HYDROGEOLOGY OF GROUNDWATER REGION 7

POLOKWANE/PIETERSBURG PLATEAU

Prepared for the Water Research Commission

by

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EXECUTIVE SUMMARY

The more important findings of this study are summarised below under "Statistical analyses", "Role of geophysical methods" and "Hydrogeological control of drilling operations"

General

Groundwater Region 7, a rectangular area of about 12 000 km^2, is located in the Limpopo Province. Its eastern boundary is the watershed between the Sand River and its tributaries and the eastward draining Letaba and Pafuri Rivers. Its northern boundary is formed by Formations of the Soutpansberg Group that built the mountain range of that name. The western boundary consists from north to south firstly of Waterberg Group sedimentary rocks, followed by mafic Bushveld rocks and lastly by strata of the Wolkberg Group including the Black Reef Formation. These strata build the Highlands Mountains and the east-northeasterly trending Strydpoort Mountains that form the southern boundary. Main centres are Polokwane/Pietersburg in the south and Makhado/Louis Trichardt in the northeastern corner of the Region.

The catchment of the northward flowing Sand River comprises the major part of the Region. In the far south several streams flow towards the Olifants River. Along the western boundary drainage is directed towards the Mogalakwena River. The Region's surface varies from a strongly undulating plain in the southwest to a slightly undulating surface over the northern two-thirds. Elevation ranges mainly between 1200 and 900 m.a.m.s.l.

The climate is semi-arid, warm to hot. The Region is part of the Savannah biome. It enjoys summer rainfall, which ranges from an average of 625 mm in the high-lying southeastern corner to an average of around 400 mm over most of the rest.

As rivers only flow after rain and as there is no major storage dam within the Region, groundwater is of paramount importance to the Region's economy. Agriculture and a large number of rural communities depend on groundwater. This also applies in a limited degree to Polokwane/Pietersburg and Makhado/Louis Trichardt, which are mainly supplied from surface storage in adjoining catchments.

Geology

Except for two narrow northeasterly trending belts of supracrustal rocks in the vicinity of Polokwane/Pietersburg, gneisses and granites of Swazian to Randian age underlie Region 7. The supracrustal rocks include a variety of schists, quartzite, magnetic quartzite, shale, metavolcanics,.serpentinite, metapyroxenite. In the north of the Region highly deformed keels consisting of marble, calc-silicate rocks, metaquartzite, metapelite, and amphibolite are present within the gneisses. A notable feature is the swarm of northeasterly trending diabase dykes.

Occurrence of groundwater

Alluvial deposits along the Sand, Hout and Brak Rivers, the Diepsloot and Turfloop are important sources of groundwater. However no thorough investigation has been undertaken on them. This report is principally concerned with the occurrence of groundwater in the hard rock formations – mainly the Hout River and Goudplaats Gneisses, and Younger Granites.

The current state of knowledge about groundwater in the hard rock formations is limited to:

- Brief *ad hoc* reports on the scientific selection of drilling sites on farms
- Investigations for the Pietersburg and Louis Trichardt Town Councils aimed at augmenting and assessing municipal water supplies
- Hydrocensuses along the Sand River and in the Hout and Brak River catchments were irrigation is practised.
- Estimates of groundwater recharge in the Houdenbrak Subterranean Water Control Area.
- Set of national groundwater maps

A comprehensive description of the occurrence of groundwater requires detailed field studies to identify, catalogue and map not only existing sources of supply but also those localized geomorphologic and geological features that are indicative of favourable conditions for siting boreholes. Furthermore the potential of such superficial indications ideally requires confirmation by geophysical surveying. Such detailed investigations have not yet been undertaken. At this stage a detailed map and account of groundwater occurrence and exploitation possibilities are obviously out of the question. The only possibility is a statistical analysis of NGWDB data more elaborate than that undertaken for the production of the national set of groundwater maps.

Statistical analyses

The statistical analyses yielded the following information, which also serves as guidelines for the successful siting of boreholes and for reducing drilling costs:

- Of scientifically selected drilling sites 66.3% proved successful (borehole yields $\geq 0.1\ \ell\ s^{-1}$) compared to 48.7% of those selected by boring inspectors, drillers, water diviners and farmers.

- Scientific siting of boreholes consists of tracing magnetically dykes where not exposed and determining depth of weathering/fracturing by electrical resistivity depth probing. Frequency-domain electromagnetic surveying may be used to locate narrow steeply dipping fracture zones.

- The majority of groundwater strikes in the hard rock formations have been made within 80 metres from the surface. Within this band strikes are concentrated around the transition from weathered and fractured to fresh rock. Where the base of weathering/fracturing as deduced from drill cuttings is less than 25 metres deep, water is largely struck within the first 20 metres below the base. Where its depth exceeds 40 metres water is struck mostly above the base. Between 25 and 40 metres water is struck either above or below the base. .

- Boreholes should ideally be sited where weathering/fracturing extends to below the groundwater level.

- Weathering and fracturing generally extend to between 15 and 50 metres below surface. It exceeds 50 metres in 1 out of 6 boreholes.

- Less than 10% of the NGWDB boreholes have groundwater levels exceeding 50 metres. Water levels generally lie between 0 and 25 metres below surface except that they tend to be deeper in the Goudplaats Gneiss.

- The majority of water strikes are made within 40 m below groundwater level.

- In the Hout River and Goudplaats Gneisses and in the batholith aureoles water is struck mostly between 30 and 50 metres below surface. The probability of striking water down to 75 metres below surface is best in the Hout River Gneiss. In the Younger Granites, which appear to be least weathered and fractured, the peak strike range is 15 to 20 metres below surface.

- Dykes and their contact zones feature as drilling targets only if weathered and fractured to below groundwater level.

- The most prolific aquifers are found in weathered and fractured xenoliths and the Hout River Gneiss. The Younger Granites are the least favourable.

- The thickness of weathered and fractured rock at any point is dependent on the mineralogical composition and texture of the rock i.e. on its weatherabilty and on the extent of jointing/faulting.

Role of geophysical methods

- The presence of a substantial thickness of weathered and fractured rock underfoot may be evident from a lack of rock exposures, vegetation and other surface indications. In looking for areas or zones of weathered/fractured rock, satellite, aerial and aeromagnetic images may assist by elucidating structure.

- However as the vertical extent of weathering/fracturing can not be deduced from these observations, recourse has to be taken to geophysical exploration.

- The geophysical method mostly employed is that of electrical resistivity depth probing whilst dykes that are not exposed, may be traced magnetically. The weathered and therefore conductive upper part of narrow steeply dipping fracture zones may be located by frequency-domain electromagnetic surveying.

- During the course of the Batholith project no attempt was made to determine the nature, form and depth of the conductive bodies responsible for the EM anomalies on which boreholes were sunk. There is accordingly little difference between the manner in which the EM method has been employed and a shot in the dark.

- It is necessary to recognize that EM anomalies are produced largely, if not solely by the upper weathered extremity of fracture zones and not by deeper-lying water-bearing fractures.

- To determine the reason for an EM anomaly and thus obtain optimal drilling results, a procedure needs to be followed whereby:

EM and magnetic traversing are combined with electrical depth probing.

Drilling operations, which essentially have to be of an exploratory nature, are guided by concomitant geological and geophysical logging and on-site re-interpretation of the data.

The premise is that a single borehole may miss or penetrate a narrow steeply dipping fracture zone either too shallow or too deep. Several boreholes of different depths may be needed to locate the best and final borehole position.

Hydrogeological control of drilling operations

- Generally speaking drilling depths should not be predetermined but be based on the conditions encountered during the course of drilling. Optimal results, both yield and cost-wise, demand that drilling programmes be organized so as to allow continuous scientific supervision. Decisions to continue or to cease drilling operations in any particular borehole should be based on the statistically established criteria: optimal strike depths below surface, or below water level or below base of weathering and fracturing.

Large scale irrigation in the Dendron area

Since the 1950's large volumes of groundwater have been abstracted for irrigation in the Dendron-Vivo area (currently designated the Houdenbrak Subterranean Water Control Area). The threat of eventual depletion induced the Geological Survey to institute water level monitoring in the late 50's and periodic estimation of volumes abstracted. This work was later transferred to the Directorate of Geohydrology. On the basis of these data several recharge estimates from rainfall in the Doornlaagte catchment have been made.

The recharge estimates range from:

- 3.84 % of a rainfall of 440 mm a^{-1} that would balance abstraction at the rate of 8.6×10^6 m^3 a^{-1};
- 4.3% of annual rainfall varying from 180 to 400 mm and averaging 240 mm over a 5-year period;
- Annual recharge (mm) = 0.08 x (annual rainfall in mm - 342).

Owing to a dearth of input data simplifying, not necessarily valid assumptions had to be made and a lumped parameter model had to be adopted.

Optimal utilisation of Doornlaagte groundwater requires development of a management model preferably three-dimensional whereby the response of the groundwater system to varying conditions of climate/rainfall and exploitation may be predicted. It should be obvious that a satisfactory management model can be developed only on the basis of a greatly expanded data set collected over a number of years covering:

- spatially and temporally varying data on:
    1. Rainfall
    2. Groundwater levels
    3. Volumes of water abstracted
    4. Irrigation efficiency
    5. Return flow of irrigation
    6. Surface runoff and storage if any
    7. Groundwater loss, if any, through natural discharge and evapoteranspiration
    8. Areas under natural vegetation and cultivation
    9. Groundwater quality

- spatially variable data on
    1. the depth of decomposition and fracturing

    2. the storativity of the decomposed and of the fractured rock
    3. the transmissivity of the decomposed and fractured rock
- knowledge about
    1. the dynamics of water exchange between porous decomposed rock and fractures
    2. the effect of variations in moisture content of the zone of aeration on percolation to the saturated zone
    3. the effect of changes in land-use e.g. through bush clearing and agriculture on groundwater recharge

It should also be evident that abstraction of groundwater in the Doornlaagte catchment diminishes groundwater flow downstream and must have led to a reduction in the availability of surface water in the Hout River and affected its ecosystem adversely.

Hydrochemistry and groundwater quality

Calcium-magnesium bicarbonate and calcium-magnesium chloride/sulphate are the dominant chemical groundwater types of Region 7. Total dissolved solids lie in the 300 to 1500 mg l^{-1} range. Just more than 20% of the 975 groundwater analyses are regarded as not potable. Nitrate and fluoride are the harmful constituents in 85% of the cases. Electrical conductivity was found to exceed the limit laid down in 5.6% of the analyses.

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

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The late Mr. H. Maaren	Water Research Commission (Member and Chairman 1998- 1999)
Mr. K. Pietersen	Water Research Commission (1999)
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1. INTRODUCTION

1.1 LOCATION AND EXTENT

Region 7 consists of a rectangular area 11980 km^2 in extent. It is located in the Limpopo (formerly Northern) Province (Figure 1). Its eastern boundary is the watershed between Drainage Regions A7, (Sand River) and B8 and B9 (Letaba and Pafuri Rivers). The watershed coincides roughly with longitude 30^o, east of which lies Region 19, the Lowveld. The northern boundary is formed by Formations of the Soutpansberg Group, which built the mountain range of that name. The boundary is more or less coincident with latitude 23^o. The western boundary consists from north to south firstly of Waterberg Group sedimentary rocks (Region 6), followed by mafic Bushveld rocks (Region 16), and lastly by strata of the Wolkberg Group including the Black Reef Formation. These strata (Region 12) build the Highlands Mountains and the east-northeasterly trending Strydpoort Mountains that form the southern boundary.

Main centres are Polokwane/Pietersburg in the south and Makhado/Louis Trichardt in the northeastern corner of the Region where it straddles the boundary between Regions 7 and 8 (Soutpansberg). There are in addition several hundred rural villages.

1.2. PHYSIOGRAPHY

The central and greater part of the plateau has an elevation of between 900 and 1200 m.a.m.s.l. Elevations along the eastern watershed decrease from about 1500 m in the vicinity of Haenertsburg to between 1000 and 1200 m.a.m.s.l in the north. South of the Soutpansberg and Blouberg, the confluence of the Sand and its tributaries and the confluence of the Brak and its tributaries drop to below 900 m.a.m.s.l.

The Region's surface varies from a strongly undulating plain in the southwest to slightly undulating over the northern two-thirds of its area. The monotony of the plateau is broken by Archaean greenstone ridges such as the Renosterkoppies northeast of Pietersburg, and by inselbergs such as the Machihaan, Matlala, Moletsi, and Matok hills formed by intrusive granites.

Partridge and Maud (1987) designate the southern third of the plateau a dissected African surface (date of inception Early Cretaceous). Mountainous ground above the African surface is found in the extreme southwestern and southeastern corners of the Region. The northern two-thirds is classified as an undifferentiated Post-African surface (date of inception Early Miocene to Pliocene).

The northward flowing Sand River and its main tributaries, the Hout and the Brak (Drainage Region A7) occupy the greater part of Region 3. In the south the upper reaches of the Sand and its tributary the Bloed River follow a northeasterly course as far as Polokwane/Pietersburg. The southward draining Nkumpi, Chunies, Hakaro and Tlhabasane Rivers rise just within the southern border of Region 7 (Drainage Region B5). They leave the Region through narrow gaps in the Strydpoort Mountains. In the west the Seepabane, Matlala and smaller streams flow towards the Mogalakwena River (Drainage Region A6)

1.3. CLIMATE AND RAINFALL

The climate is semi-arid. Average daily maximum temperatures are about 32^o C in January and 22 ^{o} C in July. The average daily minima are about 18^o C in January and 4^o C in July. Frost occurs on average during the months June to August (Schulze 1994).

The rainy season lasts from about November to March. Rain is mainly in the form of thunderstorms. Mean annual rainfall along the southern boundary varies around 550 mm.

Along and directly west of the N-S trending eastern watershed, mean annual precipitation decreases from 625mm in the southeast to 575 mm in the northeast. In a parallel N-S zone farther west of the watershed, mean annual rainfall drops to somewhat less than 400 mm, before picking up and maintaining a steady 425 mm over the greater part of the Polkwane/Pietersburg Plateau.

Effective mean annual rainfall (based on the ACRU model) ranges from 300 mm to more than 400 mm.

1.4. NATURALVEGETATION

Region 7 is part of the Savannah Biome (Rutherford and Westfall 1986; Low and Rebelo 1996). The latter authors classify the vegetation as Mixed Bushveld on the southern higher-lying ground and Sweet Bushveld in the north. Veld types (Acocks 1953) range from False Grassveld in the south through Mixed Bushveld to Arid Sweet Bushveld in the north.

1.5. ROLE OF GROUNDWATER IN THE REGION'S ECONOMY

None of the rivers in Region 7 are perennial. There is also no major dam. Groundwater is therefore of paramount importance to the Region's economy. This applies not only to rural communities and to farming – especially irrigation – but also to the municipalities of Polokwane/Pietersburg and Makhado/Louis Trichardt including Tshikota

Until 1958 Pietersburg was solely dependent on groundwater. To the extent that the demand of the Pietersburg Municipality could not be met from groundwater sources, water had to be imported from adjoining drainage regions. Dap Naude Dam on the upper reaches of the Great Letaba River (Drainage Region B8) and owned by the Municipality of Pietersburg commenced supplying water to Pietersburg in 1958. The Ebenezer dam, which is also situated in the upper reaches of the Great Letaba River and is owned and operated by the Department of Water Affairs and Forestry, followed suite in 1974. Since 1997 water is also obtained from the Flag Boshielo Dam (previously known as Arabie) on the Olifants River (Drainage Region B5). The role of groundwater in Pietersburg municipal supply is illustrated in Table 1.

TABLE 1 ROLE OF GROUNDWATER IN PIETERSBURG MUNICIPAL WATER SUPPLY

Year	Supply from groundwater million m^3	Supply from surface water sources million m^3	Groundwater contribution as a % of total
1952/53	1.06	0	100
1957/58	1.54	0	100
1965	0.11	3.62	2.9
1971	1.76	3.86	31.3
1973	1.42	4.69	23.2
1976	3.26	6.25	34.3
1981	3.79	7.54	33.5
1985	3.17	5.13	38.2
1990	2.17	10.73	16.8
1994	4.01	8.78	31.4
2000	2.45	11.39	17.7

The Pietersburg groundwater supply is obtained from some 50 municipal boreholes, which are situated along the Sterkloop and Sand River. The northernmost of the two Sand

River borehole fields is situated downstream of the municipal sewage works from where purified effluent is discharged into the river.

Du Toit (1986) reckoned that in addition to the municipal boreholes about 1900 privately owned boreholes existed throughout the town. They were/are used for watering homestead gardens. He estimated that about 1.2 million m^3 per annum was extracted from them in 1986. A recent independent estimate (C. Haupt private communication) puts the number of private boreholes at 1200 and the volume pumped at 75 000 m^3 per month or 0.9 million m^3 per annum.

The neighbouring town of Seshego (part of the Polokwane Municipality) is also partly dependent on water obtained from boreholes in the town and on the adjoining Pelgrimshoop agricultural holdings. A supply is also obtained from Flag Boshielo Dam.

To the extent that Makhado/Louis Trichardt's and the adjoining Tshikota township's demand can not be met from the Albasini Dam on the Levuvhu River (Drainage Region A8), as happens from time to time, the short fall has to be obtained from boreholes situated on the town lands along the Dorps River. For example during the period 1986/87 to 1990/91 from 0.12 to 0.45 million m^3 per annum had to be withdrawn from groundwater. The average groundwater draught of 0.275 million m^3 per annum over this period represented 20.5% of the town's total consumption.

