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# THE USE OF ELECTRICAL GEOPHYSICAL TECHNIQUES FOR THE DEVELOPMENT OF GROUNDWATER SUPPLIES IN SOUTH AFRICAN NATIONAL PARKS

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*Abstract* – Geo-electrical investigations have been carried out along the Nossob River in the Kalahari Gemsbok National Park and in the Nwanedzi area of the Kruger National Park. The object of these investigations was to locate potable groundwater supplies with a greater degree of accuracy than the random drilling of boreholes was able to do. The successful completion of the investigations has proved that when correctly applied the geo-electrical technique is a valuable aid to locating favourable target zones for groundwater development, thus resulting in considerable economic benefits.

## *Introduction*

Hydrogeological investigations in the Republic of South Africa to locate and develop potable groundwater supplies for the Nossob Camp in the Kalahari Gemsbok National Park (KGNP) and the Nwanedzi area of the Kruger National Park (KNP) were carried out in 1973 and 1976 respectively. These investigations involved the extensive use of electrical geophysical exploration techniques.

The KGNP lies in the northern Cape Province to the north of Upington. South West Africa is adjacent to its western boundary while the Nossob River forms the eastern boundary. The Nossob tourist camp is situated next to the Nossob River, some 140 km north of the Park headquarters at Twee Rivieren.

The KNP is in the lowveld of the eastern Transvaal and follows the Mozambique border from the Limpopo River in the north to Komatipoort in the south. The Nwanedzi area is situated on the Mozambique border approximately 20 km east of the Satara tourist camp.

Earlier drilling carried out along the Nossob River and in the Nwanedzi area, had shown a varying degree of success. It was subsequently decided that the application of hydrogeophysical techniques could substantially improve the accuracy of locating groundwater supplies. This paper outlines the investigations carried out in the two areas.

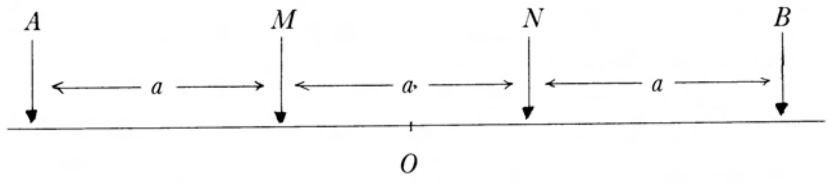
## *Methods*

The geophysical technique employed in both investigations was the geo-electrical method. The theoretical background of this method is described by Kunetz (1966) and Van Zijl (1977). The applicability of these techniques to groundwater exploration is widely recognized (Astier 1971; Worthington 1977; Van Zijl 1977; Martinelli 1978).

A brief description of the electrical techniques employed in the investigations is given. Geo-electrical techniques basically involve the passage of a known artificial current through the ground and the measurement of the resulting potential difference produced. The current is introduced into the ground via two current electrodes (designated *AB*) and the potential difference is measured between an inner pair of potential electrodes (designated *MN*). The method allows the resistivity of the volume of ground below the potential electrodes to be measured. The significance of this is that different lithologies are usually characterised by different resistivities. In addition, weathering within the same rock mass generally manifests itself through changes in resistivity of the rock. Furthermore, the resistivity of the rock is affected by water content and quality. For example, an increase in water salinity produces a decrease in the electrical resistivity of the formation. Changes in the electrical properties of an area can therefore be interpreted in terms of either change in lithology, change in weathering, or changes in water quality.

Various electrode configurations may be used for geo-electrical investigation. For the surveys undertaken two electrode configurations, the Wenner electrical profiling array and the Schlumberger vertical electrical sounding array were used.

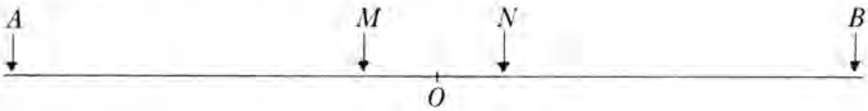
With the Wenner array the electrode configuration is as shown below where AM = MN = NB, and *a* is therefore constant.




The point *O* is the position of measurement of the resistivity of the ground. After each measurement is taken all the electrodes are moved along a straight line by a distance equal to *AM* and keeping *a* constant.

