A Hydrogeological Assessment
of the
Uitenhage - Kruis River Area,
Cape Province, South Africa.

by

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Chapter 1. Introduction.

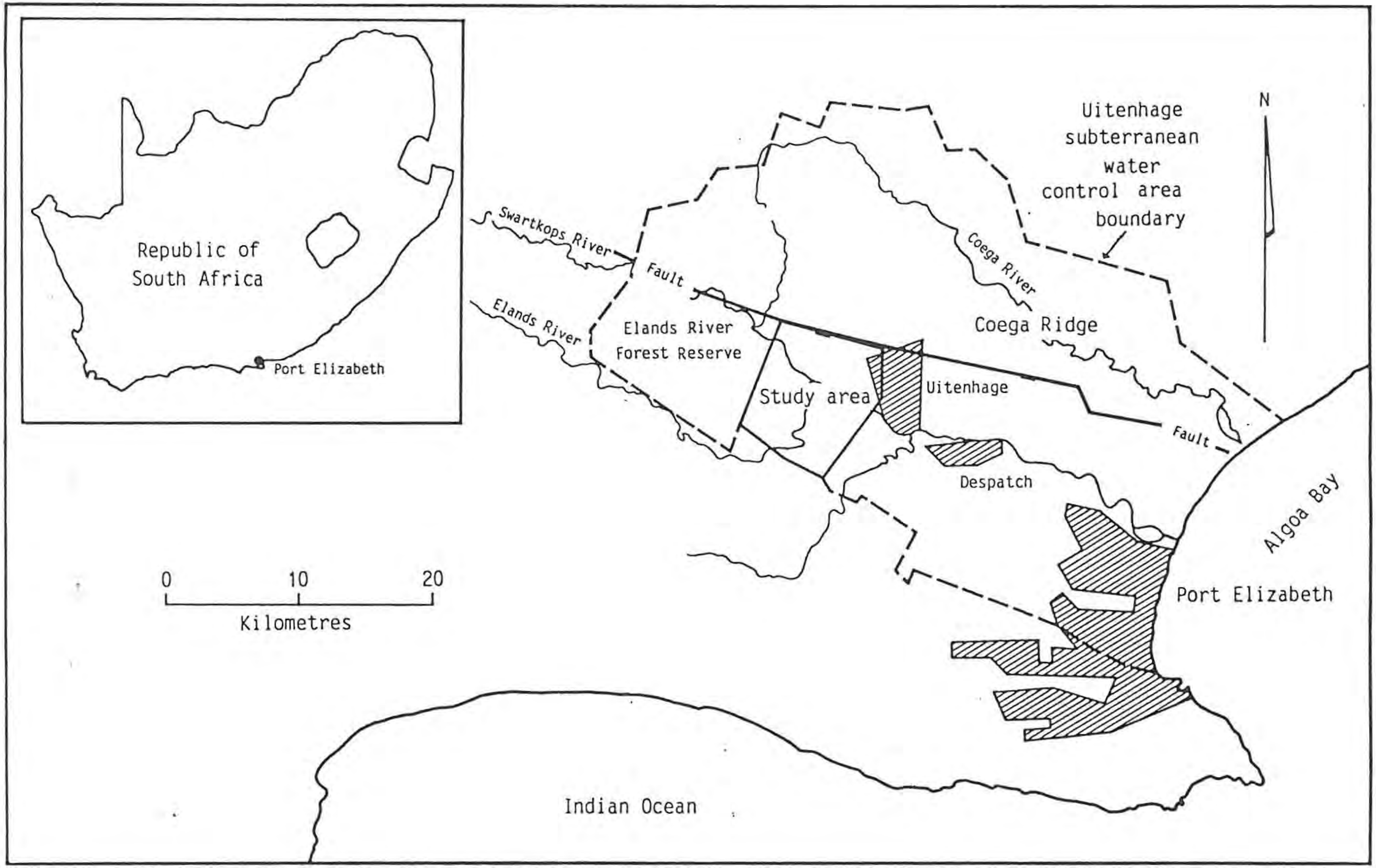
1.1 General characteristics of the Kruis River Study area.

The study area which lies south west of Uitenhage, comprises some 108km^2 and includes the cadastral farm of Kruis River from which it gets its name (Figure 1). Although little accurate data are available of the detailed climate of the Kruis River area, Marais (1964) quotes average rainfall and potential evaporation figures for the adjacent Groendal area of, 584mm and 610mm per annum respectively. Rainfall to the area is mostly in the form of hard downpours during the last four and first three months of the year.

The southern portion of the Kruis River area is drained by the Elands and Hol rivers, which enter the area in the south-west and south-east respectively. The Hol River flows north to join the easterly flowing Elands River on the farm Ecodale, from which point the Elands River changes direction and flows in a north-easterly direction to join the Swartkops River at Doornlaagte. The Swartkops River drains the northern and eastern parts entering the area in the north-west near Rooikrans and leaving the area in the East at Niven's Drift. The Swartkops River is braided in nature with large quantities of alluvial material deposited in the river valley. It is on alluvial material deposited in the Elands and Swartkops river valleys that the dominant agricultural activity of market gardening takes place.

In the east of the Kruis River area an inlier of resistant quartzites of the Table Mountain Group, (in future referred to as T.M.G.) projects through the surrounding Cretaceous strata to form a prominent hill. The mountains marking the northern boundary of the area are the physiographical expression of the Uitenhage or Coega fault which trends west-north-west/east-south-east and which is thought to separate Kruis River from the principal portion of the Uitenhage Artesian Basin. In the west of the region is a deeply dissected mountainous region which forms the Elands River Forest Reserve and is thought to constitute the main recharge area to the Kruis River system.

FIGURE 1 LOCATION OF THE STUDY AREA



1.2 Historical Review of the decline in groundwater levels.

The Uitenhage Artesian Water Control Area came into being in 1957 in terms of Government Proclamation 260. The proclamation of the control area largely resulted from pressure by the Uitenhage Municipality and a number of farmers whose established abstractions were being detrimentally effected by the increasing number of boreholes being drilled in the region. Hydrogeologically the region may be considered to consist of three separate units, the Coega Compartment, the Bethelsdorp Compartment and the Kruis River area. The Kruis River area forms the area of this study.

The first boreholes in the Kruis River area were drilled about the year 1911 (Enslin, 1962) and by 1959 approximately 36 holes had been drilled. The piezometric level exceeded collar elevation in an estimated 14 of these boreholes. By 1977 abstraction from the system is thought to have resulted in the cessation of natural flow from KR 41,the last flowing artesian hole in the area. At present although all of the 35 boreholes currently in use are still artesian in nature, in no borehole does the piezometric level exceed collar elevation.

Geological and hydrological investigations of the Uitenhage artesian Water Control Area were conducted by Enslin (1962) and Marais (1964) of the Department of Geological Survey, in order to provide information about the geohydrological conditions.

1.3 Study Objectives and Research Aims.

Despite previous studies the formations which serve as aquifers (storage and conduit) were not readily identifiable, nor were the aquifer properties or dimensions known with any certainty. This investigation aimed to broaden and deepen the understanding gained from previous reports and to provide a scientific basis for future hydrological management. Because of time and cost constraints it was necessary to impose limits on the scope of the investigation. For this purpose the most important questions concerning the hydrogeology of Kruis River were formulated as research aims.

AIMS OF THE INVESTIGATION

1. Which lithological unit/units form the aquifer/aquifers in the Kruis River area?
2. What is the lateral extent of the aquifer lithologies?
3. What is the transmissivity and storativity of the lithological unit/units which form the aquifer/aquifers?
4. To what degree is/are the lithologies hydraulically independent of one another?
5. What is the nature of the relationship between water chemistry and lithological type?

1.4 Methods of Investigation.

Davis and De Wiest (1966) give a basic guideline of what regional geohydrological investigation should encompass, when they define hydrogeology as "the study of groundwater with particular emphasis given to its chemistry, mode of migration, and relation to the geologic environment." p1. Hazel (1975) follows a more applied approach when he states that, "the science of groundwater hydrology is concerned primarily with evaluating the occurrence, availability and quality of groundwater." p1.

In order to undertake such an evaluation, additional data aquisition methods used by Walton (1970) and those used by Reeves, Skinner and Wilkinson (1975) have been considered. It was found that eight groups of survey data and information are required. The surveys are listed below in the normal sequence of execution although inevitably linked and interrelated to such an extent that progression from one survey to another should be considered gradational.

1. Desk study and literature survey.
2. Hydrocensus.
3. Geological and geohydrological mapping.
4. Geophysics survey.
5. Drilling programme.
6. Aquifer testing programme.
7. Hydrochemical survey.
8. Piezometric levels.

The eight groups of survey data and information outlined above have been selected to meet the needs of this particular investigation. Chapter three onwards considers each survey and explains the essential relevance of each in establishing an understanding of the hydrogeological system of Kruis River.

Chapter 2 Hypotheses.

To fulfill the aims of the investigation the following hypotheses have been formulated based on literature and previous work:

A. Identification of the aquifers.

1. The sandstone and conglomerate lithologies of the Kirkwood and Enon Formations form the aquifers in the area.
2. The most easily exploited portions of the aquifers are located close to pre-Cretaceous outcrop.

B. Hydraulic properties of the aquifers.

1. There is considerable hydraulic continuity between aquifer lithologies of the Kirkwood and Enon Formations.
2. Reduced transmissivity reflects the presence of sediments derived from the Bokkeveld Group in the area of mixed provenance.

C. Hydrochemical characteristics of the aquifers.

1. Better quality water is associated with arenaceous and rudaceous sediments.
2. The dominant influences on the hydrochemistry of the study area are the hydrological properties of the lithologies and the contribution of ions to the aquifer lithologies by the marine/esturine mudstones of the Kirkwood Formation.

D. Recharge.

1. The major source of recharge to the system is from Pre-Cretaceous and Cretaceous lithologies to the west of the study area.

Chapter 3 Preliminary Studies.

3.1 Desk study and literature survey.

The desk study included the study of aerial photos, orthophotos, geological maps and reports from previous investigations (Table 1). Valuable insights were obtained from two main sources, from investigations by Enslin (1962) and Marais (1964) and from borehole records held by local control authorities.

TABLE 1 PREVIOUS INVESTIGATIONS UNDERTAKEN IN OR NEAR THE STUDY AREA.

Year	Author	Field of Study or Title
1947	V.L. Bosazza	Report on the location of the Artesian waters in the Cape area, Port Elizabeth district.
1948	T.O. Morris	Notes on underground water supply prospects in the Algoa Bay area, with particular reference to Hougham Park.
1955	E.D. Mountain	The Uitenhage Artesian Basin. (Presidential address to the S.A. Association for the Advancement of Science).
1962	J.F. Enslin	Verslag oor die Uitenhage Ondergrondse Waterbeheergebied.
1964	J.A.H. Marais	Preliminary report on the geological-geophysical investigation of the Uitenhage Artesian Basin.
1980	A. Stone	Hydrogeology of the Uitenhage water control area. (Ongoing research study)
1985	A.J. Venables	A hydrogeological assessment of the Uitenhage-Coega artesian system.

Borehole records from 1957 indicate considerable uncertainty as to the stratigraphy of the water bearing zones. The high proportion of recorded drilling attempts and the frequency with which drilling tools were lost indicate difficult drilling conditions encountered within the conglomerates. Geological maps included in previous reports were deficient in detail and at an inadequate scale.

3.2 Hydrocensus.

Because of high costs of drilling it is essential to make the greatest possible use of existing boreholes. Specially drilled observation points represent in the aggregate, according to Walton (1970), a negligible proportion of the total volume of rock materials through which groundwater moves. The hydrocensus serves a dual purpose as it enables not only the formulation of a field understanding of the system by providing data on yields, formation types, and depths at which water is obtained, but also expands the basic data base of the investigation and may reveal areas requiring detailed investigation. Although complete data for each borehole are seldom available, the borehole survey involved the attempted measurement of the following four criteria:

a) depth to water level below collar elevation or piezometric water levels for artesian boreholes,

b) total drilled depth,

c) yield and annual rates of abstraction,

d) quality of water available.

An inventory of the survey results is contained in Appendix 1 and contains available data for all boreholes still in existence within the study area. It should be noted that many more boreholes were drilled, but have been excluded from the inventory because of either a total lack of available data and/or because of uncertainty of location due to total collapse and disappearance. Piezometric and yield data obtained from this survey are combined and discussed with later surveys. Water quality information obtained is discussed in Chapter 8.

Chapter 4. Geology and Geohydrology.

4.1 Geological and Geohydrological Mapping.

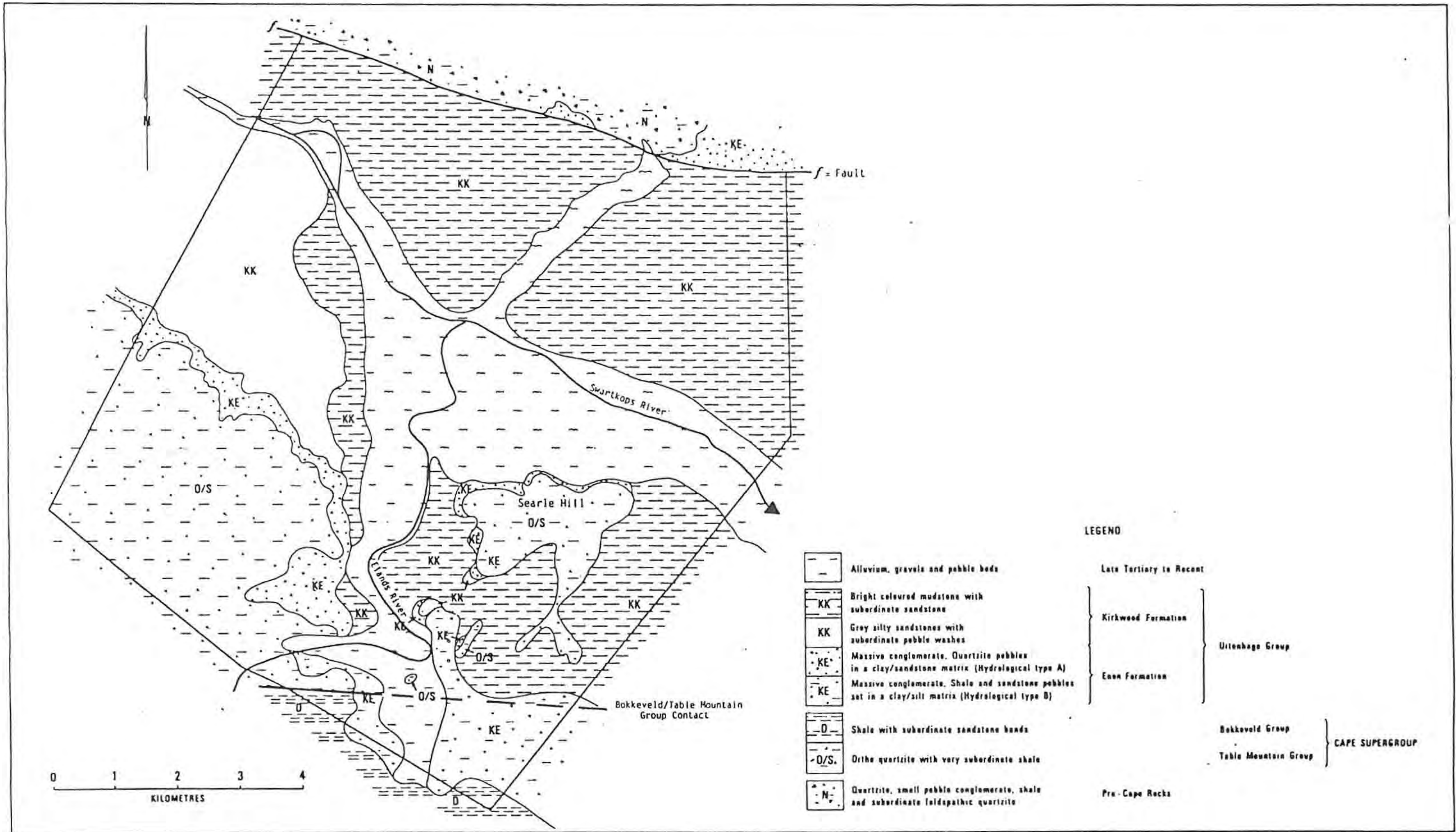
The subsurface distribution of permeable, semi-permeable and impermeable rock, although often more difficult to map than stratigraphy, is the prime factor influencing hydrogeological variations between different formations. Field mapping emphasizing lithology and associated hydrogeological variations was undertaken in the study area (Figure 2) although broad stratigraphic nomenclature was also used because of co-incidence of certain lithographic and stratigraphic boundaries. Detailed hydrogeological mapping of outcrop and structure was regarded as important in the explanation of the Kruis River geohydrological system. Todd (1980) and Freeze and Cherry (1979) emphasise that detailed knowledge of lithology and structure are a prerequisite of hydrogeological interpretation.

4.2 Regional Controls.

Structurally the Kruis River area is within the Algoa tectonic basin which according to Truswell (1977) formed as a result of faulting after the Mid-Jurassic period. Winter (1973) relates the faulting to the tensional stress fields resulting from the moving apart of the continents at the break-up of Gondwanaland. The Algoa basin however is not a simple trough but a complex assemblage of sub-basins which have culminating deeps opposite the greatest displacements along the boundary faults. The Algoa basin is classified according to the scheme of Halbouty and others (1970) as a Type 3 graben or rift-type basin. It is into such a graben that the Cretaceous lithologies found in the artesian Uitenhage trough were deposited. Mountain (1955) describes that Uitenhage trough not only as a structural basin, but also as a topographical basin being in pre-Cretaceous times, "much more of a basin than now, with higher mountains and much deeper valleys."

As the Kruis River area embraces part of the inland western portion of the Uitenhage trough, the floor configuration is strongly controlled by palaeogeomorphology and basement structure, with the underlying folded Table Mountain quartzites and Bokkeveld shales of the Cape Supergroup influencing floor morphology. Due to the close proximity of Kruis River to the source

FIGURE 2 **GEOLOGY OF KRUIS RIVER AREA**



area for Cretaceous deposits, the portion of trough under study is filled with a dominantly clastic succession. The succession represents major environmental facies of deposition commencing with high energy continental alluvial fan type deposits of continental fluvial origin. In the east of the Kruis River area deposits forming shallow-water marine and esturine facies may conformably overlie and intertongue with deposits of the fluvial environment. (Winter 1973).

4.3 Pre-Cretaceous Stratigraphy.

The Pre-Cretaceous stratigraphy may be divided into two subdivisions in terms of structural location and age rather than lithological type. The first are rocks belonging to the Pre-Cape Basement, of late Pre-Cambrian to early Palaeozoic age, which are exposed on the upthrown side of the Coega fault in a narrow band to form the northern boundary of the Kruis River area. Marais (1964) describes these rocks as quartzites with subordinate intercolations of phyllitic shale. As these rocks cover only a small area north of the study region and are structurally, lithologically and therefore presumably geohydrologically similar to the overlying Table Mountain Group (T.M.G.), they are not considered to be of any individual im-portance and will be considered together with rocks of the Table Mountain Group.

The second of the subdivisions are the rocks of the Cape Supergroup. The Cape Supergroup comprises the Table Mountain, Bokkeveld and Witteberg Groups, of which only the Table Mountain and Bokkeveld groups occur within the study area. The (T.M.G.) conformably overlies Pre-Cape rocks (Winter 1973) and is composed mainly of quartzitic sandstones and very minor interbedded shale bands. The T.M.G. attains a maximum thickness of 400m in the Western Cape (S.A.C.S., 1980) but is unlikely to reach these thicknesses in the study area due to southward and eastward thinning of the lithologies and local erosional processes.

No distinction between the various formations of the T.M.G. within the study area is made, as lithological variation is small with primary porosity and permeability being extremely low due to pressure solution and silica cementation of individual grains. Figures 3 and 4 are photographic enlargements of thin sections of T.M.G. quartzites. Figure 3 illustrates the

FIGURE 3 : PRESSURE SOLUTION IN THE QUARTZITES OF THE TABLE MOUNTAIN GROUP (Magnification x 42).

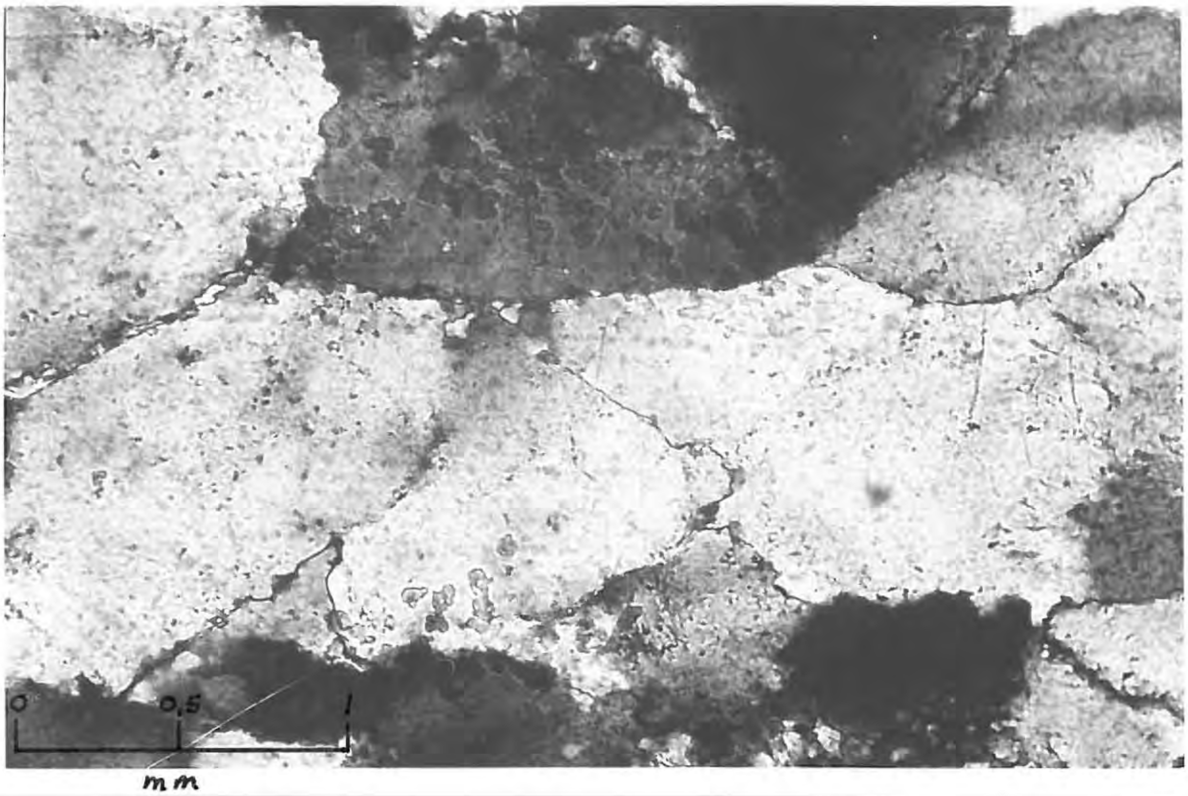
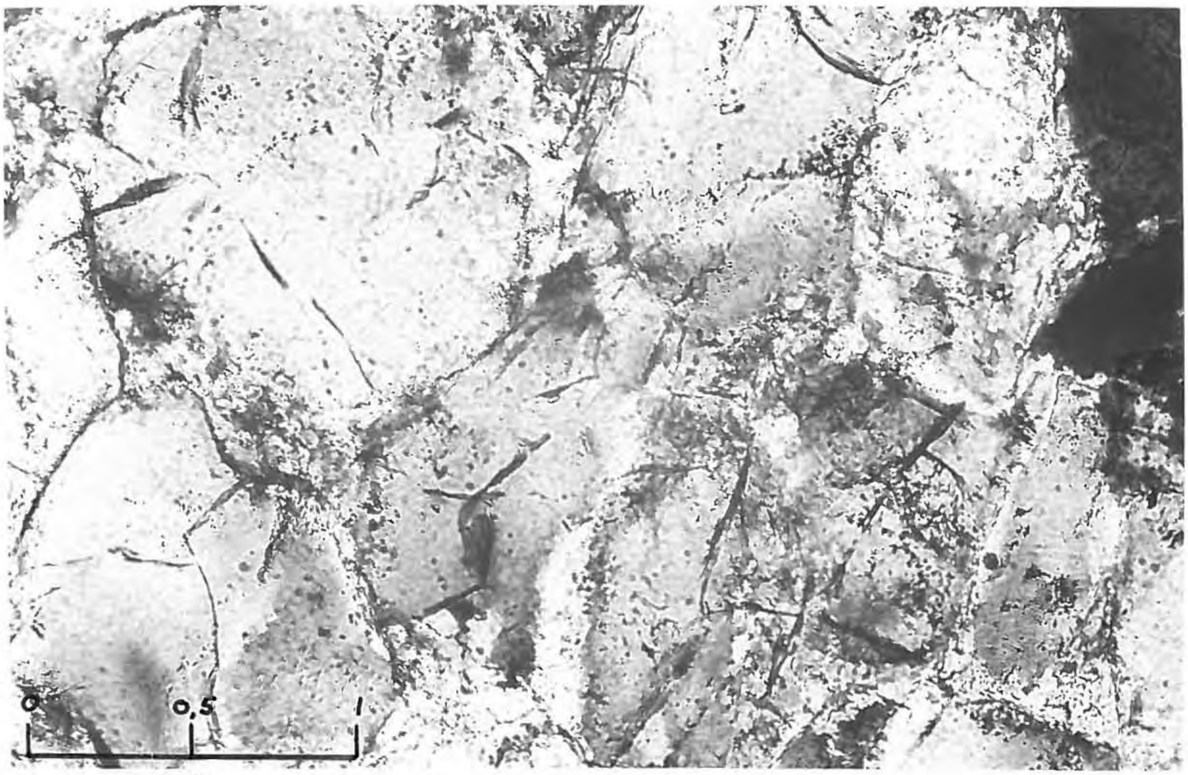


FIGURE 4 : SILICA CEMENTATION IN THE QUARTZITES OF THE TABLE MOUNTAIN GROUP (Magnification x 42).



feature of pressure solution while figure 4 shows the infilling of pore spaces by silica cement. In both instances the primary porosity of the T.M.G. quartzite is shown to be poor. T.M.G. rocks form the basement lithology to most of the study area with the exception of a small portion in the south. Because of high competence the quartzites are intensely fractured and may form an important recharge conduit from highland outcrop areas in the west to overlying Cretaceous sediments in the east of the study area. North of the Kruis River study area the T.M.G. yields plentiful quantities of high quality water and forms the most important aquifer in the region (Venables 1985)

In the south of the study area, the Bokkeveld Group of rocks conformably overlie the T.M.G. to form the basement. The Bokkeveld Group reaches a maximum thickness of 300m (Theron, 1970, 1972) and according to Du Toit (1954) is of late Early Devonian age. Dark-grey phyllitic shales dominate the group with thin impure quartzites yielding comparatively small quantities of poor quality water (Marais, 1964). Despite the fissile appearance of the shales in exposures, the strata are reported by Marais (1964) to be impervious and generally to serve as an aquiclude.

4.4 Cretaceous Stratigraphy.

The Cretaceous stratigraphy of the Uitenhage trough consists of three formations, the Sundays River Formation, Kirkwood Formation and Enon Formation. The formations are jointly known as the Uitenhage Group, and are considered by Rogers and Schwartz (1901) to be largely contemporaneous lateral facies. Shone (1981) supports the case for lateral gradation between the Kirkwood and Sundays River Formations while Winter (1973) and MacLaghlan and McMillan (1976) suggest the possible presence of a regional unconformity between them. Shone (1976) using work done by Lock (1975) states that palaeoslope angles for the deposition of the Enon Formation is markedly different from that for the Kirkwood and Sundays River formations, suggesting the existence of a regional unconformity between the Kirkwood and Enon Formations. Despite uncertainties as to the nature and exact location of the various boundaries, the Sundays River formation is shown both by Ruddock (1968) and Shone (1981) to be confined to an area of the Uitenhage trough East of the Kruis River study area.

The Enon Formation consists of conglomerates interbedded with subordinate lenticular red, yellow and green sandstone and predominantly red-brown claystones reportedly devoid of fossils (Winter 1973). The clasts are generally poorly sorted and sub-rounded. The predominant shape according to Shone (1981) is that of the Zing spheroid. Both clast and matrix material varies considerably within the study area with predominantly quartzite clasts derived from the T.M.G. rocks occurring in the Elands and Swartkops river valleys. The distribution of clast type is related to rock type in source areas with the Hol river contributing most shale clasts to the southern portion. Matrix material varies from a medium grained white sandstone to red-brown claystones. Strong red colouration dominates near Bokkeveld provenances in the south while in the Swartkops and parts of the Elands river valleys colours become generally lighter as matrix grain size increases upwards through the sequence. Figures 5 and 6 are photographic enlargements of thin sections taken from the Enon Conglomerate. Figure 5 is an example of the conglomerate in the south of the study area while figure 6 is an example of the conglomerates found in the north west.

Observed variability in yield and water quality from boreholes intersecting the Enon Formation are mainly related to matrix variability. During mapping a distinction was made between the conglomerates according to their petrology. The conglomerates are devoid of secondary structures and are quoted by Marais (1964) as being characterised by relatively low permeability and porosity. The age of the Enon Formation has been provisionally placed by S.A.C.S. (1980) in the upper Jurasic although the rocks upon which this dating is based are highly weathered and Marsh et al (1979) consider this date to be unreliable.

The Kirkwood Formation consists mainly of clastic sediments composed of cross-bedded sandstones of fluvial point bar facies with channel lag gravels and silty mudstones which characteristically show patches of greenish-grey and grey from local reducing conditions. The term "marl" applied to the mudstones in older papers according to Winter (1973) is a misnomer as the clays are very poor in lime. The sandstones which vary in size from coarse to silty sands are described by Shone (1981) as sub-mature lithic arenites. The South African Committee for Stratigraphy has accepted evidence by Winter

FIGURE 5 : ENON CONGLOMERATE FROM THE SOUTHERN PART OF THE STUDY AREA. Note the presence of both quartzite and shale pebbles with a clay matrix. (Magnification x 10,5).

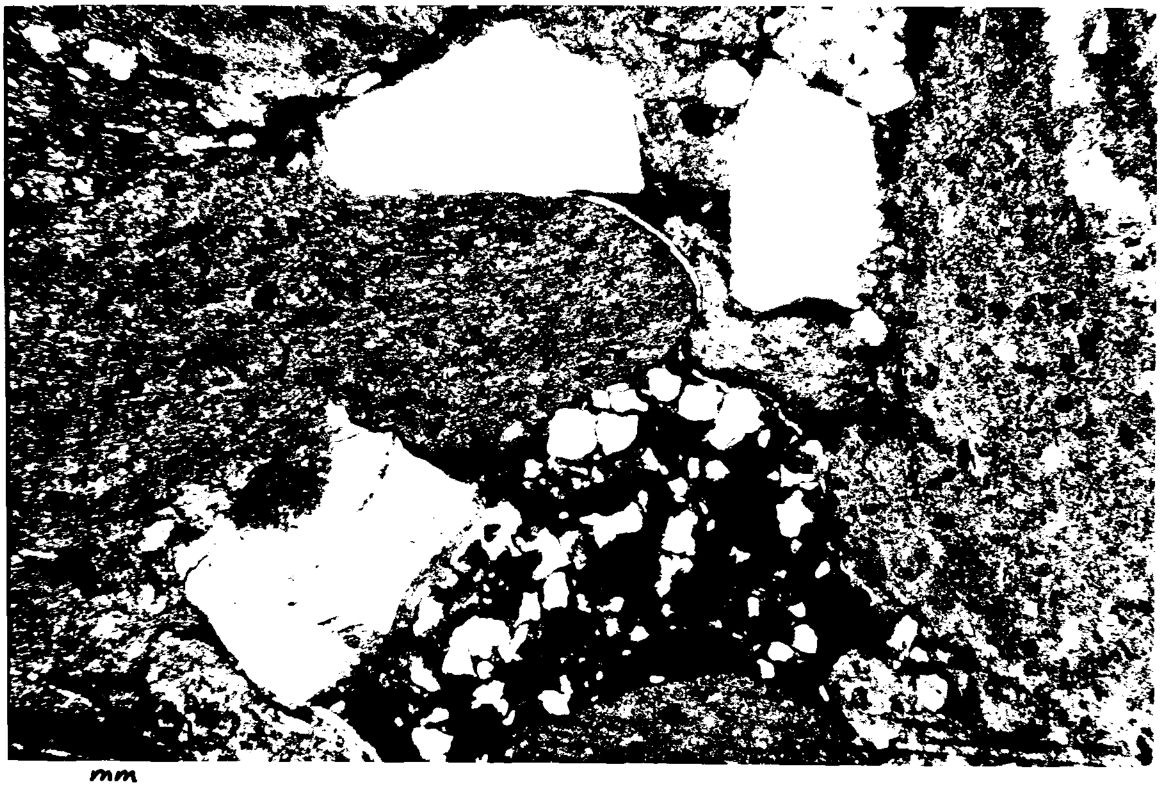


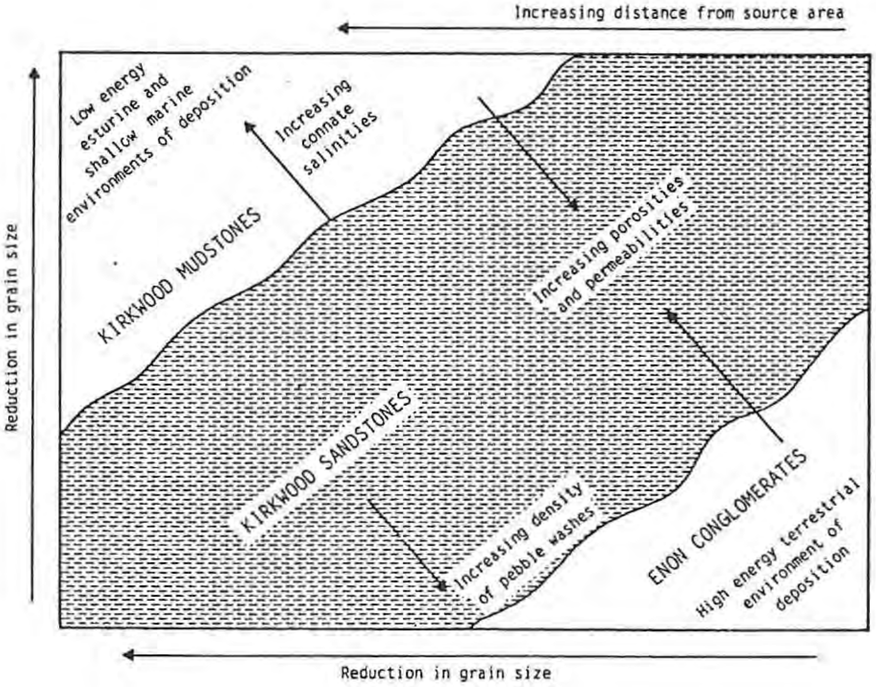
FIGURE 6 : ENON CONGLOMERATE FROM THE NORTH-WESTERN PART OF THE STUDY AREA. Note the predominantly quartzite pebbles and the silt/sandstone matrix material. (Magnification x 10,5).

(1973) to the effect that the Kirkwood Formation lies conformably upon the Enon Formation and locally interfingers with it. Shone (1981) however presents a case for the existence of an unconformity between the Enon and Kirkwood Formations.

The maximum thickness of the complete Kirkwood succession is estimated as 2210m (S.A.C.S., 1980) and is considered by Robertson Research International (1970) to range in age from possible late Jurassic to early Cretaceous. The upper limits of the Kirkwood Formation are defined by S.A.C.S. (1980) as the top of the uppermost red-brown mudstone while the lower limits are defined as the lithologies conformably following the last massive bed of Enon Conglomerate. It is possible to include in the Kirkwood Formation all conglomerates that cannot be described as massive. For this reason no geohydrologic boundary is expected to exist between the Enon and Kirkwood formations although hydrological parameters such as porosity and permeability can be expected to undergo a gradational change from the Enon to the Kirkwood Formations.

The mudstones of the Kirkwood Formation which overlie the sandstones and conglomerates are characterised by very low permeabilities and are therefore thought to constitute the aquiclude which confines the groundwater within the study area giving rise to the artesian condition. Perched water table conditions are also possible in lithologies which overlie the Kirkwood Mudstones. Connate water salinities quoted for the Kirkwood Formation by Winter (1973) are between 6000 and 6200 p.p.m. with the peak occurring at the top of the Kirkwood Formation. Marais (1964) states that most of the groundwater in the Kruis River area is encountered within the "sandstone facies of the Enon Conglomerate" the lithology now reclassified as the major lithology making up the Kirkwood Formation. The broad hydrolithological relationships of the Kirkwood and Enon Formations are summarised in figure 7.

FIGURE 7 SCHEMATIC CROSS SECTION OF THE KIRKWOOD AND ENON FORMATIONS



4.5 Post Cretaceous Stratigraphy.

The Post-Cretaceous stratigraphy in the Kruis River area is made up of late Tertiary to Recent deposits which unconformably overlie the Cretaceous strata. The deposits are made up of sand, gravel, silt and clay, and are restricted to the river valleys where intensive cash crop farming takes place on the fertile silt soil. The deposits are thickest in the Swartkops River valley and are of little geohydrological importance except where shallow wells and seepage pits have been constructed immediately adjacent to, or in the river beds. Quality of water derived from such sources is closely related to surface water quality as the pits merely tap the base flow component of the rivers.

Chapter 5 Geophysics.

5.1 Introduction.

Geophysical exploration is the scientific measurement of physical properties of the earth's crust for investigation of mineral deposits or geologic structure and lithology (Todd, 1980) or for estimating aquifer properties such as permeability and porosity (Barker and Griffiths, 1981). The most commonly used geophysical techniques used in the field of geohydrology are the electric resistivity and seismic methods. For the same depth of investigation, the resistivity method is according to Van Zijl (1977), appreciably cheaper to apply, and more flexible in application than the seismic refraction method.

Geophysical methods detect differences, or anomalies of physical properties within the earth's crust, measurements are made of variations of density, electrical conductivity, magnetic susceptibility, electrical potential, elasticity and other measurable physical properties of the earth (Todd 1980 and Davis and de Wiest, 1966). If the variations in the measured properties are small or if the spatial distribution of the geologic units is too complex, results may be difficult or impossible to interpret. Geophysical methods are therefore most useful when supplemented by drilling to obtain subsurface information. For this reason at least one correlation borehole was drilled per resistivity traverse during this investigation.

5.2 Electrical Resistivity Method.

Two types of electrical potentials can be measured with the electrical resistivity method:

1. Natural electrical potential;
2. Induced electrical potential;

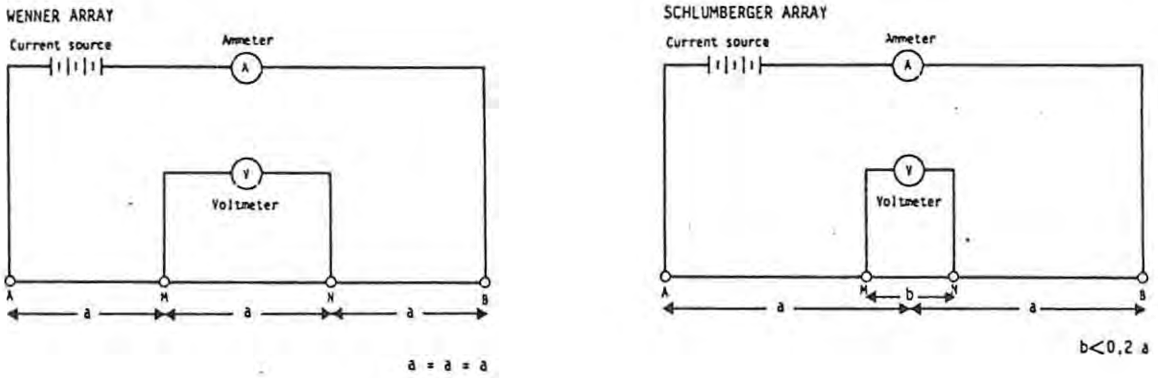
As the use of natural potentials in geohydrology has been limited to research work in areas where waters of vastly different chemical composition are in contact with each other, (Davis and de Wiest, 1966) or for use in the mining field with the detection of ore bodies, this method will not be discussed further. Induced electrical potential, is created by periodically passing a direct current through the ground usually for short periods, first in one direction then in the opposite direction. This method is known as direct current electrical prospecting and may be conducted in two ways:

1. Vertical probing, where information regarding changes in resistivity with depth are obtained by progressively increasing the depth of investigation. The method is most effective when geoelectric horizons are relatively flat lying or gently dipping and are laterally homogeneous and extensive (Van Zijl, 1977).
2. Lateral profiling, where a constant electrode spacing is selected to produce the desired depth of the survey. Measurements are taken at different locations to yield a map of isoresistivity lines.

Vertical probing is most useful in providing information regarding changes in resistivity with depth while vertical discontinuities are mainly investigated using the lateral profiling technique. Both methods are used to provide data on bedrock or aquifer depths, groundwater quality changes and fresh water/salt water interfaces.

Measurement of apparent resistivity is possible from numerous standard electrode spacing arrangements, of which the most commonly used are the Wenner and Schlumberger arrangements (Figure 8). The Wenner configuration has the advantage of a more direct relation between electrode spacing and depth of current penetration than the Schlumberger configuration although errors in calculated depth of several hundred percent are quoted by Davis and de Wiest (1966). The Schlumberger configuration is preferred by Van Zijl (1977), Smith (1982) and others as the sounding curve is only minimally distorted by electrode effects (A and B). The configuration allows a clearer definition of subsurface conditions for a given outer electrode spacing than does the Wenner configuration whose soundings are distorted by both AB and MN electrode effects. As vertical definition is considered important, the Schlumberger configuration was used exclusively in this investigation.

FIGURE 8 SCHEMATIC REPRESENTATION OF THE WENNER AND SCHLUMBERGER ELECTRODE ARRAYS



All earth materials conduct electricity although the resistivity of different layers varies widely as a result of the variable influences of highly resistive minerals such as quartz, feldspar, and calcite, and fluids of varying but generally low resistivity which may be present in the rock. Electrolytic conduction, or the conduction of electricity due to the presence of mineralized water contained in pores and fissures, is attributed by both Van Zijl (1977) and Davies and DeWiest (1966) to be the primary conduit for electrical conduction. Electrolytic conduction is largely a function of the chemistry of the saturating fluid, the degree of saturation and the combined primary and secondary porosity of the rock. The presence in rocks or sediments of clay minerals which when saturated have an abundant availability of mobile ions, results in a reduction in resistivity giving rise to the observation that argillaceous rocks have lower resistivities than arenaceous rocks. The resistance of a layer to the passage of an electric current therefore depends on the following five factors:

1. Rock type;
2. Porosity;
3. Degree of saturation;
4. Amount of dissociated or mobile ions in the saturating fluid.
5. The presence of clay minerals.

(Davies and de Wiest, 1966; Van Zijl, 1977).

The electrical resistivity method suffers from two major limiting factors, these are;

1. The method can only be used in rural areas or areas distant from steel and other conducting materials in contact with the soil. The presence of such objects as pipelines, underground cables, railway lines and metal fences within the area of influence of the sounding, will according to Bouwer (1978), usually give erroneous results.
2. Because apparent resistivity is a measure of the combined effects of all layers between the maximum depth of penetration and the surface, the method is unable to define individual geoelectric horizons when deeply buried. The depth of penetration is limited to approximately 500m for most portable instruments due to a lack of sufficient power and the geologic complexities of large volumes of earth (Davies and DeWiest, 1966).

The measurements produced in a resistivity survey are apparent resistivity, obtained by progressively expanding the current, electrode spacing AB and measuring from the mid point O, the potential difference between potential electrodes M and N. Apparent resistivity is only a true resistivity in the unique case of the earth in question being homogeneous. In all other cases apparent resistivity is defined by Van Zijl (1982) as the ratio of the measured potential to the theoretical potential of the actual field strength to the theoretical field strength at a given point when the resistivity of the reference medium equals unity.

The concept of resistivity is based on the electrical resistance of a length of wire to electric flow under the influence of an electrical potential.

The relation is described by Ohm's Law which states:

$$R = \frac{\Delta V}{I}$$

where R is the resistance, V is the potential difference between the ends of the wire and I is the intensity of the current which flows in the wire in the direction of decreasing potential. In order to use this relationship for geophysical purposes it is necessary to introduce a geometric factor, or a factor which will take the influence of the electrode configuration into consideration. The factor is represented by the coefficient K for any specific four electrode array.

$$\text{where } K = \frac{2\pi}{1/_{AM} - 1/_{AN} - 1/_{BM} + 1/_{BN}}$$

and has the dimensions of (m) in the SI system of units. The relationship for describing the apparent resistivity (a) of a volume of heterogeneous earth can then be written as

$$\rho a = K \frac{\Delta V}{I}$$

Values of ρa are plotted as a function of $\frac{AB}{2}$ on a standard international 62,5mm bilogarithmic graph paper and forms the basis for interpretation by comparison with other field and master theoretical curves (Van Zijl, 1977).

5.3 Interpretation of vertical electric sounding curves.

The interpretation of the data obtained from the resistivity survey was undertaken in 3 steps as follows:

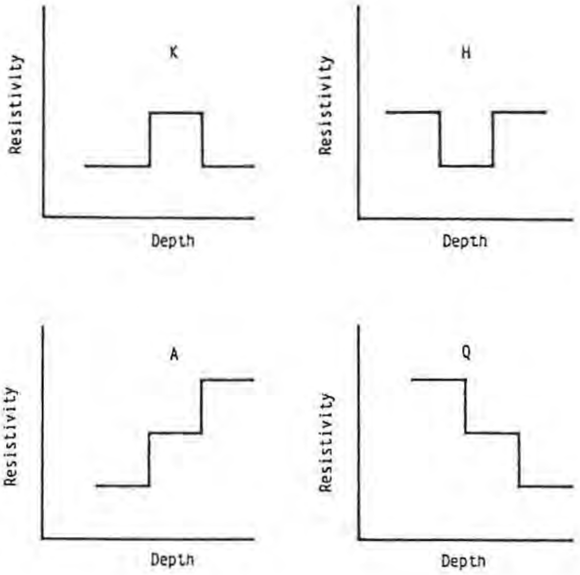
1. A comparative study of the progressive deformations and common characteristics of all the sounding curves and interpretation using master curves (Joubert, 1977).
2. Modification of initial curve matching results by a computer technique.
3. The calibration of results using soundings carried out at correlation boreholes where the thicknesses and nature of the various strata are known.

In the study area, steel casing frequently extends through large portions of the borehole so that geoelectric borehole correlation logging is frequently not feasible.

The initial interpretation of the Schlumberger field curves by comparison with theoretical master curves is based on the determination for each geoelectric layer of two parameters, T and S. These parameters are known as the Dar Zarrouk parameters, where T represents the transverse resistance and

S the longitudinal conductance of the geoelectric layer. The transverse resistance of a layer is measured for layers sandwiched between two more conductive layers as an electric current will tend to flow normal to the bedding of the resistive layer along a path of least resistance. Transverse resistance (T) is equal to the product of the resistivity (ρ) and thickness (h) of the layer ($T= h\rho$). For a conductive layer sandwiched between two more resistive layers an electrical current will tend to flow along the conductive layer such that longitudinal conductance is equal to the quotient of the thickness of the layer and its resistivity. ($S = {}^{h}/\rho$). To facilitate interpretation, all multi-layered field curves of four or more layers are first divided into simpler three layer segments from which values of S and T are calculated and estimates of resistivity and thickness made. It is therefore possible to have for each three layer segment, one of four field curve types; (Figure 9).

FIGURE 9 TYPES OF THREE LAYER SEGMENTS



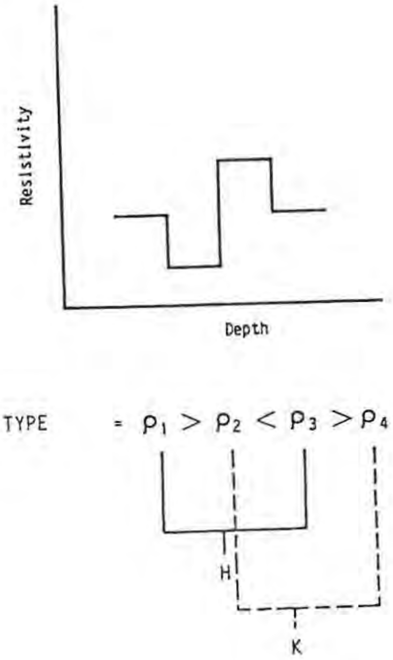
a) Type K, where the resistivity of the first and third layers is exceeded by the resistivity of the second layer.
b) Type H, where the resistivity of the first and third layers exceed the resistivity of the second layer.

c) Type A, where the resistivity of the first layer is exceeded by the resistivity of the second layer, which is in turn exceeded by the resistivity of the third layer.

d) Type Q, where the resistivity of the first layer exceeds the resistivity of the second layer, which in turn exceeds the resistivity of the third layer.

The simpler three layer segments are then joined and used to describe the field curves (Figure 10).