As may be seen from Table 2 a rural population of over half a million persons is solely dependent on groundwater. The remainder (378 000) are partly dependent on groundwater and partly on storage of surface runoff. Consumption figures are not available. It is thought that groundwater use may be in the order of five million m^3 per annum.

TABLE 2 COMMUNITY WATER SUPPLIES

Source	Type of Community	Number	Population
Groundwater	Formal towns	3	< 1 000
	Dense rural villages	13	134 000
	Small rural villages	204	370 000
	Scattered	22	6 000
Surface And Groundwater	Black townships	2	63 000
	Formal towns	7	78 000
	Dense rural villages	8	86 000
	Small rural villages	63	149 000
	Scattered	8	2 000

Data obtained from the Department of Water Affairs and Forestry

The greatest demand on groundwater is for irrigation in the Dendron-Vivo area and along the Sand River between Hollandsdrift 15 KS and Breypaal 760 LS. Table 3 summarizes the latest available hydrocensus data (Jolly 1986; Orpen 1989a, b and c). The relevant areas are shown in Figure 23. Data of the Hout River catchment has been split into Doornlaagte and remainder Hout River.

TABLE 3 IRRIGATION WITH GROUNDWATER

Catchment	Gh report No	Survey date	Author	Area of Irrigated crops (ha)	Volume pumped million m^3 per annum
Doornlaagte	3495	1986	Jolly J.L. 1986	3579	21.7
Remainder Hout Riiver	3624	1988	Orpen W.R.G 1989	7198	34
Brak River	3626	1989	Orpen W.R.G 1989	2820	15.4
Upper Sand	3625	1988/9	Orpen W.R.G 1989	10319	43.3
Total				23916	114.4

Note: Several crops are grown on a single cultivated land per annum. Irrigated area is a multiple of cultivated area.

2. GEOLOGY

The geology of the Region (Figure 2) is summarized in Table 4.

TABLE 4 LITHOSTRATIGRAPHY OF REGION 7

Erathem	Lithostratigraphic unit		Lithology
Cenozoic	Q	Quaternary	Soil, sand, alluvium, calcrete
Mokolian/Vaalian		Dykes (Vdi)	Diabase
Vaalian	Palmietontein Granite (Rpa)		Medium-grained biotite-muscovite granite
Randian	Mashashane Suite	Lunsklip Granite (Rlu)	Adamellitic to granodioritic
		Uitloop Granite (Rui)	Adamellitic
	Hugomond Granite (Rhu)		Coarse grained biotitic granite
	Matok Porphyroblastic Granite (Rmt)		Adamellitic to granodioritic granite Older mafic enderbitic – charno-enderbitic phase
	Matlala Granite (Rma)		Biotitic – granodioritic composition
	Utrecht Granite (Rut)		Fine-grained pink biotite granite
	Meinhardtskraal Granite (Rme)		Pink and red granite with pegmatite and granophyre
	Moletsi Granite (Rml)		Biotite granite
	Smitskraal Granite (Rsm)		Biotite granite
	Turfloop Granite (Rtu)		Biotitic, adamellitic to granodioritic
	Goudplaats Gneiss (Zgo)		Gneiss, banded gneiss, migmatite associated with leucocratic granite in varying proportions
	Hout River Gneiss (Z-Rh)		Leucocratic migmatite and gneiss, biotite and hornblende-biotite gneiss, pegmatitic rocks
Randian to Swazian		Intrusive ultramafic rocks	Talcose serpentinite, metapyroxenite
	Pietersburg Group (Zp)	Uitkyk Formation	Quartzite, conglomerate, shale, quartz-mica schist, banded ironstone
		Vrischgewaagd Formation	Quartz-chlorite schist
		Zandrivierspoort Formation	Mafic metalava interlayered with magnetite quartzite
		Eersteling Formation	Mafic metalava
		Ysterberg Formation	Salic lavas and tuff, shale, quartzite, quartzitic schist, banded chert and ironstone
		Mothiba Formation	Ultramafic metavolcanics: talc, talc-chlorite and amphibole-chlorite schists serpentinite,

TABLE 4 LITHOSTRATIGRAPHY OF REGION 7 (continued)

Erathem	Lithostratigraphic unit		Lithology
Swazian	Bandelierkop Complex Zb		Marble, cals-silicate rocks
			Metapelite
			Magnetite quartzite, metaquartzite
			Mafic granulite, amphibolite
			Peridotite, dunite, metapyroxenite, hornblendite

Note: Lithostratigraphic symbols are those shown on the 1:1 000 000 Geological map of South Africa that was published in 1997. In the table the lithostratigraphic units have been grouped under Erathems according to the Stratigraphic Table of South Africa, which the Council for Geoscience published in 1998. It differs somewhat from that of the 1:1 000 000 map of 1997.

Region 7 is covered by geological sheet 2328 Pietersburg. A small portion in the extreme southwest falls on geological sheet 2428 Nylstroom. The following description is mainly based on Brandl's explanation (1986).

The northern portion of Region 7 is part of the Southern Marginal Zone of the Limpopo Mobile Belt. The boundary between it and the Kaapvaal Craton to the south is taken as the ortho-amphibole isograd, which has been poorly established in the field

The Bandelierkop Complex is part of the Southern Marginal Zone of the Limpopo Mobile Belt. It has been subdivided into ultramafic, mafic and pelitic units plus meta-quartzite and marble. These rocks which have been subjected to granulite-facies metamorphism occur as highly deformed keels in the Goudplaats and Hout River Gneisses. The meta-pelites are very resistant and form flat barren pavements or large boulders. .

The Goudplaats Gneiss of Randian age is mainly confined to the northeastern part of the Region. It was previously considered as basement to the Swazian Bandelierkop Complex and Pietersburg Group. The Goudplaats Gneiss consists of gneiss, banded gneiss and migmatite and leucocratic granite.

The Hout River Gneiss includes a variety of granitoid rocks that show clearly intrusive relationships. It includes leucocratic migmatite and gneiss, hornblende-biotite gneiss, biotite gneiss and pegmatite. Its mapped contact with the Goudplaats Gneiss is arbitrary.

Rocks of the Pietersburg Group occur as two belts and as scattered xenoliths enveloped in granitoid rocks. The southern belt stretches east northeastwards from the Ysterberg in the southwest past Pietersburg in the direction of Duiwelskloof in Region19. The Zandrivierspoort Formation forms conspicuous ridges known as the Rhenosterkoppies some 25 km northeast of Pietersburg.

Younger Randian granitic intrusions occur as scattered bodies, the more important of which are:

- the Matoks Porphyroblastic Granite on Matokslokasie 492 LS 55 km north of Polokwane/Pietersburg;
- the Moletsi.Granite 25 km north-northwest of Polokwane/Pietersburg;
- the Mashashane pluton north of Mokopane/Potgietersrus;
- the Turfloop granite which flanks the southern edge of the Pietersburg Group and covers a large area in the southern part of the Region;
- the Matlala Granite Batholith about 35 km northwest of Polokwane/Pietersburg and
- the Meinhardskraal Granite in the extreme southwestern corner of the Region.
- the Utrecht Granite stock

Diabase dykes occur throughout the Region. They appear to be most plentiful in the south and northeast of Pietersburg where they form northeasterly trending swarms. To the north they appear to be less plentiful perhaps owing to poorer exposure. Other strike directions, particularly in the northern part of the Region, are northwest and west-northwest. Crosscutting relationships and other field evidence – differences in aeromagnetic and photogeological signatures (Anon 1974) – suggest that there were at least three periods of emplacement. In addition to the diabase dykes ENE trending lineaments inferred from aerial photography, LANDSAT images and aeromagnetic surveys are indicated on the quarter million Pietersburg sheet. Several N-S aeromagnetic lineaments have been mapped west of Polokwane/Pietersburg (Geological sheets 2328 Pietersburg and 2428 Nylstroom).

A number of southwest-northeast trending faults are present in the southwest. Most prominent of them is the Ysterberg tear fault. Its northeastward continuation has however not been mapped on the Pietersburg geological sheet. It appears to follow the valley of the Sand River. In the far north the E-W Vivo fault has a downthrow to the north. Several northwest-southeast trending faults have been identified on the basis of aeromagnetics on sheet 2329A (Anon 1974). A NW-SE striking metaquartzite band also on sheet 2329A seems to be displaced dextrally by an ENE trending aeromagnetic dyke-like feature.

In the Southern Marginal Zone of the Limpopo Mobile Belt four periods of deformation have been recognized:

- Isoclinal folding about east-west trending axial planes
- Tightening of the existing isoclinal folds
- Open cross-folding about upright north-west trending axial planes
- Shearing indicated by northeast trending lineaments

Rocks of the Pietersburg Group with the exception of the Zandrivirspoort Formation are folded presumably isoclinally, about northeast trending axes. The deformational history of the Zandrivierspoort Formation is probably similar to that of the Southern Marginal Zone.

Deposits of Quaternary age consist of soil, alluvium and calcrete. A large proportion of the northwestern part is covered by light coloured soil. Alluvial deposits along rivers such as the Sand, Diep, Hout and Brak Rivers, the Sandsloot and Turfloop are important sources of groundwater.

3. OCCURRENCE OF GROUNDWATER

3.1. BOREHOLE SITING

In areas underlain by hard rock formations such as the Pietersburg Plateau, each and every borehole does not necessarily strike a supply of groundwater. The question is whether geoscientists and geotechnicians fare better than laymen do, in minimizing the risk of drilling failures. The National Groundwater Database provides an opportunity for comparing their respective performances in Region 7.

Virtually all the data abstracted from the National Groundwater Database are of boreholes sunk by the Department of Water Affairs and its predecessor the Department of Irrigation during the period 1910 to 1984. The overwhelming majority of these boreholes were either sited or approved of by departmental boring inspectors. Landowners, drillers and water diviners selected those sites that were merely approved. Drilling results on the selected and approved sites (designated "lay" for want of an apt term) are compared in Table 5 to those selected by geoscientists and geotechnicians attached to either the Geological Survey or the Directorate of Geohydrology.

TABLE 5 “LAY* AND SCIENTIFICALLY SITED BOREHOLES

Yield ℓ s^{-1}	Number of boreholes on sites selected by		Percentage of total number of holes sited by		Percentage of boreholes yielding ≥ 0.1 ℓ s^{-1} sited by	
	lay persons	geoscientists/ geotechnicians	lay persons	geoscientists/ geotechnicians	lay persons	geoscientists/ geotechnicians
0 - 0.099	830	110	51.3	33.7	-	=
0.1 - 0.99	324	86	20.0	26.4	41.1	39.8
1.0 - 4.99	378	86	23.3	26.4	47.9	39.8
5 -9.99	60	28	3.7	8.6	7.6	13.0
≥ 10	27	16	1.7	4.9	3.4	7.4
Total	1619	326	100	100	100	100

*Lay persons: boring inspectors, landowners, drillers and water diviners

Up to about 1940 scientific siting was based solely on surface configuration and exposed geology as expressed in one of the early Geological Survey reports (De Wet 1938):

> "For the selection of sites in this area (i.e. Moletsi Location 25 km northwest of Pietersburg) it was always necessary to concentrate on drainage lines – where the underlying rock should be fairly decomposed – and wherever possible advantage was taken of the upstream sides of doleritic intrusions and one or two quartz veins".

The obsession of "taking advantage of dykes" is also evident from Frommurze (1940): Of 8 sites selected in the Matlala-Machichaan area (40 to 60 km west of Pietersburg) six were sited on granite alongside dykes. At the remaining two sites dykes were evidently absent. Drilling results are not available.

In a report commenting on a geophysical survey on the Pietersburg Town Lands Truter and Enslin (1941) state:

> "In granite the presence of a dyke is no criterion of the existence of undergroundwater unless the contiguous granite or the dyke itself has been decomposed to depths greater than the average. If the dyke has suffered more decomposition than the granite, it acts as an aquifer and the borehole should be drilled in it. Vice versa if the granite is more decomposed than the dyke, the latter acts as a barrier and the water occurs in the basins of decomposition in the granite".

Enslin (1961) later analysed the results of drilling at the contacts of diabase dykes in Northern Transvaal (currently known as Limpopo Province). He found that the percentage of failures was higher than the norm for the Northern Transvaal. Of 134 boreholes on dyke contacts 57 only (i.e. 43%) were successful whilst in basins of decomposition 198 (68%) out of 290 boreholes were successes. See also de Villiers (1969) on the role of dykes on the Pietersburg Plateau and in the Lowveld.

As the occurrence of groundwater in hard rock is dependent on the formation of interstices by weathering and fracturing geophysical prospecting methods have to be employed to establish the existence of openings below groundwater level. Consequently from 1940 onwards magnetometric and electrical resistivity surveys have been conducted by the Geological Survey and later by the Directorate of Geohydrology. Enslin's (1955) and Vegter's (1962) galvanic EM techniques have not been employed to any extent. The application since 1990 of the Geonics EM-34 and Genie SE-188 frequency domain systems will be discussed under paragraph 3.3.4.2.

The bulk of the scientifically sited boreholes featuring in Table 5 consequently have been selected on the basis of magnetic and electrical resisitivity work. Unpublished correlation graphs of resistivity of weathered granite-gneiss versus percentage successful boreholes and yield were compiled by Enslin for Northern Transvaal (see Vegter 1953). The optimal resistivity range is 100 to 250 ohm m. The resistivity of weathered to fractured granite, amphibolite and dyke rock ranges from 10 to 1000 ohm m according to electrical borehole logging.

As is evident from Table 5 the success rate as well as yield of scientifically selected boreholes is considerably better than that of the so-called lay sited boreholes. The question however arises whether further improvement is not possible. Enslin (1961) analysed failures and found that 72% of them can be ascribed to incorrect geophysical interpretation – mainly failure to recognize the effect of lateral resistivity changes on electrical depth probe curves (Enslin 1948) – 8% to incorrect geological interpretation and 17% to other causes including hydrological factors.

During the 1960s the Geological Survey decreased its borehole siting activities and concentrated on quantitative assessment of groundwater (Vegter 2000). Since that time the grounds for selecting sites regretfully have not been evaluated in terms of drilling results. This would have improved not only drilling success but also knowledge about groundwater occurrence and its variability within a particular area.

3.2 ALLUVIAL DEPOSITS

Water-bearing alluvial deposits are found along the Sand River and its tributaries, the Sterkloop, Sandsloot, Bloed, Diep, Hout and Brak Rivers. Except for drilling results along the Sand River immediately downstream of the Pietersburg sewage works (Orpen 1986) and on the Mara Agricultural Research Station (Orpen and Fayazi 1984) very little is known about the nature, thickness, extent and water-bearing properties of the alluvial deposits. The deposits are apparently exploited only in conjunction with underlying decomposed and fractured granite-gneiss and not on their own.

In twelve exploratory boreholes drilled downstream of the Pietersburg sewage works alluvial deposits vary in thickness between 4 and 16 metres. They are composed largely of clay and sand in varying proportions. Layers of sand, gravel and pebbles between 2 to 4 metres thick are found directly above weathered bedrock only where the alluvium is thicker than 6 metres. The situation is very similar along the Sand River on the Mara Agricultural Research Station. Here the sequence consists typically of red or sandy clay calcified in places and between 10 to 14 m thick, which overlies sand, gravel and pebbles 4 to 10 m thick. According to C. Haupt (verbally communicated) alluvial deposits up to 30 metres thick have been encountered along the Sand River upstream of Pietersburg.

3.3 HARD ROCK FORMATIONS

3. 3.1 Drilling results per National Groundwater Data Base

Tables 6, 7 and 8 are based on data of 4833 boreholes contained in the National Groundwater Database as of June 1998. Of 1945 holes lithology has been recorded.

TABLE 6 YIELD DISTRIBUTION IN THE REGION AS A WHOLE

Yield ℓs^{-1}	Number of holes	Percentage of holes
0 – 0.099 (failures)	940	48.3
0.1 – 0.99	410	21.1
1.0 – 4.99	464	23.9
5.0 – 9.99	88	4.5
≥ 10	43	2.2

TABLE 7 DRILLING SUCCESS RATE IN TERMS OF LITHOSTRATIGRAPHY

Lithostratigraphic Unit	Number of boreholes	Percentage successful boreholes (yield ≥ 0.1 ℓs^{-1})
Hout River Gneiss	780	60.3
Goudplaats Gneiss	893	53.1
Younger Granites	457	47.9
Pietersburg Group	134	57.5
Xenoliths	380	65.8

With the exception of xenoliths, lithostratigraphic classification is based on the geographic location of boreholes on geological maps – not on the examination of drill cuttings or on log descriptions. Lithological logs however were used to extract data about boreholes that were drilled in schist, amphibolite, quartzite, sandstone and shale. These have been grouped under the term "xenoliths".