This method is suitable for measuring sub-surface variations of resistivity at an approximately constant depth of investigation. In this way the electrical properties are measured as a horizontal profile. The data are plotted as a graph showing resistivity versus the central point of measurement and from which geological contacts, lateral and vertical changes in the lithology and degree and type of weathering can be identified. The method is generally used as a reconnaissance technique for the selection of target areas to be investigated in detail by means of Schlumberger vertical electrical soundings. Qualitative information is obtained from traversing.

The electrode configuration used for Schlumberger vertical electrical soundings is as shown in the diagram below:




where $\frac{OA}{MN}$ is always greater than 1,5.

A Schlumberger vertical electrical sounding is performed by progressively increasing the current electrode spacing *(AB)* about the central point *O* and measuring the corresponding potential drop between the potential electrodes *(MN)*. Expansion of *MN* is carried out only when the potential difference becomes too small to be measured. As the distance between the current electrode is increased the total volume of ground sampled is also increased both vertically and laterally and a vertical resistivity profile is built up. The resistivity data gathered is plotted against half the corresponding current electrode separation and a curve is obtained. Using graphical or computer analytical techniques it is possible to quantitatively interpret the curve and calculate the vertical distribution of electrical resistivity below the central reference point 0.

In a homogeneous stratified ground the vertical distribution of the resistivity will be strictly related to variations of lithology, weathering, water quality etc, with depth. Geological information of different lithology and water bearing characteristics can therefore be recognised by vertical variations in the resistivity values.

The main advantage of using these methods are that the geological and hydrogeological formations of a given area can be rapidly surveyed without the comparatively high cost and long duration of a borehole survey of similar detail, and the risk associated with the drilling of random boreholes is eliminated.

*Case Histories*

In order to illustrate the advantages attached to the use of geo-electrical techniques for groundwater exploration in different geological and hydrogeological environments two case histories are described below.

*Development of potable groundwater supplies for the Nossob camp – Kalahari Gemsbok National Park*

The survey area is shown in Fig. 1. Previous drilling operations carried out along the Nossob River from the Nossob camp north to Kwang

