VSA GEOCONSULTANTS
A MEMBER OF THE SET POINT TECHNOLOGY GROUP

EL NINO MITIGATION PROGRAM

GROUNDWATER REVIEW

PHALABORWA AREA

FINAL REPORT

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ABSTRACT

This study forms part of the El Nino Mitigation Program under management of EVN Consulting Engineers aimed to upgrade the existing resources to the new DWAF specifications. This report evaluates existing groundwater sources in the area from a geohydrological and hydrochemical point of view.

A total of 8 villages in the Phalaborwa area were involved in the program. Existing boreholes, of which there are 47 not belonging to the Department of Agriculture, were identified, tested and upgraded where possible. Additional two targets were located and drilled in the period November 1997 to February 1998. The Phalaborwa North area, specifically Namakgale and Ritavi, has a total population of 105 016 and thus requires 2625,4 m^3 of water per day to meet the RDP standard of 25 litres per person per day.

To prevent confusion, boreholes were discussed under the lithologies encountered at surface. Due to the granitic and gneissic nature of basement lithologies, geological contacts were difficult to distinguish in the field. Consequently, the exact geological positiions of the waterstrikes are unclear.

It is important to note that the recommendations are made on a regional scale and it is therefore still the Consultant,s responsibility to pinpoint the groundwater source to be exploited.

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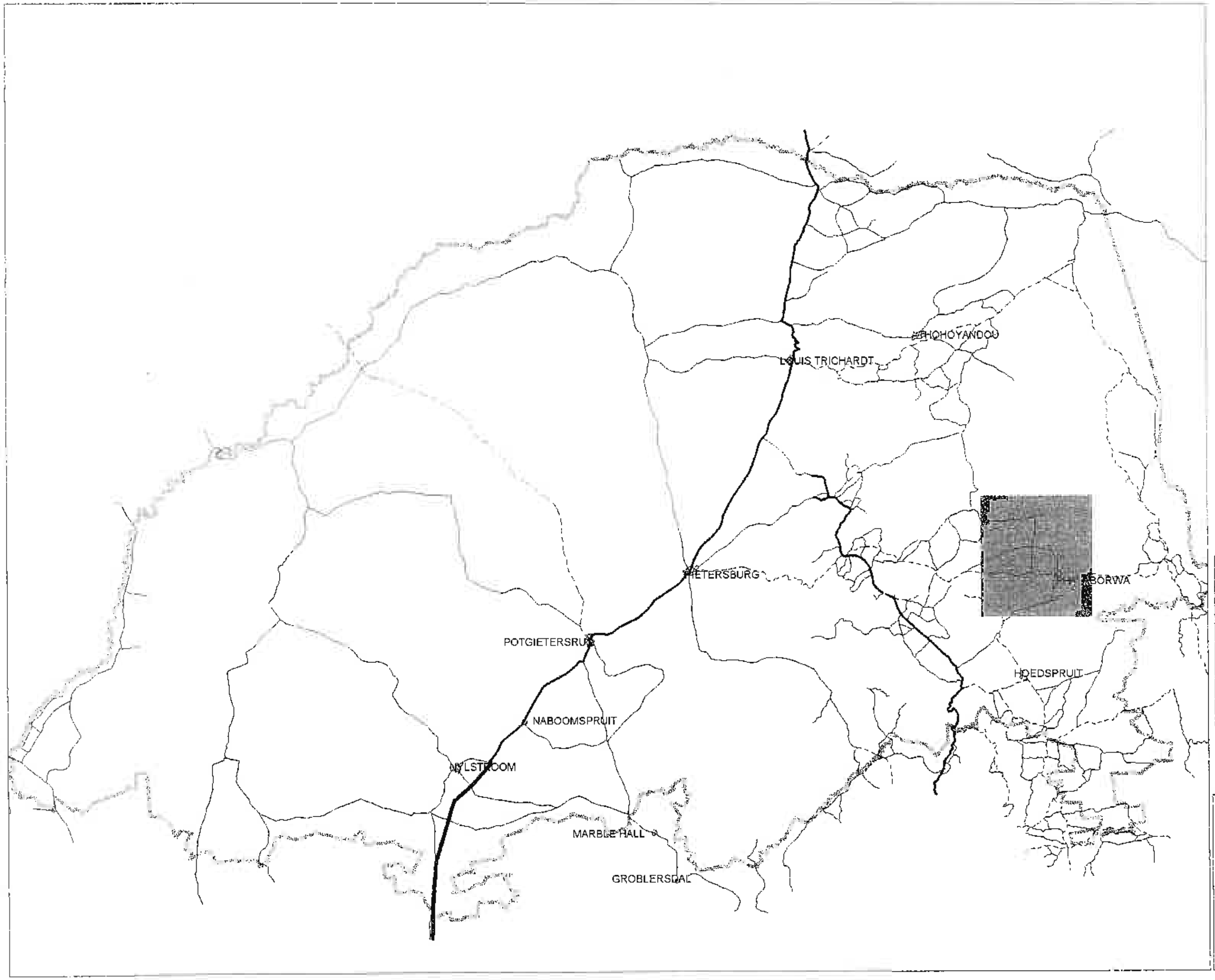
MAP A



LOCALITY MAP

Phalaborwa

Legend:

- Freeway
- Arterial Road
- Main Road
- Other Road
- Northern Province Boundary
- Urban areas
- Study area

N

0 40 80

Kilometers

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1. INTRODUCTION

1.1. Location

The Phalaborwa region is delineated by the Letaba River in the North and Bushbuck Ridge in the south. Although covering a large area, the focus of this report is on northern Phalaborwa, specifically Ritavi 3 and 4 and Namakgale 1 and 2 (**MAP A**). Covering a surface area of some 51 km², Ritavi and Namakgale are framed by lines of latitude 30°50' and 31°10'S and lines of longitude 23°35' and 24°05'E and encompasses 1:50 000 mapsheets 2331 CC Phalaborwa, 2330 DD Mutali, 2330 DB Ka-Makhuva and 2430 BB Mica.

1.2. Background

VSA GeoConsultants was appointed by the Department of Water Affairs and Forestry in October 1997 as Hydrogeological Consultants in the Phalaborwa TLC area with the aim to upgrade the resources to the new specifications set by the Department.

On the 4 th of February 1998 the program was continued under the El Nino Mitigation Program under management of EVN Consulting Engineers. The project was subdivided into two phases: Phase one commenced with the liasing of existing sources, followed by testing, rehabilitation and redrilling of poorly constructed boreholes. Phase two entailed the siting, drilling and testing of new sources. The drilling and testing activities were not completed due a lack of funding.

1.3. Objective

The aim of the program was to alleviate the critical shortage of water in the rural communities by exploiting groundwater sources. Groundwater resources suitable for human consumption were to be located and developed and existing boreholes had to be evaluated and upgraded.