TABLE 8 YIELD DISTRIBUTION OF SUCCESSFUL BOREHOLE ACCORDING TO LITHOSTRATIGRAPHY

Lithostratigraphic Unit	Number of successful boreholes (yielding ≥0.1 ℓs^{-1})	Percentage of successful boreholes yielding			
		0.1 - 0.99 ℓs^{-1}	1 - 4.99 ℓs^{-1}	5 - 9.99 ℓs^{-1}	≥ 10 ℓs^{-1} [1]
Hout River Gneiss	470	35.5	45.7	12.8	6.0
Goudplaats Gneiss	474	33.5	53.4	8.0	5.1
Younger Granites	219	58.9	35.2	3.7	2.3
Pietersburg Group	77	42.9	50.7	6.5	0.0
Xenoliths *	250	32.8	49.7	11.2	6.8

Holes in xenoliths are scattered throughout the Region. In the Bochum area a number of boreholes, which have been drilled in Bandelierkop Complex xenoliths struck supplies of 40 ℓs^{-1} and more in micaceous quartzite.

Conditions governing the occurrence of groundwater in the Region's hard-rock formations are broadly outlined in Figures 3 to 6. The analysis is based on a sample of 256 boreholes spread more or less uniformly over the Region regardless of lithostratigraphy.

FIGURE 3 RELATION BETWEEN WATER STRIKES AND GROUNDWATER LEVELS

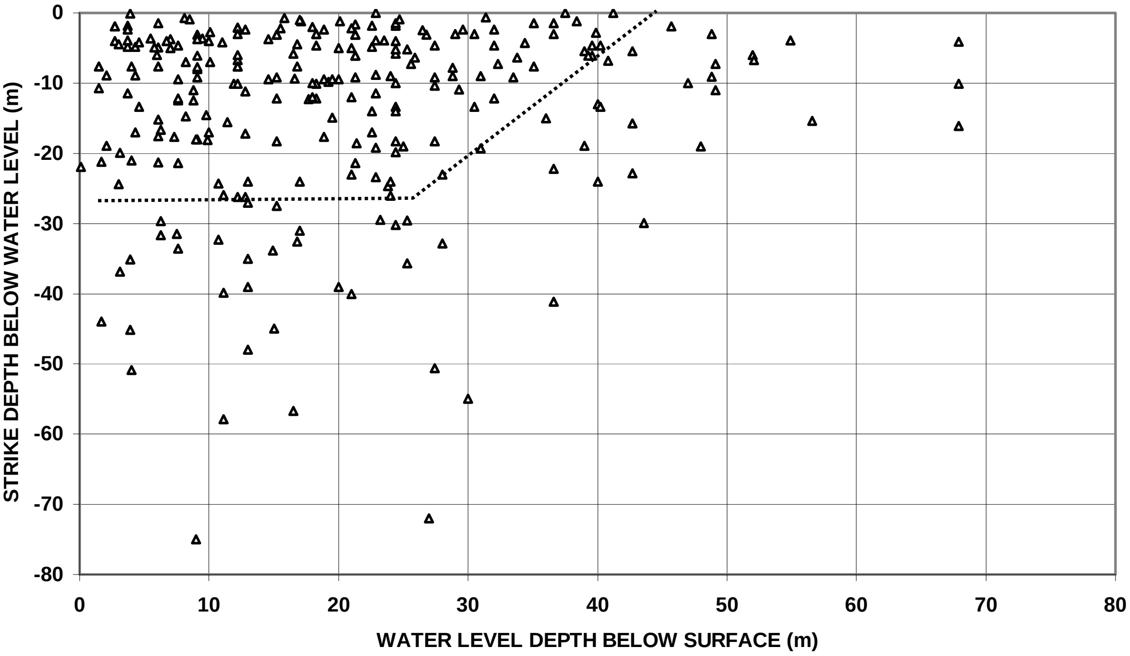


FIGURE 4 RELATIONSHIP BETWEEN WATER LEVEL AND DEPTH OF WEATHERING PLUS FRACTURING
(according to borehole logs))

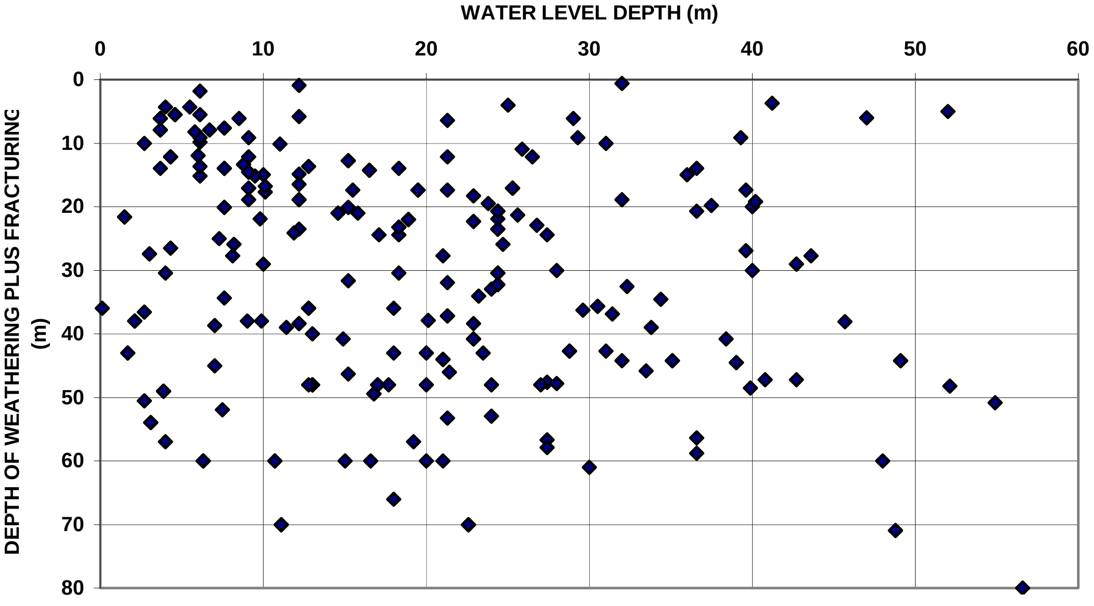


FIGURE 5 DEPTH DISTRIBUTIONS OF WEATHERING AND OF WEATHERING PLUS FRACTURING
(according to geological logs of boreholes)

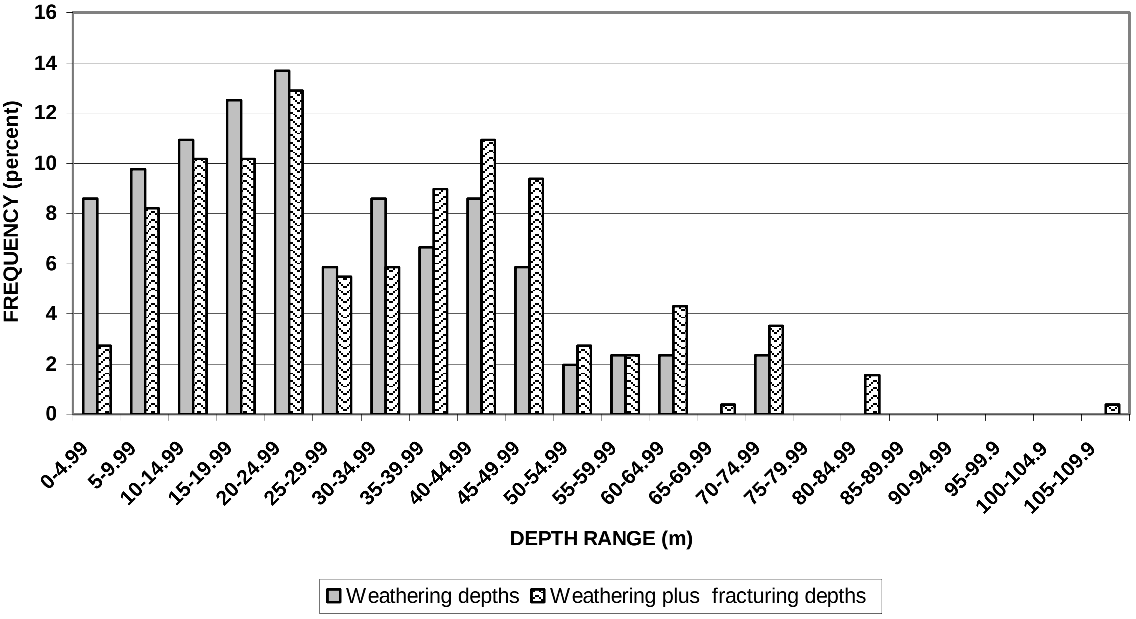
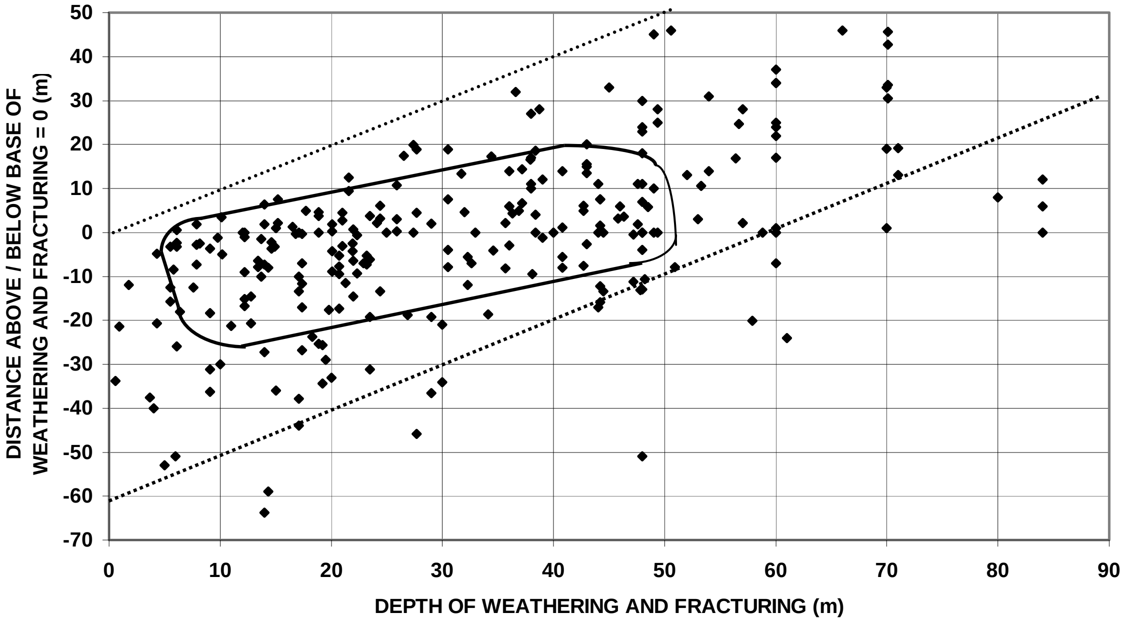


FIGURE 6 WATER STRIKES RELATIVE TO BASE OF WEATHERING AND FRACTURING
(REGION AS A WHOLE)



The following is evident:

- Approximately 93% of the water levels lie within the 0 to 40-metre depth range (Figure 3).
- Water was mainly struck within a 10-metre wide zone directly below the water level that ranges from 1 to about 35 m in depth. A fair number of strikes have also been made

down to about 27 m below groundwater levels that range from 1 to 25 below surface. About 78 % of the water strikes lie within the demarcated area of Figure 3.

- There is no correlation between water level and depth of weathering/fracturing (Figure 4).
- Weathering exceeds a depth of 50 metres in only 9% of the test sample of 256 boreholes. Weathering plus fracturing exceeds 50 metres in only 15% of the boreholes (Figure 5).
- Figure 6 is a plot of water strikes relative to the base of the weathered/fractured zone as deduced from drill cuttings:
  – Water strikes are virtually confined to a superficial zone 80 metres thick.
  – Ninety-four percent of the strikes lie within 60 m below the surface i.e. in a band that is demarcated by stippled lines, which cut obliquely across the base of the weathered/fractured zone.
  – Seventy percent of the strikes lie within the 30-metre thick oblong shaped zone between depths of weathering/fracturing of 5 to 60 metres.
  – Water is struck mainly within the weathered/fractured zone where its base exceeds a depth of 25 metres. Where the weathered/fractured zone is less than 25 metres thick, water is mostly struck below the base.
- The relationship between water strikes and the base of weathering and fracturing where the latter is deeper than the water level is shown in Table 9.

TABLE 9 BASE OF WEATHERING/FRACTURING AND WATER STRIKES

Depth range (m) relative to base of weathering/fracturing (minus = below ; plus = above	Number of boreholes passing through depth range	Number of strikes within depth range	Strike frequency (percent)
-29.9 to -25	24	1	4.2
-24.9 to -20	34	3	8.8
-19.9 to -15	50	3	6
-14.9 to -10	69	10	14.5
-9.9 to -5	87	14	16.1
-4.9 to 0	99	31	31.3
+0.1 to +5	114	41	36
+5.1 to +10	114	16	14
+10.1 to +15	115	13	11.3
+15.1 to +20	115	13	11.3
+20.1 to +25	115	5	4.4
+25.1 to +30	115	6	5.2
+30.1 to +35	115	1	0.9
+35.1 to +40	115	1	0.9
+40.1 to +45	115	1	0.9

The table is based on 115 boreholes. Depths range as follows:

Boreholes below surface	19.5 to 102 m
Water levels below surface	4.3 to 67.9 m
Strikes below surface	8.5 to 84 m
Strikes below water level	0.1 to 50.9 m
Weathering/fracturing below surface	4.3 to 84 m
Weathering/fracturing below water level	0.3 t0 53.7 m

The peak strike zone is within 5 metres above and below the base of weathering and fracturing as deduced from drill cuttings provided of course that the base lies below the water level. From 15 metres downwards the probability of striking water drops to about 1/5th of the peak value. The number of strikes above the base is limited by shallow depths of weathering/fracturing.

3.3.2 Statistical analysis of NGWDB borehole data in terms of lithostratigraphy

The results of statistical analyses of NGWDB borehole data are presented in figures 7 to 11.

Figure 7.

- Few boreholes have been drilled deeper than 110 m. In the Hout River Gneiss the peak depth range representing 75% of the boreholes is from 25 to 75 metres. The corresponding peak depth range in the Goudplaats Gneiss is 30 to 85 m and in the Younger Granites 30 to 80 m.
- In all three instances the depth distributions are not smooth. This is ascribed to the tendency of drilling to predetermined depths such as 50, 60, 75 or 90 metres rather than being guided by conditions encountered during drilling.

Figure 8

- Distributions of water levels differ in the three lithostratigraphic units Seventy-four percent of the water levels in the Younger Granites lie within the depth range of 0 to 25 metres. In the Hout River and Goudplaats Gneiss respectively 58 and 34% of the groundwater levels lie between 0 and 25 m.
- Seventy-six percent of water levels in Goudplaats Gneiss fall within the 15 to 55 metre range, whereas approximately 83% of the water levels in Hout River Gneiss occur in the range 0 to 40 metres.
- It follows from foregoing that groundwater levels generally are shallowest in the Younger Granites and deepest in the Goudplaats Gneiss

Figure 9

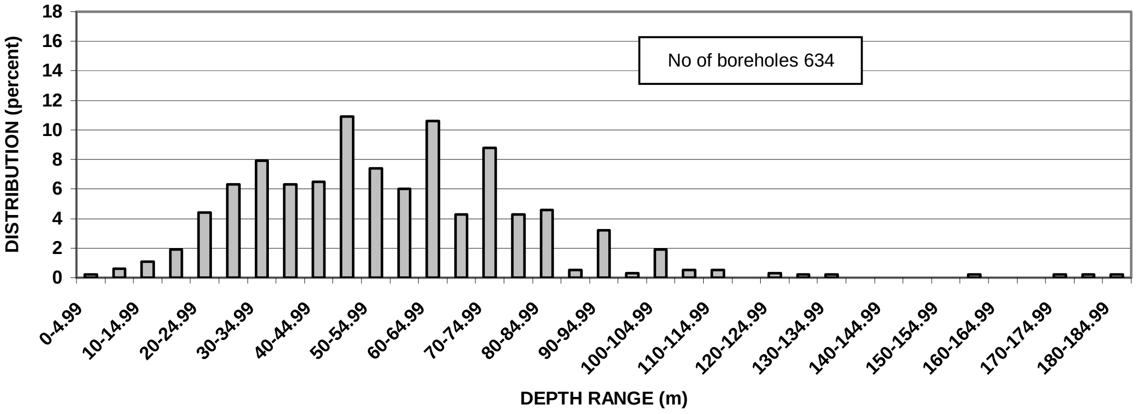
- Chances of striking water are greatest in the Hout River Gneiss, next best in the Goudplaats Gneiss and least in the Younger Granites. In Hout River Gneiss strike frequency per 5-metre depth interval averages 14% between 35 and 45 metres; in Goudplaats Gneiss 11% between 40 and 50 metres and 10% between 15 and 25 metres in the Younger Granites
- A mean strike frequency well in excess of 8% per 5-metre interval is maintained in Hout River Gneiss over the 15 - 75 m depth range. The corresponding depth range in Goudplaats Gneiss is 20 to 65 m and in the Younger Granites 10 to 40 m below surface.

