HYDROGEOLOGY OF GROUNDWATER REGION 19

LOWVELD

Prepared for the Water Research Commission

by

JR Vegter

Hydrogeological Consultant

WRC Report No. TT 208/03

October 2003

Obtainable from:

Water Research Commission
Private Bag X03
GEZINA 0031
Pretoria

The publication of this report emanates from a project entitled: *Hydrogeology of groundwater region 19 Lowveld* (WRC Consultancy No. K8/463)

ISBN No. 1-77005-026-4
ISBN Set No. 1-86845-645-5

Printed in the Republic of South Africa

EXECUTIVE SUMMARY

The study provides important guidelines for the successful and cost-effective siting of boreholes for water – refer to titled section below.

Groundwater Region 19 Lowveld lies between the Great Escarpment in the west and the Lebombo Range in the east. It stretches over a distance of about 300 km from the Soutpansberg in the north to the Barberton Mountain Land in the south. Width varies between 80 and 150 km. Region 19 lies partly in the Limpopo (formerly Northern) and partly in the Mpumalanga Province. The Kruger National Park occupies about one-third of the Region along its eastern boundary.

The climate is warm to hot. The biome is savannah. The greater part of the Lowveld lies at elevations of between 300 and 600 m.a.m.s.l. and receives between 500 and 600 mm of rain during the summer. Along its western boundary rainfall varies from 650 mm in the north, where the elevation is about 1000 m, to more than 1000 mm in the south where the surface reaches 1500 m.a.m.s.l.

Surface runoff is by means of

- Upper reaches of the Pafuri River(A9)
- Shingwidzi River (B9)
- Great Letaba River and tributaries (B8)
- Lower Olifants River and its tributaries the Klaserie and Selati (B7) and the Lower Blyde River (B6)
- Nwanedzi River (X4)
- Sabie and Sand Rivers (X3) and
- Lower Crocodile River (X2)

Letter and number in brackets denote Drainage Region (Department of Water Affairs and Forestry)

Along the Escarpment mean annual base flow ranges per catchment from a few millimetres in the north to more than 100 mm in the south i.e. from a few to 50 percent of the mean annual runoff. Groundwater is the sole source of supply for more than one quarter million people; the balance of the population of roughly 2 million obtains water from both surface and groundwater sources. In the Kruger National Park human consumption and game watering are provided partly from groundwater.

Folded and metamorphosed granites, gneisses and granitoids of Swazian to Randian age occupy most of Region 19. In addition highly deformed and metamorphosed Swazian sedimentary and volcanic rocks are present in the form of elongated to irregularly shaped belts or as trains of xenoliths enveloped by gneiss, granite or granitoid rock. Dyke swarms mainly composed of diabase and dolerite, have intruded these rocks.

The current state of knowledge about groundwater in the Region is confined to

- the set of national groundwater maps (Water Research Commission 1995) and
- information and data held by the Department of Water Affairs and Forestry comprising
    - Brief reports on drilling sites and several borehole censuses,
    - Hydrogeological sheets Phalaborwa and Nelspruit; and
    - The National Groundwater Database.

Except for limited stretches of water-bearing alluvium along rivers mainly below elevations of 300 to 350 m.a.m.s.l, groundwater has to be found where weathering and fracturing of the hard-rock formations extend into the saturated zone. Within any of the mapped lithostratigraphic units, local variations in mineralogical composition and texture and the presence or absence of structural features determine the variable degree and depth of weathering and fracturing.

A comprehensive description of the occurrence of groundwater requires detailed field studies in order to identify, catalogue and map not only existing sources of supply but also those particular geomorphologic and geologic features that are indicative of favourable conditions for siting boreholes. In the event of possible exploitation of the latter confirmation by geophysical surveying may be necessary. At this stage such a comprehensive account is impossible. The only alternative is to analyse data contained in the National Groundwater Database more comprehensively than was done in the case of the national set of groundwater maps and the two hydrogeological sheets mentioned above.

Siting boreholes for water

Further statistical analyses have provided guidelines for siting boreholes with a larger measure of success than hitherto and for considerably reducing the cost of drilling. They are the following:

- The chances of striking water are better in the supracrustal rocks as a unit (amphibolite, quartzite, sandstone, shale schist) than in the granitic rocks. Yields are also higher. Schist however has been found a poor groundwater target.
- The Nelspruit Granite Suite as a whole appears to be the least favourable of the granitic lithostratigraphic units.
- Fractures, which are the conduits that deliver groundwater to boreholes, are most numerous within the near-surface zone.
- The zone of weathering is mostly less than 40 metres thick. In only few cases do weathering and fracturing as deduced from drill cuttings, extend deeper than 55 metres.
- The probability of striking water is highest at the base of the near-surface zone of weathering and fracturing provided it lies below the groundwater level.
- The depth to groundwater level – i.e. the top of the saturated zone – generally lies between 5 and 40 metres below the surface. The mode is 10 to 15 metres.
- The probability of striking water is highest within the first 10-15 metres or so below the groundwater level.
- Peak strike depths range from 15 to 50 metres below the surface. Below 50 m strike frequency averages about one third of that between 10 and 40 m
- The chances of striking water are neither enhanced nor on the other hand appreciably reduced by the presence of dykes.
- Dykes should not be regarded as hydrogeologically different from the country rock in which they occur but as part and parcel of a hard-rock entirety. Their water-bearing characteristics should be seen neither as barrier nor as conduit but as variable along their strike.
- Dyke contacts are not *per se* water strike zones. Success depends on whether country rock or dyke or both are weathered and fractured to below the groundwater level.
- Deeper strikes do not necessarily result in higher yields. There is no material difference between shallow-strike and deep-strike median yields. The effect of greater pumping drawdown is apparently counteracted by a decrease of fracture aperture and permeability with depth.
- The optimal strike zone below the base of weathering and fracturing as judged from drill cuttings or below groundwater level should determine drilling depth (see Table 15). A third approach is to limit deeper drilling to 15 metres once water has been struck and to a maximum depth of 60 metres should no strike be made. Compared to NGWDB borehole

depths, drilling costs may be reduced in this manner by about 25% or alternatively the same drilling distance may result in about one-third more successful boreholes.

Just more than 20 percent of the 1398 water samples that have been analysed over the years are not potable mainly due to harmful concentrations of nitrate and fluoride.

From the study of the available reports the lack of knowledge about the following aspects became apparent:

1) Which geomorphologic and geological features and which flora if any are indicative that weathering/fracturing may extend to below groundwater level? Geological characteristics include the mineralogical composition and texture of different rock types, weatherability, the spacing, orientation, age and distribution of fracture and dyke systems and their relation to the neotectonic stress field. How are these characteristics distributed spatially and how do they vary within the Region?

2) The manner in which the magnetic, electrical resistivity and electromagnetic methods are being applied and interpreted needs to be reviewed and overhauled.

3) Continuity of groundwater supply for human consumption needs to be assured. How steady are supplies from groundwater schemes serving rural communities? What are the criteria to take into account in siting borehole fields to ensure a continuous supply? Studies need to be undertaken of local groundwater schemes in order to translate their performance in terms of the local hydrogeology, rainfall and recharge. The purpose would be to ensure that groundwater schemes are sited and designed so as to fulfill their envisaged role.

4) Where and under which geological and other conditions does groundwater unfit for human consumption occur?

5) How are surface and groundwater resources to be managed jointly, particularly in those parts where irrigation of crops is practised?

6) The role of groundwater in the maintenance of the environment, particularly the riparian vegetation e.g. in the Kruger National Park needs determination.

ACKNOWLEDGEMENTS

The research covered by this report is a continuation of an earlier project funded by the Water Research Commission, which came to a close in 2000 when allocated funds were depleted. Since beginning 2001 the author continued on similar lines with analyses and study of the Lowveld Region.

The earlier project was entitled

"A MONOGRAPH ON SOUTH AFRICA'S GROUNDWATER RESOURCES"

The Steering Committee initially responsible for this project consisted of the following persons:

The late Mr. A.G. Reynders	Water Research Commission (Chairman 1995-98)
The late Mr. H. Maaren	Water Research Commission (Member and Chairman 1998- 1999)
Mr. K. Pietersen	Water Research Commission (1999)
Mr. Z. M. Dziembowski	Geohydrology, Department of Water Affairs and Forestry
Prof. J.O.G. Kirchner	Institute for Groundwater Studies, U.O.F.S. (only 1995)
Dr. R.J. Kleywegt	Council for Geoscience
Mr. R. Meyer	Division of Earth, Marine and Atmosphere Science and Technology - now Environmentek – CSIR
Mr. J.M.C. Weaver	Division of Water Technology – now Environmentek CSIR
Mr. D. Huyser	Water Research Commission (Committee Secretary 1995)
Mrs. C. M.Smit	Water Research Commission (Committee Secretary 1996 – 1999)

Alternates

Ms L. Godfrey	Representing Mr. R. Meyer (1998)

The financing of the current project by the Water Research Commission is gratefully acknowledged, as is also the contribution of the members of the Steering Committee In guiding the previous project. The present project is largely patterned on the research and reports on Regions 1 and 3 that were completed under their guidance.

This project was only possible with the co-operation of many individuals and institutions. The author therefore wishes to record his thanks to the following:

Department of Water Affairs and Forestry

Mr. E. Braune	Director Geohydrology
Mr. E. Bertram	Assistant Director Geohydrology
Mr. B.L. Venter	Chief Technician
Mr. C. Erasmus	Junior Programmer Geohydrology
Mrs. M. van Wyk	Senior Data Controller
	Council for Geoscience
Mr. L. G. Wolmarans	GIS specialist
Dr. H.J. Brynard	Chairman Spatial Data Management Unit

Mr. M. Simonic	Hydromedia Solutions (Pty) Ltd

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

HYDROGEOLOGY

OF

REGION 19 LOWVELD

1. INTRODUCTION

1.1. LOCATION AND EXTENT

See Figures 1 and 2 (at back of report). Region 19 covers an area of 35 500 km^2. It stretches over a distance of about 320 km in a north-south direction - from the Soutpansberg to just north of the Barberton Mountain Land. Its width varies between 80 and 150 km. The Region lies partly in the Limpopo (formerly Northern) Province and partly in Mpumulanga. The Kruger National Park occupies the eastern third of the Region.

Geological formations of the Soutpansberg Group (Region 8) form the northern boundary. From near Louis Trichardt to the Wolkberg, south of Haenertsburg, the Region's western boundary is the watershed between Drainage Region A7 (Sand River) in the west and B8 (Letaba River) and B9 (Pafuri River) in the east. South of Haenertsburg the western boundary follows the basal formations of the Wolkberg Group as far as Sabie, from where the base of the Black Reef Formation or of the Godwan Formation takes over to Kaapse Hoop. Region 12, Eastern Bankeveld, lies to the west. The southern boundary, which is formed by rocks of the Barberton Sequence (Region 45 Northeastern Middleveld), stretches from Kaapse Hoop eastwards to a point about midway between Hector Spruit and Komatipoort. The Region is adjoined in the east by Karoo strata of Region 20, Northern Lebombo.

1.2. PHYSIOGRAPHY

From elevations varying between 1000 and 1500 m.a.m.s.l along the western boundary, the ground surface drops eastwards to about 300 m.a.m.s.l. Most of the Lowveld Region is a plain, which lies at elevations of between 300 and 600 m.a.m.s.l. South of Acornhoek the plain undulates moderately; northwards between Acornhoek and Phalaborwa its surface is highly irregular, almost hilly. Further northwards the plain grades from somewhat irregular to slightly undulating in the far northeastern corner of the Region. Northeasterly-trending Archaean greenstone belts give rise to the Murchison Range and a series of hills in the vicinity of Giyani.

The watershed between Region 7 (Polokwane/Pietersburg Plateau) and Region 19 is strictly speaking not an escarpment. The transition from the plateau to the Lowveld ranges from a sloping, strongly undulating surface in the upper catchment of the Pafuri River (Drainage Region A9) to low mountainous terrain southwards as far as to Haenertsburg. A prominent feature of the watershed is the series of northeasterly trending mountain spurs, containing the upper reaches of rivers such as the Magoebaskloof, the Koedoes and Middel Letaba.

From Haenertsburg more or less as far south as Graskop, the western boundary of the Region practically coincides with the Drakensberg Escarpment. The Escarpment veers west of south from Graskop, whilst the base of the Black Reef Formation continues almost due south to Kaapse Hoop. Whereas the transition from the escarpment to the Lowveld plain is rather sharp between Haenertsburg and Graskop, a zone of low mountains and hills intervenes south of Graskop between the western boundary and a moderately undulating plain to the east.

The following rivers discharge from region 19 (drainage regions in brackets Department of Water Affairs 1996):

- Upper reaches of the Pafuri (A9)
- Shingwidzi (B9)
- Great Letaba and tributaries (B8)
- Lower Olifants and its tributaries the Klaserie and Selati (B7)
- Lower Blyde (B6) tributary of the Lower Olifants (B7)
- Nwanedzi (X4)
- Sabie and Sand (X3) and
- Lower Crocodile (X2)

The following north-south trending cyclic land surfaces of Partridge and Maud (1987) are present in Region 19 (see Figure 1 back of report)):

- The escarpment perhaps more correctly termed a transition zone, separating the elevated interior from the coastal hinterland. It is strictly not everywhere an escarpment.
- A dissected African surface directly to the east of it, narrow between the 24^0 and 25^0 parallels; but up to 75 km wide north of Tzaneen and between 25 and 60 km wide, south of the 25^0 parallel.
- A dissected Post-African I surface further east. The original Post-African I surface has been preserved on the interfluves.
- A partly planed Post-African II surface entering the Region from the east along the lower Olifants River and its tributaries, the Letaba and Selati and from about 30 km north of Skukuza to the southern boundary.

1.3. CLIMATE AND RAINFALL

The climate is warm to hot and a fairly high humidity makes summer days very oppressive. Cooler weather obtains against the Escarpment. Average daily maximum temperatures are of the order of 30^0C in January and 23^0C in July. Average daily minima are about 18^0C in summer and 8^0C in midwinter. At Phalaborwa evaporation from a class A pan is around 2000 mm per annum (Schulze 1994).

The rainy season lasts from about November to March. Rain is mainly in the form of thunderstorms. Against the Escarpment orographic rain and mists are of frequent occurrence. Rainfall decreases eastwards from the edge of the elevated interior. Along the western boundary of the Region mean annual precipitation varies from 650 mm in the north to over 1000 mm in the south. The highest – 1400 mm – is recorded in the vicinity of Graskop. The greater part of the Lowveld receives between 500 and 600 mm per annum Rainfall drops below 500 mm in the northeast and around Mica.

Effective rainfall according to the ACRU model (Schultze 1989) follows the same pattern. It averages over 600 mm per annum in the west and drops to less than 400 mm in the east.

1.4. NATURALVEGETATION

The biome is Savanna (Rutherford and Westfall 1986). In the west, north of the Olifants River, Lowveld Sour Bushveld (Acocks 1953) occupies the higher ground. Eastwards the vegetation changes to Arid Lowveld and eventually gives way to Mopani veld.
Mopani is absent south of the Olifants River. South of the Olifants River Lowveld Sour Bushveld in the west grades eastwards into Lowveld and thence into Arid Lowveld vegetation.

1.5. ROLE OF GROUNDWATER IN THE REGION’S ECONOMY

Surface water resources determine the Region's economy. The mean annual base flow or groundwater component of surface runoff that is generated in streams rising along the Escarpment in the west ranges per catchment from a few millimetres in the north to over 100 mm in the south. It thus varies from a few to 50 percent of the mean annual runoff (Water Research Commission 1995; Vegter 1995). The major portion of the base flow is however generated not within Region 19 but is derived from the overlying dolomitic and other strata that cap the Escarpment.

Away from the escarpment slopes and foothills negligible or no base flow is produced. Even so because groundwater is being recharged throughout the Region (see Chapter 6) and because it flows to near-by lower-lying areas, it plays a role in watering riparian vegetation and thus imperceptibly augmenting stream flow.

According to information obtained from the Department of Water Affairs and Forestry, somewhat more than a quarter million people are solely dependent on groundwater supplies for human consumption. This population is distributed between 3 formal towns, 11 dense and 58 small rural villages and 16 dispersed communities. The balance of the roughly 2 million people living in Region 19 obtain water from both surface and groundwater sources. They are resident in 133 formal towns, 282 small and 82 dense rural villages and 10 scattered communities. Proportions obtained from surface and groundwater are unknown. Groundwater provides partly for human consumption and game watering in the Kruger National Park.

Notable abstraction of groundwater to supplement surface water supplies for irrigation of crops, especially during droughts, has taken/takes place in the following areas:

- Valleys of the Koedoes, Middel Letaba and Brandboontjie Rivers in the vicinity of Mooketsi
- Along the Letaba River between Letsitele and the Eiland Mineral Baths
- Levubu Settlement
- Along the Ga-Selati and Tsolomeetse Rivers in the vicinity of Trichardtsdal

.