1.4. Methodology

VSA GeoConsultants were instructed to:

- investigate groundwater as a source of water supply
- locate existing boreholes and indicate their locations on 1:50 000 toposheets
- test boreholes to determine their short and long term productivity potential

- identify siting and drilling targets
- co-ordinate all borehole testing, re-drills, siting and drilling
- obtain water samples for hydrochemical analyses
- compile a full report on the above with recommendations

2. PHYSIOGRAPHY

2.1. Morphology and drainage

Physiographically Phalaborwa North area comprises low-lying, flat or slightly undulating terrain having average elevations of between 400m and 500m. The relief is negligible, allowing for a few isolated elevated outcrops of syenite plugs of the Phalaborwa Complex and granite.

Four of the quaternary sub-catchment areas as defined by the Water Research Commission in their 1994 report fall within the area. Each sub-catchment location is indicated on **MAP D** with mean annual precipitation and run-off indicated in Table 1.

Table 1: Mean annual precipitation and run-off per sub-catchment

Sub-catchment	Mean annual precipitation (mm)	Mean annual run-off (mm)
B81J	**502**	**9.4**
B83A	**515**	**10**
B72J	**459**	**9.8**
B72K	**495**	**8.1**

The main drainage throughout the area is the southeast flowing Ga-Selati River flowing through the south of Namakgale 1, and the Great Letaba river to the north forming the northern boundary of Namakgale 2 and Ritavi 3.

2.2. Climate and rainfall

The region experiences a sub-humid warm climate with a mean daily maximum temperature of 24,3°C and a minimum temperature of 16,6°C measured over eighteen years. The summers are hot and the winters cool to moderate. The average minimum and maximum temperatures for each month of the year are represented in Diagram 1. Data was obtained from the Institute for Soil, Climate and Water, Pretoria with the weather station (0182/505) situated at 30°55'S and 30°17'E

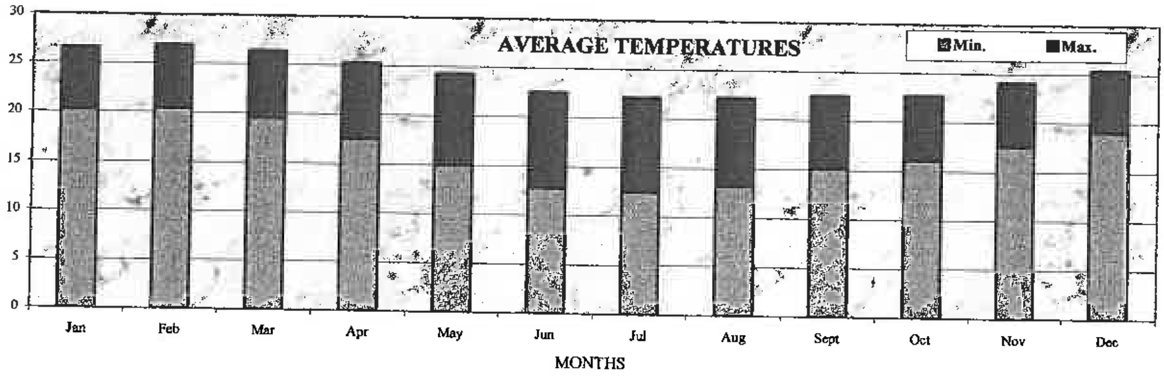


Diagram 1: Phalaborwa average temperatures

The long-term rainfall records for station 0182/505 reveal a mean annual rainfall of between 500 and 600mm (Midgley et al., 1994). Most of the rainfall occurs as afternoon thundershowers between January and February. The mean annual evaporation varies around 1 700mm (Midgley et al., 1994). The mean annual precipitation figures as represented on Diagram 2 were obtained from the Institute for Soil, Climate and Water, Pretoria, and calculated for the period 1970 to 1998.

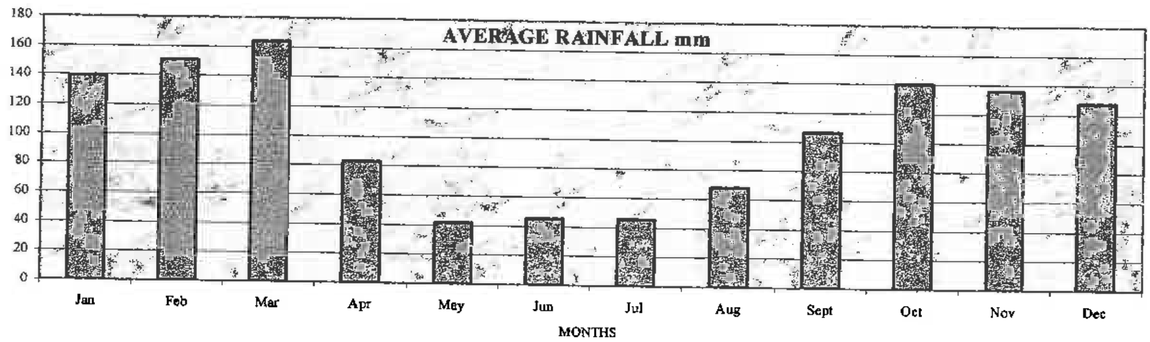
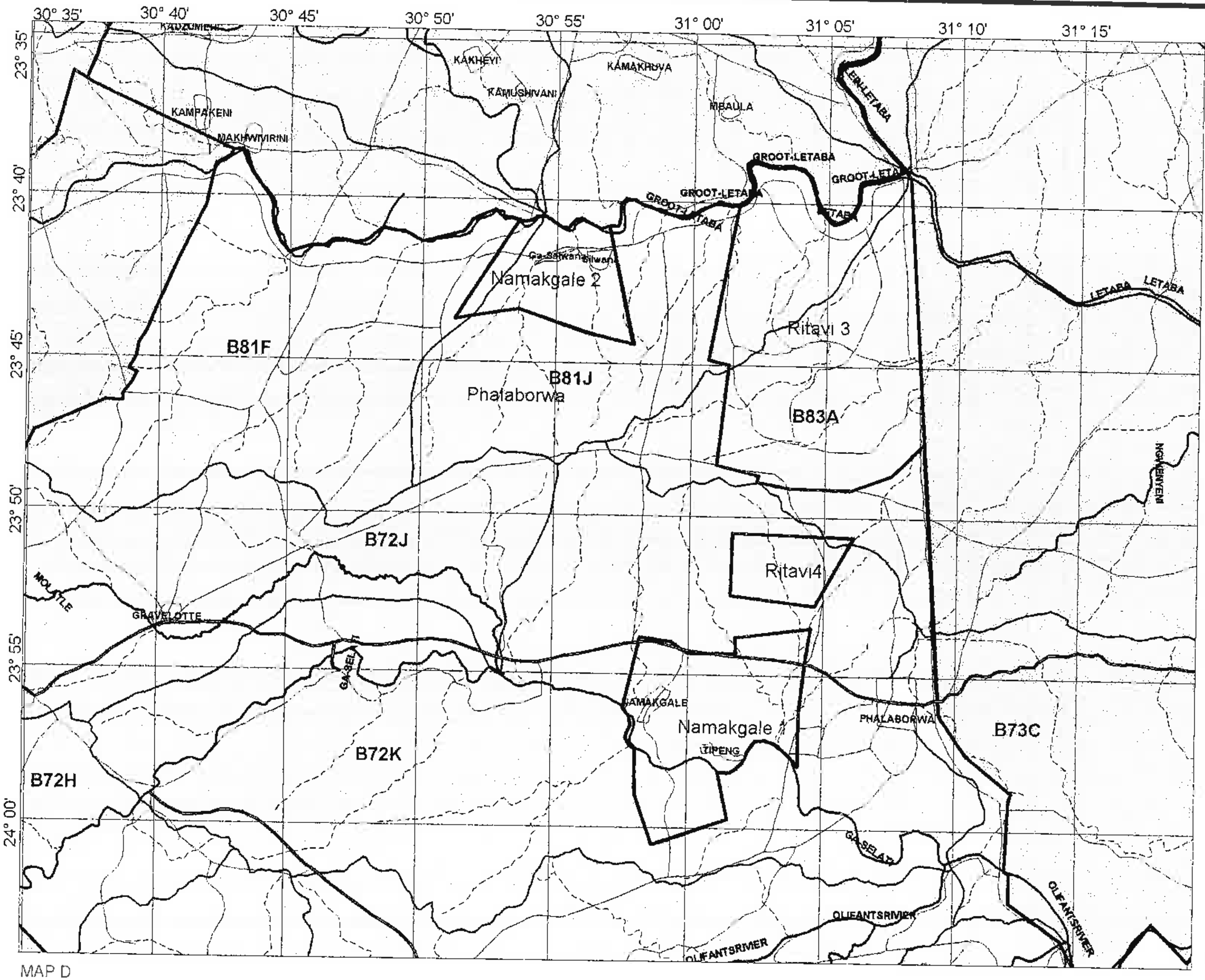