Figure 10

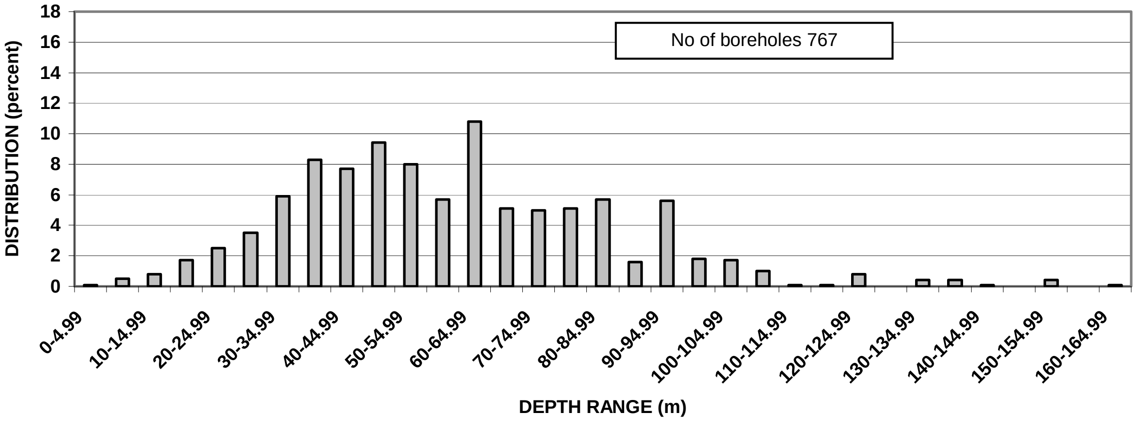
- Chances of striking water: per 5-metre depth interval below water level are greatest between 5 and 10 metres – 37.3% in Goudplaats Gneiss; 29.9% in the Younger Granites; and 25.9% in Hout River Gneiss.
- Strike frequency decays fastest with increasing depth below water level in the Younger Granites — it drops to less than 10% per 5-metre depth interval below 25 metres.
- In the Goudplaats Gneiss strike frequency is slightly less than 15% between 25 and 30 metres.
- In the Hout River Gneiss an average strike frequency of 17% per 5-metre depth interval is maintained to 40 m below water level.

FIGURE 7 DISTRIBUTION OF BOREHOLE DEPTHS

a) HOUT RIVER GNEISS



b) GOUDPLAATS GNEISS



c) YOUNGER GRANITES

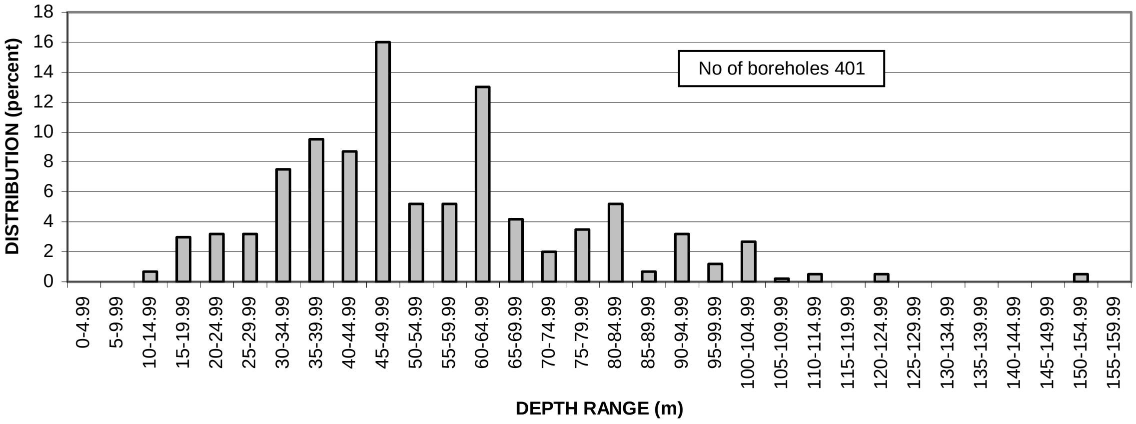
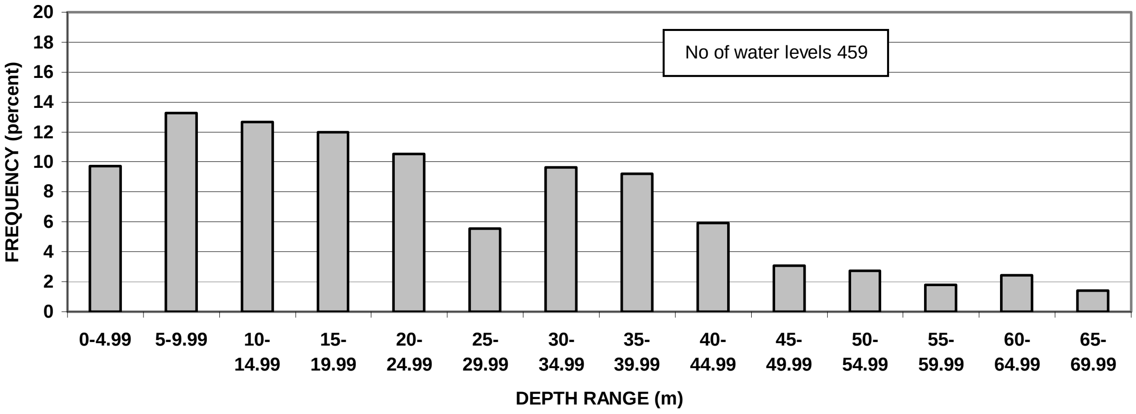
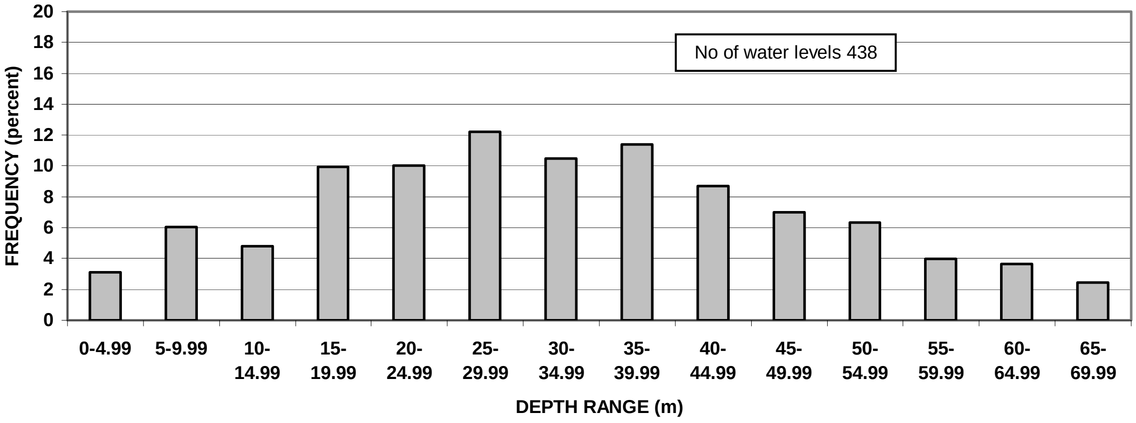


FIGURE 8 DISRIBUTION OF WATER LEVELS

a) HOUT RIVER GNEISS



b) GOUDPLAATS GNEISS



c) YOUNGER GRANITES

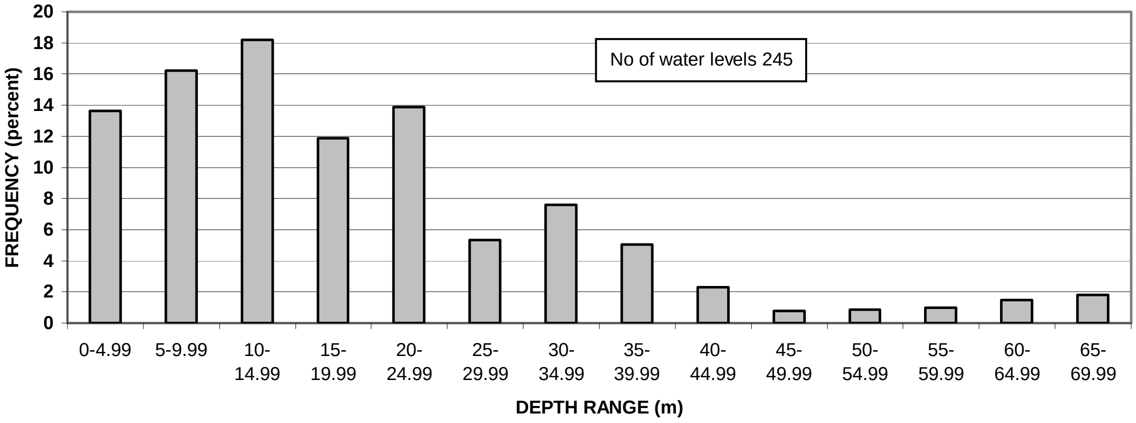
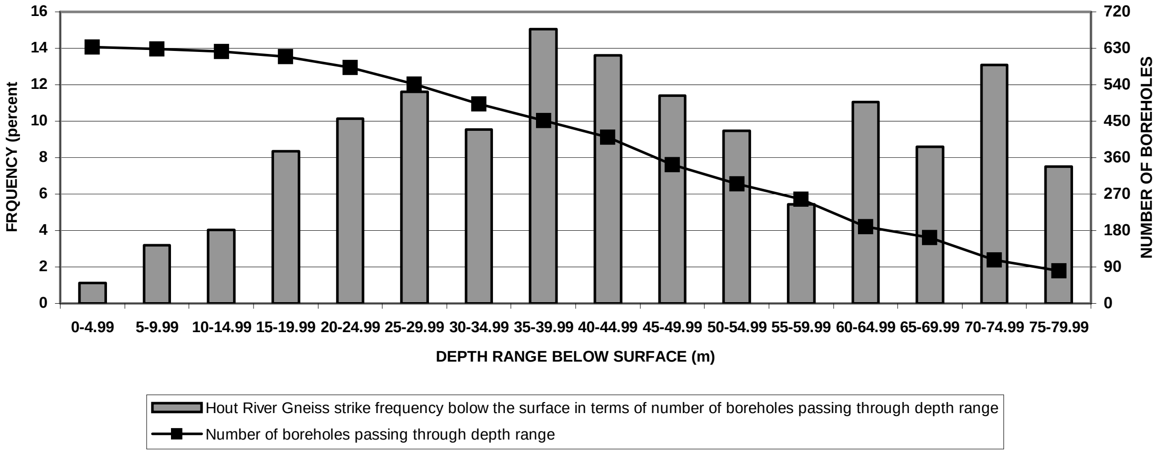
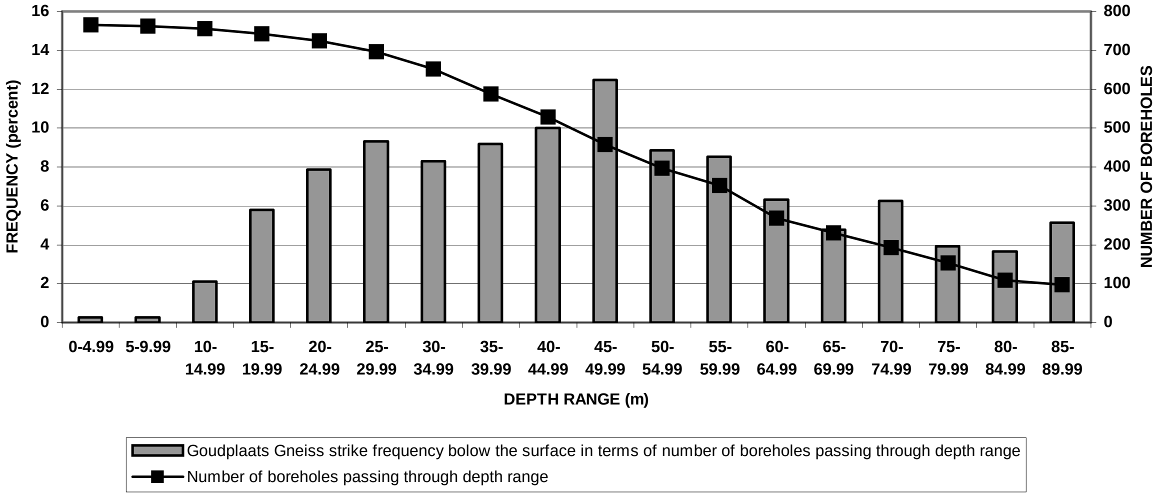


FIGURE 9 STRIKE FREQUENCIES BELOW SURFACE

a) IN HOUT RIVER GNEISS



b) IN GOUDPLAATS GNEISS



c) IN YOUNGER GRANITES

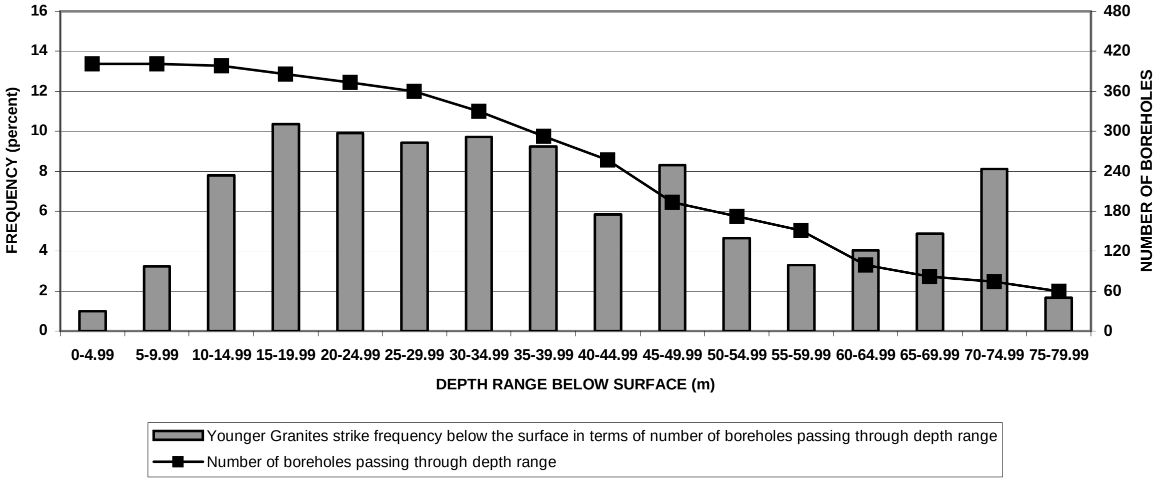
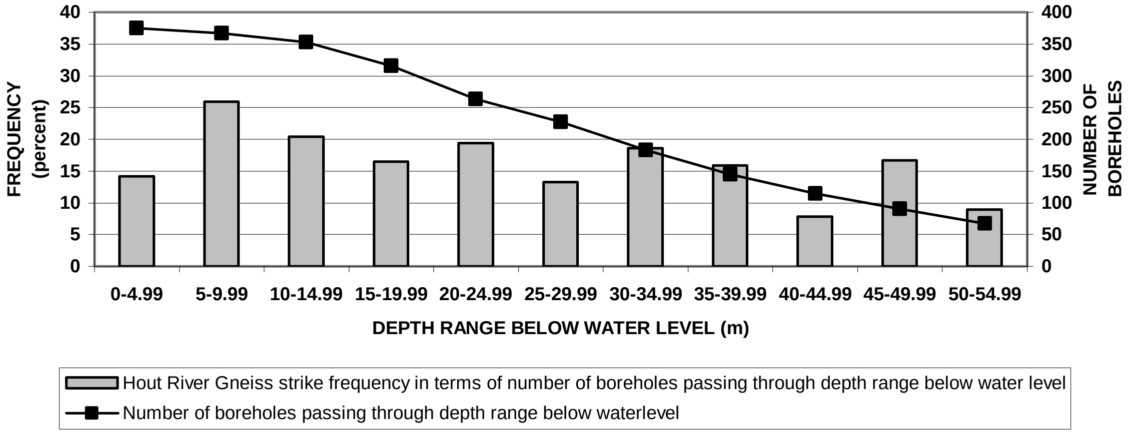
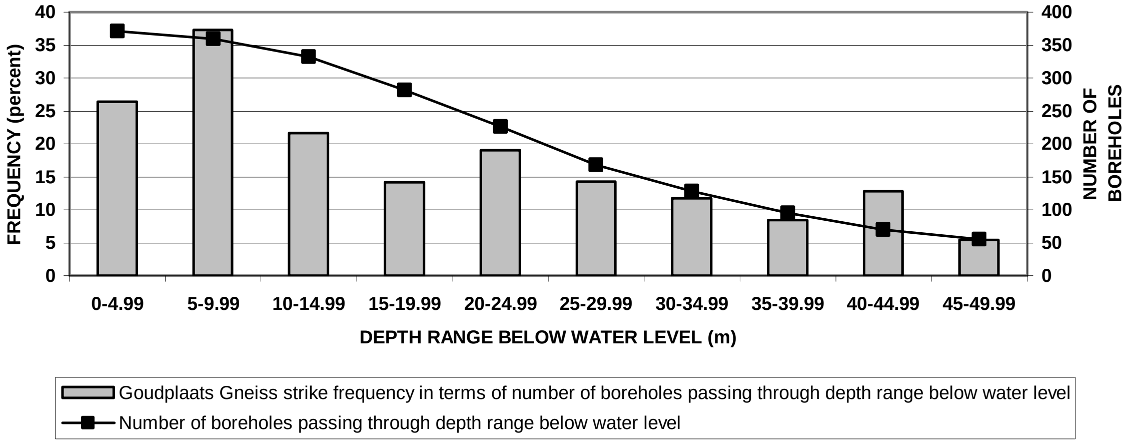