FIGURE 10 H K TYPE CURVE



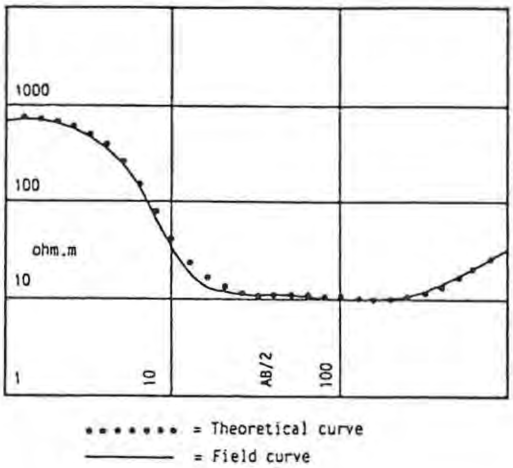
As a check on the feasibility of the interpretation made by curve matching, a computer technique devised by Patra and Mulluk (1979) has been used to compare and adjust the interpreted curve to the actual field curve.
Figure 11 is a copy of the printout for resistivity sounding T3ES3 and shows the close correlation of the final theoretical curve to the field curve.

FIGURE 11

RESISTIVITY SOUNDING T3 ES 3

EARTH MODEL

Layer thickness	Resistivity
2,1	780
5,5	30
10,18	7
13,3	20
21,8	10
204	8
	700

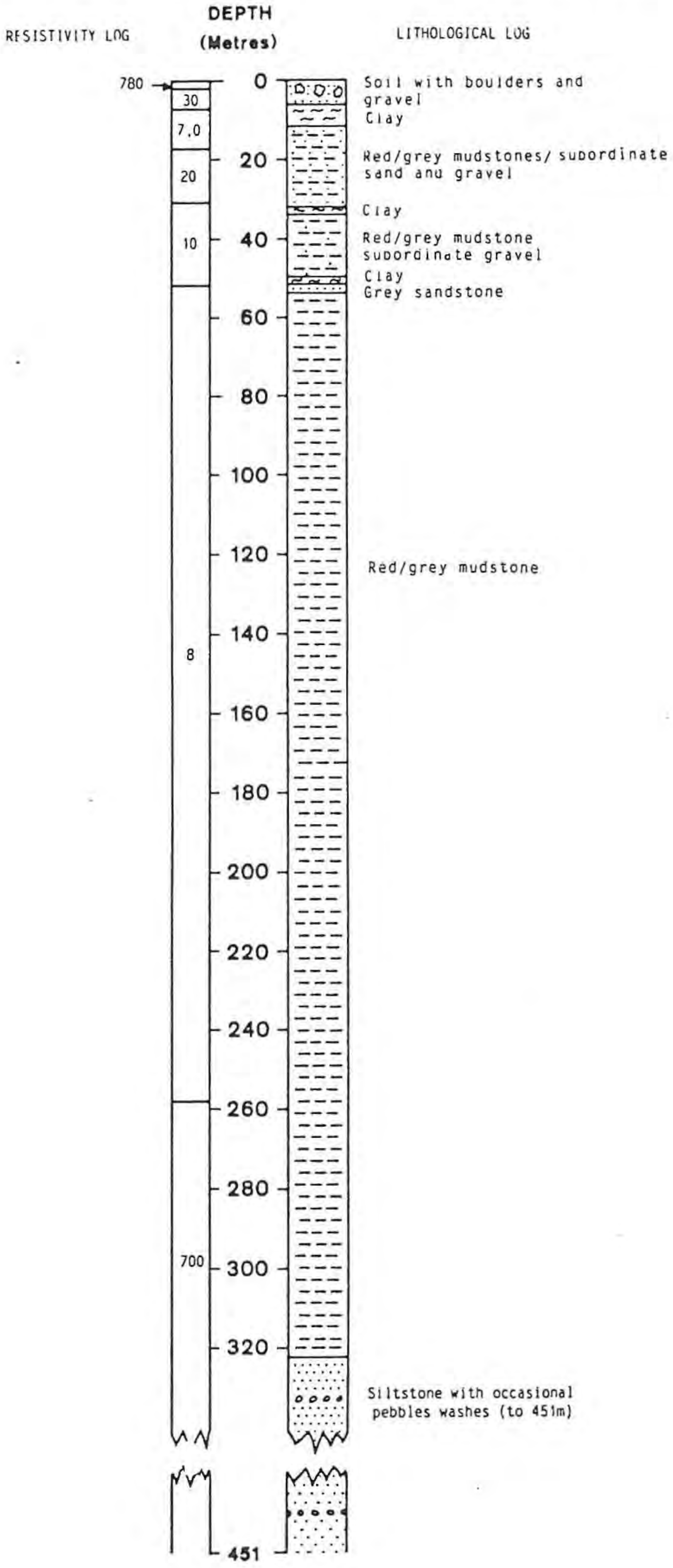


Once the geoelectric section has been determined, comparisons and modifications are made according to geological logs from correlation and other boreholes. Figure 12 shows the relationship between the lithological log and interpreted resistivity log for borehole KM1G. A correlation factor of 1,26 for the adjustment of the resistivity log is obtained by equating the change in apparent resistivity from 8 to 700 with the lithological change from mudstone to sandstone. Once the correlation factor has been obtained, all resistivity soundings on the traverse of the correlation borehole are adjusted accordingly and an expanded geological section is interpreted. Table 2 gives the correlation factors calculated for each traverse.

TABLE 2. RESISTIVITY/LITHOLOGICAL CORRELATION FACTORS

Correlation Sounding/Borehole	Factor	Soundings to which relavent
T1ES3 / KR71G	1.30	TIES1; TIES2; TIES4
T2ES2 / KR75G	1.37	T2ES1; T2ES3; T2ES4; T2ES5
T3ES3 / KM1G	1.26	T3ES1; T3ES2
T4ES3 / MD20G	0.86	T4ES1; T4ES2A; T4ES2B
T5ESA / MD21G	1.36	T5ES1; T5ES2.

FIGURE 12 RESISTIVITY/LITHOLOGICAL LOG FOR BOREHOLE KM 1 G



5.4 Resistivity Data Collection and Results.

The objectives of the resistivity survey were to provide data on :

1. lithological thickness and variation in thickness with lateral extent,
2. the distribution of non outcropping bedrock types in the south.

In order to accomplish these objectives, five traverses were undertaken, four of which radiated outwards from Searle Hill (Figure 13). A total of twenty soundings were undertaken with maximum electrode spreads (AB/2 distances) varying between 200 and 750m. The average AB/2 distance for all soundings is just over 570m. Distances between individual soundings vary about an average 450m due to there being only limited suitable sites for resistivity work. In all cases the soundings were only terminated after the final rising portion of the curve had been defined, as this is required to determine the apparent resistivity of the bedrock lithology/ies. Figure 13 shows the position of soundings and detailed resistivity logs are presented in Appendix 2.

Although an objective of the resistivity survey was to determine the distribution of bedrock types in the south of the study area, electrode spread directions were not always parallel to the strike of bedrock lithologies for two reasons:-

1. In order to obtain the best possible data for Cretaceous lithologies, electrode spreads were run parallel to Pre-Cretaceous valley systems wherever possible.
2. The nature of the vegetation and terrain frequently necessitated the execution of electrode spreads along roads, fence lines or areas which are relatively flat or distant from conductors in contact with the ground.

Despite the inaccuracies possible from an inadequate electrode spread and non-ideal orientation, the large difference between the resistivities of the two bedrock lithologies did enable the approximate delineation of lithologies to be made.

The number of interpreted geoelectric layers varied between three and seven (Table 3) with an average of five layers being encountered. Complexity of

FIGURE 13 LOCATION OF RESISTIVITY TRAVERSES AND RESEARCH BOREHOLES

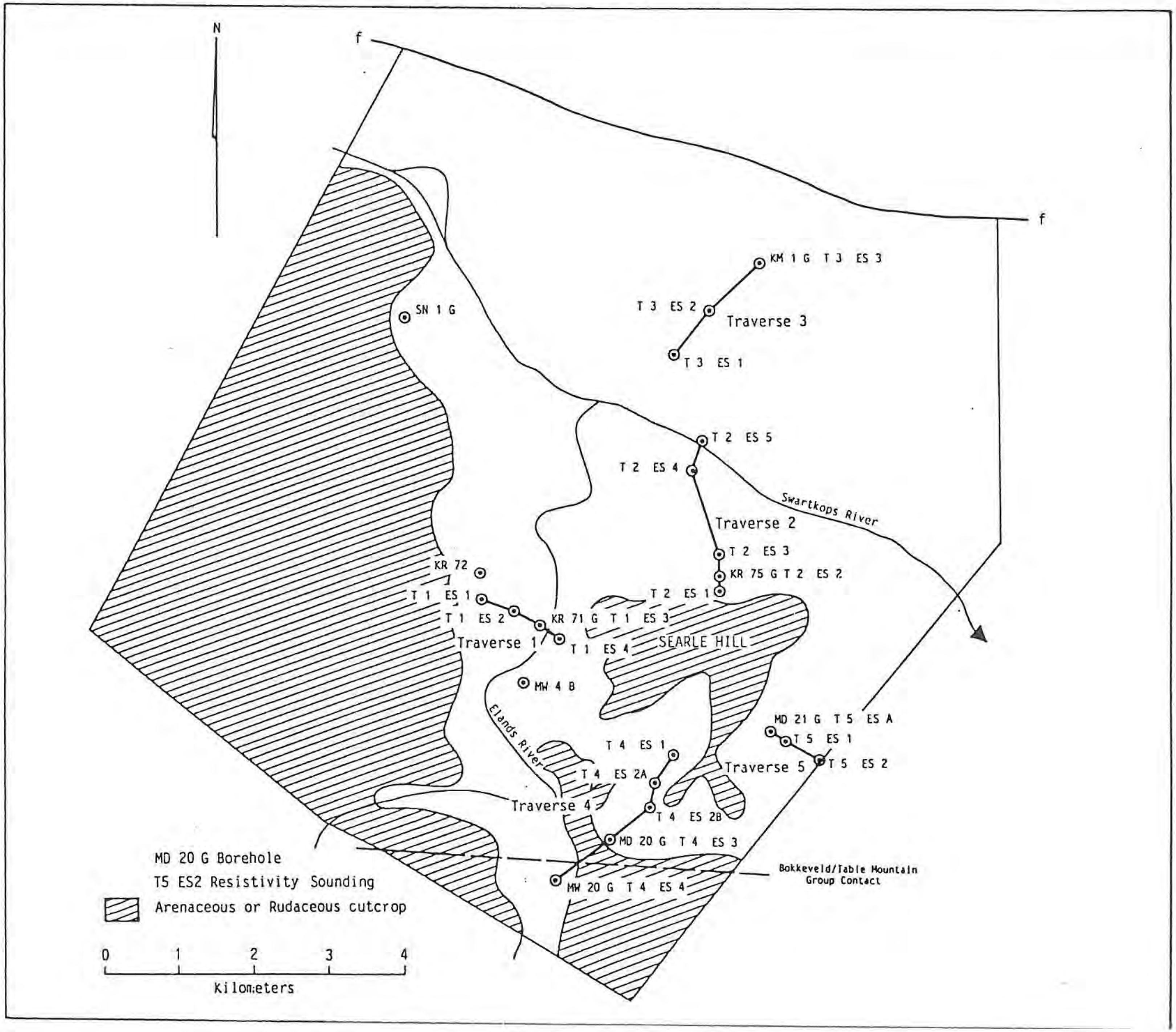


TABLE 3 INTERPRETED RESISTIVITY RESULTS

TRAVERSE NUMBER	ELECTRODE SPREAD NO	LAYER NO 1		LAYER NO 2		LAYER NO 3		LAYER NO 4		LAYER NO 5		LAYER NO 6		LAYER NO 7	
		THICKNESS (M)	RESISTIVITY (. M)	THICKNESS (M)	RESISTIVITY (: M)	THICKNESS (M)	RESISTIVITY (· M)	THICKNESS (M)	RESISTIVITY (M)	THICKNESS (M)	RESISTIVITY (M)	THICKNESS (M)	RESISTIVITY (M)	THICKNESS (M)	RESISTIVITY (M)
1	1	1,6	138	9,6	6,0	9,45	15	38,1	200	60	80	--	697	--	--
1	2	1,3	190	10,7	60	15,49	7	50	200	--	697	--	---	--	--
1	3	1,75	600	6,48	90	35,64	18	91	260	--	700	--	---	--	--
1	4	0,957	57	4,7	20	13,8	6	30	200	--	700	--	---	--	--
2	1	2,3	328,5	23,5	4,3	--	697	--	--	--	--	--	---	--	--
2	2	2	27	17,65	7	18,24	30	20,08	3	--	700	--	---	--	--
2	3	1,168	90	2,784	29	2,884	103	115	8	--	700	--	---	--	--
2	4	0,8	100	9,12	9,5	13,36	3,5	49,6	20	124,8	8	--	700	--	--
2	5	1,34	250	3,589	85	8,4	260	165,1	8,5	--	700	--	---	--	--
3	1	4,5	1300	108,2	12,5	162,9	11,5	--	700	--	--	--	---	--	--
3	2	0,82	85	3,2	170	425	1	--	700	--	--	--	---	--	--
3	3	2,1	780	5,5	30	10,18	7	13,3	20	21,8	10	204	8	--	700
4	1	2,2	63	36,6	2,5	--	700	--	--	--	--	--	---	--	--
4	2A	2,3	110	10,8	3	28,6	11	--	700	--	--	--	---	--	--
4	2B	1,3	40	8,82	2,8	34,4	8	--	700	--	--	--	---	--	--
4	3	0,4	60	60	8	--	700	--	---	--	--	--	---	--	--
4	4	1,7	60	3	15	14,4	8	108	30	--	185	--	---	--	--
5	A	0,55	280	17,1	1,8	27,8	4	34	2,5	--	700	--	---	--	--
5	1	1,1	30	13,6	2	22,4	10	83,73	6	--	1000	--	---	--	--
5	2	1,8	29	2,134	11	54	9	93,3	14	118	8	--	700	--	--

near surface geoelectric layering was found to be largely a function of the complicated hydrogeological relationships with many of the near surface layers being attributable to variations in moisture content, water quality and complex lithological facies variations. Figure 14 illustrates the differing geoelectric response of the mudstone lithology. As little petrological variation is evident in the mudstones and a geoelectric change of apparent resistivity from 4 to 2,5 takes place at an estimated 62m, only 5m below the level at which water was struck, the interpreted geoelectric layering within the mudstone lithology was assumed to be explained by variations in water content and quality.

Because of features of equivalence and suppression (Kunetz, 1966; Van Zijl, 1977) deeper lithological variations were frequently not reflected by geoelectric layering. Figures 14 and 15 illustrate the feature of equivalence encountered on traverses two and five where the relatively conductive Enon Conglomerate lithology is sandwiched between highly resistive quartzites at the top of the Enon Formation and quartzites of the T.M.G. below. Figure 16 illustrates the principal of suppression encountered on traverses three and four due to intermediate resistivities as a result of gradational contacts between lithologies. For the above cases the resistivity data could only be used to distinguish between argillaceous and arenaceous/rudaceous rock types. On traverse one, simple contacts were found to exist between the mudstones and sandstones of the Kirkwood Formation and between the sandstones of the Kirkwood and conglomerates of the Enon Formations (Figure 17). It was therefore possible to use resistivity data to map the thickness of the Kirkwood Sandstones for traverse one.

The range of resistivities established for the lithologies encountered are shown in Table 4. Because of a lack of suitable sounding sites, no range of values were obtainable for shale and shale clast conglomerate lithologies, but only an average value was calculated for each from a single electrode spread.

FIGURE 14 RESISTIVITY/LITHOLOGICAL LOG FOR BOREHOLE MD21G

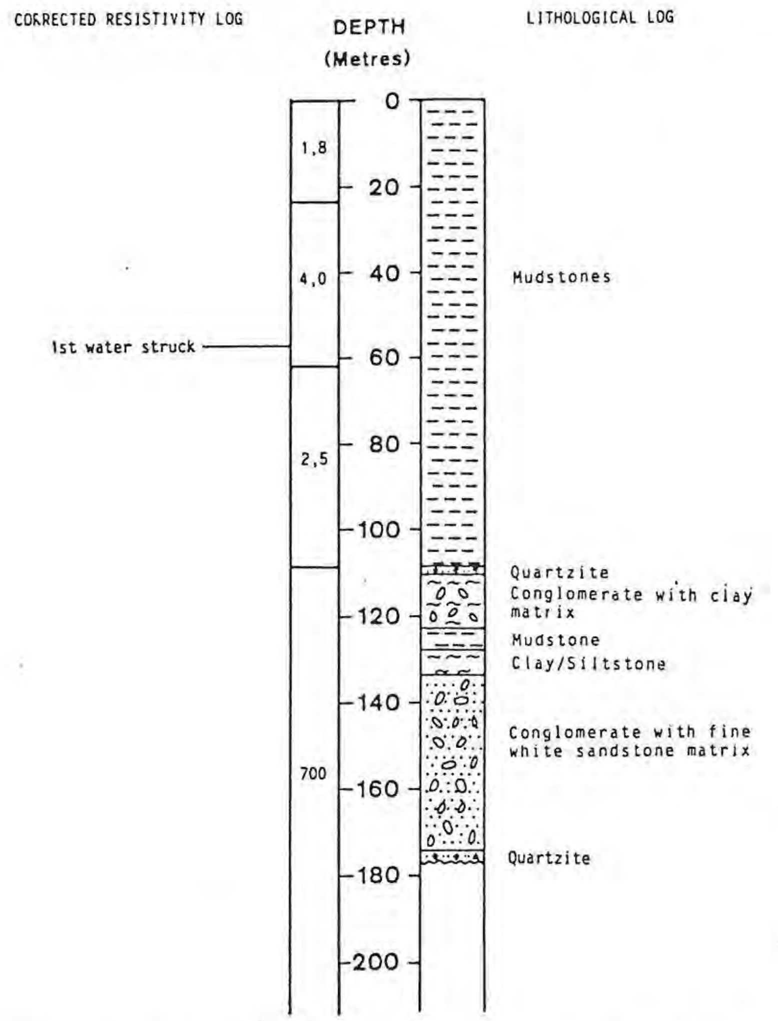


FIGURE 15 RESISTIVITY/LITHOLOGICAL LOG FOR BOREHOLE KR 75 G

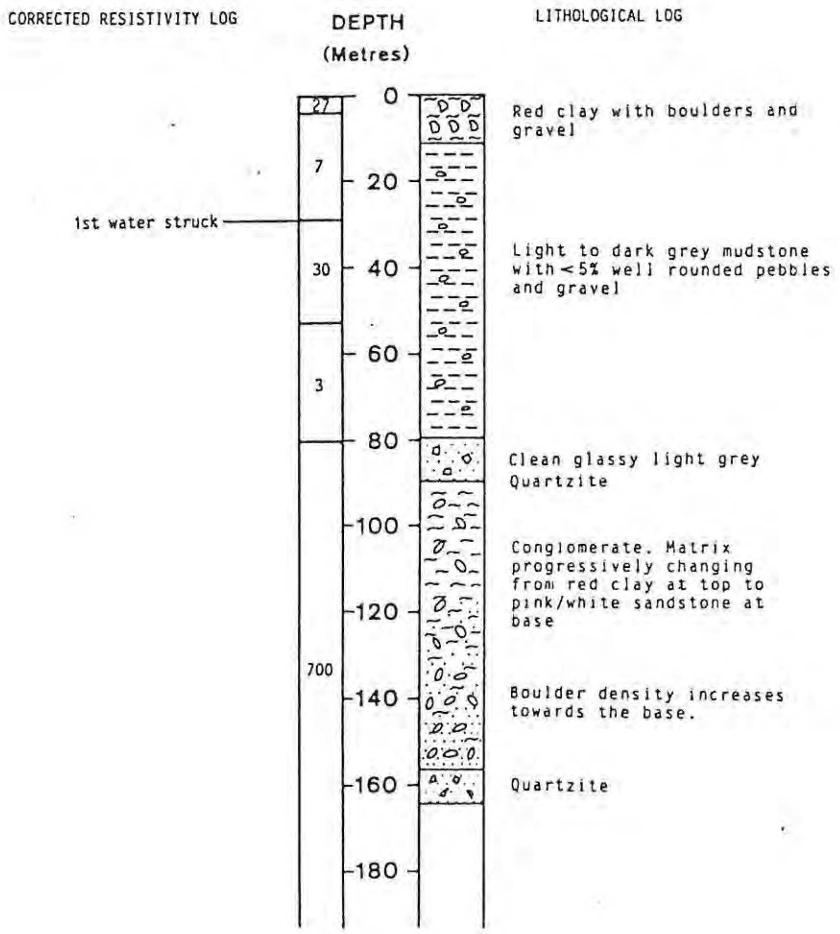


FIGURE 16 RESISTIVITY/LITHOLOGICAL LOG FOR BOREHOLE MD 20G

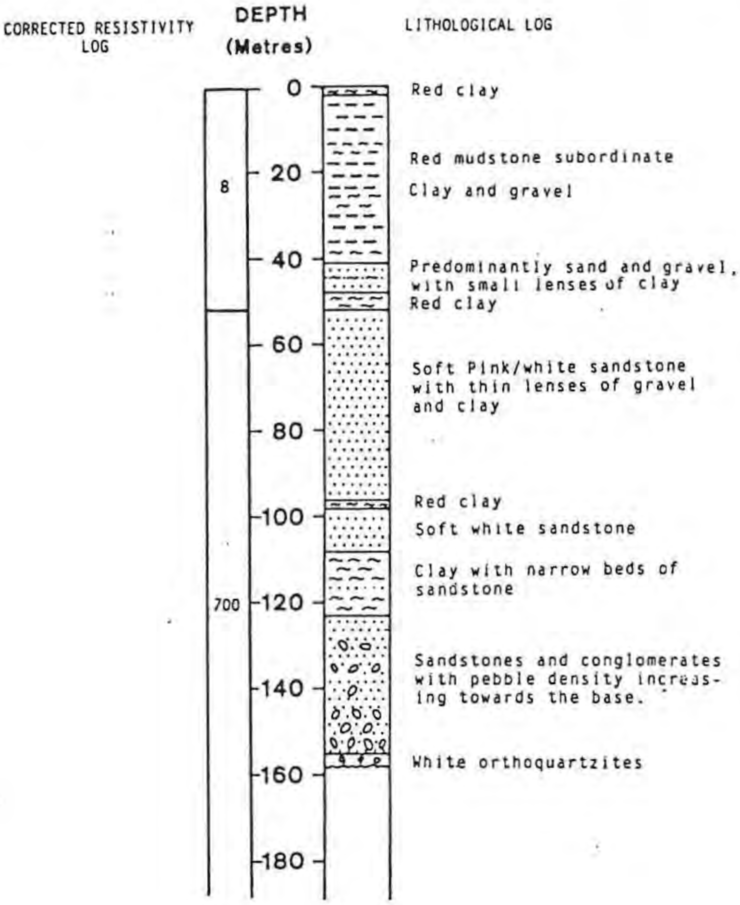


FIGURE 17 RESISTIVITY/LITHOLOGICAL LOG FOR BOREHOLE KR 71G

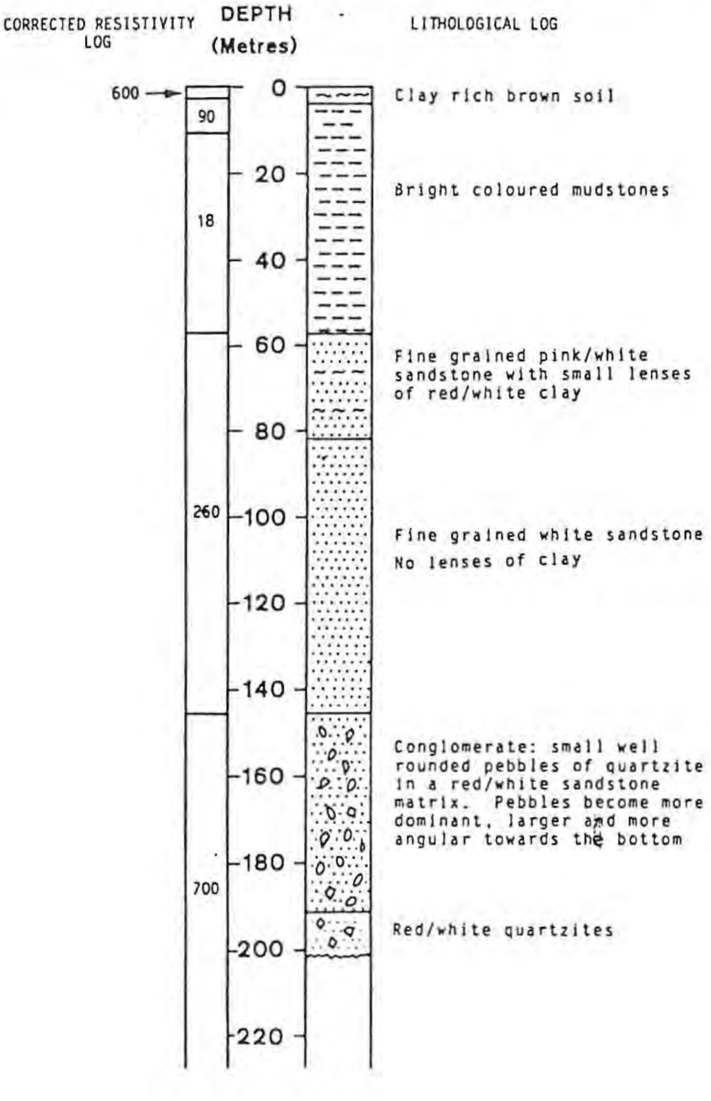


TABLE 4. RESISTIVITY RANGE OF LITHOLOGIES.

Lithology	Ω m
Alluvial soils	60 - 1300
Clay (Dominant) and Gravels and boulders	7 - 103
Mudstones; Mudstones (Dominant) and pebbles	1,0 - 90
Fine grained silt/sandstone	200 - 260
Shale	185 average
Shale clast conglomerate with clay or clay/silt matrix	30 average
Quartzites; quartzite clast conglomerate with silt/ sandstone matrix	697 - 1000

In order to verify/calibrate geophysics, drilling was undertaken at sites along resistivity traverses. The results of drilling both for calibration and for test pumping are discussed in Chapter 6.

Chapter 6. Drilling.

6.1 The need for drilling.

The value of the drilling programme is that it represents a direct method of obtaining accurate lithological data and provides access to the aquifer/aquifers for purposes of test pumping. Drilling results were also used to supplement, verify and interpret geophysical methods of investigation.

Because of the high costs involved in drilling and the depth of boreholes required to reach the Pre-Cretaceous basement, no observation boreholes for use in aquifer tests could be drilled. Aspects of hydraulic data potential were therefore sacrificed for greater lithological and stratigraphic information and for the need to site boreholes on resistivity traverses to correlate lithological and geoelectric layering. Six of the seven boreholes drilled during the investigation were used to obtain data for three purposes:

1.) to reveal the character, depth and thickness of the aquifer units,
2.) to obtain information on hydraulic properties of the aquifers,
3.) in order to correlate lithological and geoelectric layering.

The seventh borehole was not sited on a resistivity traverse, but was located in a recharge area to provide data on the first two criteria only.

6.2 Rock drillability and drilling systems.

The subject of drilling can be subdivided into

1.) Rock drillability
2.) Drilling systems

(Campbell, M.D. and Lehr, J.H., 1973).

Rock drillability is an important consideration in determining the availability of water and the choice of the most suitable drilling system. Although Campbell and Lehr (1973) state that more than 40 variables are generally assumed to influence drilling, the most important influences on drillability in the study area were found to be the compressive strength and cohesive properties of the rock. Because of equipment availability, the choice of drilling system used during this investigation was limited to cable-tool percussion or low pressure air rotary percussion systems. In most of the boreholes drilled, the cohesive nature of the upper Cretaceous formations and the depths to less cohesive more competant rocks inhibited the effectiveness and use of the low pressure air rotary percussion (L P A R P) system. This was particularly found to be the case where only small quantities of groundwater were encountered within the Kirkwood mudstones. Mixing of the groundwater and mudstones during drilling resulted in a tacky mass forming a plug around the drill bit, preventing the expulsion of air from the bit. Where either no groundwater or greater quantities of groundwater were encountered drilling progress was less difficult. Attempts to alleviate the problem by introducing anti-coagulant foams into the borehole met with little success. In all only two boreholes SN1G and MD21G were partially drilled using the L P A R P system, the remainder being drilled with the cable-tool percussion system.

The cable-tool percussion system of drilling is usually considerably slower than that of the L P A R P system, but does offer certain advantages;

a) it is better able to cope with extremely cohesive rock types;
b) greater drilling depths may be reached than is possible with the L P A R P system in artesian aquifers;
c) it is better able to handle the sometimes complicated casing requirements when drilling through formations prone to cave-ins;
d) the system allows geological sample collection at prescribed depths to be undertaken with a greater degree of accuracy than is possible with the L P A R P system. It should be noted that hydrochemical samples obtained during drilling with the cable-tool percussion system are frequently partially mixed as a result of the action of the bailer into and out of the boreholes.

6.3 Sampling procedures during drilling.

During drilling a minimum of two rock samples were taken every metre, one washed and one as close to unwashed as possible. All samples were placed in labelled watertight plastic bags and collected during each site visit. Where lithological changes were very frequent, additional samples were taken. A problem when determining the characteristics of the silt/sandstones of the Kirkwood Formation is the difficulty of obtaining a

truly unwashed sample, as fines are removed in suspension.
Rock samples representing conglomerates of the Enon Formation can usually be distinguished from quartzites of the T.M.G. by the following features:

a. larger proportions of fine grained material,
b. rock fragments exhibit rounded and weathered facets,
c. quartzite fragments of generally greater size than fragments from the more competant T.M.G. quartzites.

For some boreholes, however, distinguishing between samples representing these two formations was complicated by the following:

a. fines were removed in suspension from samples obtained from the Enon Conglomerates,
b. in some partially cased holes samples from the T.M.G. of rocks were contaminated by fines from overlying formations.
c. the large pebble size of the Enon Conglomerates encountered in some boreholes made identification by the presence of rounded or weathered facets difficult.

As Enon Conglomerates are softer than T.M.G. quartzites allowing more rapid drilling progress, a partial solution to the problem was found in the careful monitoring of the drilling rate. As an indication of geological sample contamination borehole depths were carefully measured at the end of drilling and prior to the start of drilling the following day. Rest water levels taken prior to the commencement of drilling each day indicated when artesian water had been struck.

6.4 Results of Drilling.

A total of seven boreholes were drilled with the monitoring of a further two private boreholes, one of which was deepened by 30m in order to reach basement. A summary of borehole statistics is given in Table 5. One research borehole was stopped at 451m after failing to reach Pre-Cretaceous formations. A total of 1543m was drilled with completed boreholes having an average depth of 216m. Of the 1543m drilled, 274m was drilled with the LPARP system the remaining 1269m being drilled with cable-tool percussion rigs. Detailed logs of all boreholes are presented in appendix 3. All boreholes drilled to basement provided full lithostratigraphic data for the overlying Cretaceous deposits. The location of drilled boreholes is

TABLE 5 SUMMARY OF BOREHOLE STATISTICS

Site and Borehole no.	Depth (M)	Casing (M)	First Water Struck (M)	Final Yield (ℓ/s)	Depth to Water below Collar Elevation (M)	Collar Elevation above Mean Sea Level	Type of Drill used
KR 71 G	200	0-59 (155mm Steel)	44	13,0	±25,426	66	Cable Tool Percussion
KR 72	200 (170-200M drilled for project	0-53 (165mm Steel 0-200 (127mm P.V.C.)	Private Hole not known	12,9	±12,565	64	Cable Tool Percussion
KR 75G	164	0-97 (152mm Steel)	29	10,4	±18,790	67	Cable Tool Percussion
MD 20G	157	0-121 (165mm Steel) 0-120 (127mm Steel)	30	4,1	±37,710	74	Cable Tool Percussion
MD 21 G	167	0-117 (165mm Steel)	131	0,34	±51,265	110	Air Rotary Percussion Cable Tool Percussion
MW 20G	107	0-86 (165mm Steel)	No Water			84	Cable Tool Percussion
SN 1G	258	0-86 (165mm Steel) 0-255 (127mm P.V.C.)	22	11,4	36,840	103	Air Rotary Percussion to 110m Cable Tool Percussion
KM 1G	451 Not Drilled to Basement	0-335 (165mm Steel)	55	0,04	34,95	85	Cable Tool Percussion
MW 4B	126	0-12 (203mm Steel) 0-68 (178mm Steel)	Private hole not known	9,9	30,450	67	Air Rotary Percussion

Boreholes drilled for this investigation may be identified by the letter G at the end of the number.

shown in figure 13.
The results of drilling in the Elands River valley (Boreholes KR 71G, KR 72, and SN 1G) show the main aquifers to be the arenaceous lower Kirkwood and predominantly rudaceous Enon Formation. The argilaceous upper Kirkwood Mudstones form the aquiclude in the region. In the southern margins of the Swartkops river valley (Borehole KR 75G) the sandstones of the Kirkwood Formation are absent. Groundwater in this region occurs in the conglomerates of the Enon Formation.

Borehole MD 21G was drilled east of Searle Hill to investigate the reported presence of shale and the source of low yields of poor quality water. Drilling data indicate that the 'shales' are well consolidated mudstones of the Kirkwood Formation and the source of low yielding poor quality water is the conglomerates of the Enon Formation. In both boreholes KR 75G and MD 21G, where the arenaceous sandstone member of the Kirkwood Formation was found to be absent, the start of the Enon Formation was marked by a narrow bed of clean glassy quartzite which appears similar to quartzites of the Table Mountain Group. The similarity could explain reports in old borehole records of water being encountered at relatively shallow depths in the T.M.G. of rocks in the area. South of Searle Hill boreholes MD 20G and MW 20G were drilled. Borehole MD 20G although intersecting the same formations as boreholes KR 75G and SN 1G yielded smaller quantities of poorer quality water. This occurrence may be explained by a change in source area of the water. Because of altitude and location, both boreholes MD 20G and MD 21G are unlikely to derive their water from the recharge areas feeding the low lying artesian area, but rather to derive their recharge locally from outcrops forming Searle Hill. This assertion is further supported by piezometric data obtained during other phases of investigation (Figure 31).

In the south of the region borehole MW 20G confirmed the presence of shales of the Bokkeveld Group which form the Pre-Cretaceous basement in this part of the study area. In addition borehole MW 20G intersected a major conglomerate lithology, the clasts of which are made up of shale pebbles (Figure 5). The matrix of the conglomerate is made up of clay resulting in the lithology being essentially devoid of water. The conglomerate lithology comprises the Enon Formation in areas adjacent to provenance of shale belonging to the Bokkeveld Group. In a surface outcrop nearby, the conglomerates are found to grade progressively into typical conglomerates of the Enon Formation as the influence of the adjacent quartzite provenance (Rocks of Table Mountain Group) becomes stronger. As borehole MW 20G is located in the Hol River valley, a tributary of the Elands River, the earlier assertion (page 14) that the Hol River is the main contributor of Bokkeveld derived Enon conglomerates to the upper Elands River valley in the region is confirmed.

During the investigation the drilling of private borehole MW 4B was monitored and later tested. MW 4B is located on the the east bank of the Elands River, between the river and Searle Hill. Formations encountered were similar to those encountered in borehole SN 1G with the two dominant aquifer lithologies being sandstones and conglomerates of the Kirkwood Formation and conglomerates of the Enon Formation. This borehole was found to have the highest specific capacity of all boreholes drilled during the investigation.

Immediately south of the Uitenhage fault on the down-thrown side, borehole KM1G confirmed the presence of considerable thickness of mudstones of the Kirkwood Formation. Problems with the insertion of borehole casing, resultant cave-ins and contamination of lithological samples made the identification of the underlying lithology difficult, although it has been identified as fine grained silt/sandstone of the Kirkwood Formation. It is therefore possible that considerable additional thickness of Cretaceous lithologies may overlie the basement in this part of the study area. The lack of water bearing formations encountered by the borehole can probably be attributed to the fine grained nature of the rock. It is likely that no economically significant supplies of water occur in the region because of upward and lateral finning of the sequences related to increasing distance from palaeosediment source areas.

Chapter 7. Aquifer Testing Programme.

7.1 Introduction.

Once direct access has been gained to the aquifer by drilling, one of the fundamental aspects of groundwater resource investigations, according to Rushton (1978), is the determination of the aquifer characteristics of permeability and storage. Determinations are made on the basis of data obtained from the controlled abstraction of water from boreholes and the monitoring of associated changes in piezometric levels. A test set-up for this purpose is more properly called an "aquifer test" because it is the aquifer or water-bearing formation rather than the pump or well that is being tested (Johnson, 1966).

During this investigation 18 tests of three types were undertaken :

2 - stepdrawdown tests
8 - constant rate tests
8 - recovery tests

In order to monitor the potential yield from the borehole while drilling, a number of "aquifer indicator tests" were conducted in addition to the formal and carefully controlled aquifer tests. The indicator tests were accomplished using either the small capacity pumping facility supplied with the cable-tool percussion rigs or in the case where hydraulic-percussion rigs were used, simply by measuring the yield of water blown from the borehole by compressed air. Use of these tests allowed for estimation of the depths at which water bearing horizons were encountered and gave an indication of when a full aquifer test was required.

7.2 Preparation of boreholes prior to testing.

Prior to the start of any aquifer test, boreholes were developed to remove clogging of pore spaces by fine materials as a result of drilling. Two techniques were used, mechanical surging using the large bailer supplied with the cable-tool rigs and in the case of borehole MD 21G the method of over-pumping described by Johnson (1966) was used. The development of boreholes intersecting sandstones of the Kirkwood Formation was also necessary to prevent a buildup of sand and consequent damage to the pump.

In addition to the development of boreholes, small quantities of detergent were introduced into the borehole and piezometers several hours before the start of pumping. This was done to disperse any oil that may have formed on the water surface during drilling as this detrimentally affects readings in the piezometers.

7.3 Principles of aquifer tests.

A borehole may be tested for one of two reasons:

1. Obtain information on the performance and efficiency of a well.
2. Provide data on the geohydrological properties of the aquifer from which aquifer performance can be calculated (Johnson division 1972).

During this investigation aquifer tests were conducted for the latter reason and to provide hydrochemical data useful in other phases of the investigation. (Appendix 4)

Although aquifer tests may be conducted by either the input or abstraction of water from a borehole, practical limitations result in abstraction being the most commonly used method. Two types of abstraction tests exist:

1. Constant discharge tests.
2. Variable discharge or step tests.

Constant discharge tests, used mainly to calculate the transmissivity (T) and storage (S) of an aquifer, may be subdivided into steady-state and non-steady state or transient tests. Steady-state tests are those which are pumped for a sufficiently long duration to allow recharge to balance abstraction, such that water levels approach an equilibrium position. In nonsteady-state tests water levels drop continuously and solutions are based on plots of drawdown against time. In practice nonsteady-state tests are more common than steady-state tests. (Bouwer, 1978)

In addition to the limitations imposed by the above subdivision of constant rate tests on the selection of suitable aquifer test solution methods, cognisance must also be taken of the type of aquifer being tested. There exist four groups of aquifer test solution methods based on the classification of aquifers into the following categories:

1. Confined aquifer
2. Unconfined aquifer
3. Semi-confined aquifer
4. Semi-unconfined aquifer

(Hazel, 1975)

The grouping of aquifer test solutions under the above four aquifer categories is not arbitrary but is best understood in terms of the solution being derived to calculate aquifer properties under a set of circumstances particular to that type of aquifer. The definitions of the above aquifer classifications give an insight into the variable way in which the aquifers respond to abstraction and the need for any aquifer parameter equations to take the variable response into consideration. The following definitions are based on those given by Kruseman and De Ridder (1970), Hazel (1975) and Bouwer (1978).

A confined aquifer (Figure 18) is a completely saturated permeable formation of which the upper and lower boundaries are impervious layers. Water pressure in a confined aquifer is higher than that of the atmosphere with the result that water in boreholes penetrating the aquifer is at a higher elevation than the top of the aquifer.

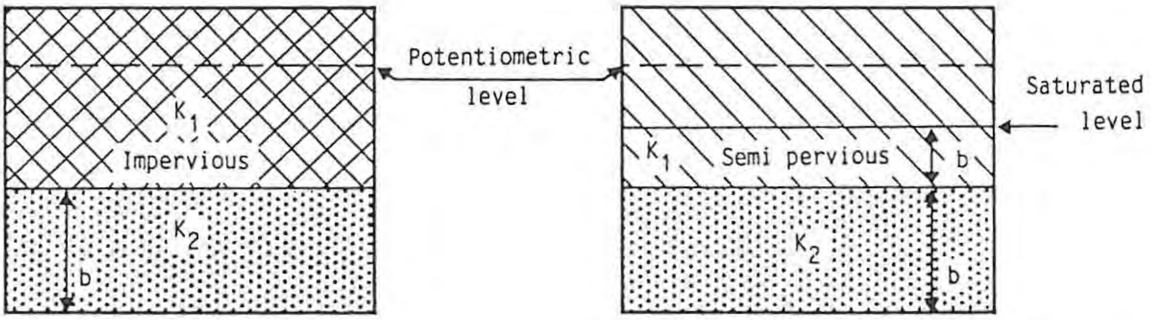
An unconfined aquifer is a permeable lithology only partly filled with water overlying a relatively impervious layer. The upper boundary of an unconfined aquifer is formed by a free water table or phreatic level which is not subject to any pressure other than that of the atmosphere and that generated by its own weight.

Semi-confined and semi-unconfined aquifers are two cases occurring on a gradational scale between the above defined cases. A semi-confined aquifer is similar to that of a confined aquifer with the exception that the confining layers are not completely impervious. Upon abstraction from a semi-confined aquifer vertical flow of water from the semi-pervious layer into the aquifer is generated. Horizontal flow in the semi-impervious layer is however small due to the low hydraulic conductivity of the layer.

The semi-unconfined aquifer is an aquifer in which the hydraulic

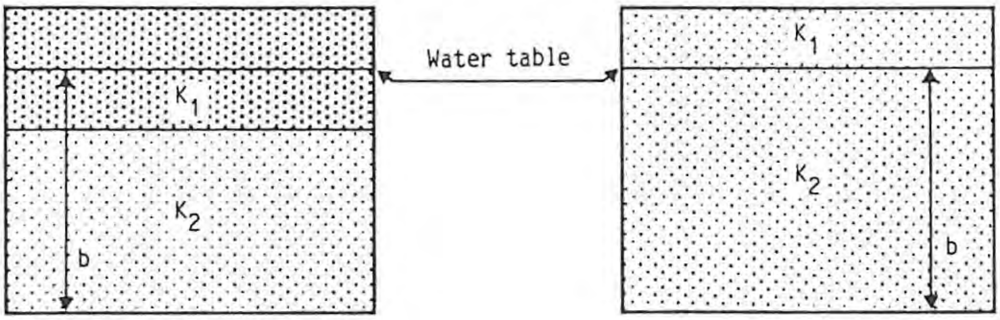
FIGURE 18 CONFINED, UNCONFINED, SEMI-CONFINED AND SEMI-UNCONFINED AQUIFERS

(AFTER HAZEL 1975)



Confined
$K_1 = 0$

Semi-confined
$K_1 \ll K_2$



Semi-unconfined
$K_1 < K_2$

Unconfined
$K_1 = K_2$

Where K = Hydraulic conductivity
b = Aquifer thickness

conductivity of the fine-grained layer is sufficiently great for horizontal flow to be significant. Such an aquifer exhibits delayed yield effects and is intermediate between a semi-confined and an unconfined aquifer.

An aquifer test is useful in determining the in situ hydraulic properties of both water-bearing and confining beds, which according to Kruseman and De Ridder (1970), are, in general representative of a larger area than are single point observations. All aquifer test solutions are however dependent on a number of assumptions which render an individual solution valid only under a restricted set of circumstances. During this investigation two solutions for drawdown and one for the recovery of constant rate tests were selected after the classification of aquifer type and test state had been made. The lack of equilibrium conditions being reached during the pumping phase resulted in the classification of tests as those of the non-equilibrium or non-steady state tests. The classification of the aquifer type as being artesian in nature is based on historical accounts of artesian flow and evidence of elevated piezometric levels obtained from the hydrocensus.

Analyses of drawdown data were conducted using the Cooper and Jacob (1946) and Chow (1952) methods while subsequent recovery was analysed using the Theis Recovery method (1935). The use of these methods requires the following assumptions to be made:

1. The aquifer has a seemingly infinite areal extent.
2. The aquifer is homogeneous, isotropic and of uniform thickness over the area influenced by the pumping test.
3. Prior to pumping, the piezometric surface and/or phreatic surface are nearly horizontal over the area influenced by the pumping test.
4. The aquifer is pumped at a constant discharge rate.
5. The pumped well penetrates the entire aquifer and thus receives water from the entire thickness of the aquifer by horizontal flow.
6. The aquifer is confined.
7. The flow to the well is in unsteady state.
8. The water removed from storage is discharged instantaneously with decline of head.
9. The diameter of the pumped well is very small i.e. the storage of the well can be neglected. (Kruseman and De Ridder, 1970).

Although assumption two is seldom met in the study area, the methods used are considered to give an adequate approximation of the hydrologic properties.

Variable rate or step drawdown tests although initially only used to determine well loss relationships may also be used to determine aquifer characteristics. Clark (1977) says that in addition to estimates of storage coefficient (S), step drawdown tests can be used to determine the aquifer transmissivity and well loss component of the drawdown in a pumped borehole. As drawdown in a borehole results from the cumulative effects of aquifer loss and well loss, once the well loss component has been calculated the true drawdown may be determined allowing more accurate analysis of constant discharge tests to be made. Transmissivity values which do not take well losses into account are usually underestimates.

The analysis of data obtained from the step-drawdown test was analysed using a method developed by Bierschenk and Wilson (1961). This method requires that the same assumptions be made as those listed on page 44, with the exception of assumption 4 which is replaced by:

4. The aquifer is pumped with a variable discharge rate.

In order to ensure accuracy a minimum of four steps were conducted during the testing of KR 71G although this was not possible for the test conducted on borehole MD 21G whose low yield prevented the execution of the final step. The results for this test as shown in Table 6 must therefore be regarded with caution.

Because of a lack of observation boreholes, values of storage coefficients could only be calculated for borehole MW 4B. Values of storage coefficient for the remainder of boreholes was approximated using a technique described by Hazel (1975). The technique is based on the compression of water alone and no adjustments are made for porosity or for the compressibility of the aquifer. The application of the technique is restricted to confined aquifer situations where values obtained using the technique are regarded by Hazel (1975) as reliable estimates.

7.4 Aquifer Test Results.

The results of aquifer tests are discussed in terms of;

1. Yield drawdown relationships.
2. Transmissivity and storage.

7.4.1 Yield Drawdown Relationships.*

Table 6 contains an analysis of the relationships between yield and drawdown taken after 300 minutes of pumping for boreholes drilled during the investigation. A period of 300 minutes was chosen for all boreholes so that comparisons between boreholes may be drawn in terms of their variation in aquifer type. The ratio of drawdown per unit yield for the same period is called specific drawdown and gives an indication of the ability of the aquifer to transmit water. The smaller the ratio of drawdown to yield the better are the transmissive abilities of the aquifer. Variation in specific drawdown ratios is a function of the variations in transmissivity, storage and borehole losses of the aquifer and borehole.