Diagram 2: Mean annual precipitation



CATCHMENTS

Phalaborwa

Legend:

- Main Road
- Secondary Road
- Other Road
- Perennial River
- Non-Perennial River
- Catchments
- B72D Catchment Number
- Urban Area
- Study Area

N

0 5 10

Kilometers

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3. GEOLOGY

The geology as discussed in this report only cover the Phalaborwa North area as indicated on MAP A. Abbreviations in brackets as seen on the 2330 Tzaneen and 2430 Pelgrim's Rest geological maps.

Table 2 : General geology of the Namakgale 1 &2 and Ritavi 3 & 4 areas (MAP B)

AGE	SEQUENCE	FORMATION	INTRUSIVES
Quaternary deposits			
Mokolian			Phalaborwa Complex
Vaalian			Mashishimale Granite
Randian			Baderoukwe Granite
			Pompey Granite
Swazian	Murchison	Rubbervale	
		Weigel	
		Leydsdorp	
		Mulati	
			Makutswi Gneiss
			Goudplaats Gneiss

Although the whole of the Phalaborwa North area is characterized by a wide variety of different rock types, Phalaborwa North specifically Ritavi 3 & 4 and Namakgale 1 & 2 are predominantly underlain by gneisses and greenstones of the Swazian basement complex as well as a variety of younger intrusive suites such as the Pompey, Baderoukwe and Mashishimale granites and the Phalaborwa Complex.
Both doleritic and diabasic dykes transect the entire region and vary in age, orientation and composition.

3.1. Goudplaats Gneiss (Zg)

The oldest lithology in the area underlying Namakgale 2, is represented by the 3295 Ma (Barton et al., 1983) year old Goudplaats Gneiss. Although being the main rock-type of the Archaean Complex in the area, outcrops are scarce and deeply weathered. The gneiss is regarded to represent a salic basement to the various greenstone belts including the Murchison Greenstone Belt (Brandl, 1987). This medium- to coarse-grained, grey biotite gneiss of tonalitic composition exhibits a strong foliation and is characterized by its banded nature. In places it grades into a migmatite variety displaying quartzo-feldspathic layers up to

10mm thick, which alternate with layers richer in biotite.

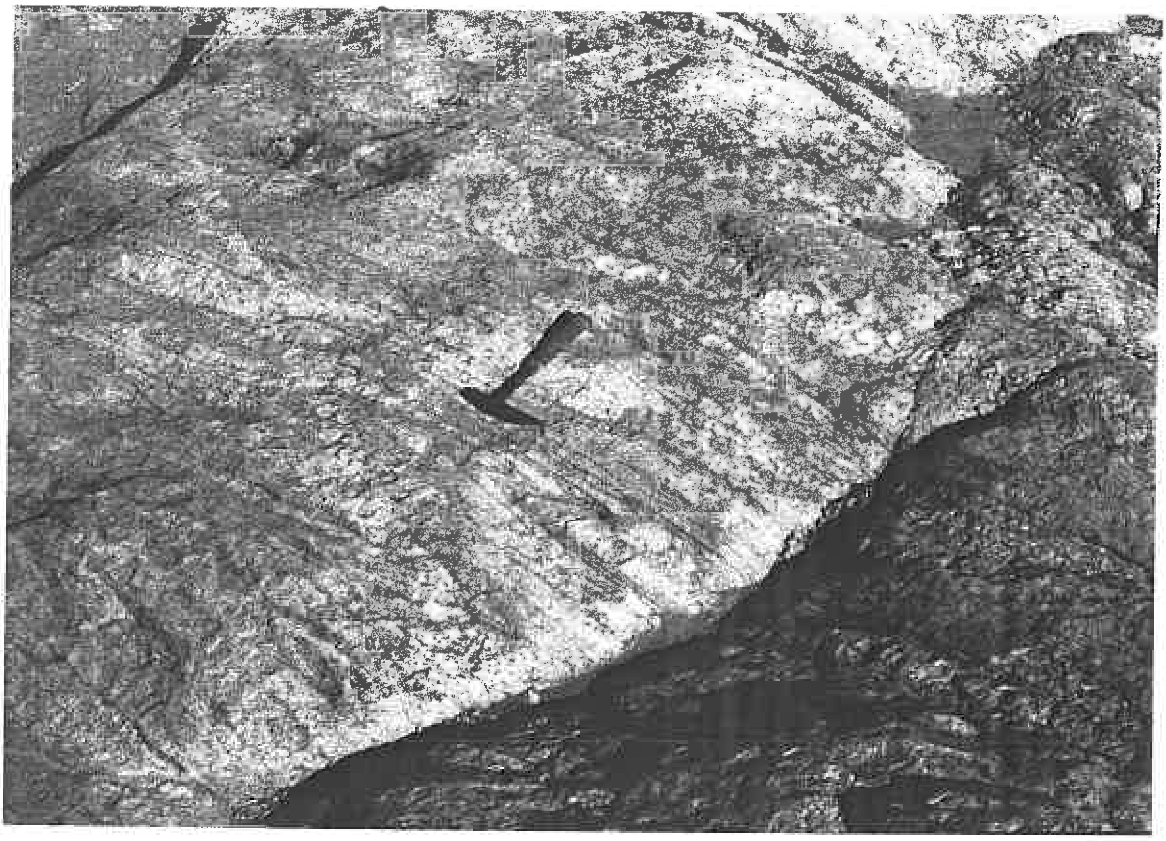

Figure 1: Grey biotite Goudplaats Gneiss exhibiting the characteristic foliation and banding.

