An Explanation of the 1:500 000 General Hydrogeological Map

Oudtshoorn 3320

By: P.S. Meyer

August 1999

DEPARTMENT OF WATER AFFAIRS AND FORESTRY

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FOREWORD

Groundwater in South Africa as a whole is under-utilised, although some local over-exploitation does occur. Groundwater schemes can generally be implemented more rapidly and at lower cost than comparative surface water schemes. They 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 sheet is an example, is to display in an easily understood format what is known about basic geohydrological properties. These General Maps represent a synthesis of the most up-to-date data and geohydrologists' knowledge. These maps are also very useful in identifying areas where additional data need to 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.

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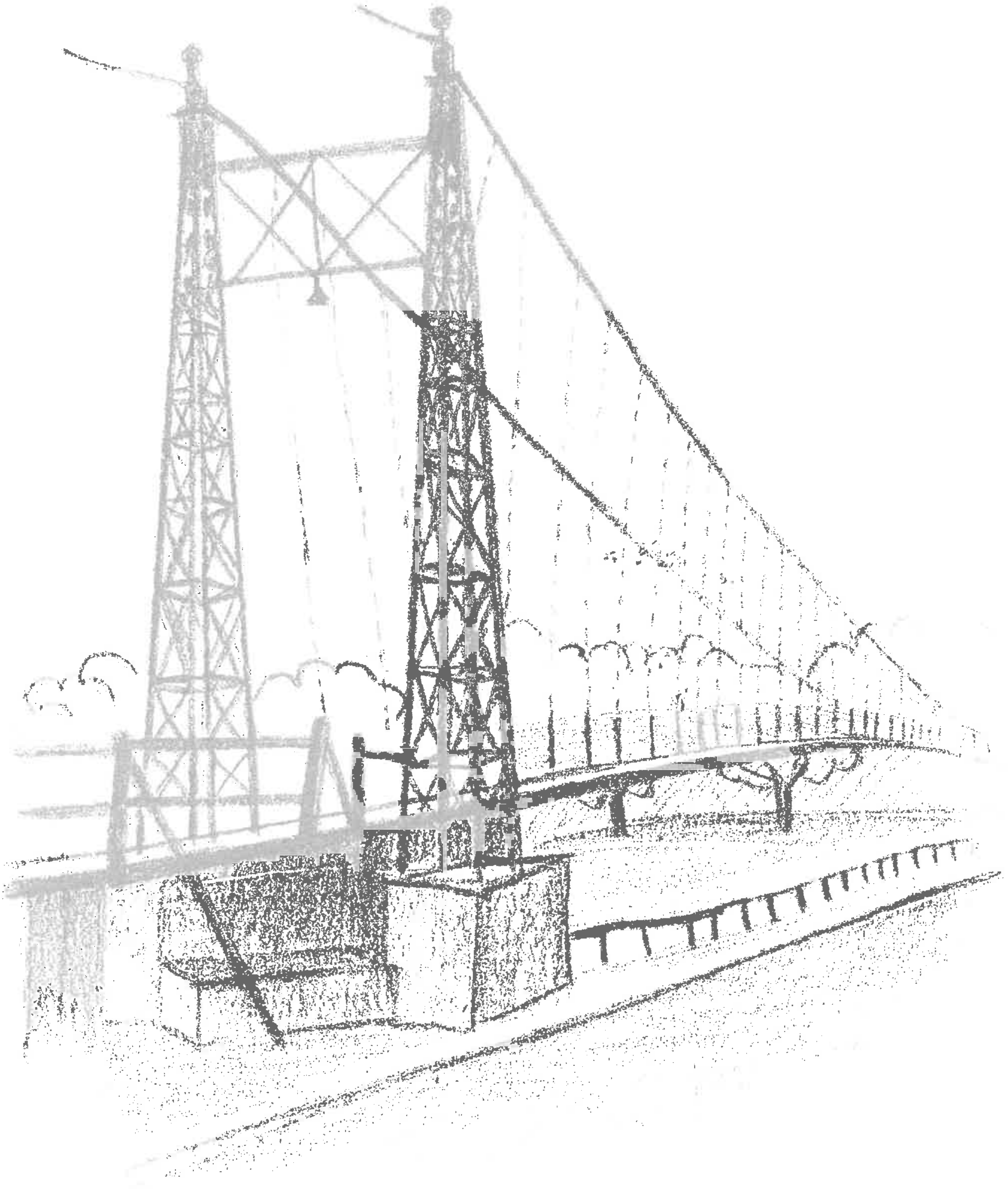


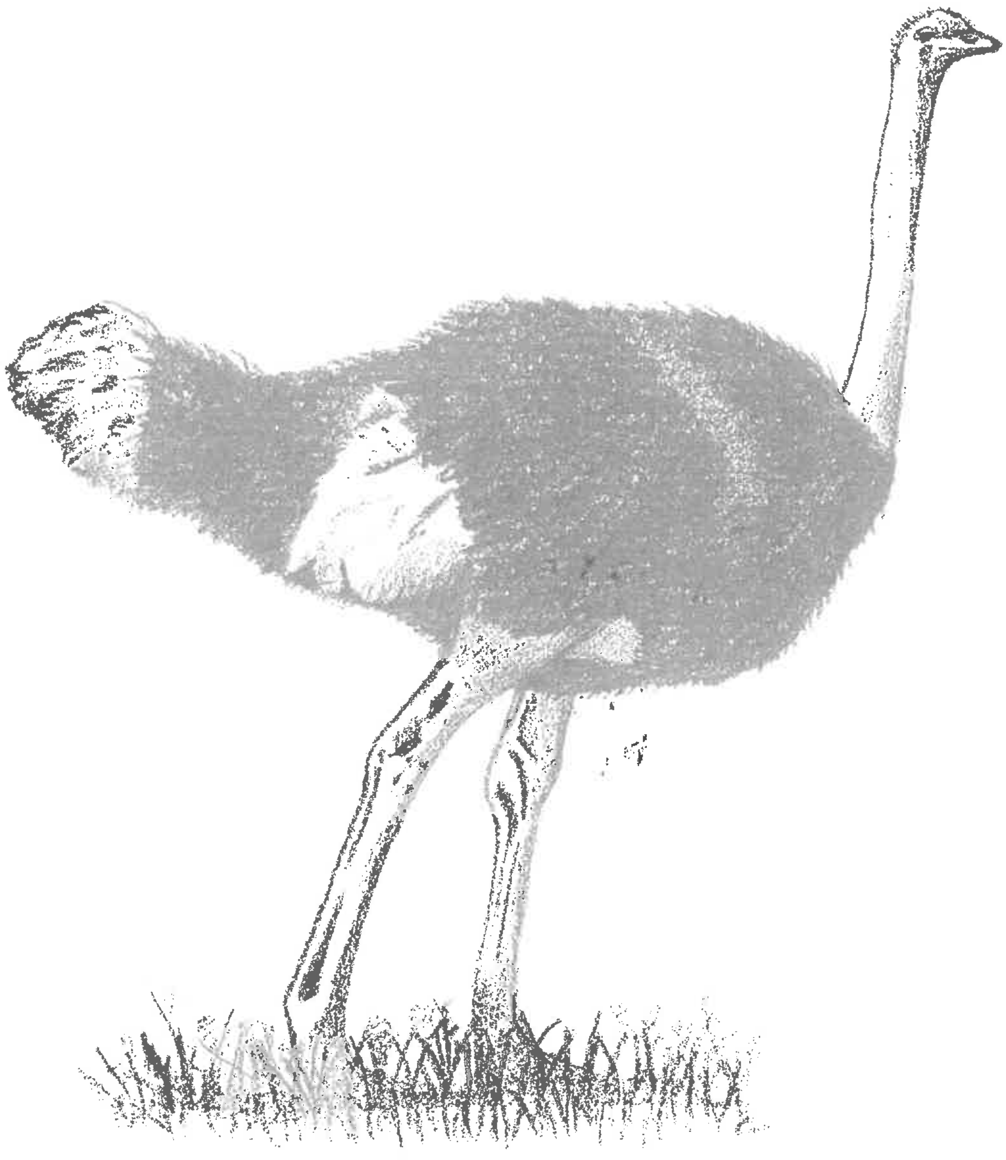
PREFACE

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 97% occurs underground (Johnson Division, 1975). To tap and develop this vast amount of underground stored water, a keen knowledge of a region's environment, and above all, its diversified geology, is of the utmost importance in order to comprehend how and where groundwater occurs.

The Oudtshoorn 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. Rough mountainous terrain and undulating plains, wet rainforest vegetation to dry semi-desert shrubland; old metamorphosed rocks to recently deposited unconsolidated sands and alluvium; highly competent quartzitic sandstones containing numerous fractures in contrast to dense, incompetent, fracture-free shales and mudstones; and solid to weathered granitic rocks, are but a few of the diversities. Under these circumstances various groundwater distinctives and characteristics can be expected, most of which have been referred to in this 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 type, groundwater quality and groundwater use, which are superimposed against a somewhat subdued surface 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 methods, groundwater management, groundwater levels, suggestions for the 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, especially in the light of the Reconstruction and Development Programme, and that they will play a constructive 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 basis for future specialized groundwater maps and groundwater studies as suggested in this brochure.



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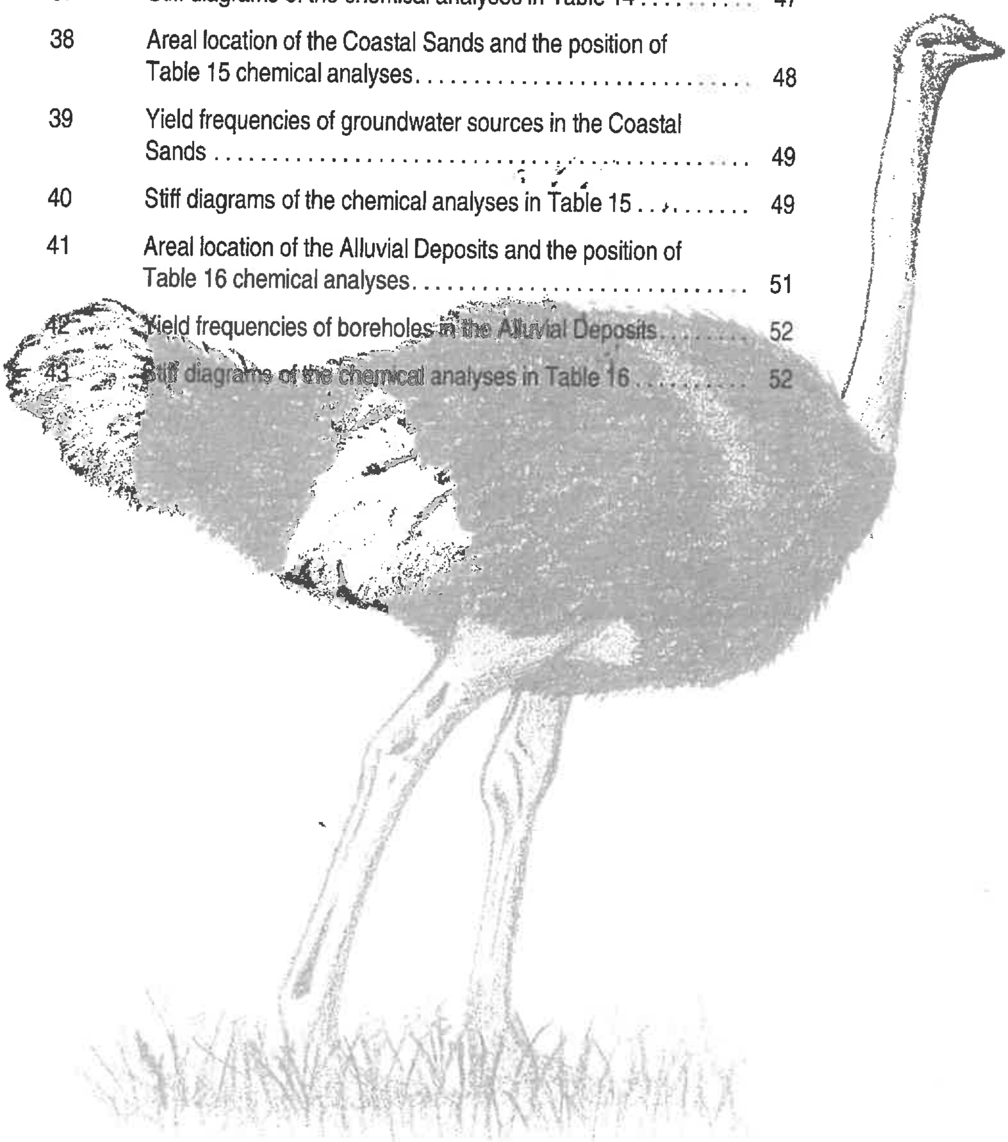

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Cover photograph:

A view of Groenvlei (Lake Pleasant) east of Sedgefield. Groenvlei is a true groundwater-fed lake situated in the Sedgefield primary aquifer. It has no surface water inlet or outlet and is the only groundwater-fed lake within the confines of the Cape Fold Belt.

ABBREVIATIONS AND UNITS

Abbreviations

AEC	Atomic Energy Corporation
CFB	Cape Fold Belt
DWAF	Department of Water Affairs and Forestry
CSIR	Council for Scientific and Industrial Research
EC	Electrical Conductivity
GIS	Geographic Information System
IWQS	Institute for Water Quality Studies
NGDB	National Groundwater Data Base
NWQDB	National Water Quality Data Base
SABS	South African Bureau of Standards
TAL	Total Alkalinity
TDS	Total Dissolved Solids
TMG	Table Mountain Group
UNESCO	United Nations Educational, Scientific and Cultural Organisation

Units

a	annum
km	kilometre
ℓ	litre
ℓ/s	litre per second
m	metre
m^2	square metre
m^2/d	square metre per day
m^3	cubic metre
m^3/a	cubic metre per annum
mg	milligram
mg/ℓ	milligram per litre
mm	millimetre
mS/m	milliSiemens per metre
s	second

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Compilation of bar graphs

1 INTRODUCTION

1.1 Map Compilation

Extensive use was made of Arc/Info for cartographic compilation, data display and manipulation. Available borehole data from the National Groundwater Data Base (NGDB) was used and supplemented by field visits to areas of sparse data coverage. The delineation of the groundwater occurrence was outlined on a scale of 1:50 000 with extrapolation from hydrogeologically well defined areas into areas of data scarcity. The boundaries of groundwater occurrences were then drawn by hand to final scale. Additional changes and minor boundary alterations were done within GIS. The same methodology was used in the compilation of the 1:1 500 000 scale groundwater quality map, using data from the National Water Quality Data Base (NWQDB). The quality parameter that is expressed is the electrical conductivity (EC) of the groundwater. The EC intervals shown are taken from the Department of Water Affairs and Forestry (DWAF) guidelines for human and stock water consumption.

A few data limitations marred the borehole analyses. Due to a shortcoming in the NGDB, which does not distinguish between dry boreholes and boreholes with no yield data, dry boreholes had to be excluded from the borehole analyses. This is unfortunate, as information on dry boreholes can be helpful to determine an area's groundwater yield potential. The most common problem encountered was the lack of complete data records. This problem was compounded by the fact that probably the majority of boreholes on record were sited either non-scientifically or were, due to difficult terrain conditions, not positioned in the most optimum hydrogeological locations. To amend for these problems, the map author had to rely on the extrapolation of reliable borehole data and his knowledge of the hydrogeological conditions of the map area.

The map portrays the principal aquifers of the region. Thus the insignificant groundwater yield of a surface sand layer, for instance, would not be depicted if the underlying bedrock was of a higher yield potential.

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

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

- ❒ lithological occurrences too small to carry a polygon and a formation code were omitted,
- ❒ lithology boundaries have in places been smoothed and boundaries will not always correspond exactly to that of the geological maps, and
- ❒ where a large number of faults are concentrated, some have been deleted to eliminate overcrowding on the map.

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

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

1.2 Legend Explanation

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

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

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

The terminology adopted by the European hydrogeological mapmakers was used. This refers to the occurrence of groundwater and further subdivides according to the mode of occurrence. For this region 'intergranular' was used for the porous mode of occurrence, 'fractured' rock for the faulted and jointed, and 'fractured and intergranular' for the fractured and intergranular mode of occurrence. These divisions are then depicted using the colour scheme in Table 1.

TABLE 1: HYDROGEOLOGICAL CLASSIFICATION OF GROUNDWATER

Occurrence	Intergranular	Fractured	Karst	Fractured and Intergranular
Description	Generally unconsolidated but occasionally consolidated. Groundwater within interstices in porous medium and in basal conglomerate. Moderate areal extent.	Fissured and fractured bedrock resulting from decompression and/or tectonic action. Groundwater occurs predominantly within fissures and fractures. Extensive in area.	Water-bearing properties depend on fractures, joints and cavities in Namibian age calcareous rocks. Very limited in areal extent.	Largely medium to coarse grained granite, weathered to varying thicknesses, with groundwater contained in intergranular interstices in the saturated zone and in jointed and occasional fractured bedrock. Generally limited in areal extent.
Example	Tertiary-Quaternary coastal deposits. Alluvial deposits along river terraces.	Sedimentary and metamorphic rocks with limited overlying unsaturated residual weathered products.	Limestone and interbedded shale is particularly groundwater bearing in valleys where sizeable alluvial deposits occur.	
Yield (ℓ/s)	TYPE COLOUR AND COLOUR SHADES			
	BLUE	GREEN	OLIVE	YELLOW-BROWN
>5,0	Dark blue (a5)	Dark green (b5)	Dark olive (c5)	Dark brown (d5)
2,0-5,0	Blue (a4)	Green (b4)	Olive (c4)	Brown (d4)
0,5-2,0	Light blue (a3)	Light green (b3)	Light olive (c3)	Light brown (d3)
0,1-0,5	Pale blue (a2)	Pale green (b2)	Pale olive (c2)	Pale brown (d2)
0,0-0,1	Blue tinge (a1)	Green tinge (b1)	Olive tinge (c1)	Yellow tinge (d1)

1.3 Borehole Yield Distribution and Lithological Boundaries

From the 1:500 000 map it would appear that yield and lithology boundaries do not always coincide. The yield boundaries were determined from the best match to the available data, which may not always be conclusive. It may be speculated that rock competency and local recharge conditions could be major factors in the overall pattern of borehole yield distributions.

2 PHYSICAL ENVIRONMENT

2.1 Climate

The Klein-Karoo and Karoo regions have typically semi-desert climates, hot summers and mild winters with summer temperatures regularly exceeding 30°C. The coastal plain experiences moderate temperatures with December maximum average temperatures for George and Riversdale being 24 and 27°C respectively. Precipitation occurs year-round with average precipitation on the coastal plain varying between 432 mm at Riversdale and 867 mm at George. Precipitation diminishes rapidly northwards with average annual precipitation at Oudsthoorn in the Little Karoo and Prince Albert in the Karoo being 245 and 174 mm respectively. Precipitation is distinctly orographically influenced.

2.2 Physiography

The map area can roughly be divided into three physiographic regions, namely the coastal plain, the Klein-Karoo and the Karoo. These regions are divided by the Outeniqua-Tsitsikamma Mountain range in the south, and the Swartberg-Baviaanskloof Mountain range in the north striking parallel to the coastline. Both the coastal plain and the Klein-Karoo narrow considerably toward the east. This narrowing is caused by the merging of the two mountain ranges resulting in a large mountainous mass south of the Baviaanskloof Mountain range in the eastern portion of the map. A number of mountain peaks attain altitudes in excess of 1 500 m within the map area.

2.3 Surface Hydrology

The map area is drained by a network of rivers of which the Olifants-Gouritz River system (drainage numbers J091, J092, J093) is the most dominant. Numerous smaller southward flowing rivers such as the Keurbooms (K1060), Knysna (K1050), Goukamma (K1040), Kaaimans (K1030) and Great Brak (K1020) occur south of the Outeniqua-Tsitsikamma Mountain range.

3 GEOLOGY

3.1 Brief Description of the Geological Units

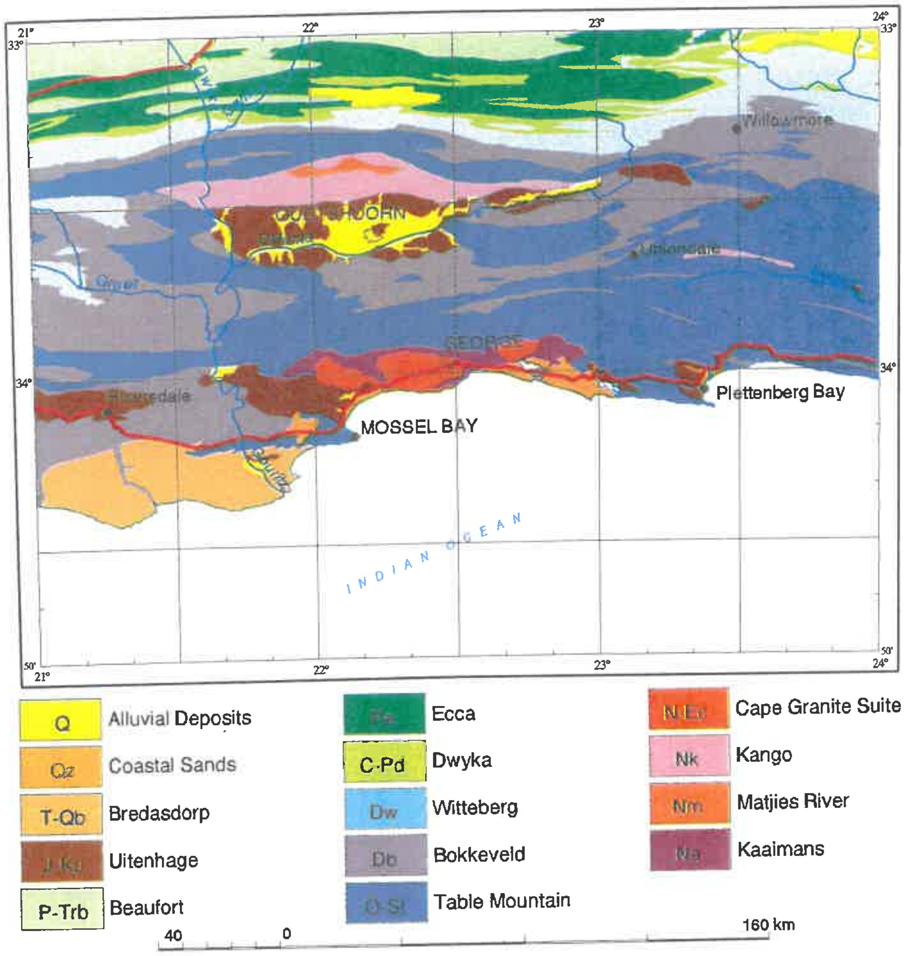
The map area is mainly underlain by sedimentary rocks of the Cape Supergroup and by the Karoo Supergroup further northward. Pre-Cape and post-Karoo rocks cover only small areas (Fig. 1).

The pre-Cape rocks comprise:

- phyllites, quartzites, grit hornfels and schist of the Kaaimans Group (Na) occupying the area south of the Outeniqua Mountains roughly between Mossel Bay and Knysna,
- granite of the Cape Granite Suite (N-Ec) which intruded the Kaaimans rocks, and
- the succession of shales, wackes, grits, conglomerates and limestones of the Kango Group (Nk) which occur in the vicinity south of the Swartberg, from northwest of Calitzdorp in the west and eastward to De Rust in the east.

The entire Cape Supergroup, comprising the lowermost Table Mountain, the Bokkeveld and the uppermost Witteberg Groups, is present and occupies the largest portion of the map

FIG 1: PRINCIPAL GEOLOGICAL UNITS



area. The predominantly arenaceous Table Mountain Group (O-St) unconformably overlies the pre-Cape rocks and is conformably overlain by the largely argillaceous beds of the Bokkeveld Group (Db) and the alternating shales and sandstones of the Witteberg Group (Dw).

The Karoo Supergroup, which occurs in the northern surrounds of the map, is represented by the basal glacial diamictite of the Dwyka Group (C-Pd), followed by the predominantly argillaceous Ecca Group (Pe), and shales and interbedded sandstones of the Beaufort Group (P-Trb).

Conglomerates and subordinate clays and sandstones of the post-Karoo Uitenhage Group (J-Ku) occur patchily south of the Langeberg and Outeniqua ranges around Heidelberg, Riversdale, Mossel Bay, Knysna and Plettenberg Bay, and further north between Calitzdorp and De Rust.

A variety of Tertiary to Quaternary (T-Qb) deposits cover older rocks along the coast. They consist essentially of unconsolidated to semi-consolidated shelly, calcareous sands and conglomerates of the Bredasdorp Group between Vermaaklikheid and Gouritzmond.