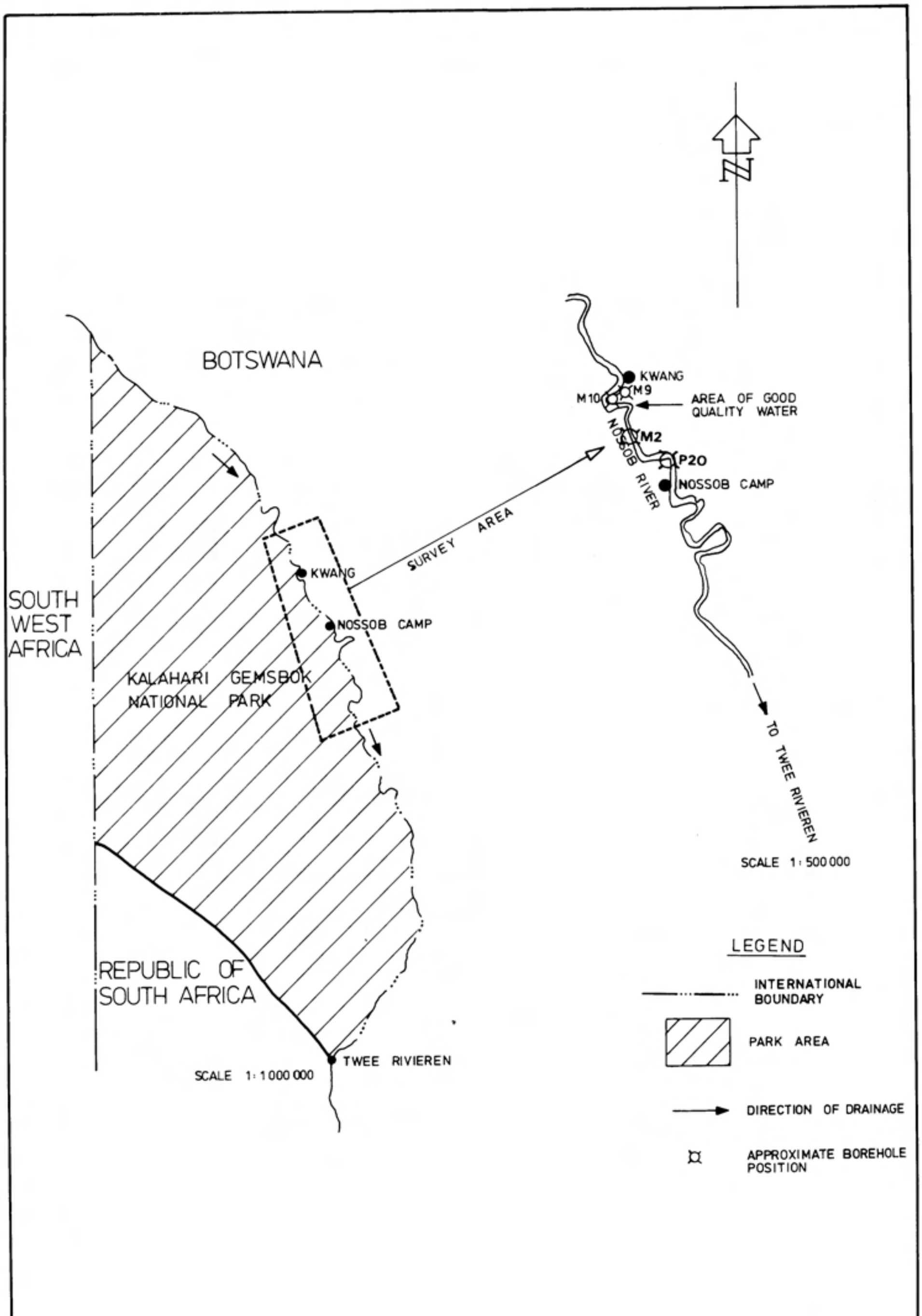



Fig. 1. Survey area, Kalahari Gemsbok National Park.

showed that the geology comprises superficial sand and clay, calcareous sands and gritty limestones, and sand with thin gravel intercalations, overlying shale and dolerite of the Karroo System. This unconsolidated sequence is in excess of 100 m thick in places.

Drilling was carried out on the basis of random siting and a generally saline water body with a salinity in excess of 5 000 ppm was found to saturate the sand below a depth of approximately 75 metre. Indications were that this saline water was overlain by lenses of marginally fresh water. These lenses were of varying thickness and possessed a salinity of approximately 1 500 ppm. (Water of this quality is accepted for human consumption in this region provided that the fluorine content is less than 2 ppm). This hydrogeological situation was not, however, fully recognized by the driller and hence all the boreholes were continued until the saline water was penetrated. In every case except for two holes drilled at Kwang this resulted in the loss of the borehole as the water quality became unsuitable for human consumption.

As a result of the experience gained and because of the critical water supply situation at Nossob camp the National Parks Board of Trustees required a properly planned and thorough investigation to be undertaken to locate groundwater supplies with a high degree of accuracy.

Due to the resistivity contrast between the fresh water sands and the salt water sands it was considered that the vertical electrical sounding geoelectrical method would provide an effective means of determining where the fresh water sands were the thickest. In addition, the approximate depth of the interface between the fresh and saline water would be found. Hence boreholes could be sited in the most favourable locality.

The survey comprised calibration soundings carried out at existing boreholes followed by exploration soundings run at approximately 500 m intervals along the river course. Interpretation of the calibration soundings showed that the resistivity of the fresh water sands is of the order of 150 $\Omega$m, while that of the saline water sands is less than 10 $\Omega$m. It was also apparent that the interface between the fresh and saline water occurred at an approximate depth of 75 m below surface. Typical soundings are illustrated in Fig. 2.

The exploration soundings indicated that the most favourable hydrogeological conditions, in terms of thick lenses of groundwater of good quality, were present just south of Kwang. On the basis of the Vertical Electrical Sounding (VES) survey four boreholes were sited and drilled.

