg/*l*)	45.0	380.0	771.0	156.0	41 %
Calcium (mg/*l* Ca)	3.0	55.0	104.0	25.0	45 %
Magnesium (mg/*l* Mg)	4.0	25.0	56.0	11.8	47 %
Sodium (mg/*l* Na)	4.0	22.0	61.0	14.0	64 %
Potassium (mg/*l* K)	0.1	2.2	5.7	1.4	64 %
Chloride (mg/*l* Cl)	3.0	47.0	216.0	49.0	104 %
Sulphate (mg/*l* SO_4)	1.0	7.8	31.0	7.6	97 %
Total Alkalinity (mg/*l* $CaCO_3$)	2.0	172.0	347.0	87.0	51 %
Nitrate (mg/*l* N)	0.1	11.0	48.0	9.9	90 %
Fluoride (mg/*l* F)	0.1	0.2	1.9	0.3	150 %
Langelier Saturation Index (LSI)	-3.4	-0.3	0.7	1.0	
Sodium Adsorption Ratio (SAR)	0.1	0.6	1.5	0.4	67 %

5.5.7 Dennilton and Bloempoort Formations (Transvaal Supergroup)

The Dennilton Formation, comprising of acid lava, tuff and gneiss, covers only a very small portion of the map area as indicated in Figure 4. It is exposed to the west of Groblersdal where it forms part of the so-called Moos River Fragment. This is also the case for the Bloempoort Formation comprising of andesite, impure quartzite and shale (Figure 4).

In both cases, insufficient data are available to characterize either the yield of boreholes or the depth of groundwater rest levels. The similar absence of hydrochemical data precludes an assessment of the quality of the groundwater associated with these Formations.

5.5.8 Timeball Hill/Rooisloot Formation(s) (Transvaal Supergroup)

The distribution of these Formations is shown in Figure 13a together with the positions of groundwater sample sources. The Timeball Hill Formation consists of one or more beds of quartzite sandwiched between shale at the base and at the top of the unit. The Rooisloot Formation comprises mainly of shales and occurs only in the Crocodile River Fragment where it is equivalent to the Timeball Hill Formation.

The water-bearing properties of the shale formations are generally more favourable than those of the quartzites due to their greater susceptibility to weathering. The quartzites do, however, constitute productive aquifers where these rocks are fractured and especially in the presence of ferruginization. It is for this reason that the quartzitic portions of the Timeball Hill Formation, where these are clearly recognizable, have been identified on the main map as fractured aquifers rather than as intergranular and fractured aquifers. Elsewhere, this Formation is grouped together with the Rooisloot Formation as an intergranular and fractured aquifer. Lesser and/or more isolated groundwater occurrences are associated with fault and associated shear zones and with contact zones between diabase sills, dykes, shale and quartzite. Water may also occur in occasional joints and fractures in fresh diabase.

The groundwater yield potential is classed as low, based on the observation that 70 % of the borehole records produce yields less than 2 *l*/s (Figure 13b). The groundwater rest level typically occurs at depths of between 5 and 40 m below surface. This large variation is ascribed to elevation differences between the higher, more rugged quartzitic portions and the lower, flatter topography associated with the shale formations.

Along the Gatsrand between Potchefstroom and Johannesburg, numerous structurally controlled springs draining the quartzite suggest that recharge could be fairly high. Gold mining exploration boreholes in the Gatsrand area also often exhibit an initial artesian character. Dewatering of the dolomitic formations to the north by mining operations might explain the eventual dissipation of these conditions by promoting subsurface drainage. A few deep exploration boreholes in the Timeball Hill Formation to the north of Delmas owe their artesian character to the fact that they penetrate the underlying dolomite.

The average EC value of 34 mS/m and mean pH value of 7.2 (Table 27 and Figure 13c) indicate that the quality of the groundwater is excellent and generally acceptable for any use. Elements that show a significant coefficient of variation are sodium, chloride, sulphate and nitrate. These circumstances, supported in a smaller measure by the coefficient of variation associated with fluoride values, indicate that caution should be exercised when considering this groundwater for domestic use. The substantial coefficient of variation for sodium is also reflected in the SAR statistics, indicating that the sodium hazard must receive greater attention than that of salinity in considering this water for irrigation use.

Table 27. Chemistry of groundwater from the Timeball Hill/Rooisloot Formation(s)

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 81 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	4.0	7.2	8.7	0.8	11 %
Electrical Conductivity (mS/m)	1.6	34.0	283.0	39.0	115 %
Total Dissolved Salts (mg/*l*)	15.5	278.0	2224.0	368.0	132 %
Calcium (mg/*l* Ca)	1.0	29.0	333.0	42.8	148 %
Magnesium (mg/*l* Mg)	1.0	19.0	139.0	22.0	116 %
Sodium (mg/*l* Na)	1.0	15.0	186.0	29.0	193 %
Potassium (mg/*l* K)	0.1	1.6	20.6	2.6	163 %
Chloride (mg/*l* Cl)	1.0	15.0	190.0	33.0	220 %
Sulphate (mg/*l* SO_4)	1.0	26.0	1214.0	133.0	512 %
Total Alkalinity (mg/*l* $CaCO_3$)	1.0	125.0	390.0	106.0	85 %
Nitrate (mg/*l* N)	0.1	2.9	39.0	6.70	231 %
Fluoride (mg/*l* F)	0.1	0.3	3.1	0.4	133 %
Langelier Saturation Index (LSI)	-7.2	-1.5	1.0	1.8	
Sodium Adsorption Ratio (SAR)	0.1	0.6	8.7	1.1	183 %

Plate 8. Reddish-stained joints in quartzite of the Timeball Hill Formation. The staining represents iron oxide precipitated from groundwater during water table fluctuations in the geological past. (Photo: M van der Neut)

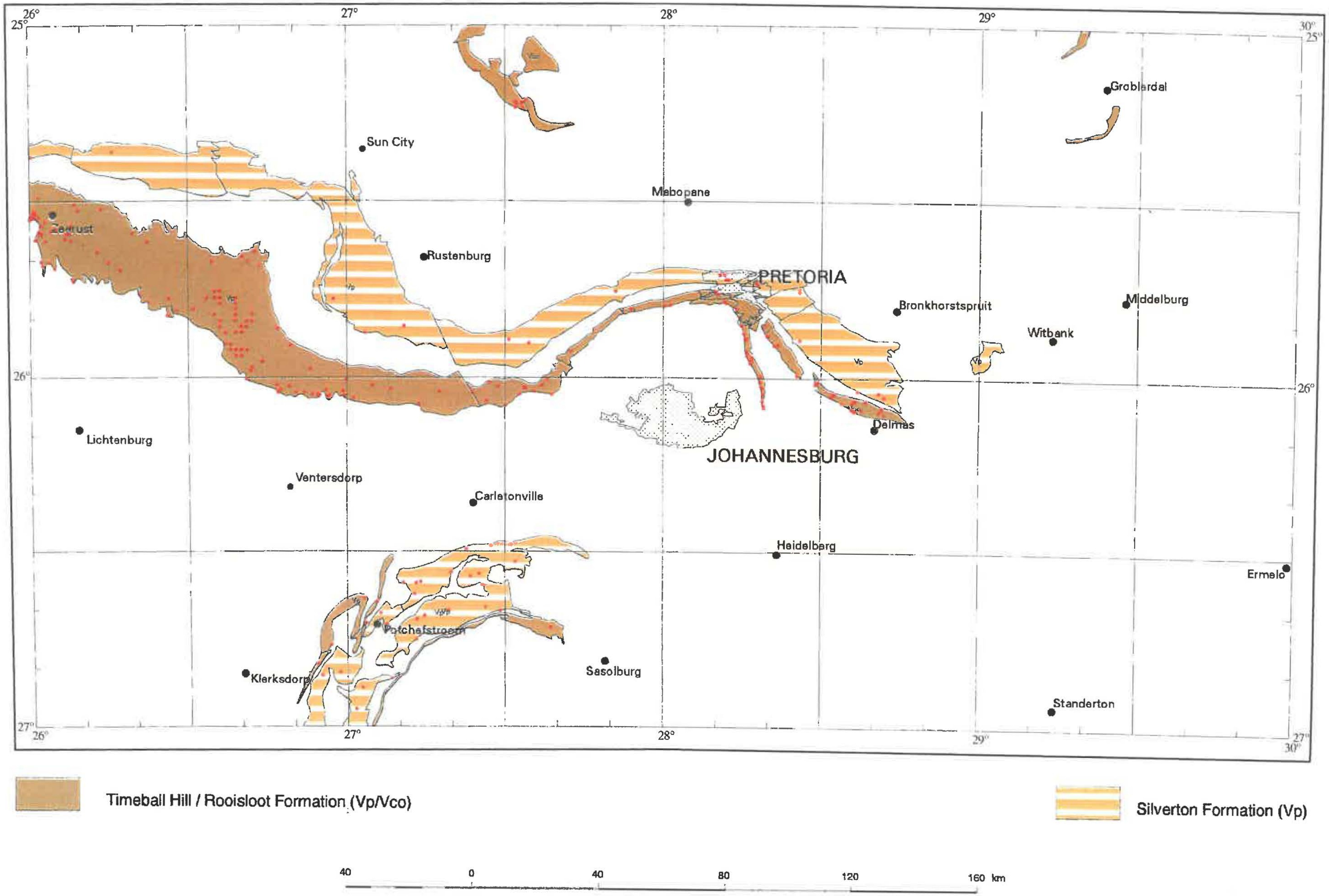


Figure 13a. Geographical distribution of the Timeball Hill/Rooisloot and Silverton Formations and associated groundwater sampling points

Figure 13b. Borehole yield distribution for the Timeball Hill/Rooisloot and Silverton Formations

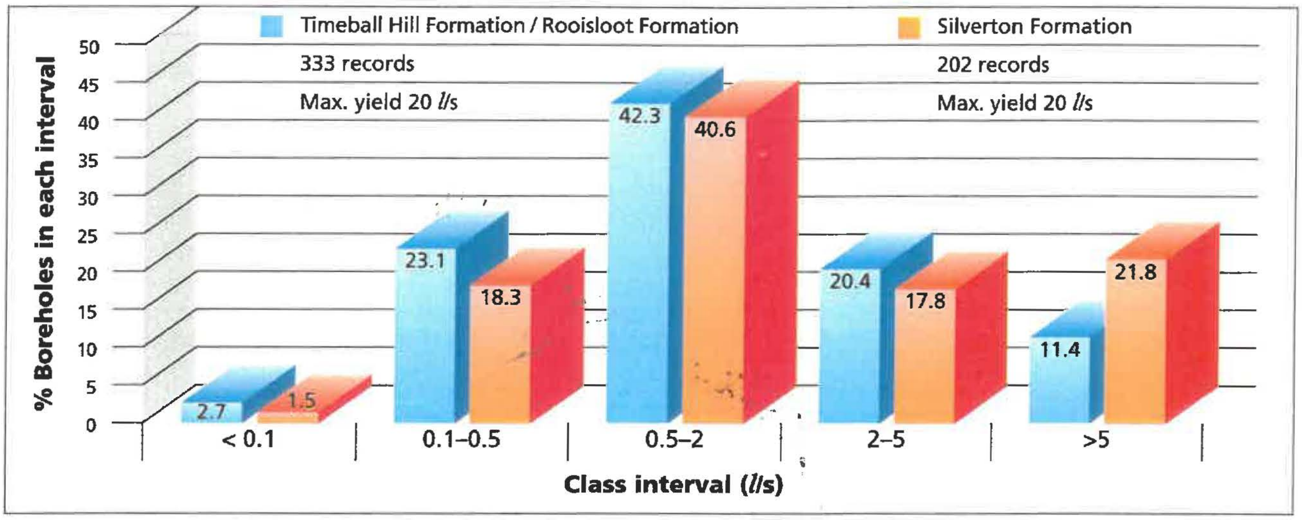
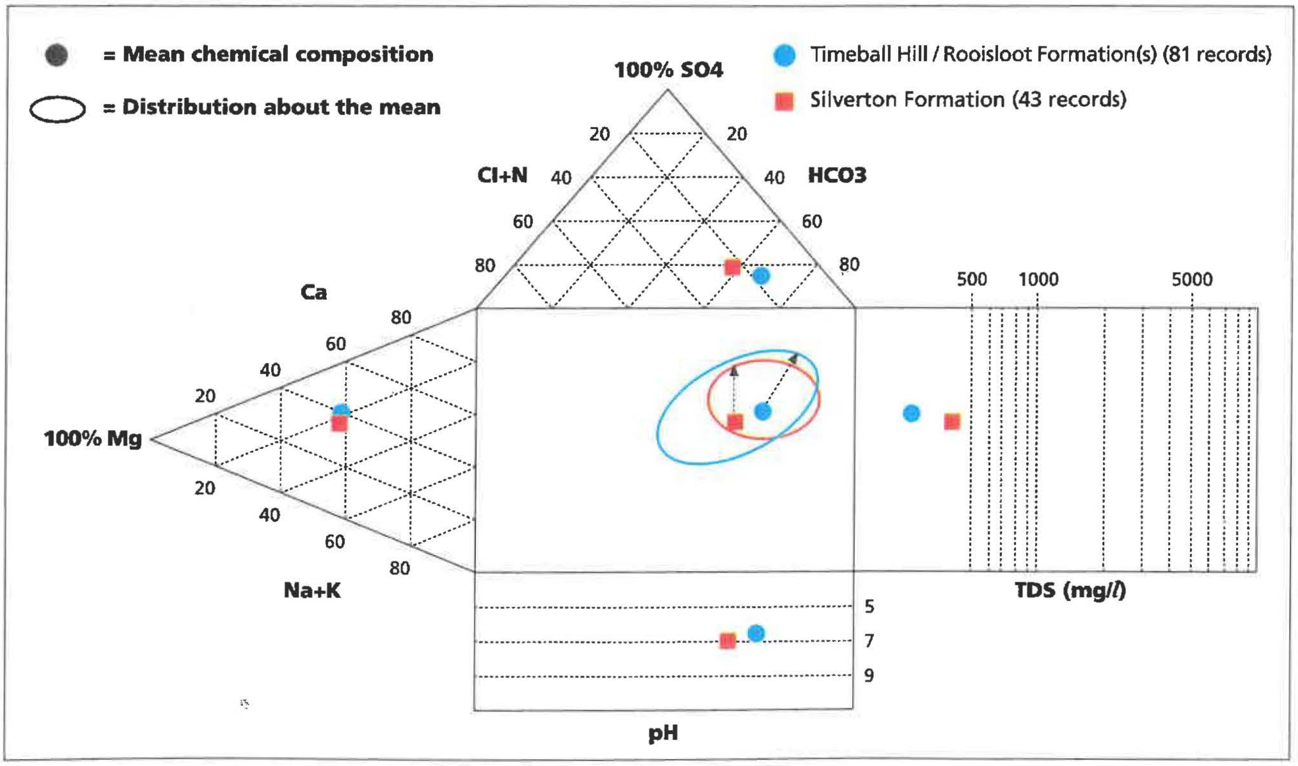


Figure 13c. Chemistry of groundwater from the Timeball Hill/Rooisloot and Silverton Formations



5.5.9 Silverton Formation (Transvaal Supergroup)

The extensive and broad valleys that extend from east to west in the vicinity of Pretoria represent the topographic signature of the Silverton Formation that comprises mainly of shales. The distribution of this Formation is also indicated in Figure 13a together with the positions of groundwater sample sources.

Groundwater occurrence favours weathered shale, brecciated or jointed zones and especially the contact zone between intrusive diabase sheets and the shale. The groundwater yield potential is classed as good on the basis that 40 % of the boreholes on record produce more than 2 *l*/s and 22 % produce more than 5 *l*/s (Figure 13b). Higher-yielding boreholes occur more often in association with the surface water drainage systems of the broad valley bottoms. The groundwater rest level occurs between 10 and 25 m below surface, although depths of up to 80 m occur at the foot of the Magaliesberg mountain range.

Changes in groundwater levels in boreholes penetrating this Formation on the Rietondale experimental farm in Pretoria have been correlated with rainfall (Figure 13d) and used by Bredenkamp (1978) to calculate an average recharge value of some 8 % for this unit. The general suitability of the groundwater for any use is indicated by the average EC value of 58 mS/m and mean pH value of 7.6 (Table 28 and Figure 13c). Elements that show a substantial coefficient of variation are chloride and sulphate. The water is generally suitable for irrigation use.

Table 28. Chemistry of groundwater from the Silverton Formation

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 43 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	5.5	7.6	8.8	0.6	8 %
Electrical Conductivity (mS/m)	5.6	58.0	340.0	56.0	97 %
Total Dissolved Salts (mg/*l*)	39.0	428.0	2118.0	383.0	89 %
Calcium (mg/*l* Ca)	2.0	44.0	304.0	54.0	123 %
Magnesium (mg/*l* Mg)	2.0	32.0	148.0	32.0	100 %
Sodium (mg/*l* Na)	2.0	30.0	200.0	37.0	123 %
Potassium (mg/*l* K)	0.2	2.8	28.0	5.0	179 %
Chloride (mg/*l* Cl)	1.0	39.0	824.0	124.0	318 %
Sulphate (mg/*l* SO_4)	1.0	56.0	953.0	162.0	289 %
Total Alkalinity (mg/*l* $CaCO_3$)	14.0	181.0	480.0	121.0	67 %
Nitrate (mg/*l* N)	0.1	3.9	39.0	6.7	172 %
Fluoride (mg/*l* F)	0.1	0.3	3.1	0.5	167 %
Langelier Saturation Index (LSI)	-4.7	-0.6	0.9	1.1	
Sodium Adsorption Ratio (SAR)	0.1	0.9	8.1	1.3	144 %

5.5.10 Hekpoort Formation (Transvaal Supergroup)

The distribution of the Hekpoort Formation comprising of andesitic lava is indicated in Figure 14a together with the positions of groundwater sample sources. The lava commonly decomposes to clayey material that can extend to depths of between 10 and 30 m below surface and which possesses a very low permeability of around 10^{-6} cm/s (Kok, 1993a).

Successful boreholes in this Formation are associated with fractured zones encountered below the weathered zone in the vicinity of faults, fractures and at the contacts with overlying and/or underlying shale formations. The groundwater yield potential is classed as moderate on the basis that 37.5 % of the boreholes on record produce between 2 and 5 *l*/s (Figure 14b). Kok (1993a) is of the opinion that borehole yields are prone to weakening due to the poor recharge conditions associated with the impermeable nature of the weathered vadose zone. The groundwater rest level is generally located between a depth of 5 and 30 m below surface.