2. GEOLOGY

2.1 INTRODUCTION

This account is based on the following:

- Geological Map of the Republic of South Africa and the Kingdoms of Lesotho and Swaziland scale 1:1 000 000 (1997).
- Explanation by D.J.L. Visser (1989) of the 1984 edition of the 1:1 000 000 Geological Map of the Republics of South Africa, Transkei, Bophuthatswana, Venda, Ciskei and the Kingdoms of Lesotho and Swaziland.
- 1:250 000 scale geological sheet maps:
  - Messina 2230 (1981) and Explanation by G Brandl (1981).
  - Tzaneen 2330 (1985) and Explanation by G. Brandl (1987).
  - Pilgrim's Rest 2430 (1986) and Explanation by F. Walraven (1989a).
  - Barberton 2530 (1986) and Explanation by F.Walraven (1989b).
- Structure Map of South Africa and the Kingdoms of Lesotho and Swaziland scale 1:1 000 000 (1995).

The lithostratigraphy is summarised in Table 1. Figure 2 (back of report) is a simplified version of the geology.

In the following paragraphs the lithologies of the more important lithostratigraphic units are briefly described in geographical order from north to south. Formation letter symbols are given in brackets as they appear on the 1:1 000 000 Geological map (1997).

2.2. GOUDPLAATS AND MAKHUTSWI GNEISSES (Zgo and Zmk)

Goudplaats and Makhutswi Gneisses underlie most of the area between the Soutpansberg in the north and latitude 24^{o} 45' south. They consist of medium to fine-grained grey biotite-bearing rocks of tonalitic composition. The Goudplaats Gneiss is strongly foliated and characterized by alternating bands of leucocratic and melanocratic material. In places it grades into migmatite. The gneiss occurring south of the Murchison Range has been termed the Makhutswi Gneiss. It is very similar to the Goudplaats Gneiss. The relationship of the Goudplaats and Makhutswi Gneiss to the greenstone belts is uncertain. The older view was that both Gneisses probably formed a basement to the Bandelierkop Complex and to the Pietersburg, Giyani and Gravelotte Groups. On the 1997 1:1 000 000 geological map and the stratigraphic table published by the Council for Geoscience in 1998 the greenstone belts occupy the bottom of the table i.e. they are assumed to be older than the Gneisses. A broad zone of leucocratic biotite granite (**Rbg**) extends from Tzaneen towards the Giyani Greenstone Belt. It is thought to have formed through complete anatexis of the Goudplaats Gneiss.

2.3. BANDELIERKOP AND SCHIEL COMPLEXES (Zb and Vsch)

The Bandelierkop Complex, which is part of the southern marginal zone of the Limpopo Mobile Belt, is restricted to the northwestern part of the Region and occurs as highly deformed bodies in the Goudplaats Gneiss (1:250 000 Sheet Tzaneen). On the 1:250 000 Messina sheet similar bodies, east of the Koedoes River Lineament, are indicated as belonging to the Giyani Group. The Complex comprises ultramafic, mafic and metasedimentary units which were subjected to granulite grade metamorphism.

The principal components of the Schiel Complex, a large mushroom-shaped intrusive body in the northwest, are syenitic rocks, subordinate hornblende-granite and gabbro.

TABLE 1 LITHOSTRATIGRAPHY OF REGION 19

Erathem	Sedimentary and Volcanic Rocks	Symbol on 1:1million geological map (1997)	Intrusive Rocks
Cenozoic	Residual soil, alluvium		
Mesozoic		Jd	Dolerite dykes
Mokolian		Mti	Timbavati Gabbro (T* & PR*)
		Msg	Sabie Sands Granophyre (PR*)
		Men	Entabeni Granite (T*)
		Mph	Phalaborwa Complex (T* & PR*)
Vaalian		Vdi	Diabase dykes
		Vsch	Schiel Alkaline Complex (T*)
Randian		Rpa	Palmietfontein Granite(T*)
		Rbg	Unnamed leucocratic biotite granite (T*)
		-	Eiland Suite (T*)
		Rms	Mashishimale Suite Granites (T* & PR*)
		Rba, Rpo, Rwi & Rle	Vorster Suite Granites (T* & PR*)
		Rje	Jerome Granite (M*)
		Rmr	Maranda Granite (T* & PR*)
		Rsh	Shamiriri Granite (T*)
		Rsi	Shirindi Granite(T*)
		-	Macetce Granite (T*)
		-	Meriri Granite (T*)
		Rtu	Turfloop Granite (T* & PR*)
		Rmg	Mpageni Granite (B*)
		Rc	Cunning Moor Tonalite (PR*)
		Rha	Harmony Granite (PR*)
		Rro	Rooiwater Complex (T* & PR*)
Swazian		ZB	Unnamed (informally Orpen) potassic granite, gneiss (PR*)
		Zgo	Goudplaats Gneiss (M* & T*)
		Zmk	Makhutswi Gneiss (T* & PR*)
		-	Hebron Granodiorite (PR* & B*)
		Zne	Nelspruit Suite Granites(PR* & B*)
		ZC	Stentor and unnamed trondhjemitic and tonalitic gneiss (B*)
	Pietersburg Group (T*)	Zp	
	Giyani Group (T*)	Zgi	
	Gravelotte Group (T* & PR*)	Zg	
	Bandelierkop Complex (M & T)	Zb	

M* = 1:250 000 Messina sheet
T* = 1:250 000 Tzaneen sheet
PR* = 1:250 000 Pilgrims Rest sheet
B* = 1:250 000 Barberton sheet

2.4. GIYANI, PIETERSBURG AND GRAVELOTTE GROUPS (Zgi, Zp and Zg)

The Giyani Group is made up of ultramafic schists, amphibolite and subordinate metasedimentary rocks: quartzitic and garnetiferous schists; quartzite, iron formation and intrusive serpentinite and metapyroxenite.

The eastern-most tip of the Pietersburg greenstone belt (the greater part is situated in Region 7) lies within Region 19. Some xenoliths occur in the vicinity of Duiwelskloof. Only the Mothiba Formation consisting mainly of ultramafic schists and amphibolite and the Zandrivierspoort Formation consisting of amphibolite, a plagioclase-hornblende rock and magnetite quartzite, are present.

The Gravelotte Group forms the narrow Murchison Range greenstone belt. The Group has been divided into six Formations. Its lithology includes tremolite-; tremolite-actinolite-; chloritic; chlorite-talc-; quartzitic; and quartz-mica-schists; quartzite; metaquartzite; conglomerate and intrusive rocks such as serpentinite and metapyroxenite.

2.5. ROOIWATER AND PHALABORWA COMPLEXES (Rro and Mph)

The Rooiwater Complex is located along the northern margin of the Gravelotte Greenstone Belt. It comprises two Suites: the Novengilla consisting of gabbroic rocks and the Beesplaas composed of diorite.

The Phalaborwa Complex constitutes a suite of rocks ranging in composition from ultramafic to peralkaline.

2.6 RANDIAN INTRUSIVES SOUTH OF THE MURCHISON GREENSTONE BELT

The Vorster Suite granites (**Rba, Rpo, Rwi and Rle**) form a number of stocks or batholiths south of the Murchison Greenstone Belt. The rocks are with the exception of the Baderoukwe Granite which lies within the eastern extension of the Murchison greenstone Belt, massive and unfoliated and probably of post-tectonic origin.

Of the grey weakly foliated biotite-bearing Turfloop granite (**Rtu**), the eastern portion only of a batholithic intrusion is present.

The Mashishimale Suite (**Rms**) of biotite-hornblende granites lies directly south of 24^0 latitude. They occur as stock-like bodies. South of the greenstone belt passing through Mica are three intrusions of biotite-muscovite granite called the Harmony Granite (**Rha**).

The southern portion of the Pilgrims Rest sheet is largely occupied by leucocratic medium- to coarse-grained granitic rocks ranging from adamellite through granodiorite to tonalite and referred to as Cunning Moor Tonalite (**Rc**).

2.7 SOUTHERN SWAZIAN INTRUSIVES

On the Pilgrim's Rest sheet, in the vicinity of Klaserie, an unnamed (informally called Orpen) variable suite of migmatite and gneiss (**ZB**) more or less intervenes between the Makhutswi Gneiss to the north and the Nelspruit Suite to the south. It consists predominantly of light-grey medium-grained biotite-rich gneiss with coarse-grained quartz-feldspar leucosomes. Amphibolite dykes and xenoliths and inter-layered amphibolite are present in the migmatite and gneiss terrain.

The greater part of the area south of latitude 24^o 45' is underlain by medium- to coarse-grained biotite granite, porphyritic granite and potassic gneiss and migmatite grouped together as the Nelspruit Suite (**Zne**). In many places a coarse-grained pegmatite is present. The Hebron Granodiorite, occurs as isolated bodies within the Nelspruit Suite.

Bodies of tonalitic biotite-trondhjemite granite and gneiss (**ZC**) border on the Barberton Mountain Land (Region 45). Divergent opinions exist about which is the older: the meta-volcanic and sedimentary rocks of the Barberton Sequence or the tonalitic granite-gneiss and migmatite.

2.8 TIMBAVATI GABBRO AND YOUNGER INTRUSIVES (Mti, Vdi and Jd)

A sill-like intrusion of Timbavati Gabbro with an overall north-south trend stretches from 23^o latitude southwards to the Crocodile River. In places its outcrop pattern is very irregular.

Dykes occur throughout the Region - in places in swarms. On the Messina sheet the strike of diabase dykes is ENE. A less prominent strike is WNW. According to Brandl (1981) the dykes give rise to high narrow ridges.

North of Giyani the strikes are 20^o and 70^o east of north. In the rest of the Tzaneen sheet strikes vary between 50^o and 70^o east of north. Few dykes strike north-south and northwest-southeast. Dykes are usually between 10 and 20 metres wide and are shown as diabase. The NNE trending Black Hills dyke stretches over a distance of 90 km from Gravelotte to the Shingwidzi River.

Three dyke trends may be recognised on the Pilgrims Rest sheet – N-S, E-W and NE-SW. On northern part of the Pilgrim's Rest sheet the NE-trending dykes, which apparently belong to the same swarm shown on the Tzaneen sheet, are indicated as dolerite. The strike of diabase dykes on the southern part of the Pilgrim's Rest sheet and the northern part of the Barberton sheet is east west. A prominent east-west dyke north of Bush Buck Ridge extends from the Escarpment up to the Lebombo Range. It predates the Transvaal Supergroup and the Timbavati Gabbro. According to Walraven (1989) the dykes exert a strong control on the topography in the area covered by the Pilgrim's Rest sheet. Much of the drainage is located on dykes.

In the area covered by geological sheet 22 Nelspruit Visser and Verwoerd (1960) mention the following intrusive rocks:

- Pre-Godwan quartz porphyry dykes that trend northeastwards.
- Pre-Godwan basic and ultrabasic sills
- Pre-Godwan diabase and allied dykes. Trends are east-west and north-northwest
- Post-Transvaal diorite and quartz-diorite dykes that trend north or northeast and are older than NW-trending diabase dykes.
- Post-Karoo NE- SW striking dolerite dykes.

The Timbavati gabbro, which Visser and Verwoerd considered to be of Karoo age, is now taken to be of Mokolian age.

2.9. LINEAMENTS

LANDSAT and magnetic lineaments tend to have the same orientation as that of the dykes. Particularly noteworthy are the northeasterly trending Koedoes River and Tzaneen lineaments. The former presents an up to 4-km wide zone of ductile shear planes. The Constantia shear zone parallels the Murchison belt. It is up to 500 m wide in places and consists of sets of vertical shear planes along which the country rock has been altered to quartz-sericite schist. Also notable are the roughly N – S trending LANDSAT, aerial photographic and magnetic lineaments which occur all along and near to the eastern boundary with the Lebombo Karoo strata.

2.10. DEFORMATION AND METAMORPHISM

The older rocks especially the Swazian migmatites and gneisses as well as the Giyani, Pietersburg and Gravelotte greenstone belts underwent several periods of deformation during which they were intensely folded and metamorphosed. The younger intrusive granites were less deformed.

Two prominent directions of shear fracture are developed in the Nelspruit area – the oldest strikes north-northeast; the second and younger trends north-northwest. The latter developed after the intrusion of the pre-Godwan diabase.

Walraven (1989) mentions the existence of north-south oriented shear zones in the area covered by the Pilgrim's Rest sheet. Faulting seen in adjoining rocks of the Tranvaal Sequence in the west and Karoo strata in the east strike NW-SE and NE- SW. North-south oriented faults are also present in the Lebombo Range.

Faulting, which is conceivably less noticeable in granitic rocks, may be deduced from that seen in the sedimentary rocks adjoining Region 19. Two intersecting fault systems trending ENE and WNW to NW affect Soutpansberg and Karoo strata north of Region 19. Some extend into Region 19. The Siloam, a left lateral strike-slip fault, is the most significant of them. Others though not so mapped may do the same.

2.11. ALLUVIAL DEPOSITS

Alluvial deposits are present along the lower reaches of the following rivers before they cross over on to Karoo rocks:

- the Shingwidzi and tributaries
- the Timbavati and tributaries
- the Nwanedzi and tributaries
- the Sweni and tributaries
- the Nwaswitsontso and tributaries
- the Sabie-Sand and tributaries.

It appears that alluvial deposits are mainly present from where the rivers have dropped to elevations of between 300 to 350 m.a.m.s.l.

Alluvial deposits have also been mapped south of Tzaneen in the vicinity of Trichardtsdal and Lorraine directly below the escarpment along stretches of the Thabina, Mude, Ga-Selati, Tsolameetsi and Makhutswi Rivers.

3. OCCURRENCE OF GROUNDWATER

3.1. GENERAL

Information is largely lacking about the extent to which alluvial deposits that are shown on the quarter-million geological sheets Tzaneen, Pilgrim's Rest and Barberton, are water bearing. On the 1:500 000 hydrogeological sheet 2330 Phalaborwa (Department of Water Affairs and Forestry 1998) water-bearing alluvium is indicated along lower stretches of the Shingwidzi and Letaba Rivers as well as in two small areas north and south of Lorraine (Trichardtsdal see section 2.11). In spite of not being depicted elsewhere on hydrogeological sheets 2330 and 2530, the likelihood can not be ruled out that water-bearing alluvium is present in places along some or all of the rivers mentioned in section 2.11. Such occurrences would presumably be of limited extent and of local importance only.

Everywhere else groundwater has to be found in hard-rock formations. Its occurrence depends on the extent to which the hard-rock formations have been subjected to brittle deformation and weathering that extend to below groundwater level.

Hydrogeological investigations to date have been confined virtually to *ad hoc* borehole siting and borehole censuses. Profound knowledge about the hydrogeology of Region 19 and the magnitude of the groundwater resource is accordingly largely lacking. The current state of knowledge about groundwater in the Region is confined to:

a) the set of National groundwater maps (Water Research Commission 1995) and
b) information and data held by the Department of Water Affairs and Forestry:
    - Hydrogeological sheets 2330 Phalaborwa and 2530 Nelspruit scale 1:500 000 At the time of writing the explanatory brochures had not been published yet;
    - The National Groundwater Database;
    - De Villiers (1967, 1969a and b) on the occurrence of groundwater in the Letaba area and in the vicinity of Mooketsi and on the role of dykes;
    - Burvenich (1973) on the application of the Potential-drop-ratio method for locating where present, the weathered/fractured contact between dyke and country rock;
    - Meyer (1974 a, b and c, 1975) reporting borehole censuses in parts of the Letaba, Klaserie, Blyde and Levubu catchments;
    - Kok (1976a and b) on the Trichardtsdal area and the testing of three high-yield boreholes;
    - Du Toit (1984, 1997) on an additional groundwater supply for Letsitele and on an evaluation of borehole data of the Kruger National Park;
    - Polivka (1986) on hydraukic fracturing experiments and
    - Sonnekus and Hendriks (1997) on borehole siting for drought relief.

The more important findings about the mode of groundwater occurrence in the Region that emanate from these reports and maps are summarized in the following section.

3.2 CURRENT STATE OF KNOWLEDGE

According to De Villiers (1967) groundwater in the Letaba area is found generally in weathered or fractured granite, gneiss, pegmatite and dolerite. With the exception of amphibolite and quartzitic rocks, other rocks mainly various schists that belong to the Giyani, Gravelotte and Pietersburg Groups (termed Jamestown and Rooiwater Igneous Complexes and Swaziland System by De Villiers) have proven considerably poorer drilling targets.

Weathering in the Letaba area seldom extends deeper than 36 metres. Rocks are less weathered on higher-lying ground and in the foothills of the Escarpment than in the valleys. Ninety percent of boreholes that had been drilled by the State at the time of the report yielded water from depths of less than 45 metres. Groundwater levels seldom exceeded a depth of 27 metres.

Favourable conditions for groundwater development are found

- along the Koedoes, Middle Letaba Rivers and Brandboontjie Laagte in the vicinity of Mooketsi, (De Villiers 1967 and 1969a)
- in the low-lying areas around Tzaneen and Duiwelskloof (De Villiers 1967),
- along the Great Letaba River northeast of Letsitele (De Villiers 1967; Meyer 1974)),
- along the Olifants River east of Mica (De Villiers 1967), and
- in the vicinity of Ofcolaco and Trichardtsdal (De Villiers 1967; Kok 1976).