3.2. Makutswi Gneiss (Zm)

The Makutswi Gneiss developed to the south of the Murchison Greenstone Belt is lithologically very similar to the Goudplaats Gneiss with the contact between the two lithologies regarded as arbitrary. Namakgale 1 and Ritavi 4 are mainly underlain by this lithology. This massive, equigranular, medium- to fine-grained biotite gneiss consists predominantly of plagioclase, quartz and biotite with minor amounts of microcline, sphene and occasionally some pyrite. The Makutswi Gneiss is characterized by its homogeneity and strong regional foliation.

Figure 2: Makutswi Gneiss - Namakgale 1

3.3. Murchison Sequence

3.3.1. Gravelotte Group

The Gravelotte Group forms a narrow linear belt that stretches in a north-northeasterly direction through the northern portion of the Phalaborwa area. Near its northeastern end (Ritavi 3) the belt has a typical arcuate shape as it splits into two arms. The group comprises six units which are the Mulati, Leydsdorp, La France, Weigel, Mac Kop and Rubbervale Formations (Jantsky, 1978). In an attempt to simplify the geology of the area and due to a lack of sufficient information, the La France, Weigel and Mac Kop Formations are grouped together. Only a minimum age of 2961 ± 75 Ma is obtainable on the Murchison Greenstone Belt (Burger and Walraven, 1977).

3.3.2. Mulati Formation (Zmm)

This formation is considered to represent the basal unit of the Gravelotte Group and is developed along the southern flank of the Murchison Range at the contact with the Lekkersmaak Granite. Ultramafic schists with extremely little mafic metalava constitute the bulk of the Mulati Formation. Two types of schists were distinguished: a light-green to greyish green rock consisting almost entirely of tremoliteactinolite with little chlorite, and a dark green rock comprising lesser amounts of tremolite with subordinate talc and chlorite.

3.3.3. Leydsdorp Formation (Zl)

Overlying the Mulati Formation are the carbonated mafic metalavas and amphibolites of the Leydsdorp Formation. The carbonated lavas are medium-grained, light green to greenish brown when fresh, but brownish on a weathered surface. They are composed largely of quartz and dolomite with minor sericite, chlorite and feldspar. The medium-grained amphibolites are dark green to blackish in colour, well foliated, often displaying compositional banding. Its main constituents are hornblende, quartz and plagioclase.

3.3.4. Weigel, La France and Mac Kop Formations (Zw)

These formations which are grouped together on the map comprise largely chloritic schists with subordinate sedimentary rocks.

The chloritic schists are fine to medium-grained, strongly foliated and fissile and range in colour from greenish grey to brownish green. They are composed predominantly of chlorite and quartz; minor constituents include feldspar, biotite and carbonate.

Sedimentary lithologies include iron formations, quartzites, conglomerates and greywackes.

3.3.5. Rubbervale Formation (Zr)

The Rubbervale Formation is characterized by extrusive and intrusive acid rocks, which are considered to form the top of the Murchison belt. Light-coloured quartz-mica schists consisting of quartz, sericite and chlorite dominate the succession.

3.4. Vorster Suite

The Vorster Suite comprises various granites, which form a number of batholiths south of the Murchison Greenstone Belt. They include the Pompey and Baderoukwe Granites.

3.4.1. Pompey Granite (Rip)

It is massive medium-grained, light grey granite, which forms a number of scattered stock-like bodies in the Makutswi Gneiss underlying Ritavi 4. Mineralogically it is composed of quartz, feldspar and mica. Its composition ranges from granodioritic to adamellitic.

3.4.2. Baderoukwe Granite (Rib)

The Baderoukwe Granite lies within the eastern extent of the Murchison greenstone belt (Ritavi 3) and has approximately an ovoid outline. The granite, which often forms flat, barren pavements or hummocks, is generally a homogeneous coarse-grained, mesocratic biotite-rich rock containing muscovite in variable amounts. A pronounced foliation is often developed becoming less prominent towards the west.

3.5. Pegmatite

Pegmatites (not shown on map) occur mainly along the southern margin of the Murchison belt at the contact between the greenstones and the granitoid rock ranging in size from small pods up to large parallel or crosscutting dykes. Their shape and size are very variable and their orientation unpredictable.

Figure 3:Pegmatite dykes cutting across the Makutswi Gneiss foliation - Namakgale 1

3.6. Mashishimale Suite (Vm)

A slightly younger suite of granites is also present along the southern boundary of the map area. Although not differentiated on the map, it consists of the Hoed, Lillie and Transport Granites occurring as stock-like bodies of biotite-hornblende or biotite granite. The suite, which is intrusive into the Makutswi Gneiss, comprises mainly fine-grained, light-coloured granite of granodioritic-adamellitic composition. Isotopic ages vary between 2554 and 2661 Ma as reported by Barton (1983).

Figure 4: Panoramic view of one of the scattered outcrops of the Mashishimale Suite - Namakgale 1

3.7. Phalaborwa Complex (Mp)

Constituting a suite of intrusive rocks ranging in composition from ultramafic to peralkaline, the 2060 Ma old Phalaborwa Complex has a surface form of a north-south elongated kidney-shaped stock. Several small scattered plugs surround the main outcrop of the complex. The complex is a pipe-like structure and consists of various types of carbonitite as well as pyroxenite and phoscorite from which copper is produced as a byproduct. The younger carbonatite carries the bulk of the copper mineralisation.