FIGURE 10 STRIKE FREQUENCY BELOW WATER LEVEL

a) HOUT RIVER GNEISS



b) GOUDPLAATS GNEISS



c) YOUNGER GRANITES

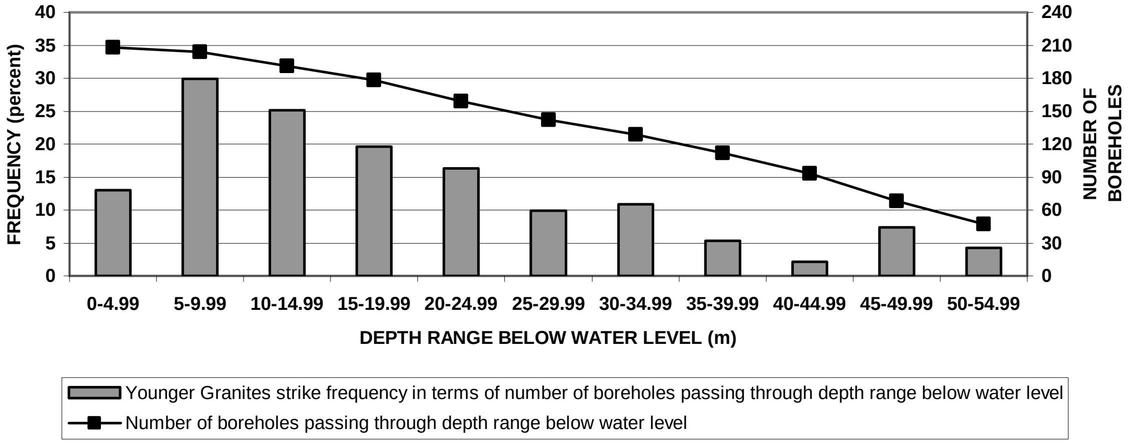
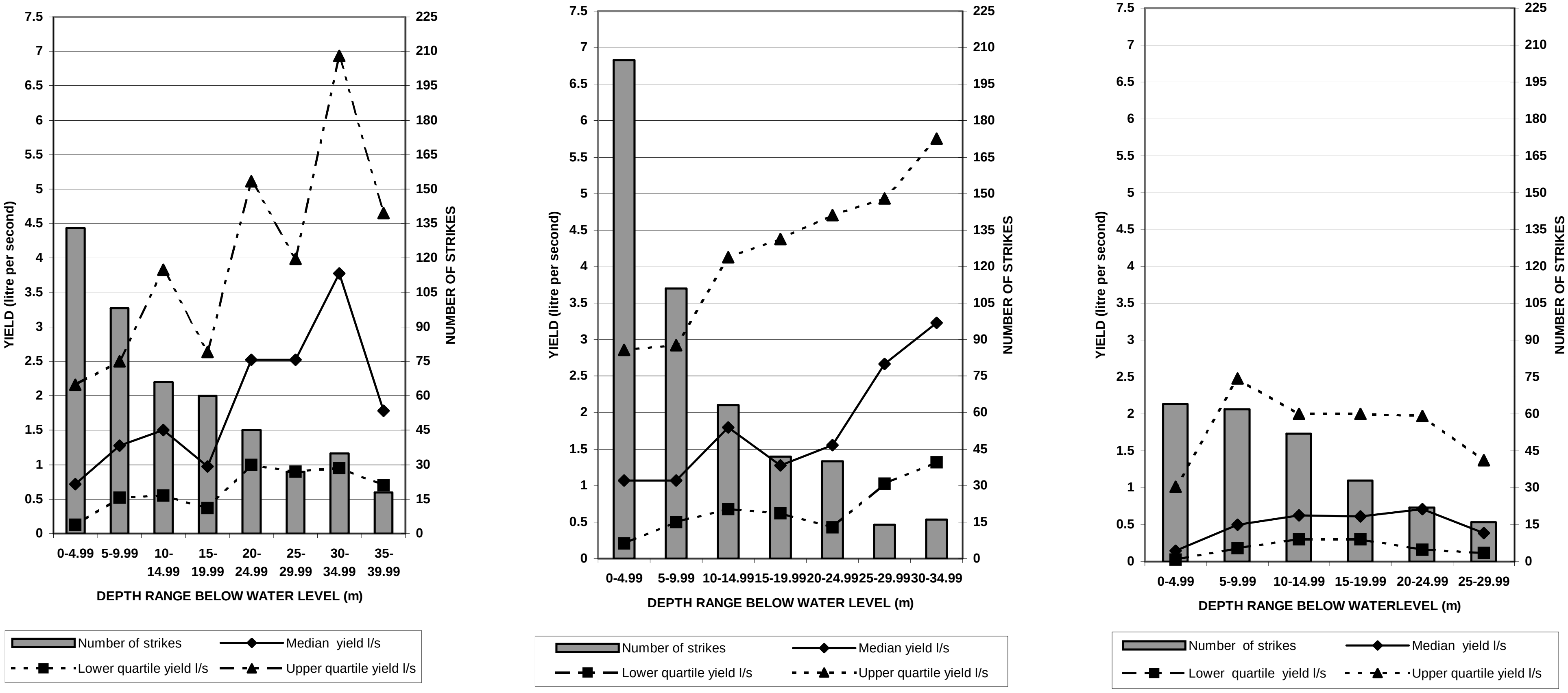


FIGURE 11 STRIKE - YIELD RELATIONSHIPS



a) HOUT RIVER GNEISS

b) GOUDPLAATS GNEISS

c) YOUNGER GRANITE INTRUSIVES

The lack of a pronounced strike peak directly below the water level in Hout River and Goudplaats Gneiss as found in the Younger Granites and in Region 19 (Vegter 2002) has to be ascribed to the existence of a considerable thickness of weathered rock below water level

Figure 11

- Contrary to findings elsewhere I.e. in Regions 1, 3 and 19 (Vegter 2000a and b, 2001) yield increases with strike depth below water level in both the Hout River and Goudplaats Gneisses. This is in marked contrast to that of the Younger Granites.

The reason for this state of affairs is likewise the existence of a considerable thickness of saturated weathered Hout River and Goudplaats Gneiss and the lack of it in the case of the Younger Granites, the Makoppa Dome, the Limpopo Granulite Gneiss Belt and the Lowveld crystalline rocks (Vegter 2002).

3.3.3 Role of dykes

Judging from geological mapping and aeromagnetic data it appears safe to assume that the bulk of the boreholes in which diabase or dolerite were reported, were drilled on or near dykes rather than in or near to other intrusive bodies. Although at least three different dyke sets are present on the Polokwane/Pietersburg Plateau (as noted in Chapter 2 Geology) it has not been possible to analyse data of each set separately as the strike of the diabase/dolerite contacts encountered in the NGWDB boreholes is unknown. Data of 1945 boreholes sunk prior to 1986 by the Department of Water Affairs and its predecessor were split into two categories – holes in which diabase or dolerite was reported and those without diabase or dolerite.

TABLE 10 DRILLING RESULTS IN THE PRESENCE AND ABSENCE OF DIABASE/DOLERITE INTRUSIONS

Yield $\ell\,s^{-1}$	Number (percentage) of borehole logs reporting		Percentage of boreholes yielding $\geq 0.1\,\ell\,s^{-1}$	
	diabase/dolerite	no diabase/dolerite	diabase/dolerite	no diabase/dolerite
0 - 0.099	281 (52.8)	659 (46.6)	-	-
0.1 - 0.99	118 (22.2)	292 (20.7)	49.0	38.7
1.0 - 4.99	109 (20.5)	355 (25.1)	45.2	47.1
5.0 - 9.99	19 (3.6)	69 (4.9)	3.7	9.2
≥ 10.0	5 (0.9)	38 (2.7)	2.1	5.0
Total	532 (100)	1413 (100)	100	100

The results of the two sets of data are compared in Table 10. The success ratio as well as the percentage higher-yielding boreholes is greater in the absence of diabase or dolerite intrusions. The reason for this difference may be ascribed to a tendency of siting boreholes where dyke rock is exposed i.e. where weathering is shallow.

Data of 90 boreholes drilled on and close to dykes were examined in more detail. Twenty-six holes started and remained in dykes. Of these eleven (42.3%) were successful. Their yields range from 0.13 to 36.7 $\ell\,s^{-1}$median 3. $\ell\,s^{-1}$. Of the 17 recorded strikes 15 were in the 7 to 40 m depth range. With two exceptions water levels are shallower than 30 metres. Sixteen of the remaining 64 boreholes started in dykes and exited from them; twenty boreholes started in country rock and entered dykes at different depths below the surface; 28 boreholes entered and exited or exited and entered dyke rock several times.

FIGURE 12 WATER STRIKES RELATIVE TO DIABASE OR DOLERITE CONTACT

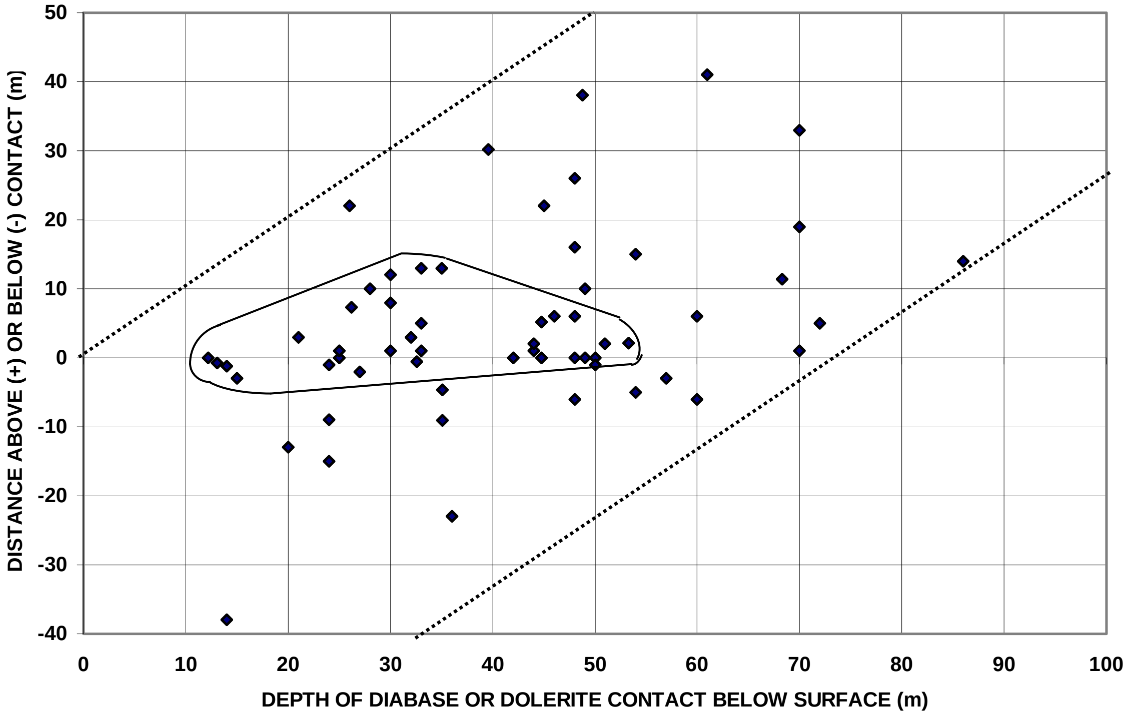
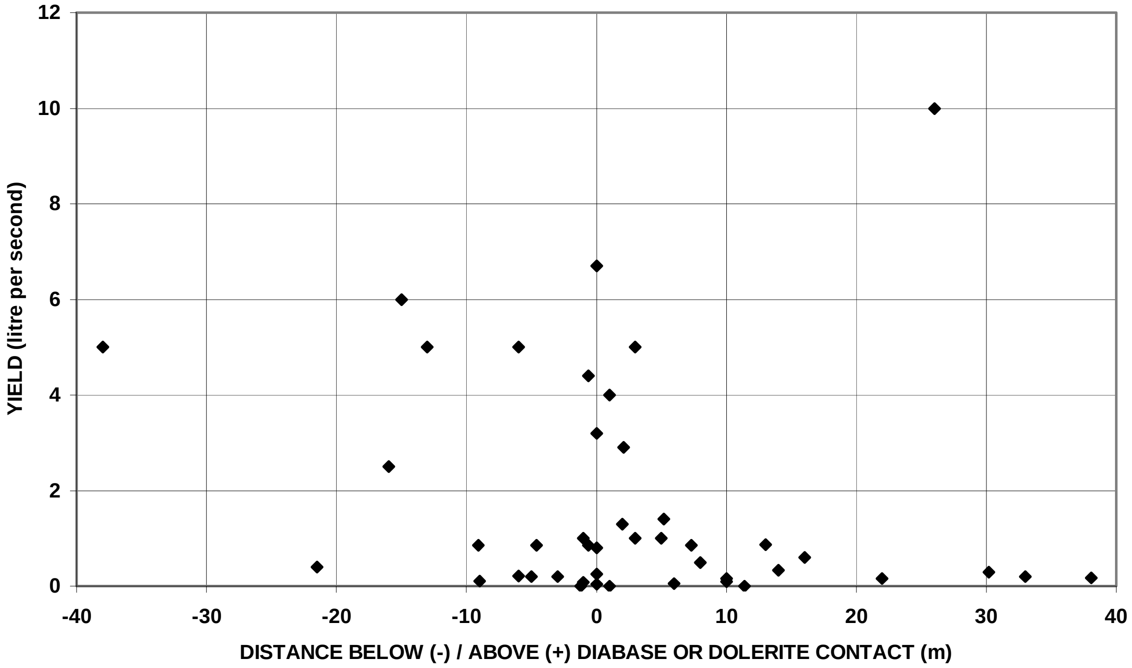


FIGURE13 YIELDS OF STRIKES RELATIVE TO DIABASE OR DOLERITE CONTACTS



In total 102 diabase and dolerite contacts were penetrated at depths varying from a few to 88 metres below surface – 78 times between 10 and 55 metres. In eleven instances only were useable supplies struck within1.5 metres from the contacts. The bulk of 51 successful strikes were recorded away from contacts.

The relation between recorded strikes and diabase or dolerite contacts is depicted in Figure 12, which is analogous to Figure 6. The strikes lie in a superficial zone 70 metres thick composed partly of weathered/fractured and partly of fresh rock. In the pseudo-section the zone is shown cutting obliquely across the diabase/dolerite contact. The majority of strikes are confined to the triangular area shown in the figure. The base of the triangle is parallel to and about 3 m below the contact between granite-gneiss and diabase/dolerite. Water strikes on or close to the contacts are practically confined to depths of 10 to 50 metres below the surface. According to Figure 13 blow yields struck on or near contacts do not differ from those struck further away.

These findings about dykes are in agreement with those of Region 19 (Vegter 2002) and are contrary to an apparently generally held opinion that dykes and their immediate vicinity are more favourable loci for siting boreholes than away from them. Boreholes should only be sited in dyke contact zones provided weathering/fracturing of the contact zone to below water level has been established geophysically or otherwise.

Dykes should not be regarded as separate hydrogeological entities different from the gneisses, granites and granitoids in which they occur. They should be viewed as part and parcel of a hard-rock entirety. The water-bearing characteristics of a particular dyke appear to be neither solely that of a barrier nor solely that of a conduit, but variable along strike just like the spatially variable hydrogeological character of the country rock.

3.3.4 Batholith project

3.3.4.1 Background

During 1997/8 155 exploratory boreholes were sunk by the Department of Water Affairs and Forestry in the aureoles of the Moletsi, Utrecht and Matlala granite batholiths. The purpose of the investigation which included geophysical surveying, test pumping of boreholes and hydrochemistry, was to determine whether the country rock was more intensely fractured in the aureoles and whether its water-bearing properties were enhanced by the intrusions (Du Toit 2000). In all three cases the country rock is Hout River Gneiss. Mafic rocks of the Rustenburg Suite have in turn invaded the Utrecht batholith.

Thirty-two exploration traverses totaling 62 km were laid out at the three batholiths. Along these lines the total magnetic field intensity was observed with the proton magnetometer, traverses were run with the portable two-coil Geonics EM-34 and Genie SE-188 electromagnetic systems and electrical resistivity depth probing was undertaken. Du Toit (2000) presented the drilling results of 135 boreholes along 15 of the traverses in the form of hydrogeological cross sections. The sections include the magnetic and electromagnetic profiles. According to Du Toit the contacts between country rock and granite that were penetrated by the drill were fresh and solid. High yields were struck in weathered and fractured roof remnants.

3.3.4.2 Some comments about the geophysical survey

Ground magnetics failed to distinguish between Hout River granite-gneiss and intrusive granites. Magnetic anomalies were observed over some diabase intrusions whereas others produced no anomaly. The magnetic field tended to fluctuate irregularly where traverses crossed outcrops and shallow weathering.