De Villiers (1969b) reports as follows on the role of dykes. Sixty-eight boreholes that were sited in the vicinity of dykes, which are intrusive into granitoid and associated rocks in the Lowveld and on the Polokwane/Pietersburg Plateau yielded the following results:

- ➢ Only two out of 18 boreholes selected directly next to dykes were successful.
- ➢ Of the fifty holes sited on weathered country rock at distances varying between 3 and 60 metres away from dykes, 40 proved successful. To be successful weathering has to extend to below the waterlevel.

Note that the geology on the Pietersburg Plateau is similar to that of the Lowveld.

Two pumping tests were carried out on Bronkhorstfontein 181 LT and Kogelfontein 183 LT under the supervision of Kok (1976). They are of interest in that water level drawdown was observed on the sides of dykes opposite to that of the pumped borehole.

At Letsitele Du Toit (1984) experienced little difficulty in siting boreholes for a supplementary town supply on the Novengilla Gabbro of the Rooiwater Complex.

Du Toit (1997) carried out a statistical analysis of borehole data of the Kruger National Park. The boreholes were grouped and evaluated according to the lithostratigraphic units in which they were drilled. Strike depths and yields of boreholes in the various granites and gneisses do not differ significantly from each other. Factors governing the occurrence of groundwater were not discussed.

Schematic cross-sections aimed at illustrating the occurrence of groundwater have been produced on hydrogeological sheets 2330 and 2530. According to the cross-sections and accompanying legend groundwater within Region 19 occurs

1. in the fractured transitional zone between weathered and fresh bedrock;
2. in fractures along contact zones of dykes and sills;
3. in basins of weathering;
4. along sedimentary or sedimentary/igneous rock contacts. A contact may either be open, weathered or fractured due to it being an unconformity, or fractured due to movement along the contact or fractured due to heating by and subsequent cooling of a large extrusive or intrusive event.
5. in fractures caused by tension or compression and/or off-loading
6. in fault or shear zones.

The reasoning behind the sections and accompanying legends elicits the following comments:

- The meaning of the words "occurs in" has not been defined. The probability that a supply of water will be struck in each of the listed entities anywhere within the area covered by hydrogeological sheets 2330 and 2530 is not stated.
- Have all six entities, in particular category 4, been identified and proven to be aquifers in the area covered by the sheets? Or are some merely hypothetical drilling targets?
- Should fractured transitional zones (category 1) and basins of weathering (category 3) be regarded as separate entities? The one grades into the other. Whether one or both yield water depends on the level of saturation as well as their permeability. Neither are *ipso facto* aquifers below groundwater level.

- It is illogical to list potentially water-bearing material – fractured transitional zone and basin of weathering as entities separate from potentially water-bearing structures – joint, fault, shear and dyke-contact zones. Structures hold and yield water provided they consist of saturated permeable fractured or weathered and fractured rock i.e. of material listed as categories 1 and 3. In fact, although the association of basins of weathering with structure may not be apparent, there can be no doubt that they owe their existence to structural features. With the exception of some fracture zones that may extend hundreds of metres in depth as evinced by thermal springs, the majority of faults, shear and dyke contact zones consist of fractured/porous material within the zone of weathering, i.e. of material classified as categories 1 or 3.
- As faults, shears, joints, dykes and other intrusions are stress-related features a separate category for fractures "related to tensional or compressional stresses" appears to be superfluous.
- The sections are distorted and misleading in that they attempt to portray simultaneously the broad regional geological structure as well as shallow small-scale water-bearing features.
- On the assumption that the sections and legends are meant as guidelines for borehole siting, two serious shortcomings have to be mentioned:
  a) No reference is made to the rather limited depth extent of weathering and fracturing.
  b) Attention is not drawn to the vitally important role of geophysical prospecting in determining depths of weathering/fracturing.

Hydraulic fracturing experiments to improve the yield of weak boreholes were carried out in southern Venda (Polivka 1986). Owing to a number of technical difficulties and shortcomings this work was inconclusive.

Findings depicted on the set of national groundwater maps will be referred to further on.

3.3 THERMAL SPRINGS

Thermal springs occurring in Region 19 are listed in table 2. They lie in a zone of thermal springs stretching from Northern KwaZulu-Natal through Swaziland and Mpumalanga into Zimbabwe which has been described by Partridge (1998) as an axis of late Neogene warping.

Soutini, Eiland, Rhoda and Makutsi are saline springs with total solids ranging from 718 to 1630 mg ℓ^{-1} and Na^+ and Cl^- predominating. Strontium is the principal trace element and the spring gas is mainly N and He. The springs are considered resurgences of meteoric water that descends to depths of between 400 and 1000 metres (Kent 1986). An explanation for the high chloride content ranging from 65 to 81 % of the anion content in mg ℓ^{-1} is according to Kent problematic. Refer to Chapter 7 for the distribution of hydrochemical classes.

Dissolved solids amount to 150 mgℓ^{-1} in water from the Richmond thermal spring. The principal ions are HCO_3^- and Na^+. There is also an appreciable amount of SiO_2. The water is considered to be of meteoric origin – water descending to a depth of about 600 m before rising to the surface (Kent and Groeneveld 1962).

Water from the Sabie River Bungalow and Sabie Mineral Bath springs is moderately mineralised – solutes between 250 and 525 mg ℓ^{-1} – with Na^+, SO_4^{2-} Cl^- and HCO_3^- as principal ions (Kent 1980).

Although the occurrence of groundwater in the Region appears to be principally confined to the near-surface zone of weathering and fracturing, thermal springs provide evidence that some fractures allow groundwater to circulate to depths of 400 to 1000 metres. The deep circulation conceivably constitutes a very minor part of the geohydrological cycle.

TABLE 2 THERMAL SPRINGS

Name of spring (Farm name)	Co-ordinates		Flow	Temperature	Geological	Reference
	Latitude South	Longitude East	ℓs^{-1}	^{0}C	Feature	
Soutini	23.416	30.924	1.6 -3 1945/80	40 - 43.9 1945/82	NE shear-zone?	Kent 1986
Eiland (Eiland 725 LT)	23.653	30.717	1.2 - 1.5 1958	39.7 - 43.3 1936 -1982	N-S fissure system associated with Black Hills dyke and ENE lineament =EM conductor.	Kent 1937(?), 1959 and 1986
Rhoda (Rhoda 9 KU)	24.030	31.131	0.54 1982	35 1965/82	Hydrothermal vein in N-S shear-zone	Hanekom et al 1965, Kent 1986
Makutsi (Harmony 140 KT)	24.191	30.596	None	33.05 -33.4 1982	W-E lineament	Kent 1986
Richmond (Richmond 573 KT)	24.997	30.983	4.4 -5.8 1958/63	27.3 - 28.0 1958/63	WNW shear-zone	Kent and Groeneveld 1962
Sabie River Bungalow (Perry's Farm 9 JU)	25.039	31.117	0.52 Sept. - Nov 1966.	26.5 - 26.8 1963 -1979	E-W jointing south of diabase dyke	Visser and Verwoerd 1960 Kent 1980
Sabie River Mineral Bath (Perry's Farm 9 JU)	25.023	31.167	0.95 - 2.6 combined flow of 2 eyes 1971 and 1979	33.3 - 33.8 1963 -1979	NE jointing and minor Shearing	Visser and Verwoerd 1960 Kent 1980
Nelspruit Townlands	25.461	30.975	Virtually no flow from three eyes	25.7 - 28.3 February 1964	Probably shear-zone striking N80^{0}E	Groeneveld and Genis 1964

3.4. STATISTICAL ANALYSIS OF BOREHOLE DATA

3.4.1 Region as a whole

A comprehensive description of the occurrence of groundwater requires detailed field studies in order to identify, catalogue and map not only existing sources of supply but also those particular geomorphologic and geologic features that are indicative of favourable conditions for siting boreholes. At this stage such an account is not possible. The only possibility is to analyse borehole data contained in the National Groundwater Database more comprehensively than for the map set "Groundwater Resources of the Republic of South Africa" (WRC 1995) and for Hydrogeological Sheets 2330 and 2530 (Department of Water Affairs and Forestry 1998 and 1999).

The National Groundwater Database (June 1998) contains data on 4760 holes. The lithology has been recorded in the case of 3481 holes. The latter consist virtually exclusively of governmentally drilled boreholes. As logs of both successful and failed boreholes have been recorded, the data set of governmentally drilled boreholes is fairly representative of groundwater conditions and superior to that of a hydrocensus. By the nature of things failures are not fully accounted for during a hydrocensus. Data of the 3481 boreholes have been analysed statistically and the results are presented in the following tables and figures:

3.4.1.1 In tables 3 and 4 drilling success rates ($\geq 0.1\ \ell\,s^{-1}$ taken as successful) and the spread of borehole yields in granite, gneiss and granitoid rocks on the one hand and supracrustal rocks on the other are listed.

Owing to a dearth of data it was not possible to deal in more detail and separately with the Giyani, Pietersburg and Gravelotte greenstone belts or with the Rooiwater Complex. At Letsitele some boreholes yielding in excess of $10\ \ell\,s^{-1}$ have been drilled in weathered gabbro of the Novengilla Suite of the Rooiwater Complex.

TABLE 3 SUCCESS RATE AND YIELD DISTRIBUTION OF BOREHOLES IN GRANITES, GNEISSES AND GRANITOIDS

Yield $\ell\,s^{-1}$	Number of holes	Percentage of holes	Percentage of successful holes
0 – 0.099	1631	53.0	
0.1 – 0.99	793	25.8	54.8
1.0 – 4.99	548	17.8	37.9
5.0 – 9.99	73	2.4	5.0
≥ 10	32	1.0	2.2
Total	3077	100	100

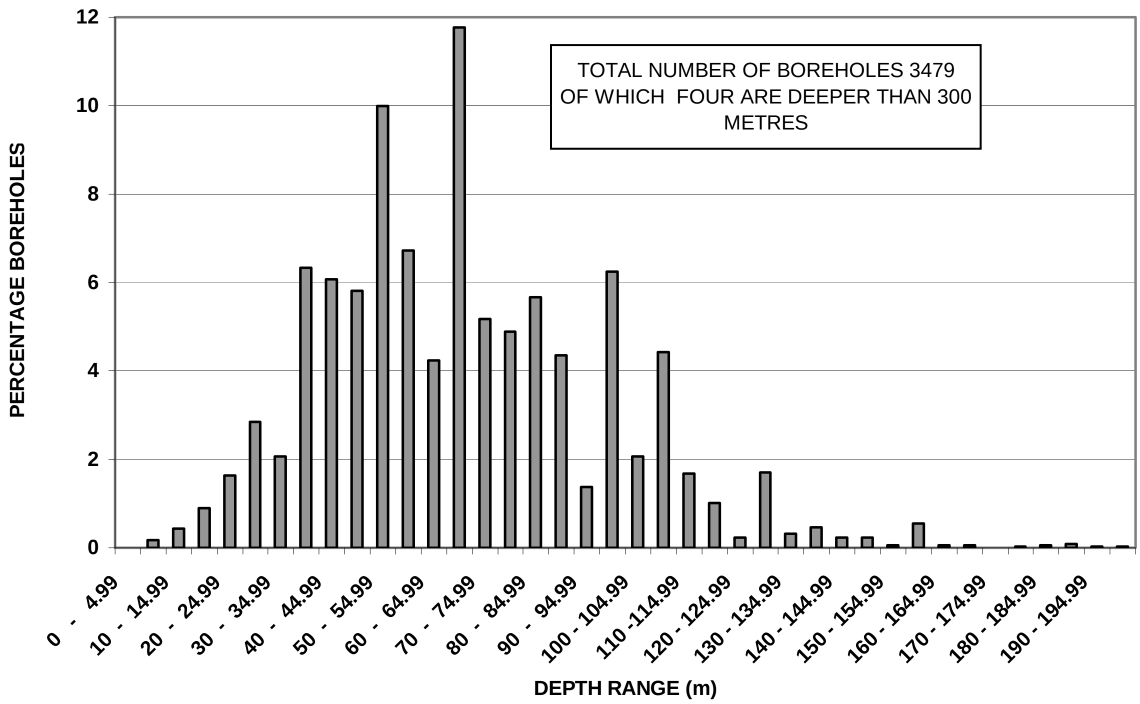
TABLE 4 SUCCESS RATE AND YIELD DISTRIBUTION OF BOREHOLES IN SUPRACRUSTAL ROCKS
(Described by driller as schist, amphibolite, quartzite, sandstone, shale)

Yield $\ell\,s^{-1}$	Number of holes	Percentage of holes	Percentage of successful holes
0 – 0.099	182	45.0	
0.1 – 0.99	91	22.5	41.0
1.0 – 4.99	112	27.7	50.5
5.0 – 9.99	12	3.0	5.4
≥ 10	7	1.7	3.2
Total	404	100	100

The spatial distribution of Borehole Prospects is shown on Sheet 1 of the set of Groundwater Resources maps of South Africa (Water Research Commission and Department of Water Affairs and Forestry 1995). The probability of drilling a successful borehole – termed "Accessibility" – ranges form less than 40 to over 60% whilst "Exploitability" i.e. the probability of a successful borehole yielding more than 2 $\ell\,s^{-1}$ varies from 20 to more than 50%.

3.4.1.2 Figure 3 - The irregular distribution of borehole depths is the result of the tendency to drill to fixed depths regardless of the hydrogeological conditions encountered during drilling. This is especially the case with contract drilling for the Government. Fifty percent of the holes are deeper than 60 m.

FIGURE 3 DISTRIBUTION OF BOREHOLE DEPTHS REGION 19



3.4.1.3 Figure 4 depicts the spread of weathering plus fracturing depths as encountered in 185 boreholes distributed over the Region. In 90 percent of the boreholes weathering varies between 0 and 40 metres. Weathering plus fracturing extend deeper than 55 m in only about 6 percent of the boreholes. The mode is 10 to 15 m. According to the Saturated Interstice map (Sheet 2 of the set of Groundwater Resources maps of South Africa 1995), groundwater is held principally in fractures directly below groundwater level. Significant storage in pores is limited to places where weathering extends to well below groundwater level. Such places evidently comprise a minute fraction of the Region.

.

3.4.1.4 Figure 5 - The skew distribution of groundwater levels peaks at 10 to 15 m. Ninety percent of the groundwater levels lie between 0 and 40 m. The spatial water level distribution is shown on Sheet 2 of the map set "Groundwater Resources of the Republic of South Africa". Over most of the Region groundwater levels lie between 10 and 20 m below the surface. Groundwater levels of between 20 to 30 m deep are found in the northwestern part of the Region and between the Olifants River and 25 ^{0} latitude.

FIGURE 4 DISTRIBUTION OF DEPTHS OF WEATHERING AND OF DEPTHS OF WEATHERING PLUS FRACTURING

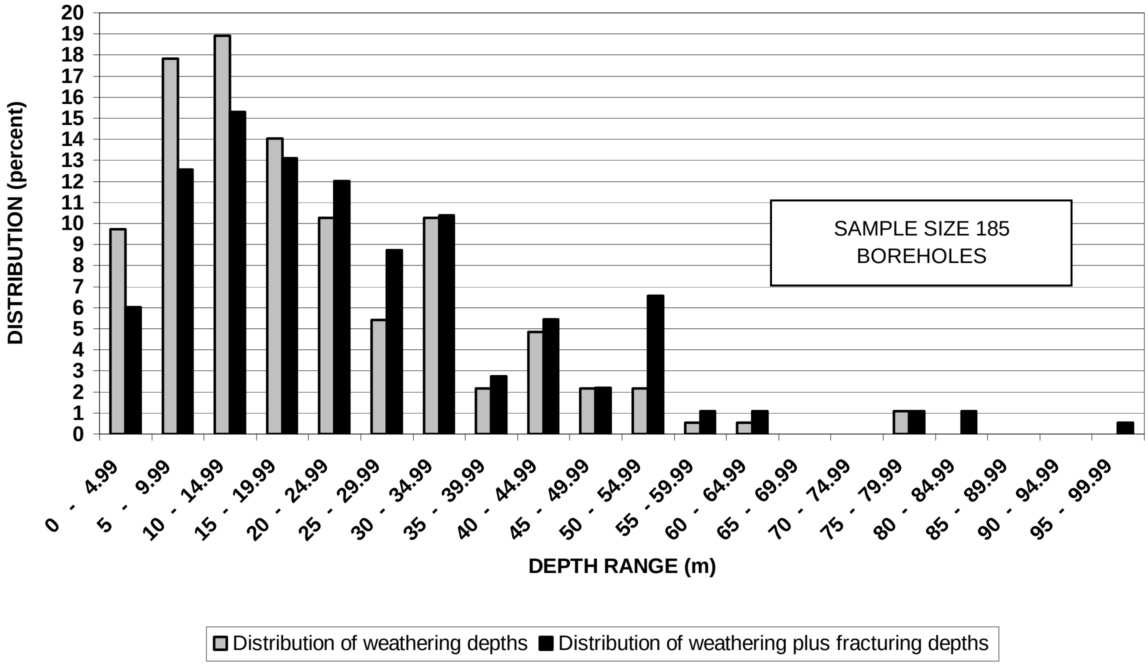
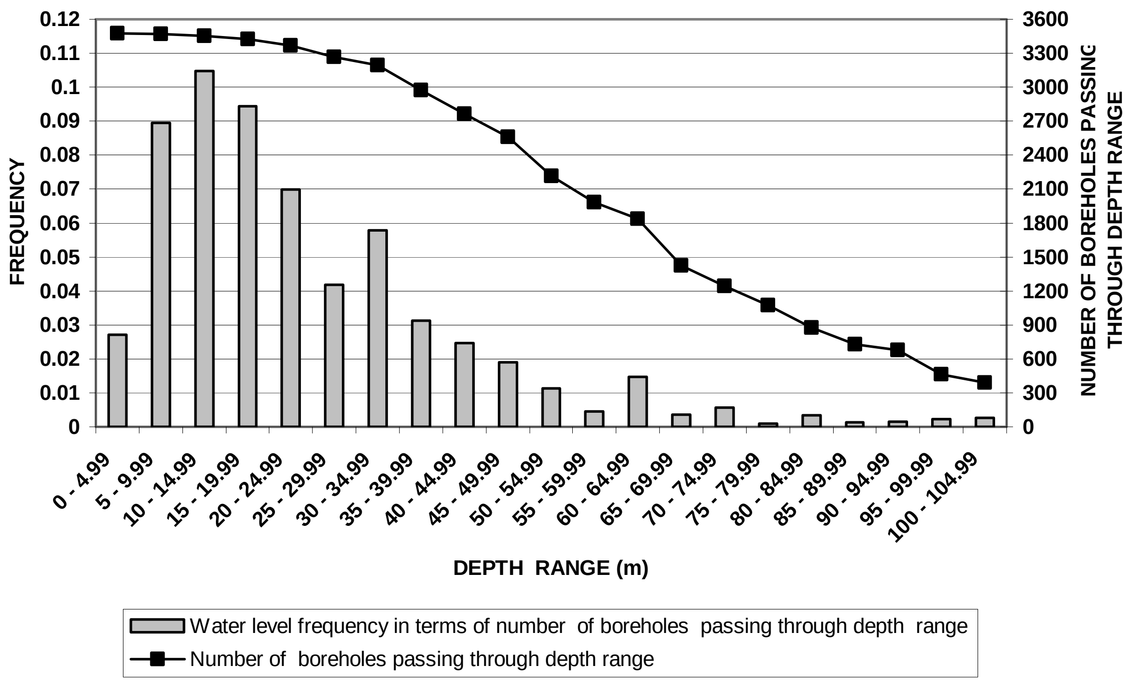