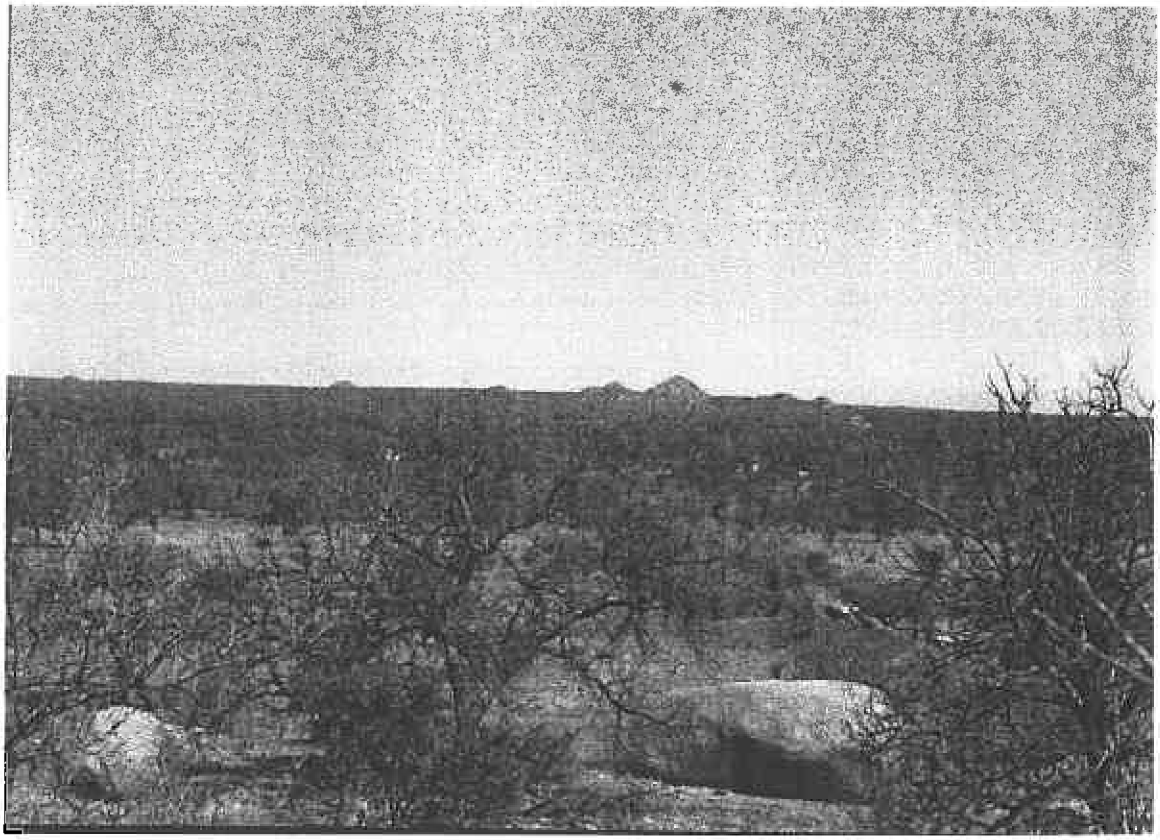

Figure 5: Small scattered plugs of syenite surrounding the main outcrop body – Phalaborwa

Figure 6: The main Phalaborwa Suite body mined at Phalaborwa

3.8. Quaternary deposits (Q)

Regolith is a general term used for the loose, incoherent, or unconsolidated rock material, of whatever origin (residual or transported) and of varied character, that covers the land surface and overlies the more coherent bedrock.

In the Phalaborwa area this includes alluvium deposits and residual soils. Alluvium results from the transportation and deposition of sediments by perennials and its associated streams. It varies with the geology of the catchment area, the site of deposition and the competence of the river; consequently vertical and lateral gradations are frequently encountered.

Residual soils are formed from the in situ weathering of the country rock. Soil formation involves addition and removal of material to and from the soil body, transfer of material within the soil body, and the transformations of material (both organic and inorganic) from one form to another.

Thin or no regolith deposits occur near outcrops, with thick deposits commonly found associated with deeply weathered bedrock or saprolite. The mineralogical composition and lithological texture of the country rock also play an important role in the development of the regolith. These are commonly thickest and most permeable on the coarse-grained salic rocks such as the granites and gneisses. When developed on mafic rocks such as the diabase and dolerites the regolith may be thick but tends to be clay-rich and poorly permeable. Not only the geology, but also factors such as the topography, climate, vegetation and time influence the distribution and thickness of regolith.

3.9. Structure

The structural history of specifically the Archaean rocks in the map area is extremely complex as they cover a timespan of almost 1000 Ma.

The Goudplaats Gneiss north of the Murchison Range and the Makutswi Gneiss to the south, both exhibit a pronounced foliation and isoclinal folding. Du Toit (1979) established that the Goudplaats Gneiss underwent at least four distinct deformational events. The earliest events produced the tight folding within the Gneiss and culminated in the development of the strong fabric of the gneiss. The last episode of deformation resulted in north-east-trending shear zones.

The Makutswi gneiss to the south appears to have gone through fewer periods of deformation than the Goudplaats Gneiss. The degree of metamorphism determine the strength of the rock against fracturing (Larson, 1977). The higher the degree of metamorphism, the stronger the lithology. Furthermore, folded gneisses such as the Goudplaats Gneiss has a very sparse post-crystalline fracture pattern and folding appears to strengthen the rock rather than weakening it. Consequently, the folded gneisses exhibit a low secondary porosity that inhibits the flow and storage of groundwater. Contrary to this, migmatization in folded rocks, with increase of quartz and feldspar, generally results in a weakening of the resistance of the rock (Larson, 1977) and consequently higher groundwater potential.

In the Murchison Greenstone Belt the structural trends are mainly in a linear east-northeasterly direction. The contact zones on either side of the belt are markedly different; the southern margin being an intrusive contact and the northern margin a sheared contact (Letaba Shear Zone). The shear zone is thought to have a right-lateral sense of movement with a late vertical movement with uplift of about 10km to the north (Fripp et al., 1980).

4. HYDROLOGY

4.1. Aerated zone:

Groundwater moves and is stored in hard rock terrain in relatively open systems of fractures in unweathered rock and also in pervious zones of the surficial weathered rock layer. Viable and productive aquifers (waterstrikes) within the low-lying areas of Phalaborwa North are predominantly a function of deep-seated fracture systems (40-50m) underlying 10-15m thick regolith horizons. The regolith performs the important function of absorbing infiltrating rainfall and transmitting it to the deeper fracture systems.

4.2. Groundwater levels:

Groundwater levels were measured in some 49 boreholes throughout the area in the period November 1997 to February 1998. Groundwater levels reveal little uniformity with regard to the geology. The shallowest groundwater levels coincide with the course of surface drainage, especially with the perennials, as is the case with H13-0321, H13-0203 and H13-0348. Anomalous perched water levels apparently results from either the damming effect of dykes and in some cases granitic intrusions (H13-0337, H13-0391) or the increase of groundwater conductivity due to lineament and faults.

4.3. Lithological Groundwater potential:

Groundwater bodies occurring in the low-lying areas of the weathered Goudplaats and Makutswi gneisses in the Phalaborwa area, tend to be small with several independent groundwater systems developed in the different surface drainage systems. Due to the metamorphic nature of these lithologies, subsurface interruptions or discontinuities of unweathered and unfractured rock (dykes) possibly divide the weathered rock, as well as the underlying fracture systems into small cells each of which functions as an independent hydrological unit in so far as the recharge and discharge of shallow groundwater and the arial distribution of water quality are concerned.