The respective mean EC and pH values of 52 mS/m and 7.5 (Table 29 and Figure 14c) indicate that the groundwater quality is generally acceptable for any use. Elements that show a significant coefficient of variation are sodium, chloride and especially sulphate. The substantial coefficient of variation associated with sodium is also reflected in the SAR statistics, indicating that the sodium hazard must receive greater attention than that of salinity when this water is being considered for irrigation purposes.

Figure 13d. Correlation of groundwater level changes with rainfall at Rietondale experimental farm in Pretoria

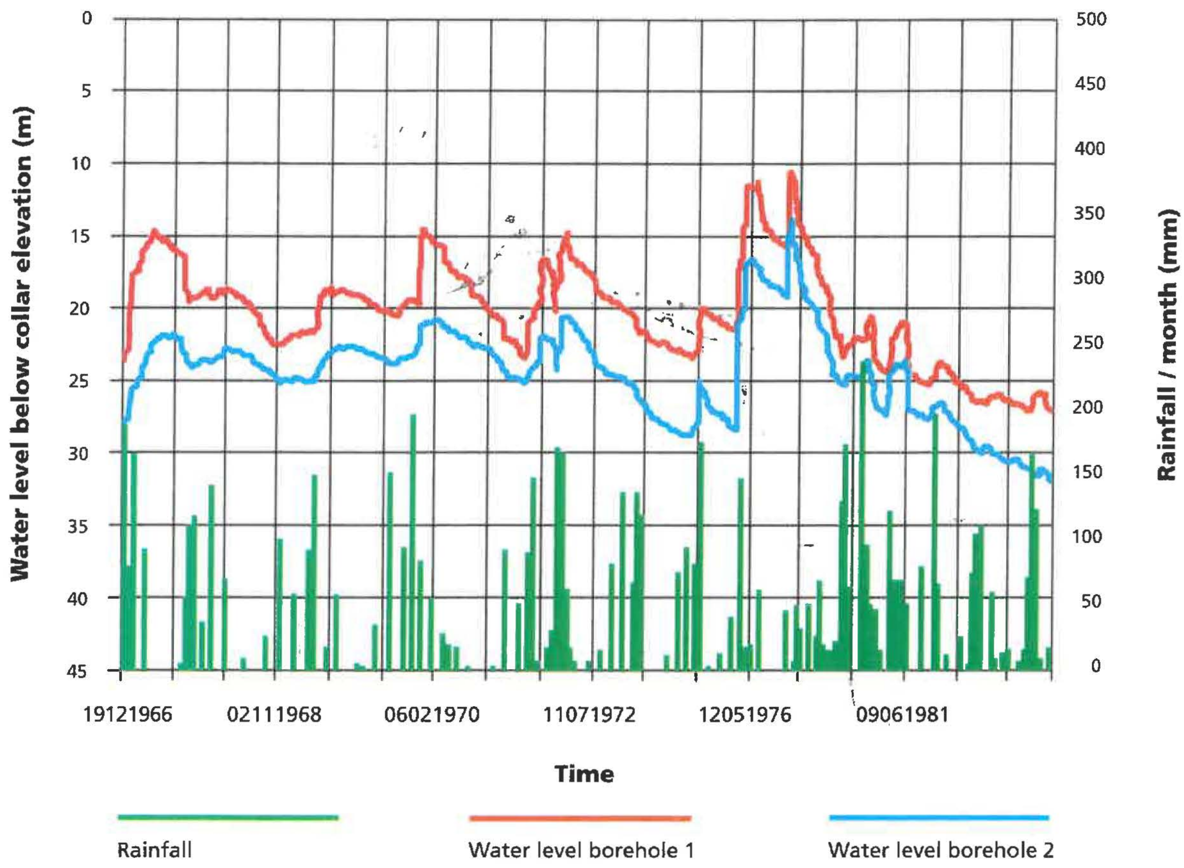


Table 29. Chemistry of groundwater from the Hekpoort Formation

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 41 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	5.7	7.5	8.5	0.5	7 %
Electrical Conductivity (mS/m)	3.5	52.0	382.0	60.0	115 %
Total Dissolved Salts (mg/*l*)	21.0	398.0	2988.0	471.0	118 %
Calcium (mg/*l* Ca)	2.0	44.0	139.0	56.0	127 %
Magnesium (mg/*l* Mg)	1.0	26.0	172.0	30.0	115 %
Sodium (mg/*l* Na)	1.0	30.0	330.0	57.0	190 %
Potassium (mg/*l* K)	0.2	2.0	17.2	3.0	150 %
Chloride (mg/*l* Cl)	1.0	23.5	227.0	42.0	179 %
Sulphate (mg/*l* SO_4)	1.0	79.0	1600.0	260.0	329 %
Total Alkalinity (mg/*l* $CaCO_3$)	8.0	156.0	516.0	99.0	63 %
Nitrate (mg/*l* N)	0.1	3.5	22.2	4.7	134 %
Fluoride (mg/*l* F)	0.1	0.3	3.1	0.5	167 %
Langelier Saturation Index (LSI)	-3.7	-0.8	1.0	1.0	
Sodium Adsorption Ratio (SAR)	0.1	1.2	23.0	3.6	300 %

Figure 14a. Geographical distribution of the Hekpoort Formation, Rooiberg Group and Loskop Formation and associated groundwater sampling points

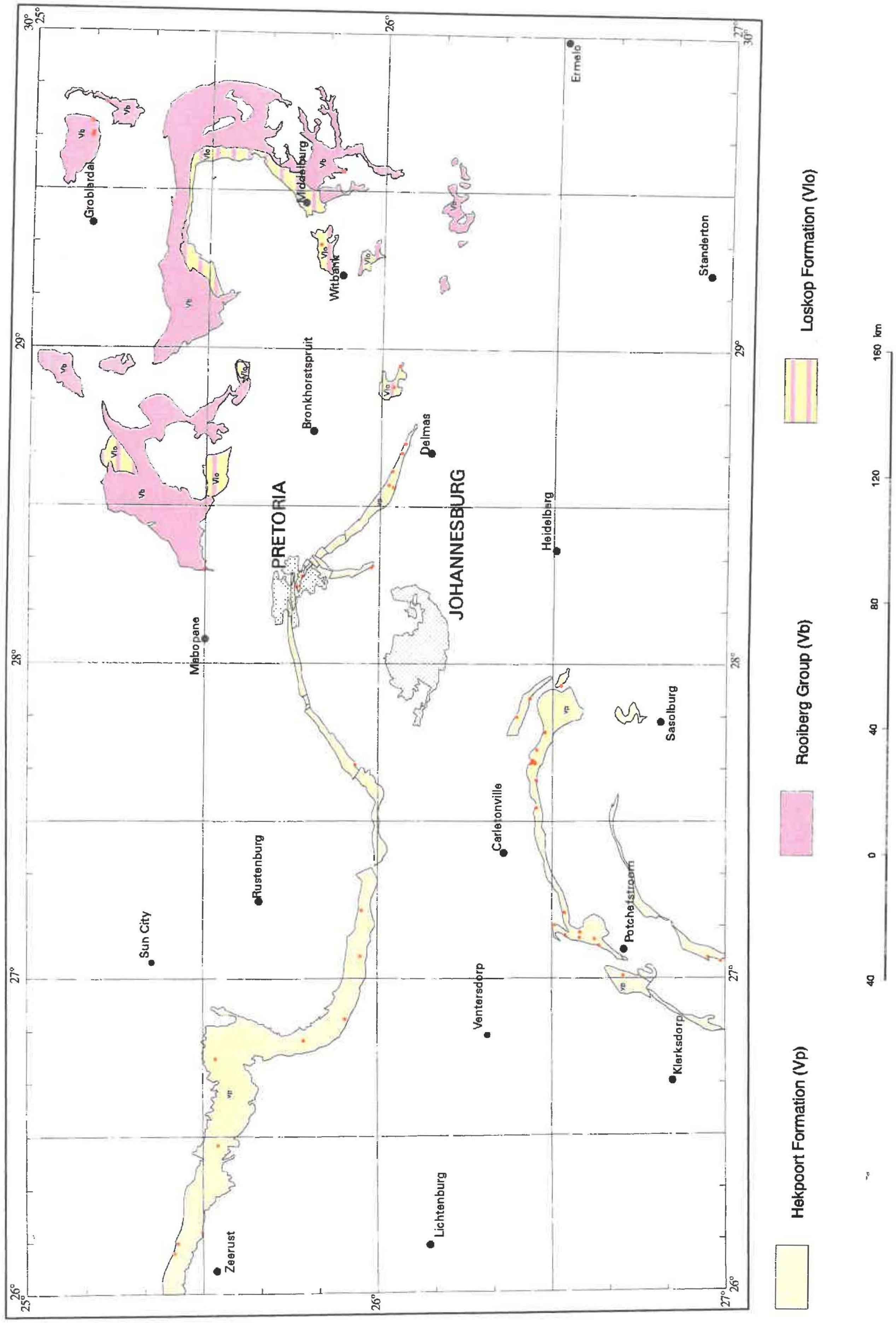


Figure 14b. Borehole yield distribution for the Hekpoort Formation, Rooiberg Group and Loskop Formation

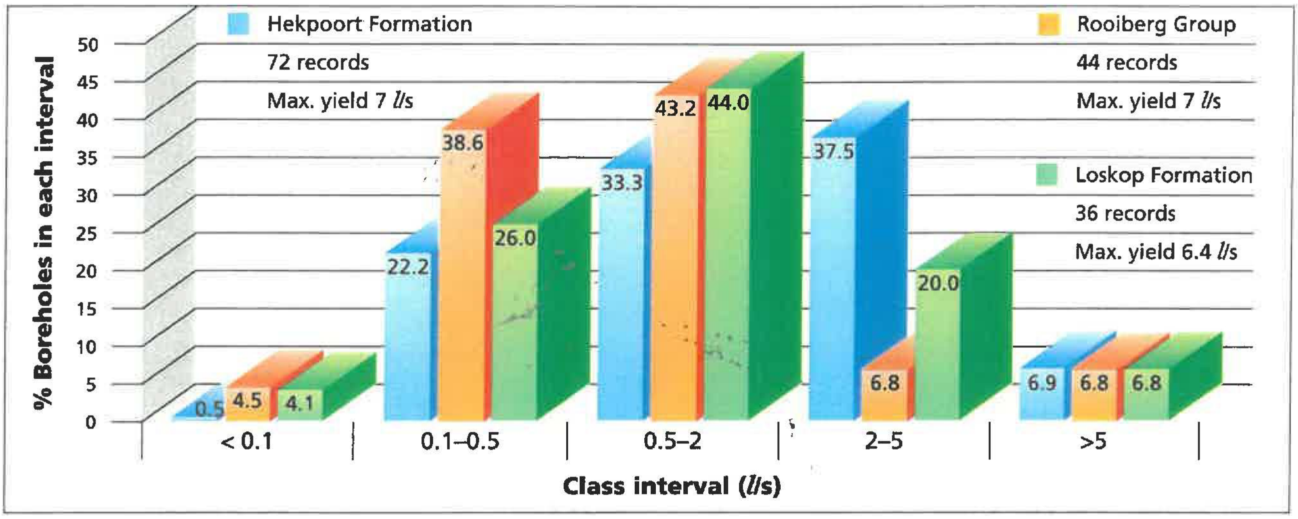
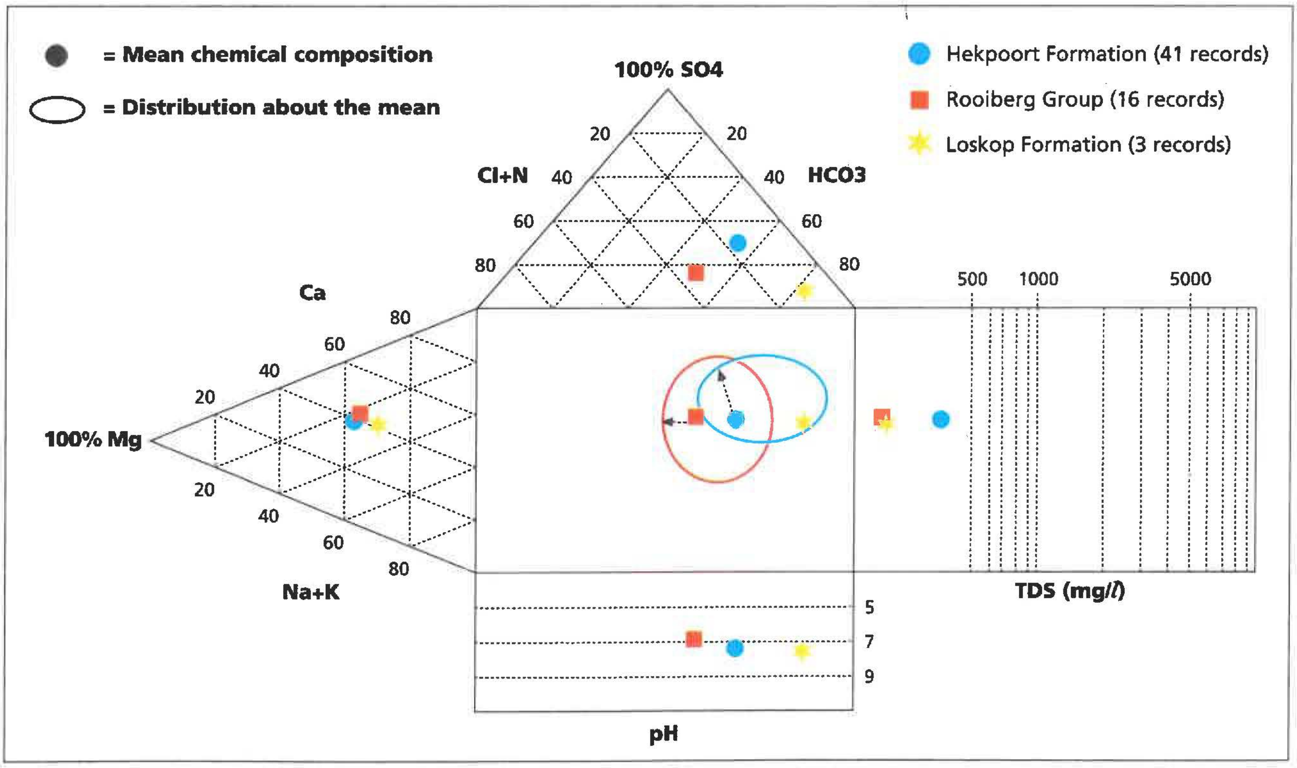


Figure 14c. Chemistry of groundwater from the Hekpoort Formation, Rooiberg Group and Loskop Formation



5.5.11 Dullstroom Formation (Transvaal Supergroup)

The Dullstroom Formation, comprising of basaltic to intermediate (andesitic) lava with agglomerate and subordinate felsite, covers only a very small portion of the map area as indicated in Figure 4. Hydrogeological information for this unit is non-existent.

5.5.12 Rooiberg Group (Transvaal Supergroup)

The distribution of this Group is indicated in Figure 14a together with the positions of groundwater sample sources. The porphyritic rhyolite and felsite associated with this unit represent acidic lava having a greater resistance to weathering than rock types which represent basic lava. The nature of these rocks and their weathering product is similar to that of granite (Section 5.5.1), so that groundwater is usually encountered in the transition zone between weathered and more solid rock. Breccia and joint zones as well as lithological and dyke contact zones also contribute to a groundwater yield potential that is classed as poor on the basis that 86 % of the available borehole yield records report a value of less than 2 *l*/s (Figure 14b). The groundwater rest level typically occurs between 10 and 30 m below surface.

The data presented in Table 30 indicate the generally excellent quality of the groundwater as borne out by the average EC value of 34 mS/m and mean pH value of 7.1. Elements that show a substantial coefficient of variation are sulphate and nitrate. The latter indicates that although a small measure of caution is required when considering this water for human consumption, it is generally suitable for all use.

Table 30. Chemistry of groundwater from the Rooiberg Group

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 16 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	4.9	7.1	8.4	0.8	11 %
Electrical Conductivity (mS/m)	4.7	34.0	116.0	33.0	97 %
Total Dissolved Salts (mg/*l*)	47.0	216.0	771.0	210.0	97 %
Calcium (mg/*l* Ca)	2.0	26.0	104.0	30.0	115 %
Magnesium (mg/*l* Mg)	1.0	14.0	56.0	17.0	121 %
Sodium (mg/*l* Na)	2.0	13.0	61.0	15.0	115 %
Potassium (mg/*l* K)	0.9	8.0	43.0	13.0	163 %
Chloride (mg/*l* Cl)	1.0	23.5	84.0	29.0	123 %
Sulphate (mg/*l* SO_4)	2.0	26.0	176.0	54.0	208 %
Total Alkalinity (mg/*l* $CaCO_3$)	23.0	81.5	347.0	83.0	102 %
Nitrate (mg/*l* N)	0.1	5.9	48.0	12.0	203 %
Fluoride (mg/*l* F)	0.1	0.4	1.0	0.2	50 %
Langelier Saturation Index (LSI)	-5.8	-1.9	0.7	1.6	
Sodium Adsorption Ratio (SAR)	0.1	0.6	1.2	0.3	50 %

5.5.13 Loskop Formation (Transvaal Supergroup)

This Formation comprises mainly of shale, siltstone, and feldspathic sandstone interspersed with extrusive acidic lava. Representing the last phase of sedimentation associated with the Transvaal Supergroup, its distribution is indicated in Figure 14a together with the positions of groundwater sample sources. Although little is known about the occurrence of groundwater in this Formation, borehole yield data indicate that 74 % of boreholes produce less than 2 *l*/s (Figure 14b) that is suggestive of a poor groundwater yield potential. The groundwater rest level generally occurs between 10 and 30 m below surface. Only three chemical analyses of groundwater from this unit are available (Table 31), precluding both a statistical analysis of the data and an assessment of its general quality and suitability for an intended use.

Plate 9. Differential weathering in bedded shale of the Silverton Formation. The softer rock (crumbled appearance) occupies a bedding plane between harder, more jointed beds. (Photo: M van der Neut)

Table 31. Chemistry of groundwater from the Loskop Formation

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 3 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH		7.6			
Electrical Conductivity (mS/m)		24.8			
Total Dissolved Salts (mg/*l*)		219.0			
Calcium (mg/*l* Ca)		20.0			
Magnesium (mg/*l* Mg)		9.0			
Sodium (mg/*l* Na)		15.0			
Potassium (mg/*l* K)		2.7			
Chloride (mg/*l* Cl)		6.7			
Sulphate (mg/*l* SO_4)		12.7			
Total Alkalinity (mg/*l* $CaCO_3$)		126.0			
Nitrate (mg/*l* N)		0.7			
Fluoride (mg/*l* F)		0.1			
Langelier Saturation Index (LSI)		-1.0			
Sodium Adsorption Ratio (SAR)		0.6			

5.5.14 Rashoop Granophyre Suite (Bushveld Complex)

The distribution of this unit is indicated in Figure 15a together with the positions of groundwater sample sources. The granophyric rock types (mainly granophyre, granophyric granite, granophyre porphyry and pseudo-granophyre) associated with this unit are very similar to granite in the nature and product of their weathering, so that groundwater usually occurs in association with the transition zone from weathered to more solid rock. Breccia and joint zones as well as lithological and dyke contact zones, however, also store and yield groundwater. The groundwater yield potential is classified as poor on the basis that 92 % of the boreholes on record produce less than 2 *l*/s (Figure 15b). The depth to groundwater rest level seldom exceeds 30 m below surface.