FIGURE 5 DISTRIBUTION OF GROUNDWATER LEVELS



3.4.1.5 Figure 6 - The chances of striking water drop below 10 % per 5-metre step from a depth of 50 m down. The slope of the cumulative strike frequency graph (Figure 7) commences flattening from 40 m onwards. The strike frequency below 50 m averages about one third of that between 10 and 40 m. Because of the very low strike rate, drilling much deeper than 50 m does not appear generally justified. Note that the probabilities of striking water in the different depth ranges can not be added together.

FIGURE 6 STRIKE FREQUENCY BELOW SURFACE

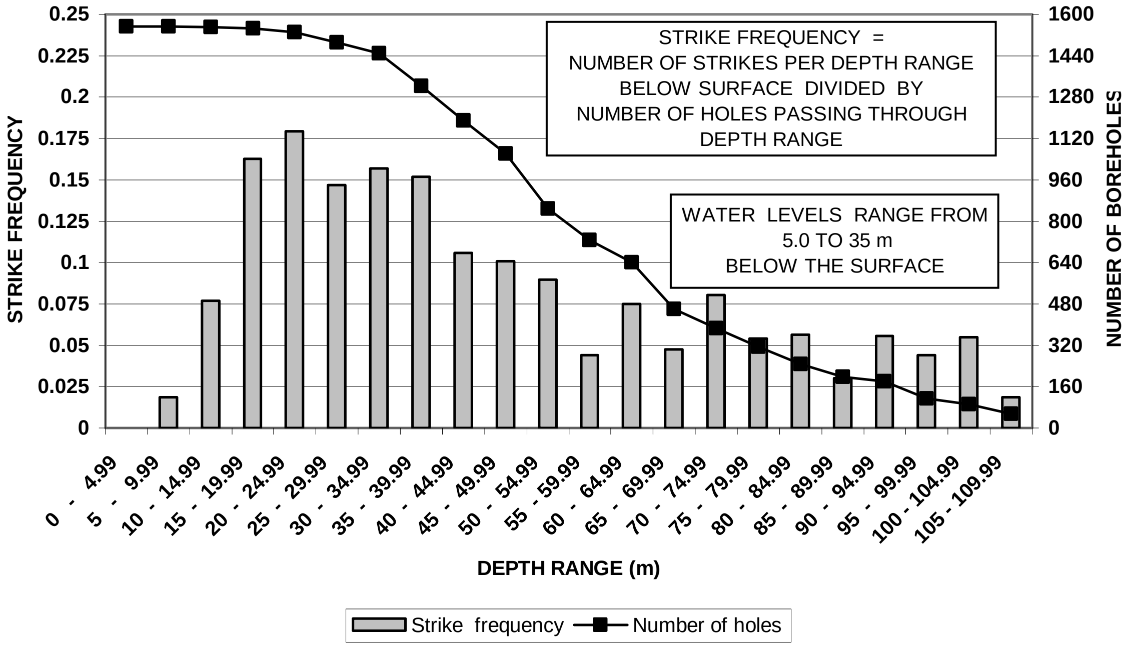
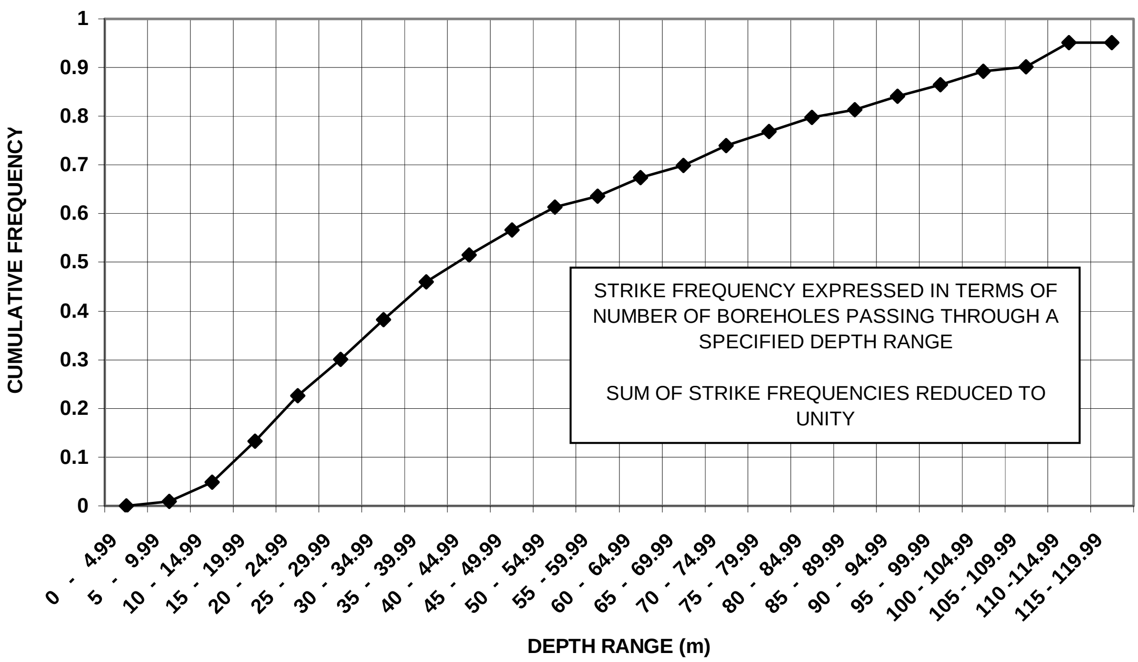


FIGURE 7 CUMULATIVE STRIKE FREQUENCY BELOW SURFACE



3.4.1.6 Figure 8 and 9 – the relationship between chances of striking water and depth below groundwater level is more pronounced than strike depth below surface. Figure 8 was compiled without regard to depth of groundwater level. Because of the large number of boreholes a smooth distribution except for the tail end is obtained.

FIGURE 8 STRIKE FREQUENCY BELOW WATER LEVEL REGARDLESS OF WATER LEVEL DEPTH

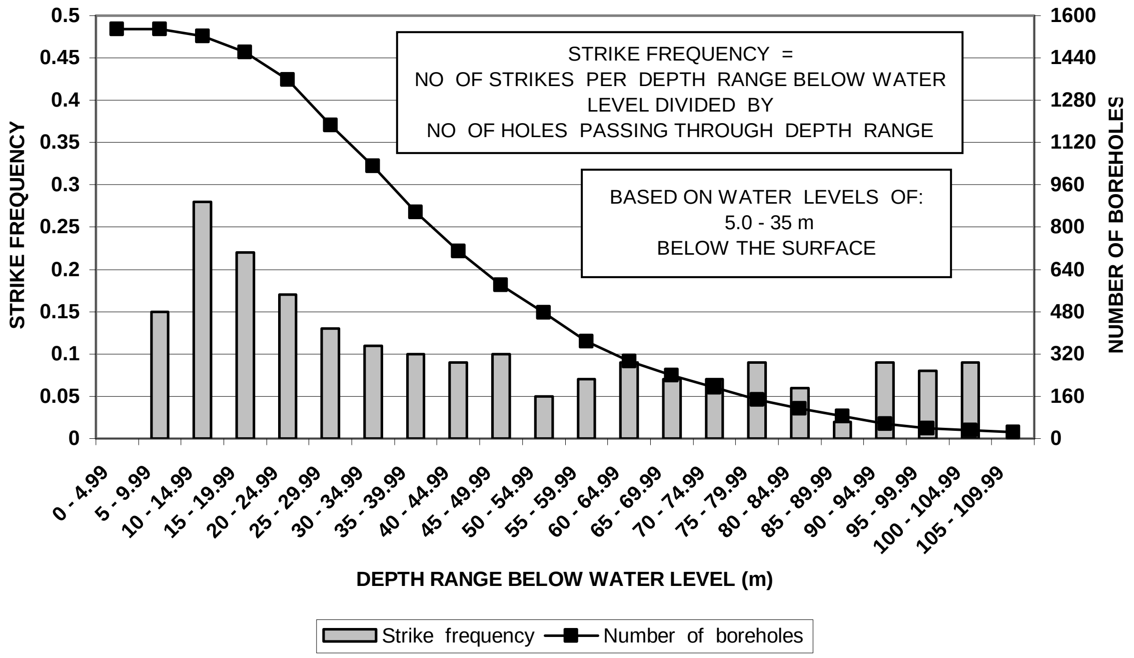


FIGURE 9 STRIKE FREQUENCY BELOW SHALLOW AND DEEP GROUNDWATER LEVELS

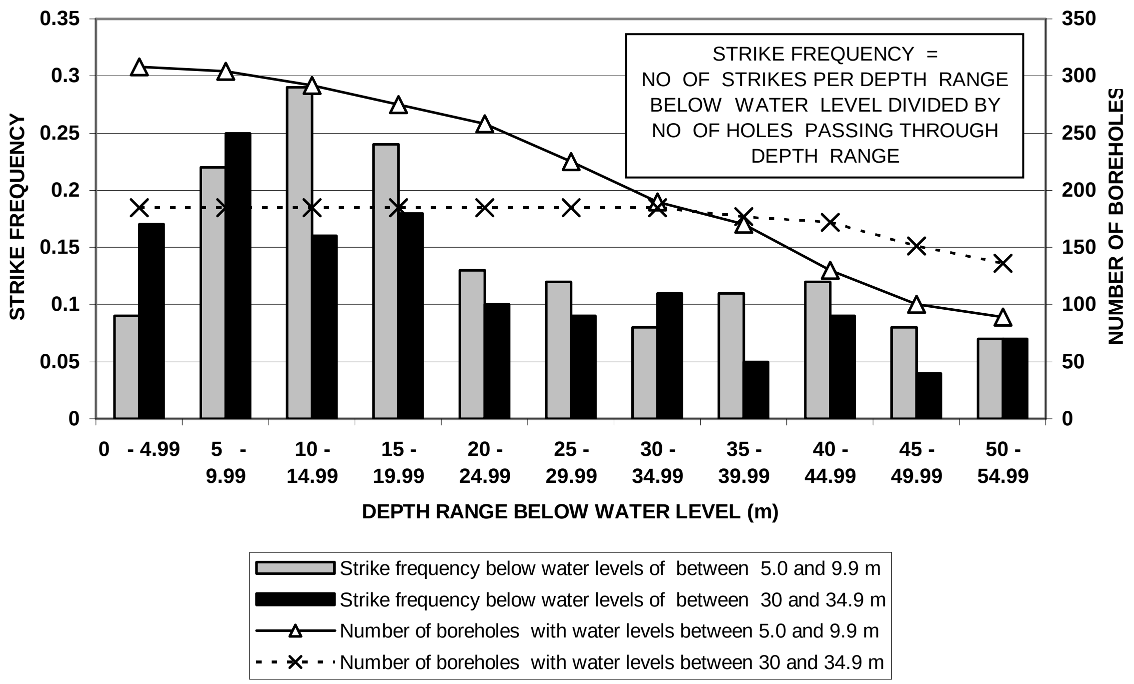


FIGURE 10 STRIKE FREQUENCY RELATIVE TO BASE OF WEATHERED AND FRACTURED ZONE (REGARDLESS OF DEPTH OF BASE)

FIGURE 11 RELATION BETWEEN DEPTH OF WEATHERING AND FRACTURING AND BAND WITHIN WHICH 80 PERCENT OF WATER STRIKES OCCURRED

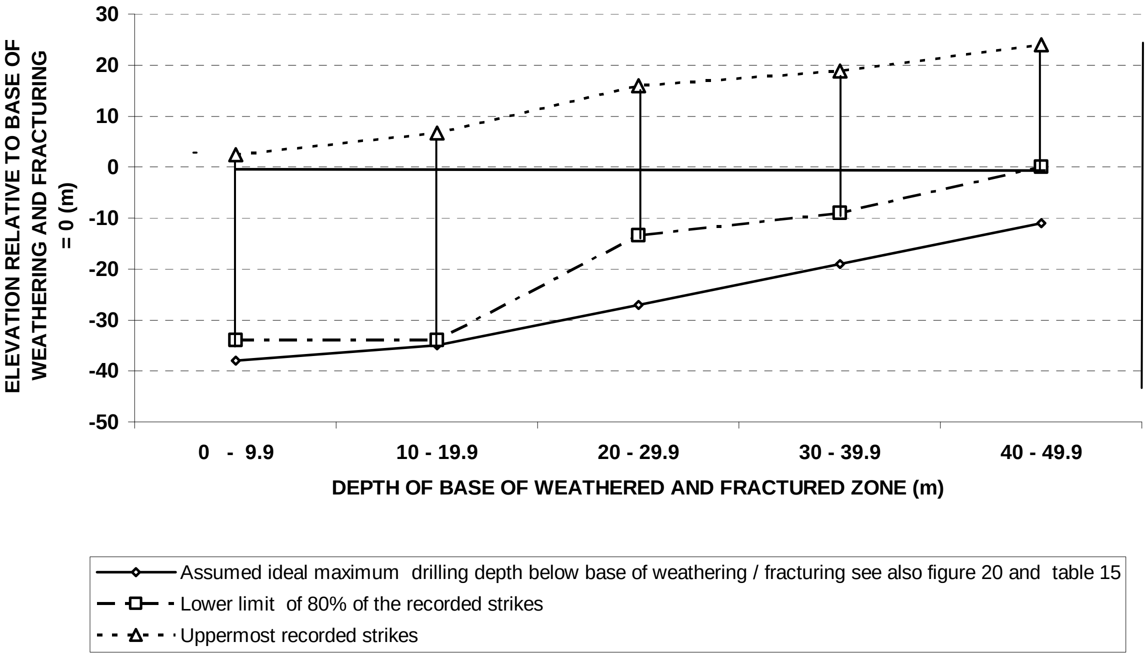


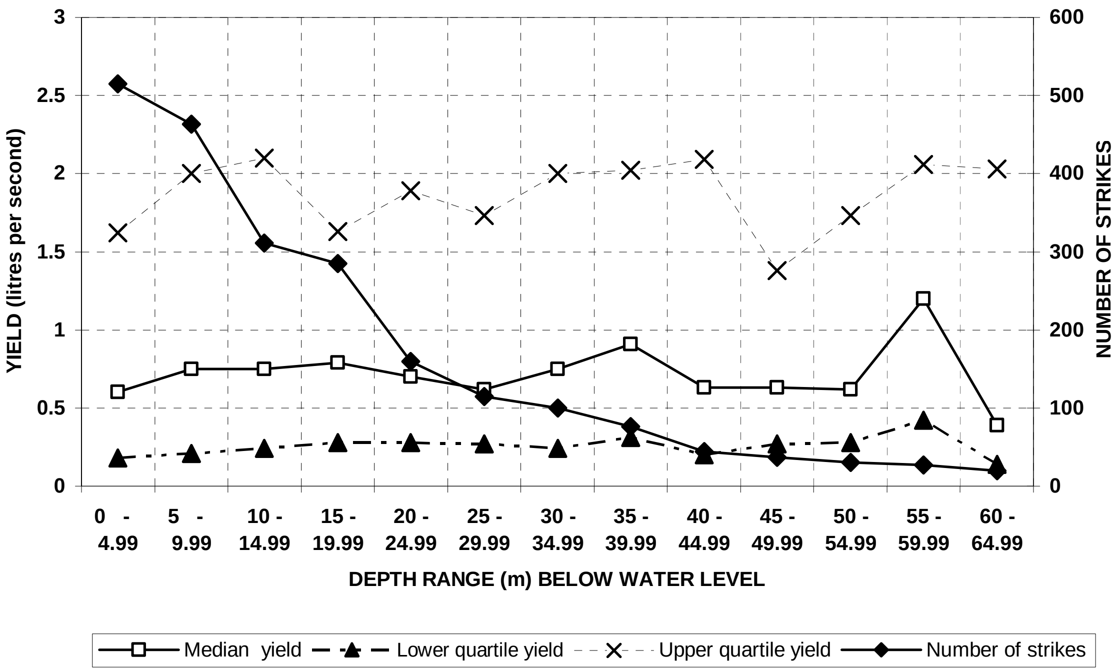
Figure 9 shows the relationship for a shallow and deep range of levels. The strike frequency is higher for the shallow water levels. It drops below 0.1 in the depth range of 40 to 44.9 m below the groundwater level. In the case of the deeper water levels strike frequency drops below 0.1 in the depth range of 20 to 24.9 m below the groundwater level.