TABLE 6 : RATIOS OF DRAWDOWN PER UNIT YIELD FOR RESEARCH BOREHOLES

BOREHOLE	YIELD (l/S)	DRAWDOWN (M)	RATIO DRAWDOWN VS YIELD (M/ls^{-1})	AQUIFER TYPE
	TAKEN AFTER 300 MIN OF PUMPING			
MW 4 B	9,9	7,3	1,4	Conglomerates with sandstone matrix and minor sandstones
KR 72	12,9	31,1	2,5	Sandstones
SN 1 G Depth at testing 257m	11,4	36,8	3,2	Sandstones and minor conglomerates with sandstone matrix
KR 71 G	13,0	52,0	4,0	Sandstones and minor conglomerates with sandstone matrix
SN 1 G Depth at testing 109m	4,6	29,2	6,3	Sandstones and minor conglomerates with clay/silt matrix
KR 75 G	10,4	74,3	7,1	Conglomerates with sandstone matrix and minor conglomerates with clay/silt matrix
MO 20 G	4,1	32,3	7,9	Sandstones and minor conglomerates with silt/clay matrix
MO 21 G	0,34	27,0	79	Conglomerates with sandstone matrix and minor conglomerates with clay/silt matrix

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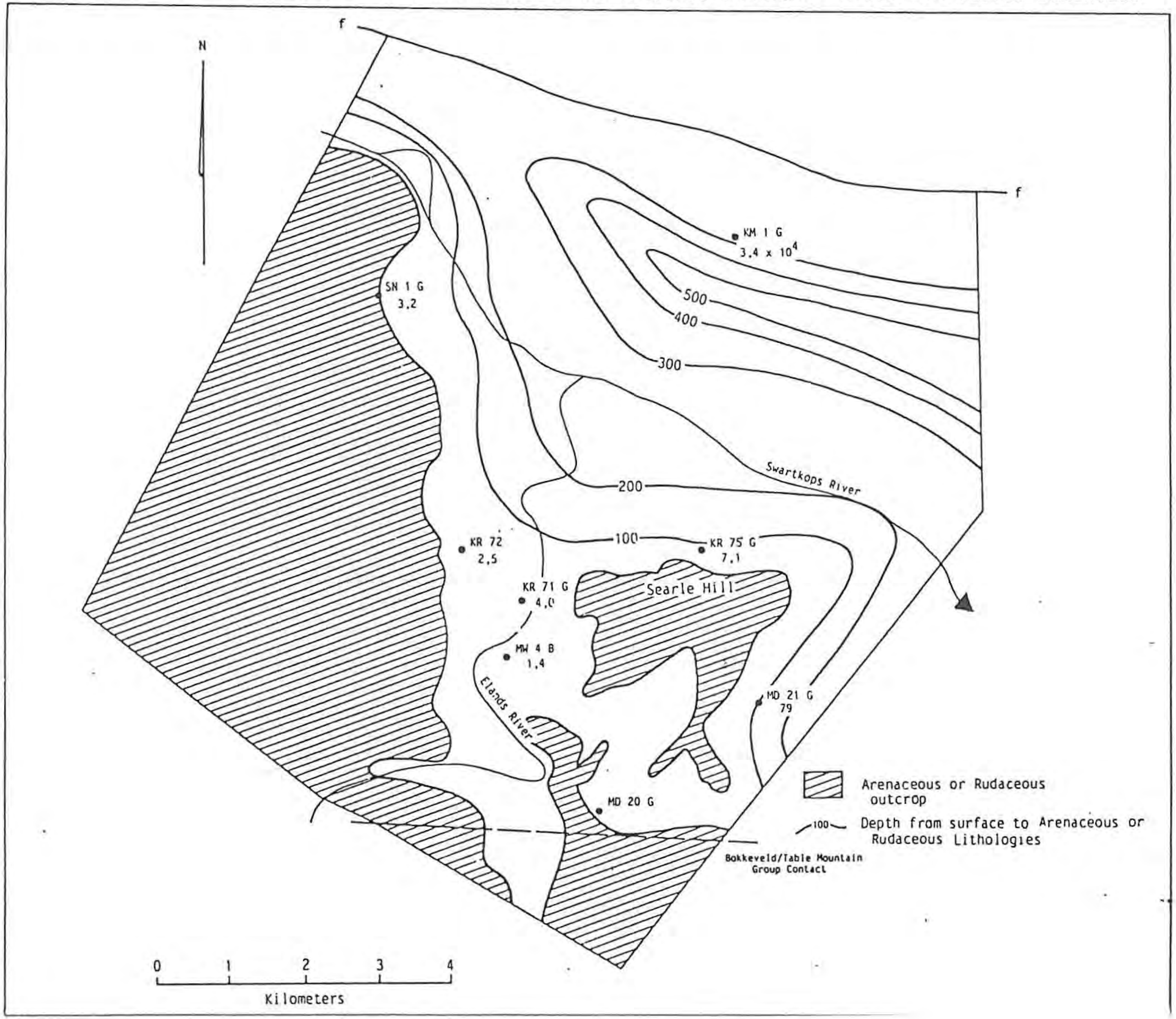
* SOMETIMES THE INVERSE RELATIONSHIP, SPECIFIC CAPACITY (Q/S) IS USED TO EXPLAIN THE ABILITY OF THE AQUIFER TO TRANSMIT WATER

7.4.1.1 Lateral variations in specific drawdown.

Boreholes located in areas in which palaeosediments were derived from the quartzite provenance were found to have the best ability to transmit water. Borehole KR 72 derives its groundwater from the sandstones of the Kirkwood Formation while boreholes MW 4B, SN 1 G and KR 71 G, derive groundwater from the sandstone and conglomerates of the Kirkwood and Enon Formations. Specific drawdown values for these formations were all less than 6,3 $m/\ell s^{-1}$. The main aquifer encountered in borehole KR 75 G is conglomerate of the Enon Formation which has a specific drawdown value of 7,1 $m/\ell s^{-1}$. In contrast, borehole MD 21 G intersects conglomerates with a fine grained matrix material and occasional intercollations of mudstone, clay and siltstone and has a high specific drawdown value of 79,4 $m/\ell s^{-1}$. Unlike the conglomerates found in borehole KR 75 G, these conglomerates differ hydrogeologically because of the added influence of palaeosediments originating not only from the quartzite (Table Mountain Group), but also from the shale (Bokkeveld Group) provenance.

In addition to lateral variation due to differing palaeosediment source area, an increase in specific drawdown from southwest to northeast is observed in the Swartkops river valley. Boreholes MW4B, KR72, SN1G and KR71G, located in the west and southwest close to the source of palaeosediments, all have specific drawdowns of 6,3 $m/\ell s^{-1}$ or less, with an average specific drawdown of 3,5 $m/\ell s^{-1}$ (Figure 19). Borehole KR75G located to the east however, has a specific drawdown value of 7,1 $m/\ell s^{-1}$. Borehole KR72 which intersects sandstones of the Kirkwood Formation in the west, has a specific drawdown value of 2,5 $m/\ell s^{-1}$ indicating a good ability to transmit/store water. In contrast borehole KM1G located south of the Uitenhage fault in an area more distant from the source of palaeosediment was found to be essentially dry, with a final yield of only 0,04ℓs^{-1}, despite having penatrated over 130m of saturated sediments of Kirkwood silt/sandstones. Although borehole KM1G was not drilled to basement and coarser grained sandstones and conglomerates may be present at greater depths, a general increase in specific drawdown in an easterly direction is indicated and in the latter case is most likely a consequence of increasing percentages of fine grained material as the energy environment under which the palaeosediments were deposited decreases eastwards.

FIGURE 19 ISOPACHS OF ARGILLACEOUS LITHOLOGIES AND SPECIFIC DRAWDOWN VALUES FOR TESTED BOREHOLES



7.4.1.2 Vertical variations in specific drawdown.

An improvement in the specific drawdown ratio from 6,3 to 3,2 m/ℓs^{-1} with depth of drilling for borehole SN1G, indicates an improvement in water transmission and storage with an increase in the relative proportion of conglomerate to sandstone. Borehole MW4B, indicates a dominant aquifer type similar to the conglomerates encountered at depth in borehole SN 1 G and has the lowest specific drawdown ratio (1,4 m/ℓs^{-1}) of all boreholes pumped during the investigation. The above relationships indicate that the conglomerates of the type encountered in borehole SN1G and MW4B, those with a relatively small pebble size and a sandstone matrix (Lower Kirkwood and Enon Formations), have a better ability to transmit/store water than do the relatively fine grained overlying sandstones of the Kirkwood Formation.

7.4.2 Hydrogeological Parameters of Transmissivity and Storage Coefficient.

Values of transmissivity and storage together with the methods used to derive them are represented in Table 7. With the exception of calculated storage coefficients for borehole MW 4B all coefficients of storage were estimated using the Hazel (1975) technique. As the technique is independent of porosity and compressibility of the aquifer, values derived using the method can not be interpreted in terms of aquifer characteristics but only aquifer thickness. In order to test the reliability of the estimation techniques for boreholes within the study area, the method was used to approximate the storage coefficient of borehole MW 4B. The approximated value of 3,05 x 10^{-4} was then compared with the calculated values of 8,2x10^{-4} and 9,3 x 10^{-4} as derived using the Cooper and Jacob (1946) and Chow (1952) methods. As the results are well within an order of magnitude of each other they are regarded as a reasonable estimate.

Values of transmissivity obtained from boreholes MD 21 G and MD 20 G may only be interpreted in terms of aquifer type if due regard is given to the following two factors:

1. The low rate at which MD 21 G could be pumped invalidated assumption nine which states, "The diameter of the pumped well is very small i.e. the storage in the well can be neglected." As the true value

TABLE 7 CALCULATED HYDRAULIC PARAMETERS

BOREHOLE NO.	DOMINANT AQUIFER/S	TYPE OF TEST	BOREHOLE DEPTH AT PUMPING (M)	TRANSMISSIVITY M^2 /DAY	REPRESENTATIVE TRANSMISSIVITIES M^2 /DAY	STORAGE COEFFICIENT	BOREHOLE EFFICIENCY AT RATE FOR C.R. TEST	METHOD OF ANALYSIS
MW 4B	CONGLOMERATES WITH MINOR SANDSTONES (KIRKWOOD & ENON FORMATIONS)	C.R.	126	31,9		$8,2X10^{-4}$		JACOB
				31,0	51,8	$9,3X10^{-4}$		CHOW
				72,2				THEIS RECOVERY
MD 21 G	CONGLOMERATES (ENON FORMATION)	C.R.	167	5,6				JACOB
				5,6				CHOW
				0,5	2,0			THEIS RECOVERY
		S.T.		2,0			77,7%	BIERSKENK & WILSON
						$2,15X10^{-4}$		HAZEL
KR 72	SANDSTONE (KIRKWOOD FORMATION)	C.R.	200	48,7				JACOB
				48,3	73,0			CHOW
				97,4				THEIS RECOVERY
						$7,05X10^{-4}$		HAZEL
SN 1 G	MUDSTONE, SANDSTONE & CONGLOMERATE (KIRKWOOD FORMATION)	C.R.	109	26,0				JACOB
				26,1	21,2			CHOW
				16,3				THEIS RECOVERY
						$4,35X10^{-4}$		HAZEL
SN 1 G	SANDSTONE & CONGLOMERATE (KIRKWOOD & ENON FORMATIONS)	C.R.	257	34,7				JACOB
				34,7	38,09			CHOW
				41,48				THEIS RECOVERY
						$1,12X10^{-3}$		HAZEL
KR 71 G	SANDSTONE & CONGLOMERATE (KIRKWOOD & ENON FORMATIONS)	C.R.	200	77,6				JACOB
				77,6	52,4			CHOW
				29,0				THEIS RECOVERY
		S.T.		25,4			78,1%	BIERSKENK & WILSON
						$6,65X10^{-4}$		HAZEL
MD 20 G	SANDSTONE (KIRKWOOD FORMATION)	C.R.	124	22,1				JACOB
				22,1	23,2			CHOW
				24,3				THEIS RECOVERY
			BARRIER BOUNDARY EFFECTS NOTABLE	1,5				JACOB
				1,2				CHOW
				16,2				THEIS RECOVERY
						$5,75X10^{-4}$		HAZEL
KR 75 G	CONGLOMERATE (ENON FORMATION)	C.R.	148	117,5				JACOB
				117,6	89,3			CHOW
				61,1				THEIS RECOVERY
						$3,35X10^{-4}$		HAZEL

C.R. = CONSTANT RATE TEST
S.T. = STEP-DRAWDOWN TEST

for transmissivity should theoretically fall between that obtained from drawdown data (5,6m²/day and that derived from recovery data (0,5m²/day) the value of 2m²/day as derived from the step-drawdown test is favoured to represent the aquifer.

2. The aquifer test of borehole MD 20 G produced evidence of barrier boundary effects* after only 20 minutes of pumping. Calculated values of transmissivity for the aquifer are based only on the first 20 minutes of pumping. All values of transmissivity calculated from data after the first 20 minutes of pumping are not regarded as representative of the aquifer as assumption one, which states "the aquifer has a seemingly infinite areal extent", no longer remains valid.

Because of the variation in transmissivity values obtained using the various analytical techniques, a representative transmissivity value for each borehole was calculated to facilitate easier comparisons between boreholes and their lithologies. For borehole KR 71 G whose transmissivity values for the Jacob and Chow methods were in close agreement as were its values for Theis recovery and Bierskenk and Wilson methods, the representative value is simply the arithmetic mean of all transmissivity values obtained. For the remainder of the boreholes the Jacob and Chow methods gave noticably different values to the single Theis recovery value. The representative value for these boreholes is taken to be the arithmetic mean of the combined Jacob and Chow average, and the Theis recovery value. (Table 7)

7.4.2.1 Variations in transmissivity.

The influence of palaeosediment source areas on the geohydrological properties of the lithologies is again made evident by a corresponding change in transmissivity values obtained (Table 8). Transmissivity values for the sandstone member of the Kirkwood Formation were found to vary between a maximum figure of 73,0m²/day for borehole KR72 and a minimum of 23,2m²/day for borehole MD 20 G (Table 8). Values of transmissivity for the conglomerates of the Enon Formation were found to vary from below 2,0m²/day for borehole MD21G to 89,3m²/day for borehole KR72G. The gradual changes in transmissivity values may be explained by increased proportions of

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* THE BARRIER BOUNDARY IS CAUSED BY A RISE IN THE PRE-CRETACEOUS FLOOR MORPHOLOGY RESULTING IN A RIDGE OF T.M.G. QUARTZITE RESTRICTING THE LATERAL EXTENT OF THE CRETACEOUS AQUIFER

interstitial clay material being present in the Kirkwood Sandstones and in the matrix material of the Enon Conglomerates in areas where the source of the palaeosediments are wholly or partially derived from rocks of the Bokkeveld group. Boreholes within the quartzite provenance, intersecting a combination of both the Kirkwood and Enon Formations have intermediate transmissivities varying from 21,2m^2/day for borehole SN1G to 52,4m^2/day for borehole KR71G.

TABLE 8 :· VARIATIONS IN REPRESENTATIVE VALUES OF TRANSMISSIVITY (M^2/DAY)

LITHOLOGY	LOWEST VALUE		HIGHEST VALUE	
	BOREHOLE FROM WHICH VALUE OBTAINED & PALAEOSOURCE	VALUE (M^2/DAY)	BOREHOLE FROM WHICH VALUE OBTAINED & PALAEOSOURCE	VALUE (M^2/DAY)
SANDSTONES (KIRKWOOD FORMATION)	MD 20 G MIXED PROVENANCE	23,2	KR 72 QUARTZITE PROVENANCE	73,0
SANDSTONES AND CONGLOMERATES (KIRKWOOD AND ENON FORMATIONS)	SN 1 G (TESTED AT A DEPTH OF 109M) QUARTZITE PROVENANCE	21,2	KR 71 G QUARTZITE PROVENANCE	52,4
CONGLOMERATES (ENON FORMATION)	MD 21 G MIXED PROVENANCE	2,0	KR 75 G QUARTZITE PROVENANCE	89,3

Table 8 indicates that of all formations found in the study area, conglomerates of the Enon Formation have the highest overall values for transmissivity. This is further evidenced by variations in transmissivity values related to vertical facies changes. In borehole SN 1 G transmissivity values were found to increase from 21,2 to 38,1m^2/day as increasing proportions of Enon conglomerates were encountered at depth (Table 7).

Transmissivity values indicate that of all the boreholes located within the quartzite provenance, borehole KR 75 G has the highest values of transmissivity. Specific drawdown values were also higher for KR 75 G than for any other borehole located within the quartzite provenance. As specific drawdown is both a measure of the storage and transmissive abilities of a borehole, this indicates that borehole KR75G has poor storage capability. When compared to estimated values of storage, using the Hazel (1975) technique, the comparison was found to be favourable with the estimated value of storage for borehole KR75G being the lowest of all boreholes located within the quartzite provenance (Page 47 and Table 7). This provides additional evidence of the reliability of the Hazel estimation technique for boreholes within the study area.

Chapter 8. Hydrochemistry.

8.1 Introduction.

The purpose of obtaining and analysing water quality data is to provide insight to the hydrochemical relationships of the various lithologic and aquifer units. In order to meet this objective 270 samples were obtained in three phases:

1. As part of the study area hydrocensus of existing abstraction points, to obtain a perspective on spatial water quality variations.
2. During drilling, to obtain information on the water quality of specific formations and of vertical variations within the aquifers.
3. During the execution of aquifer tests, as a means of detecting changes during testing and to obtain relatively uncontaminated integrated samples from a known aquifer source.

Samples were analysed at Rhodes University and at the Hydrological Research Institute, Pretoria. Analyses conducted included the following: pH, conductivity, total alkalinity (TAL), total dissolved solids (TDS), Ca, Mg, Na, K and Cl, while analyses for F, P, NO_3, Si, SO_4 and NH_4 were also made at the Hydrological Research Institute. In addition to laboratory analysis, field measurements of specific electrical conductance were made to aid decision making in the field and to provide back-up data.

A summary of analyses of hydrochemical samples obtained during drilling and test pumping is presented in Table 9.

8.2 Hydrochemical classification of the groundwater.

In order to gain an understanding of the hydrochemistry of the study area, it is necessary to consider the hydrochemistry in two ways. Attention is first given to the variability of total dissolved solid concentrations between aquifer units. Second is a more detailed study of differences in ionic ratios related to lithological types and hydrochemical facies. Differences in ionic ratios are first considered jointly with the use of trilinear plots and then in more detail as each participating ion in possible hydrochemical changes are considered in turn. Consideration of pH

TABLE 9 : SUMMARY OF WATER CHEMISTRY FROM CONSTANT RATE TESTS

Borehole Number	KM 1 G		KR 72		KR 75 G		SN 1 G (when at 109m)		KR 71 G		SN 1 G (when at 257m)		MD 21 G		MD 20 G	
Number of Samples	2		19		17		3		6		4		4		2	
	S x̄ mg/ℓ	EPM %	S x̄ mg/ℓ	EPM %	S x̄ mg/ℓ	EPM %	S x̄ mg/ℓ	EPM %	S x̄ mg/ℓ	EPM %	S x̄ mg/ℓ	EPM %	S x̄ mg/ℓ	EPM %	S x̄ mg/ℓ	EPM %
Ca	64 502	25,0 17,2	4,7 8,2	0,41 8,3	5,0 3,7	0,18 6,1	22,7 27,3	1,4 6,6	0 2,0	0,1 4,1	5,4 9,25	0,46 6,3	1,4 22	1,1 6,9	17 103	5,1 6,5
Na	2,1 2597	112,9 77,7	34,6 83,9	3,65 73,7	1,2 52,3	2,27 76,9	292 340	14,8 70,0	1,4 41,7	1,8 74,4	92 121,5	5,29 72,8	5,4 286	12,4 78,2	73,5 1334	58,0 73,3
K	25,7 23,9	0,61 0,4	0,3 1,3	0,3 0,6	0,18 2,15	0,06 2,1	2,0 3,3	0,08 0,4	0,05 0,83	0,02 0,8	0,3 2,30	0,06 0,8	0,35 5,35	0,14 0,9	1,7 67,4	1,7 2,2
Mg	37,5 81,5	6,7 4,6	4,8 10,5	0,86 17,4	0,6 5,3	0,44 14,9	52,6 60	4,9 23,0	0 6,0	0,5 20,7	15,4 17,75	1,46 20,1	0 27	2,22 14,0	4,2 173	14,2 18,0
SO_4	60,8 484	10,1 7,0	15,4 30,1	0,63 12,8	2,8 17,2	0,36 11,3	87,3 102	2,12 10,1	1,2 23,2	0,5 18,1	30,2 36,5	0,76 10,6	0,58 53,5	1,1 6,7	17,7 279,5	5,8 7,4
TAL	0 0	0 0	10,1 14,4	0,29 5,9	12,5 24,8	0,5 15,7	5,5 9,7	0,19 0,9	2,2 2,8	0,05 2,2	0,5 10,75	0,22 3,1	0,96 39,3	0,79 4,8	2,4 135	2,7 3,5
Cl	467 4789	135 93	55,1 141,6	4,0 81,3	0,87 82,4	2,32 73,0	553 660	18,6 89	1,7 78,2	2,2 79,7	171 219	6,18 86,3	4,8 518	14,6 88,5	51 2468	69,5 89,1
TDS	950 8764		144 367		19,7 197,6		1017 1208		4,3 160,2		330 393		12,2 965,5		132,9 4617	
pH	0,0 6,8		0,5 6,0		0,38 7,1		0,6 6,5		0,3 5,6		0,1 6,2		0,1 6,4		0,0 8,3	
NH_4	0,23 0,48		0,009 0,035		0,005 0,04		0,07 0,06		0,004 0,04		0,0 0,01		0,0 0,03		0,0 0,04	
NO_3	0,1 0,09		0,06 0,06		0,005 0,001		0,02 0,03		0,015 0,01		0,015 0,09		0,03 0,04		0,007 0,025	
F	0,0 0,7		0,13 0,12		0,06 0,2		0,0 0,2		0,0 0,0		0,005 0,2		0,1 0,2		0,0 0,9	
Si	0,6 2,7		0,4 4,7		0,02 4,2		1,1 2,3		0,08 4,7		0,2 4,35		0,2 5,85		0,2 4,25	
P	0,001 0,001		0,01 0,017		0,006 0,018		0,002 0,006		0,007 0,01		0,002 0,005		0,003 0,006		0,006 0,004	

TABLE 9 : SUMMARY OF WATER CHEMISTRY FROM SAMPLES OBTAINED DURING DRILLING

Borehole Number	KM 1 G				KR 72				KR 75 G				(when at SN 1 G 109m)			
Number of Samples	7				20				14				11			
	S	x̄ mg/ℓ	EPM	%	S	x̄ mg/ℓ	EPM	%	S	x̄ mg/ℓ	EPM	%	S	x̄ mg/ℓ	EPM	%
Ca	177	748	37,3	19,3	5,9	15,4	0,768	4,8	30,3	61,7	3,08	10,1	11,2	16,0	0,798	6,5
Na	309	2889	126	65,2	135,8	276,5	12,0	75,0	244,9	529,9	23,05	75,3	161,2	210,3	9,1	74,5
K	15,5	35,9	0,92	0,5	1,77	5,2	0,135	0,9	5,4	19,4	0,496	1,6	5,6	8,1	0,21	1,7
Mg	216	353	29,1	15	17,96	37,6	3,09	19,3	36,6	48,6	4,0	13,0	21,5	25,9	2,1	17,3
SO_4	213	631	17,8	9,0	61,3	117,5	2,45	15,1	212,3	288,6	6,0	19,9	39,3	56,4	1,2	9,8
TAL	5,4	2,9	0,06	0,03	15,7	48,1	0,963	5,9	23,8	177,07	3,54	11,7	10,5	9,4	0,19	1,6
Cl	1398	6404	181	91,0	216	453,2	12,8	79,0	348,9	730,2	20,6	68,4	294,8	383,7	10,8	88,6
TDS	2271	11472			514	1118,5			942,1	1970,8			574	854,4		
NH_4	0,42	0,65			0,083	0,061			0,44	0,31			0,7	0,82		
NO_3	0,44	0,43			0,03	0,041			16,2	16,41			0,05	0,04		
F	0,17	0,61			0,15	0,34			0,13	0,77			0,34	0,55		
Si	0,89	3,7			0,95	4,16			0,6	2,67			3,1	5,5		
P	0,008	0,009			0,014	0,014			3,46	0,008			0,006	0,02		

Borehole Number	KR 71 G				(when at SN 1 G 267m)				MD 21 G				MD 20 G			
Number of Samples	30				24				8				8			
	S	x̄ mg/ℓ	EPM	%	S	x̄ mg/ℓ	EPM	%	S	x̄ mg/ℓ	EPM	%	S	x̄ mg/ℓ	EPM	%
Ca	4,45	9,26	0,462	8.03	8,6	13,1	0,65	5,3	2,8	22,1	1,1	7,2	12,2	104,1	5,2	6,6
Na	48,6	100.16	4,35	75,7	111,5	208,1	9,1	74,3	10,6	279,8	12,2	79,7	93,6	1335,6	58,1	73,6
K	1,1	4,745	0,12	2,0	4,8	8,0	0,2	1,6	2,8	10,3	0,3	2,0	7,2	71,0	1,8	2,3
Mg	7,2	9,82	0,808	14,0	15,4	27,6	2,3	18,8	2,7	20,8	1,7	11,1	7,8	167,5	13,8	17,5
SO_4	24,0	29,02	0,06	10,4	not analysed				8,5	48,4	1,0	6,6	14,6	294,5	6,1	7,8
TAL	17,05	37,2	0,752	13,0	15,9	18,7	0,37	-	3,2	15,8	0,32	2,1	26,7	123,9	2,5	3,2
Cl	82,83	156,9	4,43	76,6	219,3	410,3	11,6	-	15,2	494,5	13,9	91,3	123,2	2478	69,9	89,0
TDS	196,5	426,8			407,7	801			122	1105			1552	4096		
NH_4	0,02	0,04			not analysed				0,15	0,32			0,01	0,05		
NO_3	0,04	0,06			not analysed				0,1	0,2			0,02	0,03		
F	0,12	0,23			not analysed				0,15	0,46			0,08	0,9		
Si	11,9	6,35			not analysed				1,5	1,7			0,5	4,4		
P	0,01	0,01			not analysed				0,008	0,014			0,02	0,01		

and ions that may participate in possible base exchange and sulphate reduction reactions are made using only analyses from aquifer test water samples. The usefulness of samples obtained during drilling when considering ionic ratios, is limited by possible oxidation and release of carbon dioxide from samples during filtration, and is discussed further on page 61.

Towards the end of the chapter ions which do not undergo significant hydrochemical change are briefly discussed using analyses of both pumping and drilling samples.

8.2.1 Total dissolved solids (TDS).*

The total concentration of dissolved minerals in water is a general indication of the mineralised quality of the water and its suitability for the many types of uses. The concentrations of TDS may be directly determined, by drying and weighing the residue or indirectly determined by, (a) adding together the separately determined ion concentrations, (b) determining the specific gravity of a sample or (c) measuring the specific conductance of the water.

During the hydrocensus an indication of water quality was obtained using the approximation of specific conductance. From the outset of the hydrocensus it was apparent that considerable spatial variation in water quality exists and is probably related to :

1. Variability of aquifer type, with less transmissive aquifers having higher TDS values.
2. Variability due to source area of recharge and palaeosediments. Figure 20 is a scatter plot of yield verses TDS and illustrates the generally lower TDS and higher yield values for those boreholes located within the quartzite provenance.

During aquifer testing when samples could be obtained exclusively from a known aquifer unit/units, the following mean value for TDS were obtained.

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* ALL SAMPLES WERE FILTERED IN THE FIELD BEFORE ANALYSIS

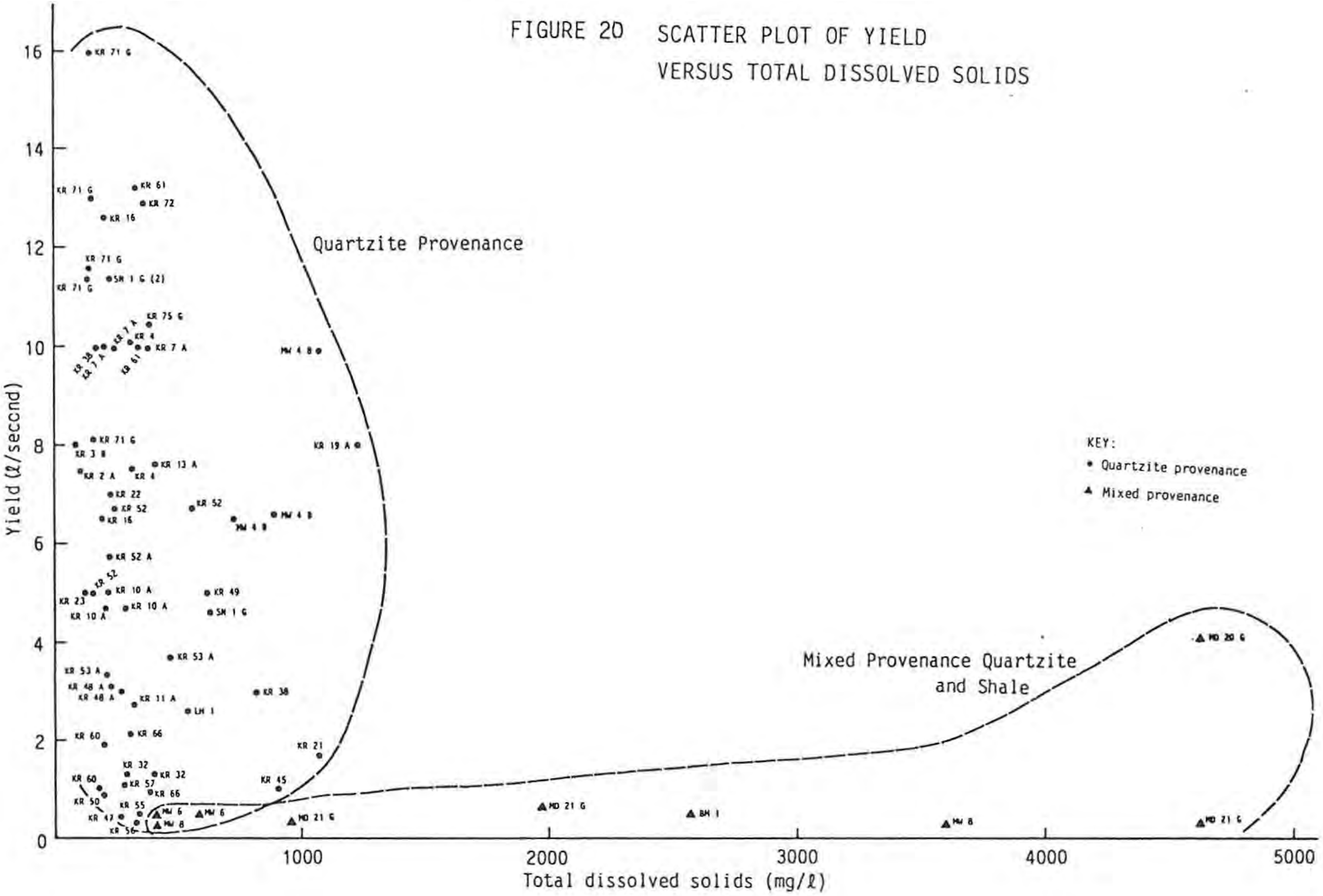


FIGURE 20 SCATTER PLOT OF YIELD VERSUS TOTAL DISSOLVED SOLIDS

TABLE 10. TOTAL DISSOLVED SOLID COMPONENT OF HYDROCHEMISTRY.

FORMATION	LITHOLOGY	PALAEOSOURCE AREA	MEAN TDS mg/ℓ*
Kirkwood	Mudstone		8764
Kirkwood	Sandstone	Quartzite	367
Enon	Conglomerate	Provenance	197
Kirkwood	Sandstone	Mixed	4617
Enon	Conglomerate	Provenance	966

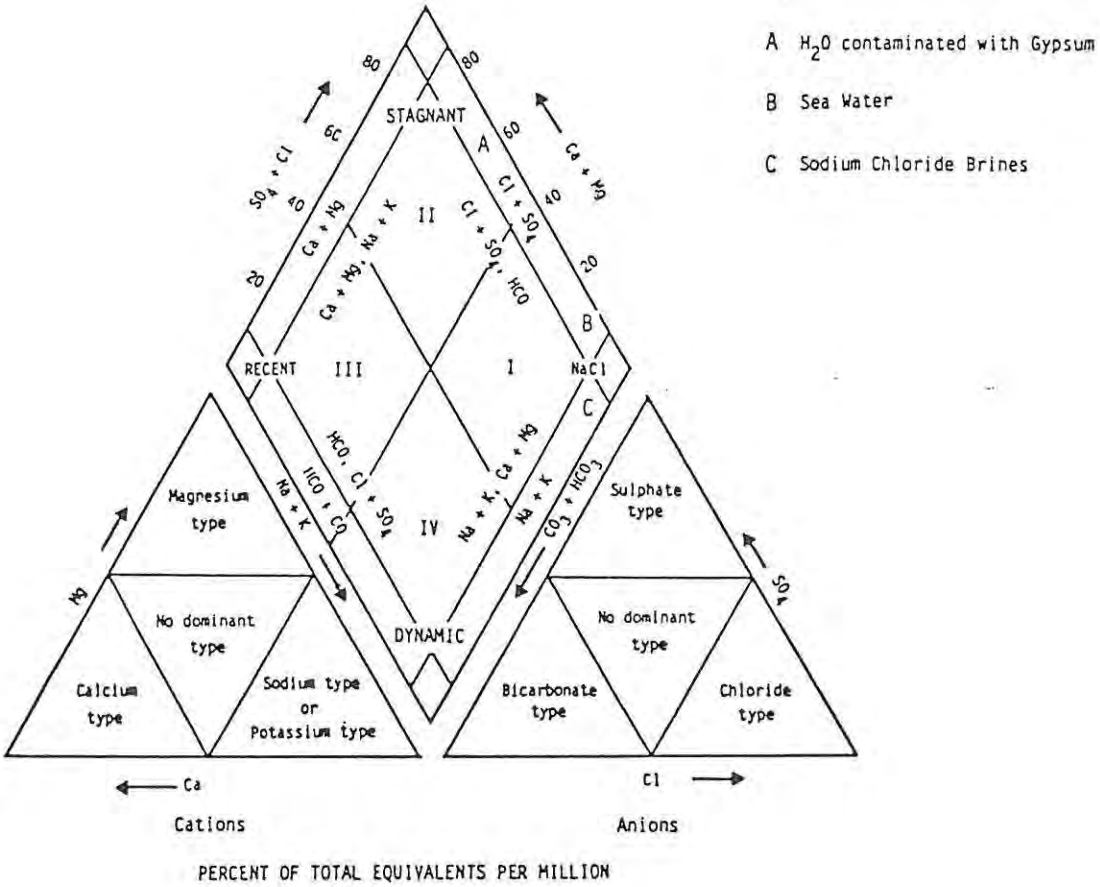
*For tables 10 to 19 the number of samples from which means are calculated together with standard deviation are the same as listed in table 9.

As expected boreholes intersecting combinations of the above lithologies have intermediate TDS values. Borehole KR71G is anomalous in this regard and will be discussed separately at the end of the chapter (Page 83).

8.2.2 Piper Diagram Analyses.

The Piper Diagram is a trilinear plot developed by Piper (1944) as a means of representing the water analysis as a whole. Ward (1975) describes it as a trilinear diagram which combines three plotting fields, two triangular fields and an intervening diamond-shaped field, all having scales of 0 to 100 representing percentage of total equivalents per million. The proportion of each cation constituent is plotted as a single point in the left-hand triangular field and each anion constituent in the right-hand triangular field. The central diamond-shaped field is used to show the overall chemical character of the groundwater by a third single point plot which lies at the intersection of the rays projected from the cation and anion points. As the plot is of relative and not absolute concentrations it serves as a diagnostic tool to distinguish between the major element chemistry of water originating from different rock types. Figure 21 illustrates the hydrochemical facies classification proposed by Back (1966) which will be used as a basis of classification during this study.

FIGURE 21 PIPER DIAGRAM SHOWING HYDROCHEMICAL FACIES
(AFTER BACK 1966)



Figures 22 and 23 show the fields into which analyses plotted from the hydrocensus and drilling programme respectively. In both cases the plots are very similar and illustrate a general characteristic of little hydrochemical variation between boreholes. On the cation diagram all samples plotted into the sodium or potassium type field, while in the anion diagram all samples plotted into the chloride type field. As the potassium ion seldom exceeds 5% of the sodium ion, the water may be described as being of the sodium chloride type, and plots as such on the central diamond shaped plot. Figure 24 is of analyses obtained during aquifer testing and represents water from the different lithologies and aquifers derived from the two palaeosediment source areas. The field into which the analyses plot, indicate that although inter aquifer differences in certain hydrochemical ratios are noticable, water from the various aquifers is generally similar, being of the sodium-chloride type.

Despite possible oxidation during filtration, figure 25 indicates that groundwater obtained during drilling through the Kirkwood Mudstones in boreholes KM1G would if no oxidation had occurred, approximate that of the mean of pumped samples from borehole KM1G. Although the determination of a typical hydrochemistry for groundwater from a particular lithology could not normally be justified on the basis of data obtained from a single aquifer test, the evidence presented in figure 25 indicates it to be, in absence of additional data, a reasonable estimate.

From figures 24 and 26 two trends may be distinguished for the cations:

1. The combined relative proportion of sodium and potassium cations are highest for the mudstones of the Kirkwood Formation and conglomerates of the Enon Formation. Where sandstones and conglomerates of the Kirkwood Formation occur alone or in combination with conglomerates of the Enon Formation, the combined proportion of sodium and potassium is reduced.

2. Mudstones of the Kirkwcod Formation have greater proportions of calcium than do the other formations whose proportions of calcium are similar and plot in a restricted field.

FIGURE 22 TRILINEAR PLOT OF HYDROCHEMICAL SAMPLES OBTAINED DURING THE HYDROCENSUS

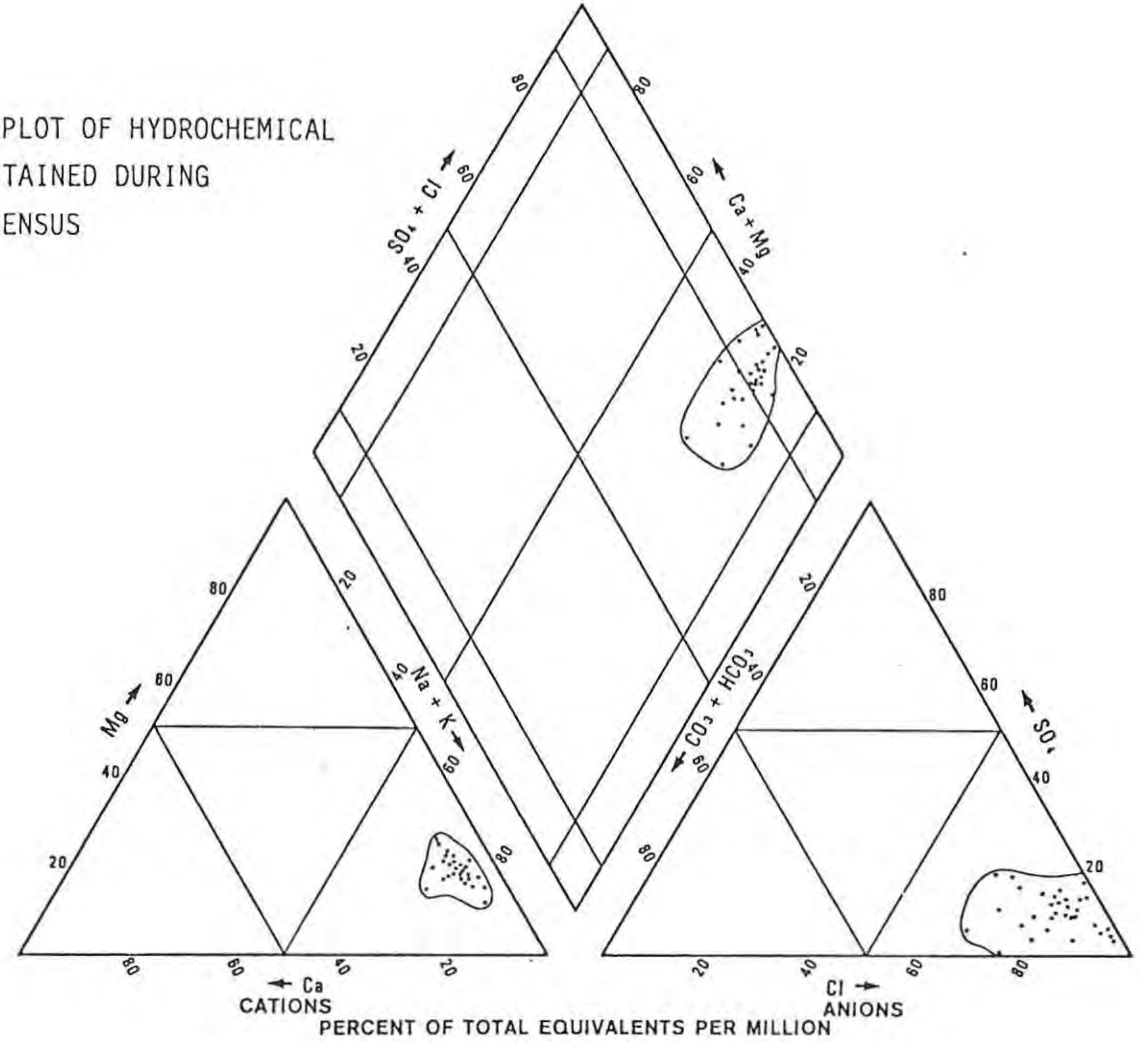


FIGURE 23 COMBINED TRILINEAR PLOT OF MEAN HYDROCHEMICAL CONCENTRATIONS OBTAINED DURING DRILLING

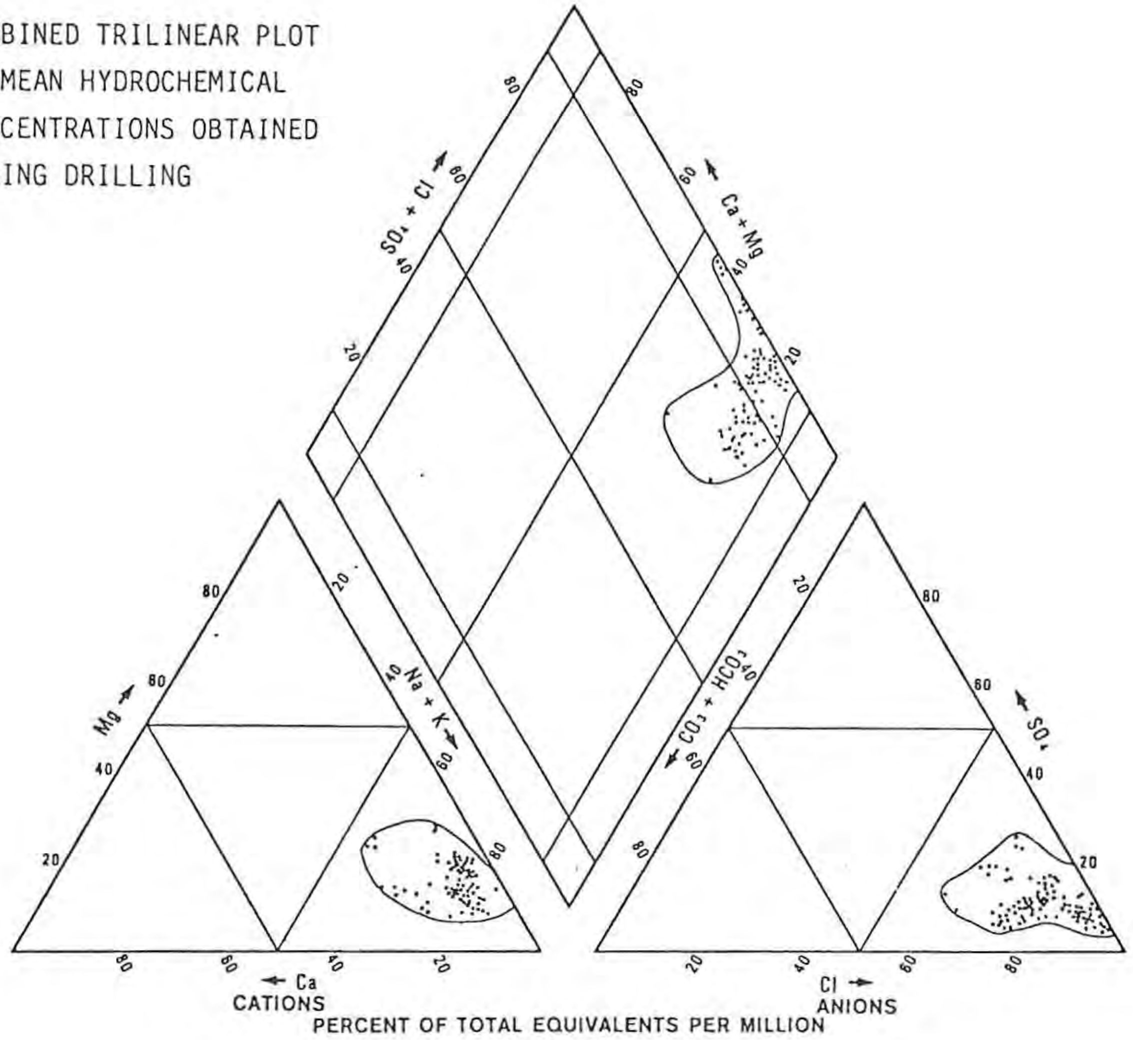


FIGURE 24 TRILINEAR PLOT OF MEAN HYDROCHEMICAL CONCENTRATIONS OBTAINED DURING CONSTANT RATE TESTS

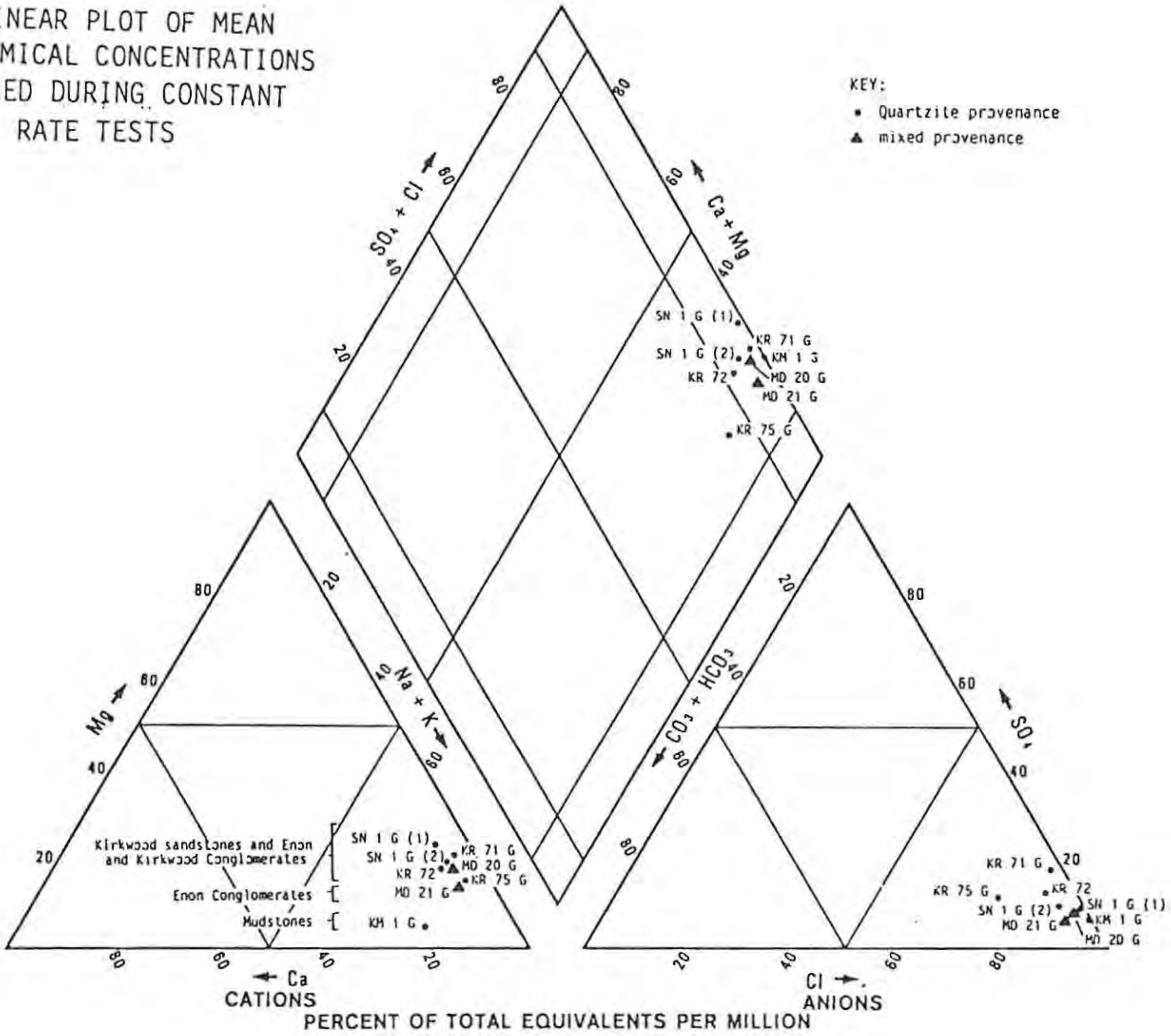
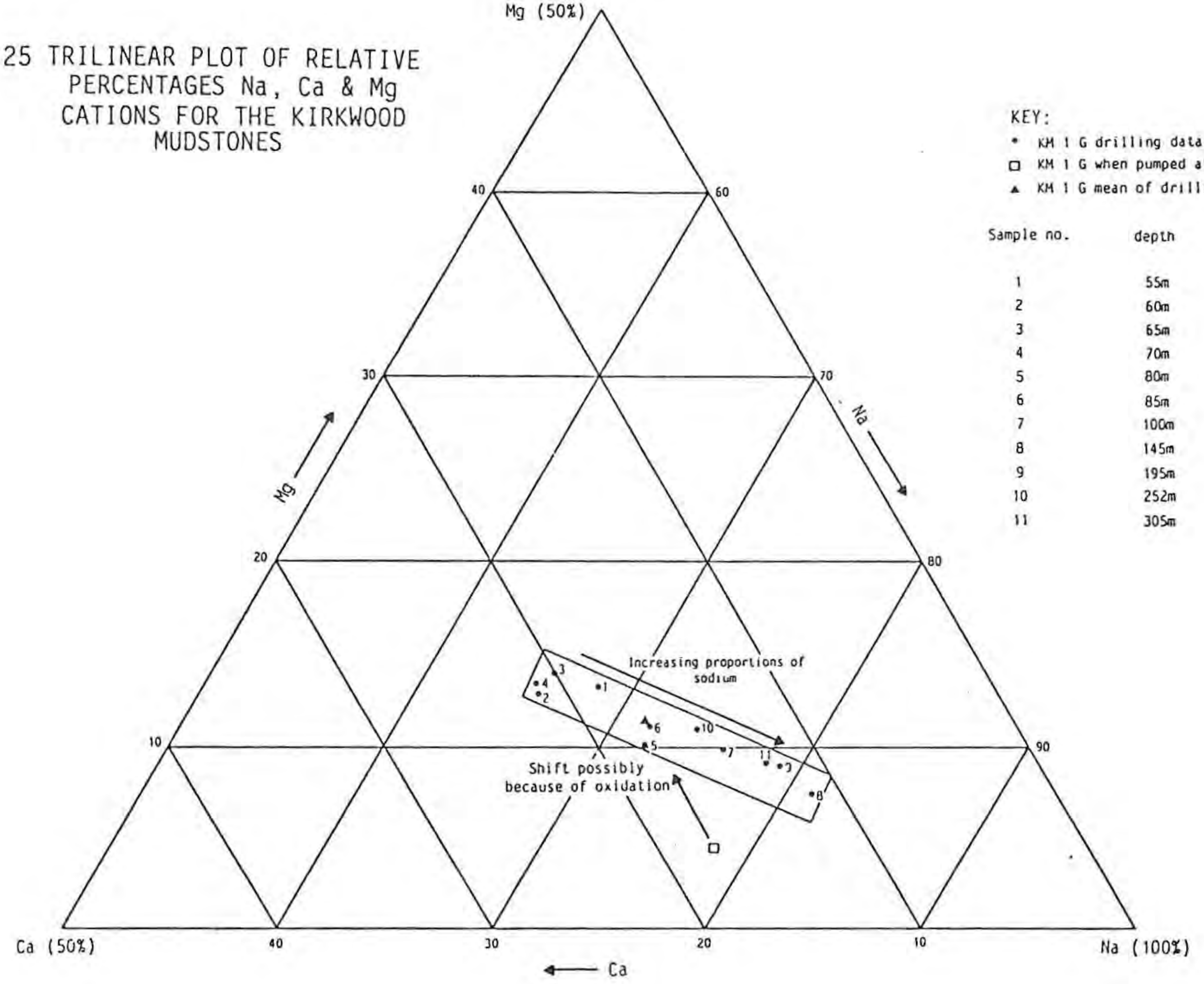


FIGURE 25 TRILINEAR PLOT OF RELATIVE PERCENTAGES Na, Ca & Mg CATIONS FOR THE KIRKWOOD MUDSTONES

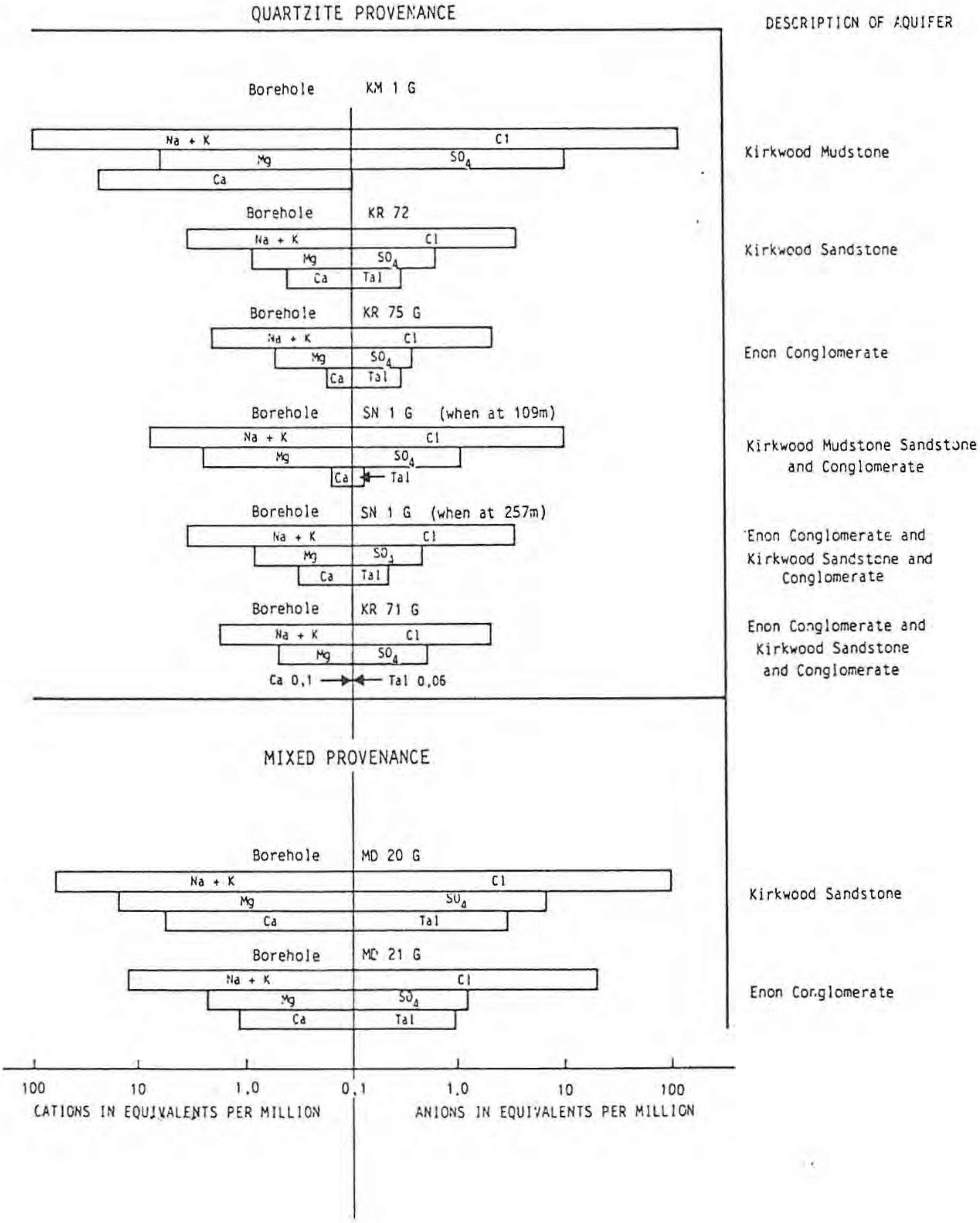


KEY:

- • KM 1 G drilling data
- □ KM 1 G when pumped at 88m
- ▲ KM 1 G mean of drilling data

Sample no.	depth
1	55m
2	60m
3	65m
4	70m
5	80m
6	85m
7	100m
8	145m
9	195m
10	252m
11	305m

FIGURE 26 DOMINANT CATIONS AND ANIONS OF SAMPLES OBTAINED DURING CONSTANT RATE TESTS



Two further trends may be interpreted from the plot of anions:

1. There is an increase in the proportion of chlorides to total anions upwards through the sequence from the conglomerates to the mudstones. Boreholes located in the mixed shale/quartzite provenance although being made up of conglomerates and sandstones, plot closer to the mudstones and siltstones of the quartzite provenance.