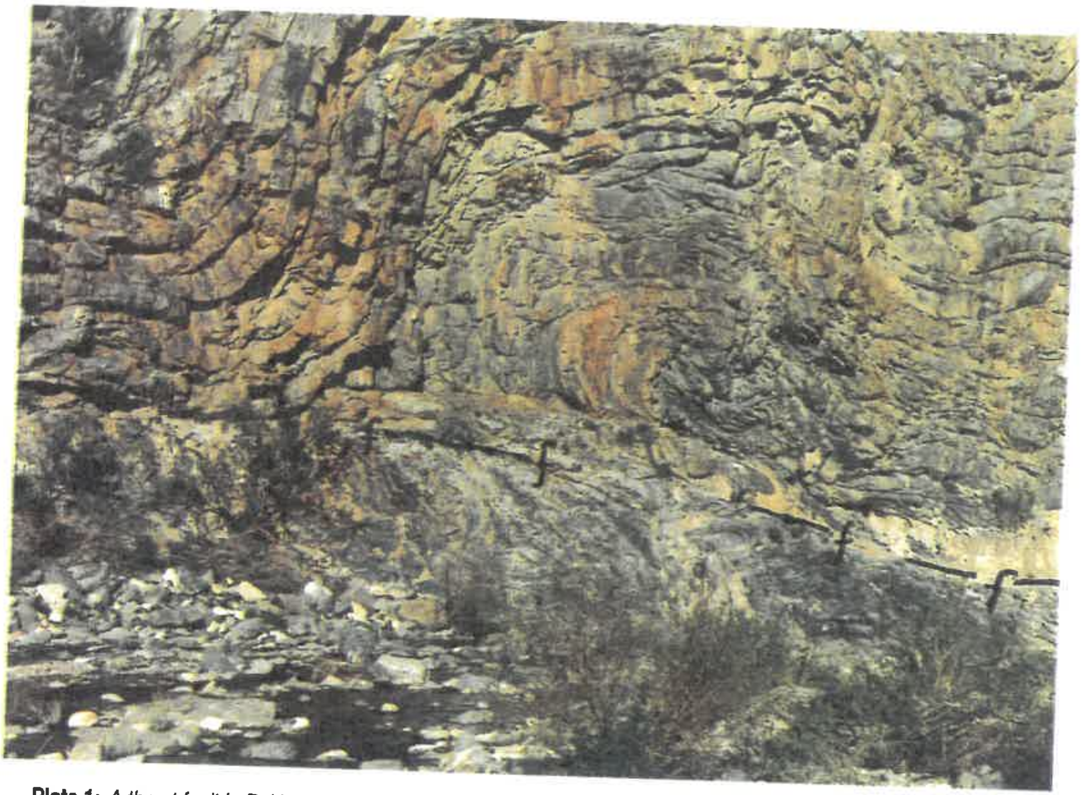


Plate 1: *A thrust fault in Bokkeveld Group sandstones in Meiringspoort between De Rust and Klaarstroom. Note the typical lack of fracturing (= almost zero fracture porosity) on the fault plane. (Photo: PS Meyer)*

Plate 2: *A fold structure in sandstone and shale of the Witteberg Group south of Ladismith. Fold structures like this increase fracture porosity in many strata of the Cape Fold Belt. (Photo: PS Meyer)*

Coastal Sands (Qz) were deposited on the coastal plain especially between Wilderness and Buffels Bay and at Keurbooms River mouth.

Alluvial Deposits (Q) occur along the valleys of larger river channels such as the Olifants and Gamka Rivers.

3.2 Structural Geology

The Cape Fold Belt (CFB) is largely east-west striking and is located approximately south of latitude 33°. It consists predominantly of sedimentary rocks, which were subjected to great pressure from the south, resulting in a variety of structural features.

The main structural characteristics of the CFB in the map area can be summarised as follows:

- The pre-Cape rocks indicate two deformational phases, succeeded by the Cape orogenic cycle which deformed both Cape and Karoo rocks (Theron et al,1991).
- The east-west elongated Cape Granite Suite is syntectonic with the pre-Cape deformation event. Low grade regional metamorphism accompanied this phase (Toerien, 1979).
- Intense folding produced large northward-directed asymmetric anticlines in the predominantly arenaceous and competent rocks of the Table Mountain Group and thus constitutes the backbone of the mountain ranges. Anticlines and synclines of parasitic asymmetric folds characterise the succeeding relatively incompetent formations (Toerien,1979).
- Overfolding and local thrusts are common features, especially along the northern boundaries of mountain ranges (Toerien,1979). A recent study by the Department of Geology of the University Port Elizabeth in the Knysna-Uniondale area suggest that thrust faulting (Plate 1) is considerably more prevalent than previously reflected and may constitute one of the most important structural features of the CFB in this area (Murray, 1996).
- The degree of deformation generally decreases considerably northwards (Theron et al, 1991).
- Reverse and normal faults (some of pre-Cape age) and numerous post-Cape strike faults with considerable displacements forming half-grabens are present (Toerien,1979).
- Brittle failure is often evident in the competent arenaceous units of the Table Mountain Group, but to a lesser degree in the arenaceous units of the Bokkeveld and Witteberg Groups. The relatively thin interbedded sandstones of the Ecca and Beaufort Groups show the least amount of brittle failure. Numerous minor fold structures abound in the incompetent strata of the Bokkeveld, Witteberg, Ecca and Beaufort Groups (Plate 2).

3.3 Intrusives

Apart from the pre-Cape Maalgaten and related granite (Cape Granite Suite) intrusions into the Kaaimans Group, dykes of fine-grained quartz-muscovite albite intruded the metasediments to the north of the granite contact (Krynauw,1983). Southwest and southeast striking dolerite dykes are also intrusive into the granites.

Mafic intrusions in the form of dykes and sills have intruded the rocks of the Kango Group (le Roux,1977).

4 HYDROGEOLOGY OF THE DIFFERENT GEOLOGICAL GROUPS AND FORMATIONS

4.1 Fractured Aquifers

Consolidated hard rocks cover approximately 92% of the map area (Table 2). This rock mass formed over a period of about 800 million years, experienced intrusion episodes in an early stage and subsequently endured several deformation phases. The deformation processes and succeeding orogenesis, continental uplift, weathering and erosion all aided in the development of the present groundwater environment. Competent rocks underwent brittle failure, resulting in numerous fracture structures in formations containing significant arenaceous material, thus furthering the formation of fracture porosity. In contrast, the incompetent rocks were more flexible and less inclined to break, thereby inhibiting the formation of fracture porosity.

The existence or absence of fracture structures and prevailing groundwater recharge conditions thus play a decisive role in the occurrence and characteristics of groundwater in the consolidated rocks of the Cape Fold Belt.

TABLE 2: DETAILS OF CONSOLIDATED ROCKS WITHIN THE MAP AREA

Geological Unit	1	2	3	4
Kaaimans (Na)	1,1	800-700	Sedimentary and Metamorphic	20:08
Cape Granite Suite (N-Ec)	1,4	610-530	Intrusive	*
Kango (Nk)	3,0	800-700	Sedimentary and Metamorphic	50:50
Table Mountain (O-St)	31,4	500-395	Sedimentary	90:10
Bokkeveld (Db)	22,5	395-365	Sedimentary	30:70
Witteberg (Dw)	8,0	365-345	Sedimentary	45:55
Dwyka (C-Pd)	3,1	340-325	Sedimentary (glacial)	20:80
Ecca (Pe)	10,9	325-240	Sedimentary	20:80
Beaufort (P-Trb)	5,4	240-230	Sedimentary	30:70
Uitenhage (J-Ku)	5,6	150-100	Sedimantary	20:80

* = Not applicable

1 = Percentage of map area covered by individual geological unit
2 = Approximate age in million years
3 = Geological origin
4 = Approximate ratio of arenaceous: argillaceous material

4.1.1 Kaaimans Group

The Kaaimans Group (Fig. 2) is divided into seven Formations, namely (maximum thickness and lithology in brackets): Silver River (1300 m; quartz schist); Saasveld (600 m; andalusite schist, hornfels, mica schist); Sandkraal (300 m; quartz schist); Skaapkop (260 m; gritty quartzite, phyllite, schist); Soetkraal (300 m; phyllite, schist, hornstone, quartzite); Victoria Bay (85 m; feldspathic quartzite) and Homtiti (1100 m; phyllite, grit, quartzite).

The following are the more important geological and groundwater characteristics:

- All the stratigraphic units strike roughly east-west and dip southwards.
- The rocks of the Kaaimans Group are primarily fine-grained metapelites and psammites (Gresse, 1983) and their argillaceous and clayey nature generally renders them less favourable for groundwater development.
- Despite the evidence that the Kaaimans Group has undergone several deformational episodes, the rocks generally show relatively little fracturing, and the Group is not known for advantageous groundwater potential.
- The Kaaimans Group rocks have been intruded by bodies of syntectonic granite, showing well-developed foliation and lineation parallel to the structure of the envelope (Gresse, 1983). These foliation and lineation patterns could in favourable recharge areas be utilized for groundwater exploitation.
- A borehole analysis indicates that 80% of boreholes yield less than 2 ℓ/s, and only 5% yield more than 5 ℓ/s (Fig. 3).
- Groundwater quality varies considerably, and ECs range between 30 and 650 mS/m. Sodium and chloride often exceed maximum recommended limits and may even exceed maximum allowable limits (Table 3). Groundwater from the Kaaimans Group is generally of a sodium-chloride nature (A in Fig. 4) and may to a lesser extent display a calcium-sulphate nature such as in the Saasveld Formation (B in Fig. 4).

FIG 2: AREAL LOCATION OF THE KAAIMANS GROUP AND THE POSITION OF TABLE 3 CHEMICAL ANALYSES

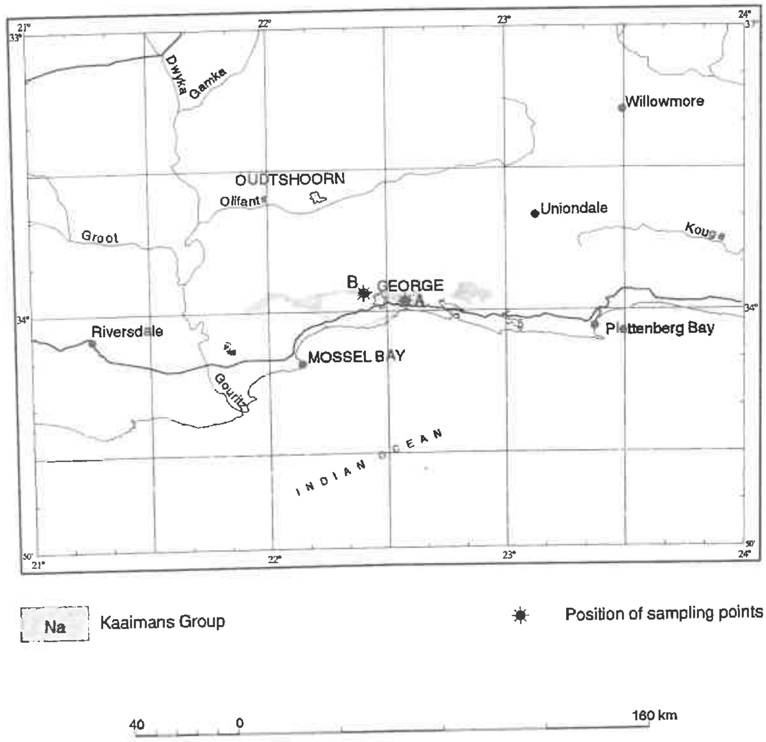


FIG 3: YIELD FREQUENCIES OF BOREHOLES IN THE KAAIMANS GROUP
(32 BOREHOLES ANALYSED)

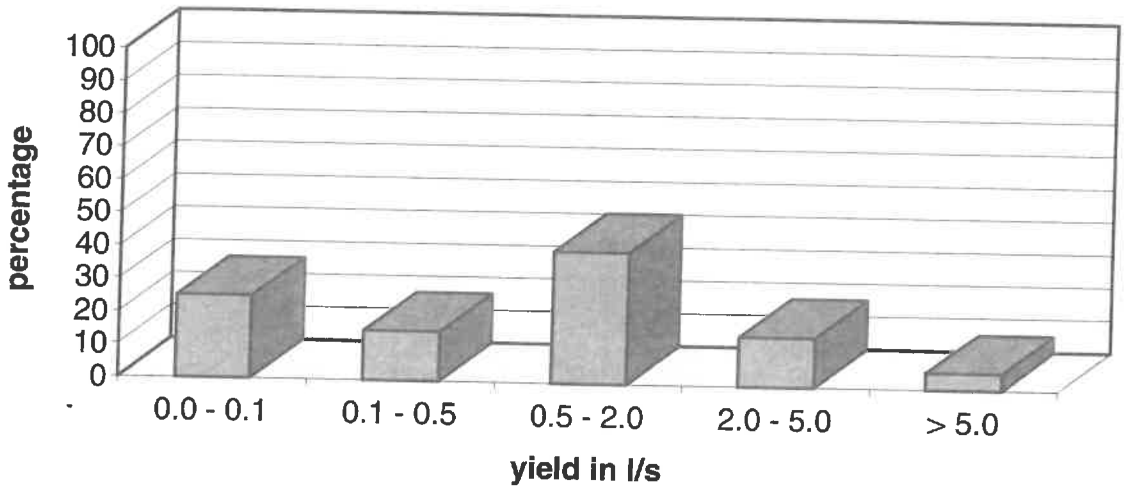


FIG 4: STIFF DIAGRAMS OF THE CHEMICAL ANALYSES IN TABLE 3 (KAAIMANS GROUP)

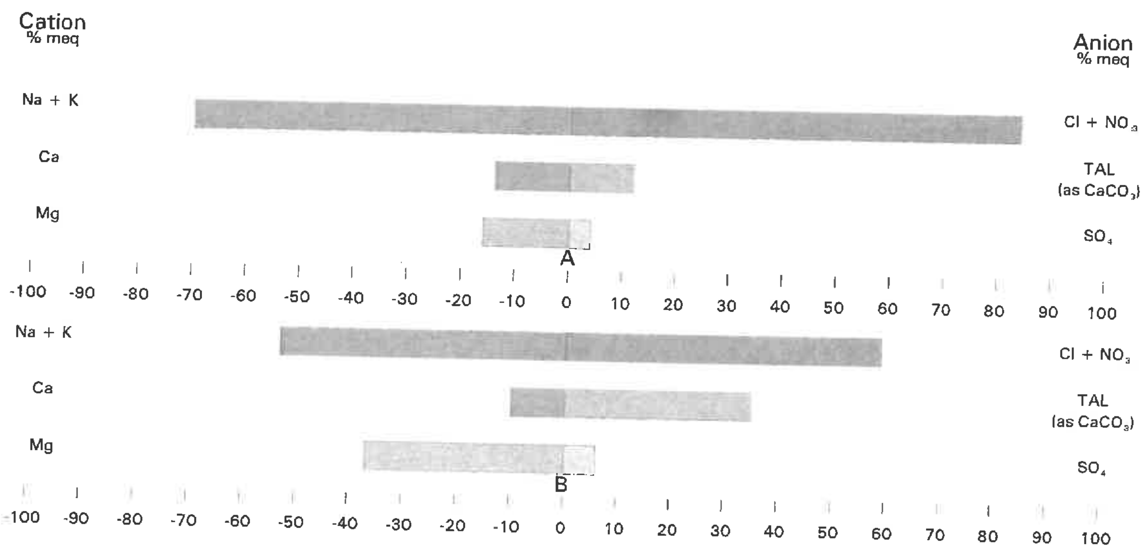


TABLE 3: CHEMICAL ANALYSES FROM DIFFERENT BOREHOLES IN THE KAAIMANS GROUP
(ANALYSED BY THE CSIR)

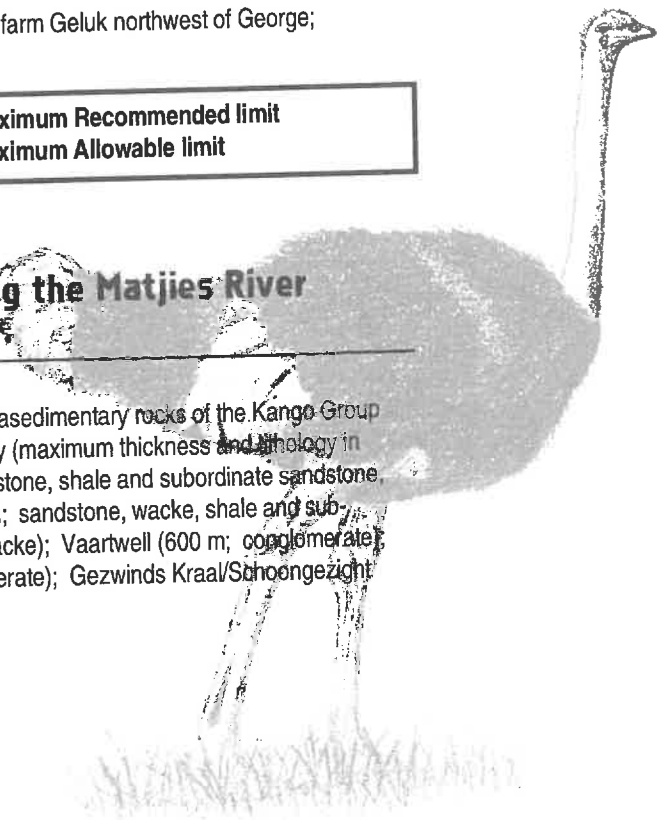
		A	B	D	E
EC	(mS/m)	199,0	26,0	70,0	300,0
TDS	(mg/ℓ)	1 199,0	125,0	1 200,0	2 000,0
pH		7,9	8,0	6-9	5,5-9,5
Na	(mg/ℓ)	309,0	24,0	100,0	400,0
K	(mg/ℓ)	4,8	1,1	200,0	400,0
Ca	(mg/ℓ)	57,0	4,0	150,0	200,0
Mg	(mg/ℓ)	37,0	8,0	70,0	100,0
Cl	(mg/ℓ)	576,0	37,0	250,0	600,0
SO_4	(mg/ℓ)	33,0	5,0	200,0	600,0
TAL ($CaCO_3$)	(mg/ℓ)	148,0	36,0	20-300	650,0
F	(mg/ℓ)	0,4	0,4	1,0	1,5
NO_3+NO_2 (as N)	(mg/ℓ)	0,04	0,38	6,0	10,0
PO_4 (as P)	(mg/ℓ)	0,02	0,005	-	-
Si	(mg/ℓ)	14,3	7,3	-	-
NH_4 (as N)	(mg/ℓ)	0,04	0,04	6,0	10,0
Fe	(mg/ℓ)	*	*	0,1	1,0

* = Not determined

Please note: In this table, and throughout Chapter 4, chemical analyses have been selected that are deemed representative of the aquifers under discussion.

A = Borehole in the Skaapkop Formation; farm Wildernishoogte north of Wilderness; yield 0,37 ℓ/s.
B = Borehole in the Saasveld Formation; farm Geluk northwest of George; yield 1,9 ℓ/s.

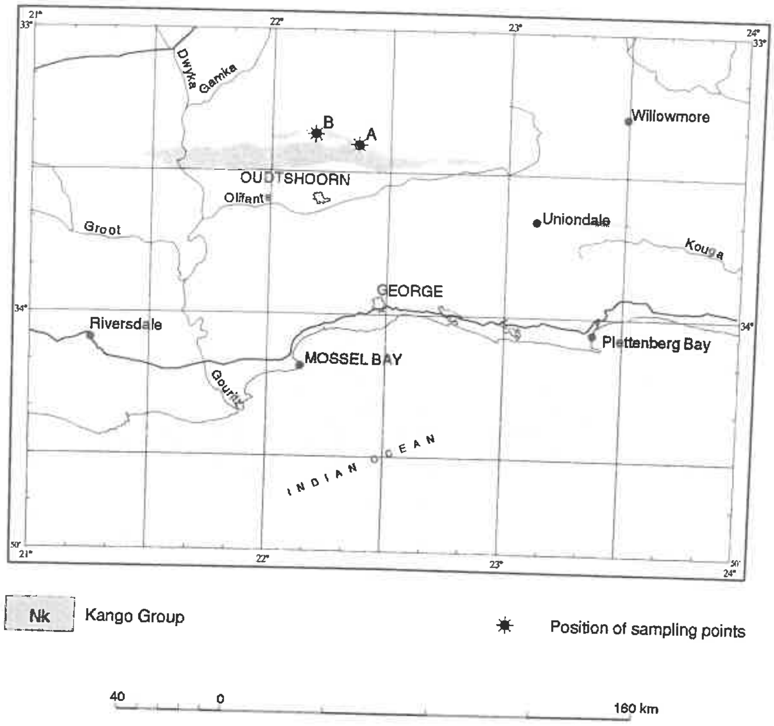
D = Drinking Water Quality Criteria: Maximum Recommended limit
E = Drinking Water Quality Criteria: Maximum Allowable limit



4.1.2 Kango Group (excluding the Matjies River Formation)

The approximately 9500 m thick sequence of metasedimentary rocks of the Kango Group (Fig. 5) are divided into seven Formations, namely (maximum thickness and lithology in brackets): the basal Matjies River (2300 m; limestone, shale and subordinate sandstone, refer to paragraph 4.3.1); Groenefontein (2400 m; sandstone, wacke, shale and subordinate limestone); Huis (1500 m; shale and wacke); Vaartwell (600 m; conglomerate); Uitvlugt (1000 m; sandstone, wake and conglomerate); Gezwinds Kraal/Schoongezight

FIG 5: AREAL LOCATION OF THE KANGO GROUP (EXCLUDING THE MATJIES RIVER FORMATION) AND THE POSITION OF TABLE 4 CHEMICAL ANALYSES



(1100; wacke, shale, sandstone and conglomerate), and the topmost Schoemans Poort (600 m; conglomerate, sandstone and shale).

The following are the more important geological and groundwater characteristics:

- According to Le Roux, 1983, some of the following geological features characterize the Kango Group:
  - An important lithological component is the occurrence of diabase dykes and sills. The dykes commonly vary between one and three metres in width and seldom exceed 30 m, and range from 50 m to 4 km in length.
  - The older diabase intrusions are so intensely sheared and altered that the rocks resemble shale.
  - The units of the Kango Group generally strike east-west and a complex fold system occurs, with northward bending folds being evident.
  - Two sets of tension joints have developed in the Kango formations. The north-south set shows as straight lines, frequently followed by streams, and generally dips vertically. The east-west set is characterised by quartz veining.
  - The Kango Group has been sliced into regional segments by five major faults. Two of these are northward thrusts and the remainder are normal faults.
- A yield analysis indicates that 64% of boreholes yield less than 2 ℓ/s, and 16% yield 5 ℓ/s and more (Fig. 6).
- ECs range between 100 and 300 mS/m. The following determinants often exceed maximum recommended limits and occasionally maximum allowable limits: dissolved solids, sodium, calcium, magnesium, chloride and total alkalinity (Table 4). Groundwater is generally of a sodium-chloride nature and in some parts of the Groenefontein Formation a sodium-chloride-alkaline nature may be evident (Fig. 7).

FIG 6: YIELD FREQUENCIES OF BOREHOLES IN THE KANGO GROUP (EXCLUDING THE MATJIES RIVER FORMATION)

(25 BOREHOLES ANALYSED)

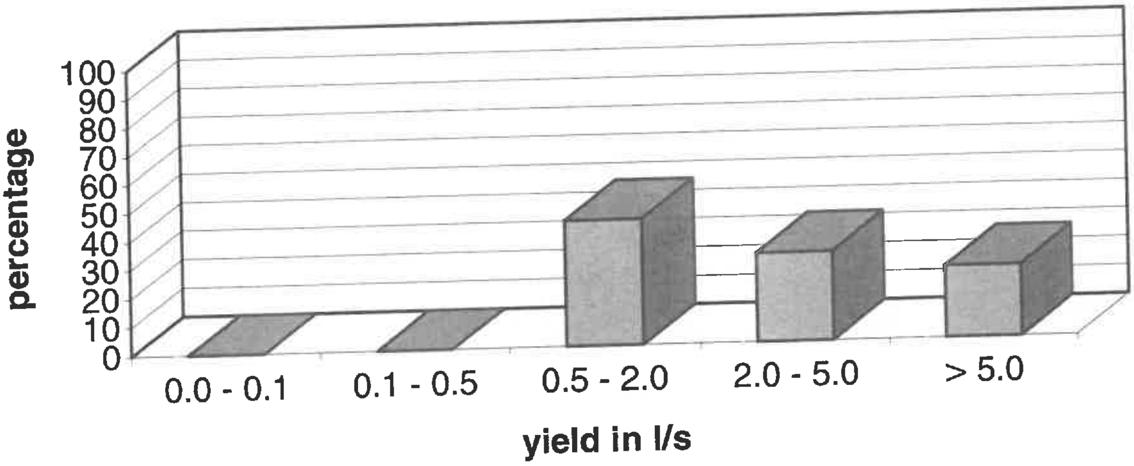


FIG 7: STIFF DIAGRAMS OF THE CHEMICAL ANALYSES IN TABLE 4 (KANGO GROUP)

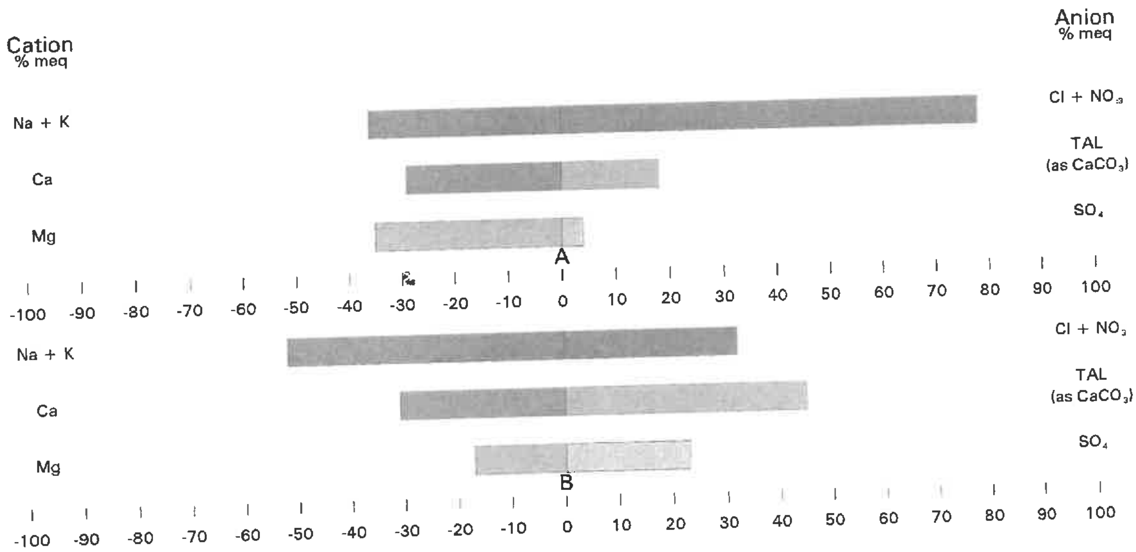


TABLE 4: CHEMICAL ANALYSES FROM DIFFERENT BOREHOLES IN THE KANGO GROUP (EXCLUDING THE MATJIES RIVER FORMATION) (ANALYSED BY THE IWQS)

		A	B	D	E
EC	(mS/m)	286,0	79,7	**70,0**	**300,0**
TDS	(mg/ℓ)	1 762,0	603,0	**1 200,0**	**2 000,0**
pH		7,8	8,2	**6-9**	**5,5-9,5**
Na	(mg/ℓ)	237,0	99,0	**100,0**	**400,0**
K	(mg/ℓ)	2,4	1,1	**200,0**	**400,0**
Ca	(mg/ℓ)	167,0	52,0	**150,0**	**200,0**
Mg	(mg/ℓ)	124,0	17,0	**70,0**	**100,0**
Cl	(mg/ℓ)	796,0	86,0	**250,0**	**600,0**
SO_4	(mg/ℓ)	47,0	84,0	**200,0**	**600,0**
TAL ($CaCO_3$)	(mg/ℓ)	317,0	216,0	**20-300**	**650,0**
F	(mg/ℓ)	0,2	0,8	**1,0**	**1,5**
NO_3+NO_2 (as N)	(mg/ℓ)	0,04	0,08	**6,0**	**10,0**
PO_4 (as P)	(mg/ℓ)	0,006	0,005	**-**	**-**
Si	(mg/ℓ)	8,1	7,4	**-**	**-**
NH_4 (as N)	(mg/ℓ)	1,93	0,04	**6,0**	**10,0**

A = Borehole in the Groenefontein Formation; farm Rust en Vrede north of Oudtshoorn; yield 0,7 ℓ/s.