3.4.1.7 Figure 10 – The probability of striking water is highest at the base of the zone of weathering plus fracturing provided of course that the latter lies below the water level. Between 30 and 40 metres below the base of weathering and fracturing the probability of a strike drops to about 1/3rd of that at the base.

3.4.1.8 Figure 11 – The width of the zone above the base of weathering and fracturing in which water is most likely struck increases with increasing depth of the base. The width of the strike zone below the base accordingly decreases with increasing depth of the base.

3.4.1.9 Figure 12 – Generally speaking yields do not increase with increasing strike depth below water level.

FIGURE 12 BOREHOLE YIELD VERSUS STRIKE DEPTH BELOW WATER LEVEL



3.4.2 Role of dykes

As dykes riddle Region 19 it is important to establish their role in the occurrence of groundwater. The study is unfortunately handicapped. Except in the case of sheet 22 Nelspruit the history of dyke intrusion and the relationship between dyke sets of differing orientations have not been determined. Neither can borehole data be classified according to dyke orientation. The data thus have to be treated as a single group.

As a first step in looking at the role of dykes or more correctly diabase/dolerite intrusions, borehole data were divided into two sets:

- Boreholes drilled partly or wholly into diabase or dolerite
- Boreholes which encountered no diabase or dolerite.

Results are compared in table 5.

The success rate of boreholes devoid of diabase or dolerite is somewhat higher – 47.1% against the 43.1% of boreholes with diabase or dolerite. The same applies to the percentage of holes yielding 1 ℓ s^{-1} and more – 46.8% against 42.7%. Contrary to the popularly held view the probability of striking water is not enhanced by the presence of dykes. Neither is it reduced appreciably.

TABLE 5 SUCCESS RATES AND YIELDS OF BOREHOLES WITH AND WITHOUT DIABASE/DOLERITE

Yield ℓ s^{-1}	Boreholes drilled partly or wholly in diabase/dolerite			No diabase/dolerite reported in boreholes		
	No of Holes	% of total number of holes	% of total number of holes yielding ≥ 0.1 ℓ s^{-1}	No of holes	% of total number of holes	% of total number of holes yielding ≥ 0.1 ℓ s^{-1}
0 – 0.099	318	56.9	-	1357	52.9	-
0.1 –0.99	138	24.7	57.3	643	25.1	53.2
1.0 –4.99	84	15.0	34.9	482	18.8	39.9
5.0 –9.99	14	2.5	5.8	56	2.2	4.6
≥ 10	5	0.9	2.1	27	1.1	2.2
Total	559	100	100	2565	100	100

For further examination 155 logs of hydrogeologically sited boreholes were selected in which diabase or dolerite was reported and which are fairly evenly spread over the Region. It is thought that the majority of these holes were sited on or alongside dykes.

TABLE 6 GROUNDWATER LEVELS AND DEPHS OF WATER STRIKES: BOREHOLES DRILLED WHOLLY OR PARTIALLY IN DIABASE/DOLERITE

Depth range (m) below surface	Distribution of g/w-levels below surface*	Distribution of borehole depths* Below		Distribution* of water strikes* below		Strike frequency below surface	Strike frequency below g/w level
		surface	g/w level	surface	g/w level		
0 – 9.9	11	154	49	4	27	0.026	0.5313
10 – 19.9	16	151	37	24	13	0.159	0.325
20 – 29.9	13	148	31	28	2	0.189	0.065
30 – 39.9	6	141	31	25	6	0.177	0.194
40 – 49.9	4	135	22	21	4	0.156	0.182
50 – 59.9	0	129	19	8	1	0.062	0.053
60 – 69.9	0	94	15	8	1	0.085	0.067
70 – 79.9	1	85	11	5	2	0.059	#
80 – 89.9	-	75	6	2	2	0.027	*#
90 – 99.9	-	47	4	3	-	0.064	*#
100 – 109.9	-	17	2	-	-	-	-
110 – 119.9	-	13	2	-	-	-	-
120 – 129.9	-	13	4	-	-	-	-
TOTAL	51	155	48	128	57		

* In terms of numbers of boreholes. # Number too small.

Some, however, may have been drilled on sheet-like intrusions. Details about these boreholes are summarized in Table 6. Ninety-one (58.7%) were successful i.e. yielded 0.1

ℓ s^{-1} and more. It is evident that the groundwater level and strike pattern conforms to the overall regional pattern as depicted in Figures 6 to 8.

FIGURE 13 STRIKE POSITION RELATIVE TO INTRUSIVE CONTACT: BOREHOLES PASSING FROM DIABASE / DOLERITE INTO GRANITIC ROCK

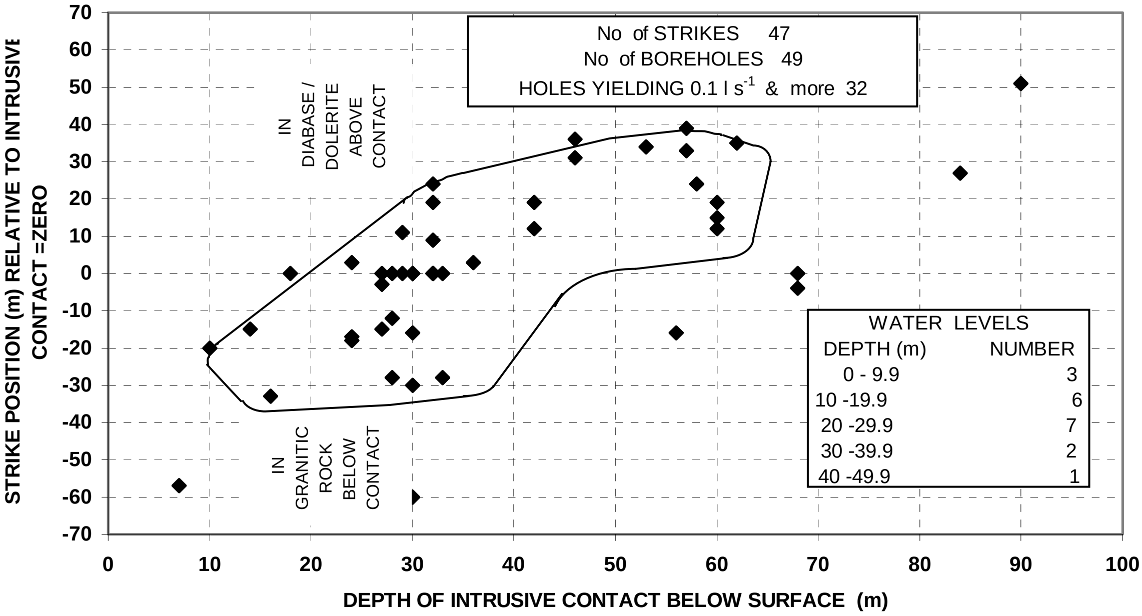


FIGURE 14 STRIKE POSITION RELATIVE TO INTRUSIVE CONTACT: BOREHOLES PASSING FROM GRANITIC ROCK INTO DIABASE / DOLERITE

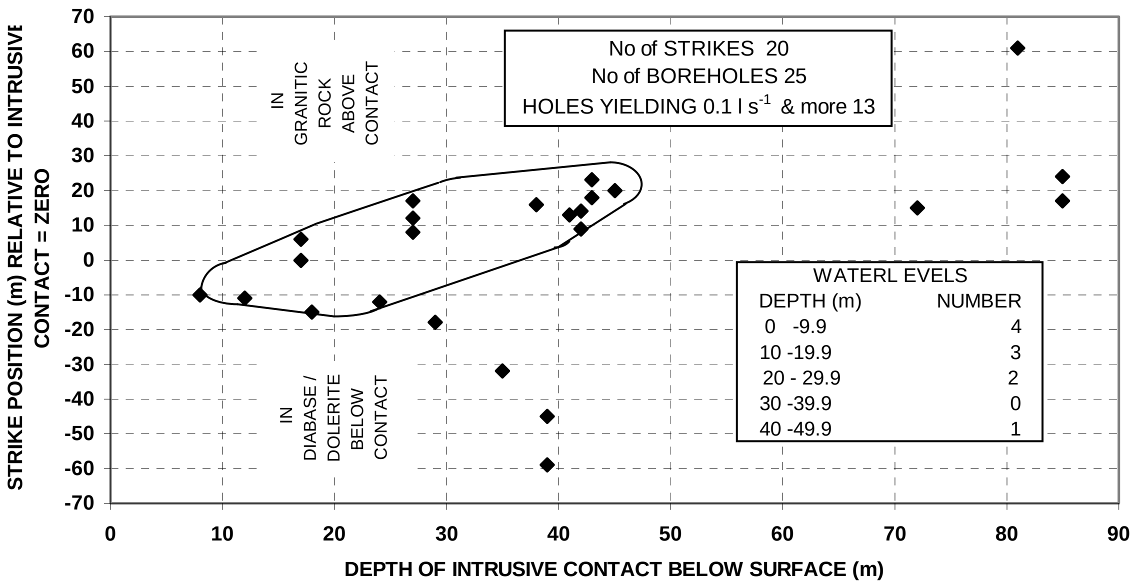


FIGURE 15 STRIKES AND GROUNDWATER LEVELS: BOREHOLES DRILLED IN DYKES

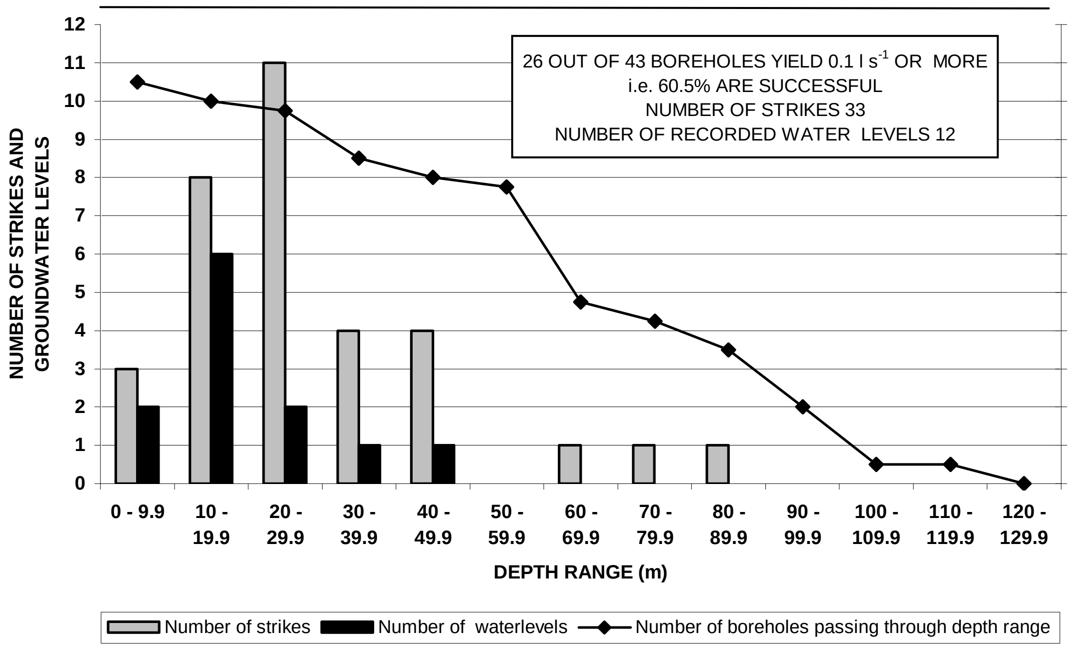
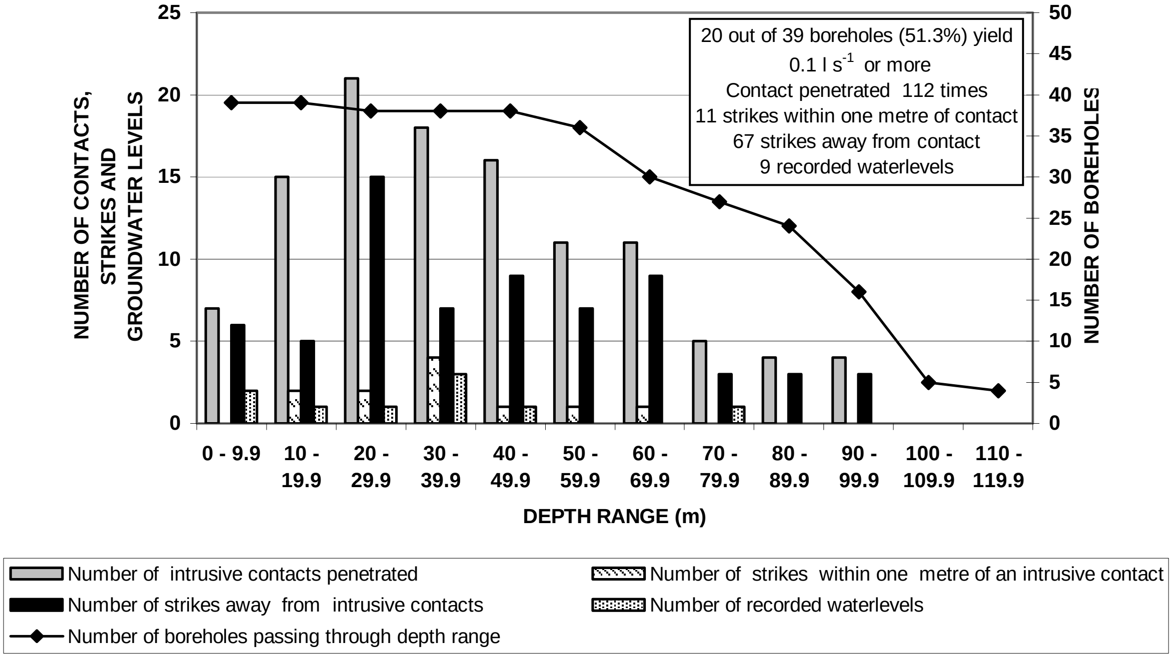


FIGURE 16 BOREHOLES PASSING SEVERAL TIMES THROUGH INTRUSIVE CONTACT



The 155 boreholes were further subdivided into:

- Boreholes drilled solely in diabase or dolerite
- Boreholes starting in diabase or dolerite and exiting in country rock
- Boreholes starting in country rock, striking and entering diabase or dolerite
- Boreholes repeatedly entering and exiting the intrusive contact.

Results of the analysis are shown in Figures 13 to 16. They demonstrate clearly that

a) water is mostly struck in a relatively shallow zone of weathering and fracturing regardless of country or dyke rock
b) dyke contacts are not pre-eminently water strike zones.