2. Within the quartzite provenance, the basal conglomerates of the Enon Formation have the highest TAL/SO_4 ratio. The TAL/SO_4 ratios then progressively decrease upwards through the conglomerates and sandstone/siltstones of the Kirkwood Formation to the mudstones of the Kirkwood Formation which do not contain alkalines. Analyses from the mixed provenance although showing the same trend, plot closer to the silt/sandstones of the quartzite provenance as in the previous case.

The above trends indicate that despite the general similarity of the groundwater, hydrochemical differences in response to lithological and therefore facies changes occur. Differences are possibly explained by base exchange reactions in the case of sodium, potassium, calcium and magnesium ions and sulphate reduction in the case of chloride ions and TAL/SO_4 ionic ratios. The hydrochemical trends are discussed further as the participating ions are considered in turn.

8.3 pH and Individual Ionic Concentrations.

8.3.1 Hydrogen Ion Concentration (pH).

Mean pH values ranged between 5,6 and 8,3 which closely corresponds to the normal range of pH values for natural groundwater of 5,5 to slightly over 8 (HEM, 1959). Mean laboratory measured pH values for the formations are as follows:

TABLE 11. THE pH COMPONENT OF HYDROCHEMISTRY

FORMATION	LITHOLOGY	PALAEOSOURCE AREA	MEAN pH
Kirkwood	Mudstone		6,8
Kirkwood	Sandstone	Quartzite Provenance	6,0
Enon	Conglomerate		7,1
Kirkwood	Sandstone	Mixed Provenance	8,3
Enon	Conglomerate		6,4

Venables (1985) working in an area bounding the northern margins of this study area found waters from the Bokkeveld Formation to have pH values of around eight. This serves to illustrate the influence of the Bokkeveld Formation on pH values for Kirkwood Sandstone in the mixed provenance whose pH value is 8,3 as compared to 6,0 for the Kirkwood Sandstones located within the Quartzite Provenance.

Borehole KR 71 G intersecting sandstones and conglomerates of the Kirkwood and Enon Formations has an anomalous pH of 5,6. Hem (1959) states that the carbon dioxide and carbonate or bicarbonate concentrations form the principal control of pH in most natural waters, the low pH value is attributed to a TAL concentration of only 2,8mg/ℓ and the associated reduced ability of the bicarbonate-carbon dioxide system to buffer the groundwater. The anomalous value for borehole KR 71 G is discussed further at the end of the chapter (page 83).

8.3.2 Total Alkalinity (TAL).

The property of alkalinity in water is its ability to neutralize acid. Total alkalinity is reported in terms of equivalent titratable amounts of bicarbonate, carbonate and hydroxide ions. Hydroxide ions in natural water very rarely occur in amounts sufficient to affect alkalinity. Groundwater with a pH below 8.2 lacks the normal carbonate phase, while most natural groundwater with a pH of 4,5 or over has a range in alkalinity reported as bicarbonate from zero to 1000 mg/ℓ. Values are however most common in the 50-400mg/ℓ range (Hem, 1959, and Davis and De Wiest, 1966). Mean TAL values, are as follows in table 12:

TABLE 12. THE TAL COMPONENT OF HYDROCHEMISTRY

FORMATION	LITHOLOGY	PALAEOSOURCE AREA	MEAN TAL mg/ℓ	MEAN TAL AS % EPMA*
Kirkwood	Mudstone		0	0
Kirkwood	Sandstone	Quartzite	14	5,9
Enon	Conglomerate	Provenance	25	15,7
Kirkwood	Sandstone	Mixed	79	3,5
Enon	Conglomerate	Provenance	39	4,8

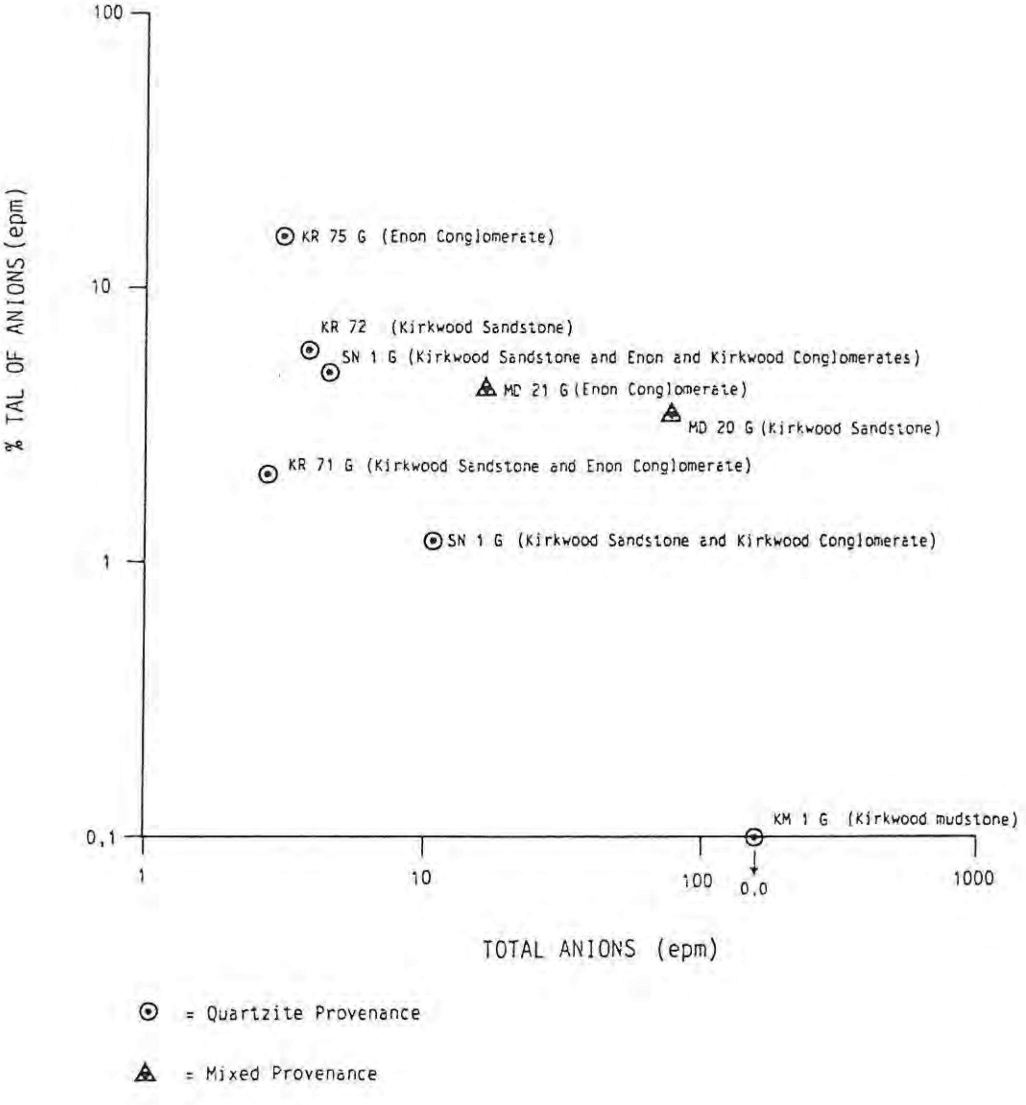
*Where EPMA = Equivalents per Million of Anions.

With the exception of Kirkwood Sandstones within the Mixed Provenance it may be concluded from the above table that while falling within the accepted range for natural waters, total alkalinities are generally lower than those commonly encountered. The Kirkwood Sandstones within the mixed Provenance have a pH value of 8,3 , making it possible for the normal carbonate phase to contribute to the value of 79mg/ℓ.

The possible contribution is however likely to be small as alkalinity reported as carbonate is generally less than 10mg/ℓ (Davies and DeWiest, 1966).

Figure 27 illustrates the trend shown in the Piper diagram analysis of decreasing TAL proportions, from the Enon Conglomerates through the Kirkwood Conglomerates and Sandstones to the Kirkwood Mudstones. The trend is probably explained by the exchange of sulphate for alkalinity (sulphate reduction) as the hydrochemical facies change towards reducing environments (Winter, 1983) in response to the artesian conditions.

FIGURE 27 SCATTER PLOT INDICATING CHANGE IN % TAL WITH LITHOLOGICAL TYPE



8.3.3 Sulphate Ion.

Mean Sulphate Ion concentrations are as follows :

TABLE 13. THE SULPHATE ION COMPONENT OF HYDROCHEMISTRY

FORMATION	LITHOLOGY	PALAEOSOURCE AREA	MEAN SO_4 mg/ℓ	MEAN SO_4 AS % EPMA
Kirkwood	Mudstone		484	7,0
Kirkwood	Sandstone	Quartzite	30	12,8
Enon	Conglomerate	Provenance	17	11,3
Kirkwood	Sandstone	Mixed	280	7,4
Enon	Conglomerate	Provenance	54	6,7

Where EPMA = Equivalents per Million of Anions.

Sulphate ions in natural waters may have an abnormally large range of concentrations, but normally occur in the 1 to 1000 mg/ℓ range (Davis and De Wiest, 1966). The most likely source of sulphate to the Kruis River system is from the reported presence of evaporates in the form of gypsum and anhydrite (Winter 1973). The presence of high proportions of calcium from the Kirkwood Mudstones further suggests the presence of evaporates. Relatively high concentrations of sulphate in the mixed provenance as compared to the quartzite provenance, may result from either one or both of the following reasons:

1. Additional sulphate may have been contributed by the influence of the Bokkeveld Shales. High concentrations of sulphate are frequently derived from ferrous sulphide contained within shales (Hem, 1959).

2. More rapid leaching of sulphate within the quartzite provenance as compared to the less hydraulically active mixed provenance. Heathcote and Lloyd (1984) found leaching efficiency to be an important factor influencing sulphate content in similar lithologies in south-east England.

The reduction in sulphate concentrations (figure 26) from the mudstones to the conglomerates is probably a result of the combined leaching of the sulphates and the process of sulphate reduction previously discussed (Page 69). Although the highest concentration of sulphate comes from the Kirkwood Mudstones, sulphate only makes up 7% of the total anions. This is lower than the combined averages for both provenances of 10% for the Kirkwood Sandstones and 9% for the Enon Conglomerates. The low percentage could be a result of sulphate reduction promoted by decomposition of organic matter by anaerobic bacteria (Rankama and Sahama, 1950) resulting in free sulphur rather than sulphides being produced (Hem, 1959). Evidence of the reaction taking place is found on the farm Fonteinshoek where sulphur is deposited by a spring emanating from the mudstones. Hydrogen sulphide a product of the reduction of sulphate within the groundwater, is responsible for the frequently noticable "bad egg" type smell of borehole water within the study area.

8.3.4 Chloride Ion.

Mean chloride concentrations are as follows:

TABLE 14. THE CHLORIDE ION COMPONENT OF HYDROCHEMISTRY

FORMATION	LITHOLOGY	PALAEOSOURCE AREA	MEAN Cl mg/ℓ	MEAN Cl AS % EPMA
Kirkwood	Mudstone		4789	93,0
Kirkwood	Sandstone	Quartzite Provenance	142	81,3
Enon	Conglomerate		82	73,0
Kirkwood	Sandstone	Mixed Provenance	2468	89,1
Enon	Conglomerate		518	88,5

Where EPMA = Equivalents per Million of Anions.

The dominance of chloride over other anions and sedimentological history of the lithologies, indicate a marine origin for the chlorides. The Kirkwood Sandstones and Enon Conglomerates were impregnated with soluble salts at the time that the more argillaceous Kirkwood Mudstones were deposited. Present concentrates of chloride are probably largely due to differential leaching and dilution of the salts from the lithologies. During drilling peak values of 16534mg/ℓ and 15729mg/ℓ were encountered in the Kirkwood Mudstones of borehole SN 1 G, only 13% and 17% below the 19000mg/ℓ of sea water (Hem, 1959). Possible inclusions of connate water within the Kirkwood Mudstones located in the low lying areas bounding the fault zone, and high concentrations of salts of possible marine origin incorporated into the mudstones in present high lying areas may be expected from the incompletely leached deposits of Kirkwood Mudstone (Winter, 1973).

The trend of increased ratios of chloride to other anions (Figure 28) upwards through the sequence to Kirkwood Mudstones, could be explained by sulphate reduction and the uncompensated removal of hydrogen sulphide from the water.

8.3.5 Sodium Ion.

Mean sodium ion concentrations are as follows:

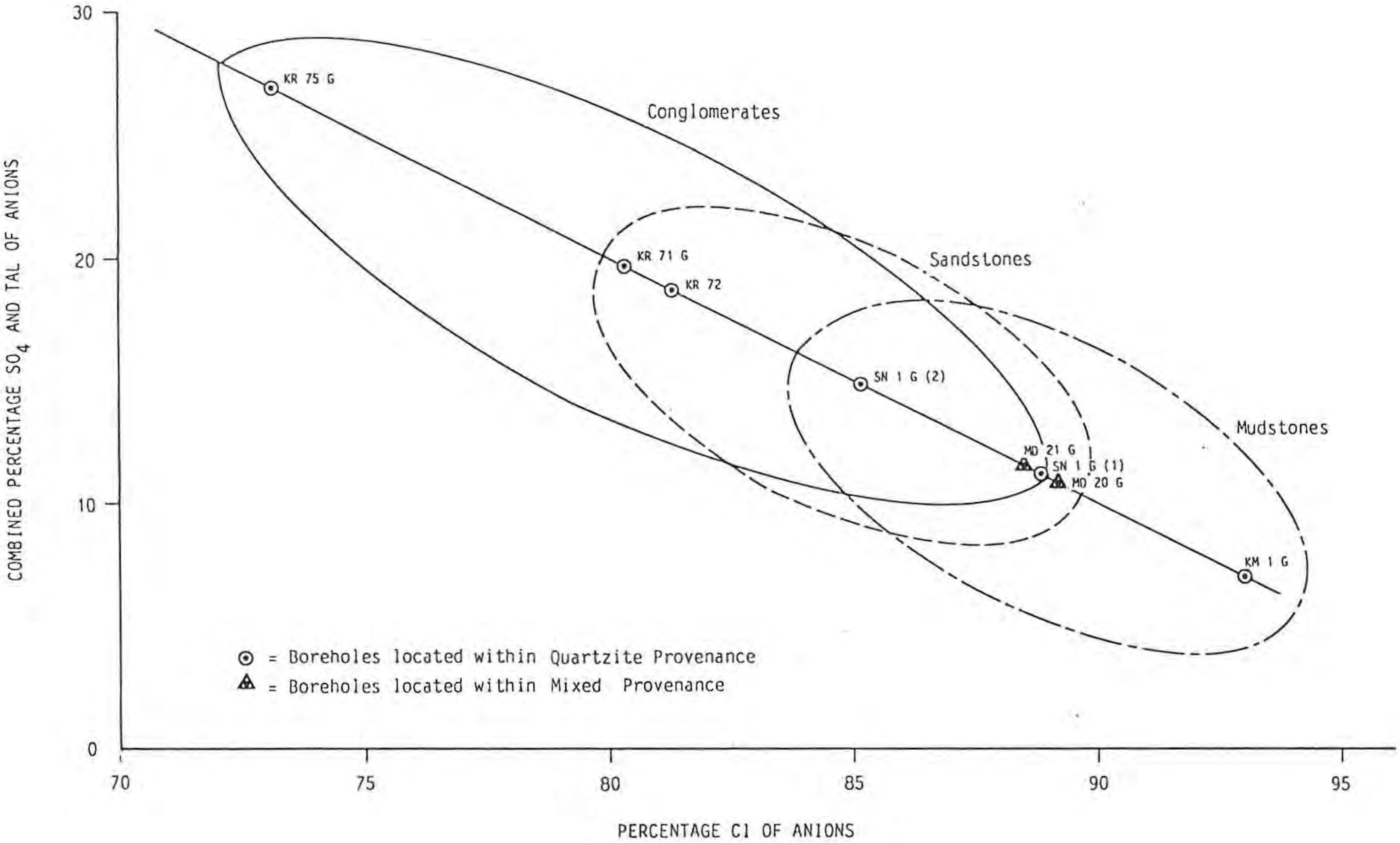
TABLE 15. THE SODIUM ION COMPONENT OF HYDROCHEMISTRY

FORMATION	LITHOLOGY	PALAEOSOURCE AREA	MEAN Na. MG/ℓ	MEAN Na. AS % EPMC
Kirkwood	Mudstone		2597	77,7
Kirkwood	Sandstone	Quartzite	84	73,7
Enon	Conglomerate	Provenance	52	76,9
Kirkwood	Sandstone	Mixed	1334	73,3
Enon	Conglomerate	Provenance	286	78,2

Where EPMC = Equivalents per Million of Cations.

As sodium ions are the dominant cations to chloride anions in sea water, the main source of sodium ions is likely to be the same as that given for chloride, namely due to sea water intrusion at the time that the Kirkwood Mudstones were deposited. As with chloride, peak sodium concentrations were encountered while drilling through the mudstone of the Kirkwood Formation and values of 8020 and 7440mg/ℓ, 20% and 26% below the 10 000mg/ℓ concentration of sea water (Hem, 1959) were obtained. Davies and DeWeist (1966) give the normal range of concentration for sodium ions in groundwater as 1 to 1000mg/ℓ. Mean concentrations for the Kirkwood Mudstones and

FIGURE 28 PLOT TO ILLUSTRATE CHANGING RATIOS OF CHLORIDE TO OTHER MAJOR ANIONS



Kirkwood Sandstones within the mixed provenance are above the norm. The high concentrations are probably attributable to high initial concentrations and poor leaching because of the inactive nature of the groundwater regime.

In the case of the conglomerates and sandstones of the Kirkwood and Enon formations, additional sodium may have been derived from unaltered silicate mineral grains. In the case of the Kirkwood mudstones, additional sodium may have been derived from the evaporate minerals halite (NaCl) and mirabilite ($Na_2SO_4 . 10H_2O$) (Hem, 1959). Many clay minerals also contribute sodium ions to groundwater.

A process enabling some minerals and clays to contribute sodium ions to groundwater is base exchange, where calcium or magnesium for sodium cation exchange is positive for release of sodium to groundwater (Lee, 1985). The trend of changing proportions of cations observed in the Piper diagram is probably due to this exchange. Figure 29 shows a probable relationship between the three major cations and indicates that base exchange would probably have taken place with calcium in the mudstones of the Kirkwood Formation and magnesium in the conglomerates of the Enon Formation. Within the Enon Conglomerates probable base exchange is likely to be controlled by clay minerals within the matrix material, as generally low concentrations of dissolved salts preclude the significant presence of evaporate minerals.

8.3.6 Calcium Ion.

Davis and De Weist (1966) give the common range of calcium cations for natural waters as 1 to 1000mg/ℓ. The concentrations vary due to such influences as :

1. The partial pressure of carbon dioxide, high partial pressures resulting in the high solubility of calcium carbonate.
2. The presence of sodium and potassium salts in the water which increase the solubility of calcium carbonate.
3. The presence of the evaporate minerals gypsum and anhydrite which contribute calcium to groundwater.

All three of the above may play a part in determining the mean calcium concentrations, which are listed in table 16:

FIGURE 29 TRILINEAR PLOT OF RELATIVE PERCENTAGES Na, Ca & Mg CATIONS

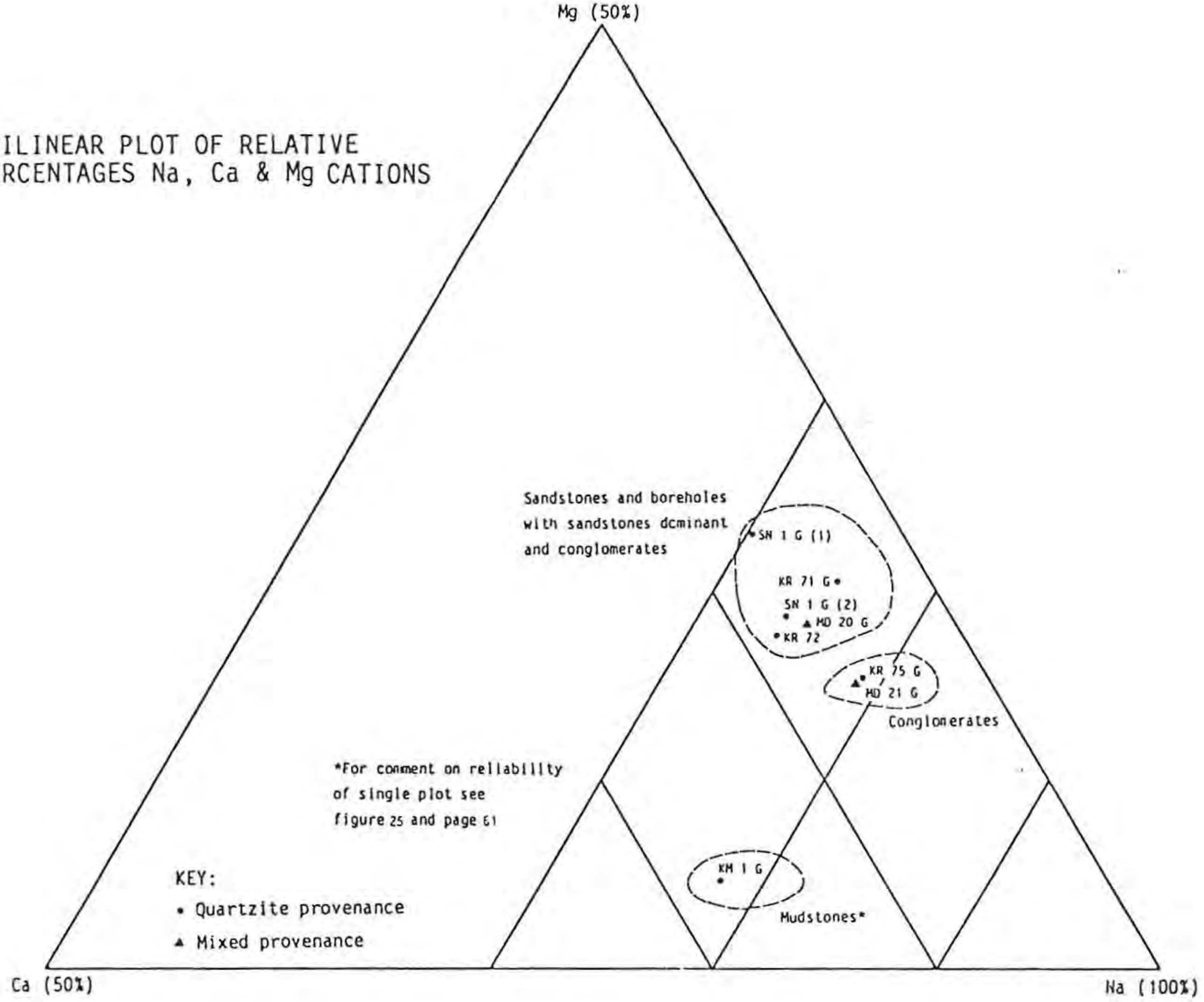


TABLE 16. THE CALCIUM ION COMPONENT OF HYDROCHEMISTRY

FORMATION	LITHOLOGY	PALAEOSOURCE AREA	MEAN Ca mg/ℓ	MEAN Ca AS % EPMC
Kirkwood	Mudstone		502	17,2
Kirkwood	Sandstone	Quartzite	8	8,3
Enon	Conglomerate	Provenance	4	6,1
Kirkwood	Sandstone	Mixed	103	6,5
Enon	Conglomerate	Provenance	22	6,9

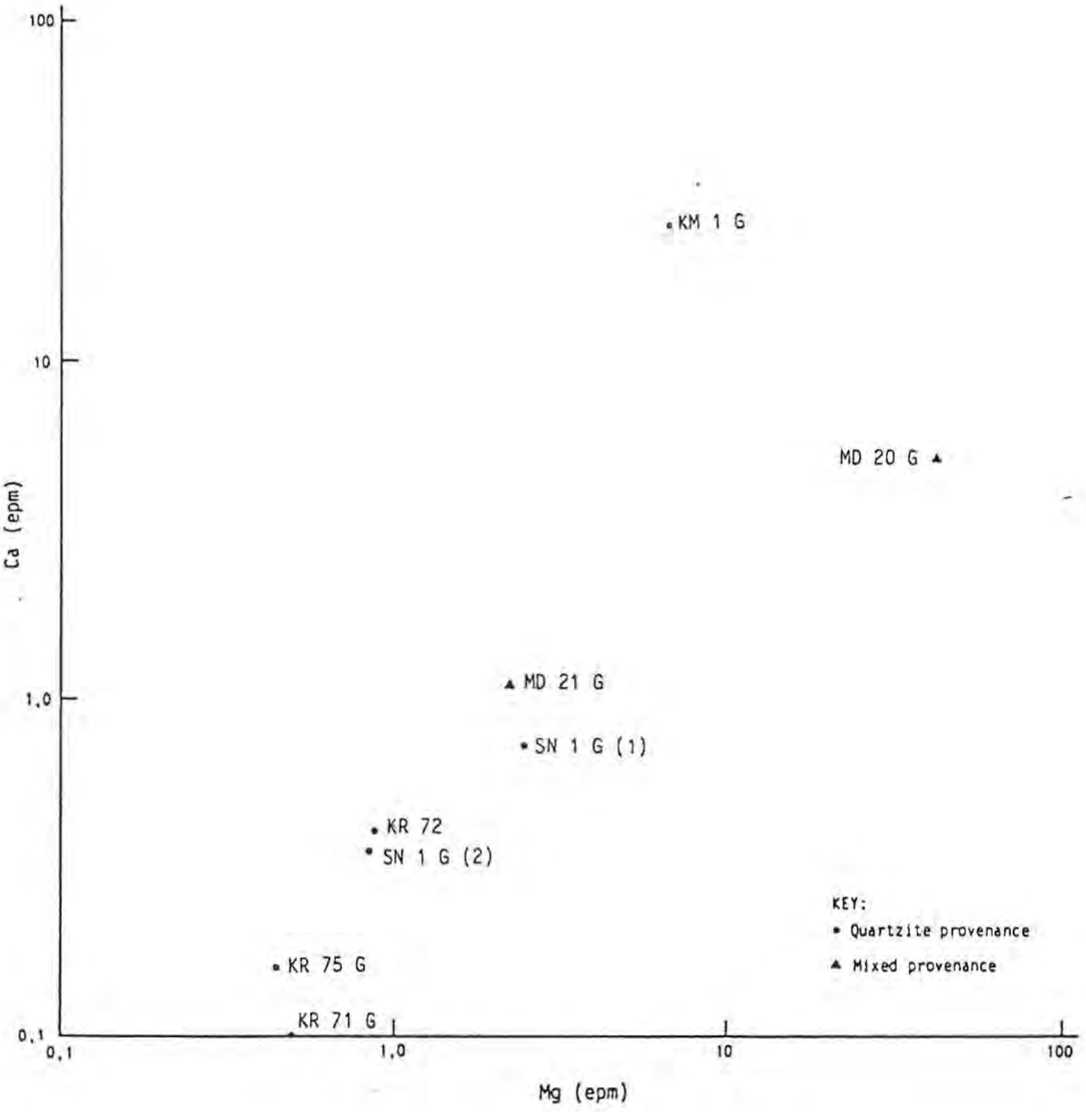
Where EPMC = Equivalents per Million of Cations.

Within the study area, two probable sources of calcium exist:

1. From redeposited calcium carbonate material in the form of interstitial cements.
2. In the form of the evaporate minerals gypsum and anhydrite.

The presence of the evaporate minerals in the Kirkwood Mudstones reported by Winter (1973) is suggested by the relatively high concentrations of calcium and sulphate (Figure 26) and high ratios of 3,7 to 1 (Figure 30), calculated from equivalents per million, for calcium to magnesium cations (Hem, 1959). It is the high ratio of calcium to magnesium within the mudstones and its availability for probable base exchange reaction that results in predominantly sodium/calcium exchange taking place within the mudstones, while sodium/magnesium exchange takes place in the other formations whose low calcium to magnesium ratio vary between 1 to 2 and 1 to 5 (Figure 30). This relationship could explain the variation in calcium ratios between the mudstones and remaining formations.

FIGURE 30 SCATTER PLOT OF CALCIUM VERSUS MAGNESIUM ILLUSTRATING THE DIFFERENCE IN CALCIUM/MAGNESIUM RATIOS BETWEEN BOREHOLE KM 1 G (REPRESENTING THE KIRKWOOD MUDSTONES) AND OTHER FORMATION TYPES



8.3.7 Magnesium Ion.

Mean magnesium concentrations are as follows:

TABLE 17. THE MAGNESIUM ION COMPONENT OF HYDROCHEMISTRY

FORMATION	LITHOLOGY	PALAEOSOURCE AREA	MEAN Mg mg/ℓ	MEAN Mg AS % EPMC
Kirkwood	Mudstone	Quartzite Provenance	82	4,6
Kirkwood	Sandstone		11	17,4
Enon	Conglomerate		5	14,9
Kirkwood	Sandstone	Mixed Provenance	173	18,0
Enon	Conglomerate		27	14,0

Where EPMC = Equivalents per Million of Cations.

Although the mean concentrations of magnesium ions are generally low (Less than 200mg/ℓ), they fall well within the range given by Davis and DeWiest (1966) of 1 to 1000mg/ℓ. Low concentrations are attributed to the lack of suitable source areas such as dolomitic terrains or ultrabasic rock types. Hem (1959) states that in most waters magnesium content is considerably less than calcium even when calculated on the basis of concentrations expressed in equivalents per million. Within the study area this is only true in the case of Kirkwood Mudstones (Figure 26). As sea water has a calcium to magnesium ratio of 1 to 5 and considering the sedimentological history of the lithologies, the source of magnesium is most likely that of sea water, intruded into the arenaceous and rudaceous sediments at the time of deposition of the Kirkwood Mudstones. The sea water could then have undergone leaching and dilution to present concentrations.

High ratios of calcium to magnesium in the Kirkwood Mudstones is probably explained by a combination of the reported presence of evaporites already discussed (Page 77), the stronger tendency of magnesium to remain in solution than does calcium, and by the higher degree of solubility of magnesium carbonate than calcium carbonate (Hem, 1959). The magnesium could thereby be partially removed by preferential leaching, further increasing the relative proportion of calcium to magnesium.

8.3.8 Potassium Ion.

Potassium comes out of solution more easily than does sodium and is easily recombined with clay minerals resulting in generally low potassium concentrations in most groundwater.

Mean potassium concentrations are as follows :

TABLE 18. THE POTASSIUM ION COMPONENT OF HYDROCHEMISTRY

FORMATION	LITHOLOGY	PALAEOSOURCE AREA	MEAN K mg/ℓ	MEAN K AS % EPMC
Kirkwood	Mudstone		24	0,4
Kirkwood	Sandstone	Quartzite	1	0,6
Enon	Conglomerate	Provenance	2	2,1
Kirkwood	Sandstone	Mixed	67	2
Enon	Conglomerate	Provenance	5	0,9

Where EPMC = Equivalents per Million of Cations.

Potassium concentrations are within the expected range with groundwater of low TDS having concentrations well below the upper limit of 15mg/ℓ for ordinary groundwaters (Hem, 1959) and for those with a high TDS value potassium concentrations are higher as expected. The source of potassium to groundwater is probably from unaltered silicate and clay minerals which form the normal source of potassium for groundwater from resistate and hydrolyzate sediments. No diagnostic relevence is seen to exist for the mean potassium concentrations measured.

8.3.9 Ammonium, Nitrate, Fluoride, Silica and Phosphate Ions.

As concentrations of these ions are low (less than 6mg/ℓ) and in no case exceed safety levels for domestic consumption as published by the World Health Organisation (1971) or the South African Bureau of Standards (1971), they are considered briefly. Individual concentrations are given below:

TABLE 19. THE AMMONIUM, NITRATE, FLUORIDE, SILICA AND PHOSPHATE ION COMPONENTS OF HYDROCHEMISTRY

FORMATION	LITHOLOGY	PALAEOSOURCE AREA	MEAN NH_4 mg/ℓ	MEAN NO_3 mg/ℓ	MEAN F mg/ℓ	MEAN Si mg/ℓ	MEAN P mg/ℓ
Kirkwood	Mudstone		0,48	0,09	0,7	2,7	0,001
Kirkwood	Sandstone	Quartzite Provenance	0,04	0,06	0,1	4,7	0,017
Enon	Conglomerate		0,04	0,00	0,2	4,2	0,018
Kirkwood	Sandstone	Mixed Provenance	0,04	0,03	0,9	4,3	0,004
Enon	Conglomerate		0,03	0,04	0,2	5,9	0,006

8.3.9.1 Ammonium Ion.

Hem (1959) states that ammonium ions occur in groundwater subject to direct pollution with organic waste products, but that nutrifying bacterial action generally converts the ammonium, usually in the form of ammonium hydroxide, to free nitrogen or oxidized forms such as nitrate or nitrite. As little bacterial activity takes place in all but very shallow aquifers (Bouwer, 1979), concentrations of ammonia are all very low (less than 0,5mg/ℓ) and the lack of hydraulic connection between surface and groundwater (page 90) all indicate that the ammonium is probably derived from the normal intake of naturally occurring ammonium from the source area rather than because of direct pollution by organic waste.

8.3.9.2 Nitrate Ion.

Although the source of most nitrates is closely related to plants and animal wastes, it may also be formed by oxidation from ammonium and by atmospheric nitrogen being converted to nitric oxide by lightening discharges (Hem, 1959). Concentrations of nitrate in natural groundwater is given by Davis and De Wiest (1966) as 0.01 to 10,0mg/ℓ. As the mean nitrate concentrations of groundwater from the aquifers are between 0 and 0,09mg/ℓ and because of the lack of hydraulic connection between surface and groundwater previously discussed, nitrate in the groundwater is probably derived from normal intake from the source area.

8.3.9.3 Fluoride Ion.

Fluoride, although a member of the halogen group of elements like chlorine, is low in solubility and concentrations rarely exceed 10mg/ℓ (Davis and De Wiest, 1966). Hem (1959) gives the most important of the numerable complex fluoride-bearing minerals as apatite and fluorite (Calcium fluoride). These minerals form the most common source of fluoride in sedimentary rocks and are probably responsible for the low concentrations (less than 1mg/ℓ) of fluoride present in the groundwater encountered within the study area.

8.3.9.4 Silica Ion.

Silica although being the second most abundant element in the earths crust, is in its most common form quartz, the most resistant of all rock minerals to weathering by water. The greater part of dissolved silica in groundwater originates in the chemical breakdown of silica in the process of metamorphism or weathering (Hem, 1959). The amorphous forms of silica such as chert and opal are more soluble than quartz and are also a source of silica in groundwater. As the mean concentrations of silica in the groundwater obtained from the various lithologies does not exceed 6mg/ℓ, it falls well within the range for most groundwaters quoted by Hem (1959) of 1 to 30mg/ℓ, while being generally low when compared to the approximation of 20mg/ℓ quoted by Bouwer (1978) for normal groundwater.

Although silica concentrations may vary due to groundwater temperature variations and partial pressures of carbon-dioxide (Krauskopf, 1956, and Garrels and Christ, 1965), lower concentrations of silica in groundwater from the Kirkwood Mudstones, as compared to the resistate lithologies, is probably largely a result of a reduced presence of amorphous silica and tectosilicate feldspars for solution.

8.3.9.5 Phosphate Ion.

Mean phosphate values for groundwater from the various lithologies varies from 0,001mg/ℓ to 0,018mg/ℓ and is well below the upper limit for natural groundwater of 2mg/ℓ quoted by Hem (1959). The phosphate is probably derived from the mineral apatite and from natural organic wastes and leaching of soils in the source area. The notably lower levels of phosphate in groundwater from the Kirkwood Mudstones as compared to the resistate lithologies is probably accounted for by the findings of Rankama and Sahama (1950), who state that phosphates usually do not remain in solution but are deposited in hydrolyzate lithologies.

8.4 Anomaly, borehole KR71G.

The hydrochemistry of groundwater from borehole KR71G, is regarded as being anomalous with lower than expected values for TDS, pH and TAL (Table 20).

TABLE 20. A COMPARISON OF APPARENTLY ANOMALOUS AND EXPECTED HYDROCHEMICAL VALUES FOR BOREHOLE KR71G.

	Borehole KR71G		Borehole on which expected values are based*		
	Anomalous Value	Expected Value Range	KR75G	SN1G (when at 257m)	KR72
Description of aquifers intersected	Sandstones and Conglomerates Kirkwood and Enon Formations		Conglomerates Enon Formation	Sandstones and Conglomerates Kirkwood & Enon Formations	Sandstones Kirkwood Formation
TDS (mg/ℓ)	160	198-367	198	230	367
pH	5,6	6,0 - 7,1	7,1	6,1	6,0
TAL (mg/ℓ)	2,8	11,0 - 24,8	24,8	11,0	14,4

* All boreholes are located within the Quartzite Provenance.

The marginally lower TDS value (Table 20) is partially explained by the lower concentration of TAL. The minimum remaining difference of 16mg/ℓ is not regarded as significant and could be accounted for by numerous local variations in the hydrogeological properties of transmissivity, availability of source minerals and leaching.

Lower than expected values for pH and TAL are likely to be related and explained by less active sulphate reduction. Less active sulphate reduction is in turn probably due to either reduced bacterial activity or lower hydrocarbon concentrations, resulting in a lower partial pressure of carbon-dioxide and reduced concentrations of TAL expressed as bicarbonate. The reduced carbon-dioxide and TAL concentrations in turn would result in the reduced ability of the bicarbonate, carbon-dioxide system to buffer the pH of the groundwater and consequentially a lower value of pH would result. Palmer and Cherry (1984) quote similar examples of different hydrochemistries within the same types of rock units, due mainly to variations in partial pressures of carbon-dioxide and differing degrees of sulphate reduction.

8.5 Summary.

The major contributor of dissolved salts to the sandstones and conglomerates of the Kirkwood and Enon Formations, which form the main aquifers is considered to be the argillaceous Kirkwood Mudstones. The mudstones' geochemistry developed during the deposition and formation of the mudstones in a marine/estuarine environment and probably includes the formation of evaporite minerals. (Page 77). Although hydrochemical modification of the groundwater in the various lithologies is shown to take place (Page 61), it is generally limited to a change of less than 30% in the relative proportions of any one element, as illustrated in the Piper Diagrams (Page 64), and has little effect on the overall quality of the groundwater. The most important influences therefore remain the hydrological properties of the lithologies and their ability to leach and dilute the salts both from within the formation and those contributed from the overlying Kirkwood Mudstones.

TABLE 21. A SUMMARY OF ABSTRACTION AND USAGE OF GROUNDWATER FROM THE STUDY AREA

	Industry	Domestic and Stock	Irrigation with minor domestic & stock	Total Abstraction from Provenance
		Quartzite Provenance		
m³/year	-	116 883	1 911 197	2 028 080
Percentage of Provenance Total	-	6,1	93,9	
		Mixed Provenance		
m³/year	3154	21 326	-	24 480
Percentage of Provenance Total	12,9	87,1	-	
Percentage of Total Usage for both Provenances	0,2	6,7	93,1	
Total abstraction from study area m³/year.				2 052 560

Table 21 is a summary of abstraction and usage of groundwater from the study area and forms a measure of the availability and quality of water from the two provenances. (The table is based on a survey of abstraction and the hydrocensus both of which may be found in the appendix). Of the total estimated abstraction 98,7% is abstracted from boreholes within the quartzite provenance, of which most (93,9%) is used for irrigation which generally requires good quality water. Groundwater from boreholes in the mixed provenance however forms only 1,3% of the total groundwater abstracted in the study area and is used mainly (87,1%) for domestic and stock watering purposes, both of which can tolerate poorer quality water than that normally required for irrigation. Groundwater used for industrial purposes within the mixed provenance is of good quality (300mg/ℓ) but only forms 12,9% of the groundwater from the mixed provenance.

It is concluded that good quality water suitable for most domestic, agricultural and industrial uses is found in association with the arenaceous and rudaceous members of the Kirkwood and Enon Formations within the quartzite provenance. Care should however be taken during borehole construction to preclude water from the Kirkwood Mudstones. Because of the mild acidity of the groundwater, corrosion proof casing should be used. Within the mixed provenance water from the sandstones of the Kirkwood Formation is unsuitable for most purposes with the exception of providing drinking water for animals. Water from the Enon Conglomerates is of better quality and has a wider range of potential usage, but remains unsuitable for most irrigation and industrial purposes.

Chapter 9. Piezometric levels and recharge.

The chapter considers piezometric changes during the time period that records and observations have been made by various authorities and private individuals. Zones of recharge are identified and the influence of the river systems on the groundwater regime is discussed.

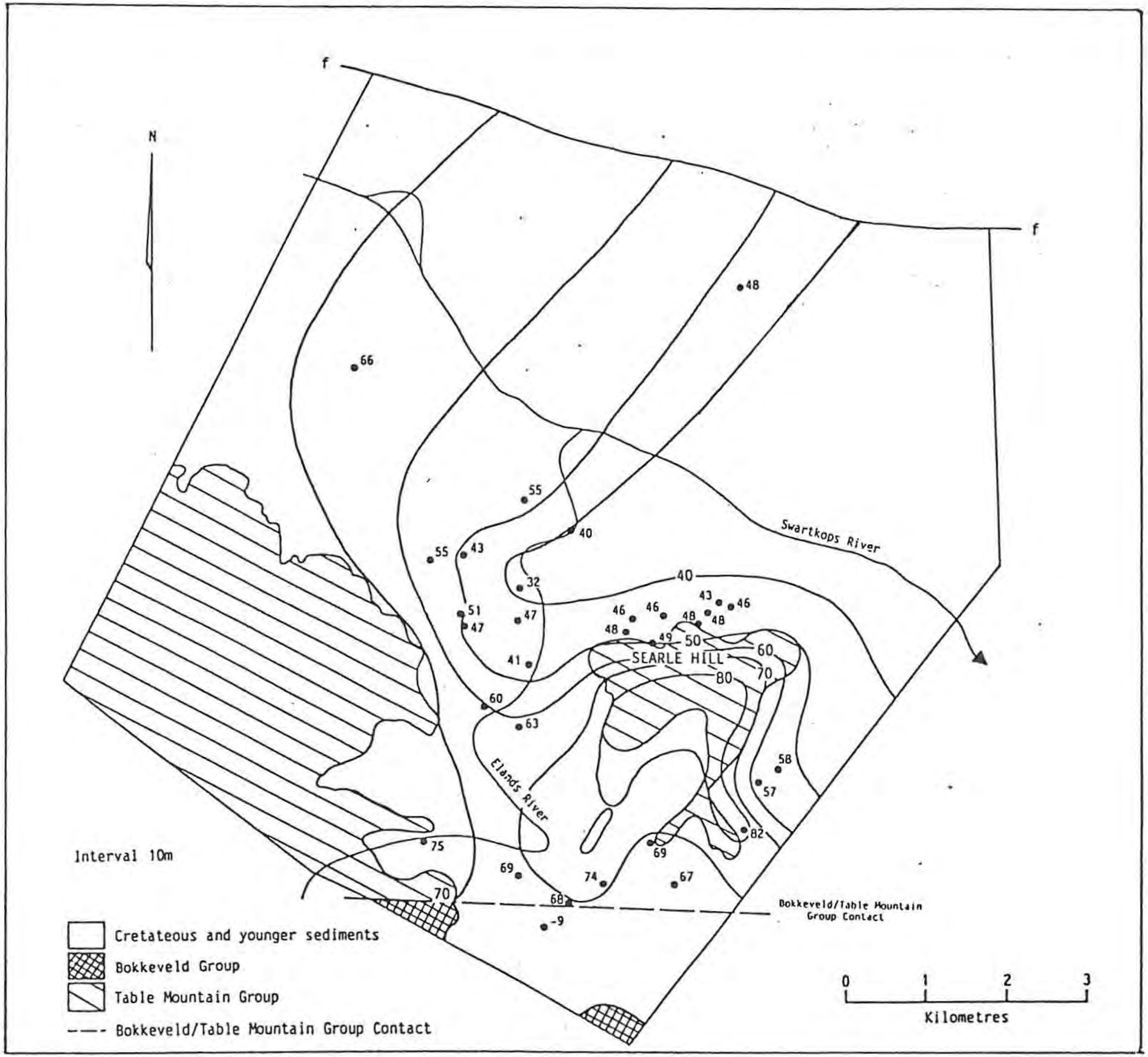
9.1 Present piezometric levels.