FIGURE 14 EM CONDUCTIVITY VERSUS BLOW YIELD
BATHOLITH PROJECT

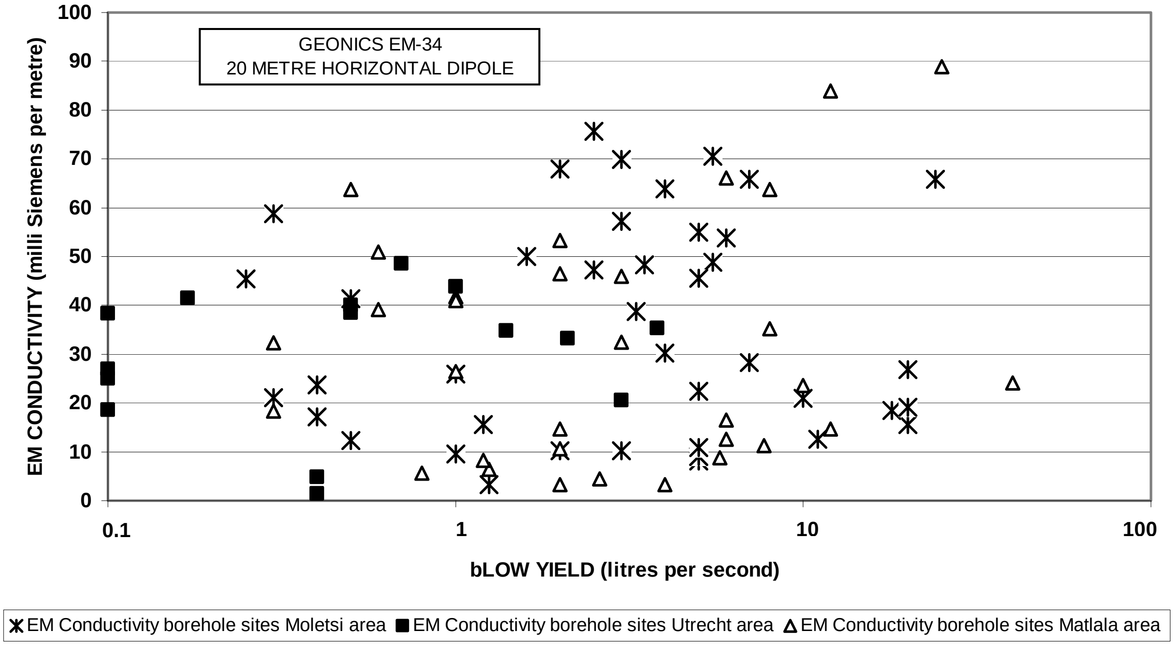
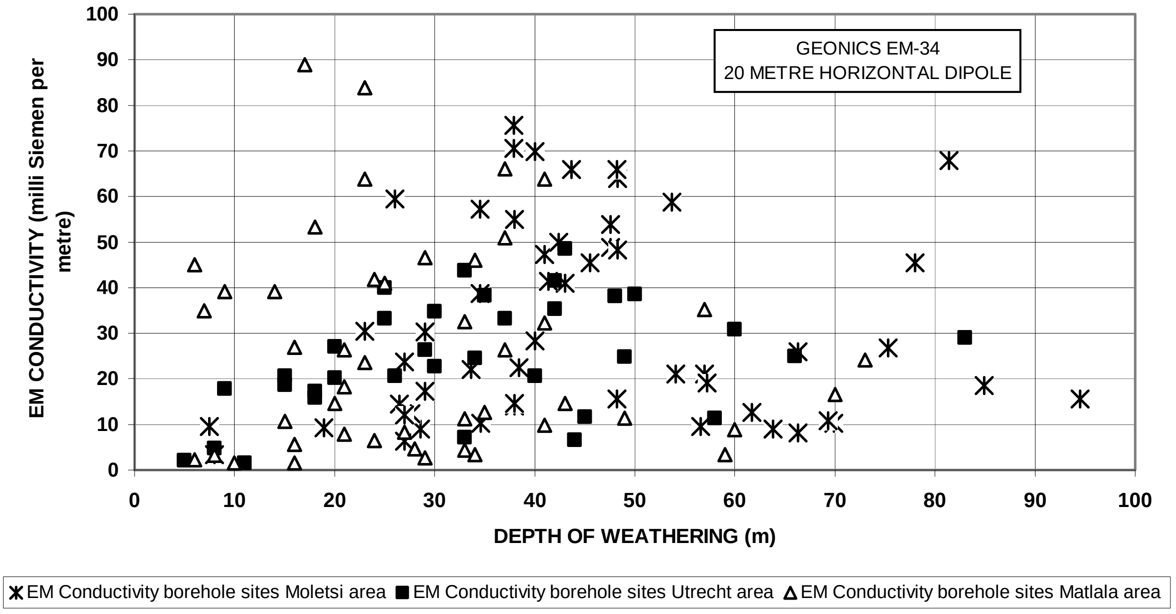


FIGURE15 EM CONDUCTIVITY VERSUS DEPTH OF WEATHERING / FRACTURING
BATHOLITH PROJECT



The role that the EM surveys played in directing the drilling operations is obscure. Apart from some introductory notes on the Geonics EM-34 and Genie SE-188 techniques, Du Toit (2001) neither presented an interpretation of the EM field data nor discussed the grounds on which each of the exploration boreholes had been sited. As may be expected EM conductivity as measured with the 20-metre horizontal dipole does not correlate with either blow yields of boreholes or depths of weathering plus fracturing – Figures 14 and 15. Owing to poor electrode contacts electrical resistivity depth probing was considered of little or no use. No attempt was made at joint interpretation of EM and depth probe data. Du Toit's post-mortem explanation of EM data in terms of borehole results is unconvincing and provides no guidelines for future work.

A large sum of money was spent on drilling 155 boreholes. It is therefore a great pity that :

- more effort was not expended on electrical resistivity depth probing
- drilling operations and geophysical borehole logging were not carried out in such a way that the form, dimensions and properties of the more conductive bodies responsible for the EM anomalies could have been determined.

The information so gained would have been of inestimable value in the application and interpretation of EM surveys not only in Region 7 but also elsewhere.

3.3.4.3 Structural environment

Six structural environments may be distinguished in which the 135 boreholes have been drilled on the 15 hydrogeological sections. Drilling results in terms of the classification are summarized Tables 11 and 12.

TABLE 11 DRILLING RESULTS IN TERMS OF STRUCTURAL FEATURES BATHOLITH PROJECT

Boreholes located	Number of boreholes	Number of boreholes yielding $\geq 0.1\ \ell s^{-1}$	% of boreholes yielding $\geq 0.1\ \ell s^{-1}$	Number of boreholes yielding $\geq 10\ \ell s^{-1}$	% of boreholes yielding $\geq 10\ \ell s^{-1}$
Within Moletsi, Utrecht and Matlala intrusions	45	28	62.2	3	6.7
Within Utrecht granite intruded by tongues of Rustenburg Suite mafic rocks	14	8	57.1	0	0
In Hout River Gneiss overlying Moletsi and Matlala granite	25	24	96	5	20
In Hout River Gneiss within 200 m from dipping contacts of Moletsi, Utrecht and Matlala granite	20	11	55	0	0
In Hout River Gneiss away from granite intrusions	29	17	58.6	4	13.8
In Mapela Gabbro-norite (west of Utrecht intrusion)	2	0	0	0	0

Boreholes, which apart from granite and granite-gneiss also penetrated Bushveld Complex rocks, were excluded from Table 11. Depths of weathering and fracturing are deepest where Hout River gneiss overlies Moletsi and Matlala granite. This appears to be the reason for the high success rate and greater percentage of high yielding boreholes. Whether these occurrences of Hout River Gneiss are remnants of the batholiths' roofs, as stated by Du Toit, can not be established from the geological sections. The occurrences appear to be associated with granite offshoots or apophyses rather than with the main intrusive bodies.

TABLE 12 DEPTHS OF WEATHERING AND FRACTURING BATHOLITH PROJECT

Boreholes located in	Depth of weathering and fracturing				
	Range (m)	Average (m)	Median (m)	25% quartile (m)	75% quartile (m)
Moletsi, Utrecht and Matlala granite	5 to 81	30	27	18	30
Hout River Gneiss overlying Moletsi and, Matlala granite)	13 to 85	45	41	23	57
Dipping contact zone between Moletsi, Utrecht and Matlala granite and Hout River Gneiss	21 to 70	44	38	29	57
Hout river Gneiss away from granite intrusions	6 to 96	36	33	26	43

Diabase in the form of dykes and irregular bodies was encountered in 33 of the 55 boreholes shown on the Moletsi sections, in 3 of the 34 holes on the Utrecht sections and in 4 of the 46 holes on the Matlala sections. Weathered diabase contacts were penetrated in 31 instances. In 14 cases water was struck on or near contacts or within the diabase intrusion. Fresh diabase contacts were penetrated 75 times. Water was struck on or near the contacts in only three instances. These data clearly demonstrate that intrusive contacts *per se* are not potential aquifers. Weathering/fracturing of contact zones below water level is essential if they are to act as aquifers. Surficial indications are not necessarily indicative of weathering/fracturing at depth.

3.3.4.4. Statistical analysis of borehole data

Further analysis in terms of each of the structural environments can not be undertaken because of the small number of boreholes involved. The batholiths and their aureoles thus have been treated as a unit.

Pseudo-section: Strikes below groundwater level – Figure 16

Nearly two-thirds of all the strikes fall within a 0 - 40 m zone below water levels which range from 3 to 23 metres compared to 64% of Figure 5. In contrast with the NGWDB analysis – Figure 3 – a distinction has been made between water strikes above and below the base of weathering/fracturing as deduced from drill cuttings. Of the strikes above the base of weathering and fracturing 94 percent lie within 60 m below surface. On the contrary as may be expected, about 60 percent of the strikes below the base of weathering/ fracturing are deeper than 60 m.

Groundwater levels and depths of weathering plus fracturing – Figure 17

There is no correlation between depth of weathering/fracturing and water level.

Distribution of depths of weathering plus fracturing – Figure 18

Weathering and fracturing as deduced from drill cuttings exceed 50 m in only 19% of the boreholes compared to the 15% in the case of the NGWDB boreholes (Figure 5). Seventy-two percent of the weathering/fracturing depths lie in the 15 to 50 m range compared to 64 % of Figure 5.

FIGURE 16 STRIKE DEPTHS BELOW WATER LEVEL BATHOLITH PROJECT

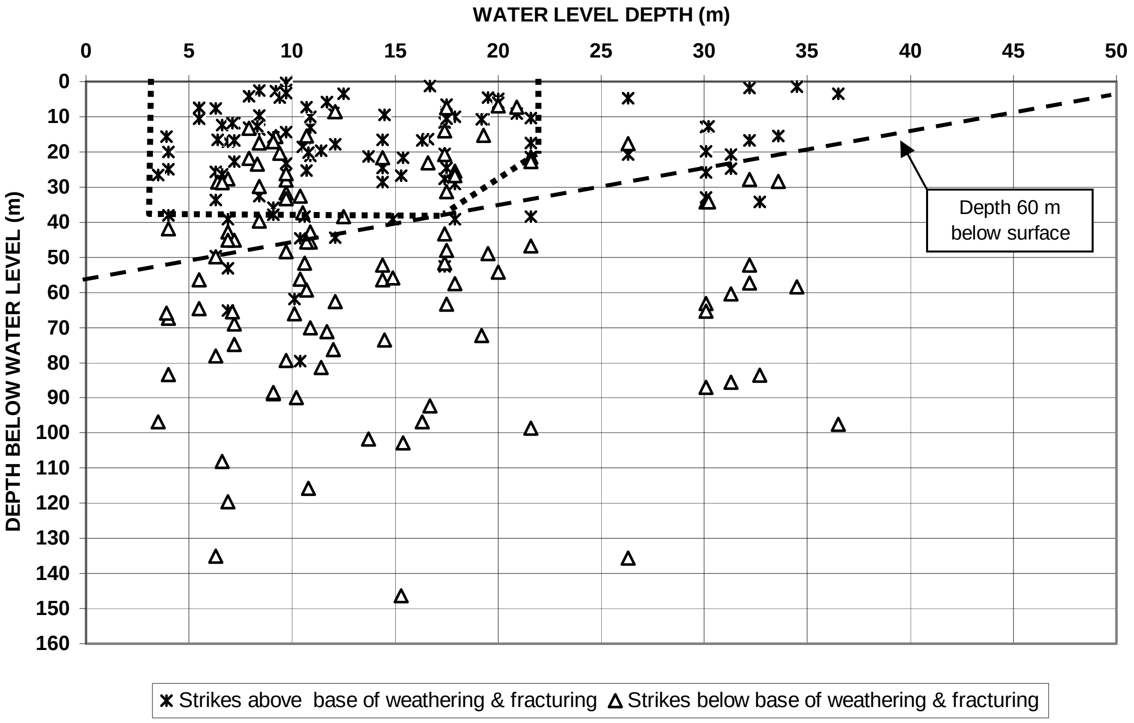


FIGURE 17 RELATIONSHIP BETWEEN GROUNDWATER LEVEL AND DEPTH OF WEATHERING / FRACTURING BATHOLITH PROJECT

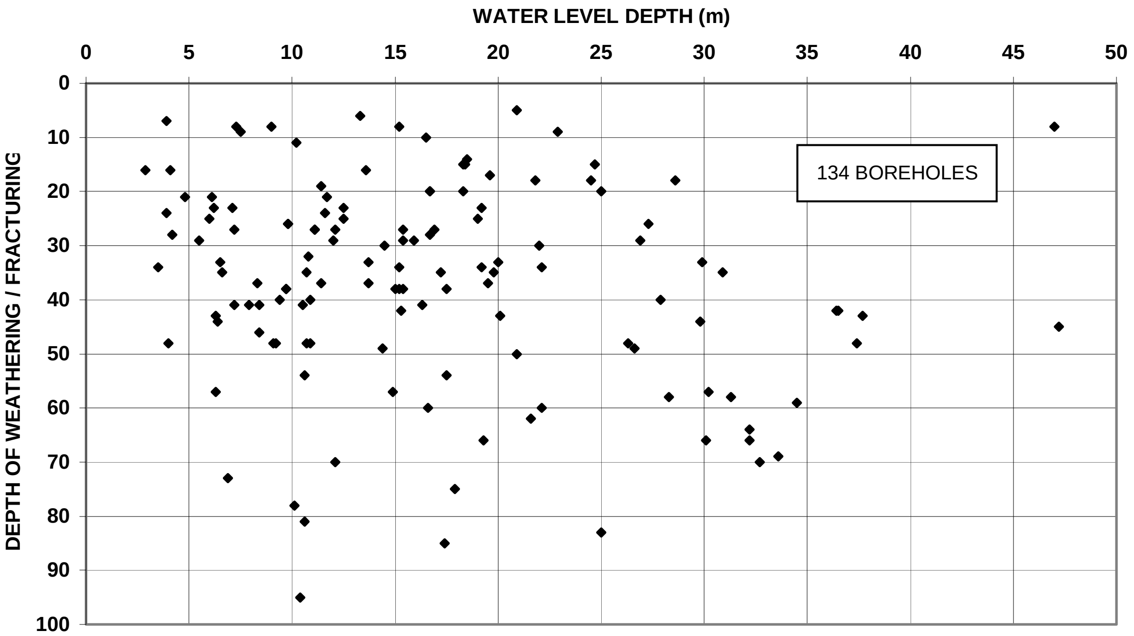


FIGURE 18 DISTRIBUTION OF DEPTHS OF WEATHERING PLUS FRACTURING BATHOLITH PROJECT

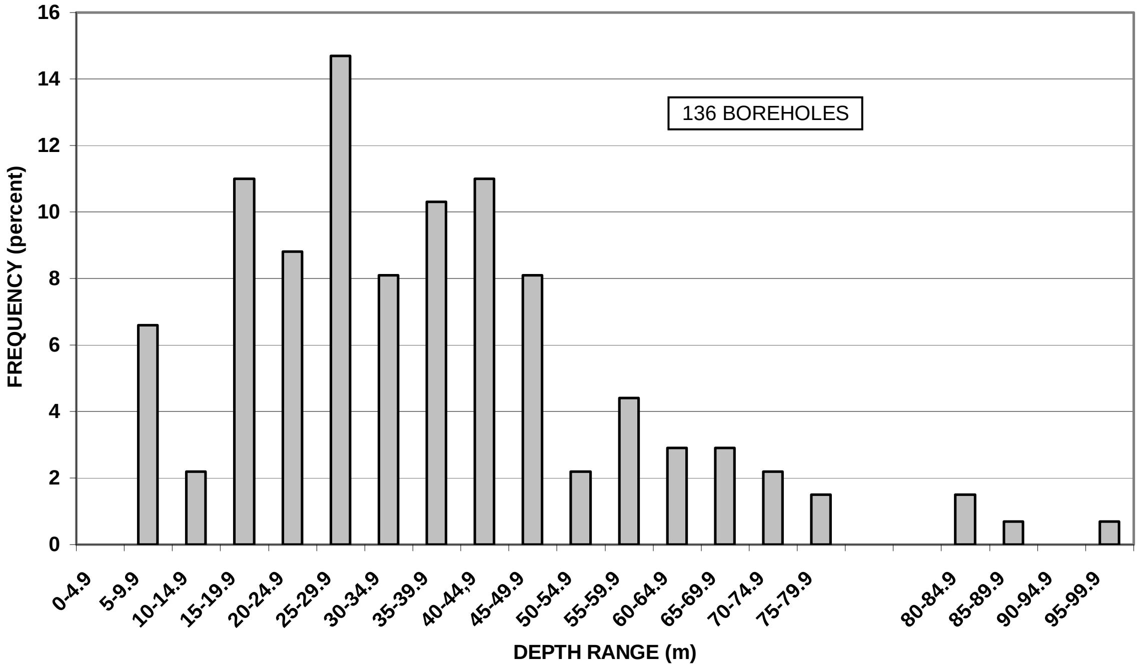
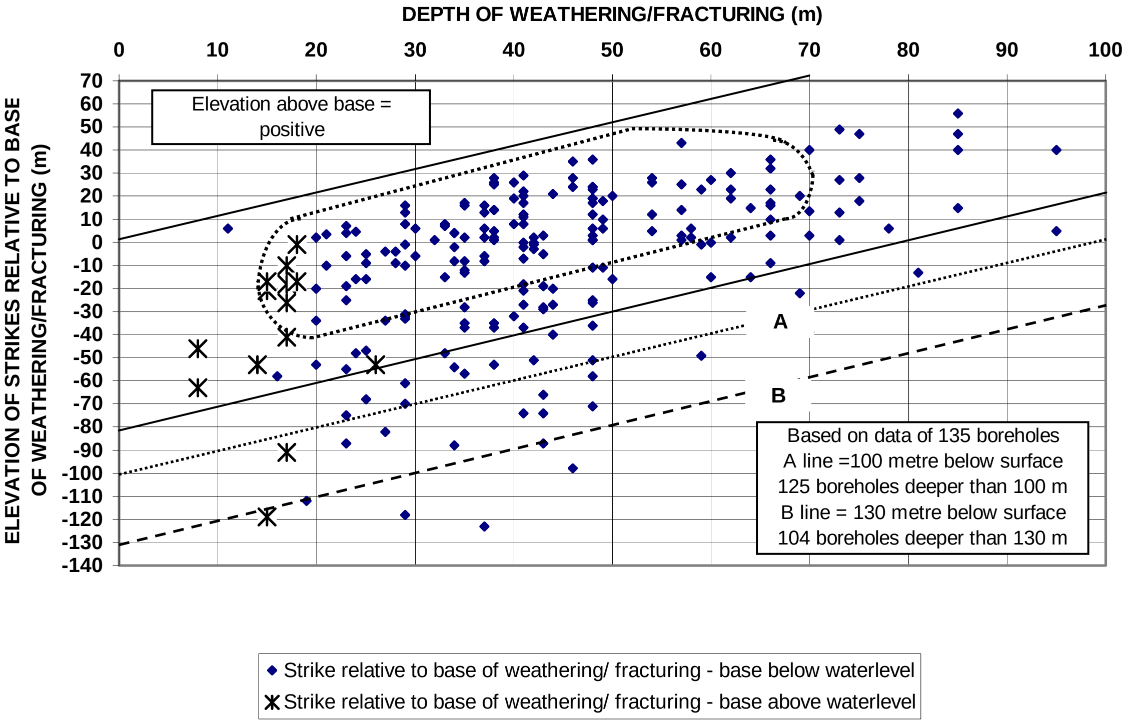