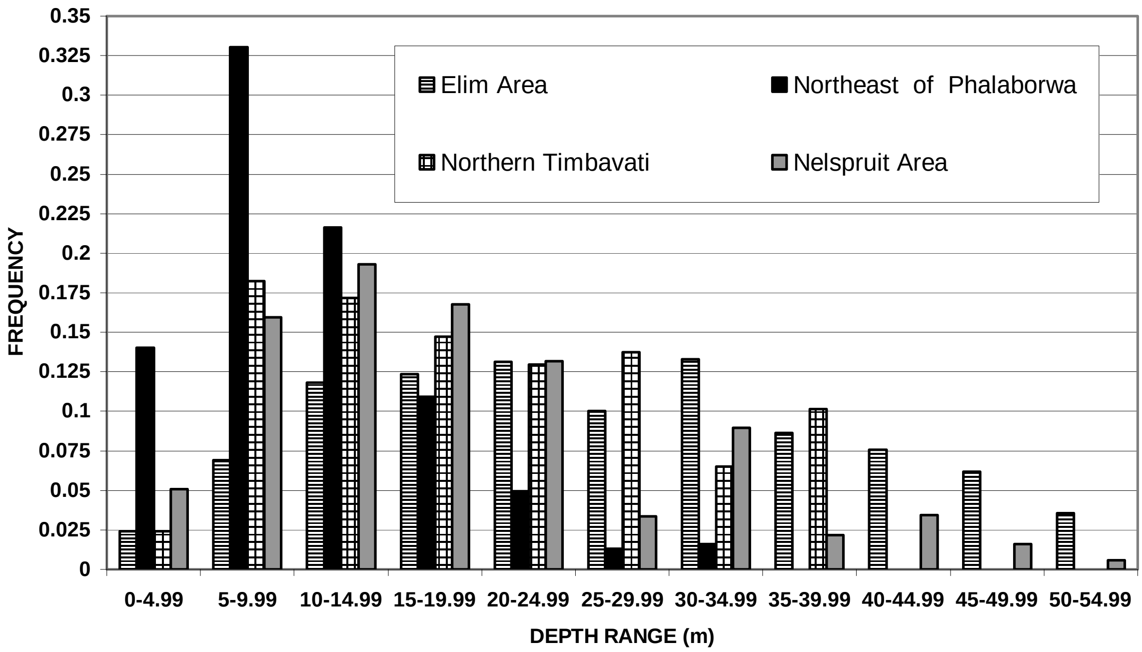
3.4.3 Statistical variableness

3.4.3.1 Figures 17 and 18 - To obtain an idea of the groundwater level and strike variability within this large Region, level and strike frequencies in four areas have been analysed. Details are given in Table 7.

TABLE 7 FOUR SELECTED AREAS

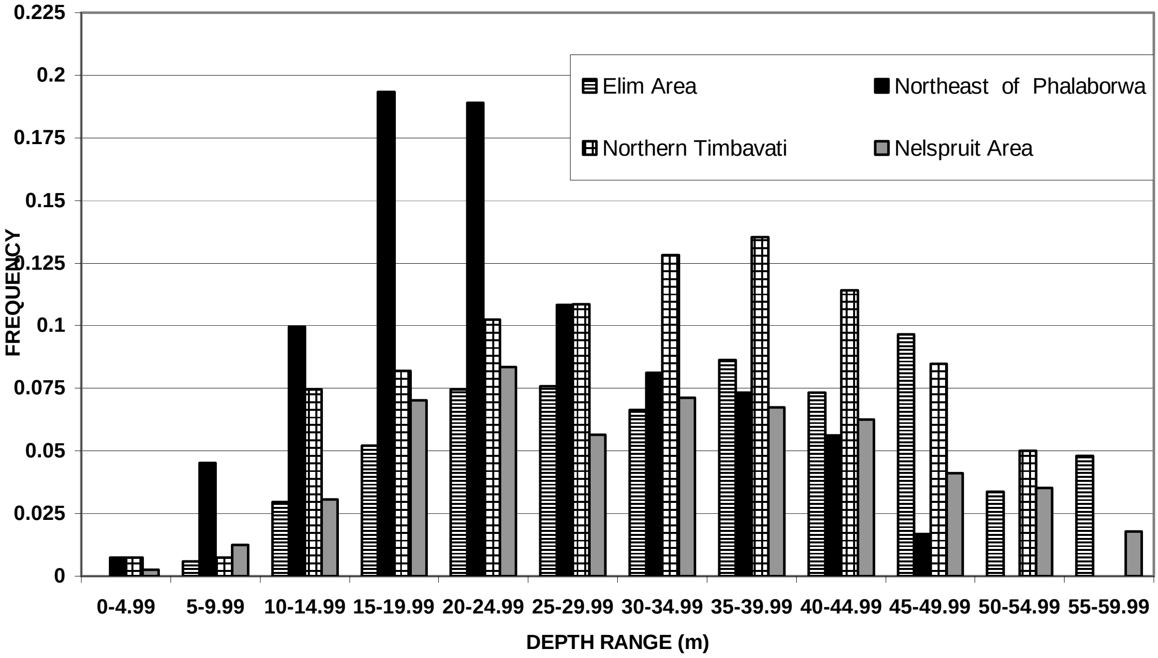
Area	Principal geological formation	Borehole Prospects	
		Accessibility	Exploitability
Surroundings of Elim (northwestern corner of Region 19)	Goudplaats Gneiss; Schiel Complex	40 – 60%	40 - >50%
Northeast of Phalaborwa-	Goudplaats and Makhutswi Gneiss	>60%	40 - >50%
Umbabat and northern Timbavati Reserves	Makhutswi Gneiss	40 – 60%	40 - >50%
Nelspruit	Nelspruit Granite Suite	<40%	10 – 30%

FIGURE 17 COMPARISON OF GROUNDWATER LEVEL DISTRIBUTIONS IN FOUR AREAS OF REGION 19 LOWVELD



The areas were selected on the basis of Borehole Prospects as depicted on the Groundwater Resources maps of the Republic of South Africa (1995). Details of the four selected areas are given in Table 7.

FIGURE 18 COMPARISON OF STRIKE FREQUENCIES IN FOUR AREAS OF REGION 19 LOWVELD



The water level patterns of the four areas and of the Region as a whole are basically similar (Figure 17). Depth differences may be ascribed to differences in surface relief. The general shallowness of the water level is

- proof of at least periodic if not regular annual groundwater recharge;
- a reflection of shallow depths of weathering and fracturing and consequently of limited groundwater storage capacity and the likelihood of depletion during droughts;
- an indication that deep fracturing as manifested by thermal springs is limited in extent.

As in the case of water levels, strike patterns in the four areas are similar (Figure 18) and conform to that of the Region as a whole. Variations in peak strike and 75% strike bandwidth depths are ascribable to

- a variable degree of topographic relief within the Region. The Elim area occupies the dissected transition from the Pietersburg Plateau to the Lowveld;
- the comparatively poorer prospects of finding water in rocks of the Nelspruit Granite Suite. Evidently basins, troughs or zones of weathering and fracturing are scarcer here than elsewhere. Compared to the strike distribution between weathered/fractured and fresh rock in the other lithostratigraphic units, a larger fraction of the strikes in the Nelspruit Granite Suite appears to be in fresh rock.

Apart from Figures 17 and 18 results of the statistical analysis of groundwater level and strike depths in these areas have also been summarized in Tables 8 and 9.

TABLE 8 VARIABLENESS OF GROUNDWATER LEVELS

Area	Peak waterlevel depth range (m)	75% waterlevel band width
Elim surroundings	10 - 35	5 – 40
Northeast of Phalaborwa	5 - 10	<5 – 20
Umbabat and northern Timbavati Reserves	5 - 15	5 – 30
Nelspruit	5 - 20	<5 – 40
Region 19 as a whole	5 - 20	5 – 35

TABLE 9 VARIABLENESS OF STRIKE DEPTHS

Area	Peak strike depth range (m)	75% strike band width
Elim surroundings	20 - 50	15 -75
Northeast of Phalaborwa	15 -25	10-40
Umbabat and northern Timbavati Reserves	30 -45	15 -50
Nelspruit	20 -25	10 -80
Region 19 as a whole	15 -40	10 -80

Because of the variableness drilling depths should not be based on the maximum bandwidth values but rather be determined by the hydrogeological conditions encountered during the drilling process.

3.4.3.2 Classification of boreholes in the Kruger National Park on the basis of litho-stratgraphic units (du Toit 1997) allows comparison of strike frequencies in some of the gneisses.
Whether the differences are inherent lithostratigraphic characteristics is open to question. Textural and structural variability are considered to be of greater importance.

TABLE 10 STRIKE DEPTHS IN GNEISSES OF THE KRUGER NATIONAL PARK

Formation	Peak strike depth range (m)	80% strike band width
Goudplaats Gneiss	10 - 30	10 – 50
Makhutswi Gneiss	10 - 20	10 – 60
Orpen Gneiss	20 - 40	10 – 60
Nelspruit Granite Suite	20 - 50	10 – 60
Region 19 as a whole	30 - 50	10 – 70

3.4.4 Bolobedu drought-relief programme

3.4.4.1 General

As part of a drought-relief programme 101 boreholes were sited geophysically in the Bolobedu District by the Directorate of Geohydrology and drilled by the Department of Water Affairs and Forestry during 1994/95. As the results were fully recorded (Sonnekus and Hendriks 1997) a more detailed examination appears justified.

The Bolobedu area is underlain by Goudplaats Gneiss and unnamed leucocratic biotite granite. The former ranges from fine-grained dark-grey biotite gneiss through leucocratic intensely migmatised gneiss to an almost-homogenized granitoid rock. The leucocratic biotite granite varies compositionally between granodiorite and adamellite. It contains rafts of porphyritic Shamiriri granite, xenoliths of Pietersburg Group greenstones and of migmatitic gneiss as well as pockets or masses of pegmatite (Brandl 1987).

These rocks have been intruded by a swarm of diabase dykes striking mainly between 050^0 and 070^0. North-south and northwest-southeast striking dykes are here and there present.

The topography varies from mountainous in the southwest to hilly in the northeast. In the southwest two parallel and similarly trending mountain spurs border the Molototsi River. The river follows the northeasterly trending Tzaneen lineament that presumably is a zone of ductile shear planes similar to the Koedoes River lineament.

3.4.4.2 Results

These are summarized in Tables 11, 12 and 13.

TABLE 11 BOLOBEDU BOREHOLE SUCCESS RATE AND YIELDS

Yield range ℓ s^{-1}	Number of boreholes	Percentage of boreholes	Distribution (percent) of boreholes yielding ≥ 0.1 ℓ s^{-1}
0 – 0.09	42	41.6	
0.1 – 0.9	32	31.7	54.2
1.0 – 4.9	21	20.8	35.6
5.0 – 9.9	4	4	6.8
≥ 10	2	2	3.4
Total	101	-	

TABLE 12 SALIENT DATA OF BOLOBEDU DRILLING PROGRAMME

1 Depth range (m)	2 Number of recorded water levels	3 Spread of borehole depths below Surface	4 In terms of number of holes		5 Number of water strikes below surface*	6 Strike frequency below surface (column 5 divided by column 3)
			Spread of weathering depths	Spread of weathering plus fracturing depths		
0 - 9.9	18	100	74	19	2	0.02
10 - 19.9	16	100	24	28	16	0.16
20 - 29.9	3	99	3	30	16	0.16
30 - 39.9	1	96	-	19	21	0.22
40 - 49.9	-	92	-	5	14	0.15
50 - 59.9	-	90	-	-	9	0.10
60 - 69.9	-	51	-	-	0	0.0
70 - 79.9	-	47	-	-	7	0.15
80 - 89.9	-	39	-	-	2	0.05
90 - 99.9	-	19	-	-	1	0.05
100 – 109.9	-	7	-	-	-	-
110 –119.9	-	3	-	-	-	-
120 – 129.9	-	4	-	-	-	-
TOTAL	37	101	101	101	88*	

* Includes strikes of less than 0.1 l s^{-1}

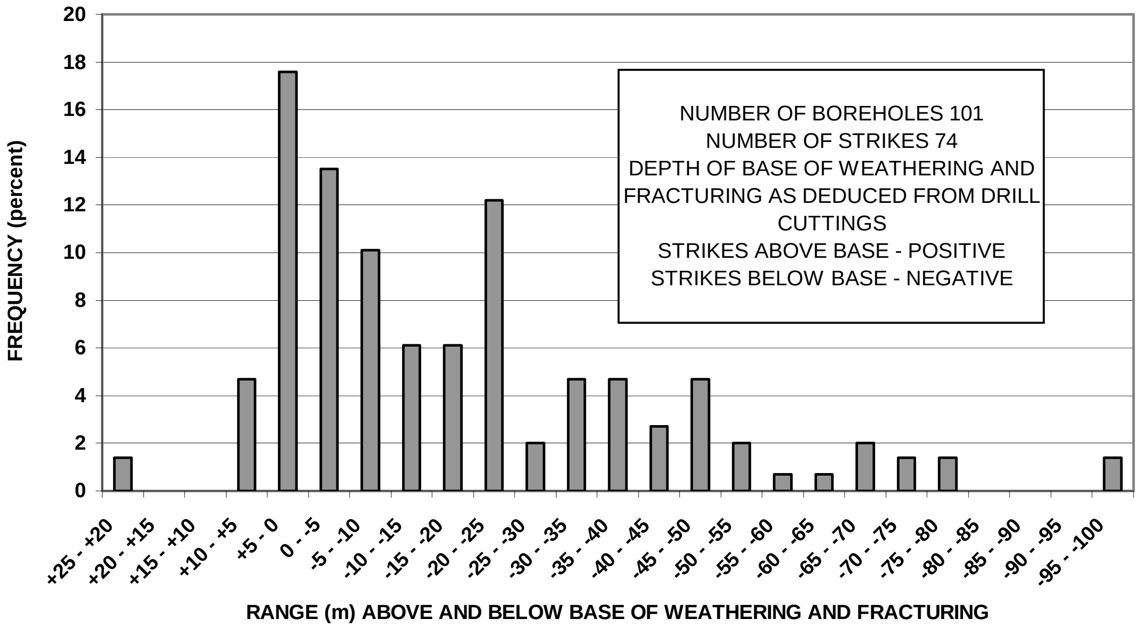
The following is evident:

- The drilling success rate of 58.4% (yields ≥ 0.1 ℓ s^{-1}) is 11.4 % above the overall rate in granites, gneisses and granitoids of Region 19 (see Table 3). It is however 6.9% less than the hydrogeological success rate for the Region as a whole (see Table 14). It is not known to what extent the selection of borehole sites was handicapped by restriction of space and time. Should these have played a role optimum results may not be expected.
- The distribution of successful borehole yields is similar to that of all the NGWDB boreholes sunk in the granites, gneisses and granitoids of the Region (see Table 3). In

the Region as a whole a higher percentage of the hydrogeologically sited holes have yields $\geq 1.0\ \ell\, s^{-1}$ (see Table 14).

- Weathering does not exceed 30 metres. In 74% of the boreholes it is less than 10 metres. Sonnekus and Hendriks (1997) describe rock that has suffered a change in colour and texture as weathered. Rock is described as fractured when drill cuttings consist of chips with discoloured plane surfaces.
- Weathering plus fracturing exceeds 30 m in only 24% of the Bolobedu boreholes compared to the 42% in the sample of 185 boreholes spread over the whole Region (Figure 5). Whether weathering and fracturing on the whole are shallower in the Bolobedu District than elsewhere in the Region or whether the difference has to be ascribed to restricted areas, within which boreholes had to be sited, is not known.
- Of the recorded groundwater levels 90% are less than 20 m deep. In the Region as a whole just less than 50% are deeper than 20 m.
- Water was struck in fractures, which are associated with the near-surface zone, which has been described as weathered and fractured on the basis of drill cuttings. Seventy percent of the strikes were made within 10 m above and 30 m below the base of weathering plus fracturing (44.6% between 10 m above and below – Figure 19).

FIGURE 19 STRIKE FREQUENCY RELATIVE TO BASE OF WEATHERING AND FRACTURING BOLOBEDU



- Strikes are not clustered around the base of weathering. Approximately 64% of the strikes lie between 5 m above and 35 m below the base of weathering – nearly 84% between 5 m above and 50 m below.
- These findings are in accordance with Figure 11 (paragraph 3.4.1.8). The optimal strike zone below the base of weathering/fracturing decreases with the depth of the base. The reason why strikes are not clustered around the transition from weathered to fractured rock lies in the shallow depth of weathering.
- Apart from the generally shallower depth of weathering and fracturing Bolobedu water level and strike patterns conform to those of the Region as a whole.

- Because of the paucity of recorded groundwater levels, strike frequency below groundwater level was not calculated. Like in the Region as a whole strike frequency conceivably should be the highest directly below the waterlevel.
- Tables 12 and 13 show further that of
  a) 88 recorded water strikes twelve only coincided with intrusive contacts
  b) 88 intrusive contacts penetrated twelve only yielded water.

TABLE 13 INTRUSIVE CONTACTS AND WATER STRIKES

Depth range below surface (m)	Number of dyke contacts penetrated	Number of water strikes on intrusive contacts
0 - 9.9	0	0
10 - 19.9	10	2
20 - 29.9	22	4
30 - 39.9	21	4
40 - 49.9	12	1
50 - 59.9	9	0
60 - 69.9	6	1
70 - 79.9	4	0
80 - 89.9	3	0
90 - 99.9	1	0
Total	88	12

4 BOREHOLE SITING

4.1 SCIENTIFIC VERSUS LAY SITING

In Table 14 results of hydrogeological borehole siting are compared to those achieved by lay persons. For this analysis data in the National Groundwater database were used which accumulated over many years. For lack of a proper collective noun the term "lay" is used to describe a group consisting of drilling inspectors, drillers, water diviners and landowners. With the exception of scientifically selected sites, drilling inspectors normally had to approve of all other sites drilled by government machines or on contract to the government. The term "hydrogeological siting" describes siting by (hydro-) geologists/geophysicists/geotechnicians on the basis of geological or geological-geophysical considerations.