The higher the degree of metamorphism, the stronger the lithology. Folded gneisses such as the Goudplaats Gneiss, could have a very sparse post-crystalline fracture pattern and folding appears to strengthen the rock rather than weakening it. Consequently, the folded gneisses exhibit a low secondary porosity that inhibits the flow and storage of groundwater (H13-0394, H13-0391).

Contrary to this, migmatization in folded rocks, with increase of quartz and feldspar, generally results in a weakening of the resistance of the rock (Larson, 1977) and in cases where these quartzo-feldspathic layers are transected by diabase dykes, the groundwater potential of the gneiss increased dramatically.

Numerous lineaments, regionally extending NE-SW, transect the gneisses, acting as conduits, concentrating groundwater flow and resulted in a marked increase of the groundwater potential of these lithologies.

Metamorphic rocks such as the Murchison greenstones are rich in open foliation, fractures and fissures, but these are isolated and poorly interconnected. Consequently, the schists are characterized by poor recharge and are poor aquifers.

The Pompey and Mashishimale granite intrusions have intrinsically well-crystallized structures with no empty pores. However, being rigid they tend to fracture and may have a limited degree of infiltration capacity and aquifer conductivity. These intrusions have low groundwater potential unless transected by deep-seated fracture zones or dykes.

Basic to intermediate dykes of various ages traverse much of the map area. Three dyke trends were identified: NW-SE, east west and NE-SW. The width of the dykes varies from a few meters up to 100 or 150m. Where they outcrop, most of the northeast trending dykes are doleritic in composition and of pre-Karoo age. Diabase dykes occur as east-west trending swarms of pre-Godwan Transvaal age. Field evidence suggests that their weathering patterns, thickness and grain size could distinguish the doleritic and diabasic dykes. Diabasic dykes commonly exhibit a spheroidal weathering pattern whereas the doleritic dykes are blocky in appearance. Furthermore, the diabasic dykes are coarser crystallized and generally thicker than the doleritic dykes. Due to the extensive thickness reached by the diabasic dykes, cooling was slow and consequently the dykes are less fractured and weathered than the doleritic dykes. The boundary zone between the dyke and the country rock often contains open fractures with high storage capacity as a result of thermal shrinkage at the time of cooling of the dyke; consequently open spaces developed between the dyke and the country rock with high storage capacity. Although this has not yet been proven it is suggested that where a diabasic dyke is encountered, siting should be close to its contact and in the case of doleritic dykes, siting should be in the dyke itself.

Figure 7: Spheroidal weathering pattern commonly found in diabase outcrop

Pegmatites are particularly abundant throughout the granites and gneisses of the basement lithologies, ranging in size from small pods up to large parallel or crosscutting dykes. Dyke pegmatites have sharp contacts and appear to be related to joint and fracture directions. Weak cohesion exists among the individual crystals and therefore the pegmatites are very brittle and fracture easily with applied stress. Their brittle and fractured nature and their coarse grain size causes pegmatite zones to be highly permeable and porous with high potential yields assuming recharge has been effective. Consequently, pegmatites dykes are high priority target areas for groundwater exploration.

Figure 8: Pegmatite dykes intruding the Makutswi Gneiss - Namakgale 1

4.4. Fractures and shear zones:

The storage capacity of unweathered rocks depends on the relative degree of fracturing the specific lithology will permit. Fractures are the structures developed by brittle failure, generally including faults, where the two sides are displaced relative to each other, joints where the two sides show no differential displacement and veins where a considerable thickness of filling material occupies the region between the fracture walls. The degree of fracturing is a function of the relative spacing of fractures, their lateral and horizontal extent and their interconnection.

Two types of fracture systems are identified in the area. These include near-surface fracture systems related to weathering and unloading, and deep-seated, fractures related to regional tectonics. The former is locally developed, and related to some occurrences of groundwater in igneous and metamorphic rocks in the area. The deep-seated fracture systems, defined by some of the NE-SW stiking lineaments on MAP B, could reach hundreds of meters in length, are widely spaced and cut across all lithologies. Fracturing, either associated with regional deformation or weathering, created significant porosity and permeability in the rocks of the area and consequently increased the lithology groundwater potential dramatically.

The storage capacity of shear fractures is very complex. Although not as commonly found as the joint fractures, a number of NE-SW and NW-SE orientated shear zones are present, varying in size and extent of deformation. In these cases intense weathering and the development of smectites (clay) commonly follow heavy fracturing. Metamorphic rocks such as the Goudplaats Gneiss and the greenstones are fractured by tectonic processes that could improve their infiltration and storage capacity. However, it seems that most, if not all of the shears in these lithologies are tightly compresses by residual stresses and consequently the groundwater potential is not influenced by the presence of shear zones.

5. GEOPHYSICS

Personnel of VSA GeoConsultants, appointed by the Department of Water Affairs carried out the initial verification of the Phalaborwa area.

The initial procedure included a detailed digital satellite image interpretation and desk study. Thereafter, electromagnetic and magnetic traverses were surveyed were possible at right angles to lineaments and dykes targeted. This was however controlled by access to the sites. Traverse lengths range from 100m to 600m, with sample intervals of 10m for the EM-34 and 5m for the magnetometer been employed. The objective was to attempt to define the regional and background features. Appropriate electromagnetic survey parameters in terms of coil separation and frequency selection were employed according to terrain conditions. Ground Magnetic and Frequency Domain Electromagnetic methods were employed to identify and locate the most suitable drill targets.

5.1. Magnetic method

The different magnetic susceptibilities of the different rock types result in contrasting magnetic signatures. Hence, the magnetic data may be interpreted to represent dykes, geological contacts and faults that may have a bearing on the occurrence, storage and movement of the groundwater. These geological structures are primary targets in selecting drilling sites for groundwater exploration.

A Chemtron model G3 proton-precession magnetometer was used, measuring directly the strength of the total magnetic field at a given locality. A total of 19 traverses were completed in the Phalaborwa North area with a station interval of 5m. The magnetic traverse positions and profiles are represented in Appendix B.

5.2. Frequency Domain Electromagnetic Methods

The operating principles of the EM-34 system (method widely used in the Phalaborwa North area) are briefly discussed below. The technique provides rapid and easy measurement of terrain conductivities and facilitates the detection of steeply dipping conductor type targets such as dykes, fracture zones, faults etc. through electromagnetic coupling. A total of 19 electromagnetic traverses were completed during the period November 1997 to February 1998.

The EM-34 is a moving source-moving receiver system, which measures the ratio of the quadrature component of the secondary magnetic field to the free space primary magnetic field. The transmitter and receiver units are connected by a cable, acting as a reference to the primary magnetic field.