B = Borehole in the Groenefontein Formation; farm Voorbedagt north of Oudtshoorn; yield 2,5 ℓ/s.

D = Drinking Water Quality Criteria: Maximum Recommended limit
E = Drinking Water Quality Criteria: Maximum Allowable limit

4.1.3 Table Mountain Group

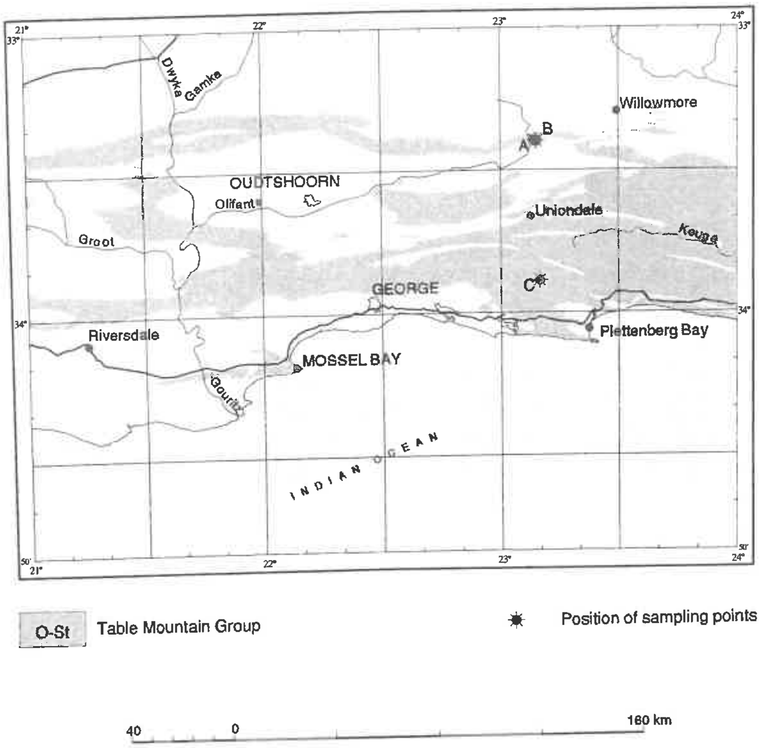
The TMG (Fig. 8) consists of three units in the map area, namely (approximate thickness in brackets): the basal Peninsula Formation (1500 m); the Cedarberg Formation (50 m), and the topmost Nardouw Subgroup (900 m). The Nardouw Subgroup is divided into the Goudini (300 m), Skurweberg (400 m) and Baviaanskloof (200 m) Formations east of 21° 30 'E and into the Goudini, Skurweberg and Rietvlei Formations west of 21° 30 'E.

The following are the more important geological and groundwater characteristics:

- Only the Cedarberg Formation is primarily an argillaceous unit, while the remaining units are predominantly arenaceous.

- A network of joints and fractures control the infiltration, recharge, storage and movement of groundwater in the competent and often brittle-natured arenaceous units

FIG 8: AREAL LOCATION OF THE TABLE MOUNTAIN GROUP AND THE POSITION OF TABLE 5 CHEMICAL ANALYSES



of the TMG. Fracturing may extend down to several hundred metres in many areas and deep groundwater circulation is one of the notable groundwater characteristics of the TMG. Despite the often highly fractured nature of the TMG sandstones, secondary groundwater storage is often limited, which could result in the rapid depletion of an aquifer under conditions of significant groundwater abstraction.

- The TMG rocks generally constitute the mountainous areas, which in turn influence precipitation to a considerable extent. Due to the fractured nature of the sandstones in generally high rainfall regions, recharge is favourable, and infiltration rates of up to 15% of the mean annual precipitation in certain areas are not unrealistic.
- An abundance of springs issue from the TMG sandstones. Three kinds of springs can be distinguished:
  - Fault and major structure controlled, generally deep circulating springs issuing often large constant supplies. The Calitzdorp hot spring with a constant yield of 11,6 ℓ/s is an example.
  - Lithologically controlled, relatively shallow circulating springs. These springs issue due to the presence of impeding layers such as the Cedarberg shale. The Marnewicks spring in the Kammanassie Mountains is an example. Yields from these springs are less constant and seasonal yield fluctuations are a distinctive feature. The yield of the Marnewicks spring varies between 9 and 19 ℓ/s. The bulk of the perennial springs issuing from the TMG are likely to be lithologically controlled.

FIG 9: YIELD FREQUENCIES OF BOREHOLES IN THE TABLE MOUNTAIN GROUP
(360 BOREHOLES ANALYSED)

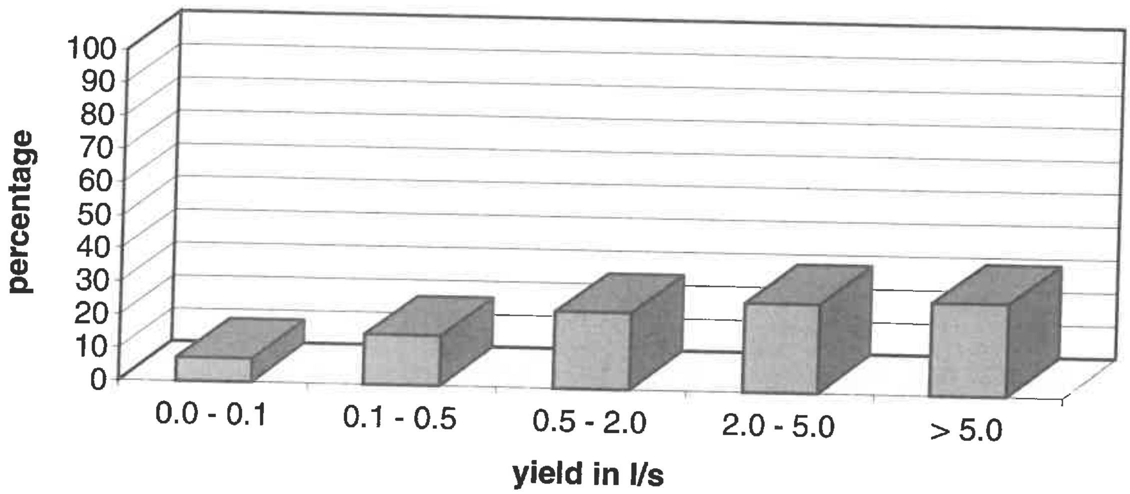
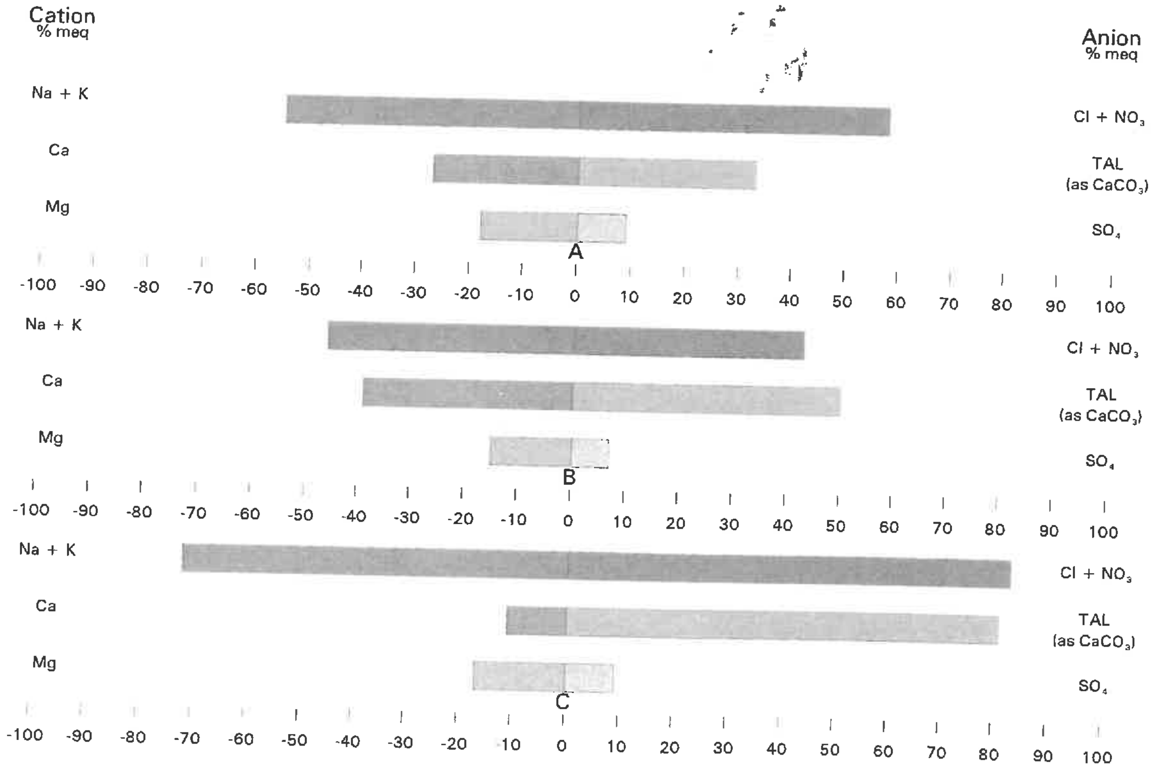


FIG 10: STIFF DIAGRAMS OF THE CHEMICAL ANALYSES IN TABLE 5 (TABLE MOUNTAIN GROUP)



- Springs seeping from numerous small fractures and joints. They are very evident during and shortly following rainy spells and are responsible for the myriad of springs in the TMG. They are however highly seasonable and cease to exist with the onset of dry weather conditions.

❒ Strong yielding boreholes can be developed in the TMG (Fig. 9), provided scientific methods for borehole siting are applied. Low borehole yields can often be attributed to incorrect borehole positioning and/or to too shallow drilling.

❒ Quality of groundwater in the TMG is generally between 10 and 100 mS/m (Table 5). Less potable groundwater is however occasionally procured from boreholes drilled into interbedded shaly layers. Groundwater is generally of a sodium-chloride nature (Fig. 10).

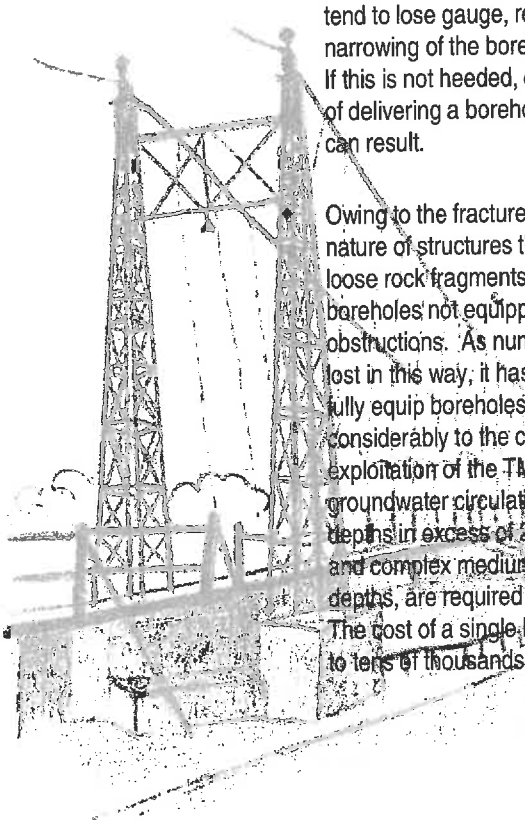
❒ Despite the relatively favourable groundwater potential in the TMG, both quantitatively and qualitatively, some adverse exploitation aspects of groundwater from the Table Mountain Group should be cited:

- Permeability inhibiting material derived from micro-breccia, mylonite, iron and manganese oxides and silica formed and deposited in many of the fracture and joint structures, renders some of them less effective groundwater conduits.

- Due to the rough, mountainous terrain, large areas of the TMG are almost inaccessible. Groundwater development is thus generally limited to the foothills of mountains.

- The TMG sandstones are hard, brittle and cross-jointed and are difficult to drill. Due to the abrasiveness of these rocks, drilling bits tend to lose gauge, resulting in a gradual narrowing of the borehole diameter with depth. If this is not heeded, considerable problems of delivering a borehole of uniform diameter can result.

- Owing to the fractured and somewhat unstable nature of structures that are often drilled into, loose rock fragments are inclined to slip into boreholes not equipped with casing, causing obstructions. As numerous boreholes are lost in this way, it has become customary to fully equip boreholes with casing, adding considerably to the cost. Effective groundwater exploitation of the TMG is thus costly. Deep groundwater circulation is a reality and borehole depths in excess of 200 m, drilled in a difficult and complex medium and cased off to great depths, are required for optimum results. The cost of a single borehole can thus amount to tens of thousands of Rand.



Bartholomew Dias, the Portuguese explorer, landed in 1488 at what is now known as Mossel Bay, and named it Angra dos Vaqueiros (bay of the cowherds). Vasco da Gama who reached the bay on 20 November 1497 established friendly relations with the Khoikhoi and thence many Portuguese ships called to obtain fresh water from a spring issuing from a fracture in TMG sandstone. This spring has now been declared a national monument. Thus some of the earliest explorers and navigators to visit this area used groundwater to fill their casks of drinking water.

Two thermal springs occur in the map area, namely the Calitzdorp Spa and the Toverwater hot spring. Both are fault-related and are situated in a TMG sandstone - Bokkeveld Group shale relationship. The water from the Calitzdorp Spa (temp. 50°C) circulates from a depth of approximately 3 300 m (about 3 100 m below sea-level), and the water from Toverswater (temp. 44°C) circulates from a depth of approximately 2 700 m (about 1 800 m below sea-level).

It is interesting to note that the combined discharge from 74 thermal springs in South Africa is 36 290 m^3/d (Kent, 1949). Though only seven of the 74 thermal springs are situated in the rocks of the CFB, the daily discharge from these seven springs amount to 42% of the total thermal springs output countrywide.

- Once a borehole is functional, the action of iron bacteria (Plate 3) can set in under certain circumstances. Iron bacteria often occur when substantial levels of iron and manganese are present in the groundwater, as is often the case with groundwater in the TMG (Plate 4). Slimy material is created which may plug screen pores and perforated slotting, and may even retard fracture permeability, rendering a once productive borehole much less effective. Borehole rehabilitation is possible with chemical treatment.

- The low pH of the groundwater and consequent corrosive action makes relatively inexpensive steel unsuitable for well screens and casing. PVC can be used to overcome these problems.

TABLE 5: CHEMICAL ANALYSES FROM DIFFERENT GROUNDWATER SOURCES IN THE TABLE MOUNTAIN GROUP

(ANALYSED BY THE IWQS)

		A	B	C	D	E
EC	(mS/m)	16,6	19,3	26,9	**70,0**	**300,0**
TDS	(mg/ℓ)	88,0	115,0	143,0	**1 200,0**	**2 000,0**
pH		7,6	6,9	5,9	**6-9**	**5,5-9,5**
Na	(mg/ℓ)	13,0	12,0	39,0	**100,0**	**400,0**
K	(mg/ℓ)	1,3	7,0	1,4	**200,0**	**400,0**
Ca	(mg/ℓ)	6,0	10,0	5,0	**150,0**	**200,0**
Mg	(mg/ℓ)	3,0	3,0	5,0	**70,0**	**100,0**
Cl	(mg/ℓ)	24,0	22,0	66,0	**250,0**	**600,0**
SO_4	(mg/ℓ)	8,0	5,0	10,0	**200,0**	**600,0**
TAL ($CaCO_3$)	(mg/ℓ)	26,0	46,0	11,0	**20-300**	**650,0**
F	(mg/ℓ)	0,4	0,3	0,1	**1,0**	**1,5**
NO_3+NO_2 (as N)	(mg/ℓ)	0,04	0,0	0,54	**6,0**	**10,0**
PO_4 (as P)	(mg/ℓ)	0,039	*	0,058	**-**	**-**
Si	(mg/ℓ)	7,4	13,9	4,0	**-**	**-**
NH_4 (as N)	(mg/ℓ)	0,04	0,00	0,04	**6,0**	**10,0**
Fe	(mg/ℓ)	*	*	0,167	**0,1**	**1,0**

* not determined

A = Borehole on farm Toverswaters Poort, east of De Rust; fault related; relatively shallow circulating groundwater; low rainfall area; yield 12 ℓ/s.
B = Hot spring east of de Rust situated 750 m east of A; fault related; deep circulating groundwater; yield 20 ℓ/s.
C = Borehole at Prince Albert pass between Knysna and Uniondale; fault related; high rainfal area; yield 17 ℓ/s.

D = Drinking Water Quality Criteria: Maximum Recommended limit
E = Drinking Water Quality Criteria: Maximum Allowable limit

Plate 3: *Iron, precipitated due to the action of iron bacteria, formed a thick covering around most of this borehole screen, and blocked most of the screen openings. The screen was recovered from a borehole in the Table Mountain Group sandstone in the Kammanassie Mountains east of Dysseldorp. (Photo: Johan Uys, Overberg Water: Oudtshoorn)*

Plate 4: *Iron oxide-stained joints in Table Mountain Group sandstones at Mossel Bay, which is indicative of the often high iron content of groundwater in the Table Mountain Group. (Photo: PS Meyer)*

4.1.4 Bokkeveld Group

The Bokkeveld Group (Fig. 11) is composed of two Subgroups in the map area, namely the basal Ceres Subgroup and the topmost Traka/Bidouw Subgroup (the latter unit is known as the Traka Subgroup east of 22° E and as the Bidouw Subgroup west of 22° E).

The more important geological and groundwater characteristics of the Bokkeveld Group are as follows:

- The Ceres Subgroup consists of three shale units, namely (approximate thickness in brackets): the Gydo (600 m), Voorstehoek (300 m) and Tra-tra (350 m) Formations, and three arenaceous units, the Gamka (200 m), Hex River (70 m) and Boplaas (100 m) Formations north of the Langeberg and Outeniqua Ranges. South of the Langeberg Range the Bokkeveld Group is essentially an undifferentiated shale unit.
- The Traka/Bidouw Subgroup is a largely argillaceous unit both north and south of the Langeberg/Outeniqua Ranges.
- The arenaceous: argillaceous ratio plays a noticeable role both quantitatively and qualitatively of the groundwater. Borehole yields and groundwater quality vary widely (Fig. 12 and Table 6). Yields of more than 5 ℓ/s are not uncommon in the sandstone-richer Ceres Subgroup, but are generally substantially less than 5 ℓ/s. Borehole yields in the sandstone-poor Traka/Bidouw Subgroup seldom exceed 5 ℓ/s and are usually well below 1 ℓ/s .

The Lower Devonian period, when the Bokkeveld Group rocks were deposited, was the stage in the history of the early atmosphere when the oxygen level presumably reached 10%. This allowed for the first land plants to advance from the security of aquatic life to the variable and harsh conditions of life on land (Plumstead, 1968).

FIG 11: AREAL LOCATION OF THE BOKKEVELD GROUP AND THE POSITION OF TABLE 6 CHEMICAL ANALYSES

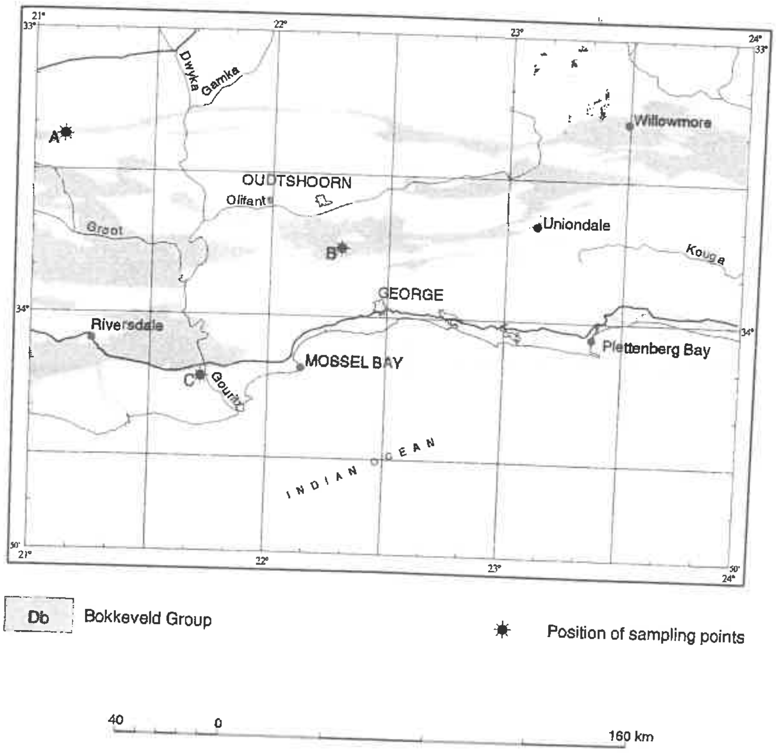


FIG 12: YIELD FREQUENCIES OF BOREHOLES IN THE BOKKEVELD GROUP
(407 BOREHOLES ANALYSED)

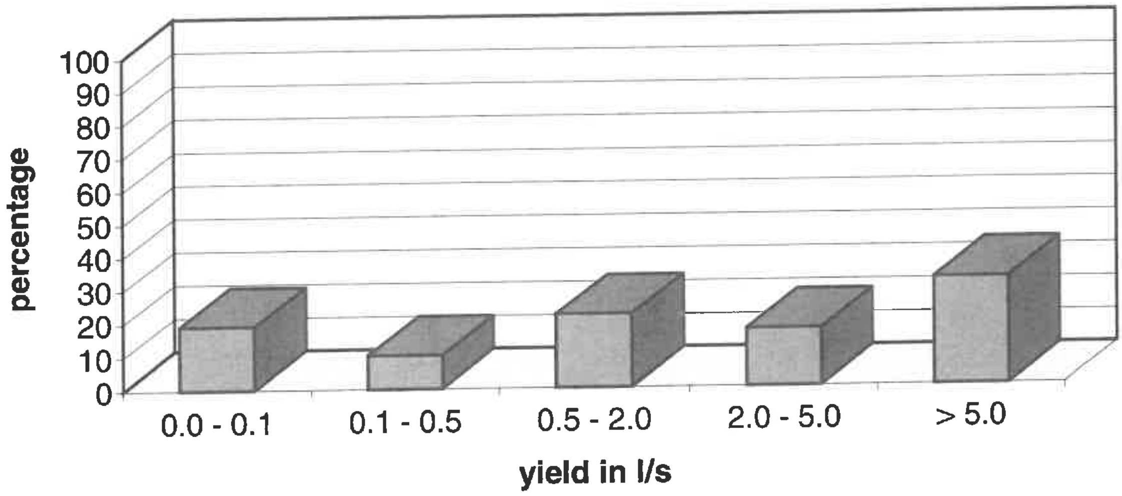
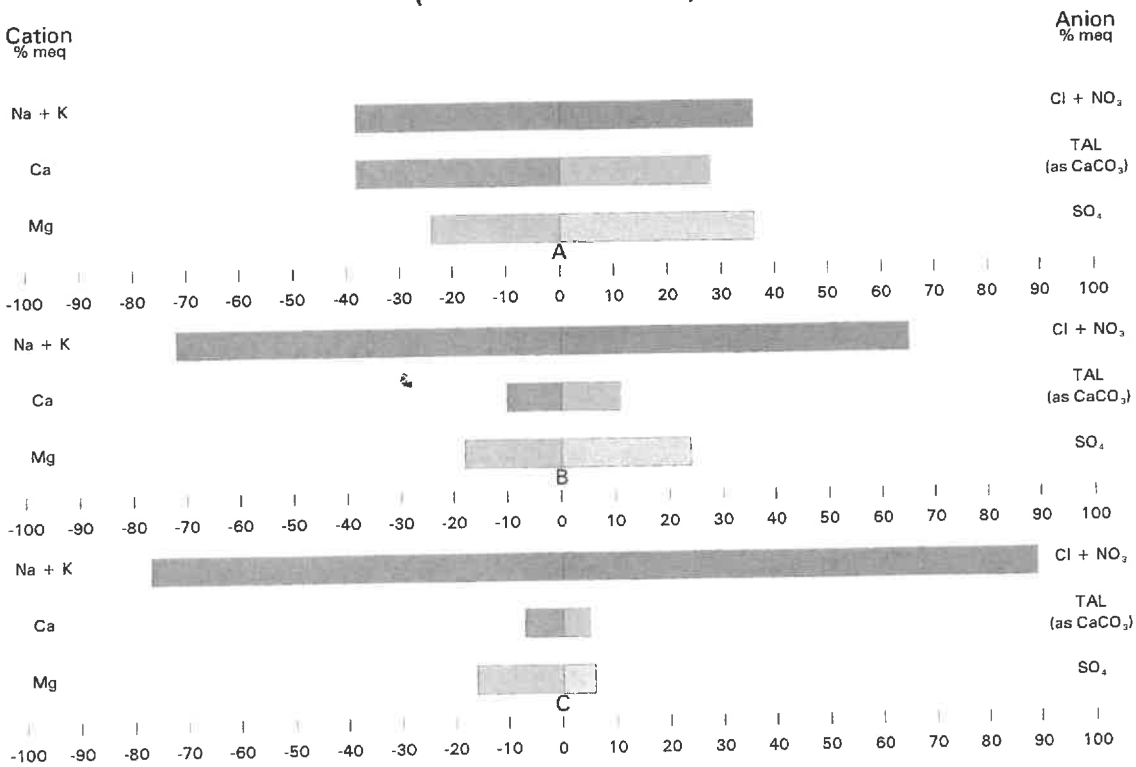


FIG 13: STIFF DIAGRAMS OF THE CHEMICAL ANALYSES IN TABLE 6 (BOKKEVELD GROUP)



- ECs of groundwater in the Ceres Subgroup vary considerably between 30 and 400 mS/m (A and B in Table 6). ECs of groundwater in the Traka/Bidouw Subgroup are usually well in excess of 400 mS/m (C in Table 6). Sodium, magnesium, chloride and sulphate often exceed maximum recommended limits, and may even exceed maximum allowable limits (A and B in Table 6). Sodium, calcium, magnesium and chloride commonly exceed allowable limits in the Traka/Bidouw Subgroup (C in Table 6). Groundwater in the Bokkeveld Group is generally of a sodium-chloride nature (Fig. 13).