The data presented in Table 32 and Figure 15c indicate that the quality of the groundwater is generally suitable for any use, revealing an average EC value of 31 mS/m and a mean pH value of 7.3. Elements that show a substantial coefficient of variation are chloride, sulphate and fluoride. The significant coefficient of variation associated with fluoride indicates that a measure of caution is required when this water is considered for human consumption. The SAR and EC statistics indicate that these parameters are of similar significance in classifying this water as generally suitable for irrigation use.

Table 32. Chemistry of groundwater from the Rashoop Granophyre Suite

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 41 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	4.5	7.3	8.2	0.8	11 %
Electrical Conductivity (mS/m)	4.4	31.0	122.0	33.0	106 %
Total Dissolved Salts (mg/*l*)	31.0	226.0	918.0	242.0	107 %
Calcium (mg/*l* Ca)	1.0	22.0	113.0	28.0	127 %
Magnesium (mg/*l* Mg)	1.0	15.0	65.0	21.0	140 %
Sodium (mg/*l* Na)	2.0	17.0	99.0	22.0	129 %
Potassium (mg/*l* K)	0.1	2.6	7.0	1.6	62 %
Chloride (mg/*l* Cl)	1.0	21.0	137.0	35.0	167 %
Sulphate (mg/*l* SO_4)	1.0	13.7	173.0	33.0	241 %
Total Alkalinity (mg/*l* $CaCO_3$)	2.0	108.0	483.0	113.0	105 %
Nitrate (mg/*l* N)	0.1	2.2	14.3	3.0	136 %
Fluoride (mg/*l* F)	0.1	0.8	4.1	1.3	163 %
Langelier Saturation Index (LSI)	-6.2	-1.6	0.6	1.6	
Sodium Adsorption Ratio (SAR)	0.1	0.9	7.3	1.2	133 %

5.5.15 Rustenburg Layered Suite (Bushveld Complex)

The rocks of this Suite are characterized by a well-developed igneous layering. The mainly mafic rocks include norite, gabbro, magnetite gabbro, anorthosite and pyroxenite. Their distribution is shown in Figure 15a together with the positions of groundwater sample sources. Groundwater occurrence is associated mainly with deeply weathered and fractured mafic rocks. Odendaal (1983) reports that some of the norite zones weather more easily than the other rock types. This characteristic, in association with north-south striking dykes that cut through and across the norite, has formed groundwater compartments especially in the area between Rustenburg and Pretoria.

With 81 % of the boreholes on record producing less than 2 *l*/s (Figure 15b), the groundwater yield potential is classified as poor. The mafic rocks tend to weather to a clay-rich soil that is represented by the well-known black turf. The very low permeability of this soil (in the order of 10^{-6} cm/s) is considered to reduce recharge to underlying aquifers. The depth to groundwater rest level typically occurs between 5 and 40 m below surface.

The data presented in Table 33 and Figure 15c indicate a marginally questionable groundwater quality associated in particular with the average EC value of 105 mS/m. Significant coefficients of variation are indicated for potassium, sulphate and nitrate. The latter indicates that a measure of caution is required when considering this water for human consumption. The data also show that salinity is an important factor in the classification of this water for irrigation purposes.

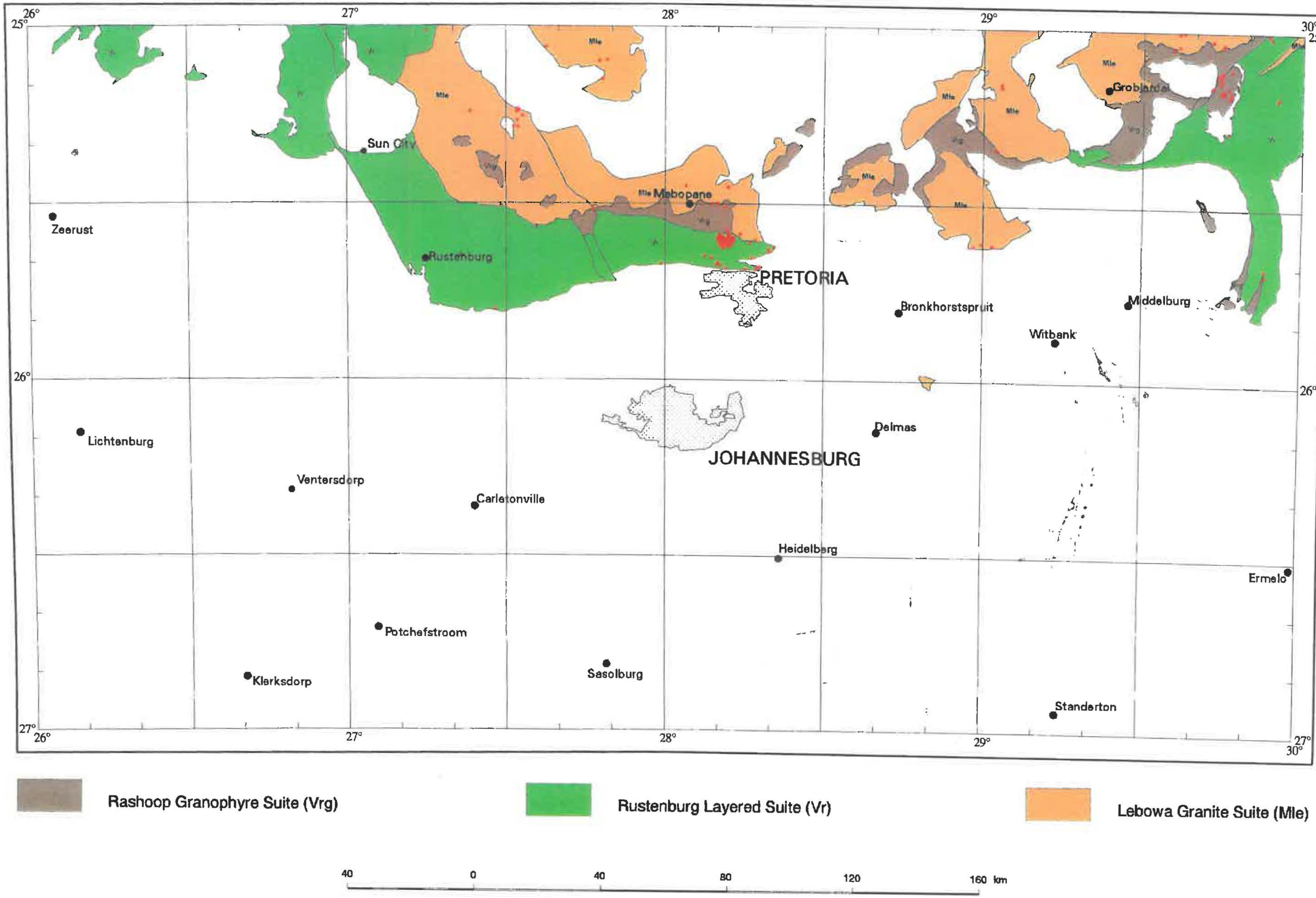


Figure 15a. Geographical distribution of the Rashoop Granophyre Suite, the Rustenburg Layered Suite and the Lebowa Granite Suite and associated groundwater sampling points

Figure 15b. Borehole yield distribution for the Rashoop Granophyre Suite, the Rustenburg Layered Suite and the Lebowa Granite Suite

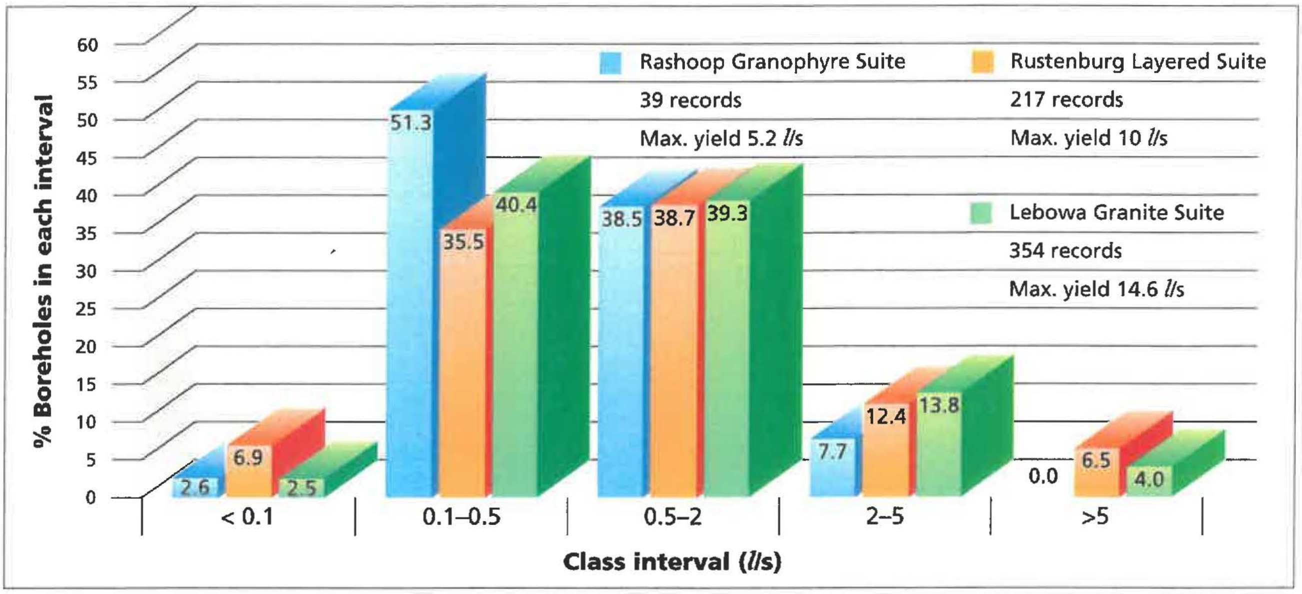


Figure 15c. Chemistry of groundwater from the Rashoop Granophyre Suite, the Rustenburg Layered Suite and the Lebowa Granite Suite

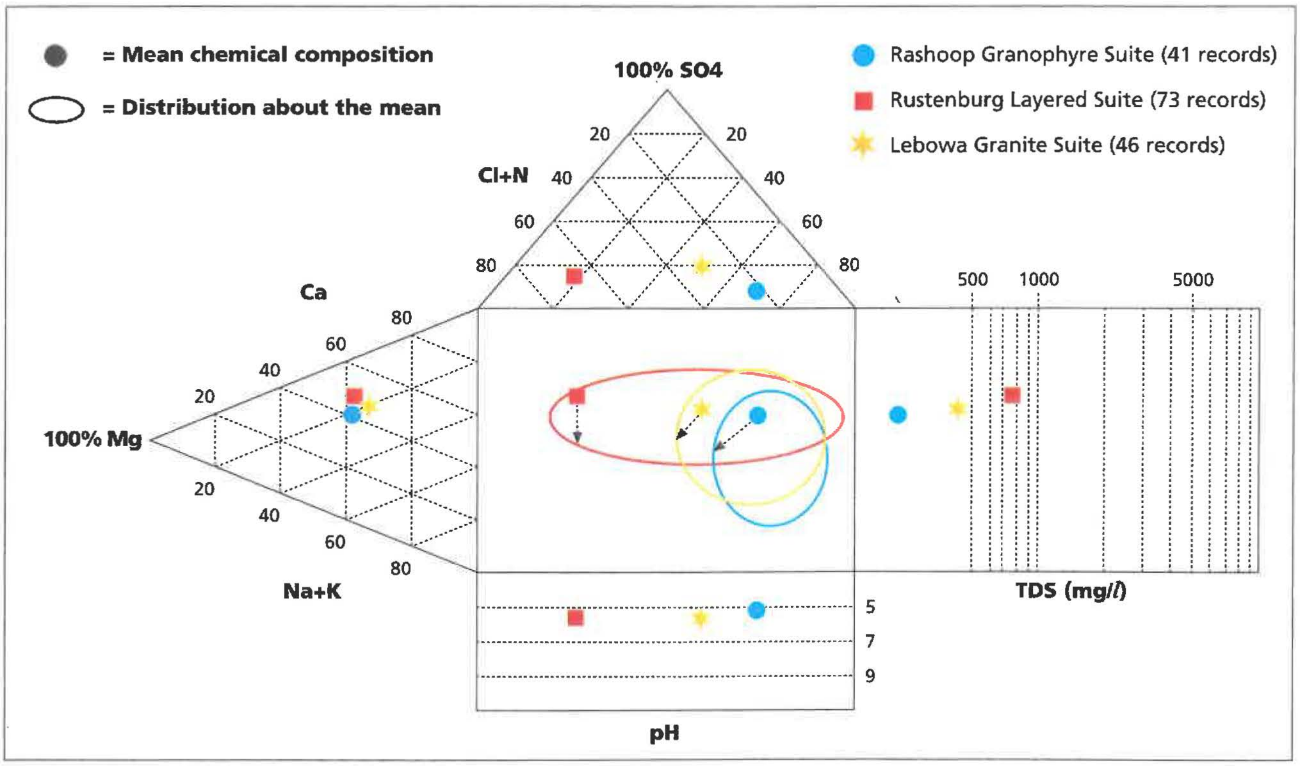


Table 33. Chemistry of groundwater from the Rustenburg Layered Suite

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 73 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	6.2	7.7	9.7	0.5	6 %
Electrical Conductivity (mS/m)	7.9	105.0	384.0	75.0	71 %
Total Dissolved Salts (mg/*l*)	52,0	760.0	2828.0	535.0	70 %
Calcium (mg/*l* Ca)	5.0	99.0	428.0	88.0	89 %
Magnesium (mg/*l* Mg)	2.0	56.0	231.0	44.0	79 %
Sodium (mg/*l* Na)	3.0	45.0	179.0	37.0	82 %
Potassium (mg/*l* K)	0.1	2.7	33.0	6.0	222 %
Chloride (mg/*l* Cl)	2.0	94.0	570.0	117.7	125 %
Sulphate (mg/*l* SO_4)	1.0	184.0	1850.0	343.0	186 %
Total Alkalinity (mg/*l* $CaCO_3$)	9.0	219.0	532.0	102.0	47 %
Nitrate (mg/*l* N)	0.1	10.6	81.0	16.0	151 %
Fluoride (mg/*l* F)	0.1	0.3	2.2	0.4	133 %
Langelier Saturation Index (LSI)	-2.8	-0.1	0.8	0.7	
Sodium Adsorption Ratio (SAR)	0.2	1.1	10.4	1.3	118 %

5.5.16 Lebowa Granite Suite (Bushveld Complex)

Incorporating all of the granitic rocks of the Bushveld Complex, the distribution of this Suite is indicated in Figure 15a, together with the positions of groundwater sample sources. Reference to Figure 4 shows that these rocks occupy the central portion of the Bushveld basin. Although several types of granite ranging from very coarse-grained to very fine-grained varieties may be distinguished, these are not identified on the main map. Fluorite occurs as an accessory disseminated mineral in these rocks. Groundwater occurrence is again associated mainly with deeper weathered zones, whereas fault and fracture zones and dyke contacts represent other less common modes of occurrence.

Table 34. Chemistry of groundwater from the Lebowa Granite Suite

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 46 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	5.9	7.6	8.4	0.5	7 %
Electrical Conductivity (mS/m)	2.6	60.0	161.0	44.0	73 %
Total Dissolved Salts (mg/*l*)	24.0	418.0	1160.0	286.0	68 %
Calcium (mg/*l* Ca)	1.0	60.0	581.0	85.0	142 %
Magnesium (mg/*l* Mg)	1.0	32.0	267.0	43.0	134 %
Sodium (mg/*l* Na)	1.0	40.0	183.0	43.0	108 %
Potassium (mg/*l* K)	0.1	3.7	30.0	5.7	154 %
Chloride (mg/*l* Cl)	1.0	63.4	458.0	92.0	145 %
Sulphate (mg/*l* SO_4)	2.0	71.0	1712.0	248.0	349 %
Total Alkalinity (mg/*l* $CaCO_3$)	10.0	168.0	495.0	106.0	63 %
Nitrate (mg/*l* N)	0.1	6.6	69.0	13.1	198 %
Fluoride (mg/*l* F)	0.1	1.7	14.2	2.7	159 %
Langelier Saturation Index (LSI)	-4.6	-0.6	0.6	1.2	
Sodium Adsorption Ratio (SAR)	0.04	1.4	9.7	2.0	143 %

The groundwater yield potential is classed as low on the basis that 82 % of the boreholes on record produce less than 2 *l*/s (Figure 15b). The depth to groundwater rest level is generally shallow and seldom exceeds 15 m below surface. The comparatively low storage capacity of the granitic rocks is reflected in the appearance of numerous springs and seepages resulting from a rise in groundwater rest levels following rainfall and associated recharge events.

The chemical data (Table 34 and Figure 15c) indicate that the groundwater is generally suitable for any use on the basis of the average EC and pH values of 60 mS/m and 7.6 respectively. Significant coefficients of variation are indicated for sulphate, nitrate and fluoride. Strong caution is therefore indicated when groundwater associated with this unit is being considered for human consumption. The statistics also indicate that the salinity and sodium hazards are of similar importance in the classification of this water for irrigation use.

5.5.17 Alkaline Complexes

Two such complexes occur in the map area. The most significant of these, the Pilanesberg Complex, is located some 50 km northwest of Rustenburg (Figure 16a) and comprises of intrusive and extrusive rocks in the form of red, white and green foyaite, syenite, lava and tuff. The complex located north of Pretoria (Figure 16a) represents the Pienaars River Complex. In regard to the Pilanesberg Complex, McCaffrey (1993) reports that groundwater is encountered in fractures, in weathered contact zones between different lithologies, in large faults, in unconsolidated sediments occupying valley floors, at the base of alluvial cones, and in vesicular lavas and a porous tuff band.

An analysis of test pumping data for ten boreholes in the Pilanesberg indicated that eight produced a maximum yield of less than 0.5 *l*/s (McCaffrey, 1993). The highest yield of 5 *l*/s was associated with groundwater encountered in saturated near-surface unconsolidated material. The depth to groundwater rest level occurs between 5 and 20 m below surface. McCaffrey (1993) further reports the existence of artesian boreholes at two locations as well as the occurrence of several springs.