In order to control the water salinity with depth the driller was instructed to drill the boreholes to a depth of approximately 75 m, the depth of the fresh water/saline water interface obtained from the interpretation of the soundings. However, once water was struck the water salinity was to be monitored at 1m intervals using a conductivity meter so that drilling could be terminated before the salinity deteriorated beyond an acceptable limit. The relationship between salinity and depth for two of the boreholes

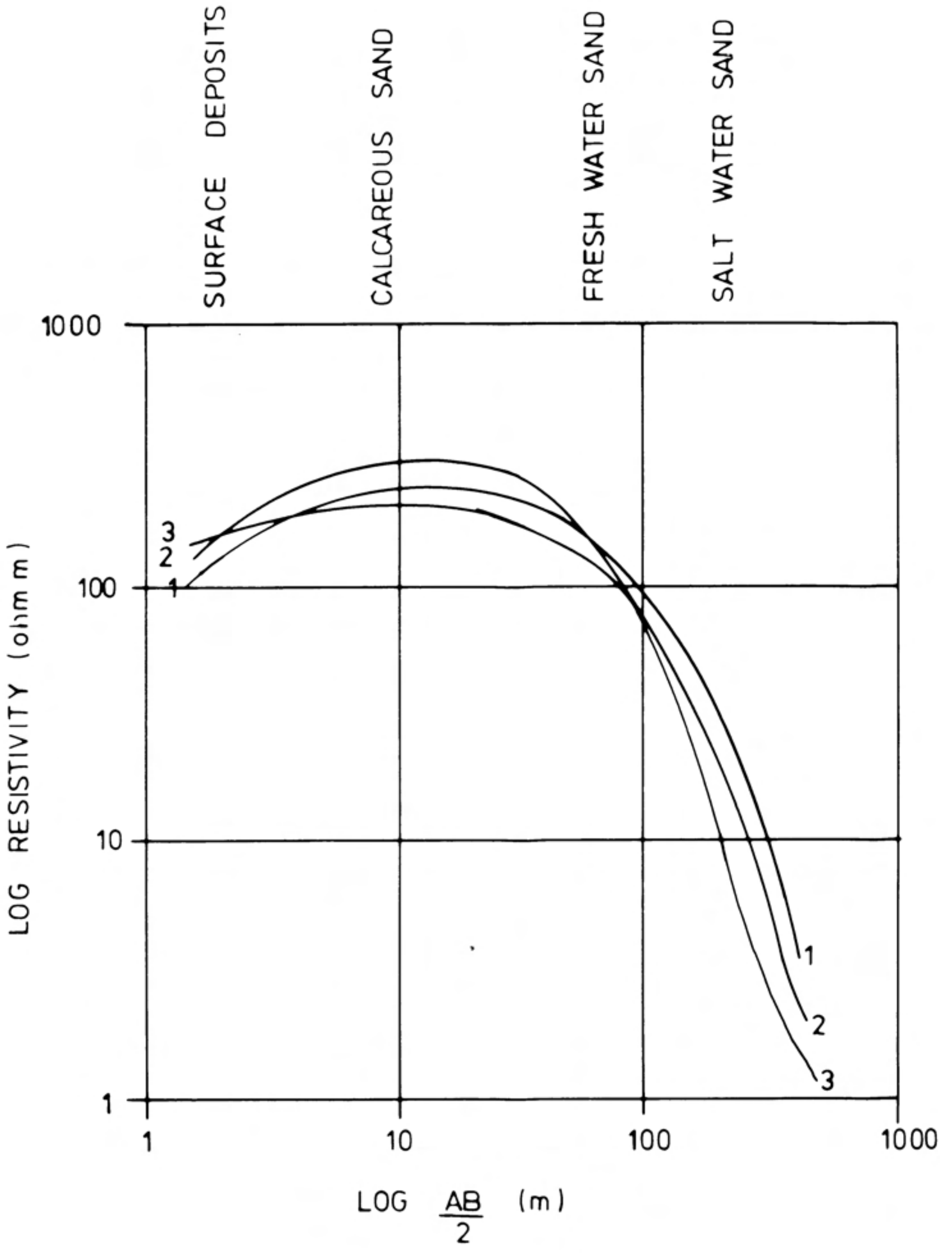



Fig. 2. Typical Vertical Electrical Soundings, Kalahari Gemsbok National Park.

(M9 and M10) is shown on Table 1. It can be seen that a sharp interface occurs between 74 m and 75 m in borehole M9, thus showing that close control of the construction depth is of critical importance in this hydrogeological environment.