TABLE 6: CHEMICAL ANALYSES FROM DIFFERENT BOREHOLES IN THE BOKKEVELD GROUP

(A AND B WERE ANALYSED BY THE IWQS, C WAS ANALYSED BY THE AEC)

		A	B	C	D	E
EC	(mS/m)	80,0	430,0	690,0	**70,0**	**300,0**
TDS	(mg/ℓ)	526,0	2 646,0	3 825,0	**1 200,0**	**2 000,0**
pH		8,2	8,6	8,0	**6-9**	**5,5-9,5**
Na	(mg/ℓ)	80,7	686,0	1 137,0	**100,0**	**400,0**
K	(mg/ℓ)	-	14,3	23,9	**200,0**	**400,0**
Ca	(mg/ℓ)	69,6	78,0	88,0	**150,0**	**200,0**
Mg	(mg/ℓ)	27,1	95,0	129,0	**70,0**	**100,0**
Cl	(mg/ℓ)	112,0	954,0	2 032,0	**250,0**	**600,0**
SO_4	(mg/ℓ)	159,7	484,0	176,0	**200,0**	**600,0**
TAL ($CaCO_3$)	(mg/ℓ)	152,7	272,0	195,0	**20-300**	**650,0**
F	(mg/ℓ)	0,01	2,2	0,5	**1,0**	**1,5**
NO_3+NO_2 (as N)	(mg/ℓ)	*	0,05	0,11	**6,0**	**10,0**
PO_4 (as P)	(mg/ℓ)	*	0,005	0,005	**-**	**-**
Si	(mg/ℓ)	*	5,4	4,0	**-**	**-**
NH_4 (as N)	(mg/ℓ)	*	0,06	0,07	**6,0**	**10,0**

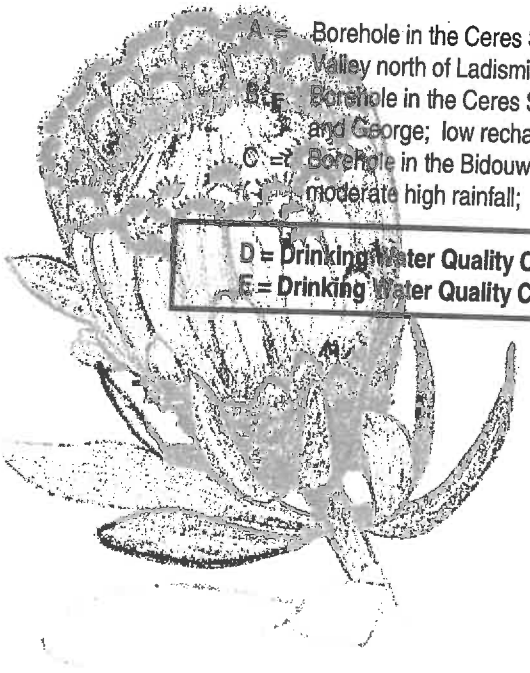
* = Not determined

A = Borehole in the Ceres Subgroup; farm Doornkloof in the Klein Swartberg Valley north of Ladismith; favourable recharge conditions; yield 15 ℓ/s.

B = Borehole in the Ceres Subgroup; farm Welbedag between Oudtshoorn and George; low recharge; yield 1,7 ℓ/s.

C = Borehole in the Bidouw Subgroup; farm Plattebos east of Albertinia; moderate high rainfall; yield 0,6 ℓ/s.

D = Drinking Water Quality Criteria: Maximum Recommended limit
E = Drinking Water Quality Criteria: Maximum Allowable limit



4.1.5 Witteberg Group

The Witteberg Group (Fig. 14) is divided into four units in the map area east of 23° E namely: namely the basal Weltevrede Formation; the Witpoort Formation; the Lake Mentz Subgroup, and the Kommadagga Subgroup. West of 23° E the Witteberg Group is divided into three units the basal Weltevrede Subgroup, the Witpoort Formation, and the Lake Mentz Subgroup.

The following are the more important geological and groundwater characteristics:

- East of 23° E the approximately 65m thick Driekuilen Sandstone Member occurs at the base of the 800m thick, largely shale and subordinate sandstone of the Weltevrede Formation. Both shale and sandstone are characteristically micaceous. The more or less 300 m thick Witpoort Formation, which is an arenaceous unit, overlies the Weltevrede Formation. The Witpoort Formation is in turn overlain by the Kweekvlei, Floriskraal and Waaipoort Formations of the Lake Mentz Subgroup. The 200 m thick Kweekvlei and 340 m thick Waaipoort Formations are argillaceous units, while the 80 m thick Floriskraal Formation is largely arenaceous. The Kommadagga Subgroup comprising the Miller, Swartwaterspoort and Soutkloof Formations is a mainly argillaceous unit and is up to 700 m thick.

> The legacy of the Khoikhoi lives on in the place names (mostly corrupted) found in the region such as Outeniqua, Knysna, Goukamma, Gouritz, Attakwas, Kammanassie, Kouga, Touws, Ganna, Kommadagga, Kango, Traka, Karatara, Tsitsikamma, to name but a few. Some of the names are water-related names such as Kango, Goukamma, Kammanassie and Tsitsikamma.

FIG 14: AREAL LOCATION OF THE WITTEBERG GROUP AND THE POSITION OF TABLE 7 CHEMICAL ANALYSES

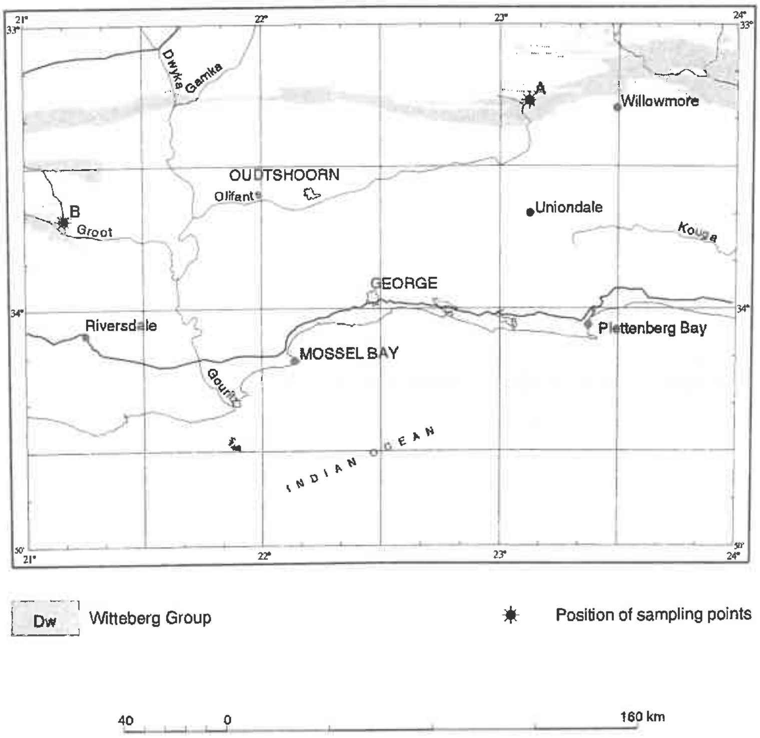


FIG 15: YIELD FREQUENCIES OF BOREHOLES IN THE WITTEBERG GROUP
(82 BOREHOLES ANALYSED)

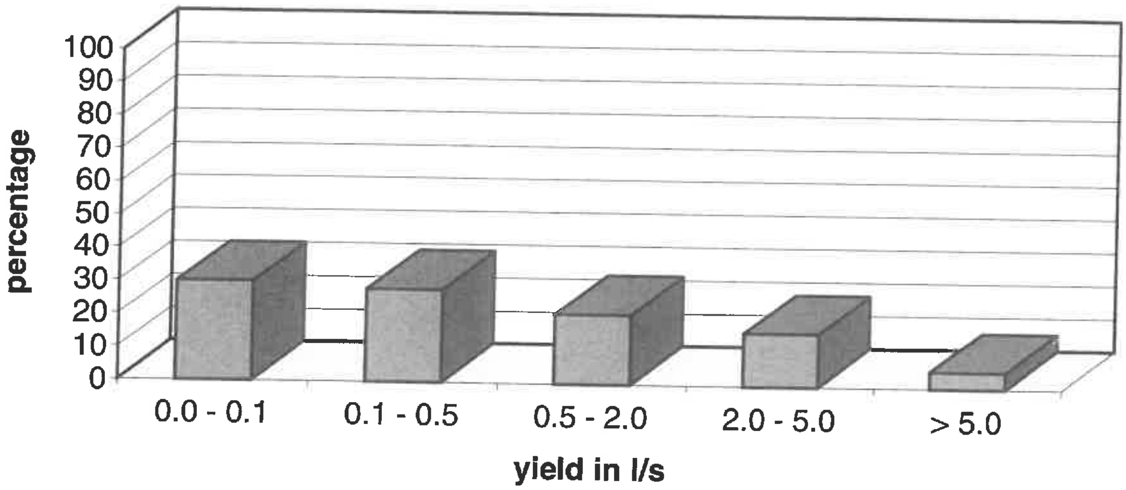
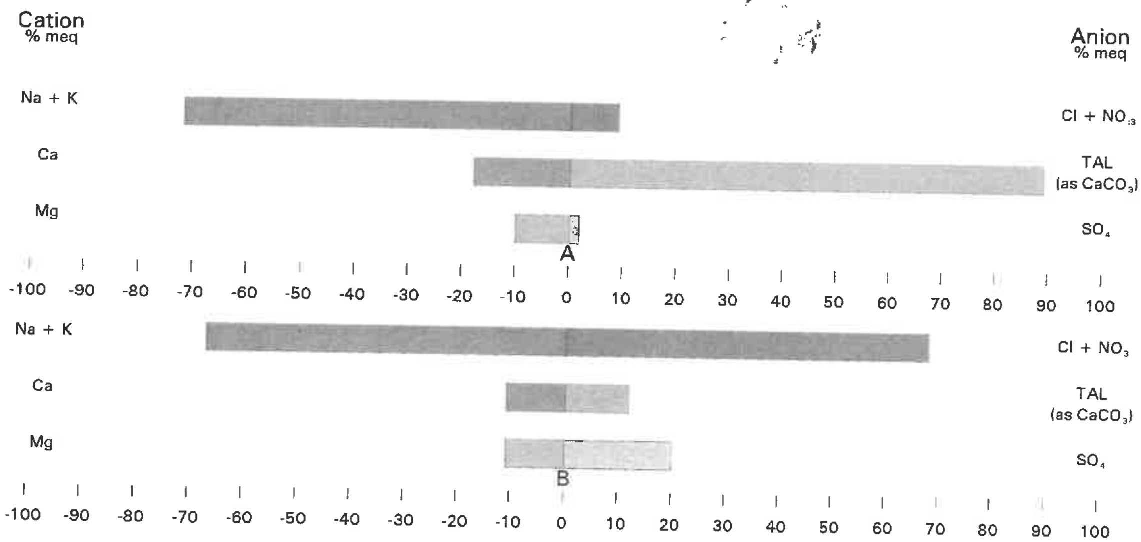


FIG 16: STIFF DIAGRAMS OF THE CHEMICAL ANALYSES IN TABLE 7
(WITTEBERG GROUP)



- West of 23° E the basal Weltevrede Subgroup, comprising the Wagendrift, Blinkberg and Swartruggens Formations is about 600 m thick. The Wagendrift and Swartruggens Formations consist of shale and sandstone, while the Blinkberg Formation (80 m thick) is an arenaceous unit. The Witpoort Formation and the formations of the Lake Mentz Subgroup display the same characteristics east and west of 23° E.

- A borehole analysis indicates that 58% of boreholes yield 0,5 ℓ/s and less than 5% yield 5,0 ℓ/s and more (Fig. 15). The borehole yields in the shale components of the Witteberg Group seldom yield more than 2 ℓ/s . The yield potential of the sandstone components are noticeably better, especially in the Witpoort Formation, with borehole yields up to 5 ℓ/s not uncommon.

- Brackish groundwater, with ECs ranging between 200 and 700 mS/m, can be expected in the shale components. The following determinants often exceed maximum allowable limits in the shales: sodium, magnesium, chloride and sulphate (B in Table 7). Groundwater from the shale components are generally of a sodium-chloride nature (B in Fig. 16).

- ECs of groundwater from the pronounced sandstone units range between 70 and 150 mS/m. The following determinants might occasionally exceed maximum recommended limits: sodium, chloride and total alkalinity (A in Table 7). Groundwater from the sandstone units is also inclined to be of a sodium-chloride nature (A in Fig. 16).

TABLE 7: CHEMICAL ANALYSES FROM DIFFERENT BOREHOLES IN THE WITTEBERG GROUP
(ANALYSED BY THE IWQS)

		A	B	D	E
EC	(mS/m)	119,0	611,0	**70,0**	**300,0**
TDS	(mg/ℓ)	931,0	4 262,0	**1 200,0**	**2 000,0**
pH		8,4	8,0	**6-9**	**5,5-9,5**
Na	(mg/ℓ)	211,0	1 004,0	**100,0**	**400,0**
K	(mg/ℓ)	3,4	10,7	**200,0**	**400,0**
Ca	(mg/ℓ)	46,0	160,0	**150,0**	**200,0**
Mg	(mg/ℓ)	15,0	199,0	**70,0**	**100,0**
Cl	(mg/ℓ)	199,0	1 638,0	**250,0**	**600,0**
SO_4	(mg/ℓ)	45,0	642,0	**200,0**	**600,0**
TAL ($CaCO_3$)	(mg/ℓ)	335,0	498,0	**20-300**	**650,0**
F	(mg/ℓ)	0,7	1,1	**1,0**	**1,5**
NO_3+NO_2 (as N)	(mg/ℓ)	0,65	0,04	**6,0**	**10,0**
PO_4 (as P)	(mg/ℓ)	0,007	0,007	-	-
Si	(mg/ℓ)	7,2	5,9	-	-
NH_4 (as N)	(mg/ℓ)	0,29	0,08	**6,0**	**10,0**
Fe	(mg/ℓ)	*	*	**0,1**	**1,0**

* = Not determined

A = Borehole in the Witpoort Formation (predominantly sandstone); farm Zoetendalsvlei east of Klaarstroom; yield 1,3 ℓ/s .

B = Borehole in the Weltevrede Formation (predominantly shale); farm Okkerskraal southwest of Ladismith; yield 0,5 ℓ/s .

D = Drinking Water Quality Criteria: Maximum Recommended limit
E = Drinking Water Quality Criteria: Maximum Allowable limit

4.1.6 Dwyka Group

The following are the more important geological and groundwater characteristics:

- The Dwyka Group (Fig. 17) is a 600 m thick diamictite unit. Much of the material is ill-sorted, and angular fragments of varying sizes are set in a dense, greenish-grey argillaceous matrix. Subordinate lenses of shale, siltstone and occasional sandstone occur sporadically.

- The Dwyka rocks are generally of a massive and impervious nature and usually offer poor groundwater potential. However, due to the location of the Group within the CFB, the rocks endured several deformational episodes and fracturing does occur from which good groundwater can be developed.

- A borehole analysis (Fig. 18) indicates that almost 60% of boreholes on record yield less than 0,5 ℓ/s . Borehole yields exceed 2 ℓ/s only where occasional fault and joint structures are intercepted.

- Brackish groundwater, with ECs in excess of 300 mS/m, can generally be expected in massive diamictite. The following determinants often exceed maximum recommended or even maximum allowable limits: sodium, calcium, magnesium, chloride and fluoride (B in Table 8). Groundwater in the fracture-poor rocks usually portrays a sodium-chloride-sulphate nature (B in Fig. 19).

- ECs of groundwater from fractured and jointed Dwyka rocks, where significant groundwater movement and turnover takes place, range between 100 and 200 mS/m (A in Table 8). Sodium and chloride often exceed maximum recommended limits, thus water with a sodium-chloride nature can be anticipated (A in Fig. 19).

During late-Carboniferous to early-Permian times (320-285 million years BP) a major ice age descended onto parts of the Gondwana landmass, including the southern half of the African continent and portions of South America. Due to the movement of large glaciers, masses of moraine (tillite) were deposited, which is known as the Dwyka Group in South Africa, and the Itararé Group in South America. Four source areas contributed to the tillite deposited within the CFB (Stratten, 1968), namely a source area from the former Transvaal, which yielded the Transvaal Ice Sheet, a source area off the present KwaZulu-Natal coast, which produced the Natal Ice Sheet, a source area off the present Western Cape coast, which generated the Atlantic Ice Sheet, and a source area off the present Southern Cape coast, which produced the Southern Cape Ice Sheet. In the area south of latitude 32° 30' the tillite was discharged into water.

FIG 17: AREAL LOCATION OF THE DWYKA GROUP AND THE POSITION OF TABLE 8 CHEMICAL ANALYSES

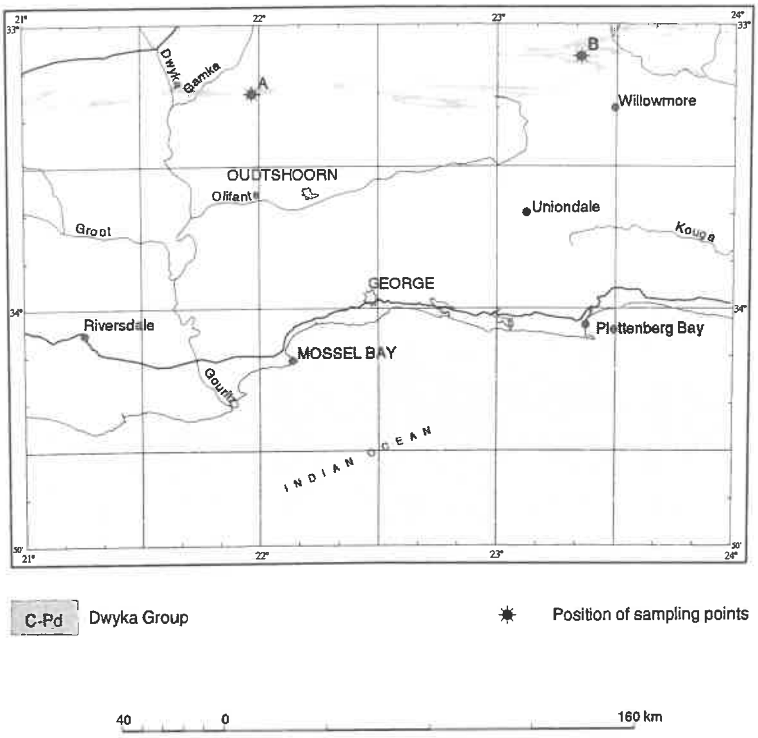


FIG 18: YIELD FREQUENCIES OF BOREHOLES IN THE DWYKA GROUP
(51 BOREHOLES ANALYSED)

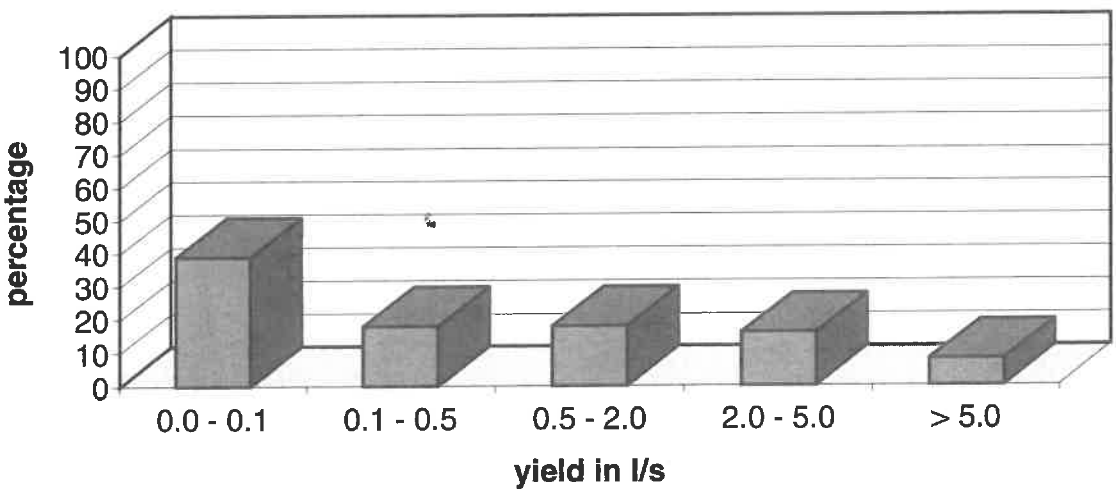


FIG 19: STIFF DIAGRAMS OF THE CHEMICAL ANALYSES IN TABLE 8 (DWYKA GROUP)

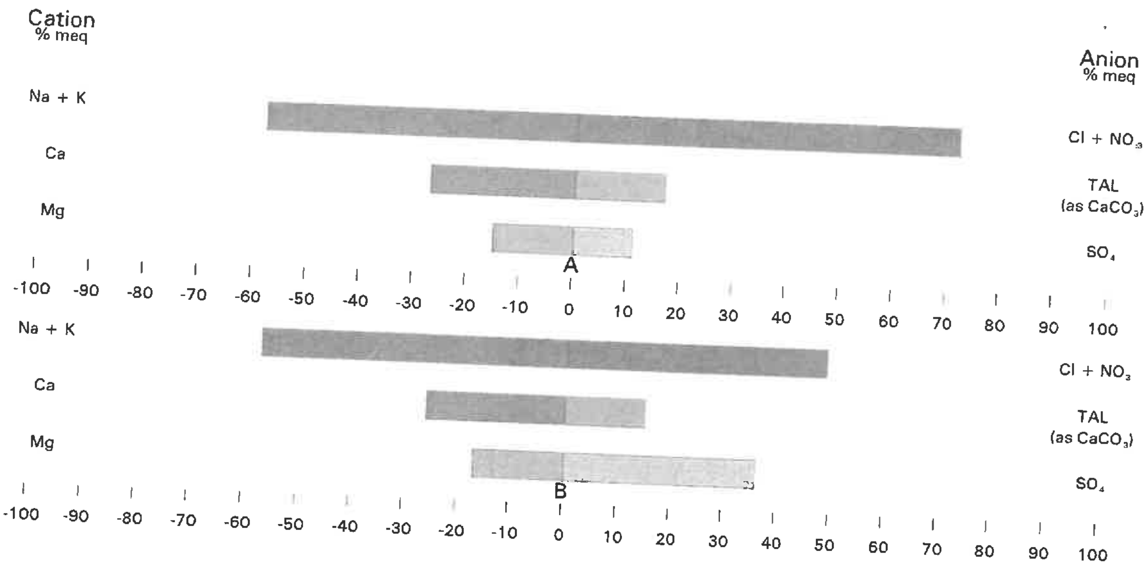


TABLE 8: CHEMICAL ANALYSES FROM DIFFERENT BOREHOLES IN THE DWYKA GROUP (ANALYSED BY THE IWQS)

		A	B	D	E
EC	(mS/m)	141,0	380,0	**70,0**	**300,0**
TDS	(mg/ℓ)	750,0	2 875,0	**1 200,0**	**2 000,0**
pH		7,4	8,3	**6-9**	**5,5-9,5**
Na	(mg/ℓ)	154,0	576,0	**100,0**	**400,0**
K	(mg/ℓ)	1,6	4,0	**200,0**	**400,0**
Ca	(mg/ℓ)	63,0	235,0	**150,0**	**200,0**
Mg	(mg/ℓ)	21,0	92,0	**70,0**	**100,0**
Cl	(mg/ℓ)	296,0	737,0	**250,0**	**600,0**
SO_4	(mg/ℓ)	62,0	740,0	**200,0**	**600,0**
TAL ($CaCO_3$)	(mg/ℓ)	125,0	393,0	**20-300**	**650,0**
F	(mg/ℓ)	0,3	1,8	**1,0**	**1,5**
NO_3+NO_2 (as N)	(mg/ℓ)	0,04	2,24	**6,0**	**10,0**
PO_4 (as P)	(mg/ℓ)	0,005	0,010	**-**	**-**
Si	(mg/ℓ)	9,5	11,5	**-**	**-**
NH_4 (as N)	(mg/ℓ)	0,14	0,15	**6,0**	**10,0**
Fe	(mg/ℓ)	*	*	**0,1**	**1,0**

* = Not determined

A = Borehole on the farm Damascus west of Prince Albert along the Tryntjies River; fault related.