Based on the estimated groundwater residence time calculated from radiocarbon (^{14}C) and tritium (^{3}H) measurements and a simple hydraulic model, McCaffrey (1993) arrived at an average recharge figure of 0.06 % of mean annual rainfall for the Pilanesberg Complex. Although this very low value is attributed to factors such as the low intrinsic porosity of the Pilanesberg igneous rocks and the steep topography, it is perhaps too conservative.

Figure 16a shows that the 22 groundwater sample locations are more or less equally distributed between the two Complexes. The chemical data (Table 35 and Figure 16b) indicate that the suitability of the groundwater for any use is slightly compromised by the average EC value of 95 mS/m. This is supported by the significant coefficients of variation shown for nitrate and fluoride, indicating that strong caution should be exercised when groundwater associated with this unit is being considered for human consumption. The substantial coefficient of variation associated with the SAR data indicates that the sodium hazard must receive greater attention than that of salinity when this water is considered for irrigation use.

Table 35. Chemistry of groundwater from the Alkaline Complexes

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 22 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	6.3	7.7	10.1	0.9	12 %
Electrical Conductivity (mS/m)	23.0	95.0	259.0	62.0	65 %
Total Dissolved Salts (mg/*l*)	165.0	631.0	1678.0	394.0	62 %
Calcium (mg/*l* Ca)	1.0	66.0	222.0	57.0	86 %
Magnesium (mg/*l* Mg)	1.0	33.0	1330.	33.0	100 %
Sodium (mg/*l* Na)	8.0	91.0	435.0	96.0	105 %
Potassium (mg/*l* K)	0.4	3.2	8.8	3.0	94 %
Chloride (mg/*l* Cl)	1.6	82.4	440.0	118.0	143 %
Sulphate (mg/*l* SO_4)	1.4	82.7	468.0	114.0	138 %
Total Alkalinity (mg/*l* $CaCO_3$)	87.0	273.0	520.0	118.0	43 %
Nitrate (mg/*l* N)	0.1	7.1	58.7	14.5	204 %
Fluoride (mg/*l* F)	0.1	6.8	79.0	16.9	249 %
Langelier Saturation Index (LSI)	-2.3	-0.2	1.0	0.7	
Sodium Adsorption Ratio (SAR)	0.3	7.5	73.4	17.4	232 %

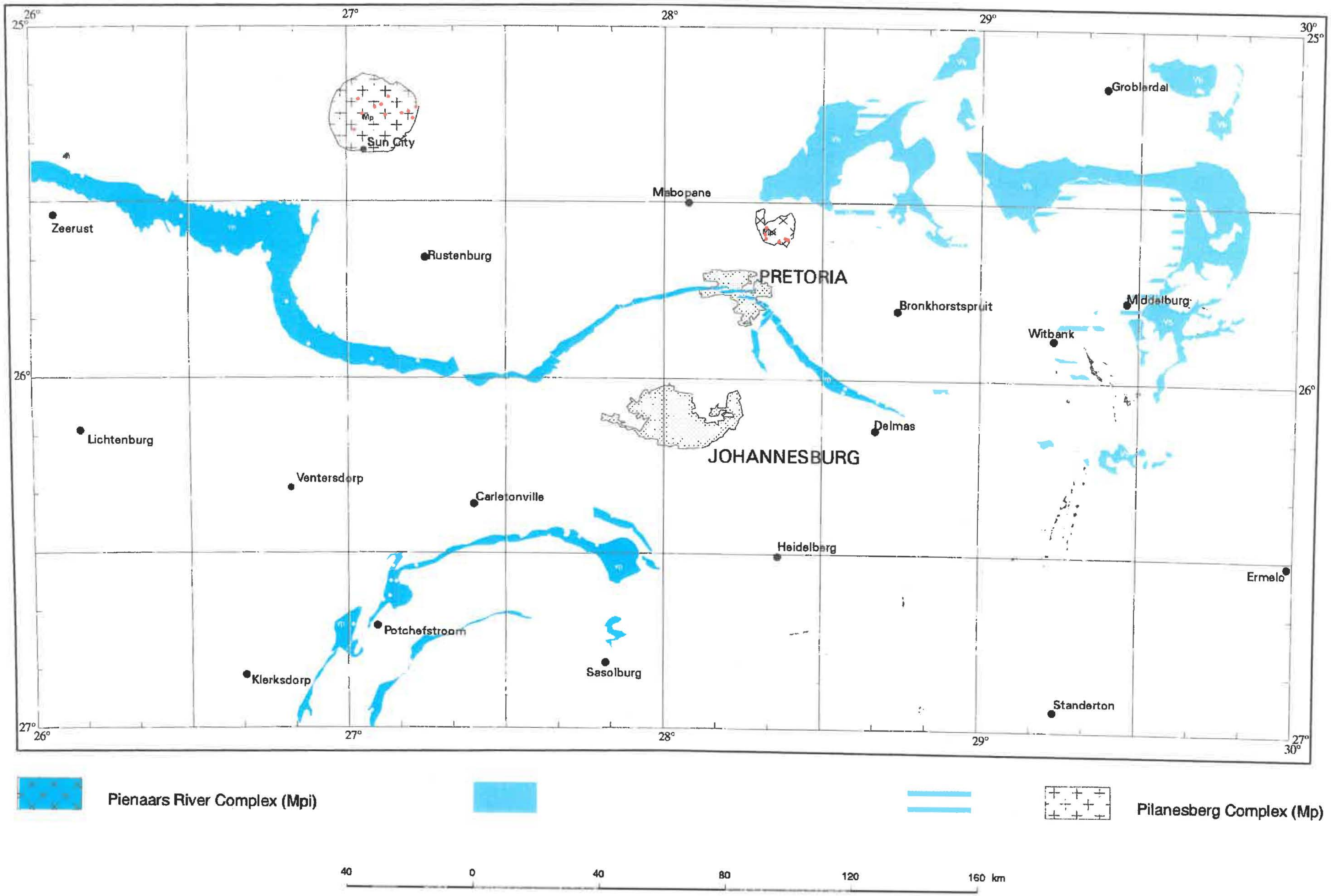
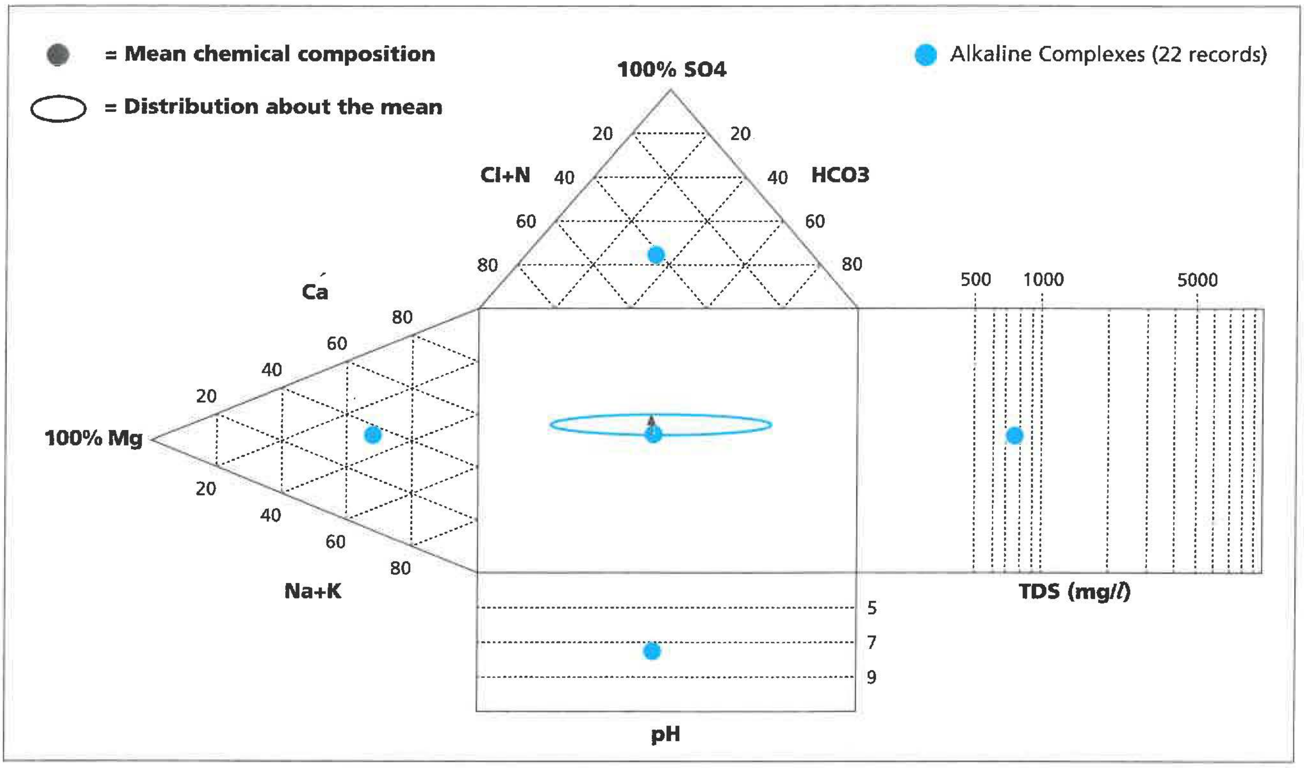


Figure 16a. Geographical distribution of the major Alkaline Complexes and associated groundwater sampling points

Figure 16b. Chemistry of groundwater from the major Alkaline Complexes



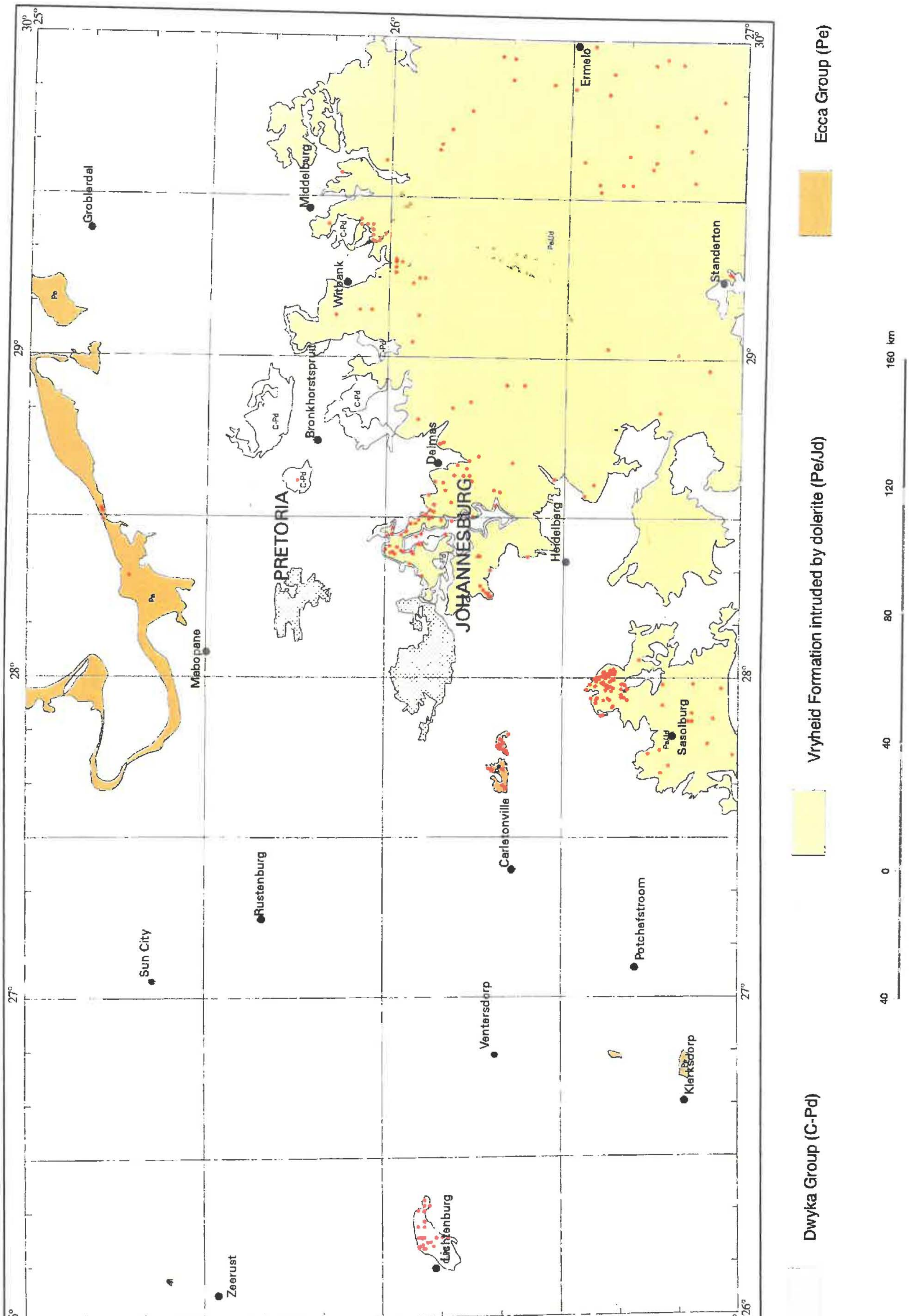
5.5.18 **Dwyka Group** (Karoo Supergroup)

The Dwyka Group comprises glacial deposits (tillite). Its distribution is shown in Figure 17a together with the positions of groundwater sample sources. The permeability of fresh tillite is generally and widely regarded as being very low. A small occurrence of tillite to the east of Lichtenburg is reported by Backström *et al* (1952) to be highly weathered in its upper portion so that shallow boreholes yield sufficient water for household supply. The groundwater yield potential is classed

Table 36. Chemistry of groundwater from the Dwyka Group

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 46 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	5.9	7.6	8.3	0.5	7 %
Electrical Conductivity (mS/m)	3.2	53.0	160.0	33.0	62 %
Total Dissolved Salts (mg/*l*)	31.0	363.0	886.0	194.0	53 %
Calcium (mg/*l* Ca)	1.0	43.0	120.0	28.0	65 %
Magnesium (mg/*l* Mg)	1.0	26.0	72.0	17.0	65 %
Sodium (mg/*l* Na)	2.0	26.0	81.0	19.0	73 %
Potassium (mg/*l* K)	0.6	3.4	24.0	3.5	103 %
Chloride (mg/*l* Cl)	1.0	51.0	274.0	63.0	124 %
Sulphate (mg/*l* SO_4)	1.0	12.0	93.0	16.0	133 %
Total Alkalinity (mg/*l* $CaCO_3$)	9.0	159.0	316.0	82.0	52 %
Nitrate (mg/*l* N)	0.1	7.8	43.0	10.0	128 %
Fluoride (mg/*l* F)	0.1	0.2	0.7	0.2	100 %
Langelier Saturation Index (LSI)	-4.8	-0.6	0.6	0.8	
Sodium Adsorption Ratio (SAR)	0.1	0.9	2.5	0.6	67 %

Figure 17a. Geographical distribution of the Dwyka Group, Vryheid Formation and Ecca Group and associated groundwater sampling points



as low on the basis that 76 % of the boreholes on record produce less than 2 *l*/s (Figure 17b). The highest recorded yield is only 4.4 *l*/s, which supports the view that this formation represents a poor aquifer. No information regarding the depth to groundwater rest level in this unit was sourced.

The data presented in Table 36 and Figure 17c indicate that the quality of the groundwater is generally suitable for any use on the basis of the average EC value of 53 mS/m and mean pH value of 7.6. Although the comparatively small coefficients of variation suggest that the quality of the groundwater associated with this formation is reasonably constant, this might merely reflect the common source area (Lichtenburg) of the majority of the samples (Figure 17a). The quality of the groundwater is generally suitable for human consumption. The SAR and EC statistics also indicate that this water can generally be considered suitable for irrigation use.

Figure 17b. Borehole yield distribution for the Dwyka Group, Vryheid Formation intruded by dolerite and the Ecca Group (undifferentiated)

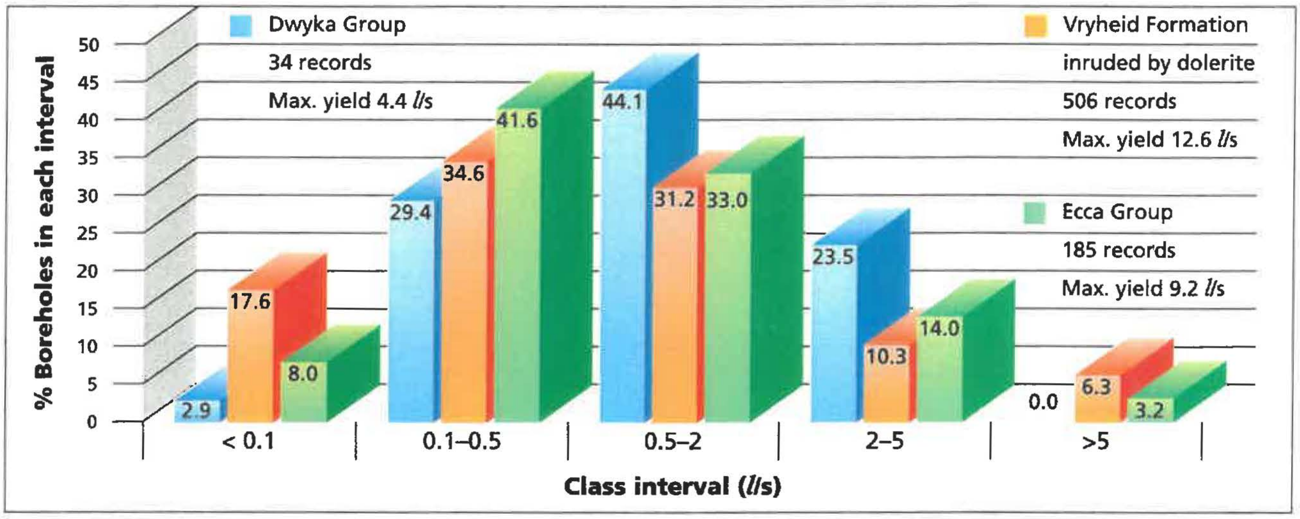
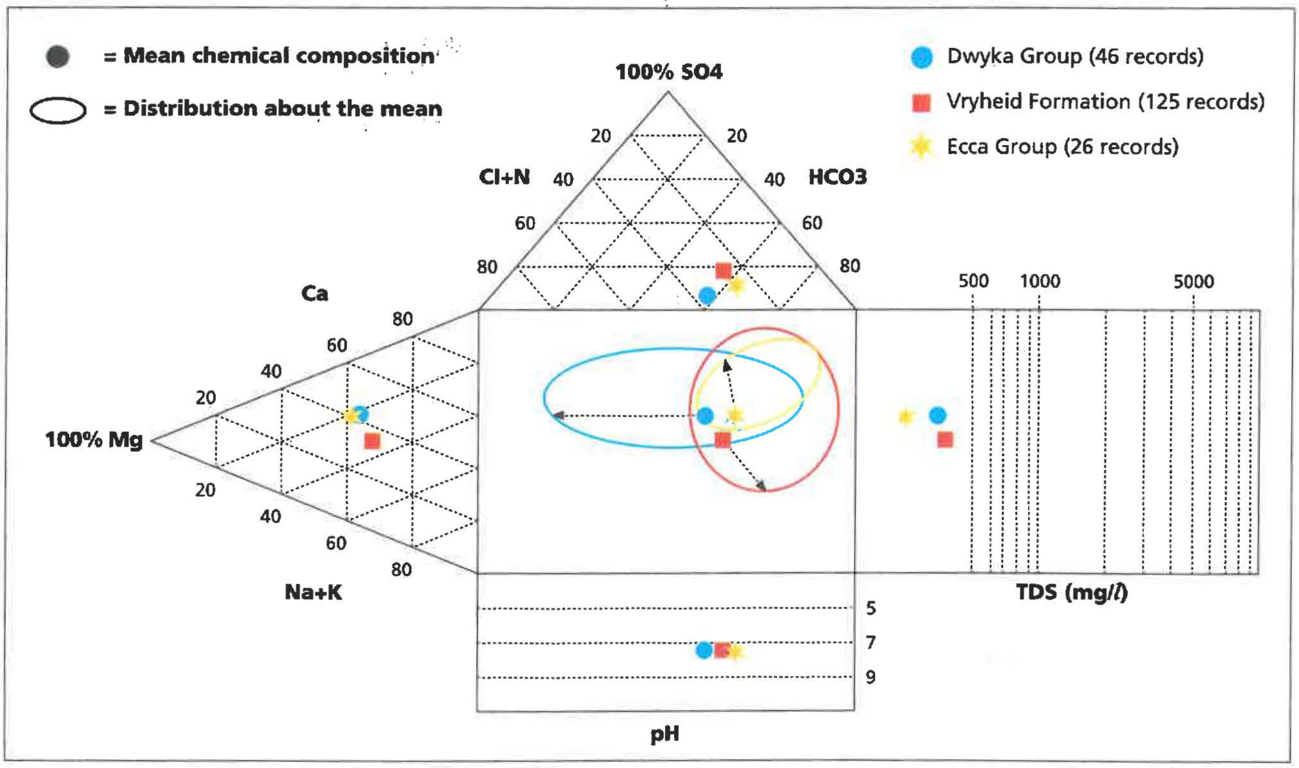