Table 1

*Relationship between water conductivity and depth, Kalahari Gemsbok National Park*

| Borehole M9 | | Borehole M10 | |
|---|---|---|---|
| Water Conductivity (μmhos/cm) | Depth (m) | Water Conductivity (μmhos/cm) | Depth (m) |
| 1 500 | 66 | 1 800 | 61 |
| 1 600 | 67 | 1 800 | 62 |
| 1 700 | 68 | 1 900 | 63 |
| 1 800 | 69 | 1 900 | 64 |
| 1 900 | 70 | 1 900 | 65 |
| 2 200 | 71 | 1 900 | 66 |
| 2 200 | 72 | 1 900 | 67 |
| 2 600 | 73 | 1 900 | 68 |
| 2 700 | 74 | 1 900 | 69 |
| 5 100 | 75 | 1 900 | 70 |
| | | 1 900 | 71 |
| | | 1 900 | 73 |

Of the four boreholes drilled, one (M2) has a very low yield and poor quality water, two (P20 and M9) have a good yield and potable water with a quality far better than any of the randomly drilled boreholes, and one (M10) possesses a good yield and good quality water.

The overall result of the survey clearly shows that the application of electrical methods in this type of hydrogeological environment is advantageous.

*The location of groundwater supplies in the Nwanedzi area of the Kruger National Park*

The Nwanedzi area (Fig. 3) is a 10 km wide strip covering an area from just south of the Nwanedzi rest camp to 20 km to the north in the Kruger National Park.

The geology of the area comprises rhyolites and basalts of the Karroo System. The rhyolites outcrop as a 2 km wide strip paralleling the Mozambique border. These rocks form the degraded Lebombo Mountains. Rhyolites are fine-grained acid igneous rocks which are resistant to weathering and erosion and are known to be generally poor water producers. Basalts