B = Borehole on the farm Slagterskuil northwest of Willowmore; massive diamictite; yield 0,2 ℓ/s .

D = Drinking Water Quality Criteria: Maximum Recommended limit
E = Drinking Water Quality Criteria: Maximum Allowable limit

4.1.7 Ecca Group

The approximately 2 000 m thick Ecca Group (Fig. 20) consists of the Prince Albert, Whitehill, Collingham, Vischkuil (west of 22° 30' E), Ripon, Fort Brown and Waterford Formations in the map area.

The following are the more important geological and groundwater characteristics:

- The Ecca Group consists predominantly of argillaceous rocks and subordinate interbedded sandstones, notably in the Ripon and Waterford Formations.
- Numerous minor fold and fracture/joint structures appear in the Ecca beds.
- A borehole analysis shows that 30% of boreholes yield less than 0,5 ℓ/s and 14 % yield more than 5 ℓ/s (Fig. 21). Borehole yields of more than 5 ℓ/s can generally be obtained in fold, joint and fault structures where favourable recharge conditions exist.

FIG 20: AREAL LOCATION OF THE ECCA GROUP AND THE POSITION OF TABLE 9 CHEMICAL ANALYSES

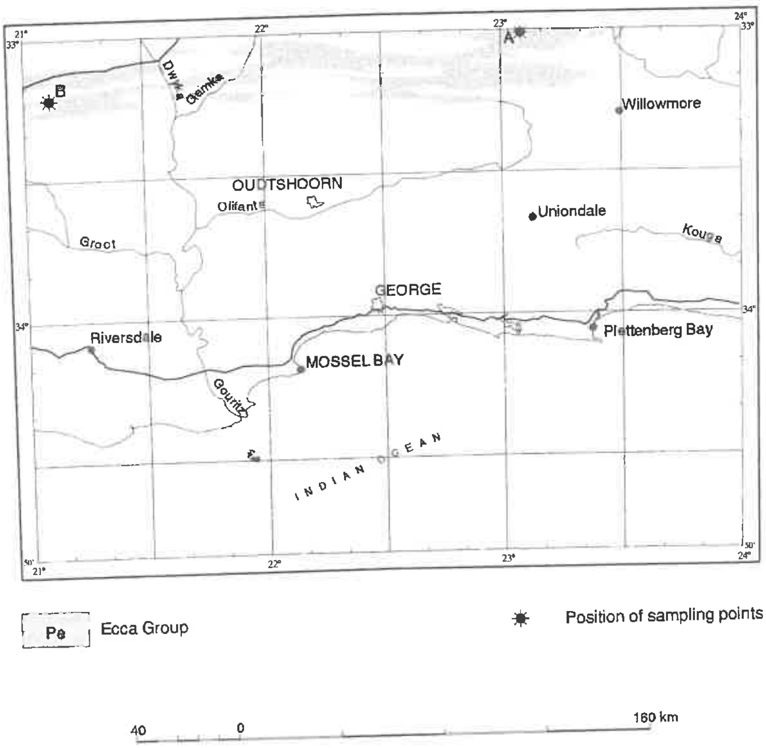


FIG 21: YIELD FREQUENCIES OF BOREHOLES IN THE ECCA GROUP
(127 BOREHOLES ANALYSED)

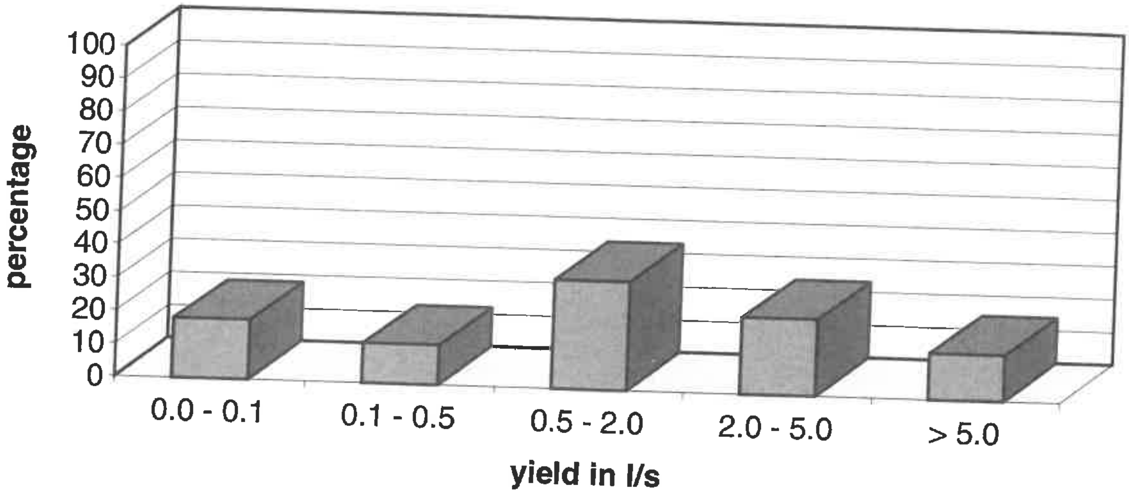
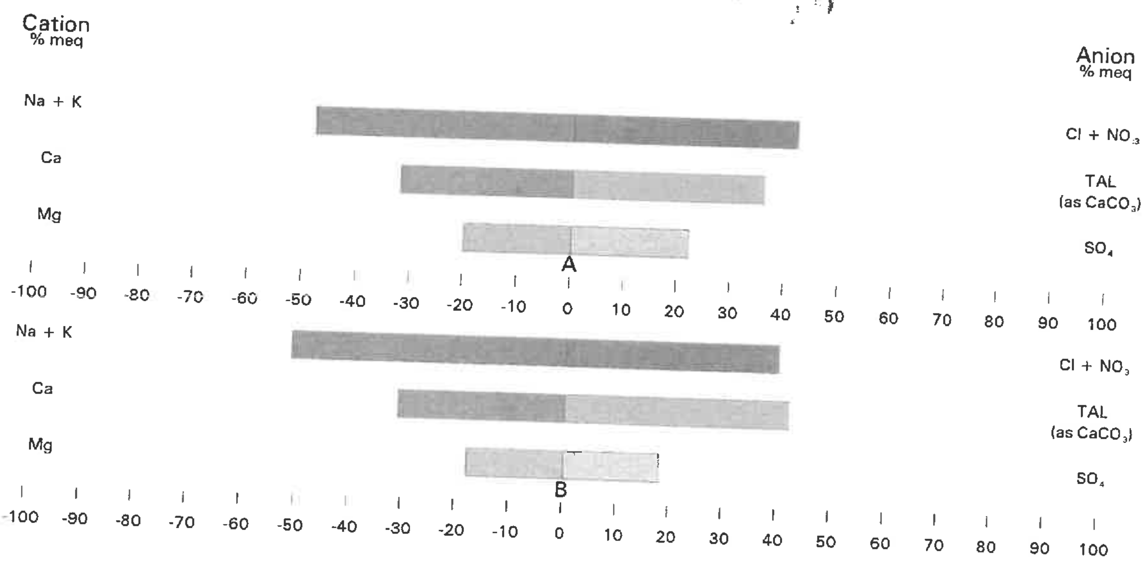


FIG 22: STIFF DIAGRAMS OF THE CHEMICAL ANALYSES IN TABLE 9 (ECCA GROUP)



- Groundwater quality varies considerably with ECs ranging between 80 and 1 300 mS/m. About 76% of boreholes registered ECs of less than 200 mS/m while nearly 10% of boreholes have ECs in excess of 500 mS/m.
- The following determinants often exceed maximum recommended and occasionally even maximum allowable limits: sodium, chloride, total alkalinity and fluoride (Table 9).
- Groundwater in the Ecca beds generally has a sodium-chloride-bicarbonate nature (Fig. 22).

TABLE 9: CHEMICAL ANALYSES FROM DIFFERENT BOREHOLES IN THE ECCA GROUP (ANALYSED BY THE IWQS)

		A	B	D	E
EC	(mS/m)	183,0	145,0	**70,0**	**300,0**
TDS	(mg/ℓ)	1 324,0	1 036,0	**1 200,0**	**2 000,0**
pH		7,9	8,5	**6-9**	**5,5-9,5**
Na	(mg/ℓ)	210,0	171,0	**100,0**	**400,0**
K	(mg/ℓ)	4,5	4,0	**200,0**	**400,0**
Ca	(mg/ℓ)	123,0	89,0	**150,0**	**200,0**
Mg	(mg/ℓ)	45,0	31,0	**70,0**	**100,0**
Cl	(mg/ℓ)	265,0	1 94,0	**250,0**	**600,0**
SO_4	(mg/ℓ)	186,0	120,0	**200,0**	**600,0**
TAL ($CaCO_3$)	(mg/ℓ)	398,0	345,0	**20-300**	**650,0**
F	(mg/ℓ)	1,0	1,0	**1,0**	**1,5**
NO_3+NO_2 (as N)	(mg/ℓ)	1,08	1,2	**6,0**	**10,0**
PO_4 (as P)	(mg/ℓ)	0,015	0,009	-	-
Si	(mg/ℓ)	8,7	8,5	-	-
NH_4 (as N)	(mg/ℓ)	0,13	0,05	**6,0**	**10,0**
Fe	(mg/ℓ)	*	*	**0,1**	**1,0**

* = Not determined

A = Borehole on the farm Naauwte northwest of Willowmore; massive Ecca beds; yield 0,1 ℓ/s.

B = Borehole on the farm Hartebeestefontein west of Dwyka; fault related; yield 5,7 ℓ/s .

D = Drinking Water Quality Criteria: Maximum Recommended limit
E = Drinking Water Quality Criteria: Maximum Allowable limit

4.1.8 Beaufort Group

The Beaufort Group (Fig. 23) is represented in the map area by the basal Abramskraal and the succeeding Teekloof Formations.

The following are the more important geological and groundwater characteristics:

- The Abramskraal Formation (maximum thickness 2 500 m) is composed of reddish mudstone, interbedded sandstone and subordinate thin limestone and chert. The Teekloof Formation consists of red mudstone and interbedded sandstone. Chert is largely absent in the Teekloof unit.

- A borehole analysis (Fig. 24) indicates that only 8 % of boreholes yield less than 0,5 ℓ/s and 11 % yield 5 ℓ/s and more. Borehole yields in excess of 3 ℓ/s can readily be obtained in joint and fault structures and occasionally in fold structures, provided favourable recharge conditions exist.

- Groundwater quality varies between 70 and 350 mS/m. About 87 % of boreholes recorded ECs of less than 200 mS/m. The following determinants may exceed maximum recommended limits: sodium, chloride and total alkalinity (Table 10).

- Groundwater in the Beaufort Group generally displays a sodium-chloride-bicarbonate nature (Fig. 25).

FIG 23: AREAL LOCATION OF THE BEAUFORT GROUP AND THE POSITION OF TABLE 10 CHEMICAL ANALYSES

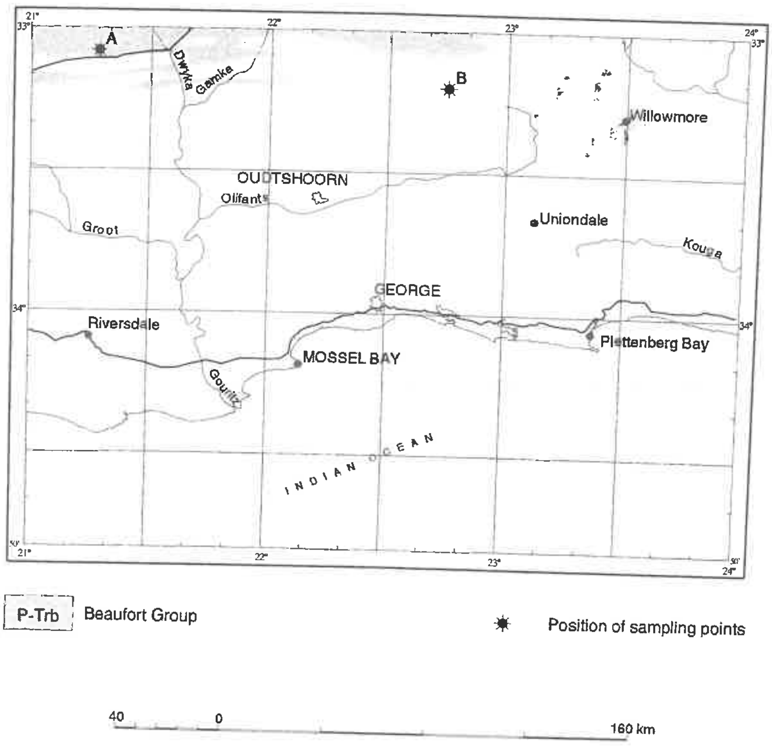


FIG 24: YIELD FREQUENCIES OF BOREHOLES IN THE BEAUFORT GROUP
(61 BOREHOLES ANALYSED)

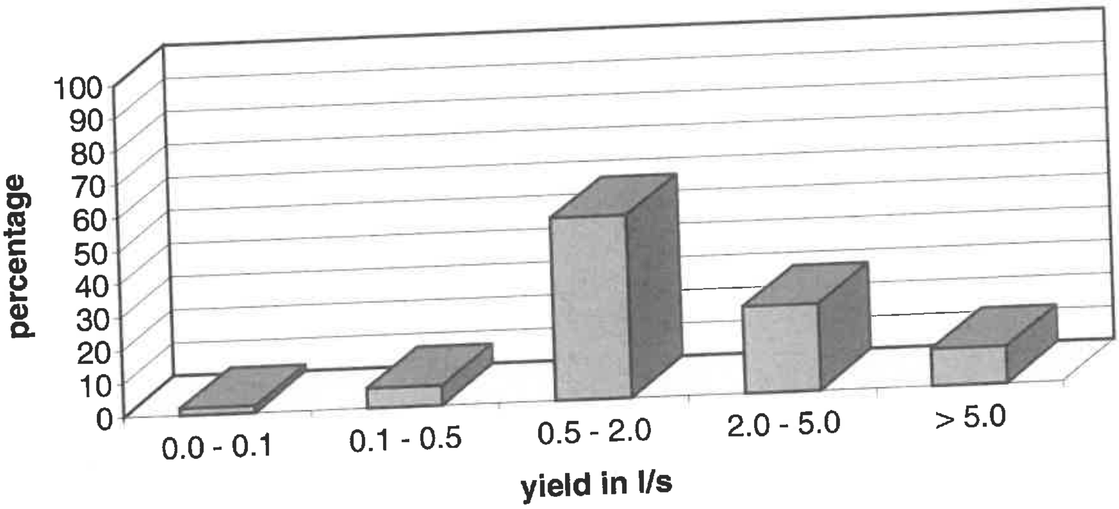


FIG 25: STIFF DIAGRAMS OF THE CHEMICAL ANALYSES IN TABLE 10
(BEAUFORT GROUP)

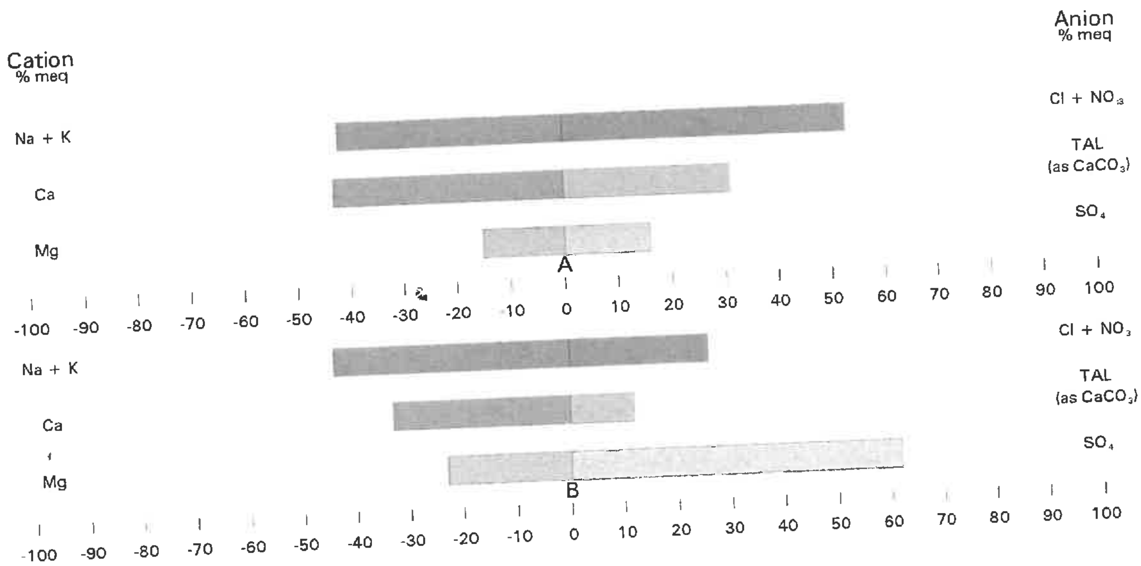


TABLE 10: CHEMICAL ANALYSES FROM DIFFERENT BOREHOLES IN THE BEAUFORT GROUP (ANALYSED BY THE IWQS)

		A	B	D	E
EC	(mS/m)	141,0	139,0	**70,0**	**300,0**
TDS	(mg/ℓ)	1 060,0	1 081,0	**1 200,0**	**2 000,0**
pH		8,2	8,7	**6-9**	**5,5-9,5**
Na	(mg/ℓ)	149,0	149,0	**100,0**	**400,0**
K	(mg/ℓ)	2,6	3,3	**200,0**	**400,0**
Ca	(mg/ℓ)	134,0	99,0	**150,0**	**200,0**
Mg	(mg/ℓ)	29,0	41,0	**70,0**	**100,0**
Cl	(mg/ℓ)	275,0	140,0	**250,0**	**600,0**
SO_4	(mg/ℓ)	110,0	440,0	**200,0**	**600,0**
TAL ($CaCO_3$)	(mg/ℓ)	276,0	106,0	**20-300**	**650,0**
F	(mg/ℓ)	0,6	1,0	**1,0**	**1,5**
NO_3+NO_2 (as N)	(mg/ℓ)	5,06	0,91	**6,0**	**10,0**
PO_4 (as P)	(mg/ℓ)	0,005	0,008	**-**	**-**
Si	(mg/ℓ)	10,2	10,7	**-**	**-**
NH_4 (as N)	(mg/ℓ)	0,04	0,09	**6,0**	**10,0**
Fe	(mg/ℓ)	*	*	**0,1**	**1,0**

* = Not determined

A = Borehole on the farm Grootfontein west of Dwyka; yield 0,8 ℓ/s .
B = Borehole on the farm Minnies Kraal; east of Prince Albert; yield 2 ℓ/s .

D = Drinking Water Quality Criteria: Maximum Recommended limit
E = Drinking Water Quality Criteria: Maximum Allowable limit

4.1.9 Uitenhage Group

Rocks of the Uitenhage Group (Fig. 26) vary from Jurassic to Cretaceous in age and are represented by the Enon and Kirkwood Formations in the Oudtshoorn Basin, and by the Robberg, Enon, Kirkwood, Buffelskloof and Hartenbos Formations in the Mossel Bay, Knysna and Plettenberg Bay areas.

The following are the more important geological and groundwater characteristics:

- The Uitenhage beds attain a thickness of 300 m in the Oudtshoorn region and up to 200 m at Knysna. Lithologically the Group consists of sandstone, conglomerate, breccia, mudstone, siltstone and tuff.

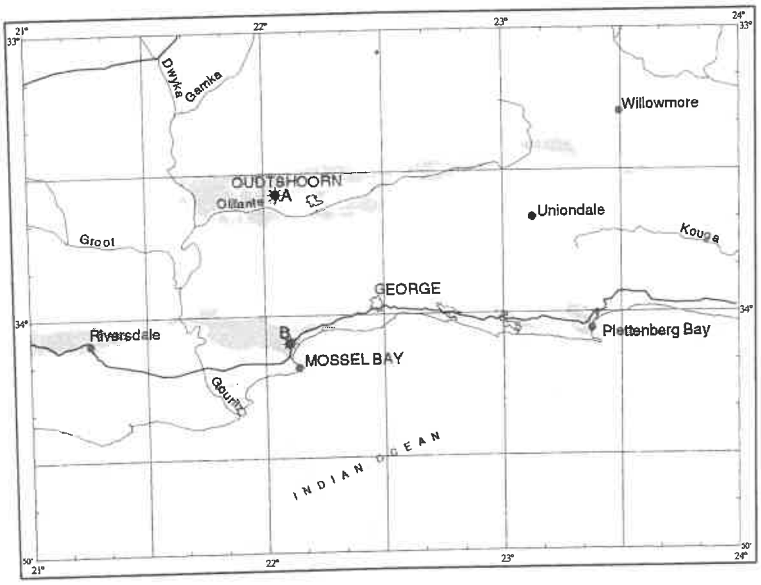
- The sequence is generally bonded into a dense and impervious mass of low permeability. The groundwater potential is thus very limited with borehole yields rarely exceeding 1 ℓ/s . (The considerably more favourable evidence displayed in Fig. 27 may be highly misleading due to the input of data from a concentration of boreholes near the Olifants River, southeast of Oudtshoorn, where high yielding boreholes could have intercepted water in alluvium or in underlying Table Mountain sandstone, rather than in Enon conglomerate. Moreover, information on numerous boreholes which were drilled unsuccessfully and which have subsequently been destroyed could not be obtained and were not used in the assessment).

- ❒ Groundwater can occasionally be obtained in interbedded sandstone lenses. The groundwater in these sandstone lenses is almost invariably of poor quality.

- ❒ ECs of groundwater from the Uitenhage beds are commonly in excess of 300 mS/m. The following determinants regularly exceed maximum recommended limits, and very often exceed maximum allowable limits as well: sodium, magnesium, chloride, total alkalinity, sulphate and fluoride (Table 11).

- ❒ Groundwater in the Uitenhage Group is usually of a sodium-chloride and to a lesser extent sulphate nature (Fig. 28).