FIGURE 19 RELATION BETWEEN WATER STRIKES AND BASE OF WEATHERING AND FRACTURING BATHOLITH PROJECT



Pseudo-section: Strikes in relation to base of weathering/fracturing – Figure 19

The 208 water strikes that were recorded in 135 boreholes are distributed relative to the base of weathering/fracturing as follows (base of weathering/fracturing as deduced from drill cuttings):

137 strikes (65.4%) between 30 m above and 20 m below base
150 strikes (71.6%) between 60 m above and 20 m below base
164 strikes (78.2%) between 30 m above and 40 m below base
177 strikes (84 4%) between 60 m above and 40 m below base

In pseudo-section the relationship between water strikes and base of weathering/fracturing resembles Figure 6. Eighty-four percent of the water strikes are confined to a 70 metre band (10 to 80 metres below surface) that cuts obliquely across the weathering/fracturing baseline of Figure 19. Note that most of the boreholes were drilled considerably deeper – 111 of the 135 boreholes exceeded a depth of 120 metres. Sixty-five percent of the strikes are concentrated in a lenticular zone between depths of weathering/fracturing of 15 to 70 m. The zone is about 50 m thick. Where the base of the weathered/fractured zone is more than 40 metres deep water is mainly struck shallower. Where the weathered/fractured zone is less than 40 metres thick, water is mostly struck below the base.

Blow yields and depth of weathering/fracturing

The relation between blow yields and depths of weathering/fracturing is expressed in Tables 13 and 14.

TABLE 13 BOREHOLE YIELDS VERSUS DEPTHS OF WEATHERING/FRACTURING BELOW SURFACE BATHOLITH PROJECT

Depth range of weathering/fracturing below surface (m)	Number of boreholes	Number of boreholes with blow yields ≥ 0.1 l s^{-1}	Percentage boreholes with blow yields ≥ 0.1 ℓ s^{-1}	Range of blow yields ℓ s^{-1}	Median blow yield ℓ s^{-1}
5 - 14.9	12	4	33.3	0 - 1.3	0
15 - 24.9	24	13	54.2	0 - 2.5	0.2
25 - 34.9	27	15	55.6	0 - 5	0
35 - 44.9	29	25	86.2	0 - 24	2.5
45 - 54.9	14	11	78.6	0 - 10	3.7
55 - 64.9	9	8	88.9	0 - 11	3.5
65 - 74.9	7	7	100	0.1 - 40	5
75 - 84.9	3	3	100	0 - 20	-
85 - 94.9	2	2	100	18 - 20	-

It is evident that:

- A 50% probability of success i.e. of striking a blow yield of at least 0.1 ℓ s^{-1} requires a minimum depth of weathering/fracturing of 15 m. The water level should not be deeper than the base of weathering/fracturing.
- Where the depth of weathering/fracturing extends to between 35 to 95 metres below surface 87.5 % of the boreholes proved successful
- Where the depth of weathering/fracturing extends to between 25 to 85 metres below the waterlevel 91.3 % of the boreholes proved successful.
- The deeper the weathering/fracturing below surface and below groundwater level the greater the likelihood of bigger blow yields.

This result is corroborated by counting the number of strikes above and below base of weathering/fracturing per blow yield category.

TABLE 14 BOREHOLE YIELDS VERSUS DEPTH OF WEATHERING/FRACTURING BELOW WATER LEVELBATHOLITH PROJECT

Difference (m) between depth of weathering/fracturing and water level*	Number of boreholes	Number of boreholes with blow yields $\geq 0.1\ \ell s^{-1}$	Percentage boreholes with blow yields $\geq 0.1\ \ell s^{-1}$	Range of yields ℓs^{-1}	Median Yield ℓs^{-1}
-15 to -5.1*	6	2	33.3	0 - 1.3	0
-5 to 4.9	19	9	47.4	0 - 2.5	0
5 to 14.9	24	14	58.3	0 - 10	0.3
15 to 24.9	31	20	64.5	0 - 20	1.4
25 to 34.9	20	19	95	0 - 7.7	1.2
35 to 44.9	17	15	88.2	0 - 24	5
45 to64.9	4	4	100	0 - 20	8
65 to 84.9	5	4	80	0 - 40	20

* Negative values: Water level deeper than base of weathering/fracturing

Holes with blow yields between

0 and 0.99 ℓs^{-1}	Of the 40 recorded strikes only 14 (35%) were made above the base of weathering/fracturing
1.0 and 4.99 ℓs^{-1}	Of the 70 recorded strikes 34 (48.6%) were made above the base of weathering/fracturing
> 4.99 ℓs^{-1}	Of the 98 recorded strikes 59 (60.2%) were made above the base of weathering/fracturing

This finding is contrary to that reported for the Beauty-Swartwater area (Vegter 2000c): The probability of striking water there is greatest where the depths of weathering and piezometric level do not exceed 40 metres.

Distribution of water levels and of strikes – Figures 20, 21 and 22

FIGURE 20 DISTRIBUTION OF WATER LEVELS
BATHOLITH PROJECT

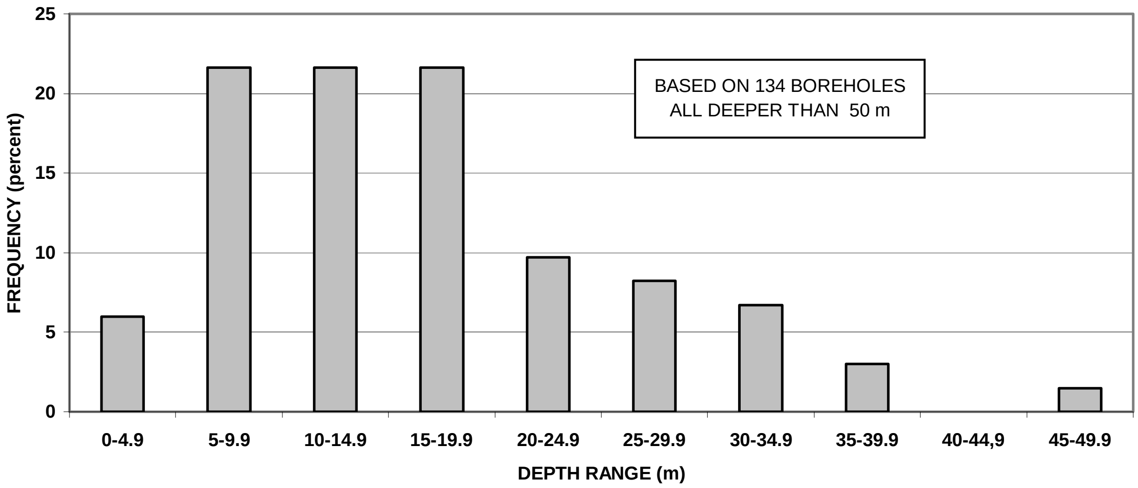


FIGURE 21 STRIKE FREQUENCY BELOW SURFACE BATHOLITH PROJECT

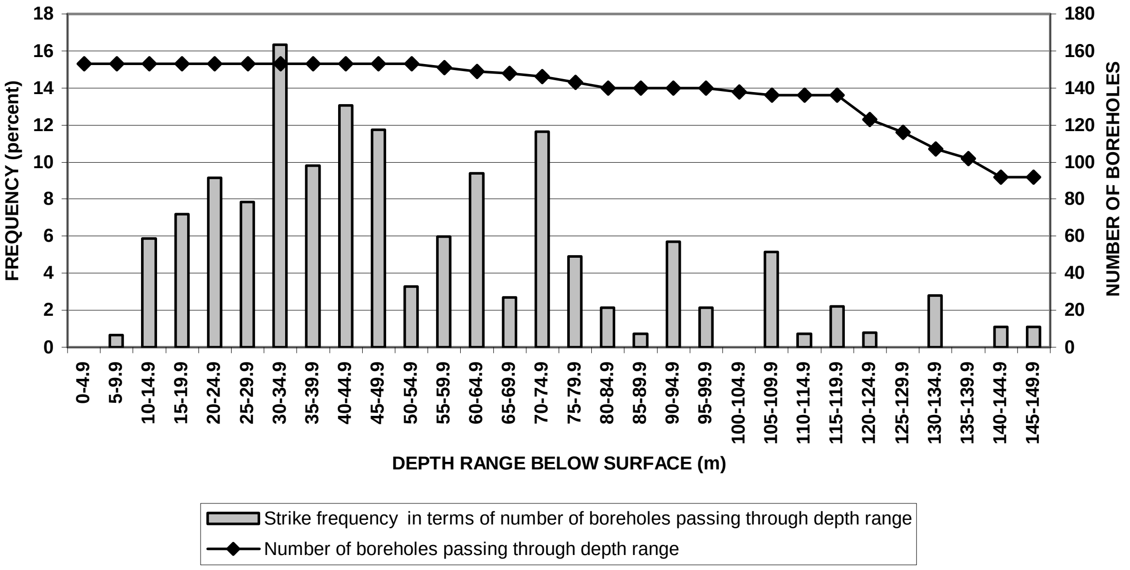
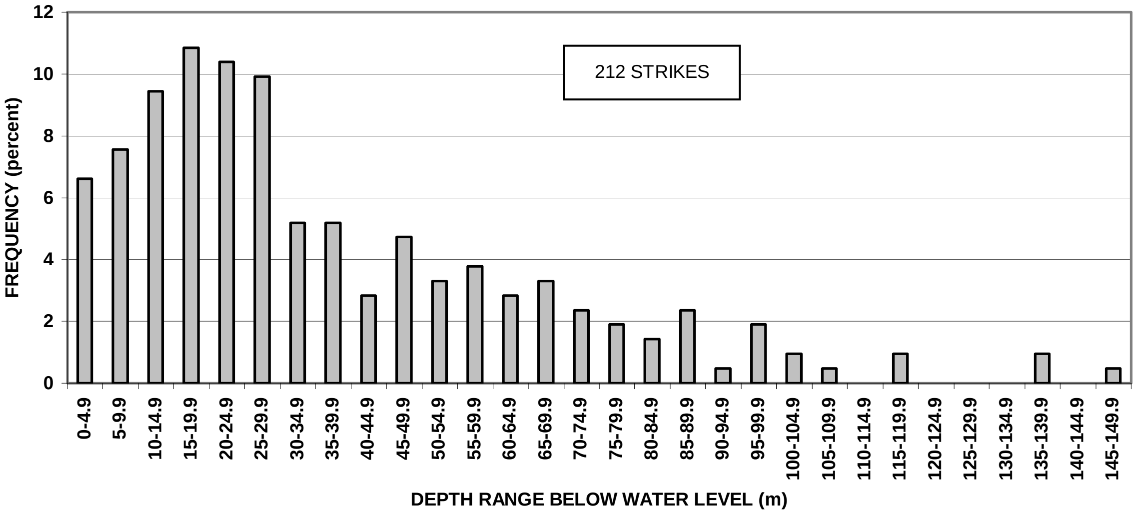


FIGURE 22 STRIKE FREQUENCY BELOW WATER LEVEL BATHOLITH PROJECT



The salient features of the batholith groundwater levels and strike depths below surface and water level are compared in Table 14 and 15 to those depicted in Figures 8, 9 and 10.

Except for a certain degree of variability, groundwater occurrence in and around the batholiths is basically similar to that elsewhere in Region 7.The principal differences are:

- Water levels are concentrated in a shallower and narrower band.
- Strike frequency peaks 5-10 m deeper below the water level.
- With the exception of the Younger Granites, the bandwidth of strike frequencies greater than 10% is shallower and narrower (i.e. strike frequency per 5 metre interval below water level).

TABLE 15 COMPARISON OF STATISTICAL DATA ON WATER LEVELS AND STRIKES BELOW THE SURFACE

Formation	Water level distribution		Strike frequency below surface	
	Peak concentration – % of water levels Apposite (depth interval)	% water levels shallower than specified (depth)	Peak strike % per 5-m depth interval apposite (depth range)	Depth range pertinent to strike frequencies of ≥ 8 % per 5-m depth interval
Batholith aureoles	64.9 (5-20 m)	88.8 (30 m)	16.3 (30-35 m)	20-50 m
Hout River Gneiss	58.2 (0-25 m)	91.6 (50m)	15 (35-40 m)	15-75 m
Goudplaats Gneiss	54 (15-40 m)	90 (55 m)	12.5 (45-50 m)	20-60 m
Younger Granites	73.8 (0-25 m)	91.8 (40 m)	10.4 (15-20 m)	15-40 m

TABLE 16 COMPARISON OF STATISTICAL DATA ON STRIKES BELOW WATER LEVEL

Formation	Strike frequency below water level	
	Peak strike % Per 5-m interval apposite (depth range)	Depth range pertinent to strike frequencies of ≥ 10 % per 5-m interval
Batholith aureoles	16.3 (15 -20 m)	0 - 30 m
Hout River Gneiss	25.9 (5 - 10 m)	0 - 50 m
Goudplaats Gneiss	37.3 (5 - 10 m)	0 - 35 m
Younger Granites	29.9 (5 - 10 m)	0 - 25 m

Except for a certain degree of variability, groundwater occurrence in and around the batholiths is basically similar to that elsewhere in Region 7.

3.3.5 Spatial distribution of borehole prospects

The Polokwane/Pietersburg Plateau is one of the more propitious parts of the country for drilling high yielding boreholes. The spatial distribution of Borehole Prospects is shown on Sheet 1 of the map set "Groundwater Resources of the Republic of South Africa" (Water Research Commission 1995). The most favourable conditions are found in the catchments of the Hout and Brak Rivers. Least favourable are the areas underlain by younger granitic intrusions notably between the Pietersburg greenstone belt and the Strydpoort Mountains i.e. in the catchments of the Nkumpi, Chunies, Hakaro and Tlhabasane Rivers. Intermediate conditions occur in the catchments of the Seepabane, Matlala and smaller streams, which are part of Drainage Region A6 Mogalakwena.

3.3.6 Summary

In the hard rock formations of the Polokwane/Pietersburg Plateau the majority of groundwater strikes have been made within 80 metres from the surface. Within this band strikes are concentrated around the transition from weathered and fractured to fresh rock. Where the base of weathering/fracturing as deduced from drill cuttings is less than 25 to 40 metres deep, water is largely struck within the first 20 metres below the base. Where its depth exceeds 25 to 40 metres water is struck mostly above the base.

Boreholes should ideally be sited where weathering/fracturing extends to below the groundwater level.

Weathering and fracturing on the Pietersburg Plateau generally extend to between 15 and 50 metres below surface. It exceeded 50 m in 1 out of 6 boreholes.

Less than 10% of the NGWDB boreholes have groundwater levels exceeding 50 metres. Water levels generally lie between 0 and 25 metres below surface except that they tend to be deeper in the Goudplaats Gneiss.

The majority of water strikes are made within 40 m below groundwater level.