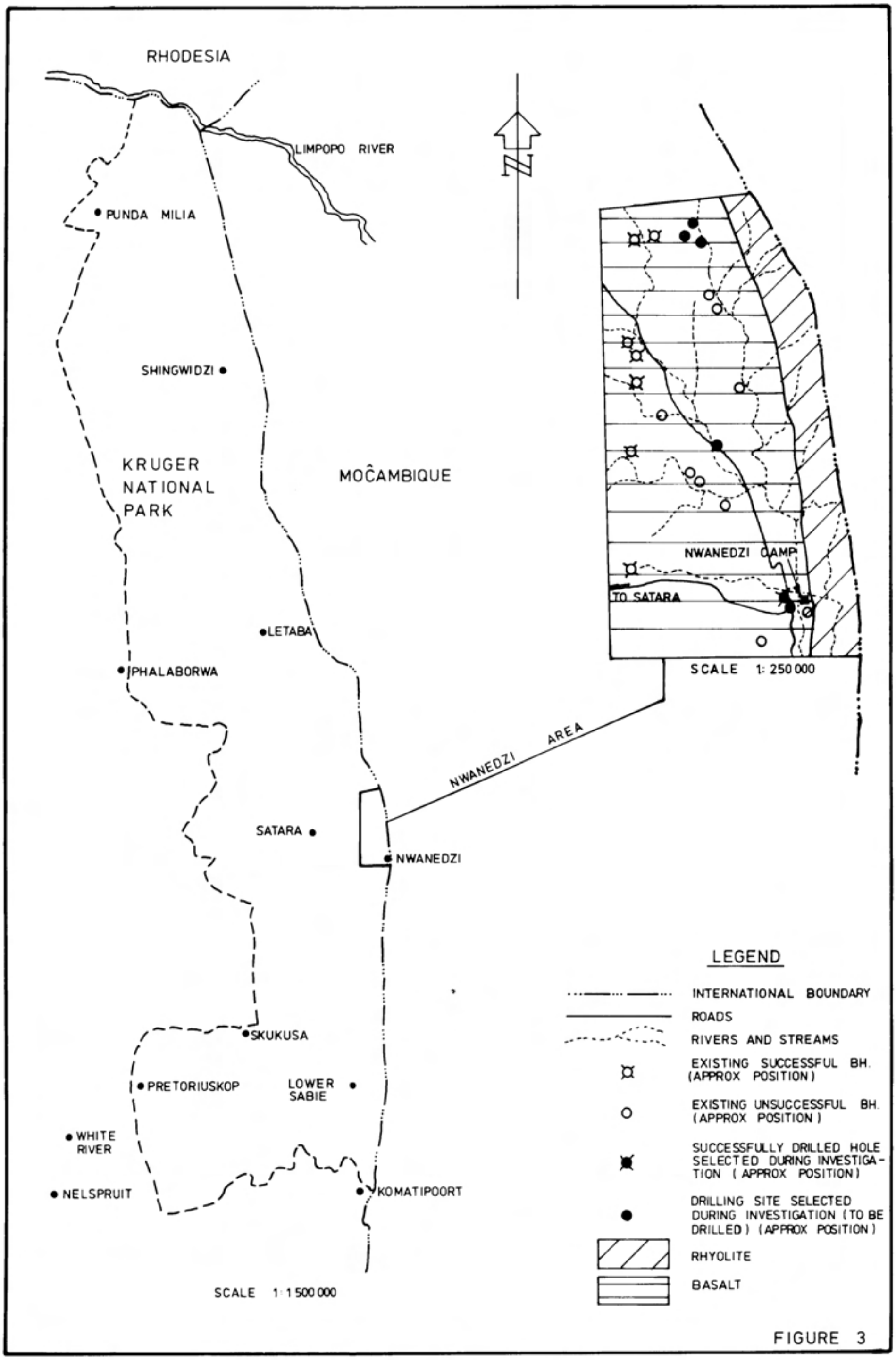



Fig. 3. The Nwanedzi area, Kruger National Park.

underlie the flat area to the west of the rhyolites and are fine grained basic igneous rocks. Basalts are susceptible to weathering and fracturing and substantial groundwater supplies may be obtained from optimumly sited boreholes where fracturing and weathering has enabled secondary permeability to be developed to a depth suitable for adequate storage of groundwater. The location of these features is essential as no water is contained in unweathered solid basalt.

A severe shortage of water for both the Nwanedzi camp and for game watering occurred and eight boreholes had been randomly drilled within the study area but with no success. The approximate positions of these boreholes are given in Fig. 3, together with seven successful boreholes drilled further to the west. Because of the complex hydrogeological situation the National Parks Board of Trustees decided to adopt a more systematic approach for the further siting of borehole supplies in the eastern portion of the area where the dry holes had been drilled.

A geo-electrical exploration programme was designed to locate and to assess the development potential of zones of fracturing and weathering within the basalts. No attempt was made to investigate the rhyolites outcropping close to the Mozambique border as it was considered unlikely that successful boreholes could be located in this rock type.

Electrical resistivity traverses were run along accessible tracks and roads, using a Wenner electrode array with $a = 30$ metre. The aim of the traversing was to locate zones of low resistivity which could represent favourable zones for groundwater occurrence. Zones of low resistivity located by the traversing were then investigated in detail using vertical electrical soundings run according to the Schlumberger electrode array. Interpretation of the soundings provided a quantitative control of the resistivity and depth of the weathered zones, this enabled the groundwater potential of these zones to be assessed.

Borehole sites were selected on the basis of a combination of favourable resistivity and favourable depth. Potentially favourable localities are where the weathered zone is in excess of 30 m and the resistivity is less than 100 $\Omega$m. It is noted that knowledge of the likely maximum depth of the water bearing zone avoids the drilling of unnecessarily deep holes, as had occurred with the randomly sited boreholes, thus resulting in cost saving.

As an example of the borehole siting method used part of the traverse run along the Nwanedzi to Olifants Camp road near the Nwanedzi crossroads is illustrated in Fig. 4. It can be seen that a background resistivity of the order of 200 $\Omega$m occurs with a resistivity low from peg 600 to peg 690. Vertical Electrical Sounding 2 was run at this site. The sounding indicated a favourable resistivity occurred at this site to a depth of 35 m – 40 metre. The borehole subsequently drilled intersected fractured water bearing basalt to 38 m, followed by unweathered non-water bearing basalt. The driller reported a yield in excess of 600 gph.

Seven further sites scattered throughout the study area were selected, but drilling has not been undertaken yet.