Figure 17c. Chemistry of groundwater from the Dwyka Group, Vryheid Formation intruded by dolerite and the Ecca Group (undifferentiated)



5.5.19 Vryheid Formation and intrusive dolerite (Karoo Supergroup)

Comprising predominantly of thick beds of yellowish to white cross-bedded sandstone and grit alternating with beds of soft sandy shale, this unit also contains the coal seams that underpin the coal mining activities in the eastern and southern portions of the map area (Figure 4). The sedimentary rocks are, however, so extensively and widely intruded by dolerite sheets and dykes that the two lithologies are considered to represent a single groundwater system. The distribution of these lithologies is indicated in Figure 17a together with the positions of groundwater sample sources. Vegter *et al* (1968) list six different modes of groundwater occurrence associated with these formations. These are (a) weathered and fractured sedimentary rocks not associated with dolerite intrusions, (b) indurated and jointed sedimentary rocks alongside dykes, (c) narrow weathered and fractured dolerite dykes, (d) basins of weathering in dolerite sills and highly jointed sedimentary rocks enclosed by dolerite, (e) weathered and fractured upper contact-zones of dolerite sills and (f) weathered and fractured lower contact-zones of dolerite sills. Minor groundwater strikes are also often encountered in association with the coal seams (Visser *et al*, 1949).

The groundwater yield potential is classed as low since 83 % of the boreholes on record produce less than 2 *l*/s (Figure 17b). The groundwater rest level is generally encountered between 5 and 25 m below surface. Numerous springs occur at lithological contacts such as where sandstone overlies an impervious shale horizon, along fault zones and along impermeable dolerite dykes. Groundwater seepage in lower lying areas contributes substantially to sustaining the dry season flow in the stream systems that drain these landscapes. Vegter *et al* (1968) consider a recharge figure of 4 to 5 % of mean annual rainfall appropriate to this groundwater regime.

The general suitability of the groundwater for any use is indicated by the average EC value of 57 mS/m and mean pH value of 7.5 (Table 37 and Figure 17c). The significant coefficients of variation for sodium, chloride and sulphate possibly reveal contamination (perhaps associated with coal mining activities?) in some of the groundwater samples.

The significant coefficient of variation for nitrate indicates that a measure of caution is required when considering this water for human consumption. The significant coefficient of variation associated with the SAR data indicates that the sodium hazard must receive greater attention than that of salinity when considering this water for irrigation use.

Table 37. Chemistry of groundwater from the Vryheid Formation

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 125 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	4.8	7.5	8.5	0.6	8 %
Electrical Conductivity (mS/m)	3.7	57.0	344.0	55.0	96 %
Total Dissolved Salts (mg/*l*)	33.0	400.0	1835.0	353.0	88 %
Calcium (mg/*l* Ca)	1.0	38.0	184.0	32.0	84 %
Magnesium (mg/*l* Mg)	1.0	24.0	174.0	26.0	108 %
Sodium (mg/*l* Na)	1.0	43.0	492.0	80.0	186 %
Potassium (mg/*l* K)	0.3	3.6	38.0	4.5	125 %
Chloride (mg/*l* Cl)	1.0	44.0	919.0	124.0	282 %
Sulphate (mg/*l* SO_4)	1.0	47.0	919.0	113.0	240 %
Total Alkalinity (mg/*l* $CaCO_3$)	12.0	162.0	539.0	106.0	65 %
Nitrate (mg/*l* N)	0.1	3.9	80.0	9.8	251 %
Fluoride (mg/*l* F)	0.1	0.4	2.6	0.4	100 %
Langelier Saturation Index (LSI)	-5.5	-0.8	1.2	1.1	
Sodium Adsorption Ratio (SAR)	0.1	1.8	31.0	3.9	217 %

5.5.20 Ecca Group (undifferentiated) (Karoo Supergroup)

Rocks belonging to this unit occupy the margin of the Springbok Flats to the north of Pretoria, occur in palaeo-sinkholes on the dolomite to the east of both Carletonville and Klerksdorp, and on sedimentary rocks of the Witwatersrand Supergroup to the northeast of Klerksdorp (Figure 17a). Comprising of an unclassified succession of fine-grained sandstone and shaly sandstone with interbedded shale and siltstone, this unit attains a maximum thickness of 100 m at the base of the Springbok Flats. Although also intruded by dolerite sills and dykes, especially in the Springbok Flats area, the extent of these intrusions is much less than in the main Karoo basin. Groundwater occurrence is generally associated with fractures and joints developed locally along bedding planes, with contact zones between different sedimentary lithologies, and with fault and associated shear zones. Fayazi (1994) reports that extensively developed fractures and joints resulting from post-Karoo tectonic episodes also favour the occurrence of groundwater. The sedimentary rocks possess a low to very low primary permeability and low storage potential. Although the groundwater yield potential is classed as low on the basis that 83 % of the boreholes on record produce less than 2 *l*/s (Figure 17b), high yields are occasionally obtained on the contact zone with the overlying Irrigasie Formation (Section 5.5.21).

The data presented in Table 38 and Figure 17c indicate that the generally excellent quality of the groundwater is tempered by significant coefficients of variation associated with the elements sodium, potassium, chloride, sulphate and nitrate. The variation in nitrate concentration indicates that a measure of caution is required when considering this water for human consumption. The SAR and EC statistics indicate that the sodium and salinity hazards enjoy similar insignificant importance in classifying this water as generally suitable for irrigation use.

Table 38. Chemistry of groundwater from the Ecca Group (undifferentiated)

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 26 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	6.2	7.6	8.8	0.6	8 %
Electrical Conductivity (mS/m)	7.8	38.0	211.0	41.5	109 %
Total Dissolved Salts (mg/*l*)	39.0	258.0	1204.0	242.0	94 %
Calcium (mg/*l* Ca)	3.0	29.0	170.0	34.0	117 %
Magnesium (mg/*l* Mg)	1.0	18.0	62.0	13.6	76 %
Sodium (mg/*l* Na)	1.0	17.0	160.0	34.0	200 %
Potassium (mg/*l* K)	0.1	2.4	47.0	8.8	367 %
Chloride (mg/*l* Cl)	1.0	21.0	385.0	73.0	348 %
Sulphate (mg/*l* SO_4)	2.0	21.0	322.0	61.0	290 %
Total Alkalinity (mg/*l* $CaCO_3$)	13.0	118.0	360.0	88.0	75 %
Nitrate (mg/*l* N)	0.1	6.0	50.0	13.6	227 %
Fluoride (mg/*l* F)	0.1	0.2	0.9	0.2	100 %
Langelier Saturation Index (LSI)	-3.8	-0.9	0.5	1.0	
Sodium Adsorption Ratio (SAR)	0.04	0.5	2.7	0.7	140 %

5.5.21 Irrigasie Formation (Karoo Supergroup)

The sedimentary rocks (mudstone, sandstone, conglomerate, grit and shale) of this Formation occupy the southern margin of the Springbok Flats north of Pretoria (Figure 18a). Groundwater occurrence in these rocks is generally controlled either by lithology or by geological structures. The latter take the form of extensively developed fractures and joints within the sediments as well as similar structures developed locally along bedding planes. Dolerite intrusions in the form of dykes and sills have also created secondary fractures and joints on the contact with the host rock.

Since 85 % of the boreholes on record produce less than 2 *l*/s (Figure 18b), the groundwater yield potential is classed as low. The groundwater rest level is shallow, generally occurring between a depth of 10 and 20 m below surface.

The data presented in Table 39 and Figure 18c indicate the potentially questionable quality of the groundwater as characterized by an average EC value of 167 mS/m and a mean pH value of 7.7. The distribution of the sample source positions is shown in Figure 18a. Significant coefficients of variation are indicated for sulphate and nitrate. The high mean concentration of nitrate indicates that caution is required when considering this water for human consumption. The mean EC value assigns a high salinity hazard rating to this groundwater, indicating that caution should also be exercised when this water is being considered for irrigation use.

Figure 18a. Geographical distribution of the Irrigasie, Clarens and Letaba Formations and associated groundwater sampling points

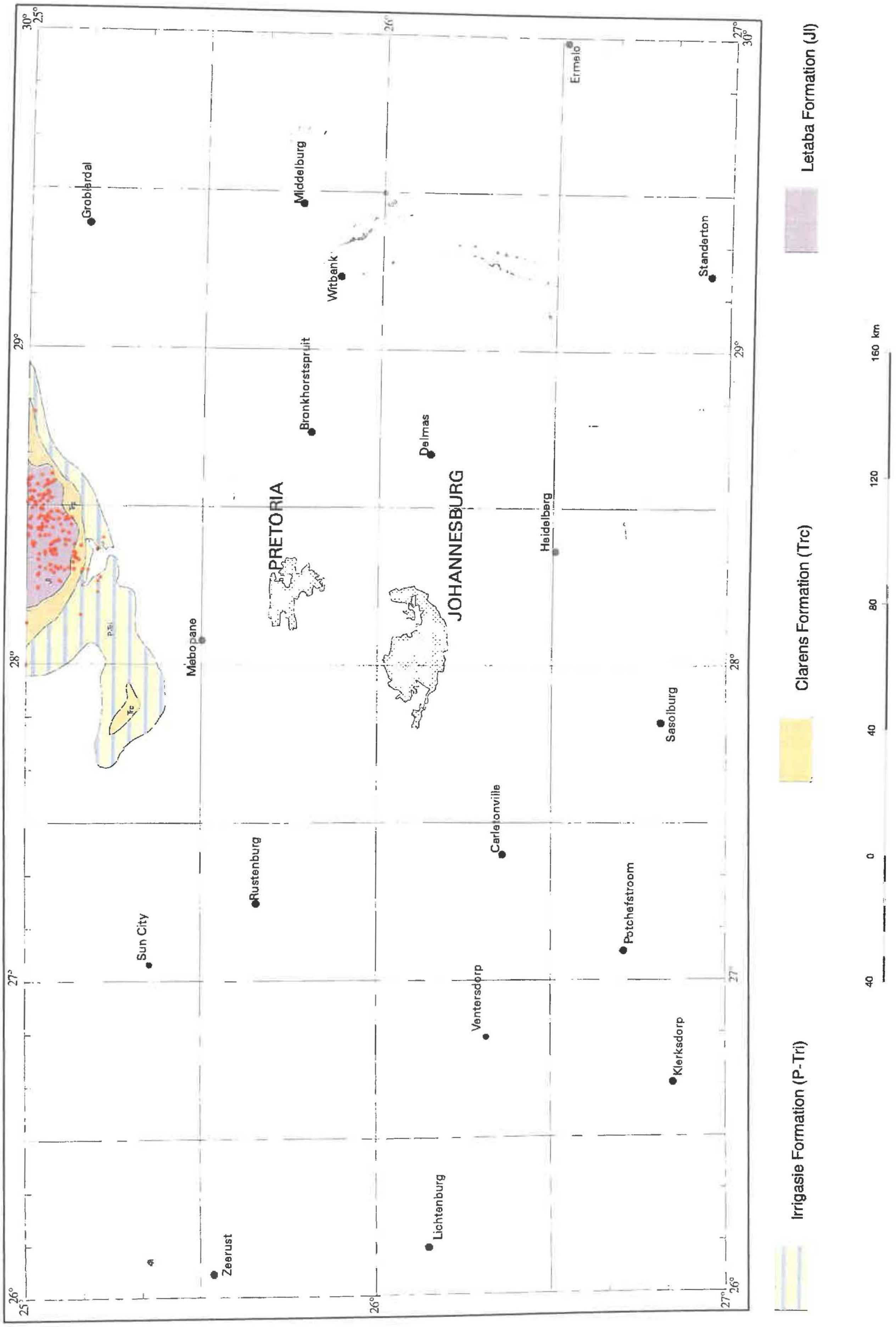


Table 39. Chemistry of groundwater from the Irrigasie Formation

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 19 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	6.6	7.7	8.3	0.4	5 %
Electrical Conductivity (mS/m)	33.0	167.0	535.0	132.0	79 %
Total Dissolved Salts (mg/*l*)	263.0	1224.0	4932.0	1116.0	91 %
Calcium (mg/*l* Ca)	15.0	96.0	260.0	80.0	83 %
Magnesium (mg/*l* Mg)	3.0	89.0	578.0	123.0	138 %
Sodium (mg/*l* Na)	2.0	161.0	589.0	173.0	107 %
Potassium (mg/*l* K)	0.3	4.8	26.0	6.6	138 %
Chloride (mg/*l* Cl)	2.0	202.0	900.0	251.0	124 %
Sulphate (mg/*l* SO_4)	9.0	288.0	3255.0	722.0	251 %
Total Alkalinity (mg/*l* $CaCO_3$)	16.0	298.0	722.0	188.0	63 %
Nitrate (mg/*l* N)	0.1	19.3	80.0	26.0	135 %
Fluoride (mg/*l* F)	0.1	0.5	1.7	0.4	80 %
Langelier Saturation Index (LSI)	-1.5	0.03	1.0	0.6	
Sodium Adsorption Ratio (SAR)	0.1	3.3	15.5	3.9	118 %

5.5.22 Clarens Formation (Karoo Supergroup)

As shown in Figure 18a, the fine-grained sandstone of this Formation shares the southern margin of the Springbok Flats to the north of Pretoria with the Irrigasie Formation (Section 5.5.21). Groundwater occurrence is associated with fractures in re-crystallized horizons within the massive sandstone or with locally developed permeability (Fayazi, 1994). Other groundwater occurrences relate to the contact margins with overlying basaltic and underlying sedimentary rock. Dolerite

Table 40. Chemistry of groundwater from the Clarens Formation

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 22 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	7.5	7.9	8.4	0.3	4 %
Electrical Conductivity (mS/m)	20.0	65.0	139.0	30.0	46 %
Total Dissolved Salts (mg/*l*)	139.0	463.0	862.0	175.0	38 %
Calcium (mg/*l* Ca)	16.0	61.0	138.0	28.0	46 %
Magnesium (mg/*l* Mg)	10.0	33.0	69.0	15.0	45 %
Sodium (mg/*l* Na)	2.0	26.0	88.0	22.0	85 %
Potassium (mg/*l* K)	0.4	1.8	7.1	2.0	111 %
Chloride (mg/*l* Cl)	1.0	30.0	156.0	35.0	117 %
Sulphate (mg/*l* SO_4)	1.0	26.0	197.0	44.0	169 %
Total Alkalinity (mg/*l* $CaCO_3$)	72.0	224.0	316.0	61.0	27 %
Nitrate (mg/*l* N)	0.2	12.9	63.0	20.0	155 %
Fluoride (mg/*l* F)	0.1	0.3	1.9	0.4	133 %
Langelier Saturation Index (LSI)	-1.2	0.2	0.7	0.4	
Sodium Adsorption Ratio (SAR)	0.1	0.6	1.6	0.4	67 %

intrusions (dykes and sills) have also created secondary fractures and joints that favour groundwater occurrence on the contact with the host rock. The groundwater yield potential is classed as low on the basis that 94 % of the boreholes yield less than 2 *l*/s. The highest yield on record is 8 *l*/s. The groundwater rest level is most commonly encountered at a depth of between 10 and 30 m below surface.

The distribution of the source positions of groundwater samples is shown in Figure 18a. The average EC value of 65 mS/m and mean pH value of 7.9 (Table 40 and Figure 18c) indicate the general quality of the groundwater to be suitable for any use. This is supported by the relatively small coefficients of variation associated with many of the elements/parameters, although that for nitrate indicates that caution is required when considering this water for human consumption. The SAR and EC statistics indicate further that this water is generally suitable for irrigation use.