FIG 26: AREAL LOCATION OF THE UITENHAGE GROUP AND THE POSITION OF TABLE 11 CHEMICAL ANALYSES



J-Ku Uitenhage Group

Position of sampling points

40 0 160 km

FIG 27: YIELD FREQUENCIES OF BOREHOLES IN THE UITENHAGE GROUP
(127 BOREHOLES ANALYSED)

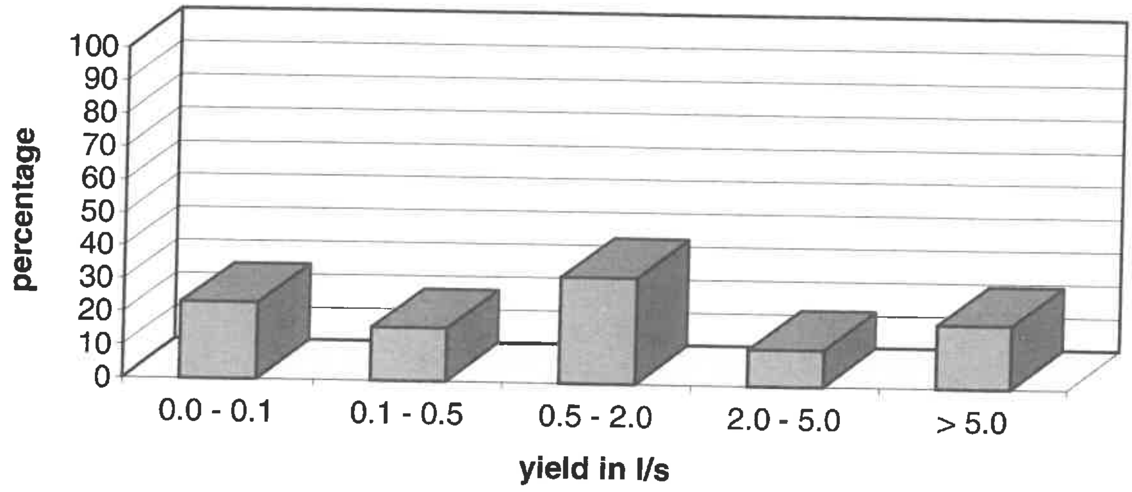


FIG 28: STIFF DIAGRAMS OF THE CHEMICAL ANALYSES IN TABLE 11
(UITENHAGE GROUP)

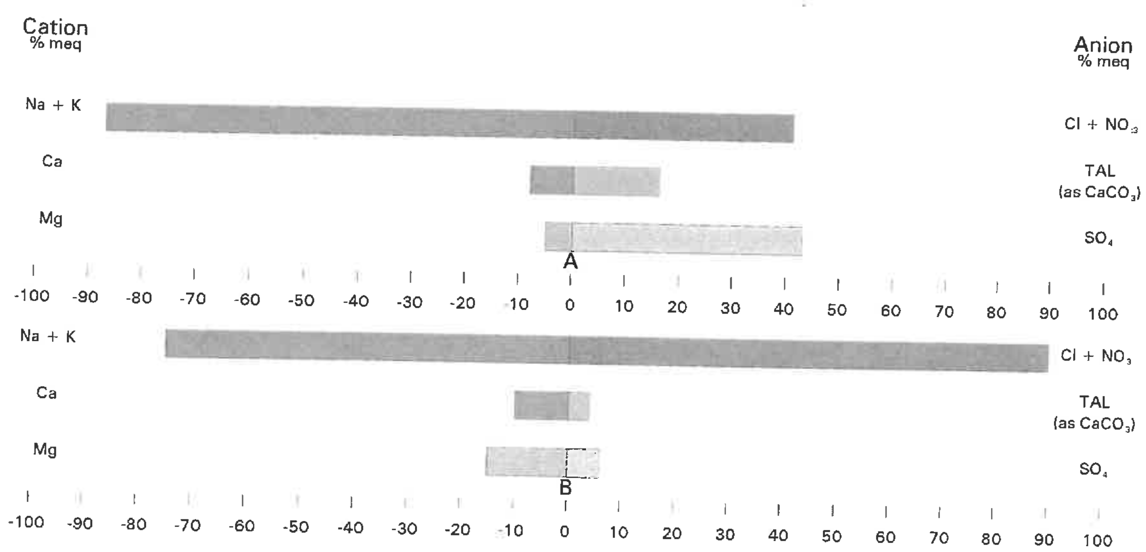


TABLE 11: CHEMICAL ANALYSES FROM DIFFERENT BOREHOLES IN THE UITENHAGE GROUP

(ANALYSED BY THE IWQS)

		A	B	D	E
EC	(mS/m)	547,1	492,0	**70,0**	**300,0**
TDS	(mg/ℓ)	3 839,0	2 672,0	**1 200,0**	**2 000,0**
pH		7,3	7,9	**6-9**	**5,5-9,5**
Na	(mg/ℓ)	1 141,0	769,0	**100,0**	**400,0**
K	(mg/ℓ)	11,5	8,6	**200,0**	**400,0**
Ca	(mg/ℓ)	92,0	94,0	**150,0**	**200,0**
Mg	(mg/ℓ)	35,0	83,0	**70,0**	**100,0**
Cl	(mg/ℓ)	773,0	1 446,0	**250,0**	**600,0**
SO_4	(mg/ℓ)	1 115,0	144,0	**200,0**	**600,0**
TAL ($CaCO_3$)	(mg/ℓ)	535,0	103,0	**20-300**	**650,0**
F	(mg/ℓ)	2,0	0,5	**1,0**	**1,5**
NO_3+NO_2 (as N)	(mg/ℓ)	3,4	0,10	**6,0**	**10,0**
PO_4 (as P)	(mg/ℓ)	0,07	0,013	**-**	**-**
Si	(mg/ℓ)	12,1	5,5	**-**	**-**
NH_4 (as N)	(mg/ℓ)	1,48	0,04	**6,0**	**10,0**
Fe	(mg/ℓ)	*	*	**0,1**	**1,0**

* = Not determined

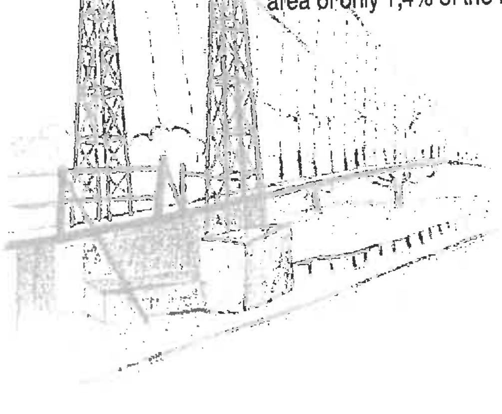
A = Borehole on the farm Welgevonden west of Oudtshoorn; Enon Formation; yield 0,4 ℓ/s .

B = Borehole on the farm Hartenbosch north of Mossel Bay; Hartenbos Formation; yield 0,2 ℓ/s.

D = Drinking Water Quality Criteria: Maximum Recommended limit
E = Drinking Water Quality Criteria: Maximum Allowable limit

4.2 Fractured and Intergranular Aquifers

The only rocks in the map area which contain a measure of groundwater in weathered material in places, and in the underlying jointed bedrock, and which can thus be termed 'fractured and intergranular', are the various granites occurring roughly between Mossel Bay and Sedgefield. These granites, collectively known as the Cape Granite Suite, cover an area of only 1,4% of the map area (Table 2).



4.2.1 Cape Granite Suite

The following are the more important geological and groundwater characteristics:

- The Cape Granite Suite (Fig. 29) in the map area consists of the Maalgaten granite, which is the main granite body, and five smaller granitic bodies, namely the Rooiklip granite-gneiss, the Klipfontein granite, the Modderfontein granodiorite, the Rooiklip leucogranite and the Woodville pluton.
- The Maalgaten granite is coarse-grained with a K-feldspar phenocryst content of 15-20%. The Kleinfontein granite is fine to medium-grained with a K-feldspar content of less than 1%. The Modderkloof and Woodville bodies are medium-grained biotite-rich bodies (Krynauw,1983).
- Since fine-grained, medium-grained and coarse-grained to porphyritic granite with varied compositions occur, diverse weathering forms can be expected, with concomitant groundwater implications. Porphyritic granite, containing abundant phenocrysts of feldspar, is likely to weather to a largely clayey substance which could impede permeability. Medium-grained granite with a more balanced composition is likely to be a better aquifer when weathered. Likewise groundwater of different qualities might be obtained due to varied rock compositions.
- Some of the granite bodies, notably the Rooiklip granite-gneiss, are known for the presence of fluoride (Krynauw,1983).

FIG 29: AREAL LOCATION OF THE CAPE GRANITE SUITE AND THE POSITION OF TABLE 12 CHEMICAL ANALYSES

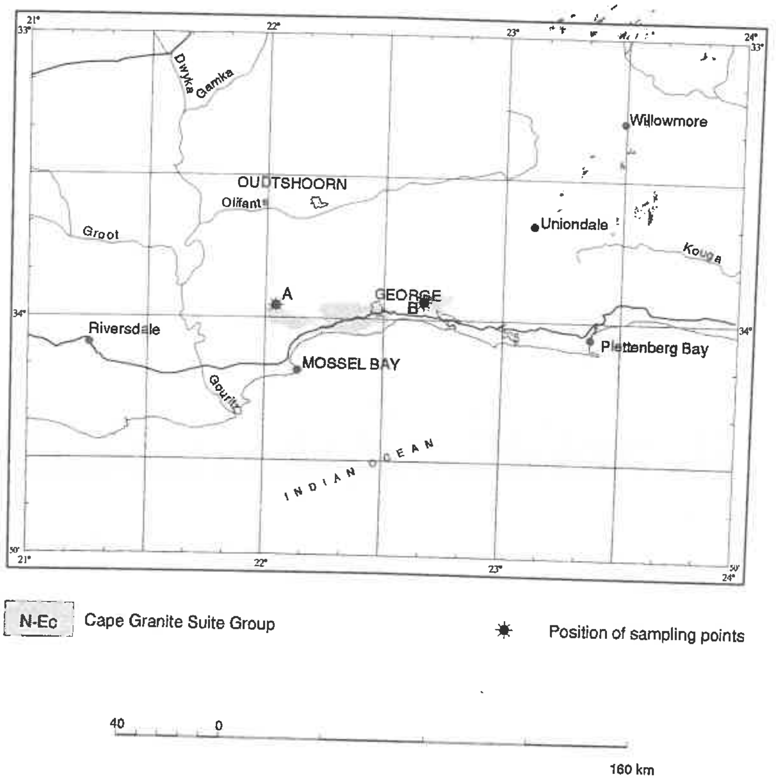


FIG 30: YIELD FREQUENCIES OF BOREHOLES IN THE CAPE GRANITE SUITE
(30 BOREHOLES ANALYSED)

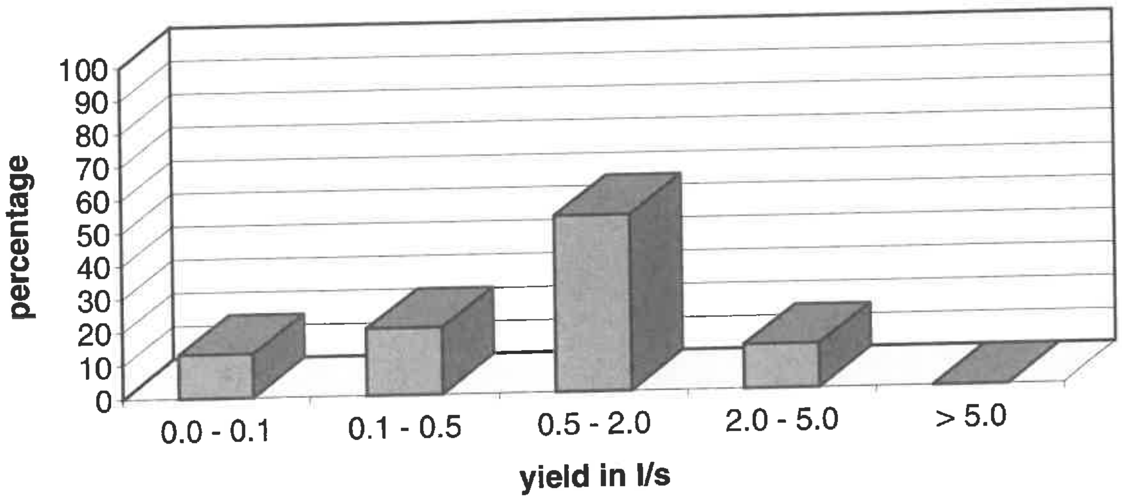
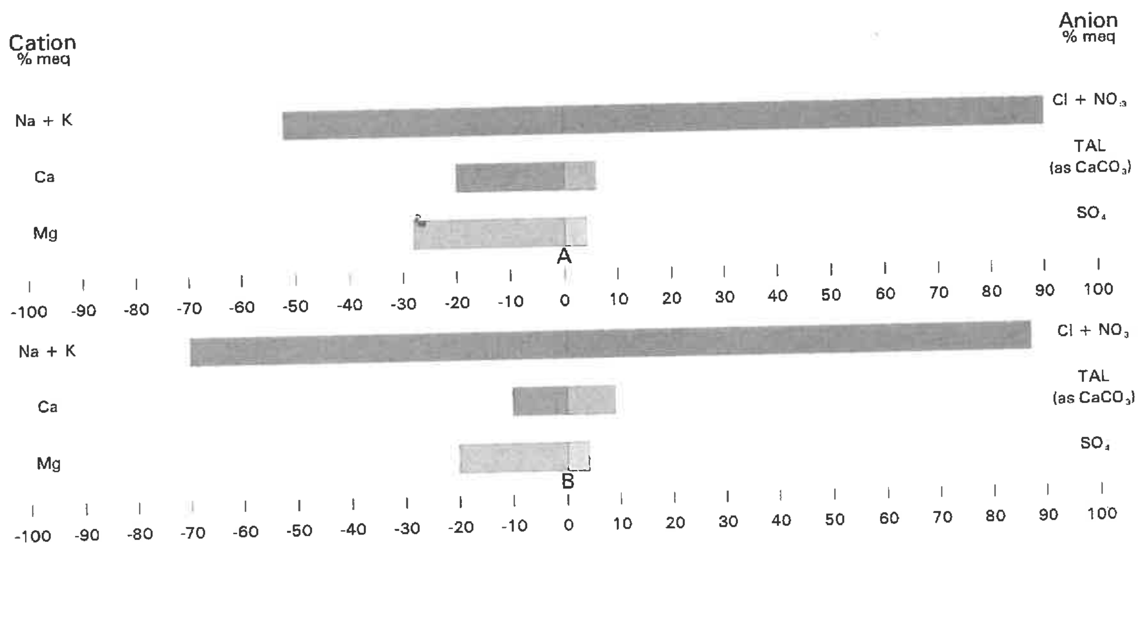


FIG 31: STIFF DIAGRAMS OF THE CHEMICAL ANALYSES IN TABLE 12 (CAPE GRANITE SUITE)



- Features within the granites which can be utilized for groundwater development are:
  - zones of weathering,
  - contact zones between granites and Kaaimans Group rocks,
  - dyke contacts, and
  - occasional fracture structures, which are generally not readily visible.
- It is often difficult to develop boreholes with strong yields in the granites due to:
  - lack of decomposition,
  - permeability inhibiting substances produced by weathering, and
  - lack of joint and fracture structures.
- A borehole analysis indicates that 86% of boreholes yield less than 2 ℓ/s (Fig. 30).
- Groundwater quality varies considerably, with ECs ranging between 60 and 1 200 mS/m. Determinants for sodium, chloride and fluoride often exceed maximum recommended and maximum allowable limits (Table 12). Groundwater from the granitic rocks displays a distinct sodium-chloride nature (Fig. 31).

TABLE 12: CHEMICAL ANALYSES FROM DIFFERENT BOREHOLES IN THE CAPE GRANITE SUITE (ANALYSED BY THE IWQS)

		A	B	D	E
EC	(mS/m)	166,0	246,0	**70,0**	**300,0**
TDS	(mg/ℓ)	851,0	1 345,0	**1 200,0**	**2 000,0**
pH		7,5	7,7	**6-9**	**5,5-9,5**
Na	(mg/ℓ)	170,0	350,0	**100,0**	**400,0**
K	(mg/ℓ)	10,3	6,1	**200,0**	**400,0**
Ca	(mg/ℓ)	59,0	45,1	**150,0**	**200,0**
Mg	(mg/ℓ)	51,0	55,0	**70,0**	**100,0**
Cl	(mg/ℓ)	471,0	688,0	**250,0**	**600,0**
SO_4	(mg/ℓ)	30,0	50,0	**200,0**	**600,0**
TAL ($CaCO_3$)	(mg/ℓ)	47,0	124,0	**20-300**	**650,0**
F	(mg/ℓ)	2,3	0,2	**1,0**	**1,5**
NO_3+NO_2 (as N)	(mg/ℓ)	0,04	0,04	**6,0**	**10,0**
PO_4 (as P)	(mg/ℓ)	0,023	0,025	**-**	**-**
Si	(mg/ℓ)	19,8	10,6	**-**	**-**
NH_4 (as N)	(mg/ℓ)	0,04	0,06	**6,0**	**10,0**
Fe	(mg/ℓ)	*	*	**0,1**	**1,0**

* = Not determined

A = Borehole on the farm Leeuwekloof north of Mossel bay; yield 0,3 ℓ/s.
B = Borehole on the farm Woodville NE of Wilderness; yield 0,3 ℓ/s.

D = Drinking Water Quality Criteria: Maximum Recommended limit
E = Drinking Water Quality Criteria: Maximum Allowable limit

4.3 Karst Aquifers

4.3.1 Matjies River Formation

The basal Matjies River Formation of the Kango Group is the only veritable karst aquifer in the map area.

The following are the more important geological and groundwater characteristics:

- The Matjies River Formation (Fig. 32) consists of limestone and subordinate shale and sandstone. Two Members can be identified, namely the basal Nooitgedacht Member (thickness 1 000 m) and the overlying Kombuis Member (thickness 1 300 m).
- The Nooitgedacht Member is composed of sandstone and shale, which form lenses within each other, or occur as alternating zones (Le Roux,1977). In addition two prominent limestone horizons can be distinguished.
- The Kombuis Member is composed of limestone, dolomitic limestone and subordinate shale and siltstone.
- The groundwater potential of the Matjies River Formation is good, especially in valleys where substantial coverages of alluvial deposits occur. A groundwater analysis indicates that 65% of groundwater sources in the Matjies River Formation yield 5 ℓ/s and more (Fig. 33).

> To the north of Oudtshoorn are the Cango Caves. The caves are situated in the limestone component of the Kango Group rocks. The vast underground limestone labyrinth of multicoloured dripstones were probably occupied by humans as far back as 8 000 years ago. There are 28 chambers, linked by 2,4 km of passages. Several other cave systems occur in the area, at least two of which are larger than the Cango Caves, but are difficult to reach and dangerous to explore. Many of the solution cavities in the limestones probably contain large quantities of groundwater.

FIG 32: AREAL LOCATION OF THE MATJIES RIVER FORMATION AND THE POSITION OF TABLE 13 CHEMICAL ANALYSES

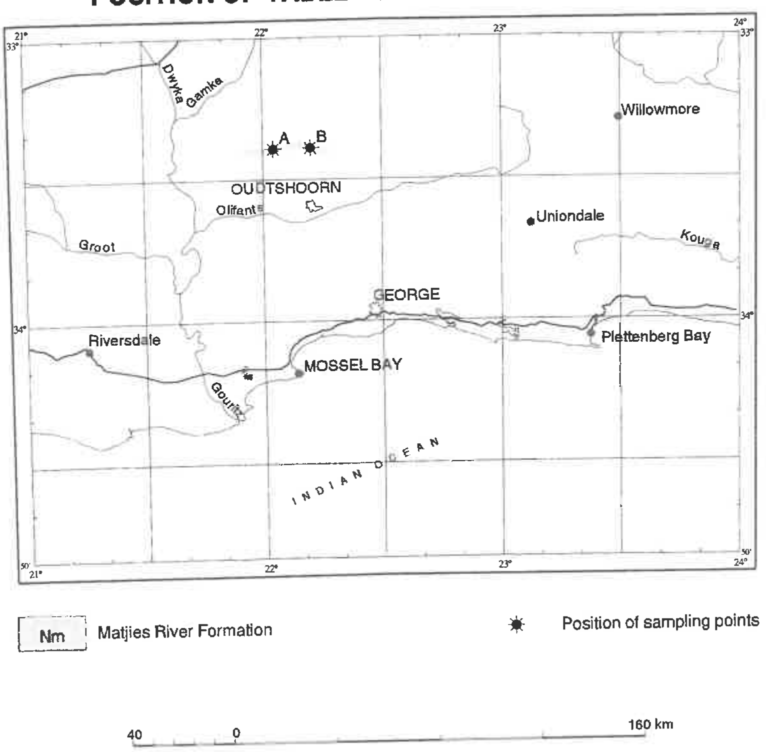


FIG 33: YIELD FREQUENCIES OF BOREHOLES IN THE MATJIES RIVER FORMATION
(27 BOREHOLES ANALYSED)

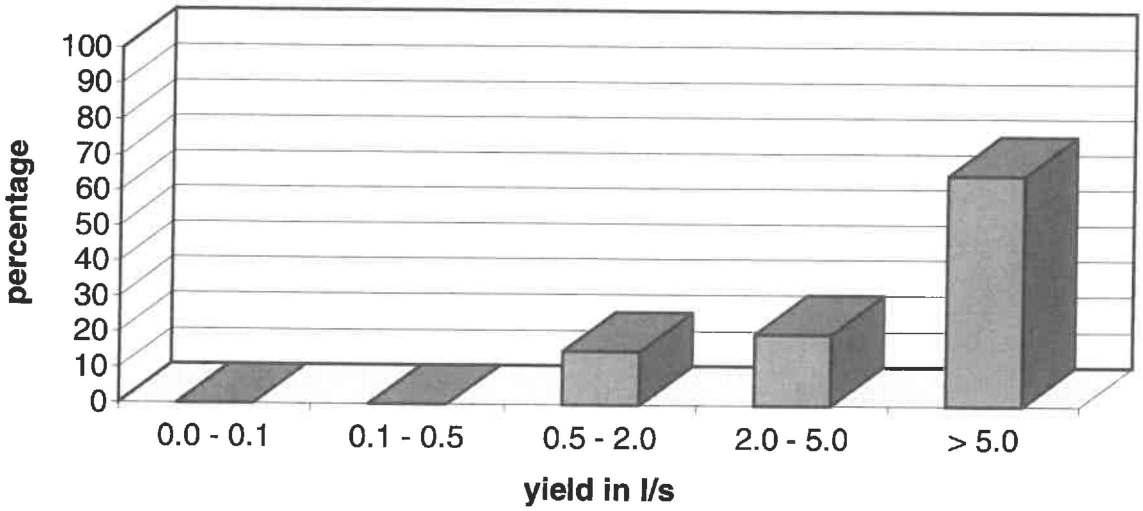
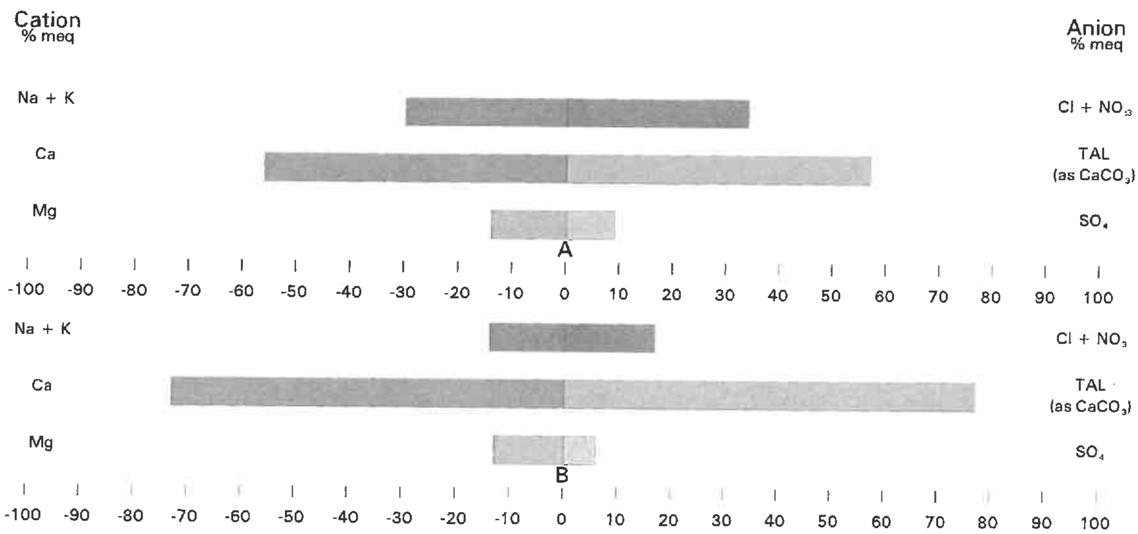


FIG 34: STIFF DIAGRAMS OF THE CHEMICAL ANALYSES IN TABLE 13 (MATJIES RIVER FORMATION)



❒ Groundwater quality varies between 20 and 200 mS/m. Determinants seldom exceed maximum recommended limits (Table 13). Groundwater from the Matjies River Formation has a notable alkaline nature (Fig. 34).

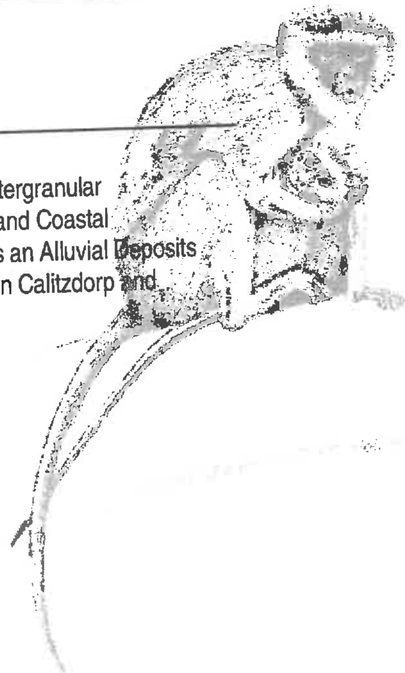
TABLE 13: CHEMICAL ANALYSES FROM DIFFERENT GROUNDWATER SOURCES IN THE MATJIES RIVER FORMATION

(ANALYSED BY THE IWQS)

		A	B	D	E
EC	(mS/m)	53,3	37,2	**70,0**	**300,0**
TDS	(mg/ℓ)	385,0	276,0	**1 200,0**	**2 000,0**
pH		8,1	8,1	**6-9**	**5,5-9,5**
Na	(mg/ℓ)	37,0	11,0	**100,0**	**400,0**
K	(mg/ℓ)	0,4	0,3	**200,0**	**400,0**
Ca	(mg/ℓ)	61,0	55,0	**150,0**	**200,0**
Mg	(mg/ℓ)	10,0	6,0	**70,0**	**100,0**
Cl	(mg/ℓ)	56,0	19,0	**250,0**	**600,0**
SO_4	(mg/ℓ)	19,0	11,0	**200,0**	**600,0**
TAL ($CaCO_3$)	(mg/ℓ)	159,0	141,0	**20-300**	**650,0**
F	(mg/ℓ)	0,1	0,2	**1,0**	**1,5**
NO_3+NO_2 (as N)	(mg/ℓ)	1,76	0,29	**6,0**	**10,0**
PO_4 (as P)	(mg/ℓ)	0,005	0,005	-	-
Si	(mg/ℓ)	6,3	4,1	-	-
NH_4 (as N)	(mg/ℓ)	0,19	0,04	**6,0**	**10,0**

A = Borehole in limestone on farm Matjiesrivier north of Oudtshoorn; yield >5 ℓ/s.
B = Cave in limestone on farm Nooigedagt north of Oudtshoorn.