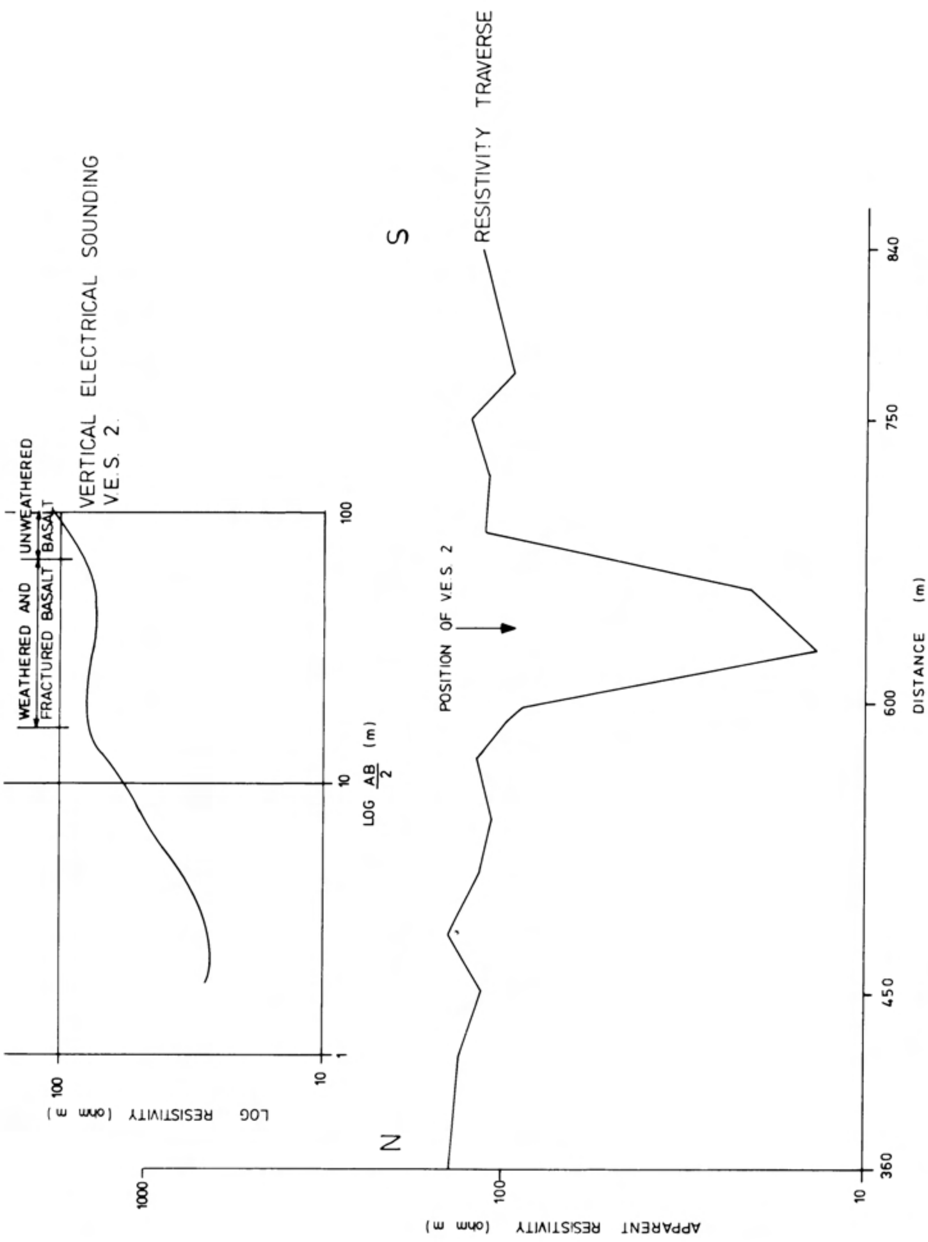



Fig. 4. Typical resistivity traverse and Vertical Electrical Sounding, Nwanedzi Camp area, Kruger National Park.

*Conclusions*

The two case histories presented have demonstrated the usefulness and versatility of the geo-electrical method when applied to groundwater investigations in the correct manner. This is evidenced by the successes achieved in the KGNP and in the Nwanedzi area compared to the results obtained from the random drilling of boreholes. It is concluded that the technique is a particularly useful exploratory tool available to assist in the location and delineation of groundwater resources in different geological and hydrogeological environments.

In addition the method has several major advantages including the rapid nature of the survey, the substantial cost savings which are derived compared to a drilling survey of the same detail, and the substantial cost saving obtained by avoiding the drilling of boreholes in areas which are devoid of any groundwater potential.

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