For the piezometric contour map illustrated in figure 31 water levels were obtained from 32 boreholes. In most instances water levels used were recorded during the eighth and nineth months of 1983. In cases where data were not obtainable for this period earlier data were used (Appendix 7). Borehole KM 1 G was completed early in 1984, the data for this borehole have been used as no earlier data for the area near borehole KM 1 G exists. Data for MW 4 B were excluded from the map because of a negative anomaly. Evidence from both water level and pump test data (Appendix 4 and 7) indicate that borehole MW 4 B was in hydrologic contact with the Elands River. The hydraulic continuity between the borehole and the river is probably related to an adjacent borehole MW 2 A whose near surface slotted casing formed the conduit for river water to enter the underlying aquifer during pumping. This assertion was confirmed when borehole MW 2 A was later sealed resulting in the water level and quality data changing to conform with the understood hydrology of the area. These later water level data were however not used as a reliable rest water level could not be obtained because of pumping in nearby boreholes.

According to Ward (1975) it can be assumed that groundwater flow is in the direction of hydraulic gradient, and at right angles to isopotential lines or piezometric surface contours.

The completed piezometric map (Figure 31) therefore indicates that recharge to the main quartzite provenance located in the Elands and Swartkops River valleys is derived from the high lying Groendal Wilderness Area and Elands River Forest Reserve to the west of the study area. Higher lying areas of the mixed provenance however, are shown by the trend of the isopotential lines to derive their recharge locally from the centrally outcropping hill

FIGURE 31 PIEZOMETRIC SURFACE CONTOURS
(metres above sea level)



of quartzites of the Table Mountain Group and local Cretaceous deposits.

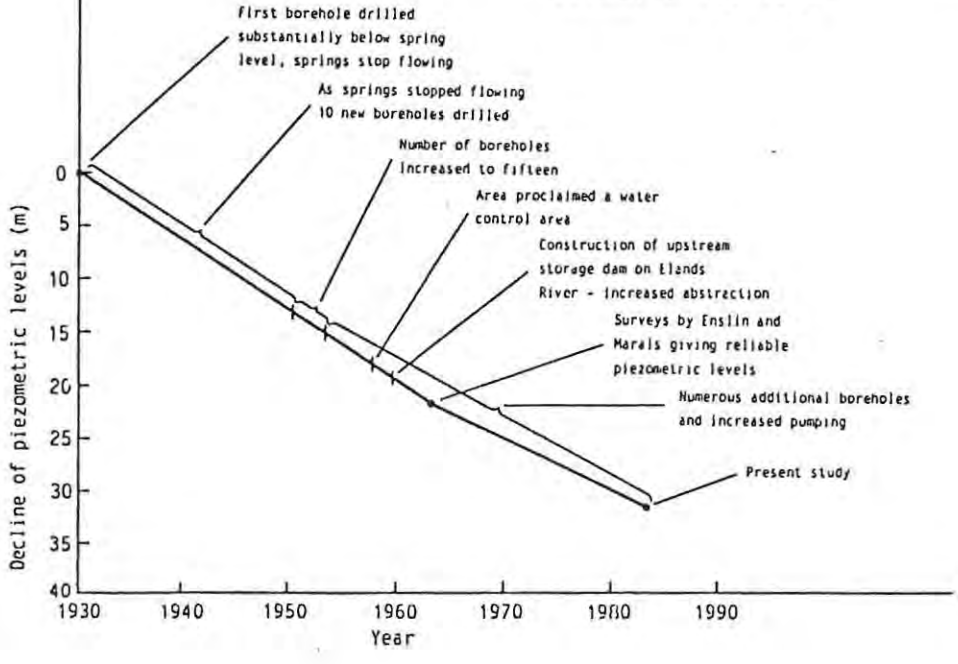
9.2 Long-term changes in groundwater levels.

Groundwater level changes between the years 1930 and 1963 have been well documented in reports written by Enslin (1962) and Marais (1964). During this period borehole water levels declined by an average of 23,5m (77,5 feet Marais, 1964). The reasons for the decline were given by Marais as:

1. Continued drilling and consequential increased abstraction.
2. Increased abstraction since storage dams constructed in 1959 reduced the flow of the Elands River.

Present abstraction is calculated at 2,05 x 10^6 m³/year (Appendix 6), approximately double the 1963 estimate of 0,99 x 10^6 m³/year (Enslin, 1963). Present abstraction figures may however be higher than average long term figures due to a severe drought during the study period and increased reliance by farmers on borehole water for irrigation purposes. A comparison of present piezometric levels and piezometric levels drawn by Enslin in 1963 indicates a 10m drop in post 1963 water levels (Figure 32). Further evidence of a gradual decline since 1963, is the Cessation of flow from the five boreholes still periodically flowing in 1963. It is concluded that long-term levels continue to decline and that abstraction exceeds long term recharge to the area.

FIGURE 32 EVENTS RESULTING IN THE DECLINE OF PIEZOMETRIC LEVELS SINCE 1930



9.3 River recharge to the groundwater system.

In order to test the possible recharge influence of the Elands River on the groundwater regime, water samples for purposes of tritium age determination were obtained from borehole KR 16. Borehole KR 16 was chosen because of its location on the banks of the Elands River and due to the certain knowledge that it intersects artesian aquifer lithologies. The tritium unit (T.U.) value obtained for this sample was 0,2 ± 0,2 T.U. which falls below the limit of detection and can therefore be taken as 0 T.U. (Verhagen, 1983). This indicates an effective age of greater than 60 years and indicates no detectable recharge to the borehole from the river.

Further evidence to support the lack of river recharge is that:

1. The aquifer test conducted on borehole KR 71 G, located close to the Elands River exhibited no boundary recharge effects (Appendix 4).
2. Piezometric data shows no gradient of obvious effluence or influence.
3. Although the mudstones of the Kirkwood Formation do not achieve the same thickness in the Elands as in the Swartkops River valleys, the stopping of recharge from the Elands River to borehole MW 4 B discussed in section 9.1 indicates that the mudstones form an effective barrier between surface and groundwater.

Considering the evidence it is concluded that the Elands and Swartkops Rivers have no direct recharge influence on the groundwater regime within the study area.

Chapter 10. Discussion and hypothesis testing.

In order to assess the extent to which research aims have been met, each aim is briefly discussed in the order presented in section 1.3. The research hypotheses are discussed in section 10.2 in the context of data contained and presented in chapters 3 to 9.

10.1 Achievement of research aims.

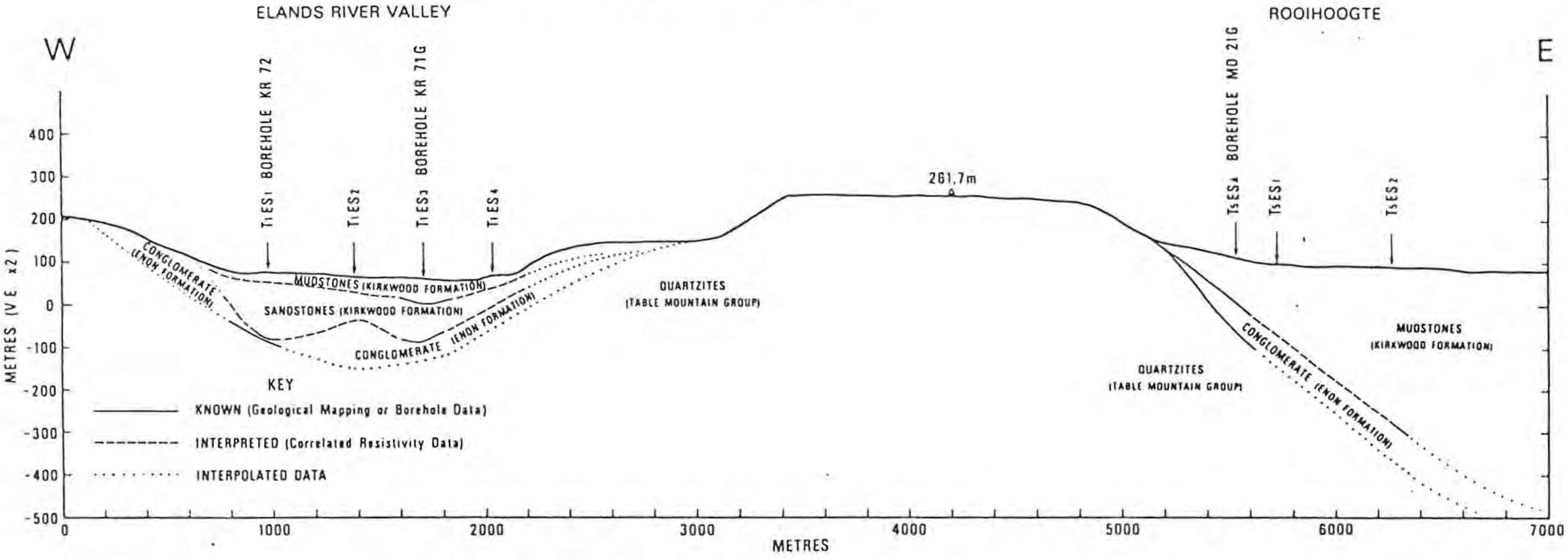
Aim 1. Which lithological unit/units form the aquifer/aquifers in the Kruis River area?

Evidence from the borehole logs listed in appendix 3, indicate that the sandstones and conglomerates of the Kirkwood and Enon Formations constitute the aquifers in the area. In areas where one aquifer lithology occurs without the presence of the other, the lithology may be regarded as a single aquifer unit. Where aquifer lithologies of the Kirkwood and Enon Formations occur together they may be regarded as one inhomogeneous aquifer unit with anisotropic hydraulic properties (Section 6.4 and 7.4).

Aim 2. What is the lateral extent of the aquifer lithologies?

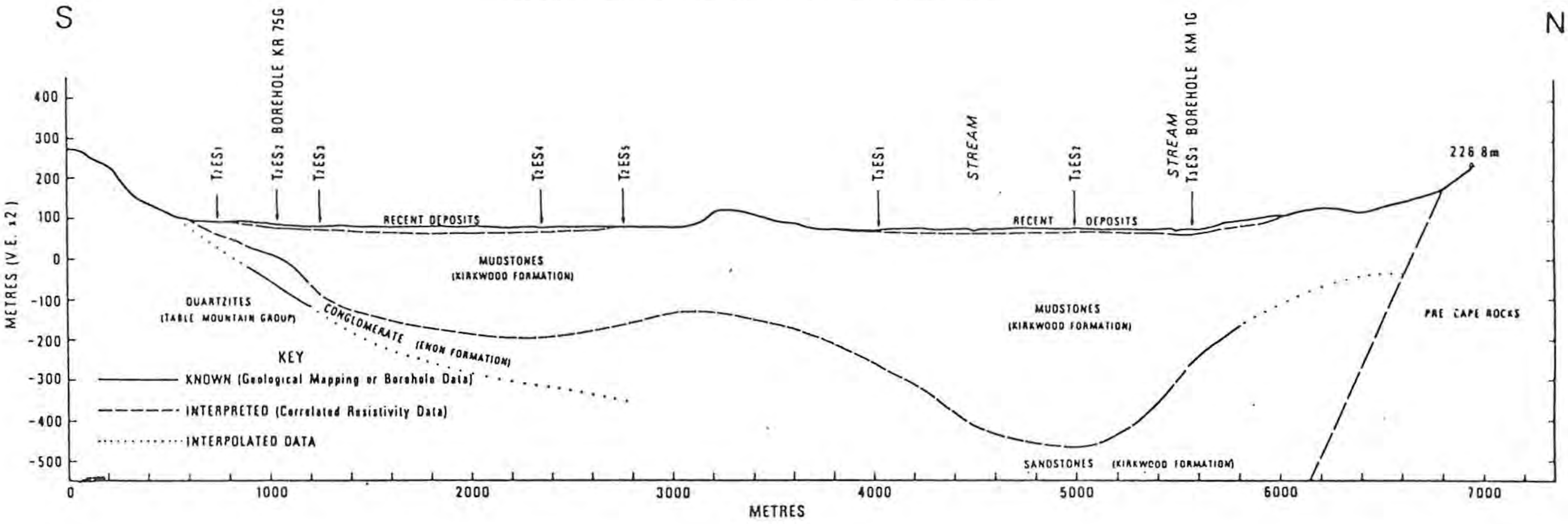
The lateral extent of the aquifer units, has been positively determined in areas where the aquifers are within economic reach by drilling, up to a maximum depth of approximately 250m (Figures 33, 34 and 35). Information on the lateral extent of aquifer units in the deeper portions of the basin has been limited to the determination by electrical resistivity methods of the approximate depth from surface to the first geoelectrically resistive sediments (Page 30) and the results obtained from two boreholes. On the southern margin of the basin borehole KR75G showed the first geoelectrically resistive sediments to be quartzites and conglomerates of the Enon Formation (Figure 15). In the northern and deeper portion of the basin adjacent to the Uitenhage Fault (Figure 34) borehole KM1G indicates that the first geoelectrically resistive sediments are sandstones of the Kirkwood Formation (Page 25). Because of possible features of equivalence and suppression discussed on page 30 identification of the geoelectrically resistive sediments between boreholes KR75G and KM1G were not possible on geoelectric

FIGURE 33 **GEOLOGICAL SECTION 1**



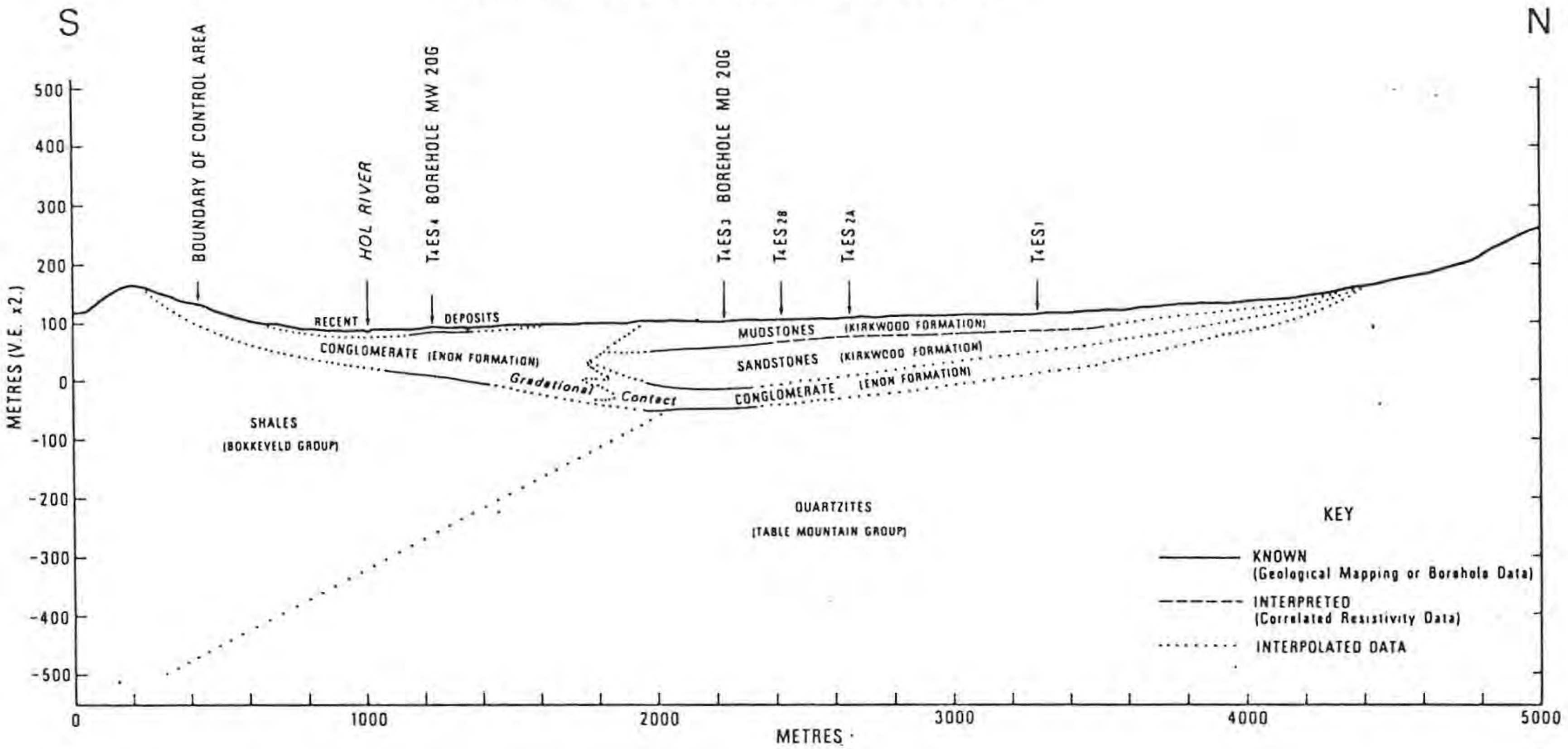
For location of section refer to figure 13.

FIGURE 34 GEOLOGICAL SECTION 2



For location of section refer to figure 13

FIGURE 35 GEOLOGICAL SECTION 3



For location of section refer to figure 13.

information, but evidence from drilling indicates that the first geoelectrically resistive sediments are probably made up of either the conglomerates of the Enon Formation or sandstones of the Kirkwood Formation.

Aim 3. What is the transmissivity and storitivity of the lithological unit/units which form the aquifer/aquifers?

The calculation of the hydraulic properties of transmissivity and storage of water within the aquifer lithologies has only been reliably determined in the case of transmissivity (Page 49). Within the quartzite provenance transmissivities were found to vary between 21,2m^2/day and 89,3m^2/day (Page 52), with the lower values being recorded for the sandstones of the Kirkwood Formation and the higher values for the conglomerates of the Enon Formation. Boreholes intersecting a combination of aquifer lithologies belonging to both formations were found to have intermediate transmissivities. Within the mixed provenance transmissivities were lower than for the quartzite provenance and varied between 2m^2/day for the Enon Conglomerates and 23,2,m^2/day for the Kirkwood sandstones (Table 8). The lower values of transmissivity within the mixed provenance could be explained by increased proportions of interstitial clay material being present in the Kirkwood Sandstones and in the matrix material of the Enon Conglomerates (Pages 47 and 51).

Financial constraints on drilling and the resulting lack of suitable observation holes made the accurate determination of storativity impossible. Estimates of storativity, regarded as reasonably accurate approximations for the various thicknesses of aquifer lithologies were made (Table 7), but may not be interpreted in terms of aquifer characteristics as the technique used is independent of porosity and compressibility (Page 49).

Aim 4. To what degree is/are the lithologies hydraulically independent of one another?

The degree of hydraulic independence between the two major aquifer lithologies is shown to be very small in areas where the aquifer lithologies overlie one another. Rather than the lithologies having independent hydraulic properties, the hydraulic properties undergo a gradational change from one aquifer lithology to the other (Pages 49 and 52). The nature of the change is possibly a consequence of the gradual change in the sedimentalogical environment at the time of deposition resulting in the frequent intertongueing of the two lithologies in the zone of transition (Page 16). The aquifer lithologies are shown however to be hydraulically separated from overlying recent and Tertiary deposits by the relatively impermeable Kirkwood Mudstones which form the confining layer in the area (Page 90).

Aim 5. What is the nature of the relationship between water chemistry and lithological type?

The concentration of TDS in the groundwater is shown to be strongly related to lithological type (Table 10) with the main source of TDS coming from the mudstones of the Kirkwood Formation. Related influences on lithological type and groundwater quality were found to be the variability in source area for both palaeosediments and recharge (Pages 38 and 57). Varying degrees of groundwater modification in the form of base exchange and sulphate reduction has probably taken place within the various lithologies (Pages 67 and 84). The limiting factor on the usefulness and quality of the groundwater from any one aquifer unit is however shown (Table 9) not to be dependent on any one ionic concentration, but rather to the concentration of total dissolved solids in the groundwater (Page 85).

10.2 Testing of hypotheses.

A. Identification of the aquifers

Hypothesis 1. The sandstone and conglomerate lithologies of the Kirkwood and Enon Formations form the aquifers in the area.

Table 22 derived from data contained in the borehole logs (Appendix 3) and table 10, indicate that the mudstones of the Kirkwood Formation account for 36% of the meterage drilled and 1,6% of the yield at an average TDS of 8764mg/ℓ. The sandstones and conglomerates of the Kirkwood and Enon Formations however, account for 64% of the drilling and 98,4% of the yield at an average TDS of 558mg/ℓ. It is therefore concluded that the sandstone and conglomerate lithologies of the Kirkwood and Enon Formations form the aquifers in the area.

The hypothesis is accepted.

Hypothesis 2. The most easily exploited portions of the aquifers are located close to Pre-Cretaceous outcrop.

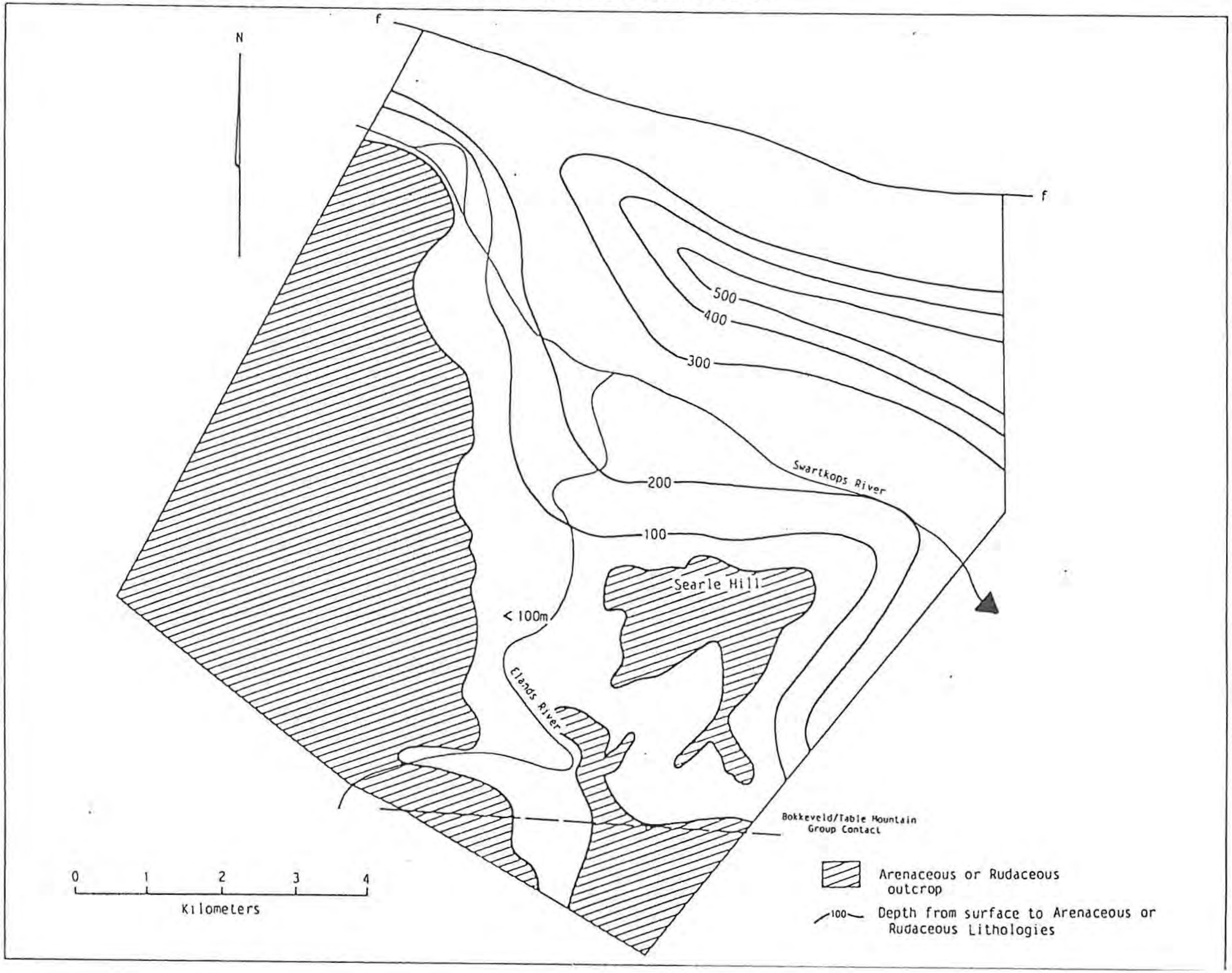
TABLE 22. THE RELATIVE IMPORTANCE OF THE MUDSTONES OF THE KIRKWOOD FORMATION AND THE SANDSTONES AND CONGLOMERATES OF THE KIRKWOOD AND ENON FORMATIONS AS AQUIFERS.

	Total drilling monitored 100% 1792m	Total Yield 100% (63,21ℓ/s)	Average TDS (mg/ℓ)
Mudstones of the Kirkwood Formation	36%	1,6%	8764
Sandstones and Conglomerates of the Kirkwood and Enon Formations	64%	98,4%	558

Figures 33, 34, 35 and 36 and information gained during drilling and aquifer testing (Sections 6.4 and 7.4), show firstly increasing depth from surface to the first arenaceous or rudaceous deposits as distance from Pre-Cretaceous outcrops increase, and second, within the Swartkops River valley, increased proportions of fine materials within the aquifer units reflecting a changing environment of deposition with increased distance from Pre-Cretaceous sediment source areas (Figure 7 and page 47). The above information together with higher piezometric levels recorded in near Pre-Cretaceous outcrop areas (Figure 31) indicate that the most easily exploited portions of the aquifer units are those close to Pre-Cretaceous outcrops.

The hypothesis is accepted.

FIGURE 36 DEPTH FROM SURFACE TO ARENACEOUS OR RUDACEOUS LITHOLOGIES



B. Hydraulic properties of the aquifers.

Hypothesis 1. There is considerable hydraulic continuity between aquifer lithologies of the Kirkwood and Enon Formations.

In areas where aquifer lithologies of the Kirkwood Formation overlie the Enon Formation, drilling logs for boreholes KR 71 G, and MW 4 B (Appendix 3) indicate that no lithology which might form a hydraulic barrier between the two formations exists. Although narrow lenses of clay are found at or near the contact between the aquifer lithologies belonging to the two formations in boreholes SN 1 G and MD 20 G (Appendix 3), they are considered to be narrow lenses of clay and not continuous impermeable clay bodies. The lenses of clay together with the frequent alternation in lithological type between sandstone and conglomerate in the case of boreholes SN 1 G and MW 4 B reflects the environment of deposition and indicates a gradational nature of change for the contact between the aquifer lithologies of the Kirkwood and Enon Formations (Page 16). The probable nature of the formational change and progressive improvement in specific drawdown ratios from $6,3m/\ell s^{-1}$ to $3,2m/\ell s^{-1}$ for borehole SN 1 G as increased proportions of Enon Conglomerate to Kirkwood Sandstone were intersected (Page 52), support the case for hydraulic continuity between formations.

To the north and east of Searle Hill (Boreholes KR 75 G and MD 21 G) the conglomerates of the Enon Formation form the only aquifer lithology (Page 38). In these areas hydraulic continuity with adjacent aquifer lithologies of the Kirkwood Formation is uncertain and may be prevented by the pinching out of the Enon Conglomerates by underlying basement and overlying impervious material.

The hypothesis is accepted for the larger proportion of the area, where aquifer lithologies of the Kirkwood Formation directly overlie aquifer lithologies of the Enon Formation. The hypothesis is conditionally accepted for the other areas where no lateral hydraulic barrier exists.

Hypothesis 2. Reduced transmissivity reflects the presence of sediments derived from the Bokkeveld Group in the area of mixed provenance.

A comparison of information contained in table 8 (Page 52) of transmissivity variations of boreholes intersecting lithologies with the same formational classification shows that the transmissivity of borehole MD20G is 23,2m^2/day and that of borehole KR72 73,0m^2/day. As both boreholes intersect the Kirkwood Sandstones, borehole KR72 within the quartzite provenance and borehole MD20G within the mixed provenance, the 68% lower value of transmissivity for borehole MD20G is attributed at least in part to the contribution of Bokkeveld Group sediments (Pages 51 and 52). A similar comparison of boreholes intersecting conglomerates of the Enon Formation from the two provenance areas, reveals that borehole MD21G located within the mixed provenance has a transmissivity of 2,0m^2/day while borehole KR75G located within the quartzite provenance has a 45 times higher transmissivity of 89,3m^2/day (Pages 51 and 52). As values of transmissivity are shown to be lower for both aquifer lithologies in the mixed provenance where sediments are partially derived from the Bokkeveld Group of rocks, the hypothesis is accepted.

The hypothesis is accepted.

C. Hydrochemical characteristics of the aquifers.

Hypothesis 1. Better quality water is associated with arenaceous and rudaceous sediments.

Using total dissolved solids (TDS) as a measure of overall quality, table 10 presented in section 8.2.1 shows that within the quartzite provenance groundwater abstracted from the sandstones of the Kirkwood Formation and conglomerates of the Enon Formation yield groundwater of 367mg/ℓ or less. The average TDS of the arenaceous and rudaceous aquifer lithologies is therefore approximately 4% of the average TDS of 8764mg/ℓ attributed to the mudstones of the Kirkwood Formation. Within the mixed provenance average TDS values are 965mg/ℓ in the case of Enon Conglomerates and 4617mg/ℓ in the case of Kirkwood Sandstones, 11% and 53% of the average TDS of groundwater from the mudstones of the Kirkwood Formation (Table 10). It is concluded that so long as the word 'better' is used to compare the quality of groundwaters from the arenaceous and rudaceous lithologies with the quality of groundwater from the argillaceous Kirkwood Mudstones within the same provenance, that the hypothesis is valid.

The hypothesis is conditionally accepted.

Hypothesis 2. The dominant influences on the hydrochemistry of the study area are the hydrological properties of the lithologies and the contribution of ions to the aquifer lithologies by the marine/estuarine mudstones of the Kirkwood Formation.

Although hydrochemical modification of the groundwater by base exchange and/or sulphate reduction has resulted in changes (less than 30%) in the ratios of ions, it does not noticably affect the degree of mineralization of the groundwater (Page 84). Hydrochemical modification of the groundwater is therefore not considered to be a dominant influence on the degree of mineralisation of water from the various aquifer lithologies.

Information from tables 8 and 10 indicate that within the quartzite provenance sandstones of the Kirkwood Formation have a maximum transmissivity of 73,0m^2/day and average TDS concentration of 367mg/ℓ, while conglomerates of the Enon Formation have a higher maximum transmissivity of 89,3m^2/day and a lower average TDS concentration of 197mg/ℓ. A comparison of information from aquifer tests conducted on borehole SN1G at 109m and 257m (Tables 7 and 9), reveal a similar reduction in the degree of mineralization of groundwater as transmissivities increase with depth in response to a gradational change in aquifer type from Kirkwood Sandstones to Enon Conglomerate. At 109m an average TDS concentration of 1208mg/ℓ and transmissivity of 21,2m^2/day was measured, while at 257m the average TDS concentration declined to 393mg/ℓ with an increased transmissivity of 38,1m^2/day.

The probable contribution of evaporates within the Kirkwood Mudstones to the calcium and sulphate concentrations of groundwater from the aquifer lithologies (Pages 71 AND 77), the marine origin of the groundwater mineraliza-tion as indicated by the Piper Diagram plots (Page 61) and calcium/magnesium ratios (Page 77) indicate the continued influence of highly mineralized groundwater from the marine/estuarine Kirkwood Mudstones on the hydrochemistry of the underlying aquifer units. Within the mixed provenance the conglomerates of the Enon Formation have a TDS concentration of 966mg/ℓ and a transmissivity of 2,0m^2/day which is 21,2m^2/day lower than that of the sandstones of the Kirkwood Formation. The average TDS concentration of which is 4617mg/ℓ (Tables 8 and 10). This apparent anomaly is explained by a lack of groundwater within the overlying Kirkwood Mudstones to the east of Searle Hill (borehole MD21G) where Enon Conglomerates are present at depth (Appendix 3). The apparent anomaly further illustrates the influence that the highly mineralized groundwater from the marine/esturine mudstones of the Kirkwood Formation have on the sandstones of the Kirkwood Formation to the south of Searle Hill.

The hypothesis is accepted.

D. Recharge.

Hypothesis 1. The major source of recharge to the system is from Pre-Cretaceous and Cretaceous lithologies to the west of the study area.

The approximately north-east to south-west orientation of piezometric contours in the northern and western portions of the study area (Figure 31), indicate that recharge to the main quartzite provenance is mainly derived from the high lying Elands River Forest Reserve and Groendal Wilderness Area (Page 87). Outcrop area is mainly made up of quartzites of the Table Mountain Group whose primary porosities and permeabilities are extremely low (Page 11). Intense fracturing has resulted in the formation of secondary porosities and permeabilities within the quartzites which may form an important recharge conduit from highland outcrop areas to overlying Cretaceous sediments in the study area (Page 13). To the north-west of the study area, Cretaceous sandstones and conglomerates of the Kirkwood and Enon Formations outcrop and also act as a source of recharge from the west.

Recharge to the topographically high lying mixed provenance to the south and east of Searle Hill and which is separated from western recharge by the Elands River Valley, derives its recharge locally from quartzites of the Table Mountain Group outcropping to form Searle Hill (Pages 38 and 87). The limited topographical extent of the recharge area and low yields obtained from the mixed provenance (Table 22), indicate that the amount of recharge from this source is small.

The hypothesis is accepted for the majority of the area with the exclusion of the high lying mixed provenance which derives its recharge locally.

Chapter 11. Conclusions.

The principal aquifers of the Kruis River area are the Cretaceous sandstones and conglomerates of the Kirkwood and Enon Formations. The hydraulic parameters of the aquifers vary greatly according to the source of palaeosediments, with transmissivities and storage being reduced in areas where palaeosediments are partially derived from shales of the Bokkeveld Group to the south of the study area. Arenaceous and rudaceous lithologies located close to Pre-Cretaceous outcrop form the most exploited portions of aquifer lithologies within the study area. The high level of exploitation in these areas is because of good yields of high quality water obtainable from boreholes of reasonable depth (±200m). The development of aquifers within the quartzite provenance is restricted in a north-easterly direction by the increased thickness of overlying Kirkwood Mudstones.

Mudstones of the Kirkwood Formation are considered to be largely responsible for the mineralization of the arenaceous and rudaceous aquifer lithologies, although additional mineralization within the mixed provenance is contributed by the increased proportions of clays derived from the Bokkeveld Shales. Higher levels of mineralization within the mixed provenance is also related to reduced hydraulic activity and the limited local source of recharge. Hydrochemical modification of the groundwater within the various lithologies, results in changes in ionic proportions and the formation of hydrogen sulphide, which leads to the "bad egg" smell of some of the groundwater.

Piezometric levels have declined by approximately 32m over the 71 years since the first boreholes were drilled. Abstraction, which has approximately doubled since 1963 because of increasingly intensive agricultural practices, exceeds recharge to the aquifer lithologies. If locally important market gardening is to continue to rely on groundwater abstraction, more careful utilization and efficient management of the groundwater supplies will have to take place to prevent long term dewatering of the aquifer lithologies.

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Index of Appendices

APPENDIX 1
HYDROCENSUS

B/H NUMBER	FARMER'S NAME AND FARM NAME	WATER USE	PUMP TYPE	TESTED YIELD AND DATE (ℓ/sec)	TDS (mg/ℓ)	ABSTRACTION QUANTITIES (m^3/year)	COLLAR ELEVATION (MAP) (m)	GROUNDWATER LEVEL			BOREHOLE DEPTH (m)
								DATE	DEPTH BELOW COLLAR (m)	HEIGHT ABOVE SEA-LEVEL (m)	
KR 1	HUMAN BRANDSKLOOF PORTION 43	HOLE COLLAPSED									UNKNOWN
KR 2A	HUMAN BRANDSKLOOF PORTION 43	IRRIGATION	TURBINE	28/9/82 - 7,5	27/2/82 - 117 4/3/83 - 136	28/9/82 177390	82				122,4
KR 3B	HUMAN BRANDSKLOOF PORTION 43	IRRIGATION	SUBMERSIBLE	28/9/82 - 8,8 8/3/83 8,0	27/2/82 - 180 8/3/83 - 92	28/9/82 - 208138 8/3/83 - 189216	65	1/9/79	6,096		152,4
KR 4	HUMAN BRANDSKLOOF PORTION 43	DOMESTIC	TURBINE	28/9/82 - 7,5	22/2/82 - 314	28/9/82 - 236520	57,5	30/8/83	2,375	55,125	152,4
KR 5A	DE KLERK DIE EIKE PORTION 108	HOLE CLOSED									64
KR 6A	DE KLERK DIE EIKE PORTION 108	HOLE CLOSED									UNKNOWN
KR 7A	DE KLERK DIE EIKE PORTION 108	IRRIGATION & DOMESTIC	TURBINE	28/9/82 - 10,0 8/3/83 - 10,0	27/2/82 - 203 385 8/3/83 - 252	28/9/82 78840	84				60,9

B/H NUMBER	FARMER'S NAME AND FARM NAME	WATER USE	PUMP TYPE	TESTED YIELD AND DATE (ℓ/sec)	TDS (mg/ℓ)	ABSTRACTION QUANTITIES (m³/year)	COLLAR ELEVATION (MAP) (m)	GROUNDWATER LEVEL			BOREHOLE DEPTH (m)
								DATE	DEPTH BLEOW COLLAR (m)	HEIGHT ABOVE SEA-LEVEL (m)	
KR 8	DE KLERK DIE EIKE PORTION 108	HOLE CLOSED									UNKNOWN
KR 9A	S. LE ROUX REPOS ALLEURS PORTION 79	HOLE CLOSED									149
KR 10A	J.J. LAURENCE LEBANON	IRRIGATION & DOMESTIC	SUBMERSIBLE	28/9/82 - 3,8 8/3/83 - 4,65	22/2/82 - 290 8/3/83 - 210	28/9/82 - 59918 8/3/83 - 73321	60				161
KR 11	S.A. KOÖPERATIEWE SITRUSBEURS BPK. PORTION 52	HOLE CLOSED									UNKNOWN
KR 11A	S.A. KOÖPERATIEWE SITRUSBEURS BPK. PORTION 52	DOMESTIC	TURBINE	22/8/83 - 2,7	22/2/82 - 322	22/8/83 - 3549	76	30/8/83	28,810	47,190	57,91
KR 12	S.A. KOÖPERATIEWE SITRUSBEURS BPK. PORTION 52	HOLE CLOSED									UNKNOWN
KR 13A	J. CLAASEN HIGHLANDS PORTION 103 OF PORTION 92	DOMESTIC & STOCK	SUBMERSIBLE	JULY/70 - 7,56 7/11/83 - 8,0	22/1/82 - 413	7/11/83 50458	65				123

B/H NUMBER	FARMER'S NAME AND FARM NAME	WATER USE ,	PUMP TYPE	TESTED YIELD AND DATE (ℓ/sec)	TDS (mg/ℓ)	ABSTRACTION QUANTITIES (m^3/year)	COLLAR ELEVATION (MAP) (m)	GROUNDWATER LEVEL			BOREHOLE DEPTH (m)
								DATE	DEPTH BELOW COLLAR (m)	HEIGHT ABOVE SEA-LEVEL (m)	
KR 14A	S.A. KOÖPERATIEWE SITRUSBEURS BPK. PORTION 52	HOLE CLOSED 1982									174
KR 15	S.A. KOÖPERATIEWE SITRUSBEURS BPK. PORTION 52	HOLE CLOSED									UNKNOWN
KR 16	VAN YUUREN, B.J. LANGLAAGTE PORTION 51/61	DOMESTIC & IRRIGATION	TURBINE	28/9/82 - 6,5	27/2/82 - 205 8/3/83 - 174 30/8/83 - 192	28/9/82 - 102492	65				176,0
KR 17	B.R. SEADY RHODECOURT PORTION 93	DOMESTIC	SUBMERSIBLE	5/9/83 - 10,25	5/9/83 - 263	10627	65,5				182
KR 18A	CLAASEN ROOIPADSBRAND PORTION 96	DOMESTIC & STOCK	TURBINE & TRACTOR		22/2/82 - 413	22/8/83 - 352	64				126,5
KR 19A	CLAASEN ROOIPADSBRAND PORTION 47	IRRIGATION & DOMESTIC	SUBMERSIBLE	28/9/82 - 8,0 22/8/83 - 6,2	22/2/82 - 1238	28/9/82 1472 22/8/83 2716	87	27/1/82 30/8/83	28,208 32,450	56,794 54,550	167,0
KR 20	CLAASEN ROOIPADSBRAND PORTION 47	HOLE CLOSED									DEPTH TO BLOCKAGE 75,35

B/H NUMBER	FARMER'S NAME AND FARM NAME	WATER USE ,	PUMP TYPE	TESTED YIELD AND DATE (ℓ/sec)	TDS (mg/ℓ)	ABSTRACTION QUANTITIES (m^3/year)	COLLAR ELEVATION (MAP) (m)	GROUNDWATER LEVEL			BOREHOLE DEPTH (m)
								DATE	DEPTH BELOW COLLAR (m)	HEIGHT ABOVE SEA-LEVEL (m)	
KR 21	LE ROUX GROOTKLOOF PORTION 105 OF PORTION 54	DOMESTIC & STOCK	TURBINE	28/9/82 - 2,7 30/8/82 - 1,7	1/4/82 - 2298 30/8/82 - 1086	28/9/82 - 3903	79	3/2/82 18/3/83	24,662 36,085	54,338 42,915	144,8
KR 22	COOKE GROOTKLOOF PORTION 54	IRRIGATION & STOCK	SUBMERSIBLE	28/9/82 - 7,0	25/2/82 - 230 8/3/83 - 193	28/9/82 - 188559	74				75,8
KR 23	COOKE GROOTKLOOF PORTION 54		SUBMERSIBLE	7/11/83 - 5,0	27/2/82 - 191 7/11/83 - 131	7/11/83 157680	90				90,9
KR 28-31	LANDMAN GROOTVLEI: REMAINDER OF PORTION 76	HOLES CLOSED									UNKNOWN
KR 32	VAN HEERDEN PORTION 97	DOMESTIC & STOCK	SUBMERSIBLE	28/9/82 - 1,3	8/3/83 - 145 5/9/83 - 299	28/9/82 - 20498	85				104
KR 34	C.J. VAN VUUREN REMAINDER OF PORTION 48	HOLE BLOCKED AT DEPTH ± 20m			27/2/82 - 3929		65	AUG/82 5/9/82	5,676 1,11 UNRELIABLE	59,324 63,890	UNKNOWN
KR 35	R.C.A. HARRIS BONNIEVALE PORTION 114 OF PORTION 46	NOT CURRENTLY IN USE					76	5/9/82	1,705 UNRELIABLE	74,295	227,3

B/H NUMBER	FARMER'S NAME AND FARM NAME	WATER USE	PUMP TYPE	TESTED YIELD AND DATE (ℓ/sec)	TDS (mg/ℓ)	ABSTRACTION QUANTITIES (m^3/year)	COLLAR ELEVATION (MAP) (m)	GROUNDWATER LEVEL			BOREHOLE DEPTH (m)
								DATE	DEPTH BELOW COLLAR (m)	HEIGHT ABOVE SEA-LEVEL (m)	
KR 36	R.C.A. HARRIS BONNIEVALE PORTION 114 OF PORTION 46	HOLE CLOSED									UNKNOWN
KR 37	R.C.A. HARRIS BONNIEVALE PORTION 114 OF PORTION 46	HOLE CLOSED					79	2/2/82 5/9/82	27,750 32,65	51,250 46,350	34,534 ORIGINAL DEPTH ± 303
KR 38	R.C.A. HARRIS BONNIEVALE PORTION 114 OF PORTION 46	DOMESTIC & STOCK	SUBMERSIBLE	28/9/82 - 3,0	27/2/82 - 820	28/9/82 - 15768	85	2/2/82	36,300	48,700	227
KR 39	BOTHA PORTION 115 OF PORTION 46	NOT CURRENTLY IN USE					80	2/2/82 5/9/82	29,019 33,59	50,981 46,410	45
KR 40 & 41	S.C. VAN NIEKERK LANGLAND PORTION 13 OF PORTION 1	HOLES CLOSED									183 198
KR 43	J.P. RENS DE HOOP REMAINDER OF PORTION 35 OF PORTION 1	HOLE CLOSED									209

B/H NUMBER	FARMER'S NAME AND FARM NAME	WATER USE	PUMP TYPE	TESTED YIELD AND DATE (ℓ/sec)	TDS (mg/ℓ)	ABSTRACTION QUANTITIES (m^3/year)	COLLAR ELEVATION (MAP) (m)	GROUNDWATER LEVEL			BOREHOLE DEPTH (m)
								DATE	DEPTH BELOW COLLAR (m)	HEIGHT ABOVE SEA-LEVEL (m)	
KR 44	J.P. RENS DE HOOP REMAINDER OF PORTION 35 OF PORTION 1	HOLE CLOSED									213
KR 45	SCHEEPERS RETREAT PORTION 120	DOMESTIC & STOCK	SUBMERSIBLE	28/9/82 - 1,0	22/8/83 - 914	28/9/82 - 5256	56	4/2/82 18/3/83 5/9/83	3,625 7,638 9,34	52,375 48,362 46,660	UNKNOWN
KR 46	SCHEEPERS RETREAT PORTION 120	HOLE CLOSED									76,2
KR 47	S.A. BARNARD HOPEDALE PORTION 101 OF PORTION 76	DOMESTIC & STOCK	POWER HEAD	28/9/82 - 0,36 30/8/83 - 1,25	22/2/82 - 273 30/8/83 - 241	28/9/82 - 946 30/8/83 - 3285	72				UNKNOWN
KR 48A	HUMAN PORTION 89	IRRIGATION & DOMESTIC	TURBINE	28/9/82 - 2,5 8/3/83 - 3,08	22/2/82 - 275	28/9/82 - 59130	64,5				154,6
KR 49	RENS AVONDSRUS PORTION 84	IRRIGATION & DOMESTIC	TURBINE	28/9/82 - 5,0 5/9/83 - 10,0	22/2/82 - 623 8/3/83 - 171 5/9/83 - 277	28/9/82 - 78840	79				133,6

B/H NUMBER	FARMER'S NAME AND FARM NAME	WATER USE	PUMP TYPE	TESTED YIELD AND DATE (ℓ/sec)	TDS (mg/ℓ)	ABSTRACTION QUANTITIES (m³/year)	COLLAR ELEVATION (MAP) (m)	GROUNDWATER LEVEL			BOREHOLE DEPTH (m)
								DATE	DEPTH BELOW COLLAR (m)	HEIGHT ABOVE SEA-LEVEL (m)	
KR 50	FERREIRA PORTION 113	DOMESTIC	SUBMERSIBLE	28/9/82 - 0,9 8/3/83 - 0,8	27/2/82 - 202 8/3/83 - 127	28/9/82 - 2365 8/3/83 - 2102	55	5/9/83	12,000	43,000	181,8
KR 52	HUMAN PORTION 38	HOLE CLOSED - 1982		28/9/82 - 6,7	27/2/82 - 250 9/6/82 - 563	28/9/82 - 158468					121,9
KR 52A	HUMAN PORTION 38	IRRIGATION & DOMESTIC	TURBINE	8/3/83 - 5,0 22/8/83 - 5,7	25/1/83 - 3884 8/3/83 - 159 5/9/83 - 231	22/8/83 - 134816 8/3/83 - 118260	62,5				
KR 53A	HUMAN, J.N. FONTEINSHOEK PORTION 36	IRRIGATION & DOMESTIC	TURBINE	28/9/82 - 3,7 30/8/83 - 3,3	22/2/82 - 476 10/6/82 - 10872 8/3/83 - 214 30/8/83 - 221	28/9/82 - 58342 30/8/83 - 52034	79				107
KR 54	KEMP, I.G. CASTANJE BOOM REMAINDER OF PORTION 44	NOT CURRENTLY IN USE BLOCKED AT DEPTH			22/2/82 - 2951 10/6/82 - 135		63,5	28/1/82 30/8/83	8,512 16,775	54,988 46,725	162
KR 55	H. HANCKE KWEPERLANDE PORTION 69	DOMESTIC	SUBMERSIBLE	28/9/82 - 0,5 8/3/83 - 0,28 5/9/83 - 0,39	8/3/83 - 335 22/8/83 - 251 5/9/83 - 322	28/9/82 - 657 8/3/83 - 368	62,5				168,9