D = Drinking Water Quality Criteria: Maximum Recommended limit
E = Drinking Water Quality Criteria: Maximum Allowable limit



4.4 Intergranular Aquifers

Intergranular aquifers cover less than 8% of the map area. Three intergranular aquifer types can be distinguished, of which the Bredasdorp Group and Coastal Sands aquifers are essentially coastal aquifers. The third comprises an Alluvial Deposits aquifer, which occurs mainly along various rivers in the area between Calitzdorp and De Rust.

4.4.1 Bredasdorp Group

The Bredasdorp Group (Fig. 35) consists of five Formations, namely (maximum thickness in brackets): the basal De Hoopvlei Formation (<17 m) which is overlain by the Wankoe (290 m), Klein Brak (<10 m), Waenhuiskrans (60 m) and Strandveld (100 m) Formations.

The following are the more important geological and groundwater characteristics:

- The sediments of the Bredasdorp Group were deposited under transgression and regression conditions in the late Tertiary to Holocene periods. At least three major transgression-regression cycles have been identified (Malan,1986).
- The Group consists of limestone, calcarenite, conglomerate, sandstone and calcareous sand. The beds dip gently seawards at 1-2°.
- The basal De Hoopvlei conglomerate (Plate 5) is the most important formation from a groundwater point of view, and is a discontinuous layer.
- The Bredasdorp Group aquifer is a unique intergranular aquifer. Water seeps relatively rapidly through the generally highly porous material to the underlying impervious pre-Bredasdorp beds. It moves in the conglomerate to lower-lying outlet points, where it frequently emerges as springs. Unlike conventional intergranular aquifers, hardly any build-up of groundwater levels takes place, and a groundwater interception in the conglomerate is likely to be the true piezometric level.

FIG 35: AREAL LOCATION OF THE BREDASDORP GROUP AND THE POSITION OF TABLE 14 ANALYSES

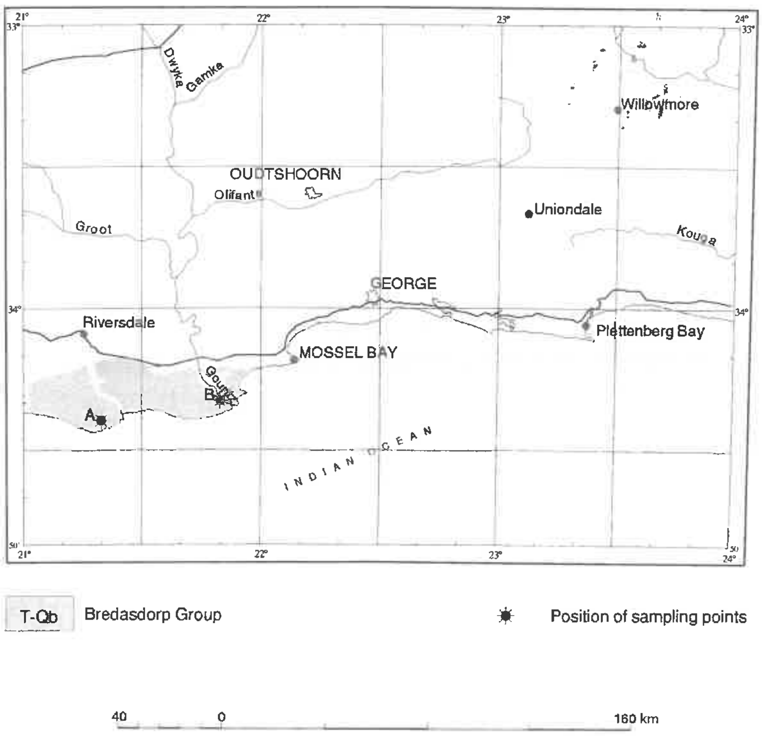


Plate 5: *Semi-consolidated calcareous sand overlies the basal De Hoopvlei Conglomerate Formation of the Bredasdorp Group near Still Bay. Impervious shale of the Bokkeveld Group underlies the conglomerate. The basal conglomerate often offer the only hope of obtaining groundwater in the Bredasdorp Group. (Photo: PS Meyer)*

Plate 6: *An artesian borehole in Bokkeveld Group rocks (Ceres Subgroup) east of Barrydale. (Photo: PS Meyer)*

- Yields generally range between 0,1 and 8,0 ℓ/s. A borehole analysis reveals that 45% of boreholes yield less than 1,0 ℓ/s and 18% yield more than 5,0 ℓ/s (Fig. 36). An analysis of 63 springs indicate that 14% yield more than 15 ℓ/s.

- ECs of groundwater are generally less than 100 mS/m, provided drilling does not extend into underlying formations where poor quality groundwater can be encountered. Determinants seldom exceed maximum recommended limits (Table 14). Groundwater from the Bredasdorp Group rocks displays a sodium-calcium-chloride-alkaline nature (Fig. 37)

TABLE 14: CHEMICAL ANALYSES FROM DIFFERENT GROUNDWATER SOURCES IN THE BREDASDROP GROUP

(A WAS ANALYSED BY THE AEC, B WAS ANALYSED BY THE CSIR)

		A	B	D	E
EC	(mS/m)	89,3	86,0	**70,0**	**300,0**
TDS	(mg/ℓ)	584,0	550,0	**1 200,0**	**2 000,0**
pH		7,4	8,2	**6-9**	**5,5-9,5**
Na	(mg/ℓ)	92,0	85,0	**100,0**	**400,0**
K	(mg/ℓ)	0,9	1,3	**200,0**	**400,0**
Ca	(mg/ℓ)	71,0	73,7	**150,0**	**200,0**
Mg	(mg/ℓ)	11,0	11,2	**70,0**	**100,0**
Cl	(mg/ℓ)	140,0	150,0	**250,0**	**600,0**
SO_4	(mg/ℓ)	13,0	14,0	**200,0**	**600,0**
TAL ($CaCO_3$)	(mg/ℓ)	199,0	180,0	**20-300**	**650,0**
F	(mg/ℓ)	0,2	0,1	**1,0**	**1,5**
NO_3+NO_2 (as N)	(mg/ℓ)	2,92	*	**6,0**	**10,0**
PO_4 (as P)	(mg/ℓ)	0,012	*	-	-
Si	(mg/ℓ)	4,7	*	-	-
NH_4 (as N)	(mg/ℓ)	*	*	**6,0**	**10,0**

* = Not determined

A = Borehole on the farm Zwarte Jongersfontein west of Stilbaai; De Hoopvlei Formation.

B = Spring on the farm Melkhoutfontein northwest of Gouritzmond; De Hoopvlei Formation; yield 30 ℓ/s.

D = Drinking Water Quality Criteria: Maximum Recommended limit
E = Drinking Water Quality Criteria: Maximum Allowable limit

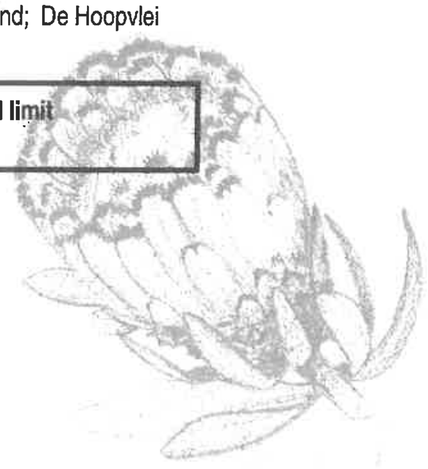


FIG 36: YIELD FREQUENCIES OF BOREHOLES IN THE BREDASDORP GROUP
(33 BOREHOLES ANALYSED)

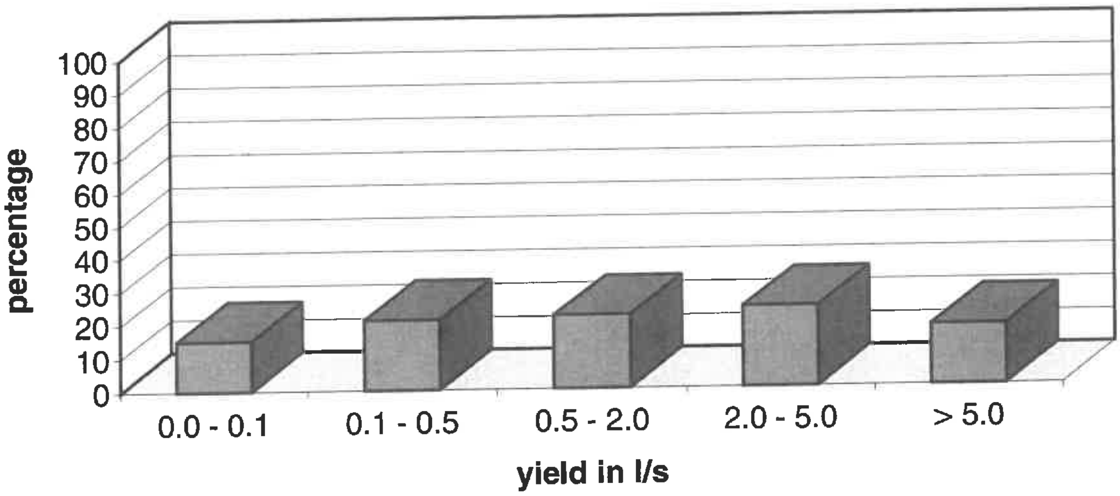
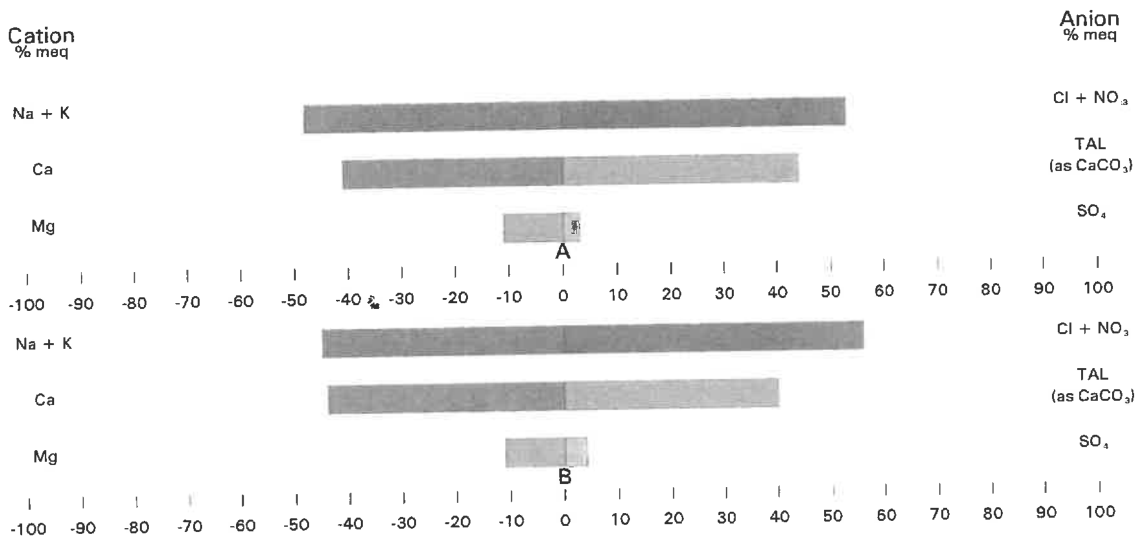


FIG 37: STIFF DIAGRAMS OF THE CHEMICAL ANALYSES IN TABLE 14 (BREDASDORP GROUP)



4.4.2 Coastal Sands

Limited deposits of coastal sand (Fig. 38) occur along the coast between Wilderness and Buffels Bay, and in the Keurbooms River mouth area.

The following are the more important lithological and groundwater characteristics:

- The Coastal Sands consist of a matrix of well-sorted, well-rounded fine- to medium-grained sand and beach sediments and occasional clay lenses. Sand thicknesses vary between 5 and 20 m.
- Coastal Sands aquifers are phreatic and generally unconfined and are highly vulnerable to pollution because of shallow water levels.
- Borehole and well yields generally vary between 0,2 and 4 ℓ/s and only rarely exceed 5 ℓ/s. A borehole and well analysis indicates that 43% of boreholes and wells yield less than 2 ℓ/s and 7% yield more than 5 ℓ/s (Fig. 39).
- Groundwater quality generally varies between 40 and 200 mS/m and an EC analysis show that 80 % of ECs are less than 200 mS/m (Table 15). Groundwater in the Coastal Sands has a sodium-chloride-calcium-alkaline nature (Fig. 40).

FIG 38: AREAL LOCATION OF THE COASTAL SANDS AND THE POSITION OF TABLE 15 CHEMICAL ANALYSES

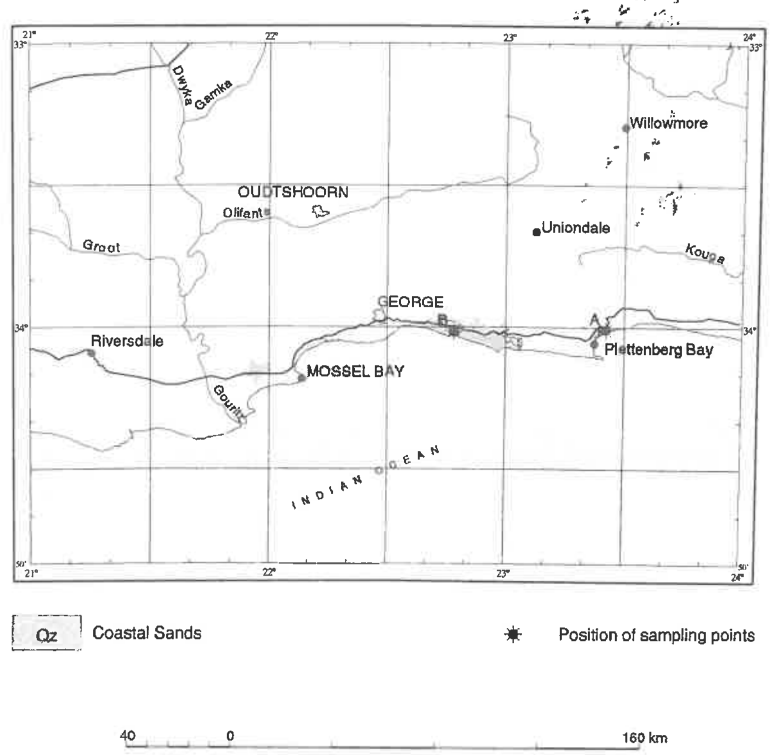


FIG 39: YIELD FREQUENCIES OF GROUNDWATER SOURCES IN THE COASTAL SANDS
(14 BOREHOLES ANALYSED)

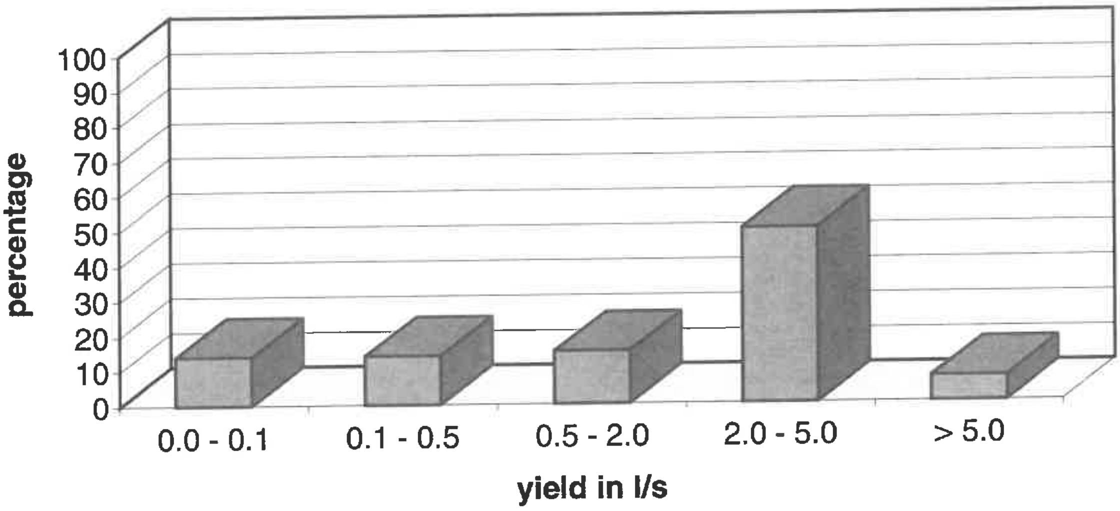


FIG 40: STIFF DIAGRAMS OF THE CHEMICAL ANALYSES IN TABLE 15 (COASTAL SANDS)

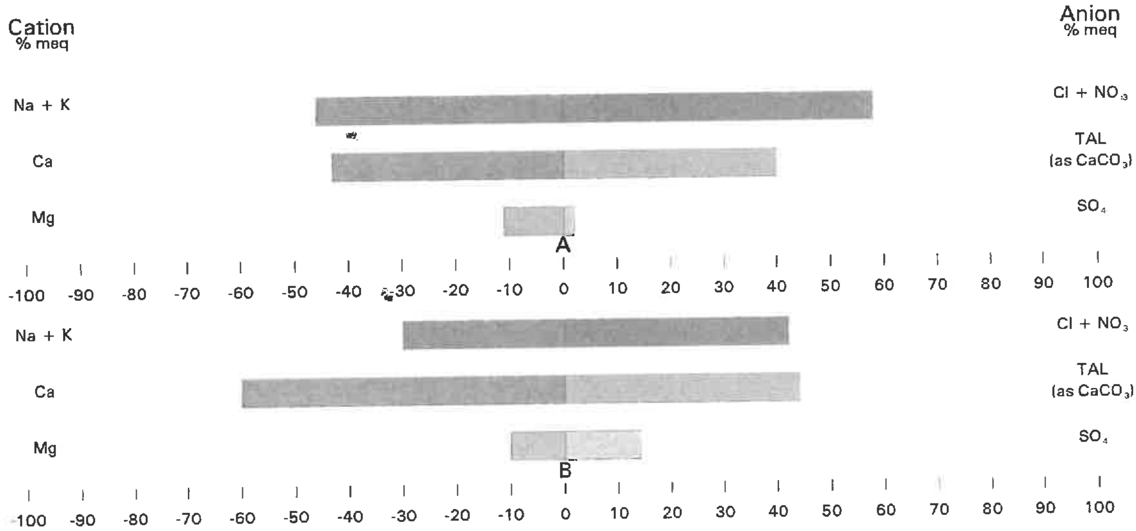


TABLE 15: CHEMICAL ANALYSES FROM DIFFERENT WELLPOINTS IN THE COASTAL SANDS
(A WAS ANALYSED BY THE IWQS, B WAS ANALYSED BY THE CSIR)

		A	B	D	E
EC	(mS/m)	130,0	76,0	**70,0**	**300,0**
TDS	(mg/ℓ)	845,0	486,0	**1 200,0**	**2 000,0**
pH		7,9	7,8	**6-9**	**5,5-9,5**
Na	(mg/ℓ)	135,0	55,0	**100,0**	**400,0**
K	(mg/ℓ)	3,8	3,6	**200,0**	**400,0**
Ca	(mg/ℓ)	110,0	95,6	**150,0**	**200,0**
Mg	(mg/ℓ)	18,0	10,4	**70,0**	**100,0**
Cl	(mg/ℓ)	260,0	106,4	**250,0**	**600,0**
SO_4	(mg/ℓ)	9,0	49,2	**200,0**	**600,0**
TAL ($CaCO_3$)	(mg/ℓ)	313,0	198,0	**20-300**	**650,0**
F	(mg/ℓ)	0,9	*	**1,0**	**1,5**
NO_3+NO_2 (as N)	(mg/ℓ)	0,3	*	**6,0**	**10,0**
PO_4 (as P)	(mg/ℓ)	0,008	<0,05	**-**	**-**
Si	(mg/ℓ)	4,7	*	**-**	**-**
NH_4 (as N)	(mg/ℓ)	0,1	*	**6,0**	**10,0**
Fe	(mg/ℓ)	*	<0,05		

* = Not determined

A = Wellpoint on the farm Matjiesfontein near Keurbooms River mouth.
B = Wellpoint alongside the Sedgefield lagoon, west of Sedgefield.

D = Drinking Water Quality Criteria: Maximum Recommended limit
E = Drinking Water Quality Criteria: Maximum Allowable limit

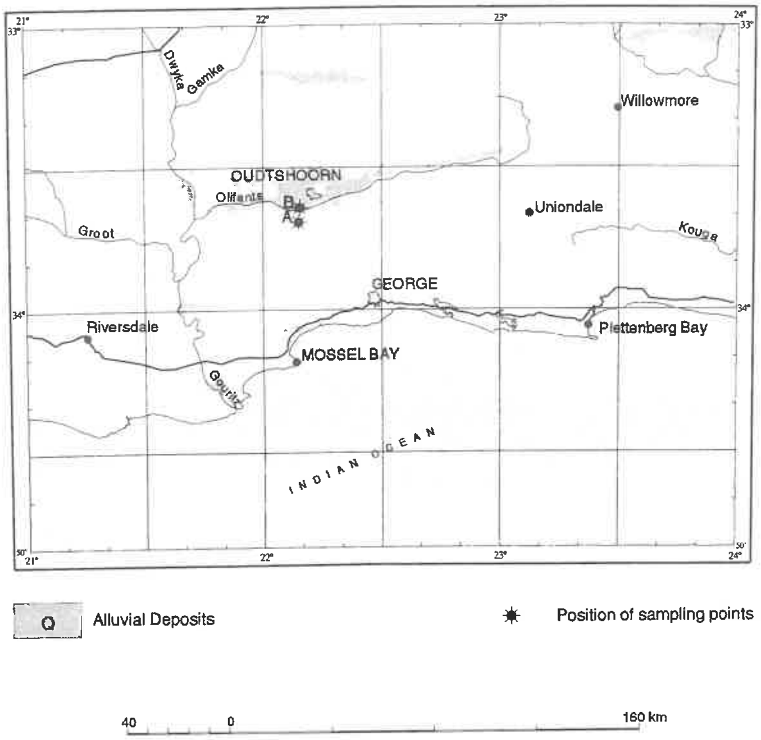
4.4.3 Alluvial Deposits

Some alluvial deposits (Fig. 41) occur largely along the Gamka and Olifants Rivers, and to a lesser extent along the tributaries of the Olifants River such as the Moeras, Wynands, Kandelaars and Grobbelaars Rivers.

The following are the more important geological and groundwater characteristics:

- An assemblage of unsorted boulders, pebbles, sand and clay can be expected.

FIG 41: AREAL LOCATION OF THE ALLUVIAL DEPOSITS AND THE POSITION OF TABLE 16 CHEMICAL ANALYSES



- ❑ Borehole yields vary between 0,1 and 20 ℓ/s. A yield analysis indicates that 46% of boreholes yield less than 2 ℓ/s and 37% yield more than 5 ℓ/s (Fig. 42).

- ❑ Groundwater quality in the alluvium along the Olifants River regularly exceeds 300 mS/m (B in Table 16). Groundwater from only one borehole in the Olifants River near Dysselsdorp is known to have an EC value of 83 mS/m. Determinants for sodium, calcium, magnesium, chloride and sulphate commonly exceed maximum allowable limits. Groundwater quality in alluvium along the tributaries of the Olifants River (A in Table 16) is generally better than that along the Olifants River. The alluvium generally has a sodium-chloride nature (Fig. 43).