Figure 18b. Borehole yield distribution for the Irrigasie and Clarens Formations

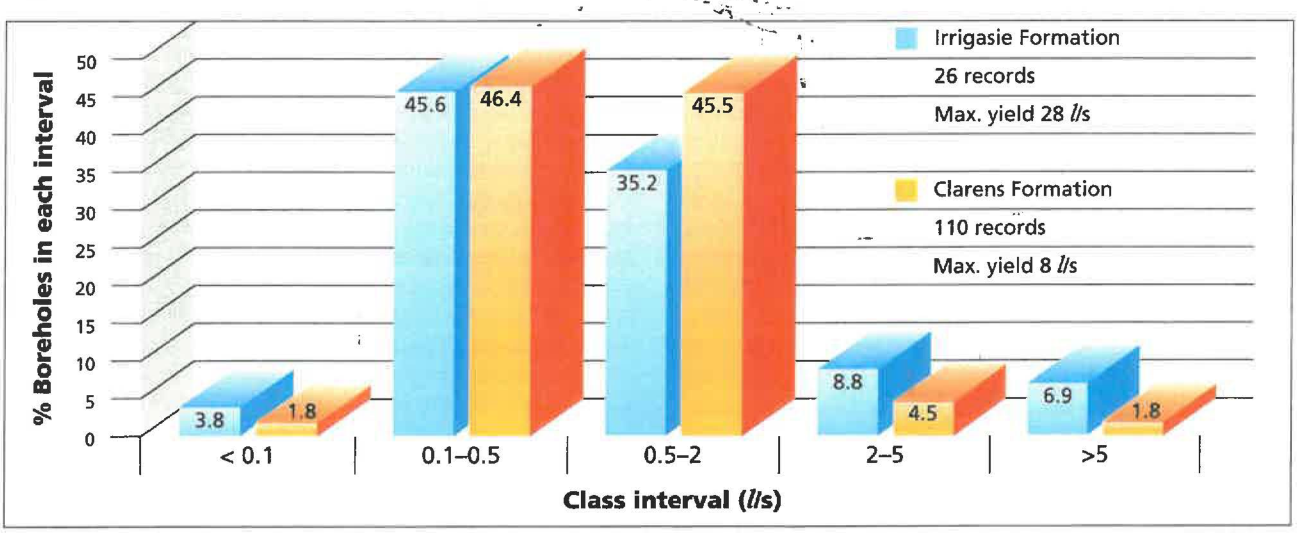
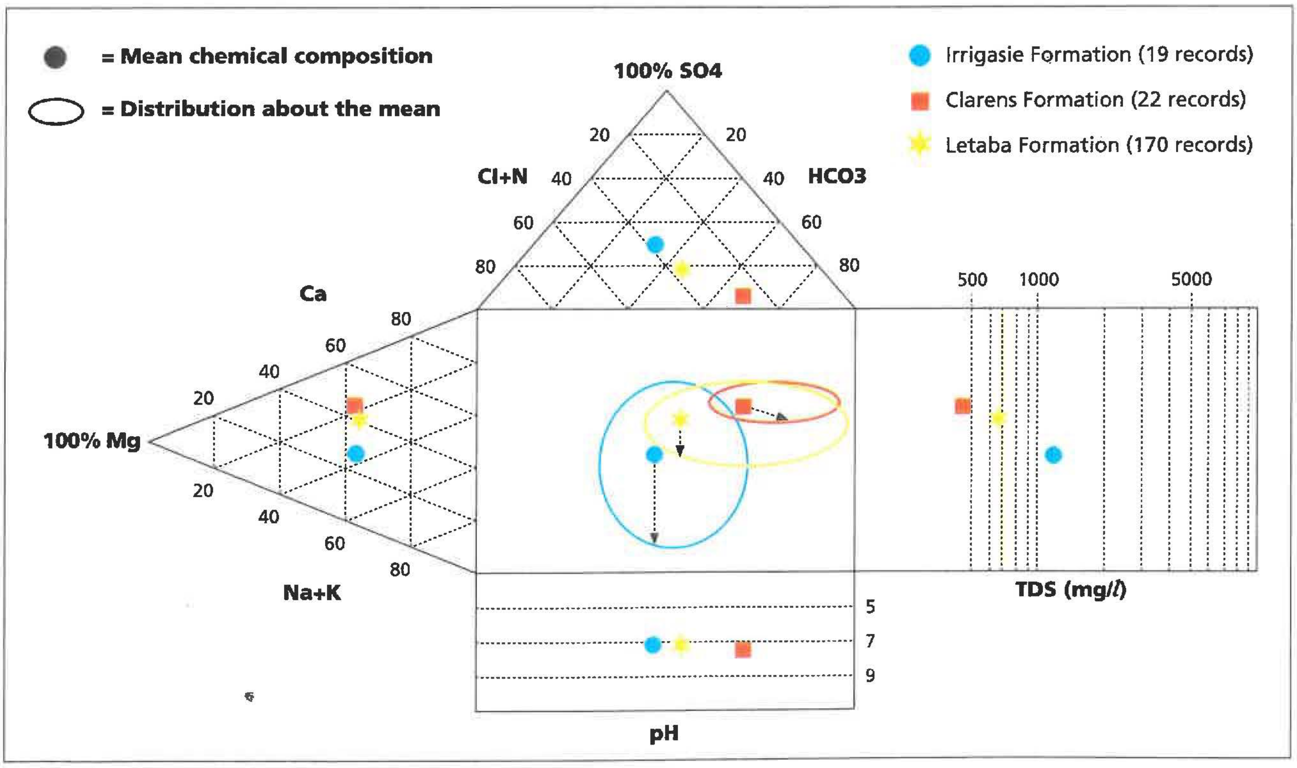


Figure 18c. Chemistry of groundwater from the Irrigasie, Clarens and Letaba Formations



5.5.23 Letaba Formation (Karoo Supergroup)

The Letaba Formation, a basalt comprising of a succession of several amygdaloidal lava flows, occupies the central portion of the Springbok Flats to the north of Pretoria (Figure 18a). An extensive surface cover of black clay-rich soils masks the basalt to such an extent that outcrops of fresh rock are scarce. Groundwater occurrence is associated both with shallow weathered and fractured basalt extending down to 50 m from surface, and with deeper fractures located within fresh basalt at depths of up to 150 m below surface (Fayazi, 1994). The shallower weathering and fracturing produces a secondary porosity and permeability which controls the storage and movement of groundwater in this Formation. Groundwater also occurs on the contact between the basalt and the underlying sedimentary rocks of the Clarens Formation.

The productivity of this groundwater system is demonstrated in studies by Zwarts (1987) which indicate that as much as 29 million cubic metres of groundwater was abstracted for irrigation purposes in the southern Springbok Flats in 1987. Du Toit *et al* (1995) report that 65 % of the successful boreholes tapping this groundwater resource yield more than 3 *l*/s. An analysis of the borehole yield information reported by Zwarts (1987) indicates that 162 out of 476 boreholes (34 %) support yields of 10 *l*/s or greater. The groundwater rest level generally occurs between 10 and 20 m below surface. Deeper water levels typically reflect the effects of over-pumping. A study of long term water level records for the area by Fayazi (1994) indicate that a minimum annual rainfall of some 300 mm causes a rise in groundwater level in both the basalt and the underlying sandstone (Clarens Formation) aquifers. Bredenkamp *et al* (1995) report that studies of groundwater recharge carried out on basalt of the Letaba Formation returned recharge values of 2.8 % of the average annual rainfall.

The data presented in Table 41 and Figure 18c indicate a marginally questionable groundwater quality associated in particular with the average EC value of 116 mS/m. The distribution of the sample source positions is shown in Figure 18a.

Although significant coefficients of variation are indicated for sulphate and fluoride, the high mean value reported for nitrate is of greater concern. Isotope studies carried out by Heaton (1985) on the source of the nitrate indicated that it derived from nitrification of the soil and not from the use of agricultural fertilizers or other sources. The concentration levels do indicate, however, that caution is required when this water is being considered for human consumption. The significant coefficient of variation associated with fluoride, together with the high maximum value (8 mg/*l* F), indicates that caution should also be exercised in regard to this element. The high fluoride concentrations are attributed to deeper boreholes located on the margins of the Formation and which are therefore more likely to also penetrate and draw water from the underlying sandstone of the Clarens Formation. The mean EC value assigns a high salinity hazard rating to this groundwater, indicating that caution should be exercised when this water is considered for irrigation use.

Table 41. Chemistry of groundwater from the Letaba Formation

ELEMENT / PARAMETER	STATISTICS DRAWN FROM A POPULATION OF 170 SAMPLES				
	Minimum Value	Mean Value	Maximum Value	Standard Deviation	Coefficient of Variation
pH	5.6	7.8	7.0	0.5	6 %
Electrical Conductivity (mS/m)	4.2	116.0	944.0	133.0	115 %
Total Dissolved Salts (mg/*l*)	31.0	674.0	3514.0	450.0	67 %
Calcium (mg/*l* Ca)	1.0	85.0	637.0	78.0	92 %
Magnesium (mg/*l* Mg)	1.0	49.0	232.0	36.0	73 %
Sodium (mg/*l* Na)	1.0	53.0	188.0	39.0	74 %
Potassium (mg/*l* K)	0.1	2.5	35.0	4.0	160 %
Chloride (mg/*l* Cl)	1.0	76.0	630.0	95.0	125 %
Sulphate (mg/*l* SO_4)	1.0	102.0	2380.0	265.0	260 %
Total Alkalinity (mg/*l* $CaCO_3$)	5.0	233.0	556.0	96.0	41 %
Nitrate (mg/*l* N)	0.1	22.5	88.0	22.0	98 %
Fluoride (mg/*l* F)	0.1	0.4	8.0	0.9	225 %
Langelier Saturation Index (LSI)	-5.4	0.01	1.3	0.8	
Sodium Adsorption Ratio (SAR)	0.03	1.4	15.2	1.8	129 %

6 Supplementary notes

6.1 Springs

6.1.1 Cold springs

The majority of cold springs in the map area, especially those that support strong yields, are associated with the dolomitic formations and have therefore been discussed in Section 5.4.

The location of all of the major springs, including those not associated with dolomitic formations, is shown on the main map as well as in Figure 10c.

6.1.2 Thermal springs

Of the 90 known thermal springs in South Africa (Kent, 1968), three occur in the map area. These are the Verenabad, the Jarrabad and the Goederede springs, all of which are situated between 20 and 30 km southwest of Groblersdal. Kent (1952) reports a temperature of 32°C, a flow of 3.8 *l*/s and the chemical analysis presented in Table 42 for the Jarrabad spring. A feature common to these three springs is that they rise in Bushveld granite.

An area 45 km southwest of Groblersdal is also known to support a number of thermal artesian boreholes. These most probably intersect fault zones between Lebowa granite and Waterberg Group sediments and in which deep groundwater circulation occurs. There are a few published records of thermal water having been struck in deep gold mines on the Witwatersrand. A supply of 8 126 m^3/day of warm water (33 to 35°C) was encountered in a fault zone in quartzitic rocks at a depth of between 1 600 and 1 850 m below surface in the East Rand Proprietary Mines (ERPM). The water temperature was 1°C lower than the temperature of the host rock.

In the absence of active volcanic regions in South Africa, Kent (1949 and 1968) has suggested that the origin of thermal groundwater is rainwater that has infiltrated along fractures, joints and, with increasing depth, into narrow conduits to depths where it is heated by the higher internal temperature of the earth. The resulting development of localized convection cells serves as the driving mechanism that transports the heated groundwater to surface.

Table 42. Chemistry of groundwater from the Jarrabad spring (after Kent, 1952)

ELEMENT / PARAMETER	VALUE / CONCENTRATION
pH	7.6
Electrical Conductivity (mS/m)	40.0
Total Dissolved Salts (mg/*l*)	306.0
Calcium (mg/*l* Ca)	6.0
Magnesium (mg/*l* Mg)	1.0
Sodium (mg/*l* Na)	97.0
Chloride (mg/*l* Cl)	71.0
Sulphate (mg/*l* SO_4)	12.0
Total Alkalinity (mg/*l* $CaCO_3$)	80.4
Nitrate (mg/*l* N)	0.0
Fluoride (mg/*l* F)	20.0

6.2 Artesian boreholes

Artesian conditions are known to have existed in gold mining exploration boreholes north of the Gatsrand area between Potchefstroom and Johannesburg, but would appear to have dissipated as a result of the dewatering of the dolomitic compartments to the north by the gold mines (Section 5.5.8). Three localities where artesian conditions continue to occur (mainly in the form of flowing boreholes) in the map area are north of Zeerust, north of Delmas and southwest of Groblersdal.

The artesian borehole located north of Zeerust is associated with quartzite of the Timeball Hill Formation. A few artesian boreholes located to the north of Delmas occur in association with sedimentary rocks of the Pretoria Group that overlie dolomite of the Chuniespoort Group. These are deep exploration boreholes that extend into the underlying dolomite. The artesian conditions are considered to derive from the pressure of the overlying Pretoria Group sediments on the dolomitic aquifer and from hydraulic pressures created within the dolomitic aquifer itself as a result of recharge accruing in the higher-lying outcrop area located to the south.

Two artesian boreholes located a distance of some 15 km southwest of Groblersdal, close to the Goederede and Jarrabad thermal springs, penetrate Bushveld granite and produce cold water. It would appear that artesian conditions in this region are controlled by the so-called Dennilton anticline located immediately to the north. A geological description of the area in the brochure of explanatory notes to the published 1:250 000 geological map 2528 Pretoria states that the Dennilton anticline plunges to the south and that the Bushveld granite cuts across this structure.

6.3 Groundwater movement

The groundwater drainage pattern in the map area generally mimics that of surface water which, in turn, is determined by the topography. The groundwater divides therefore also commonly coincide with surface watersheds. Diffuse seepages typically occur along the base of valley slopes where the groundwater level intersects the land surface. Since these seepages contribute to stream flow, the exploitation of groundwater locally in instances where this contribution is large invariably results in a reduction of stream flow. The intensive abstraction of groundwater can lead to the development of a cone of depression around the point of abstraction, causing a disturbance to the natural groundwater flow pattern. This pattern is restored when abstraction is stopped and groundwater levels are allowed to recover.

6.4 Borehole siting

The scientific siting of a borehole relies on the application of any one or more of a wide variety of techniques. These include, amongst others, an interpretation of aerial photographs and satellite images, field observations of the geology, field measurements in existing boreholes and the application of geophysical exploration methods. The various geophysical techniques that are recommended for the different geological units are presented in Table 43. A broad description of drilling targets for most of the geological units is presented in each relevant subsection of Section 5. The importance of using trained personnel to locate suitable drilling targets for water boreholes cannot be over-emphasized.

6.5 Subterranean government water control areas

Four relatively small subterranean government water control areas (SGWCAs) occur in the map area. These are the Bo-Molopo, the Kroondal/Marikana, the Schoonspruit (Ventersdorp Eye) and the Crocodile River Valley (Western Transvaal) SGWCAs.

The Bo-Molopo SGWCA located north of Lichtenburg was proclaimed in 1966 to control groundwater abstraction from dolomitic aquifers in order to ensure the sufficiency of water supplies for Mmabatho, Mafikeng and surrounding urban areas. The eastern portion of this SGWCA occurs in the map area. The Kroondal/Marikana SGWCA situated east of Rustenburg between Kroondal and Marikana was proclaimed in 1963 to control groundwater abstraction from the norite and gabbro of the Rustenburg Layered Suite (Section 5.5.16). This control was requested by land owners concerned at the loss of groundwater resources locally through dewatering activities employed by the platinum and chrome mines in the area. The Crocodile River Valley (Western Transvaal) SGWCA extends along the Crocodile River from north of Brits as far downstream as Thabazimbi. The southern portion of this SGWCA therefore occurs in the map area. The area was originally proclaimed a Government (Surface) Water Control Area in 1968 to effect control over the abstraction and use of surface water released from Hartbeespoort Dam for irrigation purposes as far downstream as Thabazimbi. Its subsequent proclamation as a SGWCA was precipitated by the realization that the groundwater stored in the alluvial deposits adjoining the river, and which was increasingly being exploited by farmers for irrigation purposes in the late 1970s, was being recharged from the river (Hobbs, 1982). Initially limited to a northern (downstream) portion proclaimed in 1981, the SGWCA was extended to the south (upstream) by a further proclamation in 1983, and it is this portion that occurs in the map area.

The Schoonspruit (Ventersdorp Eye) SGWCA was proclaimed in 1995. It is situated north of Ventersdorp and encompasses the catchment of the Schoonspruit dolomitic compartment. The necessity for control was again prompted by the need to protect the flow of the spring, which supplies the town of Ventersdorp with drinking water, from being impacted on by the uncontrolled abstraction of groundwater for irrigation purposes.

6.6 Groundwater management

The management of water resources essentially entails assessing their sustainable delivery capacity and controlling the use accordingly. The management of groundwater has, however, not reached the level of sophistication already achieved in the management of surface water resources. This is due mainly to the classification of groundwater as private water in the previous Water Act (No. 54 of 1956), so that the control required for management by the DWAF could only be exercised in proclaimed areas (Section 6.5). This limitation has been removed by the new National Water Act (No. 36 of 1998), which draws no legal distinction between surface water and groundwater. As such, it provides the DWAF with a legal basis to extend the management of the nation's water resources to include all groundwater. Other factors that have contributed to the situation include a lack of reliable quantitative estimates of groundwater storage and uncertainties related to the areal extent and temporal variability of recharge. Since the development of methodologies to derive aquifer characteristics, numerical (mathematical) modelling has become a useful aquifer management tool which also extends to the predictive modelling of groundwater pollution and related problems (Bredenkamp, 1995).

The over-exploitation of groundwater resources is a common problem in areas where extensive irrigation is practiced

Table 43. Recommended geophysical techniques for groundwater exploration

GROUP / FORMATION	GEOPHYSICAL METHOD AND RATING ••• Essential / •• Useful / • Not essential					
	Electrical resistivity soundings	Electrical resistivity profiling	Electromagnetic		Magnetic	Gravity
			EM34-3	Genie SE-88		
Basement Complex	•••	••	•••	••	••	
Dominion Group	•••	•	•••	••	••	
West Rand Group	••	••	•••	•••	••	
Central Rand Group	••	••	•••	•••	••	
Klipriviersberg Group	•••	•	••	••	•	
Kameeldoorns Formation	•	••	••	••	•	
Makwassie Formation	•••	•	••	••	•	
Rietgat Formation	•••	•	••	••	••	
Bothaville Formation	•••	••	••	••	•	
Allanridge Formation	•••	••	••	•••	••	
Dennilton Formation	•••	•	••	••	••	
Bloempoort Formation	•••	•	••	••	••	
Black Reef Formation	•	••	••	••		
Chuniespoort Group			••	••	••	•••
Timeball Hill/Rooisloot Formation(s)	•••	••	••	••	•	
Hekpoort Formation	•••	•	•••	••	•	
Daspoort Formation	•	••	••	••	••	
Silverton Formation	•••	•••	••	••	•••	
Magaliesberg Formation	•	•	••	••	••	
Rayton Formation	•	•	••	••	•	
Dullstroom Formation	•	•	••	••	•	
Rooiberg Group	•	••	•••		•••	
Loskop Formation	•••	•	••	••	•	
Rashoop Granophyre Suite	•••	••	•••	•••	••	
Rustenburg Layered Suite	•••	••	•••	•••	••	
Lebowa Granite Suite	•••	••	•••	•••	••	
Wilge River Formation		••	•••		•••	
Alkaline Complexes	•••	•	••	••		
Dwyka Group	•••	••	•••	•••	••	
Vryheid Formation and intrusive dolerite	•••	•••	•••	•••	•••	
Ecca Group	••	••	•••	•••	•••	
Irrigasie Formation	••	••	•••	•••		
Clarens Formation		••	•••	••	•••	
Letaba Formation	•••	•	•••	••	••	

or where groundwater represents a substantial source of water for urban and/or industrial (including mining) use. Groundwater management practices entailing accurate measurements of groundwater levels, abstraction and rainfall on a routine basis, and better definition of natural inflows to and outflows from groundwater systems, provide a means to establish and maintain the sustainable exploitation of these resources. The DWAF operates, maintains and services numerous observation boreholes dedicated to the measurement of groundwater levels in the map area. The majority of these stations focus on monitoring groundwater level fluctuations in the various dolomitic groundwater compartments. Some of the monitoring stations incorporate automatic water level recorders, whereas the measurement and recording of groundwater levels in others is performed by hand. The typical frequency of measurement is monthly. The data collected in this manner are available on request from the DWAFs Directorate Geohydrology, the custodian of national groundwater information, in Pretoria.