B/H NUMBER	FARMER'S NAME AND FARM NAME	WATER USE ,	PUMP TYPE	TESTED YIELD AND DATE (ℓ/sec)	TDS (mg/ℓ)	ABSTRACTION QUANTITIES (m^3/year)	COLLAR ELEVATION (MAP) (m)	GROUNDWATER LEVEL			BOREHOLE DEPTH (m)
								DATE	DEPTH BELOW COLLAR (m)	HEIGHT ABOVE SEA-LEVEL (m)	
KR 56	PROVINCIAL ADMINISTRATION PORTION 117	HOLE CLOSED									192
KR 57	R.G. RUDMAN PORTION 70	DOMESTIC	SUBMERSIBLE	8/3/83 - 1,1	22/8/83 - 287	22/8/83 - 482	63	30/8/83	22,895	40,105	121,2
KR 58	SWAENEPOEL PORTION 74	NOT CURRENTLY IN USE COLLAPSED AT 33,82m					66	22/1/82 30/8/83	14,67 14,155	51,330 51,885	152
KR 59	COOKE RIETFONTEIN	HOLE CLOSED									157,9
KR 60	MULLER FONTEINSHOEK REMAINDER OF PORTION 92 OF PORTION 36	IRRIGATION & DOMESTIC	TURBINE	28/9/82 - 1,2 30/8/83 - 1,0	23/2/82 - 202 30/8/83 - 190	28/9/82 - 7884 30/8/83 - 3377	83				104,9
KR 61	A.F. GERBER PORTION 104	IRRIGATION	TURBINE	28/9/82 - 16,7 8/3/83 - 10,0	27/2/82 - 339 8/3/83 - 346	28/9/82 - 219438 8/3/83 - 131400	72	27/2/82	9,144	62,856	99,06
KR 63	BOTHA, M.D. OLIVIA PORTION 115	NOT CURRENTLY IN USE			27/2/82 - 250	28/9/82 - 506	81	23/6/80	32,2	48,800	150

B/H NUMBER	FARMER'S NAME AND FARM NAME	WATER USE ,	PUMP TYPE	TESTED YIELD AND DATE (ℓ/sec)	TDS (mg/ℓ)	ABSTRACTION QUANTITIES (m^3/year)	COLLAR ELEVATION (MAP) (m)	GROUNDWATER LEVEL			BOREHOLE DEPTH (m)
								DATE	DEPTH BELOW COLLAR (m)	HEIGHT ABOVE SEA-LEVEL (m)	
KR 64	W.R. VAN HEERDEN RETREAT PORTION 106	NOT CURRENTLY IN USE					105	3/2/82 5/9/83	50,480 55,210	54,520 49,790	121,9
KR 66	THOMPSON GREENACRES REMAINDER OF PORTION ROOILAND	DOMESTIC	SUBMERSIBLE	28/9/82 - 2,1 30/8/83 - 0,9	27/2/82 - 306 30/8/83 - 386	28/9/82 - 3587 30/8/83 - 1537	61	30/8/83	29,342	31,658	149,7
KR 70	B.R. SEADY PORTION 2 OF RHODECOURT	NOT CURRENTLY IN USE					69,5	30/8/83	9,125		130
KR 71G	B.J. VAN VUUREN LANGLAAGTE DIV. GEOHYDROLOGY PORTION 51/61	RESEARCH	-	30/5/83 - 13,0	30/5/83 - 155 to 168 VARIATION WITH PUMPING	NONE - RESEARCH	66	18/3/83 30/5/83	27,785 25,426	38,215 40,574	200
KR 72	S.A. KOÖPERATIEWE SITRUSBEURS B.P.K. PORTION 52	IRRIGATION	SUBMERSIBLE	25/8/82 - 12,9 22/8/83 - 2,6	22/9/82 - 259 to 663 VARIATION WITH PUMPING	22/8/83 - 3432	64	25/8/82 30/8/83	6,956 12,565	57,044 51,435	200
KR 75G	DE KLERK DIE EIKE DIV. GEOHYDROLOGY PORTION 108	RESEARCH	-	2/12/82 - 10,4	2/12/82 - 221 to 299 VARIATION WITH PUMPING	NONE - RESEARCH	67	2/12/82 23/8/83 5/9/83	18,257 18,768 18,790	48,743 48,232 48,210	160

B/H NUMBER	FARMER'S NAME AND FARM NAME	WATER USE ,	PUMP TYPE	TESTED YIELD AND DATE (ℓ/sec)	TDS (mg/ℓ)	ABSTRACTION QUANTITIES (m³/year)	COLLAR ELEVATION (MAP) (m)	GROUNDWATER LEVEL			BOREHOLE DEPTH (m)
								DATE	DEPTH BELOW COLLAR (m)	HEIGHT ABOVE SEA-LEVEL (m)	
BH 1	BLOM, F.P. BOSCHHOOGTE - NUWEPLAAS PORTION 3	DOMESTIC	MONO & ENGINE	16/9/83 - 0,5	16/9/83 - 2579	16/9/83 - 657	106	4/5/82 5/9/83	37,323 38,990	68,677 67,010	213,6
LH 1	SEALE WINCANTON ESTATES PORTION OF LONGHILL	STOCK	POWER HEAD	28/9/82 - 1,26	3/11/82 - 541	28/9/82 - 13245	387				149
MD 1	J.C. GERBER MIMOSADALE PORTION 40	HOLE CLOSED									210,6
MD 2	SEARLE WINCANTON ESTATES PORTION 3	NOT CURRENTLY IN USE	DIESEL & POWER HEAD	28/9/82 - 0,7		20/9/82 - 4139	111				114
MD 3	SEARLE WINCANTON ESTATES PORTION 3	HOLE CLOSED									130
MD 4	SEARLE WINCANTON ESTATES PORTION 3	HOLE CLOSED									168
MD 4A	SEARLE WINCANTON ESTATES PORTION 3	NOT CURRENTLY IN USE		ON COMPLETION - 1,25			117,5	3/2/82 11/5/82 18/3/83	48,823 48,670 48,180	68,677 68,830 69,320	248

B/H NUMBER	FARMER'S NAME AND FARM NAME	WATER USE	PUMP TYPE	TESTED YIELD AND DATE (ℓ/sec)	TDS (mg/ℓ)	ABSTRACTION QUANTITIES (m^3/year)	COLLAR ELEVATION (MAP) (m)	GROUNDWATER LEVEL			BOREHOLE DEPTH (m)
								DATE	DEPTH BELOW COLLAR (m)	HEIGHT ABOVE SEA-LEVEL (m)	
MD 6	D.J. JANSEN MAMOSADALE PORTION 22 OF PORTION 4	NOT CURRENTLY IN USE					94	18/3/83 5/9/83	11,631 11,325	82,369 82,675	128
MD 7	P.H. SCHAUTZ MAMOSADALE PORTION 33 OF PORTION 4	DOMESTIC	WINDPUMP	NOT RELEVANT	22/8/83 - 1534	NOT RELEVANT	117	7/6/83 19/4/83 5/9/83	57,940 63,000 59,58	59,060 54,000 57,420	115
MD 20G	SEARLE MAMOSADALE DIV. GEOHYDROLOGY	RESEARCH	-				112	22/10/82 5/9/83	37,5 37,710	74,500 74,290	157
MD 21G	MEIRING MAMOSADALE - ROOIHOOGTE DIV. GEOHYDROLOGY	RESEARCH	-	7/6/83 - 0,34	7/6/83 - 955 to 983 VARIATION WITH PUMPING		110	7/6/83 5/9/83	52,150 51,265	57,850 58,735	167
MW 1	SEARLE WINCANTON ESTATES PORTION 3	HOLE CLOSED									154,8
MW 2	SEARLE WINCANTON ESTATES PORTION 3	HOLE CLOSED									148,2

B/H NUMBER	FARMER'S NAME AND FARM NAME	WATER USE	PUMP TYPE	TESTED YIELD AND DATE (l/sec)	TDS (m_g/l)	ABSTRACTION QUANTITIES (m^3/year)	COLLAR ELEVATION (MAP) (m)	GROUNDWATER LEVEL DATE	DEPTH BELOW COLLAR (m)	HEIGHT ABOVE SEA-LEVEL (m)	BOREHOLE DEPTH (m)
MW 2A	SEARLE WINCANTON ESTATES PORTION 3	HOLE CLOSED					68	3/2/82	7,740	60,260	131
MW 3	SEARLE WINCANTON ESTATES PORTION 3	HOLE CLOSED									189
MW 3A	SEARLE WINCANTON ESTATES PORTION 3	TOOLS STUCK IN HOLE					67	15/2/83	27,671	39,329	122
MW 4	A.F. GERBER PORTION 3	HOLE CLOSED									101
MW 4B	A.F. GERBER PORTION 3	IRRIGATION	TURBINE	8/3/83 - 8,7 5/9/83 - 10,7	7/3/83 - 1554 5/9/83 - 290	8/3/83 - 105987 5/9/83 337435	67	3/2/83	30,450	36,550	126
MW 5	SEARLE WINCANTON ESTATES PORTION 3	HOLE CLOSED									159
MW 6	A. FROST ECODALE	DOMESTIC & STOCK	POWER HEAD	28/9/82 - 0,5	4/5/82 - 410 9/3/83 - 294	28/9/82 - 3285	78				170

B/H NO.	FARMER'S NAME & FARM NAME	WATER USE	PUMP TYPE	TESTED YIELD & DATE (ℓ/SEC)	TDS	ABSTRACTION QUANTITIES (M^3/YEAR)	COLLAR ELEVATION (MAP)	GROUNDWATER LEVEL			BOREHOLE DEPTH (m)
								DATE	DEPTH BELOW COLLAR (m)	HEIGHT ABOVE SEA-LEVEL (m)	
MW 7	A. FROST ECODALE DIV. GEOHYDROLOGY	OBSERVATION POINT					78	11/5/82 19/8/83	8,901 7,780	69,099 70,220	182,9
MW 8	A. FROST ECODALE	LIGHT INDUSTRY	POWER HEAD	28/9/82 - 0,4	11/5/82 - 3604 to 416 CHANGE DUE TO PUMPING 5/9/83 - 313	28/9/82 - 3154	89	5/9/83	20,780	68,220	369
MW 9	SEARLE	OBSERVATION		RECORDS CONSIDERED UNRELIABLE - DUE TO PROXIMITY WITH COW SHEDS			82	19/8/83	25,080	56,920	UNKNOWN COLLAPSED AT ±28m
MW 20G	A. FROST MIMOSADALE WEST DIV. GEOHYDROLOGY PORTION ECODALE	RESEARCH		SEE PAGES ONLY			84,5	5/9/83	93,64	-9,140	107
SN 1G	PRETORIUS SPRINGFIELD DIV. GEOHYDROLOGY	RESEARCH RECORDER		14/3/83 - 11,4	15/3/83 - 183 to 880 VARIATION WITH PUMPING	NONE	103	14/3/83 30/8/83	40,105 36,840	62,895 66,160	257
KM 1	UITENHAGE MUNICIPALITY KAMAEHES	RESEARCH		13/3/84 - 0,04	13/3/84 - 7722	NONE	83,3	13/3/84	34,95	48,35	451

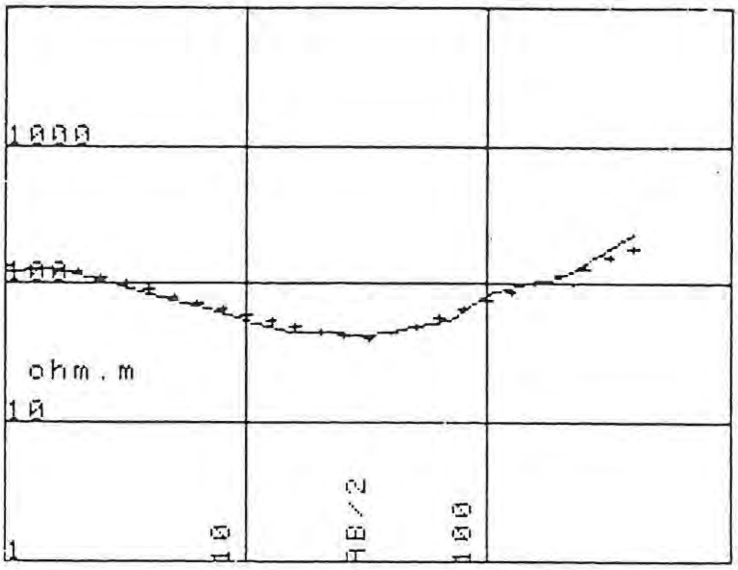
APPENDIX 2
RESISTIVITY LOGS

TITLE = T1ES1

EARTH MODEL

LAYER THICKNESS	RESISTIVITY
1.6	138
9.6	60
9.45	15
38.1	200
60	80
	697

++++ = THEORETICAL CURVE
line = FIELD CURVE
TOTAL S = 1.7420942029

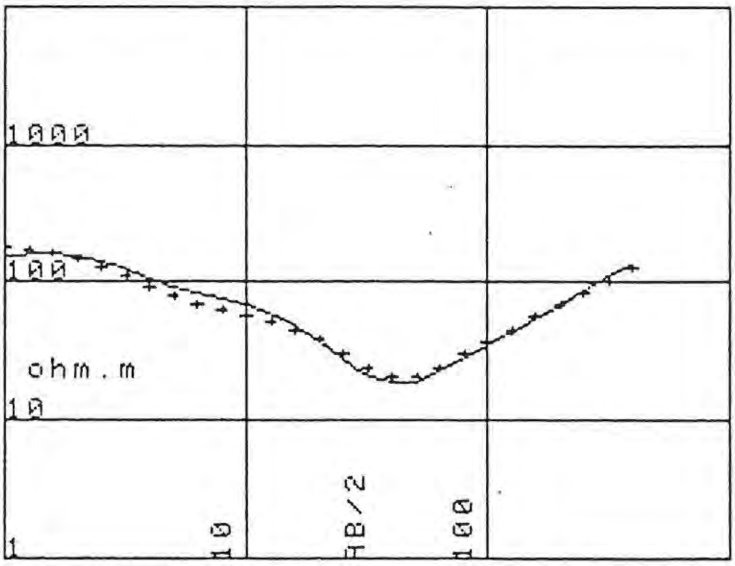


TITLE = T1ES2

EARTH MODEL

LAYER THICKNESS	RESISTIVITY
1.3	190
10.7	60
15.49	7
50	200
	697

++++ = THEORETICAL CURVE
line = FIELD CURVE
TOTAL S = 2.64803258146

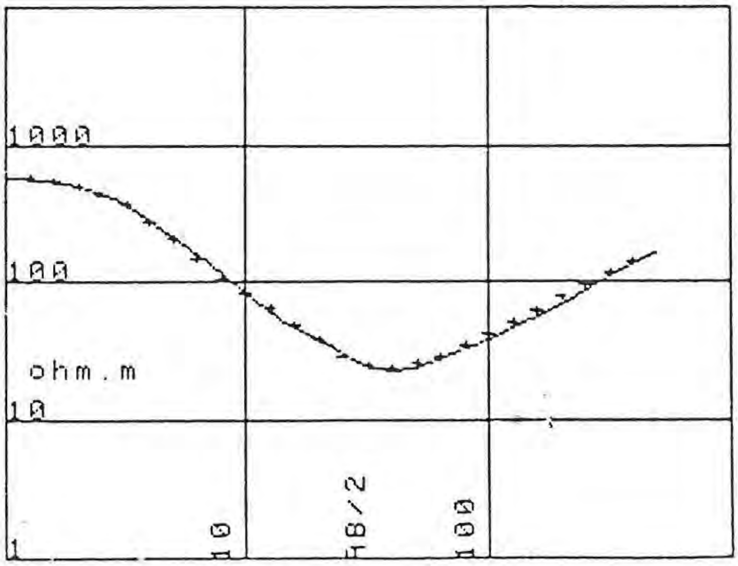


TITLE = T1ES3

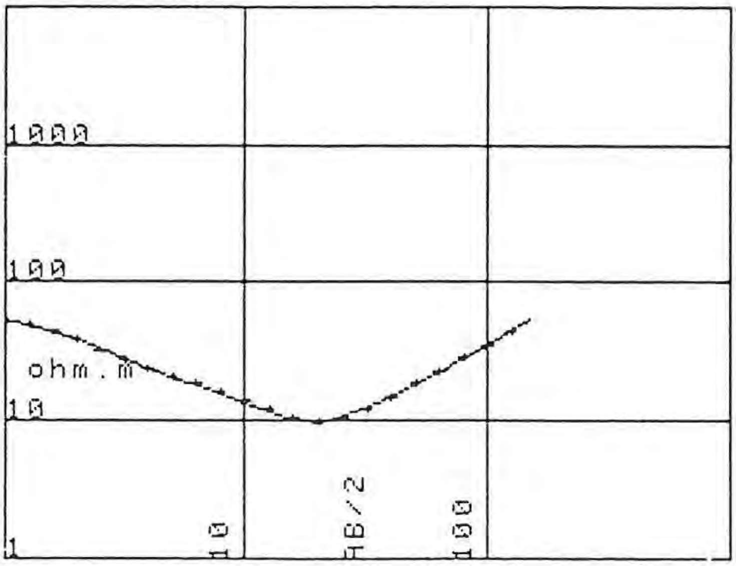
EARTH MODEL

LAYER THICKNESS	RESISTIVITY
1.75	600
6.48	90
35.64	18
91	260
	700

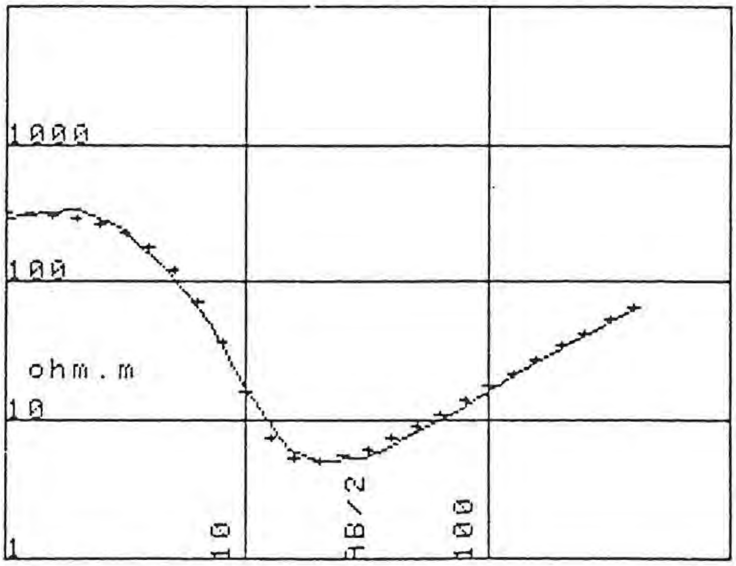
++++ = THEORETICAL CURVE
line = FIELD CURVE
TOTAL S = 2.40491666667



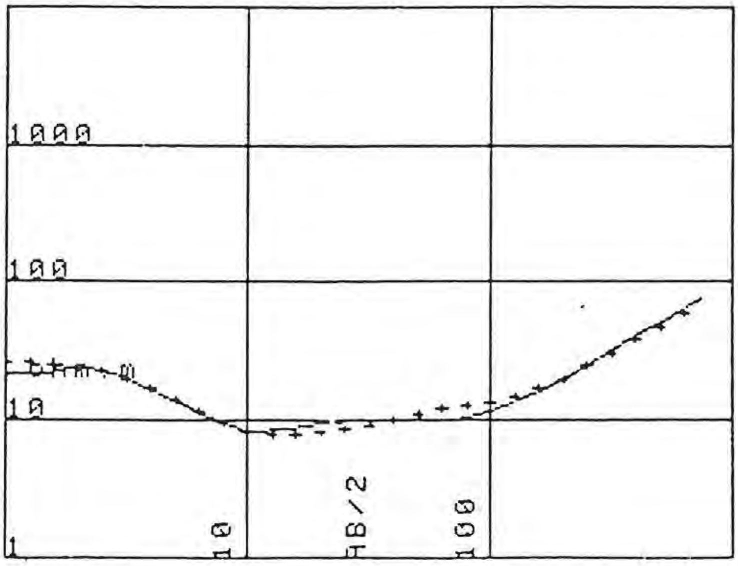
```
TITLE  =  T1ES4
          EARTH MCDEL
LAYER THICKNESS          RESISTIVITY
      .957                    57
     4.7                      20
    13.8                       6
    30                       200
                             700
++++ = THEORETICAL CURVE
line = FIELD CURVE
TOTAL S = 2.70178947368
```



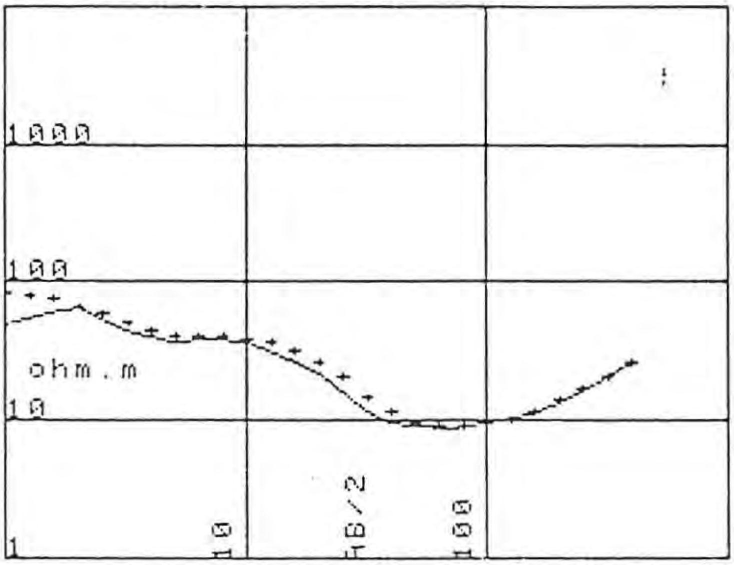
```
TITLE  =  T2ES1
          EARTH MODEL
LAYER THICKNESS          RESISTIVITY
     2.3                   328.5
    23.5                     4.3
                           697
++++ = THEORETICAL CURVE
line = FIELD CURVE
TOTAL S = 5.47211780114
```



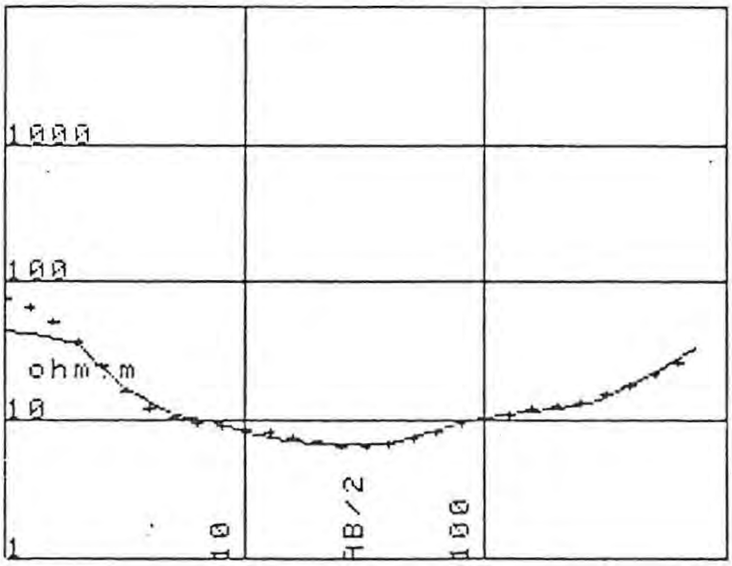
```
TITLE  =  T2ES2
          EARTH MODEL
LAYER THICKNESS          RESISTIVITY
     2                        27
    17.65                      7
    18.24                     30
    20.08                      3
                             700
++++ = THEORETICAL CURVE
line = FIELD CURVE
TOTAL S = 9.89683597883
```



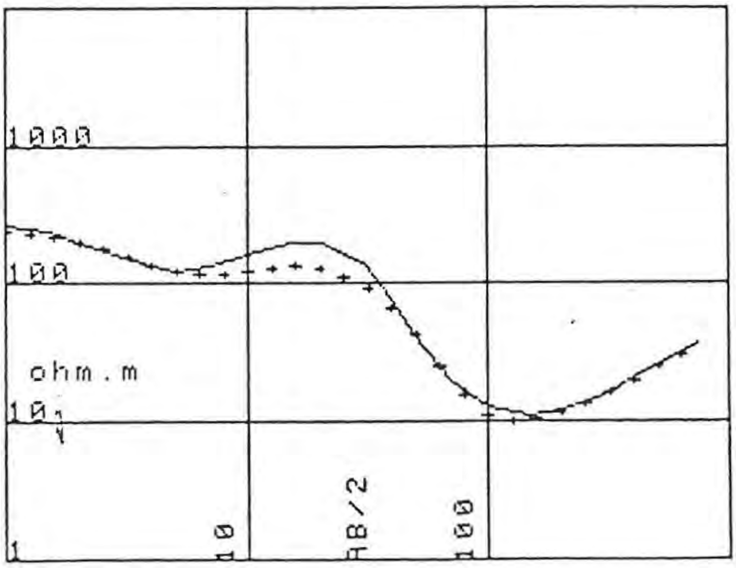
```
TITLE  =  T2ES3
          EARTH MODEL
LAYER THICKNESS          RESISTIVITY
     1.168                   90
     2.784                   29
     2.884                  103
   115                        8
                            700
++++ = THEORETICAL CURVE
line = FIELD CURVE
TOTAL S = 14.5119777778
```



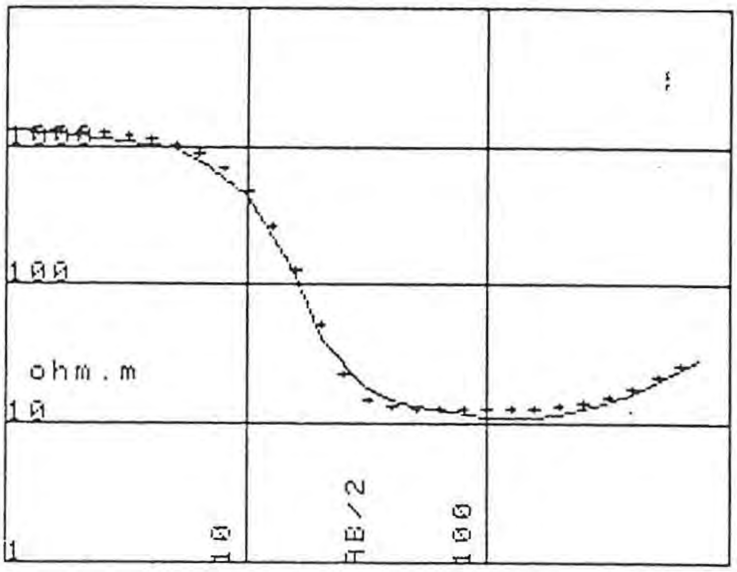
```
TITLE  =  T2ES4
          EARTH MODEL
LAYER THICKNESS          RESISTIVITY
     .8                     100
    9.12                      9.5
   13.36                      3.5
   49.6                      20
  124.8                       8
                            700
++++ = THEORETICAL CURVE
line = FIELD CURVE
TOTAL S = 22.8651428571
```



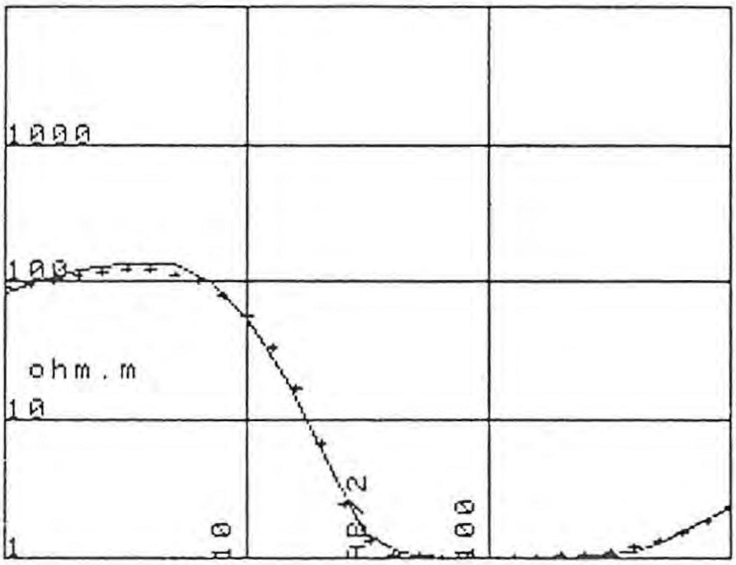
```
TITLE  =  T2ES5
          EARTH MODEL
LAYER THICKNESS          RESISTIVITY
     1.34                   250
     3.589                   85
     8.4                    260
   165.1                      8.5
                            700
++++ = THEORETICAL CURVE
line = FIELD CURVE
TOTAL S = 19.5034206335
```



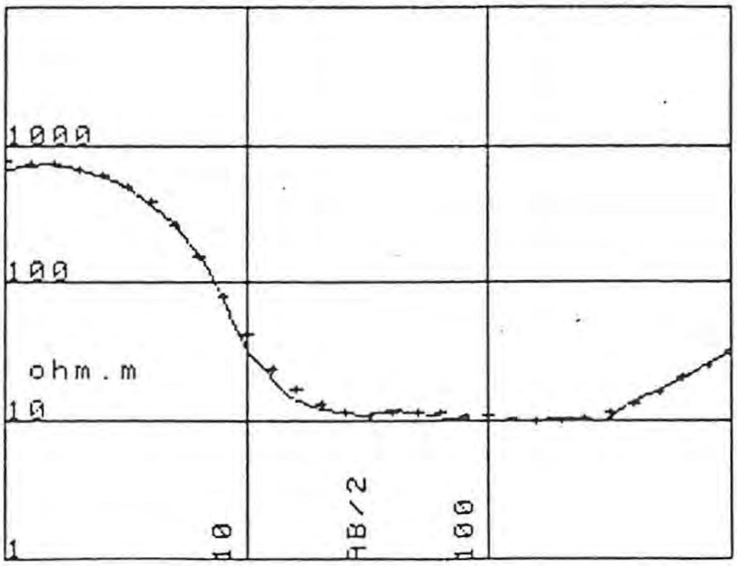
```
TITLE  =  T3ES1
          EARTH MODEL
LAYER THICKNESS           RESISTIVITY
    4.5                      1300
  108.2                        12.5
  162.9                        11.5
                              700
++++ = THEORETICAL CURVE
line = FIELD CURVE
TOTAL S = 22.8246789298
```



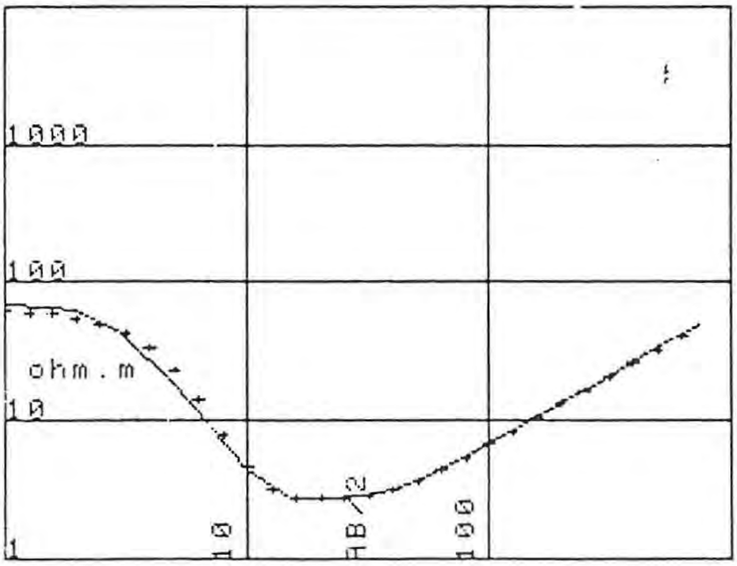
```
TITLE  =  T3ES2
          EARTH MCDEL
LAYER THICKNESS           RESISTIVITY
    .82                       85
   3.2                       170
  425                          1
                             700
++++ = THEORETICAL CURVE
line = FIELD CURVE
TOTAL S = 425.028470588
```



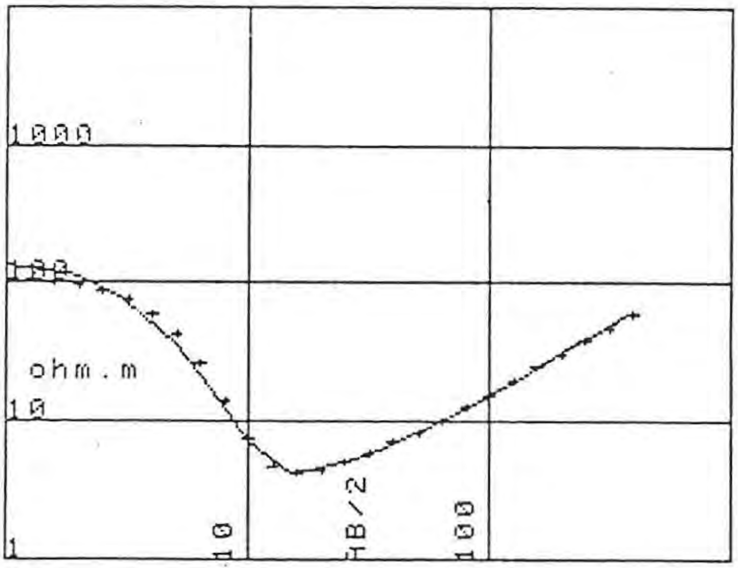
```
TITLE  =  T3ES3
          EARTH MODEL
LAYER THICKNESS           RESISTIVITY
    2.1                      780
    5.5                       30
   10.18                       7
   13.3                       20
   21.8                       10
  204                          8
                             700
++++ = THEORETICAL CURVE
line = FIELD CURVE
TOTAL S = 29.9853113553
```



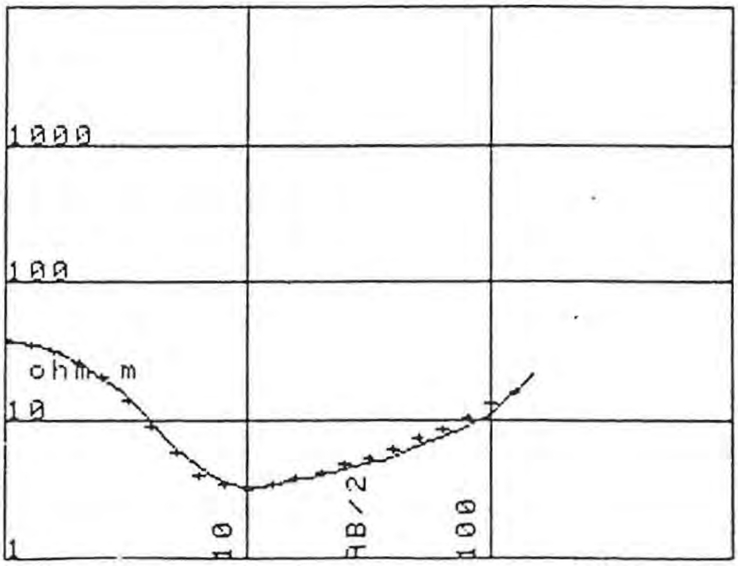
```
TITLE  =  T4ES1
          EARTH MODEL
LAYER THICKNESS          RESISTIVITY
     2.2                      63
    36.6                       2.5
                             700
++++ = THEORETICAL CURVE
line = FIELD CURVE
TOTAL S = 14.6749206349
```



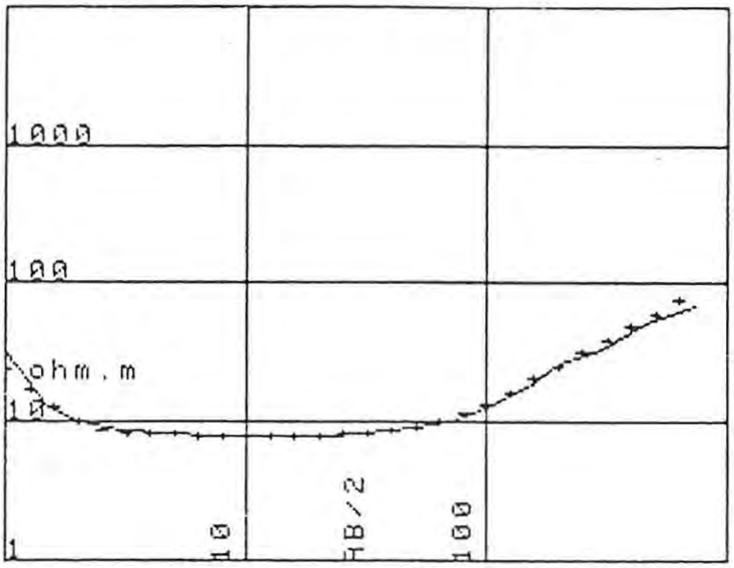
```
TITLE  =  T4ES2A
          EARTH MODEL
LAYER THICKNESS          RESISTIVITY
     2.3                     110
    10.8                       3
    28.6                      11
                             700
++++ = THEORETICAL CURVE
line = FIELD CURVE
TOTAL S = 6.22090909091
```



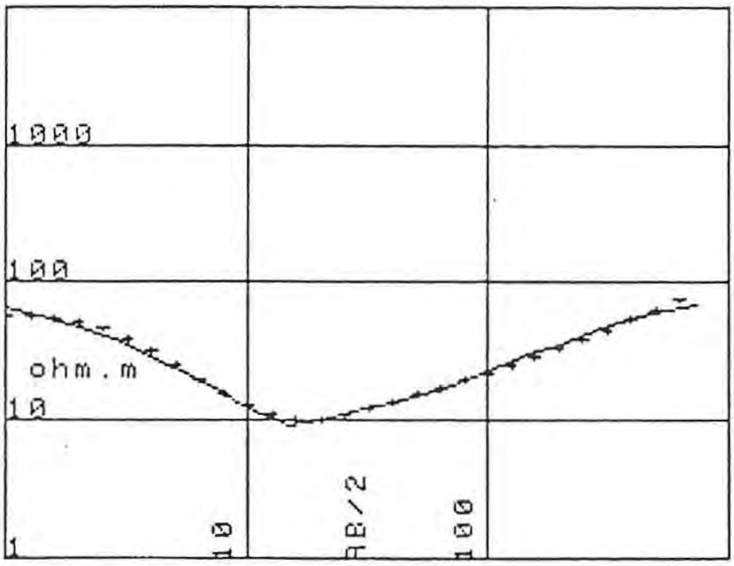
```
TITLE  =  T4ES2B
        . EARTH MODEL
LAYER THICKNESS          RESISTIVITY
     1.3                      40
     8.82                      2.8
    34.4                       8
                             700
++++ = THEORETICAL CURVE
line = FIELD CURVE
TOTAL S = 7.4825
```



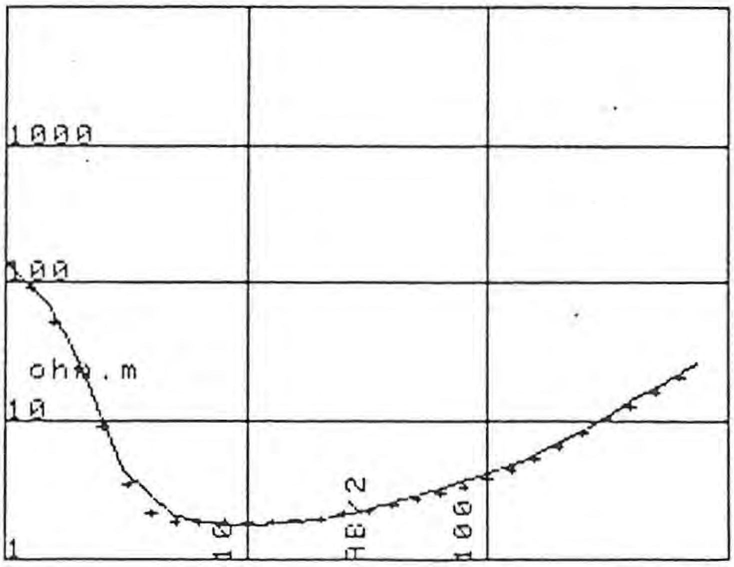
```
TITLE  =  T4ES3
          EARTH MODEL
LAYER THICKNESS            RESISTIVITY
     .4                        60
   60                           8
                              700
++++ = THEORETICAL CURVE
line = FIELD CURVE
TOTAL S = 7.50666666667
```



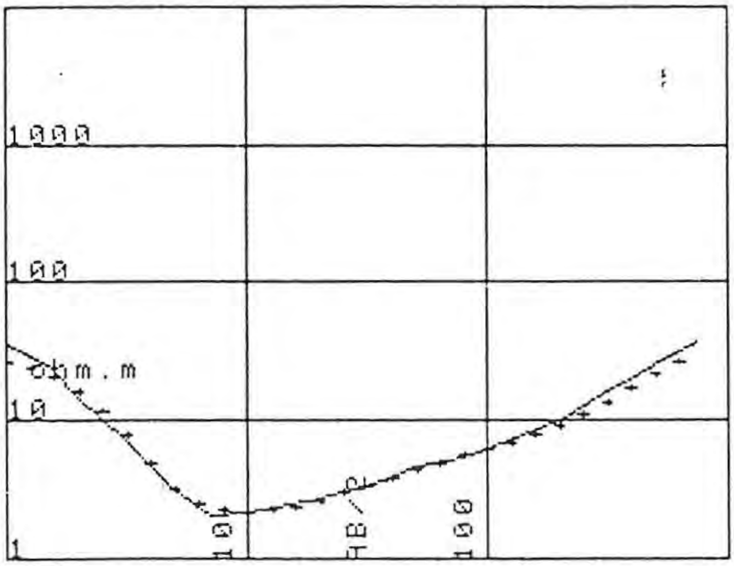
```
TITLE  =  T4ES4
          EARTH MODEL
LAYER THICKNESS            RESISTIVITY
     1.7                       60
     3                         15
    14.4                        8
   108                         30
                              185
++++ = THEORETICAL CURVE
line = FIELD CURVE
TOTAL S = 5.62833333333
```



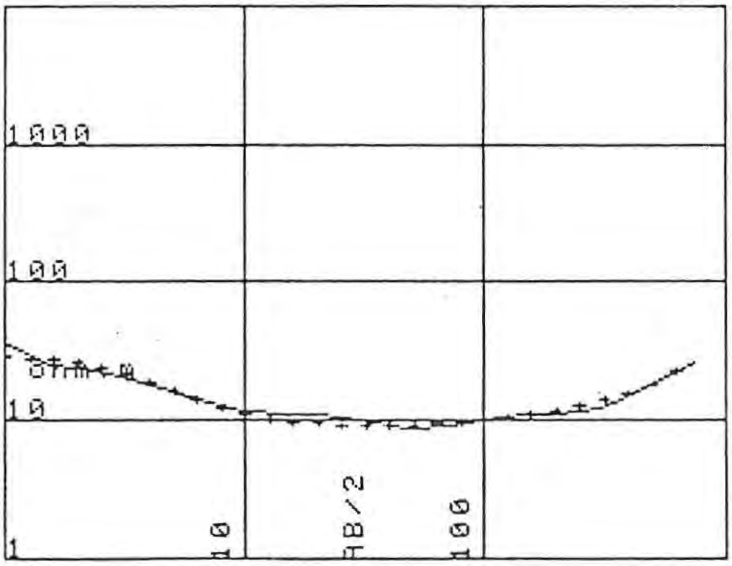
```
TITLE  =  T5ESA
          EARTH MODEL
LAYER THICKNESS            RESISTIVITY
     .55                      280
   17.1                         1.8
   27.8                         4
   34                           2.5
                              700
++++ = THEORETICAL CURVE
line = FIELD CURVE
TOTAL S = 30.0519642857
```



```
TITLE  =  T5ES1
          EARTH MODEL
LAYER THICKNESS          RESISTIVITY
     1.1                      30
    13.6                       2
    22.4                      10
    83.73                      6
                            1000
++++ = THEORETICAL CURVE
line = FIELD CURVE
TOTAL S = 23.0316666667
```



```
TITLE  =  T5ES2
          EARTH MODEL
LAYER THICKNESS          RESISTIVITY
     1.8                      29
     2.134                    11
    54                         9
    93.3                      14
   118                         8
                             700
++++ = THEORETICAL CURVE
line = FIELD CURVE
TOTAL S = 27.6703546798
```



APPENDIX 3
BOREHOLE LOGS

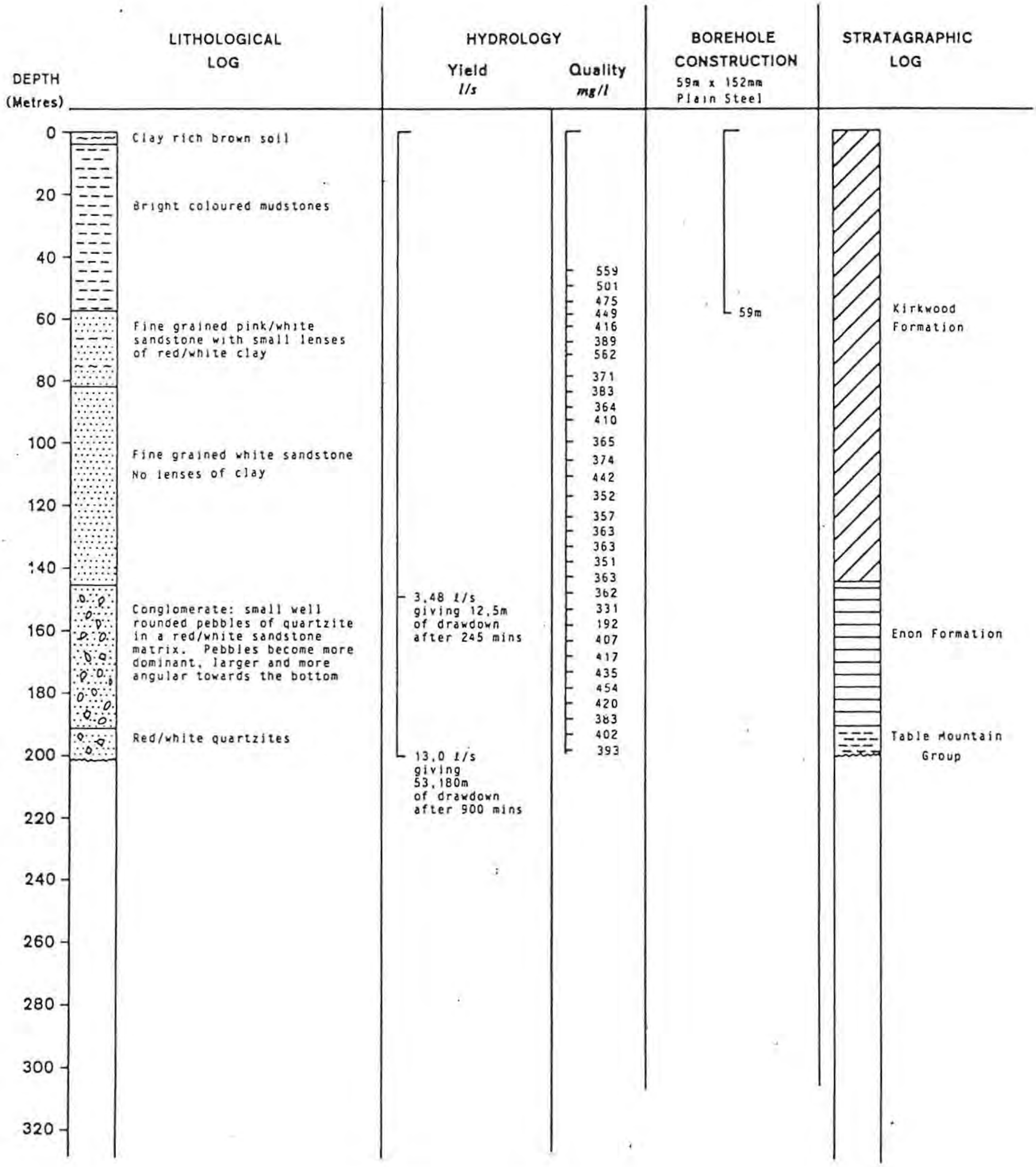
BOREHOLE NO: KR 71G

DRILL: CABLE-TOOL (PERCUSSION)