Although hydrogeological results are better than those of lay persons, they cannot be considered satisfactory. Whether the additional expense involved in hydrogeological investigations has been covered by the improvement in drilling results unfortunately cannot be determined.

TABLE 14 BOREHOLE SITING BY LAYMEN AND HYDROGEOLOGISTS/GEOPHYSICISTS

Yield $\ell\, s^{-1}$	Number of boreholes selected		Percentage of total number of holes sited		Percentage of boreholes yielding ≥ 0.1 $\ell\, s^{-1}$	
	by lay persons	On hydrogeological grounds	by lay persons	on hydrogeological grounds	by lay persons	On hydrogeological Grounds
0 – 0.099	1060	111	55.1	34.7		
0.1 – 0.99	491	94	25.5	29.4	56.8	45.0
1.0 – 4.99	337	93	17.5	29.1	39.0	44.5
5.0 – 9.99	29	14	1.5	4.4	3.4	6.7
≥ 10.0	8	8	0.4	2.5	0.9	3.8
Total	1925	320	100	100.	100	100

4.2 HYDROGEOLOGICAL GUIDELINES

Preceding statistical analyses (section 3.4) provide guidelines for further improvement in siting boreholes and for a reduction in the production cost of a successful borehole (cost of failures included):

- The occurrence of groundwater is principally associated with the near-surface zone of weathering and fracturing.
- Within any of the mapped lithostratigraphic units, local variations in mineralogical composition and texture, the presence or absence of structural features and local geomorphology determine the variable degree and depth of weathering and fracturing.
- The chances of striking water are better in the supracrustal rocks as a unit (amphibolite, quartzite, sandstone, shale schist) than in the granitic rocks. Yields are also higher. Schist however has been found a poor groundwater target.
- The Nelspruit Granite Suite as a whole appears to be the least favourable of the granitic lithostratigraphic units.
- Fractures, which are the conduits that deliver groundwater to boreholes, are most numerous within the near-surface zone.
- The zone of weathering is mostly less than 40 metres thick. In only few cases do weathering and fracturing as deduced from drill cuttings, extend deeper than 55 metres.
- The probability of striking water is highest at the base of the near-surface zone of weathering and fracturing provided it lies below the groundwater level.

- The depth to groundwater level – i.e. the top of the saturated zone – generally lies between 5 and 40 metres below the surface. The mode is 10 to 15 metres.
- The probability of striking water is highest within the first 10-15 metres or so below the groundwater level.
- Peak strike depths range from 15 to 50 metres below the surface. Below 50 m strike frequency averages about one third of that between 10 and 40 m.
- The chances of striking water are neither enhanced nor on the other hand appreciably reduced by the presence of dykes.
- Dykes should not be regarded as hydrogeologically different from the gneisses, granites and granitoids in which they occur but as part and parcel of a hard-rock entirety. Their water-bearing characteristics should be seen neither as barrier nor as conduit but as variable as the adjoining country rock.
- Dyke contacts are not *per se* water strike zones. Success depends on whether country rock or dyke or both are weathered and fractured to below the water level.
- Deeper strikes do not necessarily result in higher yields. There is no material difference between shallow-strike and deep-strike median yields. The effect of greater pumping drawdown is apparently counteracted by a decrease of fracture aperture and permeability with depth.

Based on these criteria the borehole siting and drilling procedure should be the following:
1. On the basis of surface geological and other indications choose for further investigation the more favourable part(s) of the environs where a water supply is required.
2. Establish/estimate the depth of the groundwater level in the area where a borehole is to be sited.
3. Employ geophysical techniques
   - To examine the suitability of surficial features as potential loci for borehole siting or
   - To find in the absence of surface indications basins or troughs of weathered and fractured rock that extend at least to the groundwater level, preferably deeper; or
   - To locate narrow zones of vertical fracturing.
4. Control drilling operations to obviate unnecessary drilling.

4.3 GEOPHYSICAL METHODS

4.3.1 Magnetic method

The magnetic method may be used to locate and trace dykes that are not exposed on the surface. However an appreciable number is non-magnetic according to De Villiers (1969). On the other hand ground-survey anomalies of those that are magnetic, tend to be irregular and not readily susceptible to interpretation in terms of dyke contacts and dip. The presence of amphibolite and/or ferruginous rocks complicates matters even further. It is a pity that a systematic study of the different dyke systems in terms of petrography, orientation, age and magnetization and their relationship to faulting, shearing has not yet been undertaken. Such information would doubtlessly assist in recognising along which dykes, if any, and where favourable conditions for siting of boreholes may be found.

4.3.2 Electrical resistivity method

As should be evident from previous sections, groundwater is found where weathering and fracturing extend to below the waterlevel. The resistivity method of depth probing is eminently suited not only for determining the thickness of the weathered and fractured zone but also for obtaining an indication of the degree of weathering. By correlating statistically resistivity of the weathered zone with borehole success rate and yield, an optimal bandwidth of resistivity for siting boreholes may be determined statistically.

Depth-determinations from resistivity probes rest on the assumption of a horizontally stratified earth which means that resistivity varies only in the vertical direction not laterally. As lateral resistivity changes affect depth probes in much the same manner as the vertical variations, it is essential to conduct resistivity surveys in such a manner that lateral variations are recognised and accounted for in depth interpretations.

This aspect is of great importance in Region 19

- in view of the swarms of closely-spaced diabase/dolerite dykes;
- because the resistivity of weathered basic dyke rock usually is as much as one order lower than that of adjoining weathered granitic rocks.

By mistaking the lateral effect on depth soundings for the vertical, boreholes may be sited where weathering and fracturing falls short of the required depth with the result a failed hole. Borehole siting should be based on a series of properly spaced depth probes and not on the strength of a single one.

Due to the multitude of dykes and the lack of weathering in the Letsitele - Constantia area, Burvenich (1972) targeted weathered/fractured dyke contacts for siting boreholes. As these could not be located accurately by ground magnetic surveys, he experimented with the potential-drop-ratio (PDR) technique of resistivity surveying (Heiland 1940). The advantage of the PDR procedure is that sharper indications are obtained on vertical formation boundaries. However the technique is also sensitive to near-surface resistivity variations not associated with weathered intrusive contacts. Except that potential-drop-ratio anomalies were found to correlate well with those obtained with the electromagnetic technique using a long earthed cable (Vegter 1962), results were inconclusive as far as the siting of successful boreholes was concerned. The method does not answer the critical question as to the depth extent of weathering/fracturing. There has been no follow-on investigation.

4.3.3 Electromagnetic method

In the absence of basins or troughs of weathering/fracturing one has to fall back on narrow zones of vertical and off-vertical fracturing for siting boreholes. In as far as these are not visible on the surface, electromagnetic methods have to be employed, as the resistivity method is not well suited for locating and tracing narrow two-dimensional conductive features.

The application of different electromagnetic techniques for borehole siting in basement rocks has been discussed and demonstrated in the case of Region 3 (Vegter 2000). It was conclusively shown that the EM anomalies are caused by the near-surface weathered, low-resistivity expression of fracture zones. Because the dip, depth extent and water-bearing character of such fracture zones generally can not be deduced from the EM anomaly, they have to be established by prospect drilling. This usually entails drilling several closely spaced boreholes across the structure. For success hydrogeological drilling control ideally supported by geophysical borehole logging is essential.

4.3.4 Geophysical borehole logging

Borehole logging is an indispensable tool in directing drilling operations on two-dimensional structures such as faults, fractured dyke contact zones. The reasons are:

- Lack of width coupled with off-vertical dip.
- EM anomalies are due to the upper weathered, generally above-the-waterlevel part of the two-dimensional geological features.
- In the case of a dipping feature the anomaly is not located above its (sub)-outcrop but is displaced in the down-dip direction.

The nature of and depth at which a borehole passed through the conductive zone that caused the anomaly, may not be obvious from a geological inspection of drill cuttings. Geophysical logging is required to identify, determine or confirm the depth at which a borehole passed through the feature. Another important aspect when carrying out prospect drilling is correlation from one borehole to the next.

It should be clear that sidewall resistivity logging is required above the groundwater level. In order to eliminate drilling deeper than is necessary according to the guide lines, the latter and geological logging should go hand in hand.

4.3.5 Geophysical exploration during the Bolobedu drought relief programme

According to Sonnekus and Hendriks (1997) the majority of Bolobedu drought-relief boreholes were sited on the strength of ground magnetic and Geonics EM 34 -3 traversing supported by some resistivity depth probing. Unfortunately the manner in which the geophysical work was reported on – and apparently conducted – does not allow for a proper assessment.

- No distinction is made on the geological sections between surface observations and geophysically inferred features such as dyke contacts.
- Detailed sections with equal horizontal and vertical scales are not available of the immediate vicinities of borehole sites.
- Comparison of drilling results with antecedent geophysically inferred geological sections is not possible.
- No explanation is given of the manner in which the magnetic and electromagnetic data were interpreted and of the reasoning behind the selection of each drilling site.

Regrettably Sonnekus and Hendriks work fails in demonstrating aptly and usefully the application of geophysical methods for borehole siting in Region 19. As the drought-relief programme apparently was one of great urgency failure in these respects is perhaps understandable. The following questions are raised and comments made in the hope that they may help to improve the standard of future geophysical work:

a) What (hydro)-geological and other considerations determined the positioning of the geophysical traverses?
b) How much additional geophysical surveying, if any, was done in the vicinity of each prospect before settling for the particular traverse and the site(s) depicted in the report? Are the selected sites the best to be found within allowed confines?
c) Apart from locating and tracing dykes do ground-magnetic surveys have any other application in Region 19? Are ground magnetic anomalies in view of their variable and complex nature really of any use in determining the positions of dyke contacts accurately within a metre or so?
d) The Geonics EM 34-3 system was employed to locate basins of decomposition and weathered dyke contact zones according to Sonnekus and Hendriks. Why then was the EM method not employed in a "depth-probing" mode i.e. by traversing with 10 and 40 m coil separations in addition to the 20 metre separation?
e) Were parallel traverses run to determine the strike of magnetic and electromagnetic anomalies?
f) Is a ten-metre spacing of stations adequate for the precise location of narrow two-dimensional conductive features?
g) Electrical conductivity apparently played no role in the interpretation and selection of borehole sites.
h) An understanding and interpretation of EM anomalies in terms of local geological features is in urgent need.

i) Should greater use of closely spaced resistivity depth probing not have been made to elucidate the nature of EM anomalies and for the recognition of lateral resistivity changes?
j) The interpretation of resistivity depth probes leaves much to be desired.

5 DRILLING CONTROL

The depth of weathering/fracturing as judged from drill cuttings or alternatively the depth of the groundwater level should determine drilling depth. A third approach is to limit drilling to the optimal strike zone once water has been struck and to specify a maximum borehole depth.

The optimal strike zone below the base of weathering/fracturing decreases with the depth of the base. It ranges from 35 metres for less than 10 metres of weathering/fracturing to 0 metres for a depth of 50 metres and more of weathering/fracturing (see Figure 11). The optimal strike zone below the groundwater level decreases with depth of groundwater level. It ranges from 42.5 metres for groundwater levels of less than 10 -15 metres to zero metres for groundwater levels of 35 metres and deeper (see Figure 9).

Using these figures as guide and adding a "safety" margin varying from 10 to 3 m with increasing depth, the distances that should be drilled below the base of weathering/fracturing and below the groundwater level have been listed in table 15.

The distributions of depths of weathering plus fracturing (Figure 5) and of groundwater levels (Figure 6) provide the bases for determining ideal drilling depth distributions for the Region. The idealized distributions of borehole depths are depicted in Figure 20 together with the actual spread of NGWDB borehole depths.

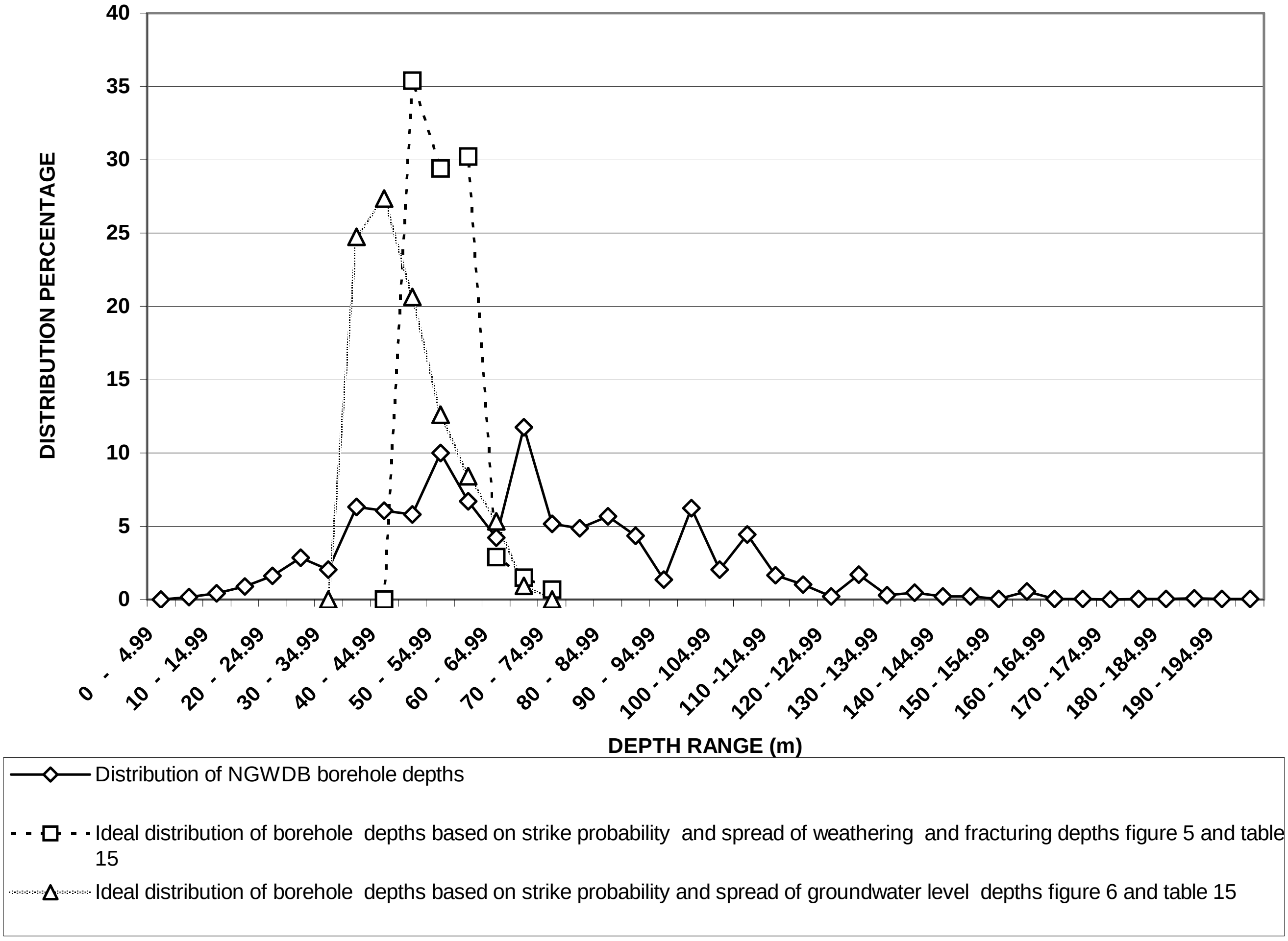
TABLE 15 DEPTHS TO BE DRILLED BELOW BASE OF WEATHERING/FRACTURING OR BELOW GROUNDWATER LEVEL

Depth range (m) of 1.Base of weathering/fracturing 2. Groundwater level	Additional metres to be drilled below	
	1. Base of weathering/fracturing	2. Groundwater level
0 - 4.9	45	42.5
5 -9.9	45	35
10 - 14.9	45	30
15 - 19.9	40	25
20 - 24.9	29	22.5
25 - 29.9	22	20
30 - 34.9	17	17.5
35 - 39.9	12	15
40 - 44.9	6	12.5
45 - 49.9	3	10
50 - 54.9	3	7.5
55 - 59.9	3	5
60 - 64.9	3	2.5
65 - 69.9	3	0
70 - 74.9	0	0

Based on the assumption that the distribution of weathering plus fracturing depths deduced from a sample of 185 boreholes is representative of the Region (Figure 5), the total distance drilled would have been 22.7 % less than the actual. According to the distribution of groundwater levels (Figure 6) the total distance drilled would have been 26.4 % less than the actual.

Note however that strikes below 70 m would not have been realized. They amount to just over 5% of the total number of NGWDB strikes. The probability of a strike below 70 metres, is less than one-third of that within the optimum strike zone of 15 - 40 metres below the surface. It is therefore considered cost-effective to rather drill another borehole than to continue deeper once a depth of 70 m or even less has been reached. This will be illustrated in the following paragraphs by an analysis of drought-relief drilling in the Bolobedu District.