The twenty and forty metres coil separations used for the EM-34 profiling allowed relatively rapid surveying and, in general, low noise levels.
The receiver unit is calibrated to indicate apparent conductivity (1-300 mS/m). At low values of terrain conductivity (<100 mS/m), apparent conductivities are linearly proportional to actual conductivities. For resistive terrains (low conductivities), the vertical depth of exploration over the homogeneous or horizontally stratified earth for coil separations of 10, 20 or 40m are 15, 30 and 60m (horizontal coils) and 7.5, 15 and 30m (vertical coils) respectively. The lateral extent of the volume of the earth, whose conductivity is sensed, approximates the vertical depth and small changes in conductivity (5 to 10 mS/m) are readily and accurately measured.

5.3. Application of Electromagnetic Systems

In general, for communities investigated, dyke intrusions were targeted together with fractured hardrock formations. The detectability of fracture zones depends on their width, the thickness and conductivity of the overburden layer, the quality of the groundwater and the depth of the groundwater level.

The distribution of fractures in hard rocks is usually irregular and geo-electrical models for quantitative interpretation are seldom applicable. For dipping conductive zones or ramp discontinuities in the overburden, drilling sites were selected down-dip side. The distance away from the top of the conductor or the top of the edge of the discontinuity was based on the anticipated depth of the groundwater level.

Different types of magnetic anomalies, often having the same order of magnitude, could be distinguished by correlating electromagnetic data with magnetic data. Electromagnetic signatures over geological contacts and faults were distinguished by a step in magnetic background response, where typical dyke type anomalies are absent. Intrusive dykes possess distinct magnetic signatures. The presence of remnant magnetism and the lack of background definition may however, hamper interpreting dip direction from magnetic data. Depending on the width of the dyke and the degree of weathering, the center of an electromagnetic anomaly may coincide with the center or edge of the dyke. The direction of dip may often be interpreted from the geometry of the electromagnetic anomaly and the width and position of the dyke contacts may be identified from the negative electromagnetic anomalies.

6. PERCUSSION DRILLING

Prior to VSA GeoConsultants' involvement in the Phalaborwa North area, the Department of Water Affairs and Forestry and the Department of Agriculture drilled 92 known holes in the period before November 1997. Within the next four months until February 1998, another 2 targets were located and drilled and 7 redrills were executed by independent contractors employed by VSA GeoConsultants. Boreholes were constructed and completed to specifications as laid down by the Department of Water Affairs and Forestry to secure the long term viability and serviceability of the installation.

The most common method employed for the sinking of a water supply borehole is that of rotary air percussion drilling employing a down-the-hole (TDH) hammer. This drilling technique is ideally suited for hard rock formations. In instances where other techniques such as Odex drilling were used, site specific circumstances required specialised techniques. In cases were boreholes were rehabilitated, the cable tool percussion drilling method were used employing the familiar jumper rig.

The cuttings brought to the surface by air return from the hammer were collected and described for each meter drilled. Where available, the lithologies described for each borehole is presented in borehole logs in Appendix A, together with all other relevant information pertaining to and obtained from the borehole.

Water intersections were recorded, and blow yields measured using the "drum-and-stopwatch" technique. By using a dipmeter, the static water level of each borehole was determined.

The extreme diverse nature of subsurface conditions, sometimes over very short distances, renders it virtually impossible to standardise borehole construction. Albeit, the majority of boreholes within the area were completed to 165mm diameter. Steel casing is installed from surface, through unstable, unconsolidated or fractured material. Perforated casing is extended across waterbearing horizons and allows groundwater to enter the borehole. Every successful community water supply borehole were provided with a sanitary seal to prevent the ingress of potentially contaminated surface water into the borehole via the borehole sidewall and the outside of the casing.

No correlation exists between the type lithology present and the drilling depth. The average depth of boreholes in the area is in the order of 55m, with an average groundwater level of 15m.

7. TESTPUMPING AND RESULTS

The correct operation and utilisation of boreholes result from the assessment of the productive capacity (yield potential) of the hole as well as the productivity of the aquifer supporting the borehole. Such knowledge is provided by two different types of pumping tests performed separately. The purpose for which the borehole is to be used and the amount of water, which it is required to supply, are the circumstances that will determine whether one or both tests are required.

Based on the airlift yield and the electrical conductivity field measurements recorded during the drilling phase, decisions to yield test or not to yield test were made. Airlift yields of less than 0.3 l/s were not yield tested as a rule.

A total of 51 boreholes were tested during the period November 1997 – February 1998 of which 47 were existing boreholes. H13-0342 was pumped constantly by the Phalaborwa Municipality and consequently it has not been tested yet, as it could not be taken out of production. The remaining 40 boreholes not tested belong to the Department of Agriculture.

The borehole-testing program consists of a calibration test, followed by a step drawdown test and a constant discharge test.

The **calibration test** is done at the beginning of every pumptest to determine the yield of the step drawdown test, to determine the efficiency of the pump to be used and to reveal any borehole construction problems (sand pumping).

The **step drawdown test** is performed to assess the efficiency of the borehole, and to determine at which rate a longer duration test (constant discharge test) can be performed. It entails pumping the hole at three or more sequentially higher pumping rates each maintained for an equal length of time (generally not less than 60 minutes and seldom longer than 120 minutes). The magnitude by which the water level in the borehole drops (known as the **drawdown**) in response to these known pumping rates is measured and recorded in accordance with a prescribed time schedule. The water level is also measured and recorded, again to a prescribed time schedule, for a period of time immediately following the period of pumping. This represents the period of recovery in which the water level rises towards its starting level before pumping. During the period November 1997 - February 1998, 46 step drawdown tests were carried out in the Phalaborwa North area.

The **constant discharge test** is performed to determine aquifer parameter values (transmissivity and storativity) and to determine the possible existence of groundwater barrier boundaries. The test entails pumping the borehole at a single pumping rate, which is kept constant for the entire duration of the test (12-72 hours). The drawdown in water level in the borehole during the course of the test is again measured and recorded according to a prescribed time schedule. In the case of the constant discharge test the recovery period is also measured and recorded. During the same period 24 constant discharge tests were done in the area.

The data obtained from the constant discharge test permits the calculation of the specific capacity of the borehole at the set-pumping rate after a substantially longer period of pumping. A comparison of this value with those obtained from the step drawdown test offers a means of assessing the more realistic productivity of the borehole under operating conditions. It also permits the **transmissivity** of the aquifer to be calculated. This parameter quantifies the ability of the groundwater resource to transmit water, thereby describing the conduit function of the aquifer. An attempt was made to determine the average transmissivity of each lithology, but due to too many external variables influencing the aquifers, it was determined that the transmissivity (T-value) of each aquifer is a function only of its immediate environment (dykes, fractures) and cannot be generalised.

Quantification of the second function of an aquifer, namely its water storage capacity (**storativity**), is achieved if the water level response in an observation borehole is known. It defines that volume of the rock material, which is able to store water (Hobbs, personal comm). Due to a lack of sufficient observation boreholes, S-values (storativity) were seldom calculated in the Phalaborwa area and only a common estimate is given in Appendix A.