LOCATION: KRUIS RIVER

33°46'35"S

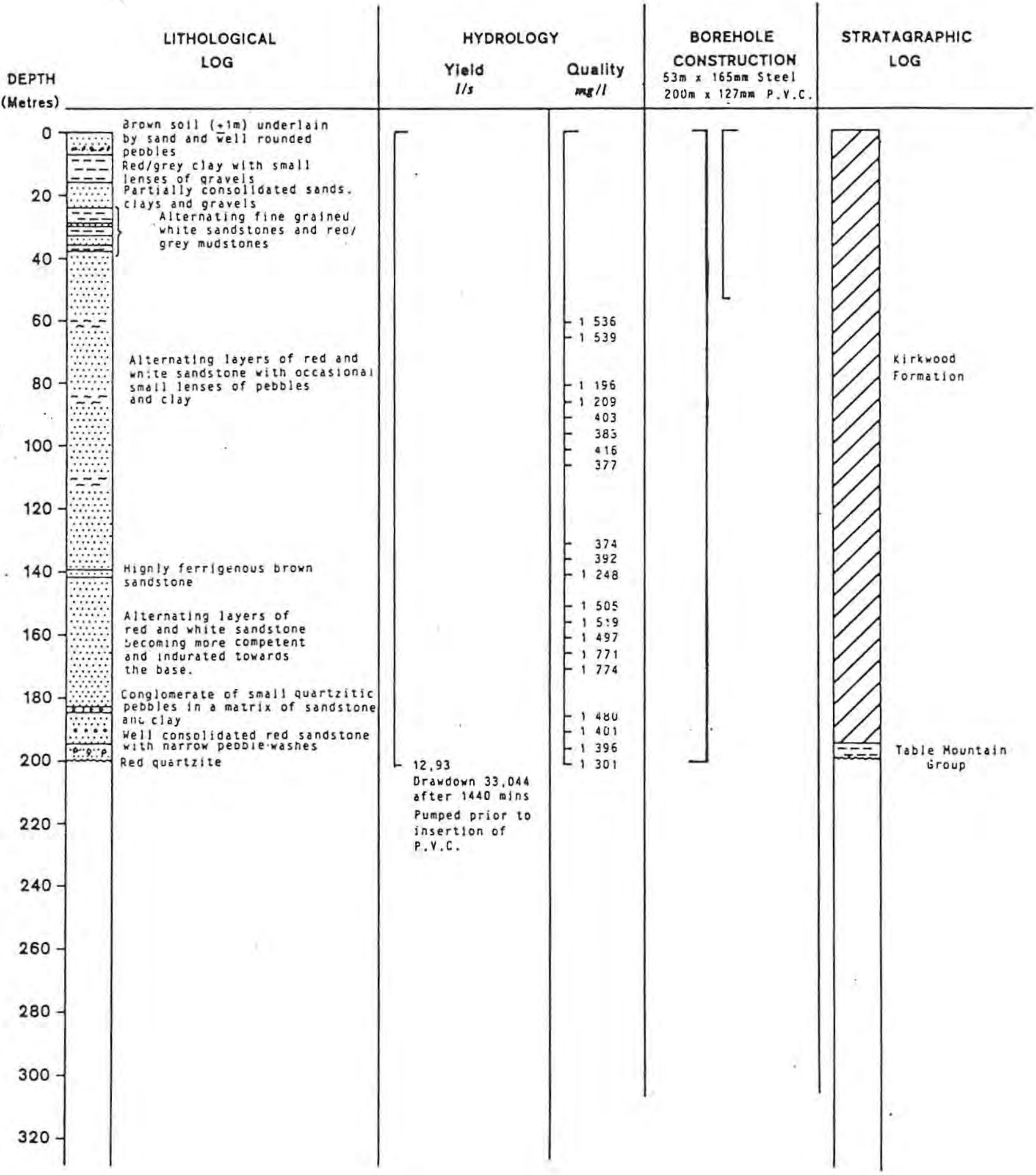
25°19'50"E



BOREHOLE NO: KR 72

DRILL: CABLE-TOOL PERCUSSION

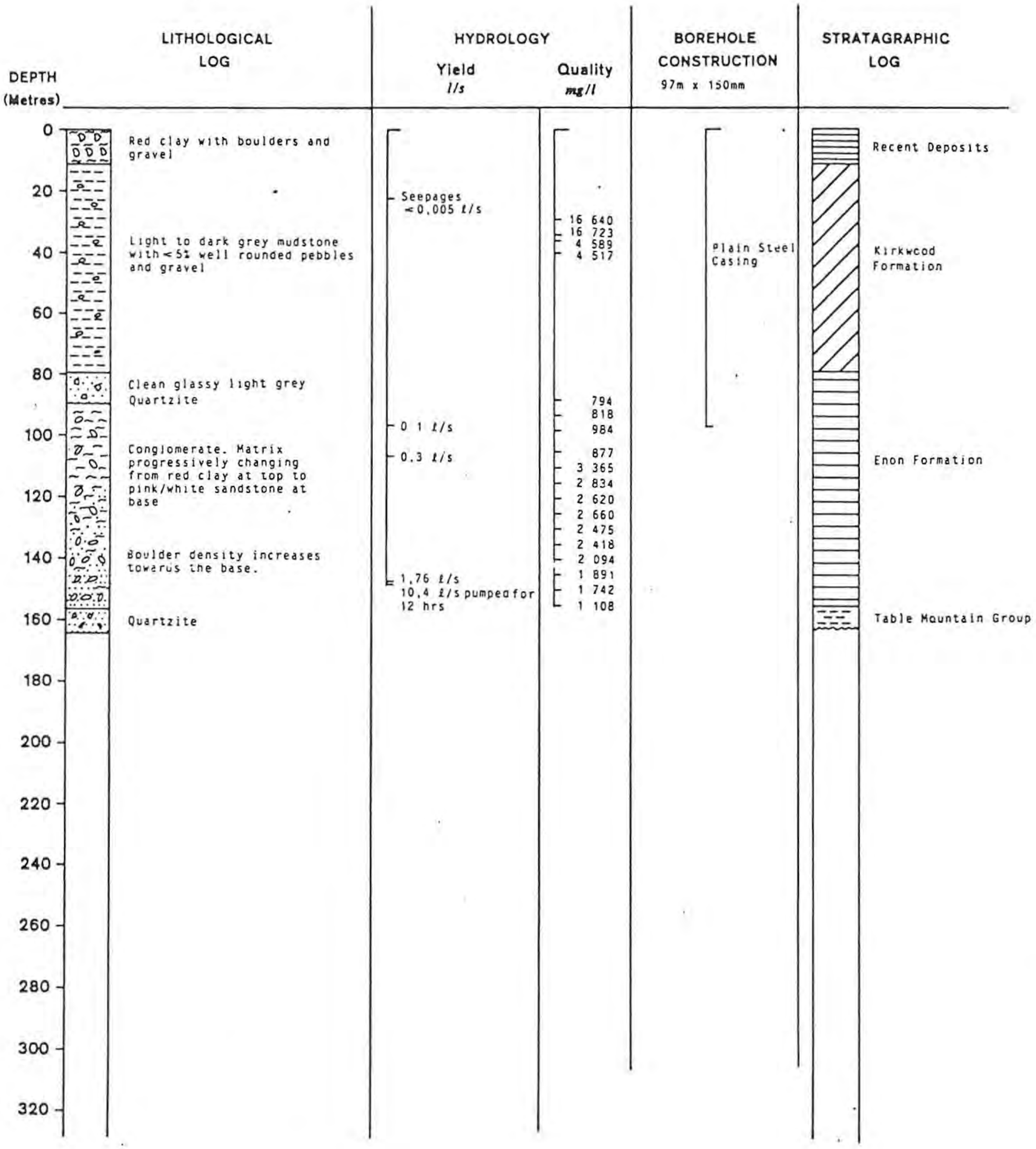
LOCATION: KRUIS RIVER
33°46'15"S
25°19'24"E



BOREHOLE NO: KR 75 G

DRILL: CABLE-TOOL PERCUSSION

LOCATION: KRUIS RIVER
33°46'15"S
25°21'20"E

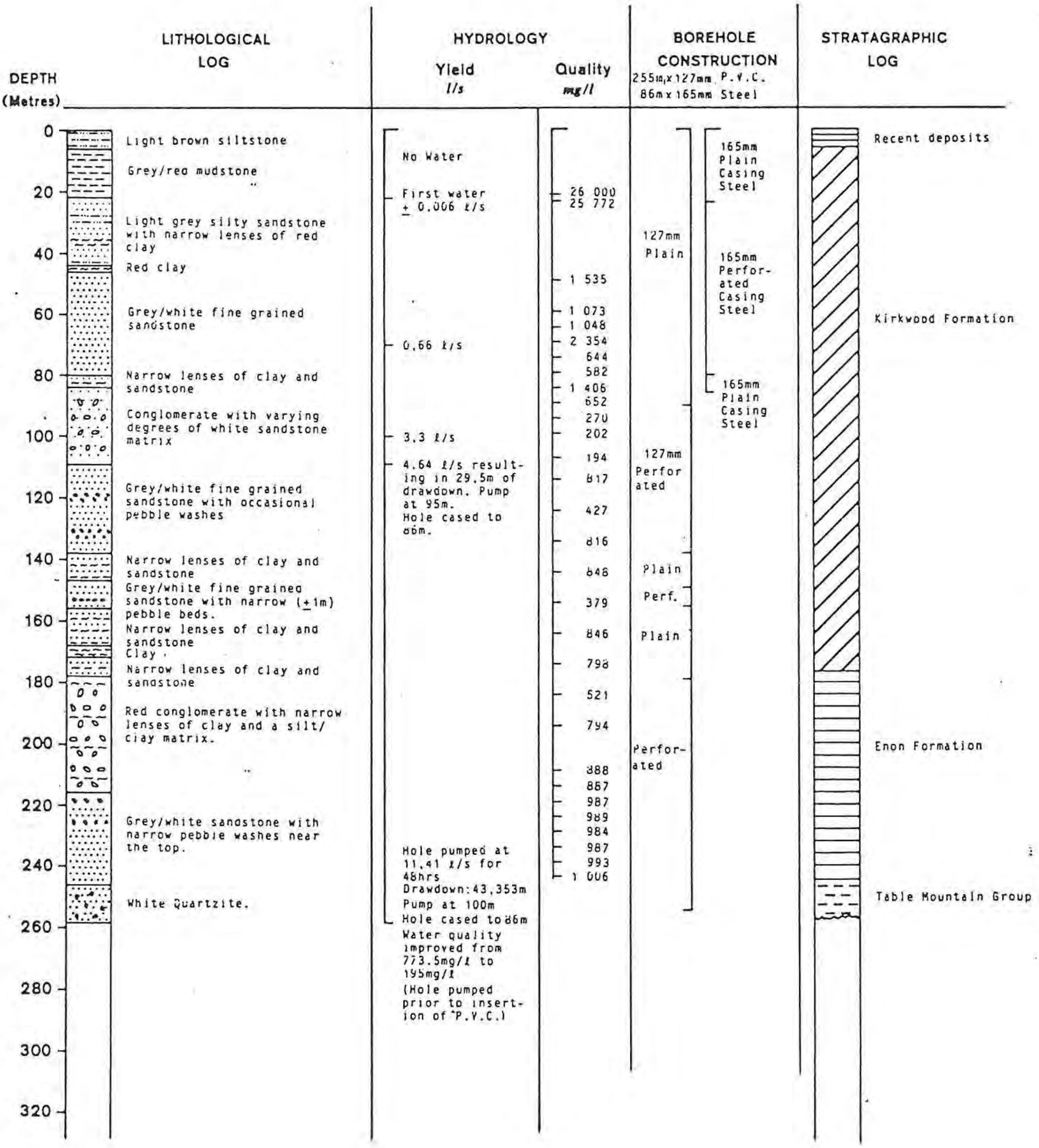


BOREHOLE NO: SN 16

DRILL: AIR ROTARY PERCUSSION TO 110M FOLLOWED BY CABLE TOOL PERCUSSION

LOCATION: KRUIS RIVER

33°44'59"S
25°18'30"E



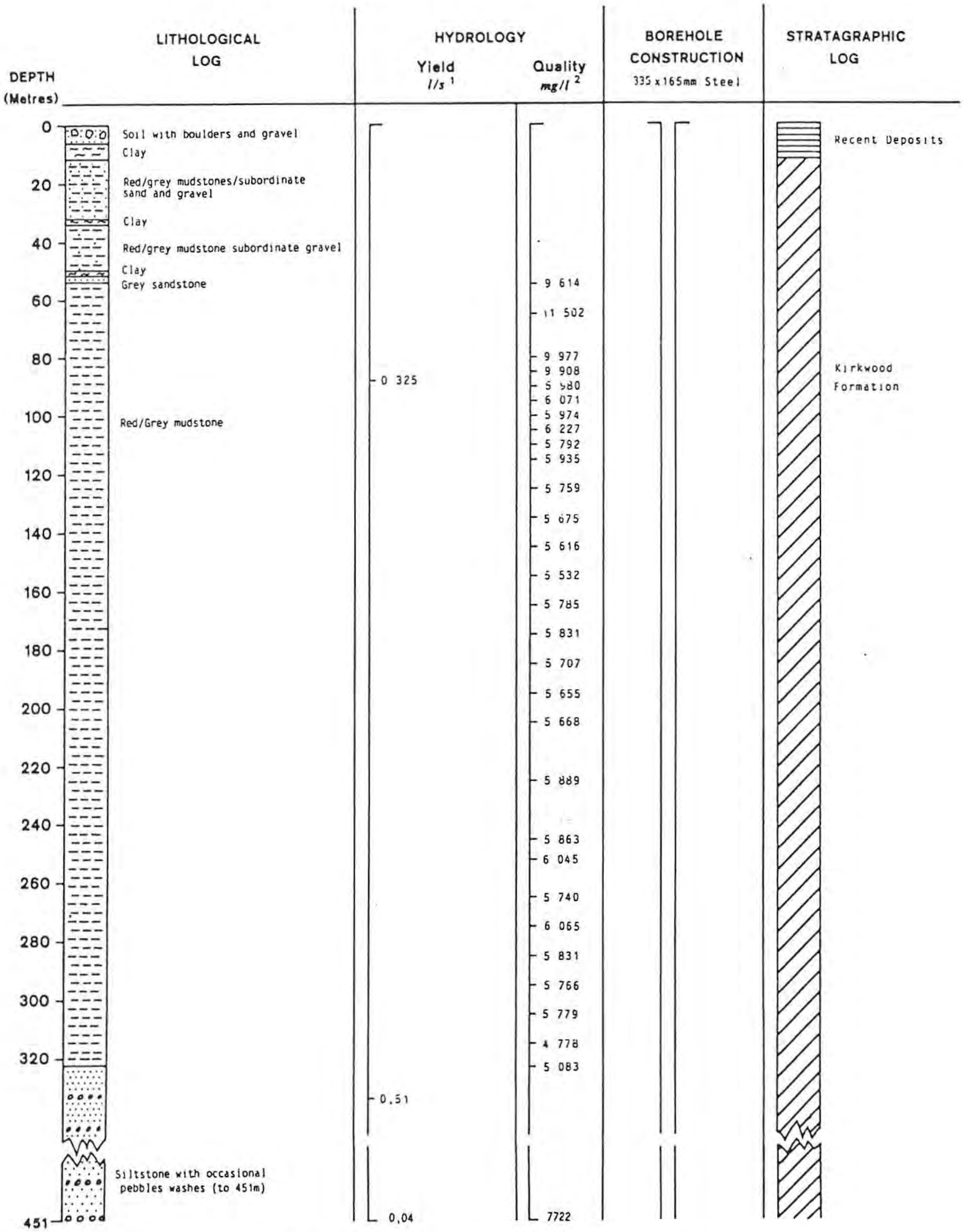
BOREHOLE NO: KM 16

LOCATION: KRUIS RIVER

33°43 56"S

25°21'48"E

DRILL: CABLE-TOOL PERCUSSION



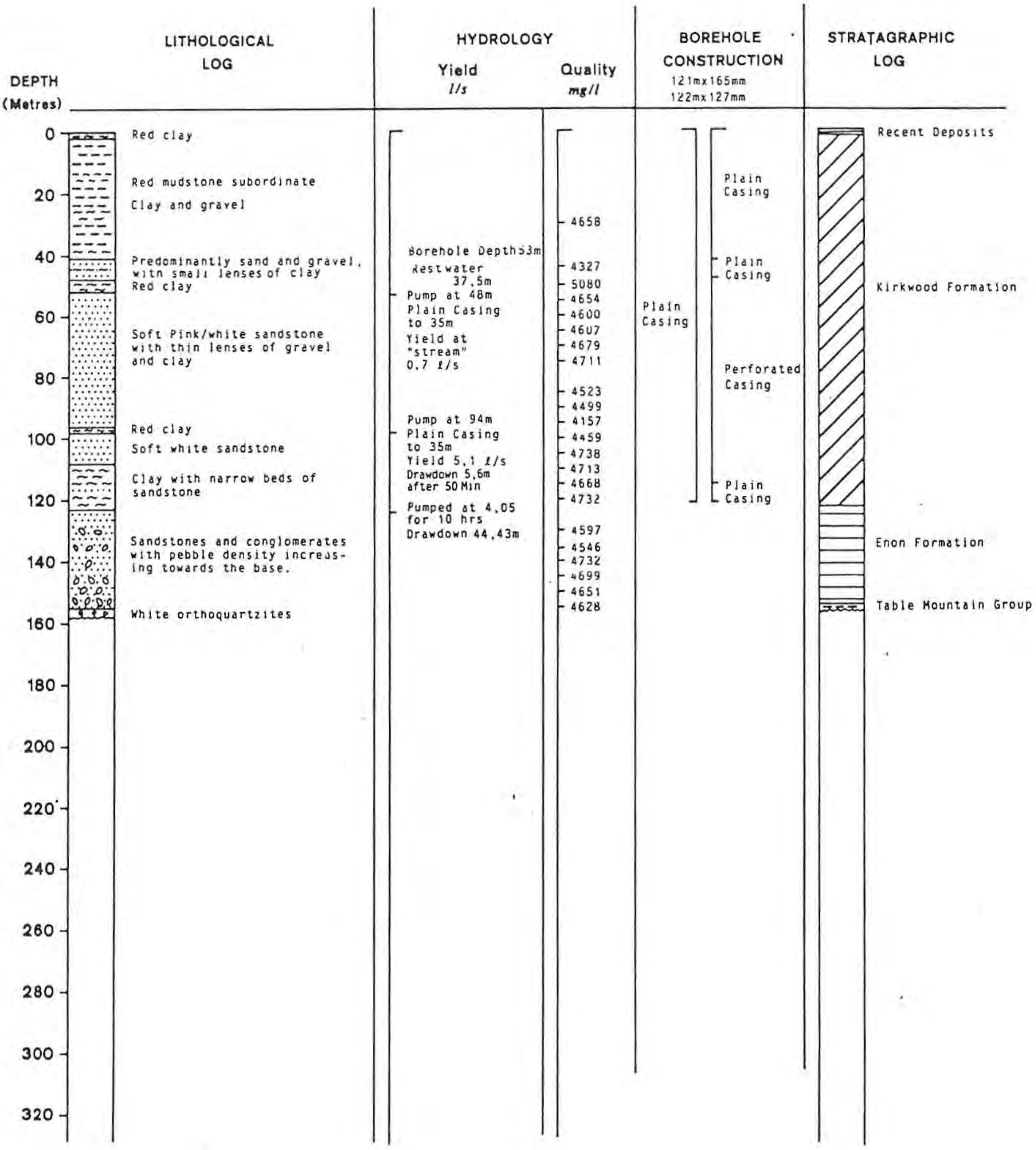
[1] Yield upon drilling indicated opposite depth of borehole at time yield measured.

[2] Quality in mg/ℓ as a calculated approximation from conductivity analysis

BOREHOLE NO: MD 20 G

DRILL: CABLE-TOOL PERCUSSION

LOCATION: KRUIS RIVER
33°48'05"S
25°20 25"E

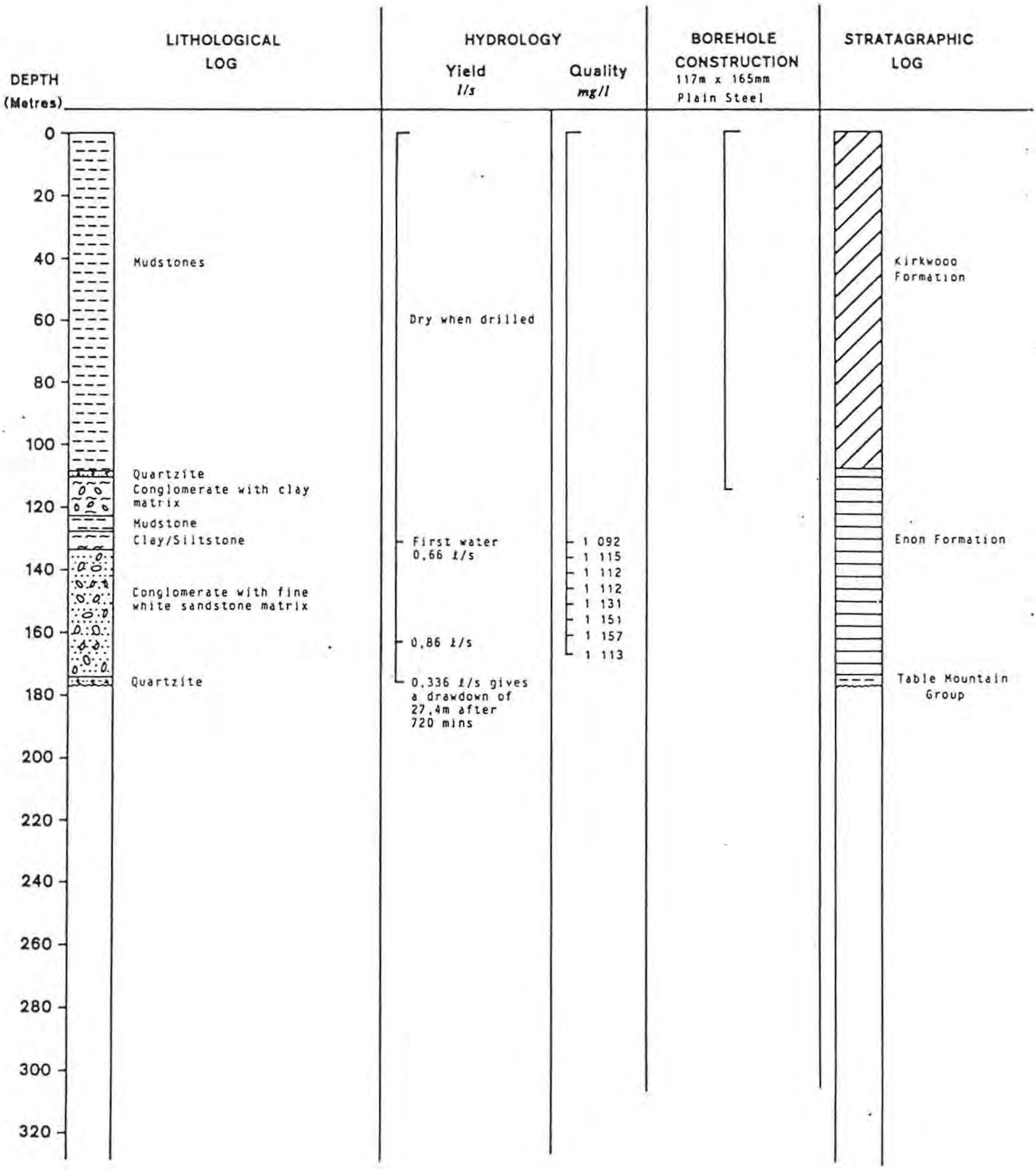


BOREHOLE NO: MO 21G

LOCATION: KRUIS RIVER

33°47'20"S
25°21'52"E

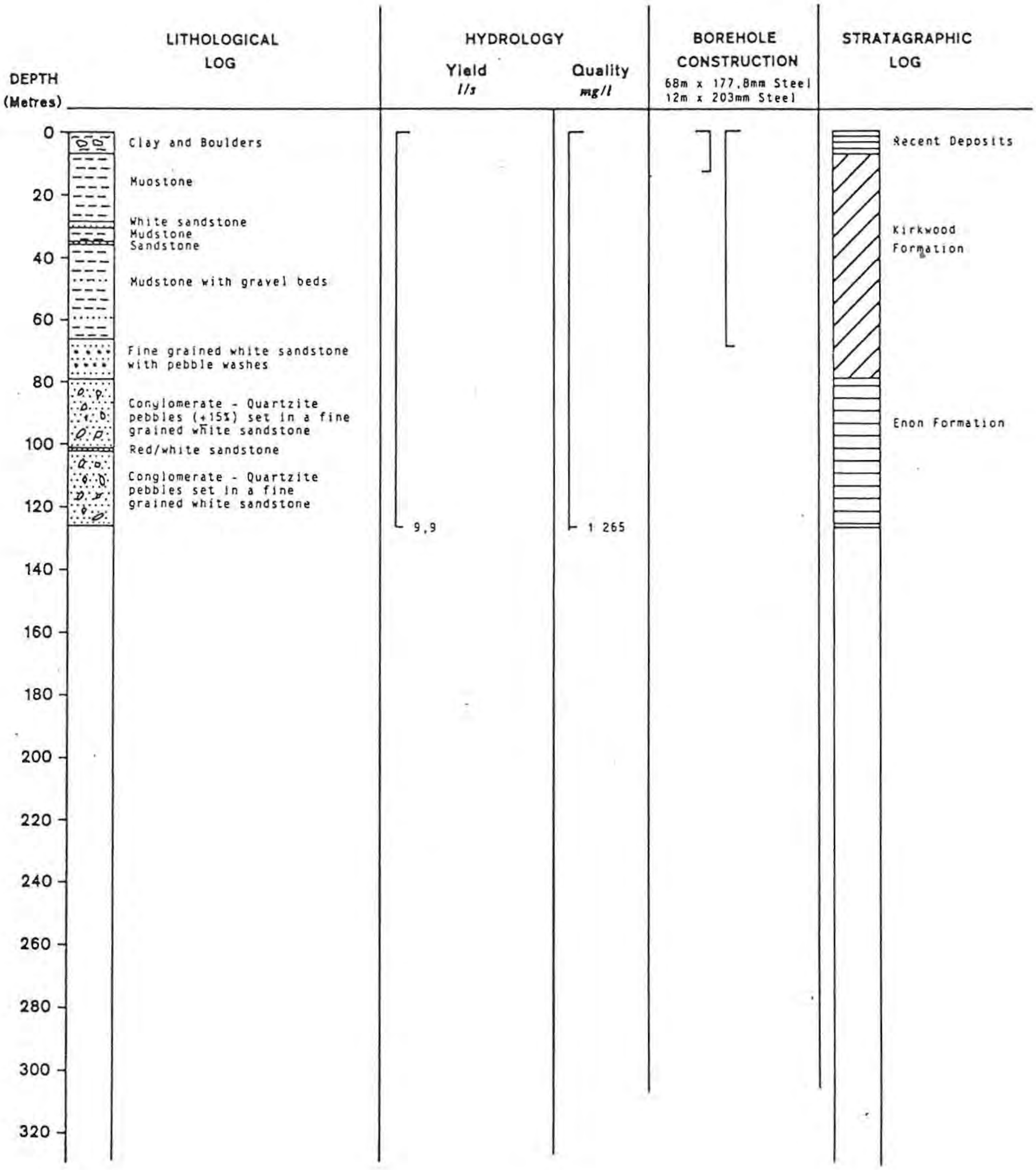
DRILL: AIR ROTARY PERCUSSION AND CABLE-TOOL PERCUSSION



BOREHOLE NO: HW 4B

DRILL: AIR ROTARY PERCUSSION

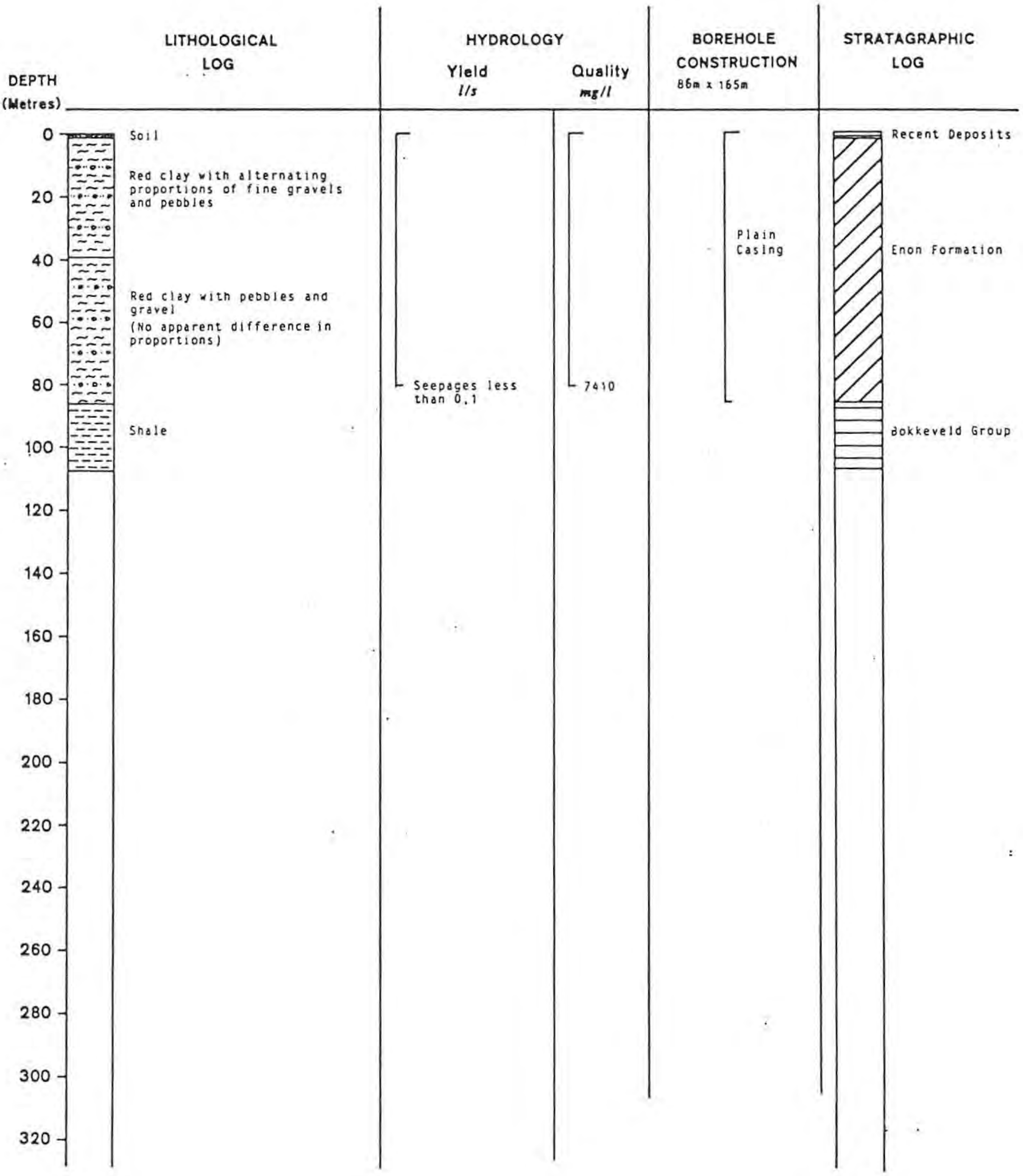
LOCATION: KRUIS RIVER
33°47'00"S
25°19'42"E



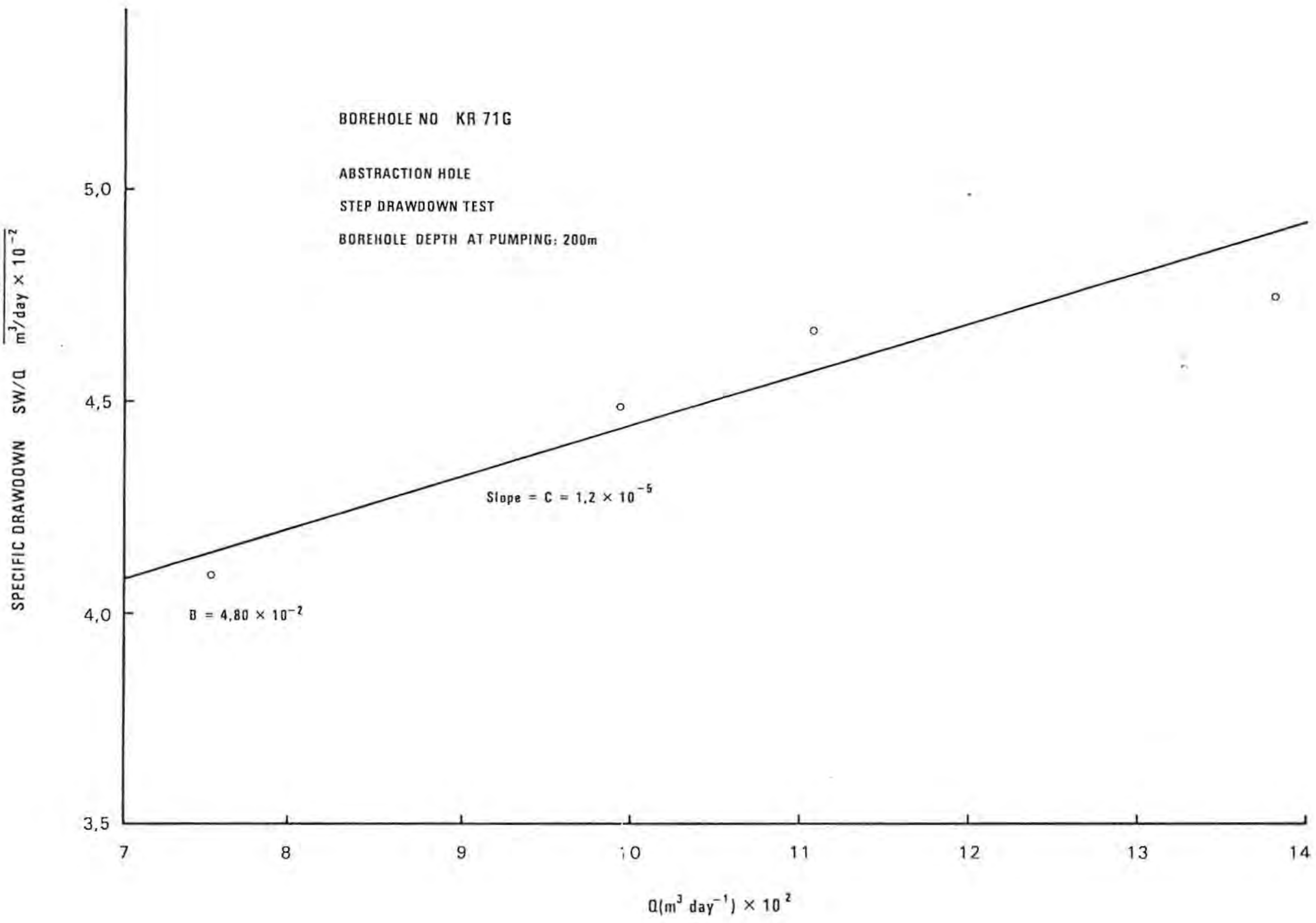
BOREHOLE NO: MW 20G

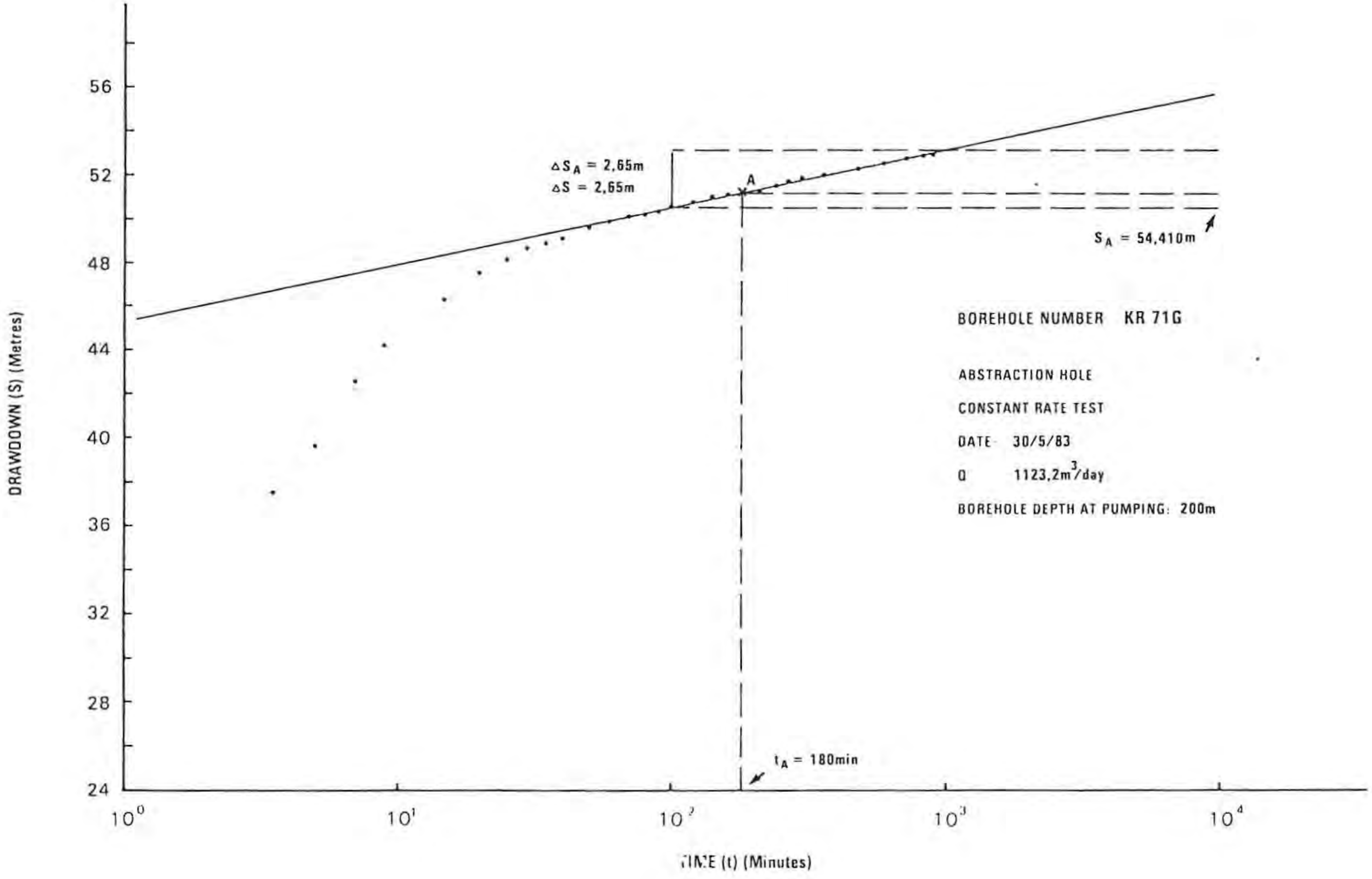
DRILL: CABLE-TOOL PERCUSSION

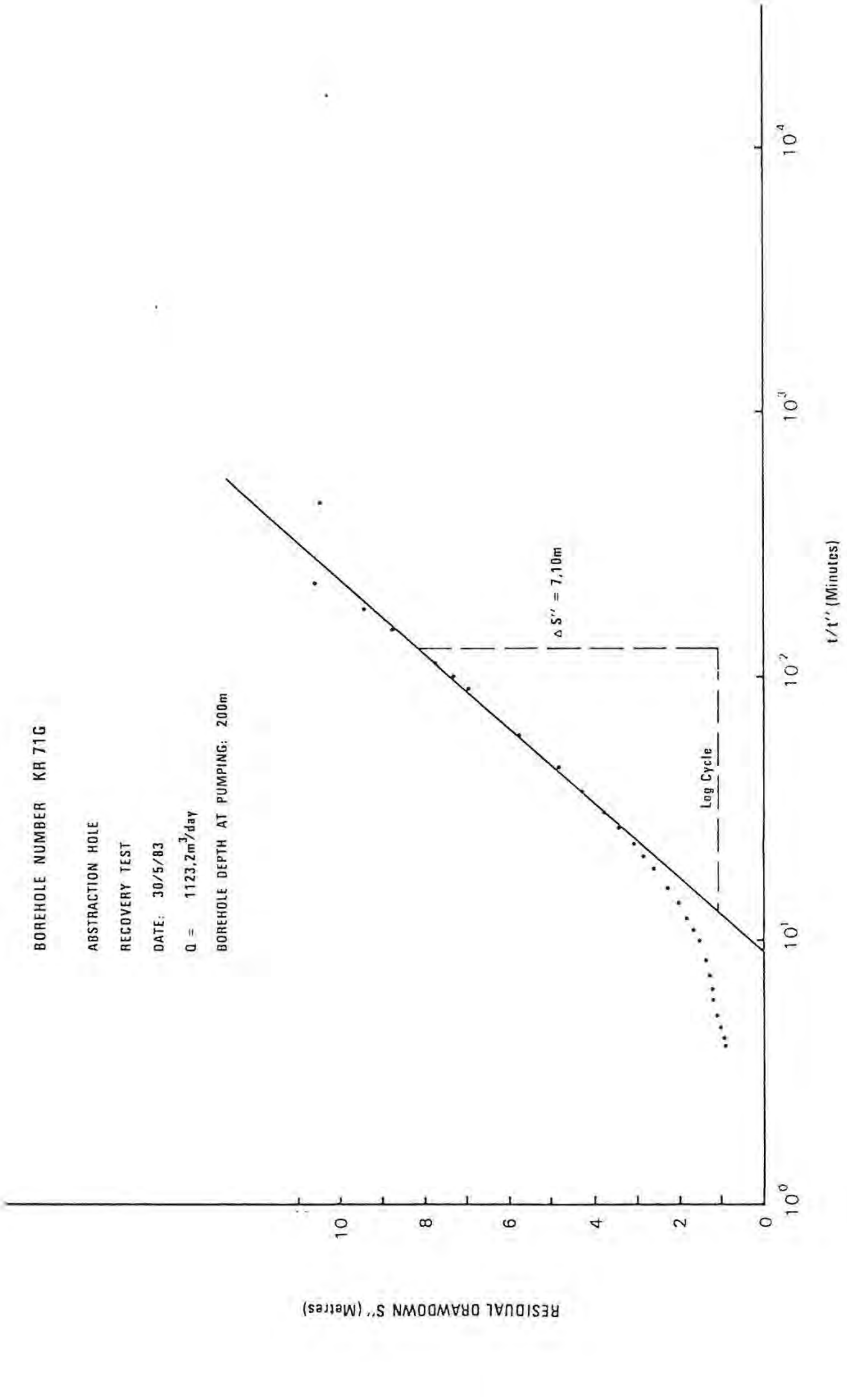
LOCATION: KRUIS RIVER
33°47'30"S
25°20'05"E

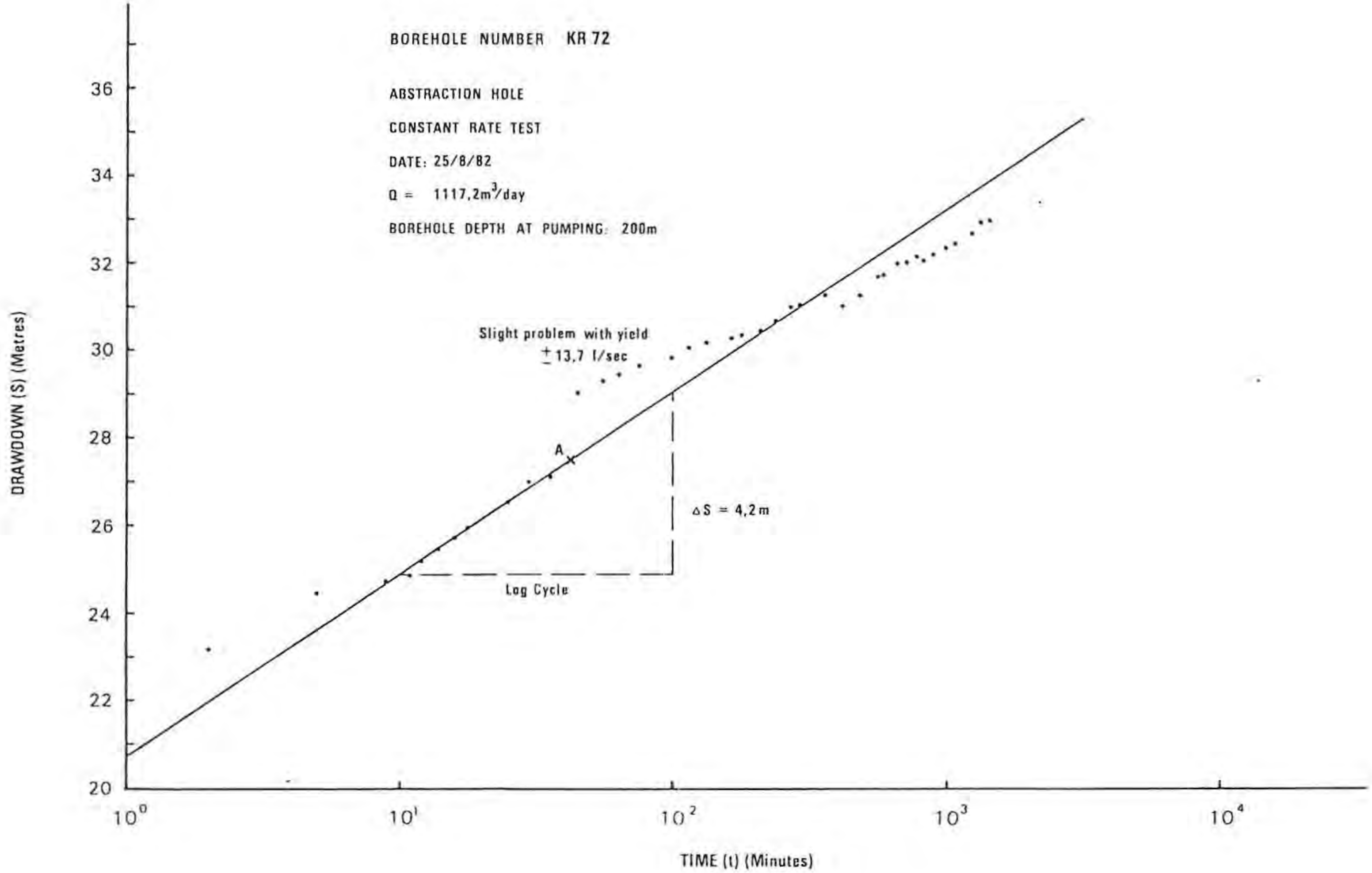


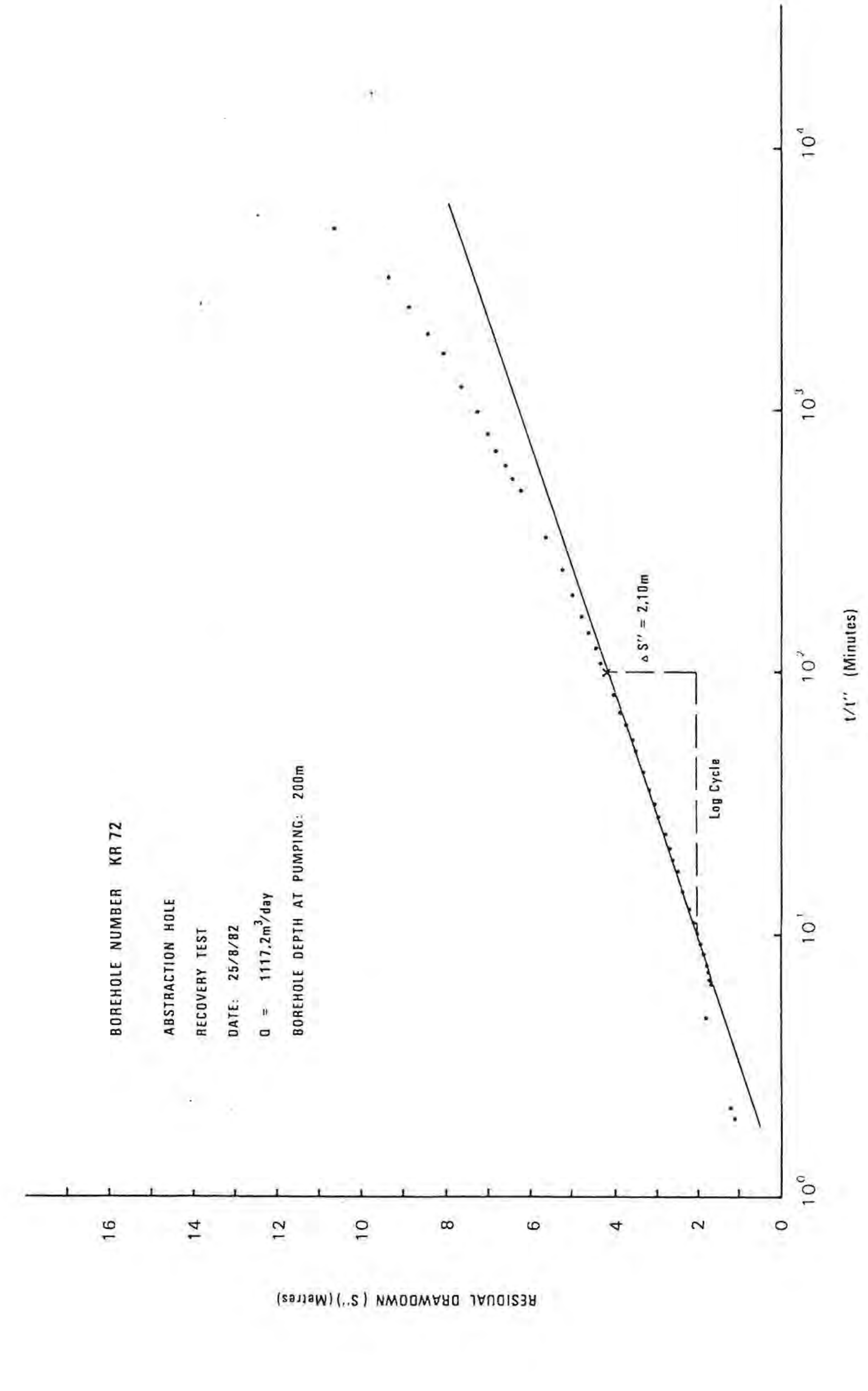
APPENDIX 4
AQUIFER TEST ANALYSES

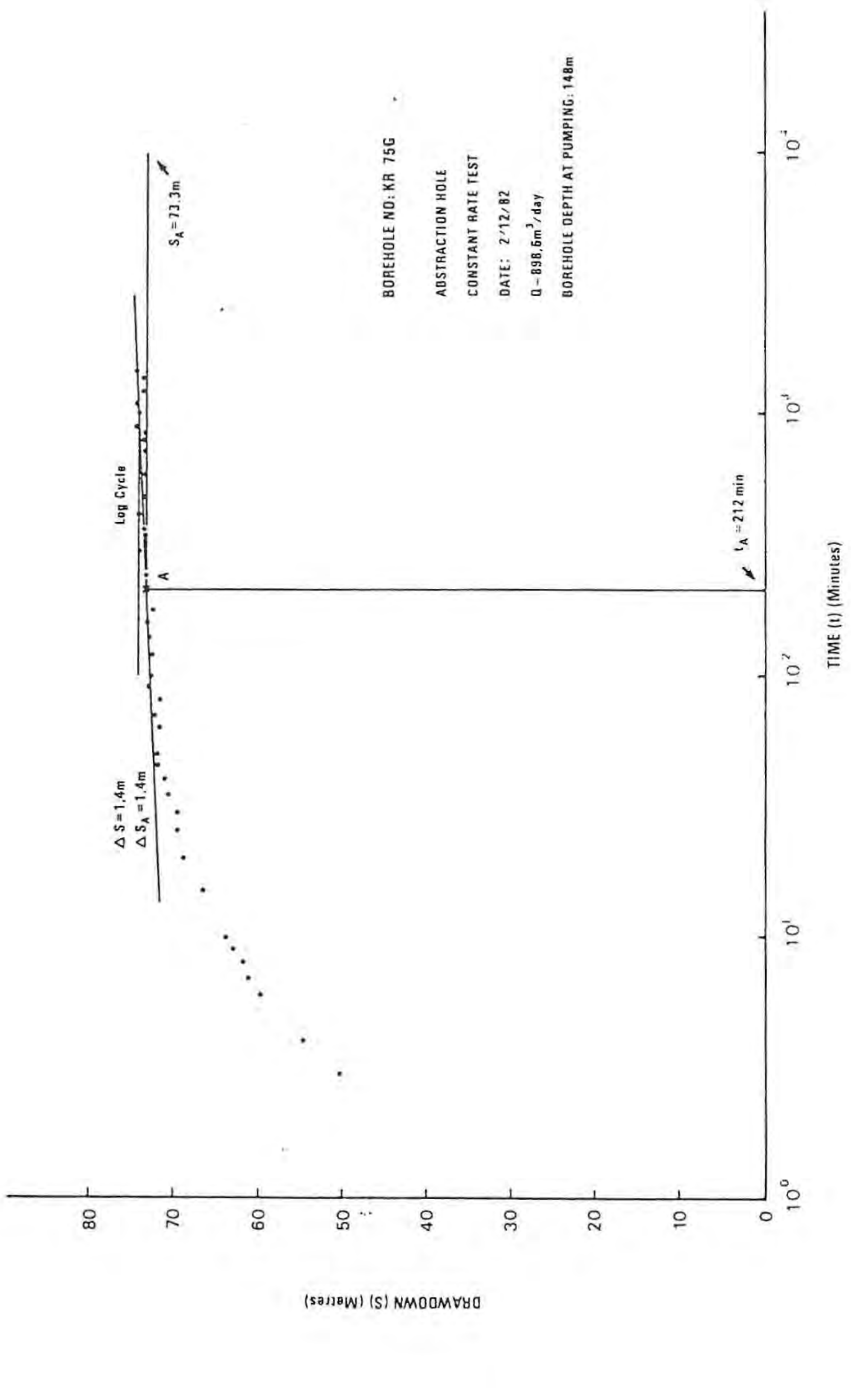

BOREHOLE NO KR 71G
ABSTRACTION HOLE
STEP DRAWDOWN TEST
BOREHOLE DEPTH AT PUMPING: 200m
Slope = C = 1,2 × 10^{-5}
B = 4,80 × 10^{-2}
SPECIFIC DRAWDOWN SW/Q $\frac{m}{m^3/day} \times 10^{-2}$
5,0
4,5
4,0
3,5
7
8
9
10
11
12
13
14
Q(m^3 day^{-1}) × 10^2