FIGURE 20 ACTUAL DISTRIBUTION OF BOREHOLE DEPTHS ACCORDING TO NATIONAL GROUNDWATER DATABASE COMPARED TO THE IDEAL



Based on the recorded depths of weathering and fracturing (Table 12) and additional drilling according to Table 15, the total distance drilled would have been 5265 metres. No borehole would have been deeper than 60 metres. Of the 59 successful boreholes sunk during the drought-relief programme, five would however not have materialized – strike depths exceed 60 m by 12 to 38 metres. The mean distance that would have been drilled per successful borehole is 97.5 m (failures included).

Based on the depth distribution of groundwater levels (Table 12) and additional drilling according to Table 15, the total distance drilled would have been 4957 metres. No borehole would have been deeper than 55 metres. In eight of the 59 successful boreholes water was struck deeper than 55 m. These holes would thus not have materialized. The mean distance that would have been drilled per successful borehole is 97.2 m (failures included).

A third approach might have been to restrict drilling to 15 metres below a water strike and in the event of no strike to a maximum borehole depth of 60 m. This would have resulted in a total of 5053 metres and 55 successful boreholes. The mean distance drilled per successful borehole would have been 91.9 metres (failures included).

The actual distance drilled in 101 boreholes of which 59 were successful was 7500 metres i.e. a mean distance of 127.1 m per successful borehole. For a proper comparison of the actual and the three idealized programmes either the drilling distances for a full complement of 59 successful boreholes or the numbers of successful boreholes that might have been completed given 7500 m of drilling, need to be estimated.

On the basis of 97.5, 97.2 and 91.9 metres per successful borehole additional distances of respectively 488, 778 and 368 m would be required to fulfill the quota of 59 successful boreholes. Adding these to above-stated respective drilling distances, savings amounting to 1747, 1713 and 2017 m is obtained. These distances are equivalent to savings in drilling cost of between 22.8 to 26.9%.

Alternatively at mean rates of 97.5, 97.2 and 91.9 metres per successful borehole the drilling distance of 7500 metres is equivalent to respectively 77, 77 and 82 successful boreholes. Eighteen to twenty-three more successful boreholes thus may have been drilled at about the same drilling cost as the actual programme. Note that these results are possible without any improvement in the siting of boreholes – only by strict hydrogeological control over drilling operations.

Deeper drilling in the expectation of higher borehole yields is statistically not justifiable as indicated by Figure 12. A significant gain in exploitable storage is also not on the cards because deeper water strikes result from occasional fractures in fresh bedrock.

6 GROUNDWATER RECHARGE AND STORAGE

The abundance of springs along the escarpment in the west (De Villiers 1967; Kok 1976; Kent and Groeneveld 1964 and Visser and Verwoerd 1960) proves that groundwater is being recharged and that it produces base flow.

Mean annual base flow is depicted on Sheet 2 of the set of maps "Groundwater Resources of the Republic of South Africa" (Water Research Commission 1995). It is expressed in terms of depth of water over catchment area. Base flow as a percentage of mean annual precipitation and of mean annual runoff is also shown in figures 5 and 6 of the accompanying Explanation (Vegter 1995).

That no base flow occurs in the flatter eastern parts of Region 19 does not mean lack of recharge. Groundwater may be discharged and lost either as spring flow that does not contribute measurably to surface runoff or through evapotranspiration where the groundwater level approaches the surface in lower-lying areas.

Except for mentioning the abundance of springs along the Escarpment virtually nothing is known about their occurrence and magnitude. This is particularly the case to the east away from the Escarpment. The few springs, which are found in the eastern drier portion of geological Sheet 22, are generally associated with major joints and less commonly with dykes or shear-zones (Visser and Verwoerd 1960).

Du Toit (1997) has listed sporadically repeated waterlevel measurements in 86 boreholes in the Kruger National Park. The measurements were made twice to five times at different times in different boreholes during the period 1935 to 1992. Maximum waterlevel fluctuation per borehole ranges from less than 1 to 24 metres. Eighty percent of the maximum waterlevel differences vary from less than 1 to 5 metres. The data confirm that recharge is taking place. Except for perhaps local over-exploitation at a few localities the data provide no evidence of a general lowering of levels and of a depletion of groundwater in the Kruger National Park.

According to the saturated interstice map (see Sheet 2 "Groundwater Resources of the Republic of South Africa" Water Research Commission 1995) groundwater is principally stored in fractured rock. The volume is therefore limited except for localized areas of deep weathering and where water-bearing alluvial deposits are present. Unfortunately information on these aspects is lacking. See also sections 2.10 and 3.2. During droughts, which may last several rainy seasons, weakening and drying-up of boreholes, may be expected in higher-lying areas of shallow weathering and fracturing.

This aspect has to be taken into account in the development of a borehole water supply for a rural community. Nearness of borehole to the community has to be weighed against the likelihood of failure during droughts.

7 WATER QUALITY AND HYDROCHEMISTRY

According to Sheet 2 of the "Groundwater Resources of the Republic of South Africa" map set (WRC and Department of water Affairs and Forestry 1995), total dissolved solids and chemical type vary geographically as tabled below.

TABLE 16 DISSOLVED SOLIDS AND CHEMICAL TYPE

Lower standard deviation mg ℓ^{-1}	Upper standard deviation g mg ℓ^{-1}	Approximate indication of area	Dominant chemical type(s)*	Nitrate and fluoride risk
300	500	Nelspruit - Witrivier surroundings south of 25^0 10' and west of 31^0 20'	B and C	F exceeds 1.5 mg l^{-1} as F in more than 20% of the analysed samples
500	1000 - 1500	North of a line joining Tzaneen and Giyani and west of 30^0 30' E	A and B	NO_3 as N exceeds 10 mg l^{-1} in 20% of the analysed samples
500	1500- 2000	a) West of 31^0 15'.E between the Olifants River and 24^0 35' south b). South of 24^0 35' S with the exclusion of the Nelspruit -Witrivier surroundings	C	F exceeds 1.5 mg l^{-1} as F in more than 20% of the analysed samples
500 - 1000	1500 - 2000	West of 31^0 15' E between the Murchison Range and the Olifants River	D	-
500	> 2000	Between the Murchison Range and a line joining Tzaneen and Giyani and west of the Klein Letaba River	A	F exceeds 1.5 mg l^{-1} as F in more than 20% of the analysed samples
500 - 1000	1500 - 2000	Remaining eastern part of Region north of 24^0 35' S	C except B and C north of 23^0 30' S	-

*Dominant hydrochemical types:

A = Dominant cations Ca^{2+} and/or Mg^{2+} and dominant anions Cl^- and/or SO_4^{2-}

B = Dominant cations Ca and/or Mg and dominant anion HCO_3^-

C = Dominant cations Na^+ and/or K^+ and dominant anion HCO_3^-

D = Dominant cations Na^+ and/or K^+ and dominant anions Cl^- and/or SO_4^{2-}

Simonic of Hydromedia Solutions (Pty) Ltd. classified the overall potability of 1398 water samples. The chemical criteria are laid down in the manual "Quality of domestic water supplies Vol.1 Assessment Guide" of the Department of Water Affairs and Forestry, the Department of Health and the Water Research Commission. The result is produced in table 17.

TABLE 17 POTABILITY CLASSIFICATION

Class	1-blue	2-green	3-yellow	4-red	5-purple
Description	Ideal	Good	Marginal	Poor	Unacceptable
No of samples	437	314	362	223	62
% of samples	31.3	22.5	25.9	16	4.4

Just over 20 percent of the water samples are not suitable for drinking. The spatial distribution of the samples is shown in Figure 21.

TABLE 18 DISTRIBUTION OF HARMFUL ION CONCENTRATIONS

Ion	**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**Cl^{-}**	**SO_4^{2-}**	**NO_3^{-}**	**F^{-}**	**$EC^{\#}$**
No of analyses	1416	1416	1406	1394	1416	1406	1230	1416	474
No of samples containing harmful concentration	2	11	72	nil	63	nil	128	109	30
% of samples	<0.01	0.8	5.1	nil	4.5	nil	10.4	7.7	6.3

$^{\#}$ EC = Electrical conductivity

Harmful constituents in order of frequency of occurrence are NO_3^-, F^-, Na^+ and Cl^-.

8 CONCLUSIONS AND RECOMMENDATIONS

The map set "Groundwater Resources of South Africa" (Water Research Commission 1995) provides a broad outline of the groundwater situation in Region 19 in terms of

- borehole prospects;
- principal type of saturated interstice;
- depth of groundwater level;
- groundwater quality and chemistry;
- a rough indication of groundwater recharge.

Statistical analyses of borehole data contained in the National Groundwater database described in this document have produced important guidelines for the siting of boreholes and for drilling control. In spite of this contribution several questions remain unanswered:

1) Which geomorphologic and geological features and which flora, if any, are indicative of weathering/fracturing that may extend to below groundwater level? Geological characteristics include the mineralogical composition and texture of different rock types, weatherability, the spacing, orientation, age and distribution of fracture and dyke systems and their relation to the neotectonic stress field. How are these characteristics distributed spatially and how do they vary within the Region?

2) The manner in which the magnetic, electrical resistivity and electromagnetic methods are being applied and interpreted needs to be reviewed and overhauled.

3) Continuity of groundwater supply for human consumption needs to be assured. How steady are supplies from groundwater schemes serving rural communities? What are the criteria to take into account in Region 19 in siting borehole fields to ensure a continuous supply? Studies need to be undertaken of local groundwater schemes in order to translate their performance in terms of the local hydrogeology, rainfall and recharge. The purpose would be to ensure that groundwater schemes are sited and designed so as to fulfill their envisaged role.

4) Where and under which geological and other conditions does groundwater unfit for human consumption occur?

5) How are surface and groundwater resources to be managed jointly, particularly in those parts where irrigation of crops is practised?

6) The role of groundwater in the maintenance of the environment, particularly the riparian vegetation e.g. in the Kruger National Park needs determination.

REFERENCES

Acocks, J.P.H., 1953. Veld types of South Africa with map, scale 1:1 500 000. bot. Surv. S.Afr. Mem 28

Brandl, G., 1981. The Geology of the Messina area. Expl.Sheet 2230 S. Afr. geol. Surv.

Brandl, G., 1987. The Geology of the Tzaneen area. Expl.Sheet 2330 S. Afr. geol. Surv.

Burvenich, T.M. 1973. Experimental application of the potential-drop-ratio method in the Letsitele - Constantia area Letaba District, for the siting of water boreholes. Report Gh 1866, Geohydrology, Dept. Water Affairs and Forestry.

De Villiers, S.B. 1967. Voorkoms van grondwater in die Letaba streek. Report Gh 1373, Geohydrology, Dept. Water Affairs and Forestry.

De Villiers, S.B. 1969a. Verslag oor grondwateropname in die omgewing van Mooketsi Distrik Letaba. Report Gh 1444, Geohydrology, Dept. Water Affairs and Forestry.

De Villiers, S.B. 1969b.Boorplekaanwysing by gange Noord-Transvaal. Report Gh 2923 Geohydrology, Dept. Water Affairs and Forestry.

Du Toit, W.H., 1984. Grondwaterondersoek Letsitele. Report Gh 3377, Geohydrology, Dept. Water Affairs and Forestry.

Du Toit, W.H., 1997. Geohidrologie van die Nasionale Kruger Wildtuin gebaseer op die evaluering van bestaande boorgatinligting (3 volumes). Report Gh 3798, Geohydrology, Dept. Water Affairs and Forestry.

Groeneveld, D. and Genis, L.M., 1964. Verslag oor die ondersoek van louwarmfonteine wat in die industriële gebied van die Stadsraad van Nelspruit geleë is. Report Gh 1229, Geohydrology, Dept. Water Affairs and Forestry.

Hanekom, H.J., Van Staden, C.M. van H., Smit, P.J. and Pike, D., 1965. The geology of Palabora Igneous Complex. Mem. geol. Surv. S. Afr. 54.

Heiland, C.A., 1940. Geophysical exploration. Prentice-Hall New York

Kent, L.E., 1937? Sheet 28 Murchison Range: The Letaba hot spring. Report Gh 551, Geohydrology, Dept. Water Affairs and Forestry.

Kent, L.E., 1959. The Letaba hot spring supplementary report. Report Gh 1055, Geohydrology, Dept. Water Affairs and Forestry.

Kent, L.E., 1980. Warm springs near Hazyview, Eastern Transvaal. Ann. geol. Surv. S. Afr. 14/2 p 33 - 42

Kent, L.E., 1986. The thermal saline springs of the north-eastern Transvaal. Ann. geol. Surv. S. Afr. 20 p 141 - 154

Kent, L.E. and Groeneveld, D., 1964. Warm and cold springs on Richmond, Pilgrim's Rest District, Transvaal. Ann. geol. Surv. S. Afr. 1 p 175 – 182

Keyser, N., (compiler) 1997. Geological Map of the Republic of South Africa and the Kingdoms of Lesotho and Swaziland scale 1:1 000 000.

Kok, T.S., 1976a. Voorlopige evaluasie van die grondwaterpotensiaal van plase by Trichardtsdal, Distrik Letaba, Steelpoort Distrik Lydenburg en F.C. Erasmus, Distrik Pelgrimsrus. Report Gh 2900, Geohydrology, Dept. Water Affairs and Forestry.

Kok, T.S., 1976b. Toets van boorgate op plase Bronkhorstfontein en Kogelfontein van Lornadawn Beleggings. Report Gh 2900, Geohydrology, Dept. Water Affairs and Forestry.

Meyer, P.S., 1974a. Letaba Opvanggebied – boorgatopname. Report Gh 2840, Geohydrology, Dept. Water Affairs and Forestry.

Meyer, P.S., 1974b. Klaserie- en Blyderivierboorgatopname. Report Gh 2842, Geohydrology, Dept. Water Affairs and Forestry.

Meyer, P.S., 1974c. Levubu en omliggende riviervalleie – boorgatopname. Report Gh 2845, Geohydrology, Dept. Water Affairs and Forestry.

Meyer, P.S., 1975. Letabarivier Kleinhoewes – boorgatopname. Report Gh 2848, Geohydrology, Dept. Water Affairs and Forestry.

Partridge, T.C.,1998. Of diamonds, dinosaurs and diastrophism: 150 million years of landscape evolution in southern Africa. S. Afr. J. Geol. Vol. 101 No 3 pp 167-184.

Partridge, T.C. and Maud, R.R., 1987. Geomorphic evolution of southern Africa since the Mesozoic. S. Afr. J. Geol. Vol. 90 No 2, pp 179 - 208.

Polivka, J., 1986. Hydraulic fracturing experiments to improve the yield of low yielding boreholes in the southern part of the Republic Venda. Report Gh 3451, Geohydrology, Dept. Water Affairs and Forestry.

Rutherford, M.C. and Westfall, R.H., 1986. Biomes of Southern Africa – An objective categorization. Mem. 54 bot. Surv.S. Afr.

Schulze, B.R., 1994. Climate of South Africa Part 8 General Survey. Weather Bureau, Dept. Environ. Affairs

Schultze, R.E., 1989. ACRU: Background, concepts and theory. WRC Report No 154/1/89.

Sonnekus, C.J. and Hendriks, E., 1997. Ontwikkeling van grondwaterbronne vir noodwatervoorsiening in die Bolobedu Distrik. Report Gh 3901, Geohydrology, Dept. Water Affairs and Forestry.

Vegter, J.R., 1995. An explanation of a set of national groundwater maps. Water Research Commission Report No KV 77/95. Pretoria.

Vegter, J.R., 2000. Hydrogeology of groundwater region 3 Limpopo granulite-gneiss belt. Water Research Commission Report TT 136/00
.
Visser, H.N. and Verwoerd, W.J., 1960. The geology of the country north of Nelspruit. Expl. sheet 22 (Nelspruit) geol. Surv. S. Afr.

Visser, D.J.L., 1989. Toeligting tot die 1:1 000 000 Geologiese kaart 4e uitgawe 1984. geol. Surv. S. Afr.

Walraven, F., 1989a. The geology of the Pilgrim's Rest area. Expl.Sheet 2430 S. Afr. geol. Surv.

Walraven, F., 1989b. Die geologie van die gebied Barberton. Expl.Sheet 2530 S. Afr. geol. Surv

MAPS CONSULTED

Topocadastral Map Sheets 2230, 2330, 2430 and 2530 (scale 1:250 000) Dir. Surveys and Mapping Mowbray.

Geological Map Sheets scale 1:250 000 2230 Messina,(1981), 2330 Tzaneen (1985), 2430 Pilgrim's Rest (1986) and 2530 Barberton.1986) geol.Surv. S. Afr.

Geological Map of the Republics of South Africa, Transkei, Bophuthatswana, Venda, Ciskei and the Kingdoms of Lesotho and Swaziland 1984 edition on the scale1:1 000 000 geol.Surv. S. Afr.

Geological Map of the Republic of South Africa and the Kingdoms of Lesotho and Swaziland scale 1:1 000 000 (1997) geol.Surv. S. Afr.

Structure Map of South Africa and the Kingdoms of Lesotho and Swaziland (1995) scale 1:1000 000. geol.Surv. S. Afr.

Hydrogeological Map Sheets scale 1:500 000 2330 Phalaborwa (1998) and 2530 Nelspruit (1999). Dept. Water Affairs and Forestry

Groundwater resources of the Republic of South Africa: 2 map sheets (1995) Water Research Commission and Dept. Water Affairs and Forestry.