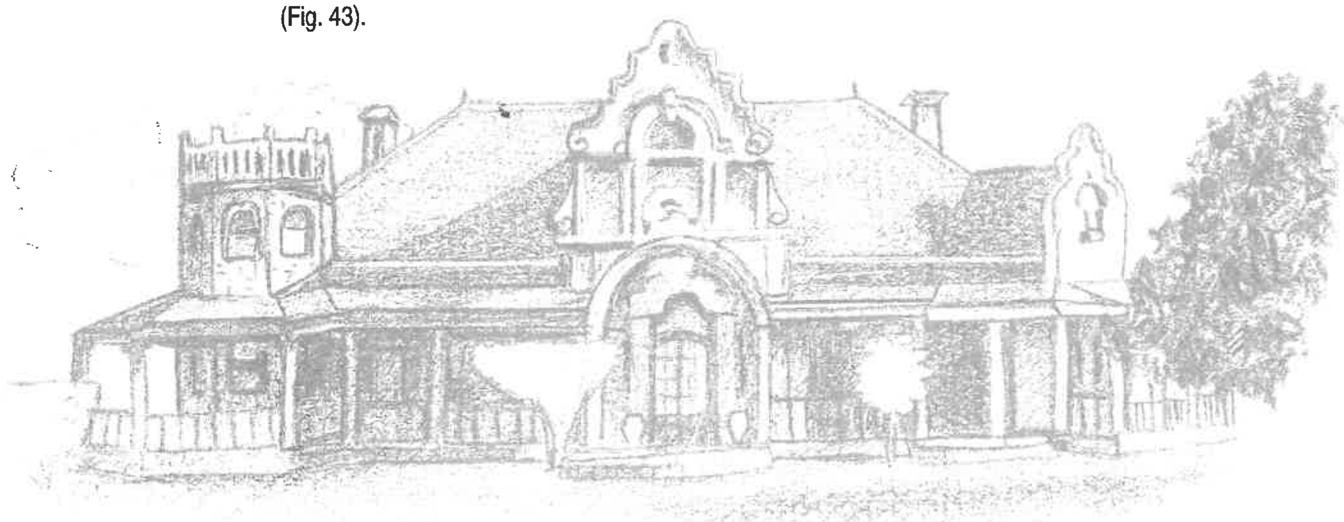


FIG 42: YIELD FREQUENCIES OF BOREHOLES IN THE ALLUVIAL DEPOSITS
(106 BOREHOLES ANALYSED)

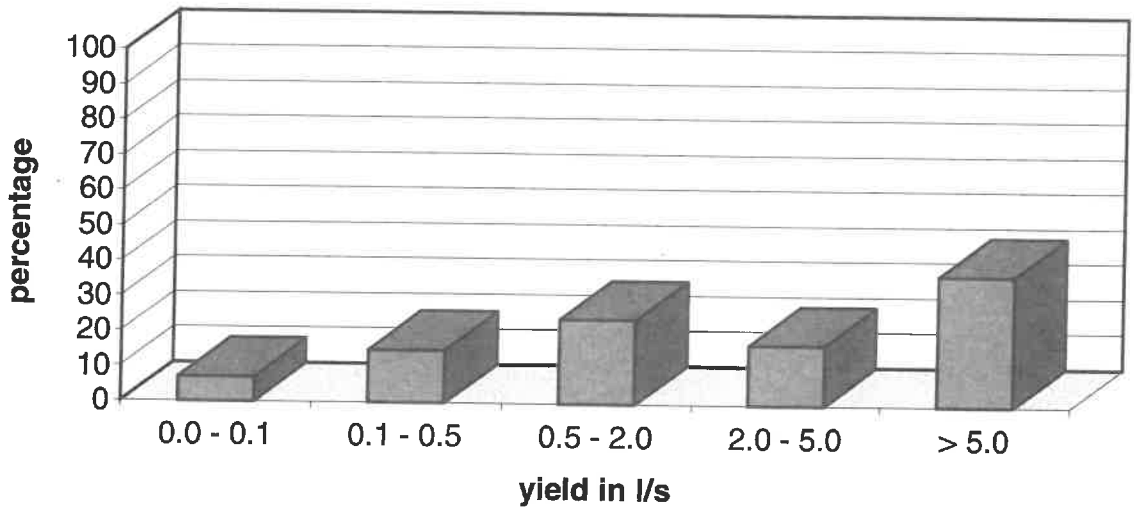


FIG 43: STIFF DIAGRAMS OF THE CHEMICAL ANALYSES IN TABLE 16
(ALLUVIAL DEPOSITS)

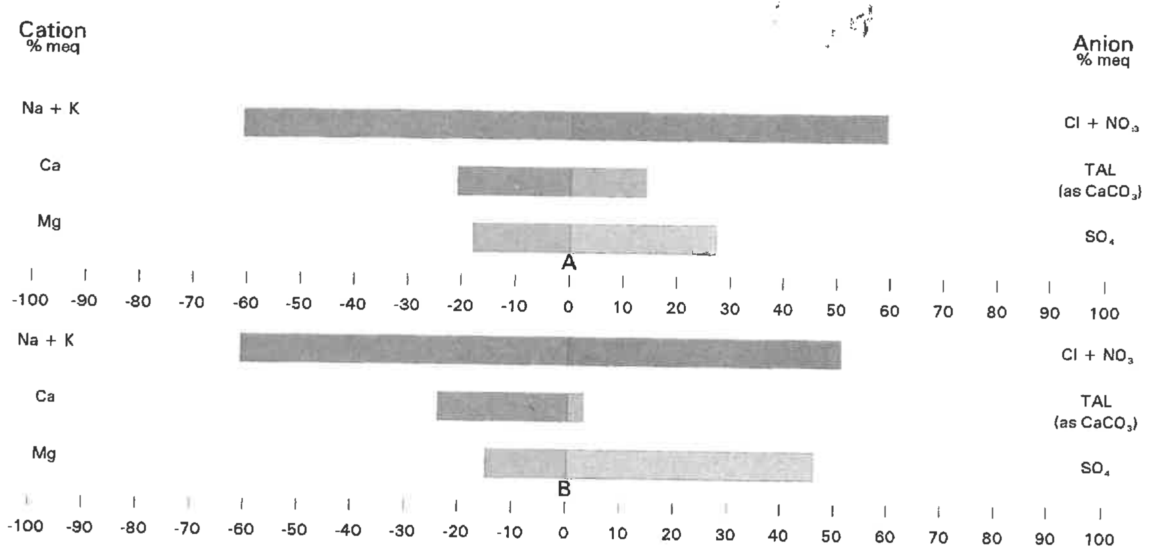


TABLE 16: CHEMICAL ANALYSES FROM DIFFERENT GROUNDWATER SOURCES IN THE ALLUVIAL DEPOSITS
(ANALYSED BY THE IWQS)

		A	B	D	E
EC	(mS/m)	200,9	624,0	**70,0**	**300,0**
TDS	(mg/ℓ)	1 306,0	4 056,0	**1 200,0**	**2 000,0**
pH		7,6	7,5	**6-9**	**5,5-9,5**
Na	(mg/ℓ)	274,0	932,3	**100,0**	**400,0**
K	(mg/ℓ)	2,9	23,3	**200,0**	**400,0**
Ca	(mg/ℓ)	81,1	330,6	**150,0**	**200,0**
Mg	(mg/ℓ)	44,4	122,7	**70,0**	**100,0**
Cl	(mg/ℓ)	409,6	1 195,1	**250,0**	**600,0**
SO_4	(mg/ℓ)	248,2	1 480,8	**200,0**	**600,0**
TAL ($CaCO_3$)	(mg/ℓ)	164,3	137,7	**20-300**	**650,0**
F	(mg/ℓ)	0,7	0,7	**1,0**	**1,5**
NO_3+NO_2 (as N)	(mg/ℓ)	*	*	**6,0**	**10,0**
PO_4 (as P)	(mg/ℓ)	*	*	-	-
Si	(mg/ℓ)	9,6	11,8	-	-
NH_4 (as N)	(mg/ℓ)	*	0,04	**6,0**	**10,0**

* = Not determined

A = Well alongside the Kandelaars River south of Oudtshoorn; yield <1 ℓ/s.
B = Spring near the Olifants River on farm Zeekoegat southwest of Oudtshoorn; yield <1 ℓ/s.

D = Drinking Water Quality Criteria: Maximum Recommended limit
E = Drinking Water Quality Criteria: Maximum Allowable limit

5 GROUNDWATER RELATED ISSUES

5.1 Previous Investigations

The Oudtshoorn Hydrogeological Map and Explanatory Brochure were compiled utilising data obtained from various previous investigations and research projects. These investigations and research projects were conducted by the Department of Water Affairs and Forestry, various Universities and a number of groundwater consultants. Investigations include amongst others, borehole sitings for farmers and groundwater exploration for municipal water supplies such as that for Willowmore, Oudtshoorn, Albertinia, Plettenberg Bay, Still Bay, and broader investigations conducted in the Olifants River Valley, the Kango region, the Kammanassie Mountains and the mountain foothills southwest of Calitzdorp. A fair regional spread of data was obtained from numerous borehole surveys.

5.2 Groundwater Levels

Taking all the geological units into account, an analysis of the available data indicates that the highest percentage of groundwater levels shallower than 10 m occur in the Kango, Table Mountain, Bokkeveld and Ecca Groups as well as the coastal sands and alluvial deposits (Table 17). This phenomenon can amongst others be attributed to:

- low relief conditions in the Coastal Sands, alluvial deposits and certain areas of the Bokkeveld and Ecca Groups,
- sub-artesian and even artesian conditions (Plate 6) in especially the Coastal Sands, the Bokkeveld Group, and the Matjies River Formation, and
- favourable and regular recharge conditions in especially the Bokkeveld Group, and Matjies River Formation.

The relatively high percentage of groundwater levels exceeding 30 m in the Bredasdorp, Kaaimans, Table Mountain and Uitenhage Groups (Table 17), can broadly be ascribed to:

- high relief conditions in the Table Mountain Group,
- the imperviousness of, and lack of groundwater recharge in, the Kaaimans and Uitenhage Groups,
- the lack of groundwater build-up in the Bredasdorp beds, and
- over-abstraction from the Table Mountain rocks in localities such as Wanhoop, Dysselsdorp and Albertinia.

With the exception of localities such as Wanhoop, Dysselsdorp and Albertinia, no particularly deep groundwater levels caused by over-abstraction are found. At the above-mentioned localities abstraction takes place year round, no groundwater management is practised, and groundwater levels do not recover adequately during wet seasons. In some areas of large-scale groundwater abstraction such as in the Klein Swartberg valley (Vleiland), seasonal groundwater level fluctuations of up to 30 m occur. Due to groundwater management by means of the conjunctive use of groundwater and surface water at these localities, groundwater recharge during rainy periods is usually satisfactory. Excluding areas of major groundwater abstraction, seasonal fluctuations of groundwater levels over the rest of the map area, commonly vary between 1 and 5 m.

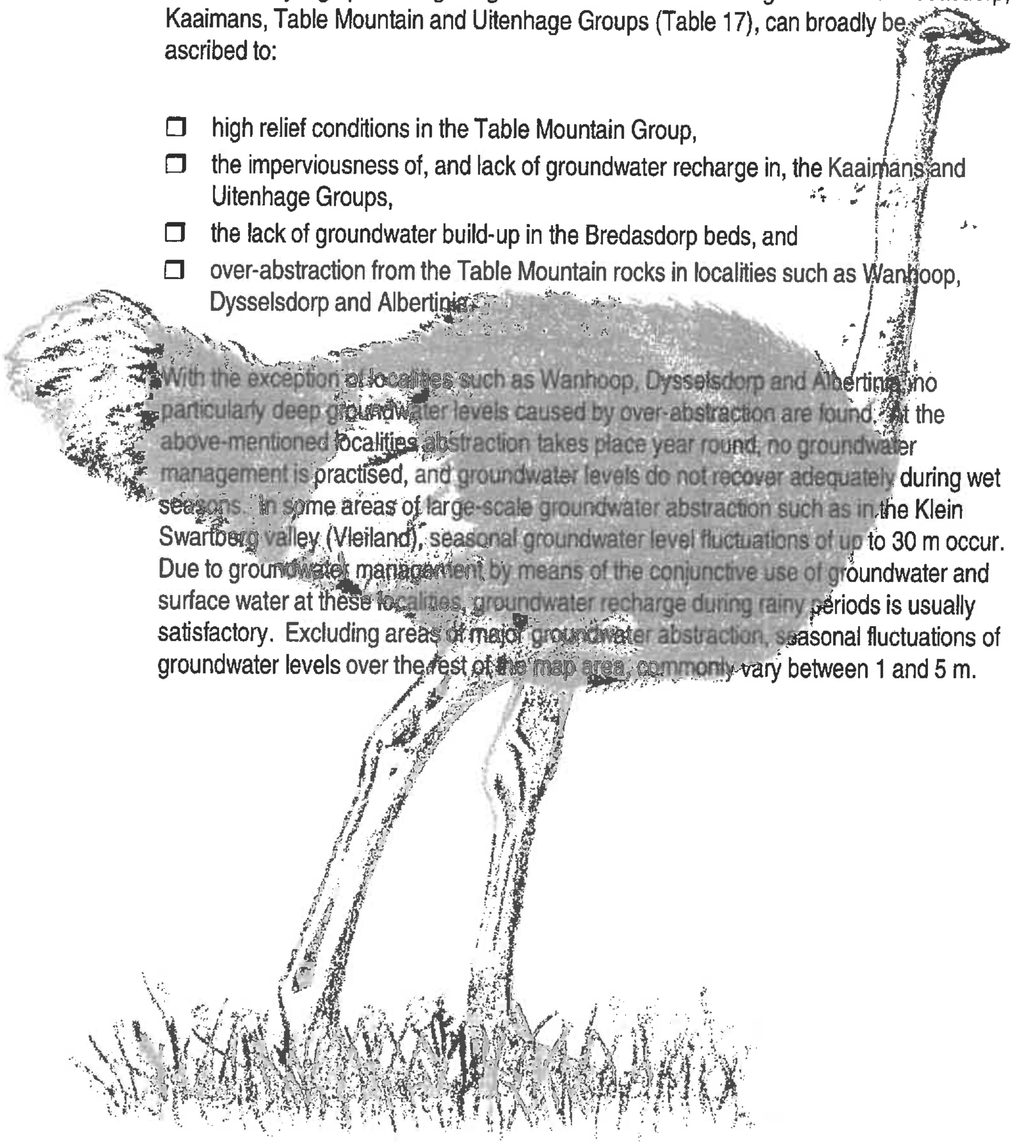


TABLE 17: GROUNDWATER LEVELS BELOW SURFACE FOR THE DIFFERENT GEOLOGICAL UNITS, EXPRESSED AS PERCENTAGES

Geological Unit	1	2	3	4	5
Kaaimas	21,4	35,7	14,3	28,6	14
Granites	25,0	10,0	35,0	30,0	20
Kango	55,5	16,7	16,7	11,1	18
Table Mountain	46,5	19,5	7,8	26,2	282
Bokkeveld	85,1	6,8	3,1	5,0	161
Witteberg	40,5	28,4	17,6	13,5	74
Dwyka	15,2	37,0	30,4	17,5	46
Ecca	52,9	21,2	23,5	2,4	85
Beaufort	38,5	28,1	24,0	9,4	96
Uitenhage	40,4	20,2	12,5	26,9	104
Bredasdorp	38,3	13,6	13,6	34,5	81
Coastal Sands	43,3	16,7	26,7	13,3	30
Inland Alluvium					

1 = percentage of groundwater levels <10 m from surface
2 = percentage of groundwater levels >10 m <20 m from surface
3 = percentage of groundwater levels >20 m <30 m from surface
4 = percentage of groundwater levels >30 m from surface
5 = number of groundwater levels analysed

5.3 Borehole Siting Methods

In the Cape Fold Belt, geophysical methods of siting boreholes are limited in their application and are used only as an aid when surface features are obscured. As fracture, joint and fold structures are generally the principal features to focus on when siting boreholes (Table 18), the use of aerial photographs is crucial. A thorough field reconnaissance of the geology, topography and climate, together with the collection and interpretation of hydrocensus data is essential. Once a broad picture of conditions on the ground has taken form, obscured features can be traced geophysically, applying the electrical resistivity and electro-magnetic methods, and in exceptional cases the magnetic method. The seismic and gravity methods are generally applied only when more extensive regional surveys are required.

The necessity of using trained personnel to site boreholes cannot be over-emphasised.

TABLE 18: GUIDELINES FOR SITING BOREHOLES

Geological Unit	1	2	3	4	5	6	7	8
Kaaimas	**	*	*		**			
Granites	*			**				
Kango	**	*	**					
Table Mountain	***				*	***		
Bokkeveld	**	*	*					
Witteberg	**	*	*					
Dwyka	**			*				
Ecca	**			*				
Beaufort	**			*				
Uitenhage		*						
Bredasdorp								**
Coastal Sands							***	
Alluvial Deposits							***	

* used on limited basis   ** moderately used   *** widely used

1 = Targeting fracture, joint and fold structures
2 = Targeting interbedded sandstone
3 = Employing alluvium as recharge medium to underlying rock
4 = Targeting weathering zones
5 = Targeting intrusion contact zones
6 = Targeting karstic features
7 = Targeting favourable sand/alluvium thicknesses
8 = Targeting basal conglomerate

5.4 Groundwater Management

For the optimum development of a groundwater resource, sound groundwater management practices are essential in order to prevent over-exploitation and/or pollution of these resources, and in order to achieve some measure of sustainable resource yield.

The most common groundwater management approach applied in the map area is the conjunctive use of groundwater and surface water. Groundwater is accordingly utilised during dry periods when little surface water is available. Surface water is utilized during wet periods, allowing recharge of groundwater resources. This commendable strategy should be employed wherever possible.

A fairly recent groundwater management approach is the continuous abstraction of groundwater at low abstraction rates to prevent turbulence and to minimise groundwater level fluctuations, which in turn will discourage the development of iron bacteria. This

The classic example of the mismanagement of a groundwater resource is the story of Dysselsdorp's water supply.

The town was founded by the Catholic Mission Church a couple of decades ago. A cluster of springs, situated at the western edge of the Kammanassie Mountains supplied the water-supply needs of the community. As the population gradually expanded, the water-supply from the springs became inadequate, and the authorities were compelled to drill a borehole in the TMG sandstones to augment the water-supply. With the sustained population growth, more boreholes had to be drilled and pumped, which was found to have an adverse influence on spring discharge. Springs ceased to flow towards the end of the 1970's and increased pressure was subsequently placed on borehole supplies to meet the demand. All this led to the current situation where the groundwater levels in the boreholes in the Dysselsdorp area is now about 100 m below ground level.

management strategy is currently being implemented in the Klein Karoo Rural Water Supply Scheme.

Seawater intrusion into both the Coastal Sands aquifers and the Table Mountain sandstone aquifer, and saline-water up-coning in the Coastal Sands aquifer are the most common forms of groundwater contamination in the map area. These forms of salinisation occur amongst others at Vleesbaai, Mossel Bay, the Sedgefield area and at Keurbooms River mouth.

Saline water intrusion can, in all instances, be attributed to over-exploitation. Groundwater management by means of groundwater level monitoring, evaluation with regard to volumes abstracted, and suitable water quality monitoring should be applied where groundwater is exploited from aquifers vulnerable to salinisation.

Waste disposal and sewage sites should be selected with utmost care by groundwater pollution specialists in order to protect aquifers in areas where contamination from a surface source is possible.

A knowledge of the National Water Act (1998), the purpose of which is to ensure that water resources are protected, used, developed, conserved, managed and controlled for the benefit of all, could prove to be advantageous with regard to some aspects of groundwater management.

5.5 Groundwater Utilization

An important aspect of water utilisation in the map area is the conjunctive use of surface water and groundwater from boreholes. During the hot and often dry summer months towns such as Plettenberg Bay and Prince Albert use groundwater to supplement surface water supplies. In the agricultural sector, surface water and groundwater are likewise being used conjunctively for irrigation and stock watering purposes (Table 19).

In the area south of latitude 34° S, roughly between Heidelberg and Mossel Bay (excluding the areas covered by the Bredasdorp Group) which is largely underlain by undifferentiated Bokkeveld Group rocks, the groundwater potential is so limited that water from the Duiwenhoks River Scheme is distributed to meet the needs of the farming community, and groundwater utilisation in that area is thus now insignificant.

Another region of seriously restricted groundwater potential is the Olifants River basin between Calitzdorp and de Rust. The Klein Karoo Rural Water Supply Scheme, which is being fed by groundwater from the bordering TMG sandstones, currently supplies the domestic and stock watering needs of the Olifants River basin community.

The rest of the map area is largely dependent on informal groundwater supplies for domestic and stock watering requirements.

Large scale groundwater abstraction occurs at several localities as listed in Table 19.

The Olifants River valley between De Rust and Calitzdorp has always been a water-poor area, and the lack of potable water seriously restricted development in the valley. Aware of this, the authorities initiated the Klein Karoo Rural Water Supply Scheme (KKRWSS) in the 1970's with the objective of supplying the valley with potable water for domestic and stock-watering purposes. Following a number of investigations, two groundwater well-fields were established in the 1980's in the Kammanassie Mountains east of Dysselsdorp and at the foothills of the Hoëberg south-west of Calitzdorp respectively. An effective distribution system and a sophisticated management programme in terms of groundwater abstraction measuring and water level and quality monitoring are in operation. The KKRWSS currently abstracts groundwater at a rate of approximately 3 200 m^3/d in order to supply 4 200 households and 48 800 stock units with good quality groundwater.

TABLE 19: LOCALITIES WHERE LARGE-SCALE GROUNDWATER ABSTRACTIONS (>100 000 M^3/A) TAKE PLACE

Locality/Area	Approximate abstraction (x$10^6$$m^3$/a)		
	Urban	Agriculture	Recreation
Van Wyksdorp area	-	2,30	-
Dysselsdorp	2,30	-	-
Klein Swartberg Valley	-	6,34	-
Herold/Wabooms River area	-	1,60	-
Studtis	-	1,90	-
Willowmore (Wanhoop)	0,22	-	-
Prince Albert	0,10	-	-
Miller area	-	0,25	-
Stilbaai	0,70	-	-
Kango area	-	1,10	-
Calitzdorp Spa	-	-	0,24
Toverwater Hot Spring	-	-	0,36
Albertinia	0,10	-	-
Plettenberg Bay	0,70	-	-
Vermaaks River	0,50	-	-
Kandelaars River	-	1,60	-
Klip River	-	1,30	-
Leeublad Area	-	1,50	-
Caltizdorp	0,10	-	-
TOTAL	**4,72**	**17,89**	**0,60**

5.6 Recommendations for Future Studies

Suggestions for more detailed groundwater related studies include the following:

- Evidence exists of deep groundwater circulation mainly in the TMG sandstones. To elucidate this phenomenon, the tectonics of the CFB and associated fracturing of the deeper sections of the TMG and its groundwater exploitation potential should be comprehensively studied.

- The relative competency of rocks in the CFB plays a key role in the occurrence of groundwater. Relative rock competencies and associated brittle failure should be studied to target areas of promising groundwater potential.

- Core drilling on a variety of faults is recommended in order to establish to what extent permeability inhibiting material occurs in joints and fractures, and to shed light on depth of fracture occurrence.

- Little is known about groundwater parameters in rocks of the CFB such as recharge, transmissivity, storage, etc. Isotope studies as well as more conventional study methods to gain further knowledge in this field should be encouraged.

- The influence of afforestation and deforestation on the groundwater regime is relatively unknown at present and needs further investigation.

- Although the Matjies River karstic aquifer is known for it advantageous groundwater potential, relatively little is known about its general groundwater conditions. An in-depth study is recommended in order to determine, amongst others:

  - the impact of alluvium on groundwater occurrence, and

  - the possibility of groundwater compartmentalisation due to the occurrence of intrusive mafic dykes.

- The distribution and mode of occurrence of springs in the CFB with particular emphasis on their occurrence in the TMG, needs to be examined.

REFERENCES

ANON/UNESCO, 1983
International Legend for Hydrogeological Maps, Revised edition, 1983. Unesco techn. Document, SC-84/WS/7, 51 p., Paris.

GRESSE PG, 1983
Lithostratigraphy and Structure of the Kaaimans Group. In: Söhnge APG and Hälbich IW (Editors). Geodynamics of the Cape Fold Belt. pp. 7-19.

JOHNSON DIVISION, JOP INC., 1975
Groundwater and Wells

KENT LE, 1949
The Thermal Waters of the Union of South Africa and South West Africa. Transactions of the Geological Society of South Africa.

KRYNAUW JR, 1983
Granite Intrusion and Metamorphism in the Kaaimans Group. In: Söhnge APG and Hälbich IW (Editors). Geodynamics of the Cape Fold Belt. pp.21-32.

LE ROUX JP, 1977
The Stratigraphy, Sedimentology and Structure of the Kango Group North of Oudtshoorn, C.P. Thesis Presented for the degree of Master of Science at the University of Stellenbosch.

LE ROUX JP, 1983
Structural Evolution of the Kango Group. In: Söhnge APG and Hälbich IW (Editors). Geodynamics of the Cape Fold Belt. pp.47-56.

MALAN JA, 1986
The Bredasdorp Group in the Southern Cape Province. Occasional Publication of the S.A. Society for Quaternary Research (Editor JH Deacon). Vol. 1, pp. 15-17.

MURRAY J, 1996
Structural and Hydrogeologic Investigation of the Table Mountain Group Rocks in the Cape Fold Belt, Southern Cape. Thesis Presented for the degree of Master of Science at the University of Port Elizabeth.

PLUMSTEAD EDNA P, 1968
Three Thousand Million Years of Plant Life in Africa. The Geological Society of South Africa. Annexure to volume LXXII. Alex du Toit Memorial Lectures No.11.

STRATTEN T, 1968
The Dwyka Glaciation and its Relationship to the pre-Karoo surface. Unpub. Ph.D. thesis, University of the Witwatersrand, Johannesburg.

THERON JN, WICKENS H.DE V. and GRESSE PG, 1991
The Geology of the Ladismith Area, Explanation Sheet 3320, Geological Survey of South Africa, 99 pp.

TOERIEN DK, 1979
Geology of the Oudtshoorn Areas. Explanation Sheet 3322, Geological Survey of South Africa, 13 pp.