It is equally important to monitor the quality of groundwater on a regular basis in order to detect any changes, particularly deterioration, in advance. The frequency of sampling depends largely on the water use (human, agricultural and industrial) and the vulnerability of the groundwater system to pollution. The chemical elements and parameters that need to be determined analytically depend on the water use and most likely nature of the pollution. Groundwater samples are most commonly analyzed for their major ion composition. Trace element concentrations are generally determined to establish industrial pollution, and bacteriological concentrations to establish the contamination of drinking water by bacteria.

6.7 Groundwater pollution

Groundwater, like surface water, is vulnerable to pollution. The vulnerability of dolomitic aquifers is especially high due to the large volumes of groundwater they can contain and the often rapid rate at which surface water can enter these systems via streams and surface depressions. A groundwater system containing contaminated groundwater is also very difficult to clean up.

High concentrations of nitrate have been introduced into groundwater systems via pit latrines in informal settlements/ squatter camps, via cattle kraals and feedlots, from sewage plant effluent and, to some degree, also from the excessive use of fertilizer in agriculture. Especially the rural areas in the northern portion of the map area show a susceptibility to nitrate contamination.

Other potential sources of pollution are waste disposal sites. The establishment (or closure) of such sites is strictly controlled by the DWAF in order to protect the water resources of the country. Despite the vulnerability of dolomitic aquifers to pollution, there are some 32 waste disposal sites in the Highveld region that overlie, either directly or indirectly, dolomitic formations (Kok, 1993). The undesirable practice of using excavated depressions on Karoo rocks as convenient and inexpensive landfill sites is being curtailed.

The distribution and location of the various mining activities in the map area are shown in Figure 4. The potential contribution of these activities to the degradation of water quality within and downstream of their areas of influence is substantial. The nature of this degradation relates mainly to elevated sulphate concentrations. Raised levels of sulphate therefore serve as a conservative tracer of the degree and extent of mining-related pollution in an area. This characteristic is common to gold, coal and platinum mines.

A further characteristic of mining-related water pollution is a low pH value (less than 4) indicative of acid water produced by mine drainage. These characteristics are produced by the oxidation of the pyrite mineral contained in the ore and waste rock. This mineral is present in the surface rock piles, in sand and slimes dumps, in backfill material and spoil heaps, and in stopes and haulages. The pyrite oxidizes to sulphuric acid when exposed to air and water. Further chemical reaction results in the generation of sulphate and the leaching of heavy metals from the material. An increase in salinity (EC) values and total dissolved salts (TDS) concentrations also generally accompanies an increase in sulphate levels.

Plate 10. Acid rock drainage from a defunct opencast coal mine in the Vryheid Formation. White coating on rocks and elsewhere represents precipitated salts. (Photo: F von M Wagener)

The identification of polluted areas in dolomitic aquifers of the PWV area was attempted by Walton *et al* (1993) from an examination of available water quality records contained in the DWAFs Water Quality Data Base. Boreholes previously identified as producing polluted groundwater were resampled with the aim of establishing the type, the magnitude and the temporal variation of the contamination. The study succeeded primarily in identifying areas of local contamination. Similarly, groundwater pollution in areas of coal mining activity is generally localized. This might be ascribed to the fact that the groundwater level generally follows the topography, and any contaminant plume therefore spreads to the nearest stream or river where it emanates as seepage. For instance, many of the rivers and streams that drain the coal mining areas in the eastern part of the map area show elevated sulphate and salinity values.

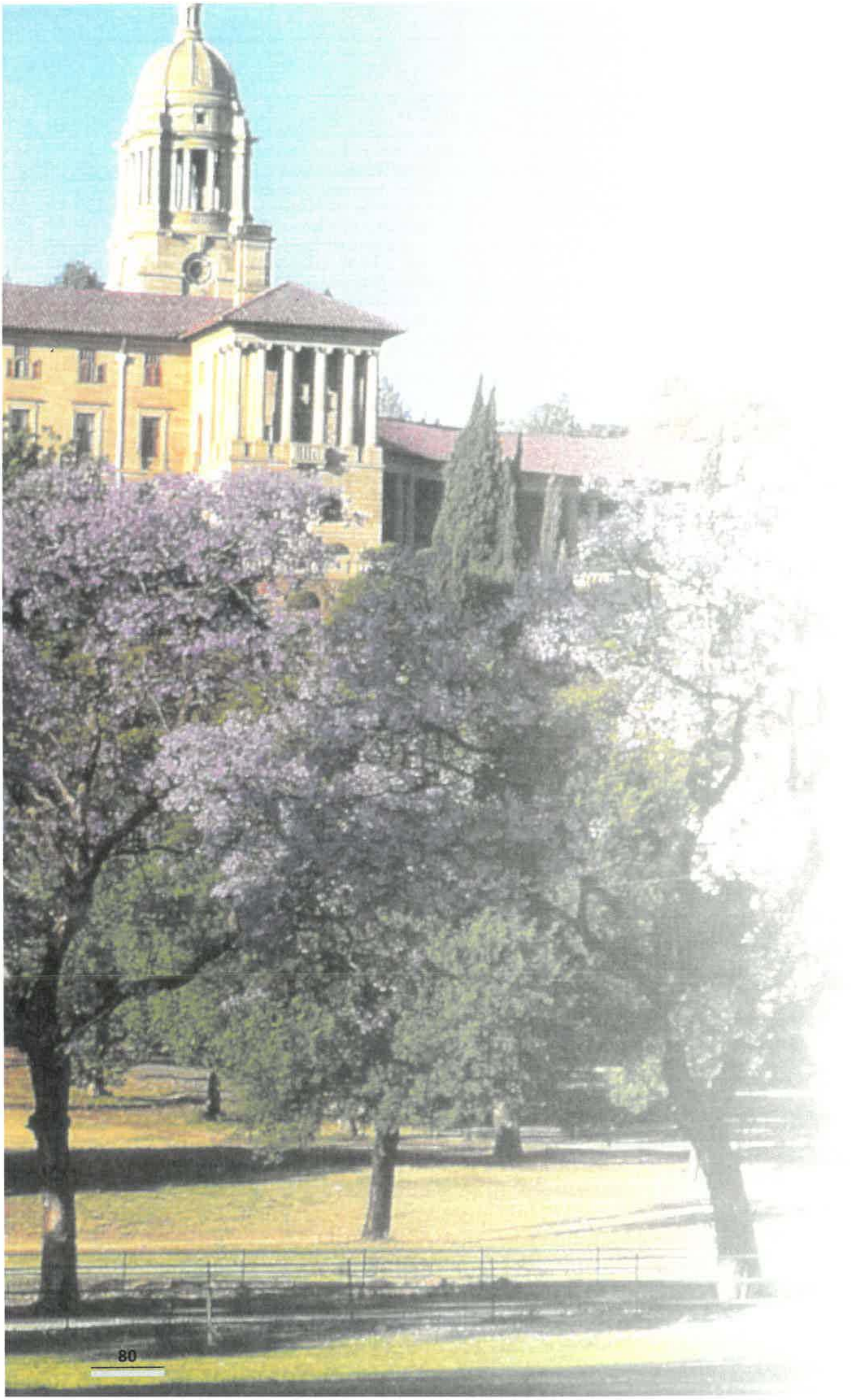
A further source of pollution are bacteriological constituents which occur in the effluent produced by sewage works that do not function properly or that dispose of their effluent into rivers and streams. Particularly sensitive drainages are those that traverse dolomitic groundwater systems. Examples of these are the Klipriver traversing the Klipriver compartment, the Sesmylspruit/Hennops River crossing the West Fountain, West Doornkloof and East Doornkloof compartments, the Blesbokspruit of the East Rand Basin and the Rietspruit that flows across the Steenkoppies and Zwartkrans compartments.

6.8 Groundwater utilization

Groundwater is the only source of water supply in many places, especially rural areas, where it is used mainly for domestic and stock watering purposes. The agricultural sector, however, remains the largest consumer of groundwater in the map area. Localities where groundwater abstraction occurs on a large scale in the map area are listed in Table 44 together with an indication of the quantities involved.

Table 44. Locality and magnitude of large-scale groundwater abstraction

<table>
<tr><th rowspan="2">LOCALITY / AREA</th><th rowspan="2">SOURCE</th><th colspan="3">APPROXIMATE ABSTRACTION (million cubic metres per annum)</th></tr>
<tr><th>Municipal</th><th>Agricultural</th><th>Mining</th></tr>
<tr><td>Lichtenburg</td><td>Municipality (1998)</td><td>3.6</td><td>9.5</td><td></td></tr>
<tr><td>Coligny</td><td>Municipality (1994)</td><td colspan="2">0.1</td><td></td></tr>
<tr><td>Ventersdorp</td><td>Kotze et al (1994)</td><td>2.5</td><td>27</td><td></td></tr>
<tr><td>Hartbeesfontein</td><td>Municipality (1994)</td><td>0.3</td><td></td><td></td></tr>
<tr><td>Koster</td><td>Municipality (1995)</td><td>0.1</td><td></td><td></td></tr>
<tr><td>Kroondal-Marikana</td><td>Odendaal (1983)</td><td colspan="2">24</td><td></td></tr>
<tr><td>Holfontein Compartment</td><td>Bredenkamp et al (1986)</td><td colspan="2">6</td><td></td></tr>
<tr><td>Steenkoppies Compartment</td><td>Barnard (1997)</td><td>2</td><td>19</td><td></td></tr>
<tr><td>Zwartkrans Compartment</td><td>Bredenkamp et al (1986)</td><td colspan="2">18</td><td></td></tr>
<tr><td>Pretoria-Verwoerdburg area</td><td>Hobbs (1988)</td><td>4.1</td><td></td><td></td></tr>
<tr><td>Delmas/Bapsfontein Compartment</td><td>Leskiewicz (1984b)</td><td>6</td><td>5</td><td></td></tr>
<tr><td>Varkfontein/East Rand Compartment</td><td>Leskiewicz (1984b)</td><td>1</td><td>2.5</td><td>24.5</td></tr>
<tr><td>Natalspruit Compartment</td><td>Kafri et al (1985)</td><td></td><td>20.4</td><td></td></tr>
<tr><td>Klipriver Compartment</td><td>Kafri et al (1985)</td><td>1.3</td><td>23</td><td></td></tr>
<tr><td>Zuurbekom Compartment</td><td>Fleisher (1981)</td><td>10</td><td></td><td>7.6</td></tr>
<tr><td>Gemsbokfontein Compartment</td><td>Leskiewicz (1984a)</td><td></td><td>1.5</td><td>43.2</td></tr>
<tr><td>Venterspost Compartment</td><td>Fleisher (1981)</td><td></td><td></td><td>27</td></tr>
<tr><td>Bank Compartment</td><td>Fleisher (1978)</td><td></td><td></td><td>36</td></tr>
<tr><td>Midrand/Kempton Park Compartment</td><td>Kuhn (1989)</td><td colspan="2">1.6</td><td></td></tr>
<tr><td>Oberholzer Compartment</td><td>Fleisher (1981)</td><td colspan="2"></td><td>19</td></tr>
<tr><td>Crocodile River Valley</td><td>Hobbs (1982)</td><td colspan="2">25</td><td></td></tr>
<tr><td>Balfour</td><td>Wiegmans et al (1983)</td><td>0.1</td><td></td><td></td></tr>
<tr><td>Southern Springbok Flats</td><td>Zwarts (1987)</td><td colspan="2">29</td><td></td></tr>
</table>



7 Recommended future studies

It is recommended that topics which are identified as possibly worthwhile for future study and further characterization of groundwater resources in the map area be integrated into the much broader objective of catchment management as is championed in the National Water Act (No. 36 of 1998). This implies that any such studies should be directed at addressing and meeting the perceived needs of a Catchment Management Agency specifically in regard to groundwater resources. It implies further that a suitable "theatre" should be identified within which the desired integration of hydrogeological investigations and catchment management can be explored and acted out. The following list of topics is presented for consideration.

- The hydrogeological mapping and groundwater resource evaluation of the dolomitic formations in areas where these rock types disappear beneath other rock formations such as the sedimentary rocks of the Karoo Supergroup or quartzites of the Pretoria Group. The high yield potential of the dolomitic aquifers might be put to effective use in providing smaller towns or rural communities with an economical water supply.

- The identification of geological structures associated with brittle failure, especially those occurring within otherwise competent rock types such as quartzite, in order to assess and, if established, possibly utilize their groundwater yield potential.

- Pollution of the groundwater contained in dolomitic aquifers especially in areas where these groundwater systems underlie a high urban, peri-urban and/or informal population density.

- Pollution of surface and groundwater resources from mining activities and operations, including the impact that flooding of defunct opencast and underground mines may have on the groundwater environment.

Pursuing the issue of catchment management, it is suggested that implementation of any of the listed studies be performed against two backdrops both promulgated by the National Water Act of 1998. One of these is the registration and licensing of (ground)water use. The other concerns expanding the data base of national groundwater information. Such information can be derived from any borehole sunk for whatever purpose, and therefore includes individual low-volume domestic uses, multiple-source large-scale abstractions for urban water supply or irrigated agriculture, and even includes the exploration of the groundwater regime for environmental management purposes in the mining environment.

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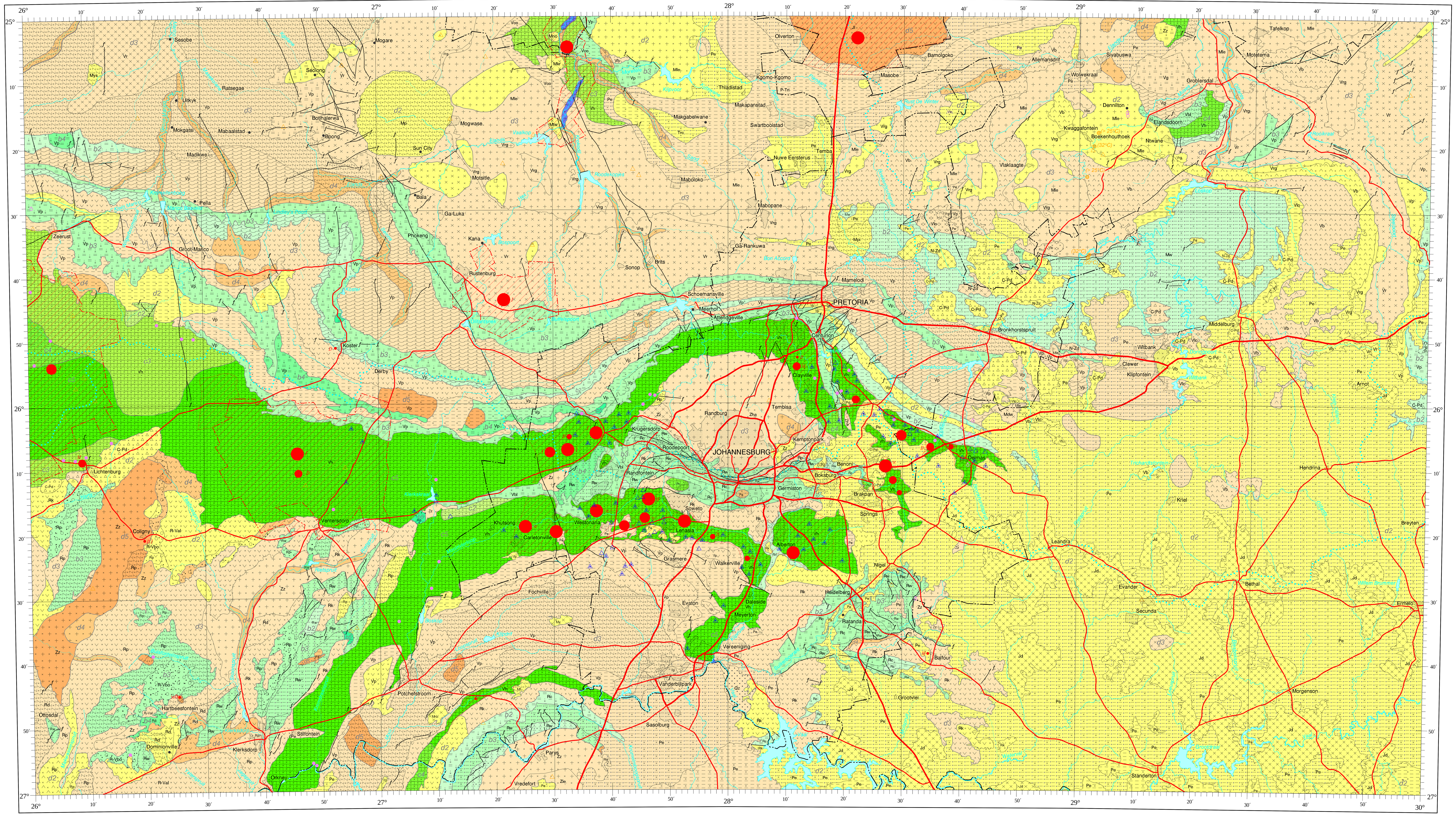
Notes



JOHANNESBURG

1999

10 0 10 20 30 40 50 60 km

Lambert´s conformal conic projection. Standard parallels 26°40´ & 33°20´. Central meridian 28°. Spheroid Clarke 1880.

Map Author - H.C. Barnard

GIS Specialist - E. Baran

Cartographer - E. Baran

Assisted by:
Mapping Management Team:
P.Seward, P.S. Meyer, H. Mullin, F. Jonck and A.E. Conley

This map was approved by the Director-General of the Department of Water Affairs and Forestry.