In the Hout River and Goudplaats Gneisses and in the batholith aureoles water is struck mostly between 30 and 50 metres below surface. The probability of striking water down to 75 metres below surface is best in the Hout River Gneiss. In the Younger Granites, which appear to be least weathered and fractured, the peak strike range is 15 to 20 metres below surface.

Dykes and their contact zones feature as drilling targets only if weathered and fractured to below groundwater level.

The most prolific aquifers are found in weathered and fractured xenoliths and Hout River Gneiss. The Younger Granites are the least favourable.

The thickness of weathered and fractured rock at any point is dependent on the mineralogical composition and texture of the rock i.e. on its weatherabilty and on the extent of jointing/faulting.

The presence of a substantial thickness of weathered and fractured rock underfoot may be evident from a lack of rock exposures, vegetation and other surface indications. In looking for areas or zones of weathered/fractured rock, satellite, aerial and aeromagnetic images may assist by elucidating structure.

However as the vertical extent of weathering/fracturing can not be deduced from these observations, recourse has to be taken to geophysical exploration.

The geophysical method mostly employed is that of electrical resistivity depth probing whilst dykes that are not exposed, may be traced magnetically. The weathered and therefore conductive upper part of narrow steeply dipping fracture zones may be located by frequency-domain electromagnetic surveying.

During the course of the Batholith project no attempt was made to determine the nature, form and depth of the conductive bodies responsible for the EM anomalies on which boreholes were sunk. There is accordingly little difference between the manner in which the EM method has been employed and a shot in the dark.

It is necessary to recognize that EM anomalies are produced largely, if not solely by the upper weathered extremity of fracture zones and not by deeper-lying water-bearing fractures.

To determine the reason for an EM anomaly and thus obtain optimal drilling results, a procedure needs to be followed whereby:

- EM and magnetic traversing are combined with electrical depth probing.

- Drilling operations, which essentially have to be of an exploratory nature, are guided by concomitant geological and geophysical logging and on-site re-interpretation of the data.

The premise is that a single borehole may miss or penetrate a narrow steeply dipping fracture zone either too shallow or too deep. Several boreholes of different depths may be needed before locating the best and final borehole position.

Generally speaking drilling depths should not be predetermined but be based on the conditions encountered during the course of drilling. Optimal results, both yield and cost-wise, demand that drilling programmes be organized so as to allow continuous scientific supervision. Decisions to continue or to cease drilling operations in any particular borehole should be based on the statistically established criteria: optimal strike depths below surface, or below water level or below base of weathering and fracturing.

4. GEOHYDROLOGY

4.1 GENERAL

The groundwater flow pattern mimics that of surface flow. Generalised groundwater contours of a portion of the Region are shown in Figure 23. Although groundwater recharge has been estimated at between 5 and 15 mm a^{-1} its contribution to stream flow is negligible except in the far southwestern corner of the Region – see Sheet 2 of the set of National groundwater maps (WRC 1995).

4.2 HOUDENBRAK SUBTERRANEAN WATER CONTROL AREA

4.2.1 Background

The importance of groundwater in the Region's economy was pointed out in Chapter 1 section 1.5. Concern about receding groundwater levels and diminishing supplies caused by irrigation led to

- the declaration in April 1994 of the Vivo-Dendron area as a Subrerranean Government Water Control Area in terms of section 28 of the Water Act 1956 (Act No 54 of 1956) and
- the establishment of a Subterranean Water Control Board.

The area, which occupies portions of the catchments of the Hout and Brak Rivers, is shown in Figure 23. Doornlaagte the subject of the following discussion is part of the Hout River catchment.

Hard-rock formations are poorly exposed. Hout River Gneiss, which contains highly deformed and metamorphosed bodies of ultramafic, mafic and pelitic units as well as meta-quartzite and marble, underlies the Vivo-Dendron area. Diabase dykes striking mainly northeast are present. Several faults have been identified from aeromagnetic coverage. The granite-gneiss is weathered to depths varying mostly between 12 and 50 metres (Dziembowski 1976).

In 1969 65.5% of the measurable groundwater levels in the Doornlaagte catchment were shallower than 30 metres. The majority lay between 20 and 30 metres. In 1976 although still peaking in the 20 to 30 metre range, the percentage water levels shallower than 30 m had decreased to 53.5%. By October 1986 the peak concentration of water levels had shifted to the 30 to 40 metre range and the percentage of water levels shallower than 30 metre had dropped to 25.2%. Groundwater levels in an eight-farm sample declined an average of 16 m between 1969 and 1986 (Jolly 1986). Yields of boreholes in use in the Doornlaagte catchment range from 1 to 45 ℓs^{-1}. Nearly 75% fall in the 5 to 25 ℓs^{-1} category.

4.2.2 Hydrocensus 1968, 1974, 1986 and 1998

Large scale abstraction of groundwater for irrigation in the vicinity of Dendron induced the Geological Survey in 1959 to institute a programme of water level measurements. In 1968 Abtmaier (1968) reported on these observations and recorded information on the yield, depth, pumping rate and water level on 102 farms in an area of about 1600 km^2 in the Hout and Brak River catchments. According to the survey 3517 ha of crops were irrigated with 24.4×10^6 m^3 of groundwater in 1968. The volume was estimated on the basis of pumping rates and hours pumped. For the Doornlaagte, sub-catchment of the Hout River, the figures were 1345 ha and 9.5×10^6 m^3.

In 1974 the area irrigated in the Hout and Brak River catchments had increased to 3965 ha (Dziembowski 1976). Based on the estimated requirements of crops the volume of groundwater abstracted was estimated at 21 x 10^6 m^3. The Doornlaagte figures were 1474 ha and 8.6 x 10^6 m^3. The 1974 estimates are believed to be more accurate than those made by Abtmaier (1968). Dziembowski divided the span 1959 to 1975 into three rainfall periods and determined the mean water level change in the Doornlaagte catchment as tabled below.

TABLE 17 RAINFALL AND WATER LEVEL CHANGE 1959 -1975
DOORNLAAGTE SUB-CATCHMENT

Rainfall period		Mean rainfall (mm a^{-1})	Mean annual change in water level (m)	Number of observation boreholes
1959 - 1966	Sub-normal	285	-0.89	20
1966 - 1971	Normal	341	-0.38	27
1971 - 1975	Above normal	470	+0.065*	14

* Because waterlevel observations were two months late a correction had to be applied which resulted in converting observed mean drop of 0.185 m a^{-1} into a rise 0.065 m a^{--1}.

According to Jolly (1986) 3579 ha were under irrigation in the Doornlaagte catchment during 1985/6 (see Table 3). The volume of groundwater abstracted for irrigation amounted to 20.8 x 10^6 m^3 plus 1 x 10^6 m^3 for domestic use and stock watering. The theoretical water requirement of the crops was estimated at 25.3 x 10^6 m^3. After allowing for the contribution by rainfall this figure reduces to 18 x 10^6 m^3.

The reliability of the data collected during the 1969, 1974 and 1986 surveys is difficult to assess being based on interviews rather than on measurement and records.

In 1998/9 OTB, a Division of Denel, surveyed the Subterranean Water Control Area. In addition to determining and mapping the extent of areas under irrigation, information was compiled on production and monitoring boreholes, irrigation systems, and availability of electricity. According to this survey 4700 ha were then being irrigated at any one time. The difference between this figure and that of Jolly may be ascribed to

- the fact that several crops are planted per annum on a single field.
- a possible decline in irrigation as a result of diminishing groundwater supply

4.2.3 Estimation of groundwater recharge

Abtmaier (1969) estimated that the volume of groundwater abstracted in the Doornlaagte catchment during 1968 represented approximately 4 percent of the annual volume of rainfall on the catchment. On farms where large volumes were abstracted the groundwater level dropped at a rate of 1.6 m per annum during the period 1959 to 1968.

Based on data covering the 1959-75 period Dziembowski (1976) concluded that 3.84% of a rainfall of 440 mm a^{-1} would balance abstraction at the rate of 8.6 x 10^6 m^3 a^{-1}. The reliability of this estimate depends almost completely on whether the water level correction noted under Table 16 was justified. As mean annual precipitation appears to be between 360 to 400 mm a^{-1}, recharge at an average rate of 3.84% of mean annual rainfall is most likely an overestimate.

Jolly estimated recharge from rainfall by means of the groundwater balance:

$$R_R + R_I + I - O - P - E = \Delta SV$$

where
R_R – Recharge by infiltration of rainwater.
R_I – Recharge by infiltration of irrigation water
I – Inflow of groundwater assumed zero
O – Outflow of groundwater assumed zero
P – Volume of groundwater pumped out.
E – Loss of groundwater through evaporation (taken as zero)
D – Discharge of groundwater by springs or seepage (assumed to be zero).
ΔV – Change in volume of saturated formation.
S – Coefficient of storage/storativity of weathered formation

Solution of the equation was based on the following estimates/assumptions:

- The volume of groundwater pumped during 1981/85 – 90 x 10^6 m^3.
- Total rainfall during the period 1981 to 1985 – 1215 mm
- Irrigation efficiency – 70% i.e. 63 x 10^6 m^3 actually applied to ground surface.
- Irrigation return-flow amounts to 20% of that applied to the ground i.e. 12.6 x 10^6 m^3 returned to groundwater (Jolly mistakenly used the figure of 18 x 10^6 m^3 based on an annual abstraction rate of 21.4 x 10^6 m^3).
- Average waterlevel decline over the Doornlaagte catchment – 10 m.
- The coefficient of storage of weathered formation – 0.01.

Based on these estimates and assumptions a figure of 26.5 mm i.e. 4.3% of annual rainfall varying from 180 to 400 mm and averaging 240 mm over the 5-year period is obtained. Note that Jolly's figures of 22 mm and 3.5% are based on the erroneous irrigation return flow figure.

Orpen and Bertram (1991) estimated aquifer storativity and groundwater recharge of the Doornlaagte catchment through finite element modelling of the saturated volume. This involved determining changes in saturated volumes and solving the overall groundwater balance on a monthly basis. Bertram (1993) describes the methodology in more detail. The three largest monthly drops in saturated volumes during 1975/89 were assumed to represent periods of no recharge. Dividing these volume drops by the volumes of groundwater abstracted a mean value of 0.01 was obtained for storativity. Note that Bredenkamp et al.'s (1987) method of determining storativity as described by Orpen and Bertram failed to yield an acceptable solution. The following rainfall-recharge relationship was obtained:

$$\text{Annual recharge (mm)} = 0.08 \times (\text{annual rainfall in mm} - 342)-$$

The best match with saturated volumes was obtained by assigning to finite elements storativity values of respectively of 0.01 and 0.005 dependent presumably on whether the water level lay within the upper weathered zone or below it in the fractured zone.

4.2.4 Discussion

The above-mentioned result, which implies that no recharge takes place for an annual rainfall of 342 mm or less, is at variance with Jolly's determination. According to him recharge amounted to 26.5 mm over the five-year period 1981/2 – 1985/6. Rainfall exceeded 342 mm only once during this period namely 400 mm in 1984/5. Therefore Orpen and Bertram's equation yields 4.6 mm for the period 1981/85. Furthermore had Jolly assumed a storativity figure of 0.015 instead of 0.01 a zero result for recharge would have been obtained.

These divergent results emphasize the problems and uncertainties attached to estimating recharge and to the development of a groundwater management model. Owing to a dearth of input data simplifying, not necessarily valid assumptions had to be made and a lumped parameter model had to be adopted. Optimal utilisation of Houdenbrak groundwater requires development of a management model whereby the response of the groundwater system to varying conditions of climate/rainfall and exploitation may be predicted. Ideally the model should be a three-dimensional dynamic flow model. Development of such a management model is hampered by:

- a lack of spatially and temporally varying data on:
    1. Rainfall
    2. Groundwater levels
    3. Volumes of water abstracted
    4. Irrigation efficiency
    5. Return flow of irrigation
    6. Surface runoff and storage if any
    7. Groundwater loss, if any, through natural discharge and evapoteranspiration
    8. Areas under natural vegetation and cultivation
    9. Groundwater quality
- a lack of spatially variable data on:
    1. the depth of decomposition and fracturing
    2. storativity of the decomposed and of the fractured rock
    3. transmissivity of the decomposed and fractured rock
- a lack of knowledge about:
    1. the dynamics of water exchange between porous decomposed rock and fractures Do borehole water levels at all times reflect the level of saturation of both the permeable and semi-permeable components of the groundwater body?
    2. the effect of variations in moisture content of the zone of aeration on percolation to the saturated zone
    3. the effect of changes in land-use e.g. through bush clearing and agriculture on groundwater recharge

Mindful of the foregoing it is obvious that a satisfactory management model can be developed only on the basis of data collected over a number of years and by successive adjustments. It appears highly unlikely that the exploitable supply can be expressed as a function of annual rainfall only although this may prove useful as an initial approximation.

It should also be evident that abstraction of groundwater in the Doornlaagte catchment diminishes groundwater flow downstream and must have led to a reduction in the availability of surface water in the Hout River and affected its ecosystem adversely.

5 QUALITY AND HYDROCHEMISTRY

Du Toit (1986) submitted water for analysis from 33 boreholes that were drilled during 1985 in parks and other open areas in Pietersburg. Electrical conductivities ranged from 37 to 149 mS m^{-1} and total dissolved solids from 301 to 1129 mg ℓ^{-1}. The dissolved solids content of the majority of water samples lay between 500 and 800 mg ℓ^{-1}. The hydrochemical type is sodium - magnesium bicarbonate and sodium bicarbonate.

Orpen (1989) sampled boreholes along the Sand River between Hollandsdrift 15 KS upstream of Pietersburg and Breypaal 760 LS downstreamn (see Figure 1). Upstream of the confluence of the Diep and Sand Rivers electrical conductivities range between 30 and 120 mS m^{-1} peaking around 70 to 80 mS m^{-1}. Downstream of the confluence (Zandrivierspoort 85 LS) electrical conductivities range from 70 to 290 mS m^{-1} averaging 150 mS m^{-1}.

It is of interest to note that:

a) groundwater from alluvial deposits along the Sandsloot, a tributary of the Diep River appears to be more saline than that of the Sand River upstream of the confluence. The electrical conductivity of two samples of groundwater taken on Majabaskraal 1005 LS was 109 and 151 mSm^{-1} (Orpen 1986).

b) some 70 km downstream of Zandrivierspoort 85 LS on the Mara Research Station sodium bicarbonate water with a salinity in the range of 70 to 120 mSm^{-1}was encountered in boreholes drilled alongside the Sand River (Orpen and Fayazi 1984)

Groundwater conductivities of less than 50 mSm^{-1} occur on the Louis Trichardt Town lands along the Dorps River. To the west and downstream in the Kutama-Sinthumule area electrical conductivities generally exceed 150 mSm^{-1} overstepping 250 mSm^{-1} in isolated localities (WSM 1991).

Electrical conductivities of 194 groundwater samples collected during hydrocensuses in the Hout and Brak River catchments range between 70 and 290 mSm^{-1} (Jolly1986; Orpen 1989a and c). Fifty percent lie in the range of 100 to 130 mSm^{-1} whilst 81% are found in the 80 to 160 mSm^{-1} range.

According to Sheet 2 of the "Groundwater Resources of the Republic of South Africa" map set total dissolved solids and chemical types range geographically as tabled below.

TABLE 18 DISSOLVED SOLIDS AND HYDROCHEMICAL TYPE

Lower standard deviation mg ℓ^{-1}	Upper standard deviation mg ℓ^{-1}	Approximate indication of area	Dominant Chemical Type
< 300	500 -1000	West of line joining GaMokopane trignometrical beacon (Magabeng Hills) with Chuniespoort*	(Ca,Mg) (HCO$_3$)$_2$
500 - 1000	1000 - 1500	Area underlain by Hout River Gneiss east of the above-mentioned line	(Ca, Mg) (HCO$_3$)$_2$ / (Ca,Mg) (Cl$_2$, SO$_4$)
< 500	1000 - 1500	Northeastern portion of Region underlain by Goudplaats Gneiss	(Ca,Mg) (HCO$_3$)$_2$ /(Ca,Mg) (Cl$_2$, SO$_4$)

* Catchments of the westward draining Seepabane and Matlala Rivers and the southward flowing Nkumpi.

According to the Groundwater Quality map nitrate exceeds 10 mg ℓ^{-1} as N in more than 20 percent of the analysed samples. This does not agree with the figure given in Table below, which is based on a later more comprehensive study.

M. Simonic of Hydromedia Solutions (Pty) Ltd classified the overall potability of analyses of 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 tabled below.

TABLE 19 POTABILITY CLASSIFICATION

Class	1-blue	2-green	3-yellow	4-red	5-purple
Description	Ideal	Good	Marginal	Poor	Unacceptable
No of samples	111	379	289	141	55
% of samples	11.4	38.9	29.6	14.5	5.6

Just more than 20 percent of the water samples are not suitable for drinking. The distribution of harmful ion concentrations follows in Table 19.

TABLE 20 DISTRIBUTION OF HARMFUL ION CONCENTRATIONS

Ion	Ca	Mg	Na	K	Cl	SO_4	NO_3	F	EC*
No of analyses	972	972	966	958	972	966	982	972	532
No of samples containing harmful concentrations	12	6	9	2	16	0	118	81	3
% of samples	1.2	0.6	0.9	0.2	1.6	0.0	12.1	8.3	5.6

*****EC electrical conductivity.

The main harmful constituents in terms of their occurrence are NO_3 and F.

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