Although test pumping cannot be considered as the ideal way of evaluating the long-term sustainability of a groundwater resource, it does provide a quick and simple way of evaluating the short to medium term performance characteristics of a borehole. It must be emphasised that calculations done from test pumping data are only representative of the aquifer characteristics in the immediate surrounding of the borehole. Factors such as aquifer transmissivity as well as the length of a test, will determine the area of influence reached during testing (the longer the test, the greater the area of influence).

8. HYDROCHEMISTRY

A total of 47 groundwater samples were collected throughout the study area during the period November 1997 to February 1998. The samples were analysed for their main hydrochemical concentrations (macro elements) at the DWAF Laboratory in Pretoria. Elements analysed for include: Ca, Mg, SO_4, NO_3, F, Cl, Na, K, N, SiO_2 and PO_4. The final laboratory analyses expressed in mg/l are presented in Appendix B. The analyses were converted to meq/l using the conversion factors presented in Hem (1970, p.83) in order to determine the various analytical parameters by which groundwater quality in the area could be evaluated.

8.1. Sampling procedure

Groundwater samples were taken at the end of the constant discharge test in order to be representative of the water of a wider zone around each borehole.

8.2. Water quality:

Water quality of domestic water, utilized for human consumption and food preparation, must be safe to use if the consumers' health is to be protected. For this reason the "Proposed Guide for the Health Related Assessment of the Quality of Water Supplies (First Edition, 1996)" was set forward by the Department of Water Affairs and Forestry and the Department of Health in 1996. This document facilitates the evaluation of water on the basis of four water quality classes:

CLASS 0 - Water of ideal quality, with no health or aesthetic effects, suitable for lifetime domestic use.

CLASS 1 - Water of good quality, suitable for lifetime use with very little health effects. Rare instances of mild health effects with lifetime use.

CLASS 2 - Water has a definite risk of health effects with long term or lifetime use. Water is suitable for short-term use only. Common instances of negative effects with long term use.

CLASS 3 - Unacceptable water quality. Water is unsuitable for domestic use, unless treated.

MAP C: "*Hydrochemistry* " " presents the application of this classification to each of the analyzed boreholes in the study area. Each borehole position is color coded to represent its overall water quality class.

Element concentrations mainly responsible for health related risks, are N and F. Approximately 96% of water in the Phalaborwa North area is classified as Class 2 or 3 due to, amongst other elements, its N and F contents. Health effects related to Class 2 and 3 nitrates are mainly limited to infants up to the age of 6 months, that are at risk of developing a condition termed *methaemoglobinaemia* (a type of blood disorder). Health effects related to Class 2 and 3 fluorides include dental mottling with associated tooth damage due to the softening of enamel.

Element concentrations mainly contributing to aesthetically related effects, includes Ca, Mg, Na, Cl and TDS. Ca and Mg ions are the main elements contributing to the hardness of the water, generally expressed as $CaCO_3$. All samples analyzed can be described as "hard" or "very hard", exceeding 200mg/l $CaCO_3$. Effects associated with hardness includes scale forming on heat exchange surfaces such as cooking utensils, hot water pipes, kettles and geysers, and an increase in soap required to produce a lather. The TDS of water serves as an indicator to the salinity of water. Although effects associated with this concentration are mainly aesthetic in nature, it can have health risks at very high concentrations (in excess of ±2000mg/l). Health effects are mainly related to a disturbance of the body salt balance in humans. Only approximately 4% of the samples exceeded the latter limit, all of which are situated in the southern corner of Namakgale 1. Approximately 78% of the analyzed samples indicated a TDS of between 1000 and 2000mg/l, which could have aesthetic effects such as a salty taste, and corrosion/scaling on plumbing and household appliances.

9. CONCLUSIONS

Data analyses of the Phalaborwa aquifers indicate that predominantly secondary aquifers could be utilized in the area. Hydrochemically, the northern part of the Phalaborwa area has a majority of class 2 or 3 water indicating that the groundwater is generally unsuitable for long-term domestic use unless treated.

Presently the total recommended groundwater abstraction in the area is 2177.28m; per day with the total population of the area (1997) being in the order of 105 016. The water requirement per person per day is 25 liters. The current recommended groundwater abstraction rate meets a water supply of 20 liters per person per day.

It is therefore concluded that the Phalaborwa area has insufficient groundwater reserves but due to a lack of funding additional target areas could not be explored.

10. REFERENCES

BARTON, J.M., DU TOIT, M.C., VAN REENEN, D.D., RYAN, B., (1983). Geochronological studies in the southern marginal zone of the Limpopo Mobile Belt, Southern Africa. *Spec. Publ. Geol. Soc. S. Afr.*, p55-64.

BRANDL, G. (1987). The geology of the Tzaneen area: Expl. Sheet *geol. Surv. S. Afr.*, 2330 (Tzaneen), 55pp.

BURGER, A.J. and WALRAVEN, F., (1977). Summary of age determinations carried out during the period April 1977 to March 1978. *Ann. Geol. Surv. S. Afr.*, 12, 209-218.

Department of Water Affairs and Forestry (1996). *Proposed Guide for the Health Related Assessment of the Quality of Water Supplies*, First Edition.

DU TOIT, M.C. (1979). *Die geologie en struktuur van die gebiede Levubu en Bandelierkop in Noord-Transvaal*. Ph.D. thesis, Rand Afrikaans Univ. (unpubl.).

FRIPP, R.E.P., VAN NIEROP, D.A., CALLOW, M.J., LILLY, P.A., DU PLESSIS, L.U. (1980). Deformation in part of the Archaean Kaapvaal Craton, South Africa: *Precambr. Res.*, 13, p241-251.

HEM, J.D. (1970). Study and interpretation of the chemical characteristics of natural water, 2nd ed. *U.S. Geol. Surv. Water Supply Paper* 1473, 363p.

JANTSKY, J.G. (1978). Proposed stratigraphy for the Murchison Range and the Rooiwater Igneous Complx: *Internal Rep. Geol, Surv. S. Afr.* (unpbl.).

LARSON, I. (1977). Torra och vattenrika bergartstyper I svenskt urberg. (Dry and water bearing rock types in hard rocks of Sweden). *J. Water Manage. Res.* (Stockholm), vol. 33, no. 2, 96-101.

MIDGLEY, D.C., PITMAN, W.V., MIDDLETON, B.J. (1994). Surface water resources of South Africa 1990. *WRC Report no 298/1.1/94, Vol. 1 Appendices* (First edition).

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CORRECTIONS TO PHALABORWA REPORT

Additional chemistry analyses indicated that all water tested in the Phalaborwa area have a class 2 or 3 chemistry. No class 0 and 1 water occurs as indicated in report.