The groundwater occurrence and groundwater quality maps, and the schematic cross-sections, were compiled by H.C. Barnard. The lithology was adapted by H.C. Barnard from 1 : 250 000 scale published Geological map series. Permission from the Council for Geoscience to make use of their information is gratefully acknowledged.

E. Baran was responsible for the complition of the borehole distribution map. Borehole data were obtained from the National Groundwater Data Base (NGDB). Precipitation and elevation data were obtained from the Computing Centre for Water Research, University of Natal, and compiled by H. Mullin. Information of roads, rivers, towns and provincial boundaries were obtained from the Chief Directorate: Survey and Mapping, Department of Land Affairs and edited by the Department of Water Affairs and Forestry.

Principal groundwater occurrence

Borehole yield class (median l/s) (excluding dry boreholes)

Aquifer type	0.0 - 0.1	0.1 - 0.5	0.5 - 2.0	2.0 - 5.0	> 5.0
Intergranular	*	*	*	*	a5
Fractured	*	b2	b3	b4	b5
Karst	*	c2	c3	c4	c5
Intergranular and fractured	*	d2	d3	d4	d5

Borehole yield boundary

Note: Groundwater occurrence depicts the aquifer type(s) with the highest borehole yield which does not always correlate with surface lithology.

Surface lithology

- Inland undifferentiated deposits (aeolian sand)
- Predominantly argillaceous rocks (shale, mudstone and siltstone)
- Predominantly arenaceous rocks (sandstone)
- Argillaceous and arenaceous rocks (approximately equal proportions)
- Predominantly carbonate rocks (dolomite)
- Predominantly rudaceous rocks (conglomerate, grit and breccia)
- Predominantly diamictite (tillite)
- Predominantly pyroclastic rocks (tuff, agglomerate and breccia)
- Ultramafic / mafic intrusive rocks (dolerite, diabase, gabbro, norite, carbonatite, anorthosite and pyroxenite)
- Acid / intermediate / alkaline intrusive rocks (various granitoids)
- Ultramafic / mafic extrusive rocks (basalt and andesite)
- Acid / intermediate / alkaline extrusive rocks (rhyolite, felsite and quartz porphyry)
- Predominantly meta-argillaceous rocks (slate and hornfels)
- Predominantly meta-arenaceous rocks (quartzite)
- Undifferentiated rocks and various mixed lithologies
- Lithological / stratigraphical boundary
- Fault
- Dolerite, syenite and diabase intruded

Large scale groundwater abstraction

- > 10 million m^3/a
- 5 - 10 million m^3/a
- 2 - 5 million m^3/a
- 1 - 2 million m^3/a
- 0.1 - 1 million m^3/a
- I Irrigation
- D Domestic
- Mining
- M Municipal
- Industrial

Area of large scale groundwater abstraction: Irrigation; Mining; Industrial

- Spring (> 5 l/s)
- Thermal spring (°C)
- Artesian borehole
- Single or more groundwater level recorder
- Single or more groundwater level monitoring points
- Groundwater quality monitoring points
- Primary drainage region boundary
- Primary / perennial river
- Secondary / perennial river
- Non-perennial river
- Dam
- Subterranean Government Water Control Area
- City / town area
- Town
- National road
- Main road; Inset map: National road
- Inset map: Main road
- Provincial boundary
- Not applicable to this map

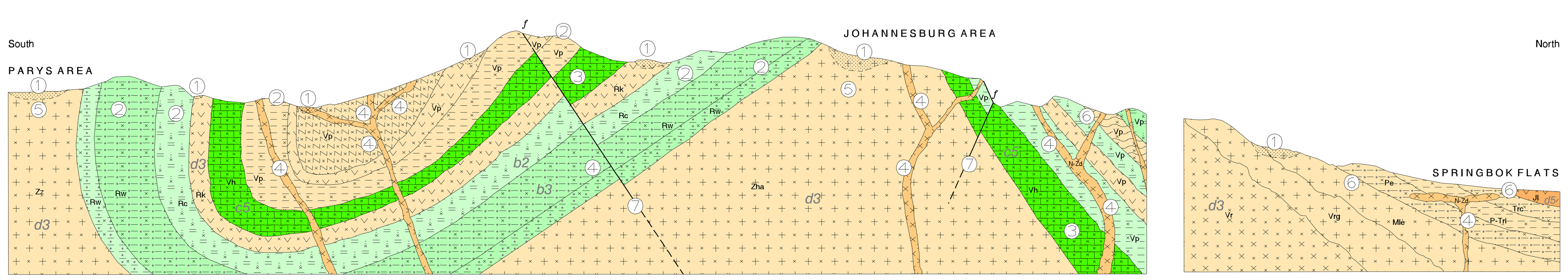
Chronostratigraphy

1	2	3	4	5	6
	PHANEROZOIC	Cenozoic	Quaternary	Q	Unnamed (Qz)
1.8			Tertiary	T	
65		Mesozoic	Cretaceous	K	
142			Jurassic	J	Lebombo G. (Jl); Dolerite (Jd)
205			Triassic	Tr	Clarens F. (Trc); Irrigasie F. (P-Tri)
248		Palaeozoic	Permian	P	Ecca G. (Pe); Dwyka G. (C-Pd)
290			Carboniferous	C	
354			Devonian	D	
417			Silurian	S	
443			Ordovician	O	
495			Cambrian	Є	
545	PROTEROZOIC	Namibian		N	
900		Mokolian		M	Pienaars River C. (Mpi); Pilansberg C. (Mp); Rietfontein C. (Mf); Roodekraal C. (Mro); Kruidfontein C. (Mkr); Nooitgedacht C. (Mno); Tweerivier C.(Mtw); Ystervarkkop C. (Mys); Waterberg G.(Mw); Dwarsfontein C. (Mdw); Losberg C. (Mx); Lebowa Granite S. (Mle)
2050		Vaalian		V	Rustenburg Layered S. (Vr); Rashoop Granophyre S. (Vrg); Loskop F. (Vlo); Rooiberg G. (Vb); Diabase (N-Zd); Pretoria G. (Vp) Crocodile River Fragment (Vco); Chuniespoort G. (Vh); Black Reef F. (Vbl); Groblersdal G. (Vg); Allanridge F.(R-Val); Bothaville F. (R-Vbo)
2650	ARCHAEOZOIC	Randian		R	Platberg G. (Rp); Klipriviersberg G. (Rk); Central Rand G. (Rc); West Rand G. (Rw); Dominion G. (Rd)
3100		Swazian		Z	Halfway House Granite (Zha); Inlandsee-Leucogranofels (Zie); Unnamed Swazian Rocks (Zz)

1 = Million years before present (Council for Geoscience, 1997)
2 = Eonothem (Eon)
3 = Erathem (Era)
4 = System (Period)
5 = Symbol
6 = Complex (C), Suite (S), Group (G), Formation (F)(with symbol)

Schematic cross-sections to illustrate typical groundwater occurrence

Not to scale



Groundwater occurs in:

1. Basins of weathering occurring mostly in igneous rocks
2. Joints and fractures in competent arenaceous rocks related to tensional or compressional stresses and off-loading
3. Solution channels and fractures occurring in the carbonate rocks of the Chuniespoort Group
4. Joints and fractures occurring in contact zones related to the heating and cooling of country rock, caused by the intrusion of dykes and sills
5. Fractures in transitional zones between weathered and unweathered rocks
6. Along sedimentary or sedimentary / igneous rock contacts. A contact may either be open, weathered or fractured due to it being an unconformity, or fractured due to movement along the contact, or fractured due to heating and subsequent cooling related to large extrusive or intrusive events.
7. Faults and associated shear zones

Weathered zone: Predominantly decomposed

Note: For additional information concerning groundwater occurrence refer to accompanying brochure.

The general hydrogeological map is part of the 1 : 500 000 Hydrogeological map series of the Republic of South Africa.

This map is not to be used for the purpose of local borehole siting. Simplified lithology may be considered as guidelines only. Further geological information can be obtained from the Council for Geoscience. The map series is produced with Arc/Info software.

Digital data, copies of this map and accompanying brochure are obtained from:

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Pretoria
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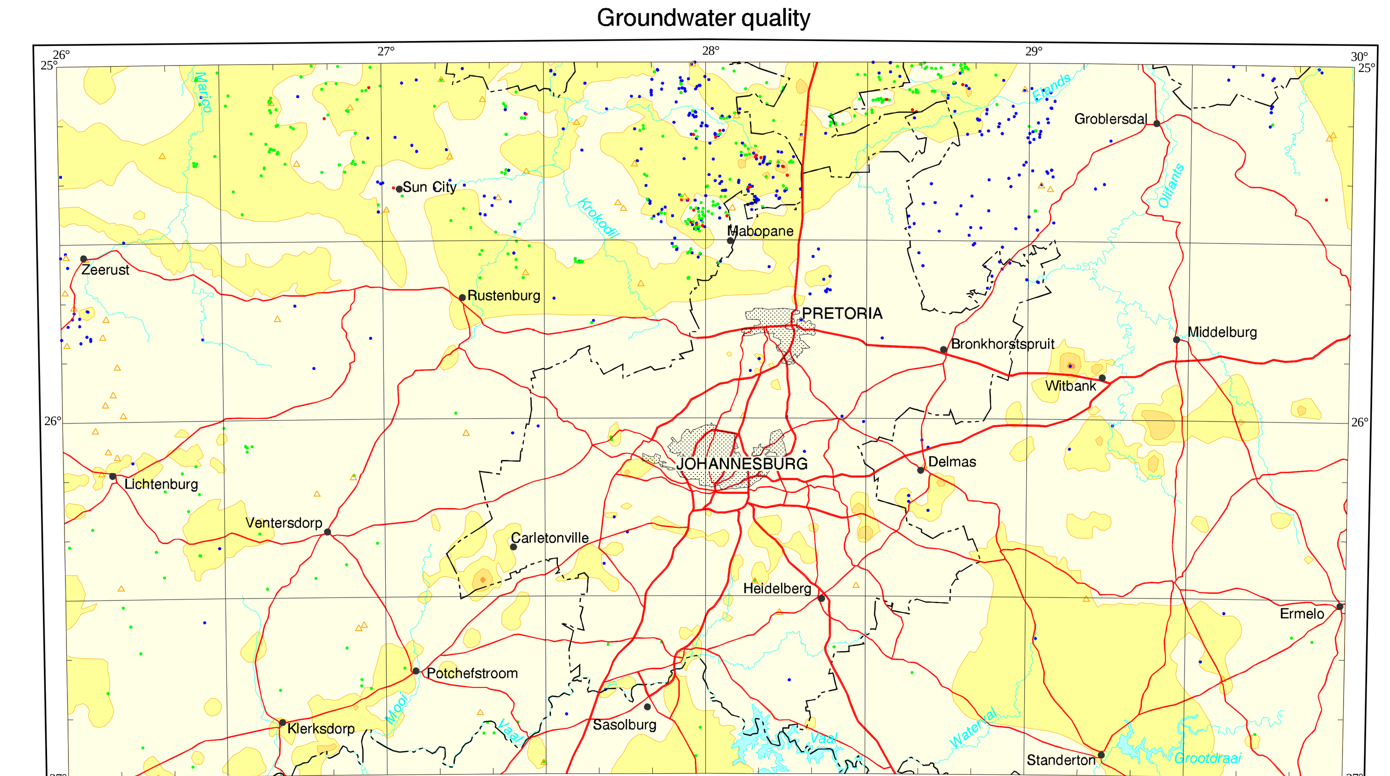
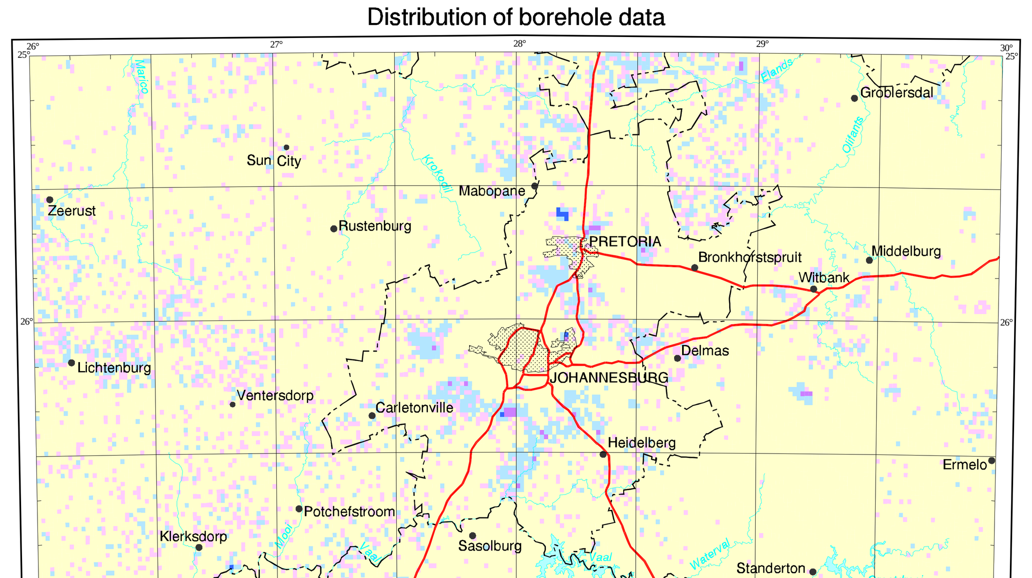
Groundwater quality



- 0 - 70 mS/m
- 70 - 300 mS/m
- 300 - 1000 mS/m
- > 1000 mS/m
- Electrical conductivity contour
- Groundwater quality monitoring points
- Groundwater chemistry: N(NO3 + NO2) > 10mg/l; F > 1,5mg/l; N(NO3 + NO2) > 10mg/l & F > 1,5 mg/l

1:1 500 000

Distribution of borehole data

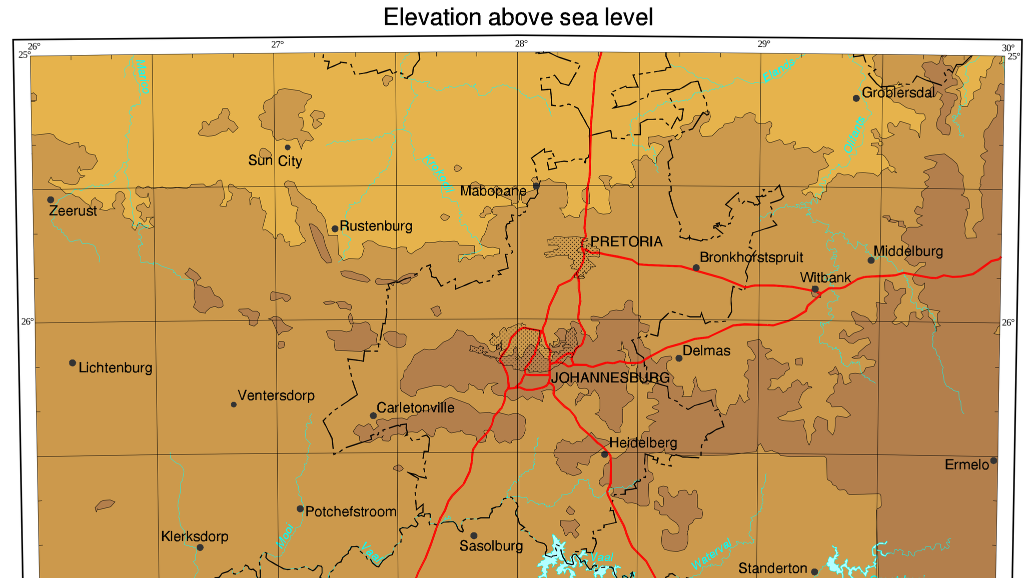


- No borehole information
- 1 Borehole
- 2 - 10 Boreholes
- 11 - 20 Boreholes
- > 20 Boreholes

Borehole data points per 1 minute grid

1:2 000 000

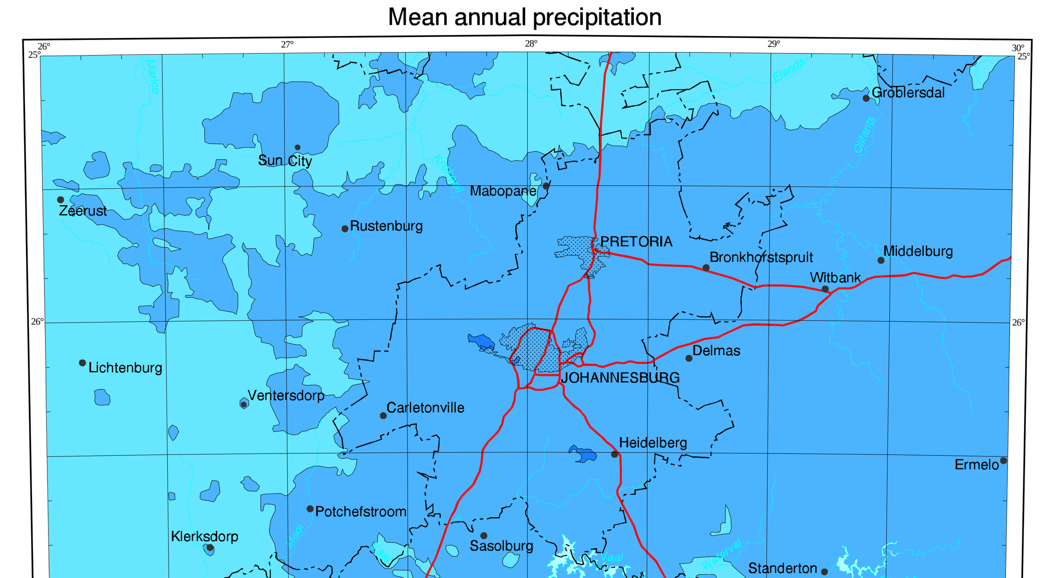
Elevation above sea level



- sea level - 200m
- 200 - 400 m
- 400 - 800 m
- 800 - 1200 m
- 1200 - 1600 m
- 1600 - 2000 m
- 2000 - 2500 m
- > 2500 m

1:2 000 000

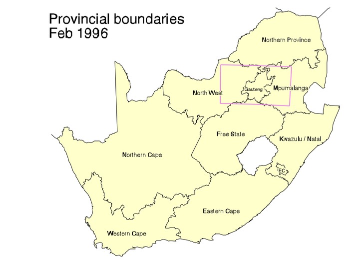
Mean annual precipitation



- 0 - 100 mm
- 100 - 200 mm
- 200 - 300 mm
- 300 - 400 mm
- 400 - 600 mm
- 600 - 800 mm
- 800 - 1000 mm
- > 1000 mm

1:2 000 000

Provincial boundaries Feb 1996



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