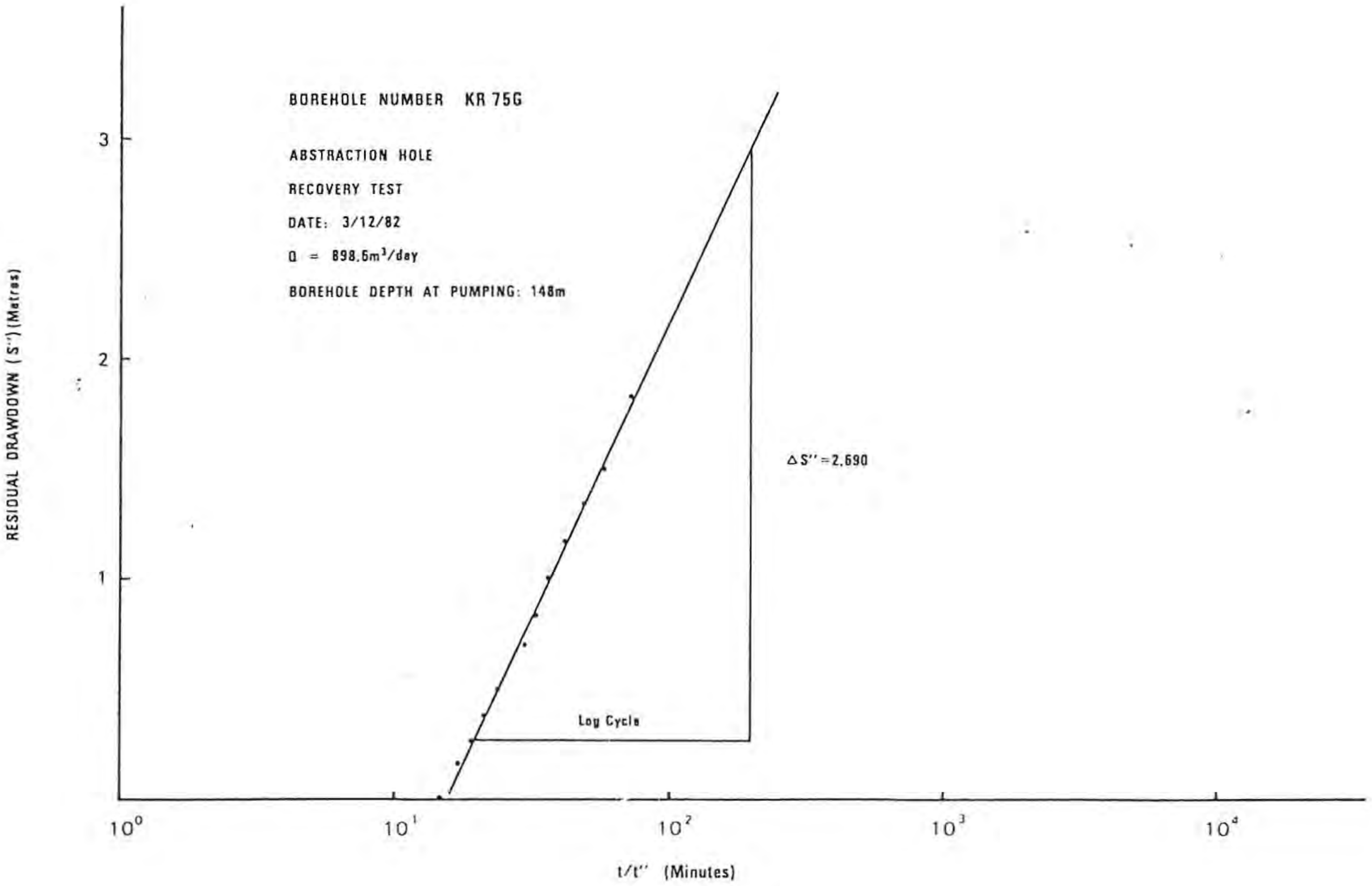

DRAWDOWN (S) (Metres)
56
52
48
44
40
36
32
28
24
10^0
10^1
10^2
10^3
10^4
TIME (t) (Minutes)
ΔS_A = 2,65m
ΔS = 2,65m
A
S_A = 54,410m
t_A = 180min
BOREHOLE NUMBER KR 71G
ABSTRACTION HOLE
CONSTANT RATE TEST
DATE 30/5/83
Q 1123,2m^3/day
BOREHOLE DEPTH AT PUMPING: 200m

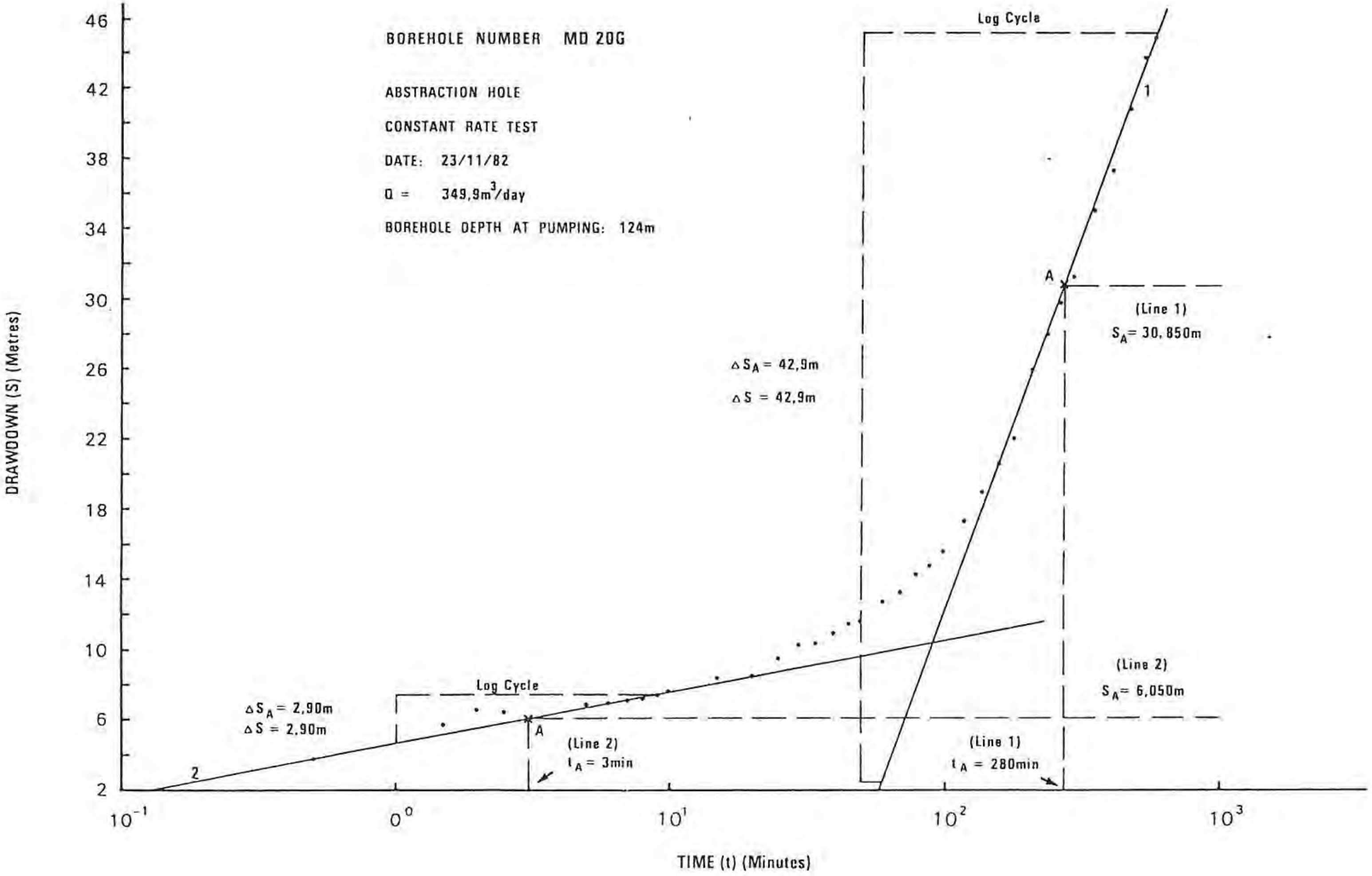

BOREHOLE NUMBER KR 71G
ABSTRACTION HOLE
RECOVERY TEST
DATE: 30/5/83
Q = 1123,2m³/day
BOREHOLE DEPTH AT PUMPING: 200m
Δ S'' = 7,10m
Log Cycle
RESIDUAL DRAWDOWN S'' (Metres)
0
2
4
6
8
10
t/t'' (Minutes)
10⁰
10¹
10²
10³
10⁴

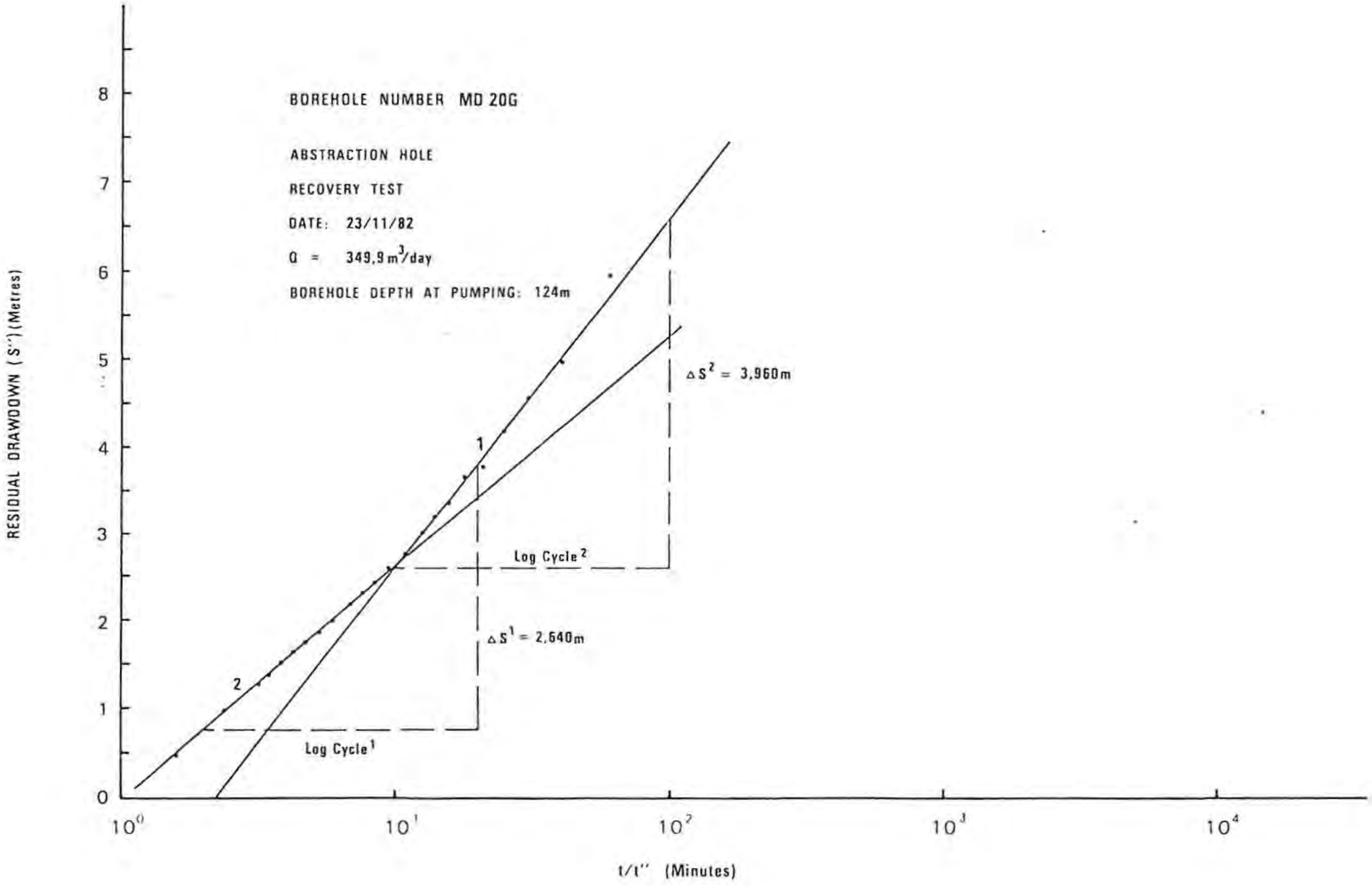

BOREHOLE NUMBER KR 72
ABSTRACTION HOLE
CONSTANT RATE TEST
DATE: 25/8/82
Q = 1117,2m³/day
BOREHOLE DEPTH AT PUMPING: 200m
Slight problem with yield
± 13,7 l/sec
A
ΔS = 4,2 m
Log Cycle
DRAWDOWN (S) (Metres)
36
34
32
30
28
26
24
22
20
TIME (t) (Minutes)
10⁰
10¹
10²
10³
10⁴

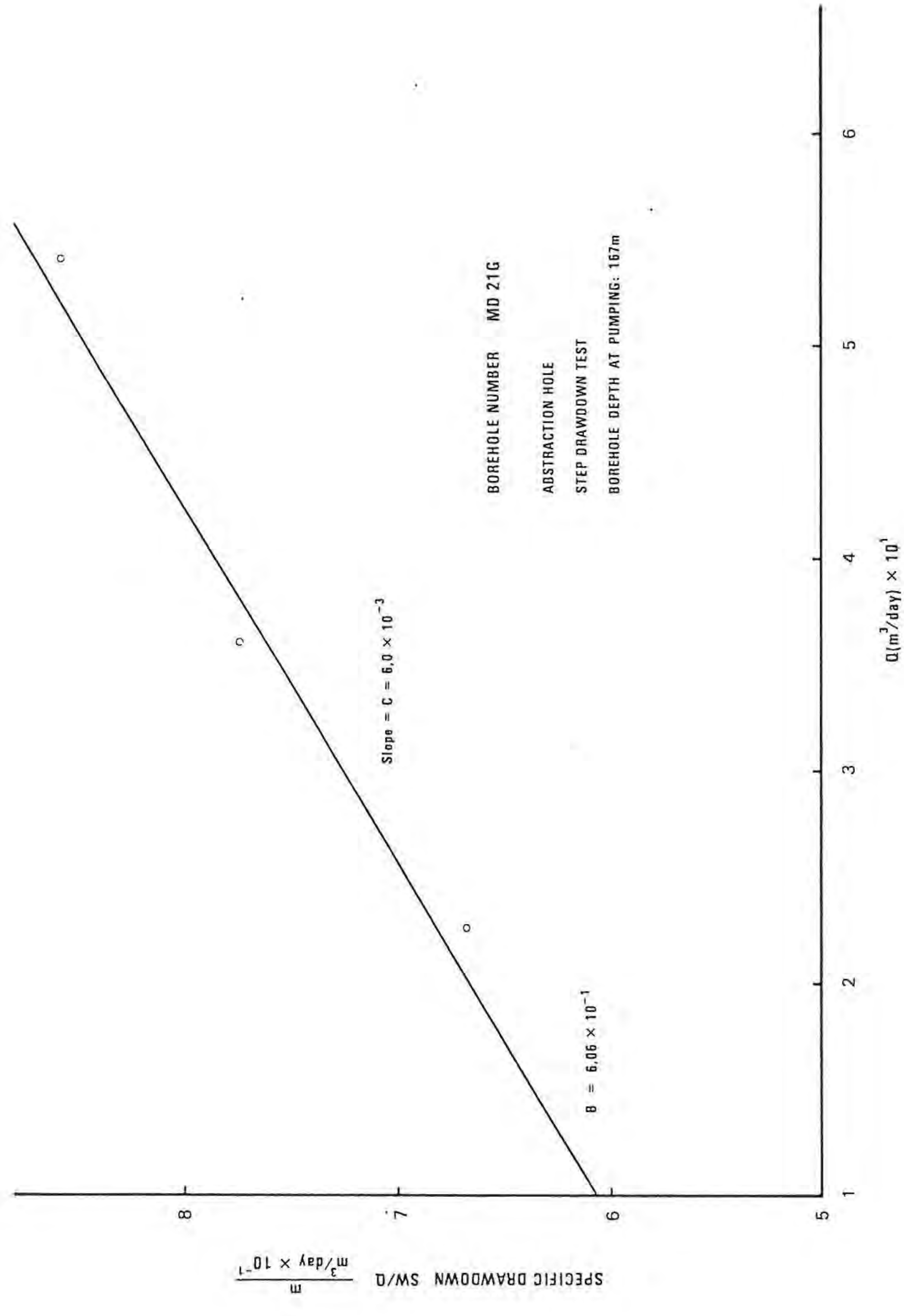

BOREHOLE NUMBER KR 72
ABSTRACTION HOLE
RECOVERY TEST
DATE: 25/8/82
Q = 1117,2m^3/day
BOREHOLE DEPTH AT PUMPING: 200m
Δ S'' = 2,10m
Log Cycle
RESIDUAL DRAWDOWN (S'')(Metres)
0
2
4
6
8
10
12
14
16
10^0
10^1
10^2
10^3
10^4
t/t'' (Minutes)

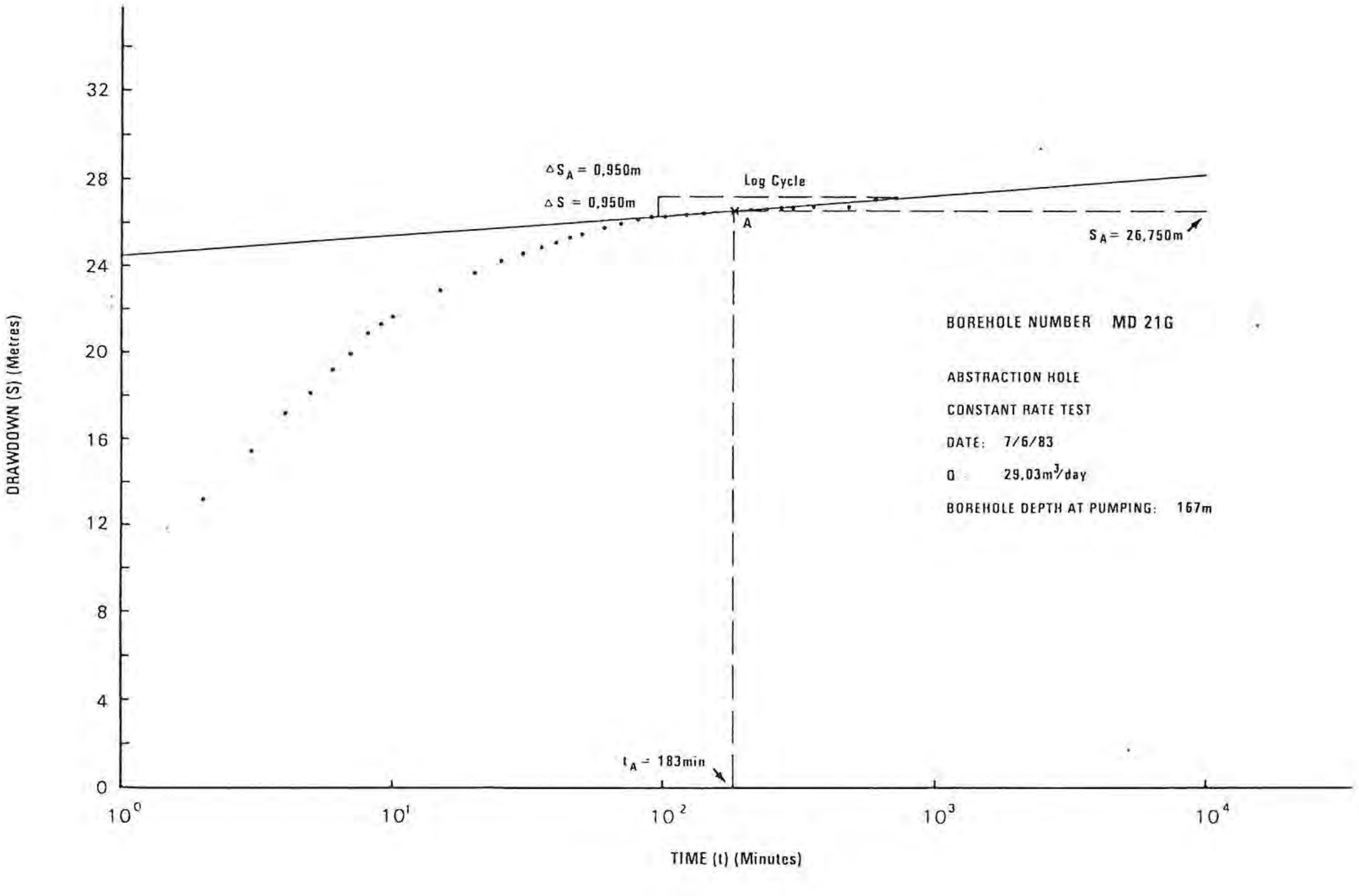

BOREHOLE NO: KR 75G
ABSTRACTION HOLE
CONSTANT RATE TEST
DATE: 2/12/82
Q - 898,6m³/day
BOREHOLE DEPTH AT PUMPING: 148m
S_A = 73.3m
Log Cycle
Δ S = 1,4m
Δ S_A = 1,4m
A
t_A = 212 min
TIME (t) (Minutes)
10⁰
10¹
10²
10³
10⁴
DRAWDOWN (S) (Metres)
0
10
20
30
40
50
60
70
80

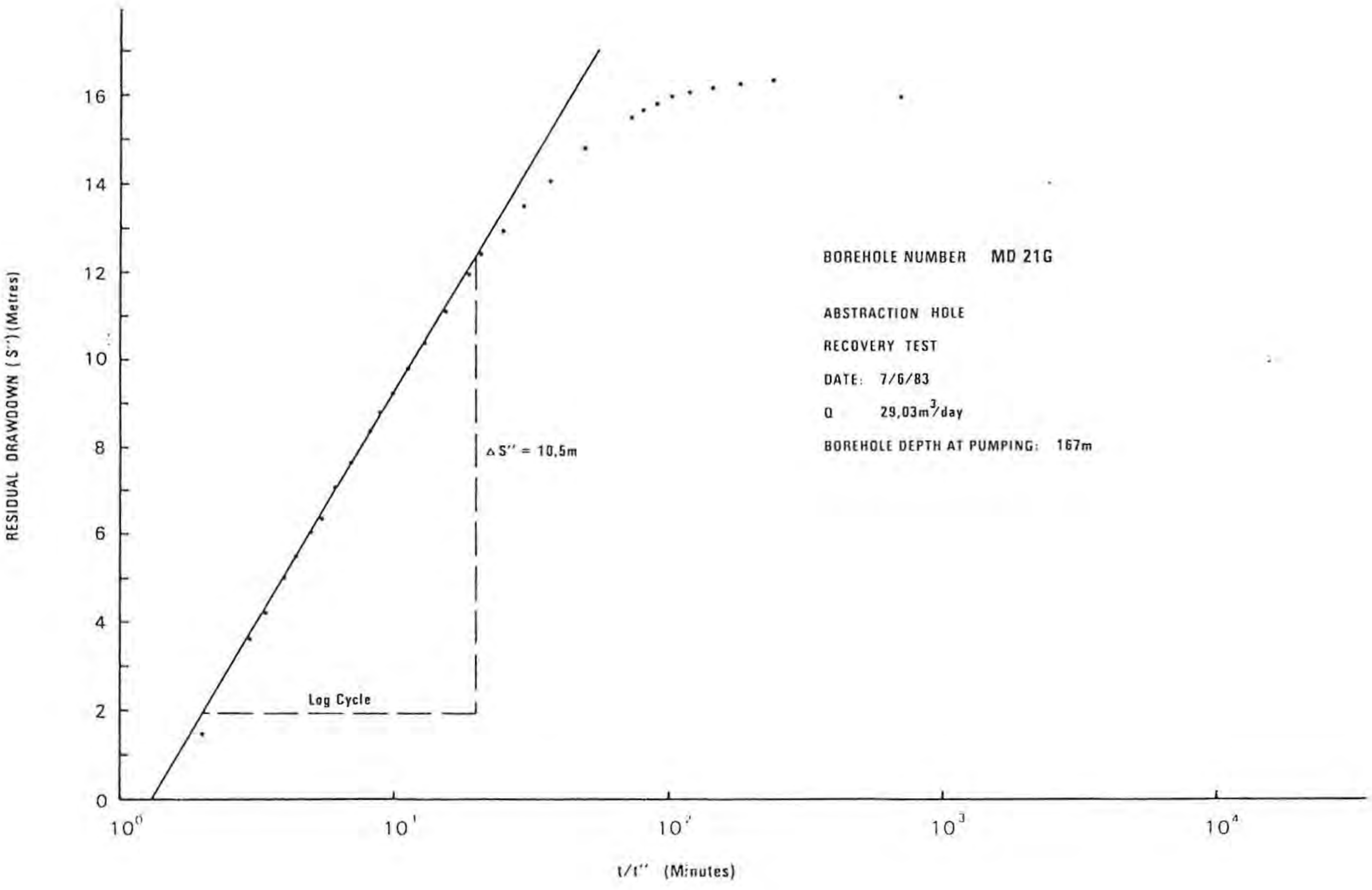

BOREHOLE NUMBER KR 75G
ABSTRACTION HOLE
RECOVERY TEST
DATE: 3/12/82
Q = 898.6m³/day
BOREHOLE DEPTH AT PUMPING: 148m
ΔS'' = 2.690
Log Cycle
RESIDUAL DRAWDOWN (S'') (Metres)
3
2
1
10⁰
10¹
10²
10³
10⁴
t/t'' (Minutes)


BOREHOLE NUMBER MD 20G
ABSTRACTION HOLE
CONSTANT RATE TEST
DATE: 23/11/82
Q = 349,9m³/day
BOREHOLE DEPTH AT PUMPING: 124m
Log Cycle
1
A
(Line 1)
S_A= 30,850m
ΔS_A = 42,9m
ΔS = 42,9m
(Line 2)
S_A= 6,050m
Log Cycle
ΔS_A = 2,90m
ΔS = 2,90m
2
A
(Line 2)
t_A = 3min
(Line 1)
t_A = 280min
DRAWDOWN (S) (Metres)
46
42
38
34
30
26
22
18
14
10
6
2
10^{-1}
10^0
10^1
10^2
10^3
TIME (t) (Minutes)


BOREHOLE NUMBER MD 20G
ABSTRACTION HOLE
RECOVERY TEST
DATE: 23/11/82
Q = 349,9 m^3/day
BOREHOLE DEPTH AT PUMPING: 124m
RESIDUAL DRAWDOWN (S'') (Metres)
0
1
2
3
4
5
6
7
8
10^0
10^1
10^2
10^3
10^4
t/t'' (Minutes)
1
2
Log Cycle 1
Log Cycle 2
ΔS^1 = 2,640m
ΔS^2 = 3,960m


BOREHOLE NUMBER MD 21G
ABSTRACTION HOLE
STEP DRAWDOWN TEST
BOREHOLE DEPTH AT PUMPING: 167m
Slope = C = 6,0 × 10^{-3}
B = 6,06 × 10^{-1}
Q(m^3/day) × 10^1
SPECIFIC DRAWDOWN SW/Q $\frac{m}{m^3/day}$ × 10^{-1}
1
2
3
4
5
6
5
6
7
8


$\Delta S_A = 0,950m$
$\Delta S = 0,950m$
Log Cycle
A
$S_A = 26,750m$
BOREHOLE NUMBER MD 21G
ABSTRACTION HOLE
CONSTANT RATE TEST
DATE: 7/6/83
Q 29,03m³/day
BOREHOLE DEPTH AT PUMPING: 167m
$t_A = 183min$
DRAWDOWN (S) (Metres)
0
4
8
12
16
20
24
28
32
TIME (t) (Minutes)
10^0
10^1
10^2
10^3
10^4



BOREHOLE NUMBER MD 21G

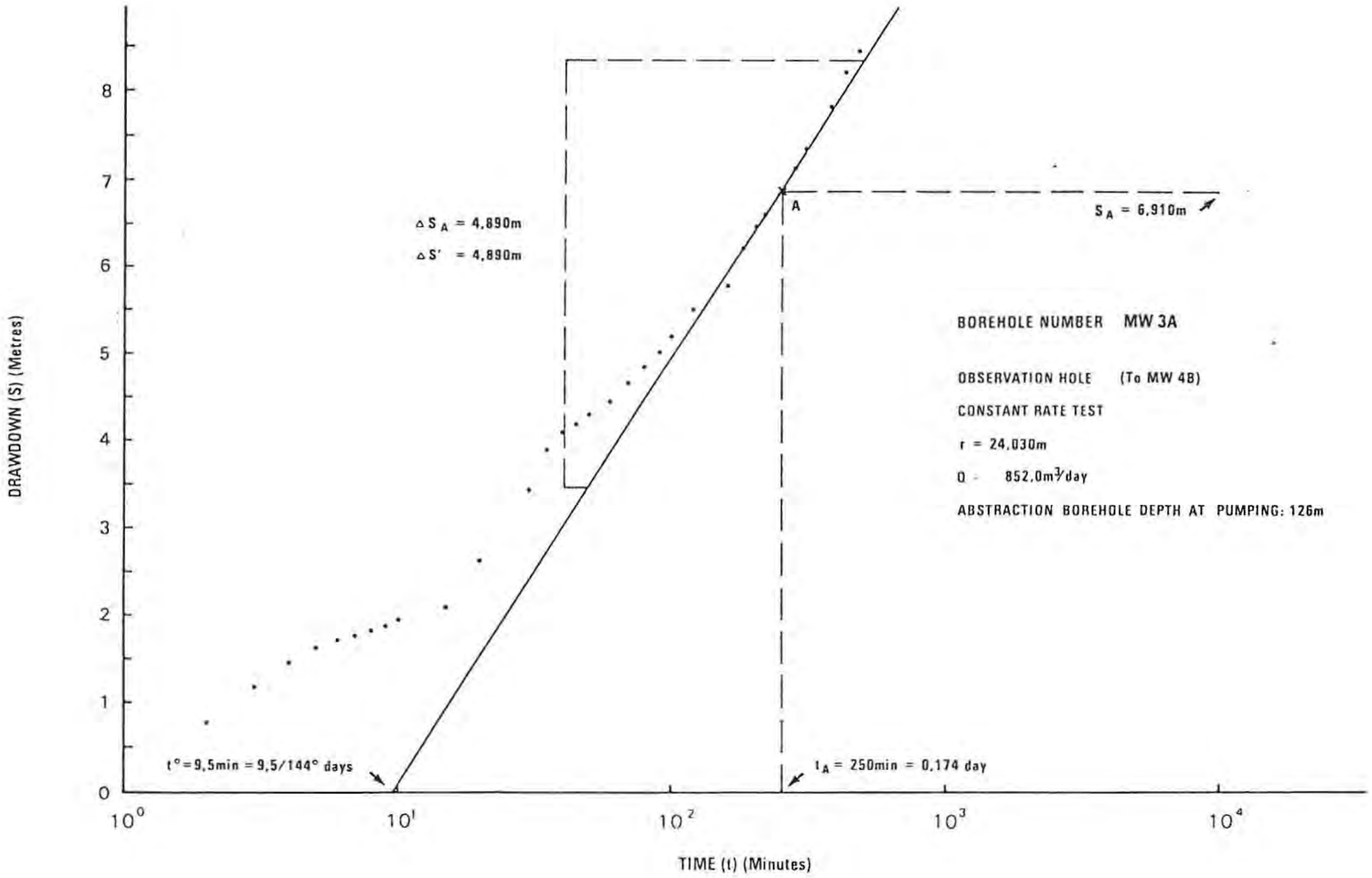
ABSTRACTION HOLE

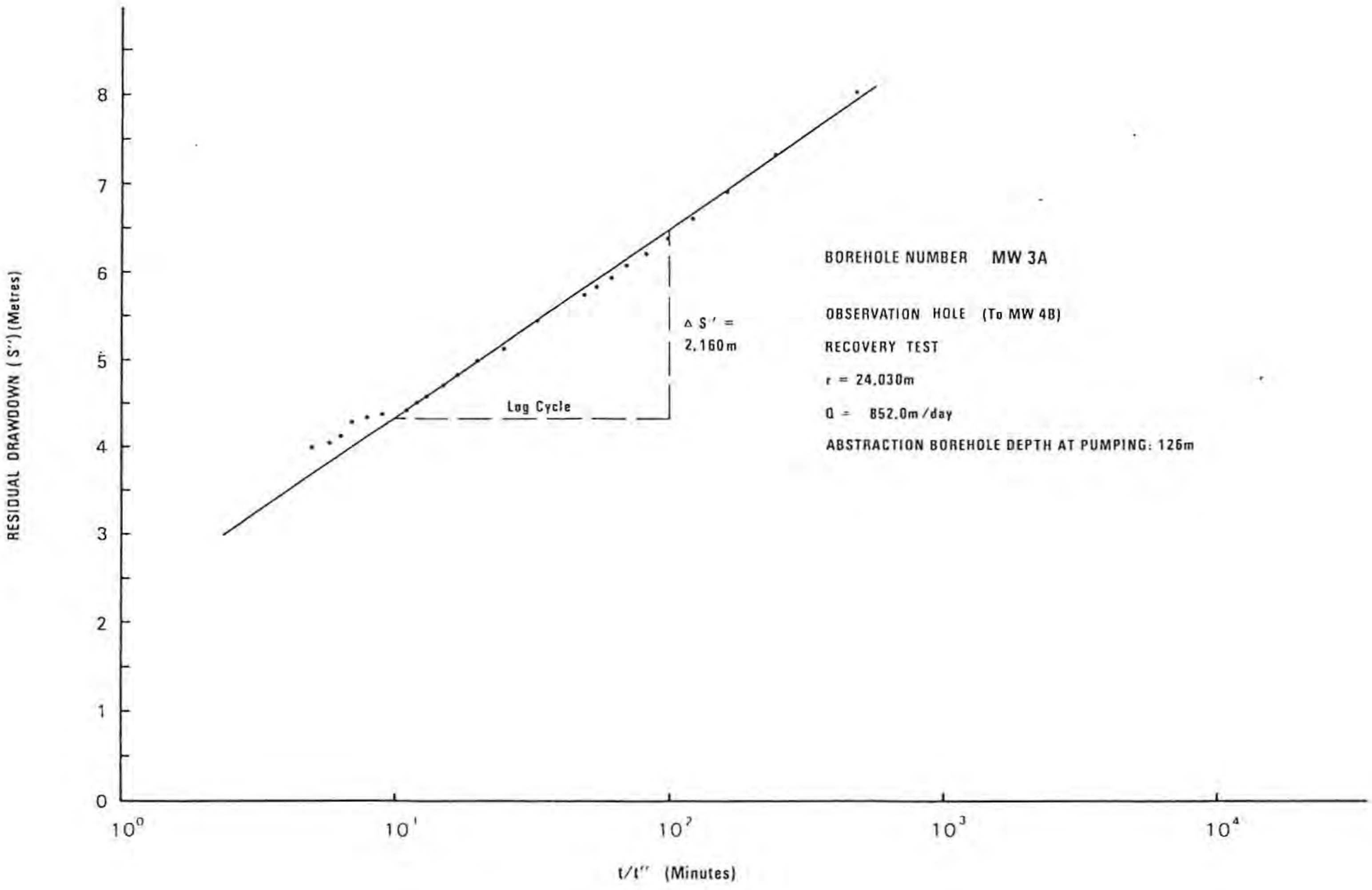
RECOVERY TEST

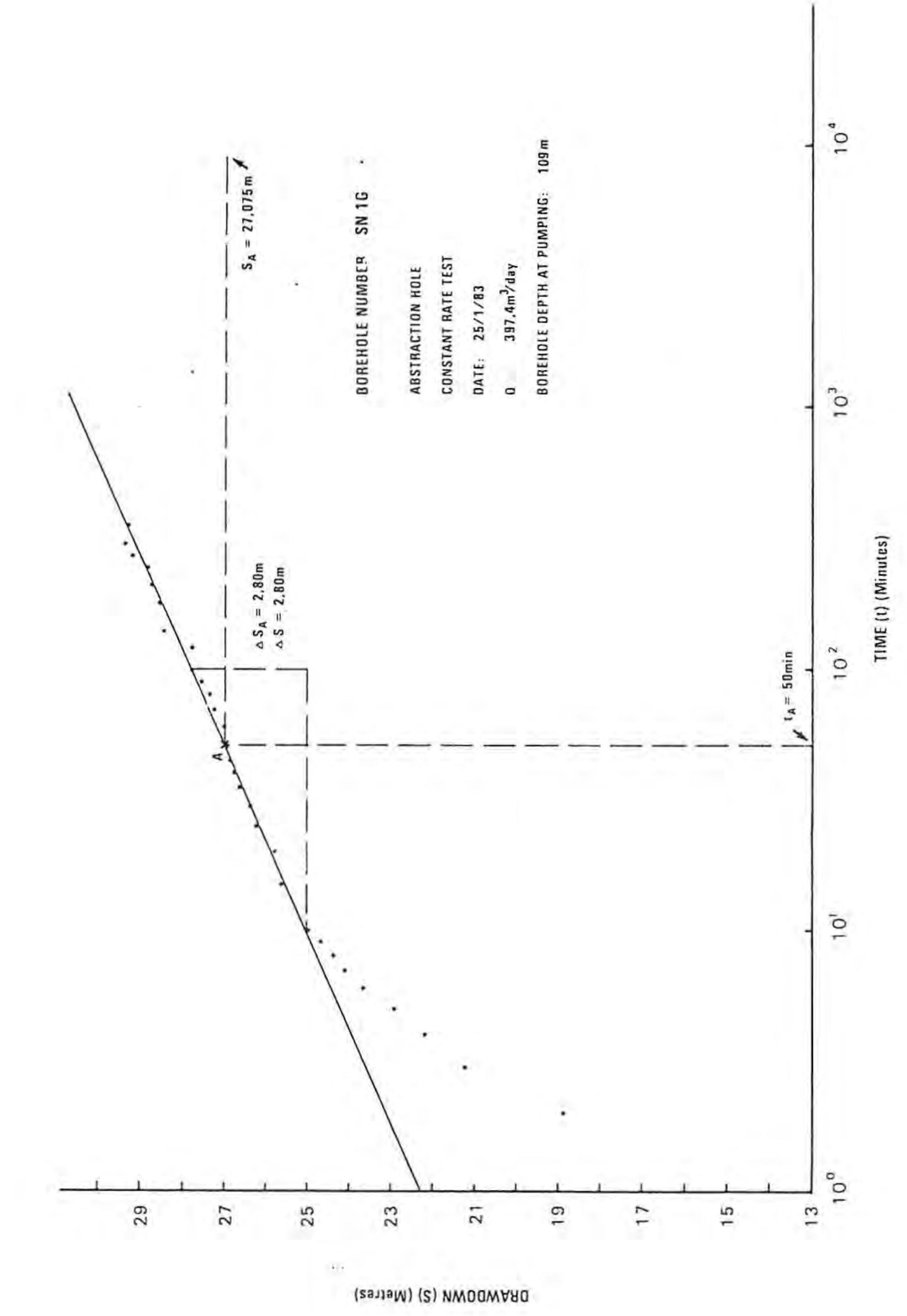
DATE: 7/6/83

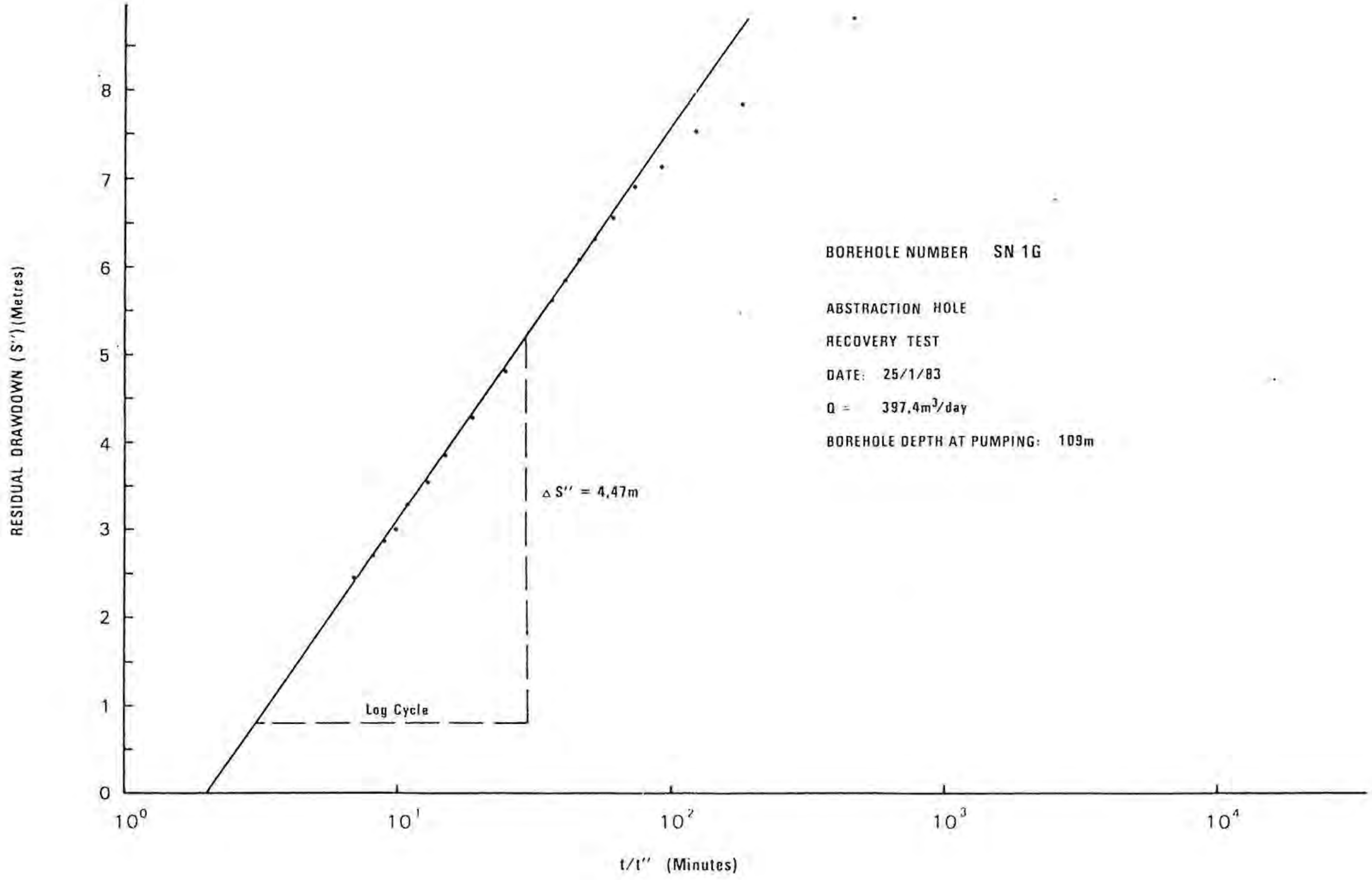
Q 29,03m^3/day

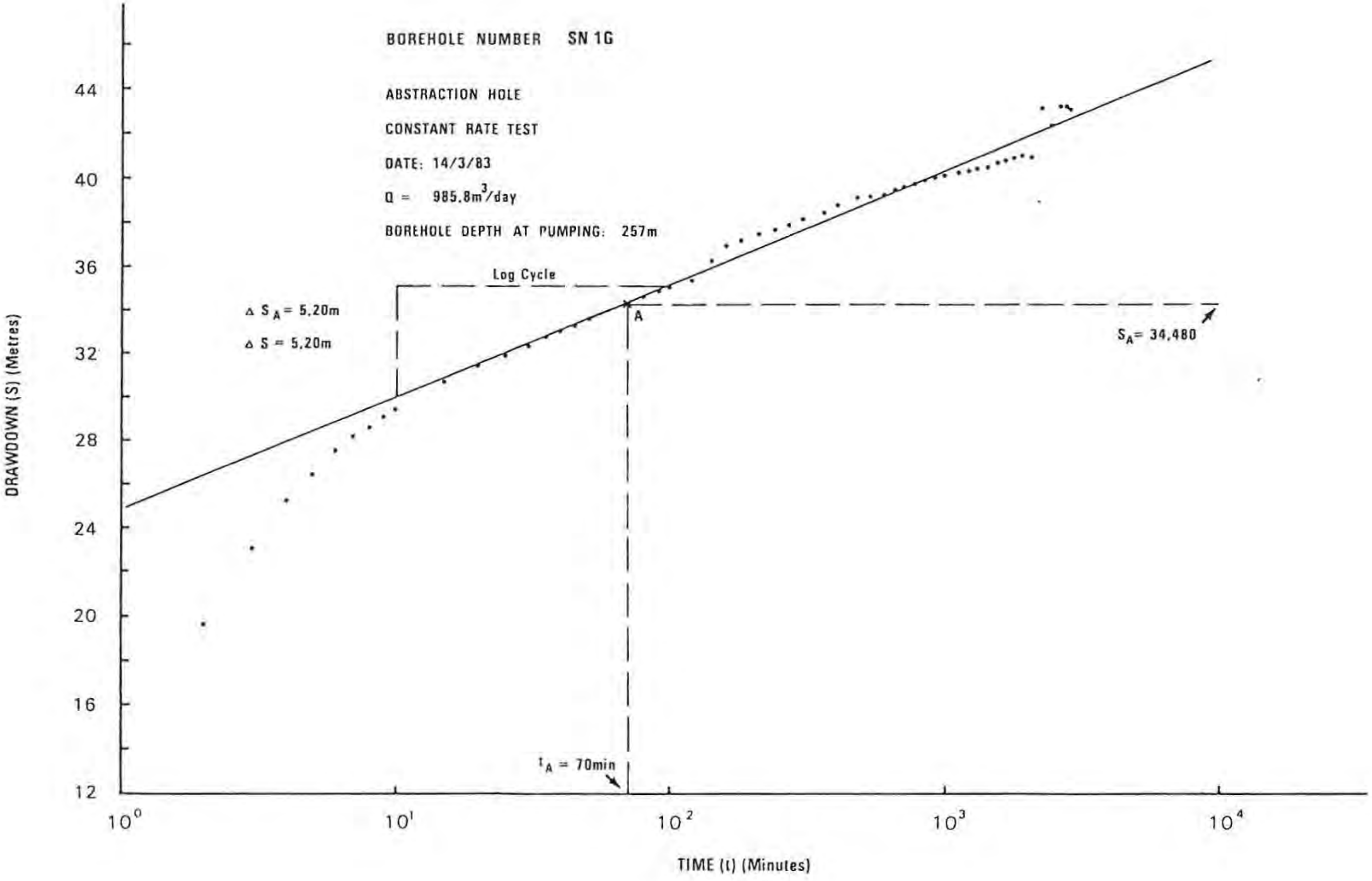
BOREHOLE DEPTH AT PUMPING: 167m

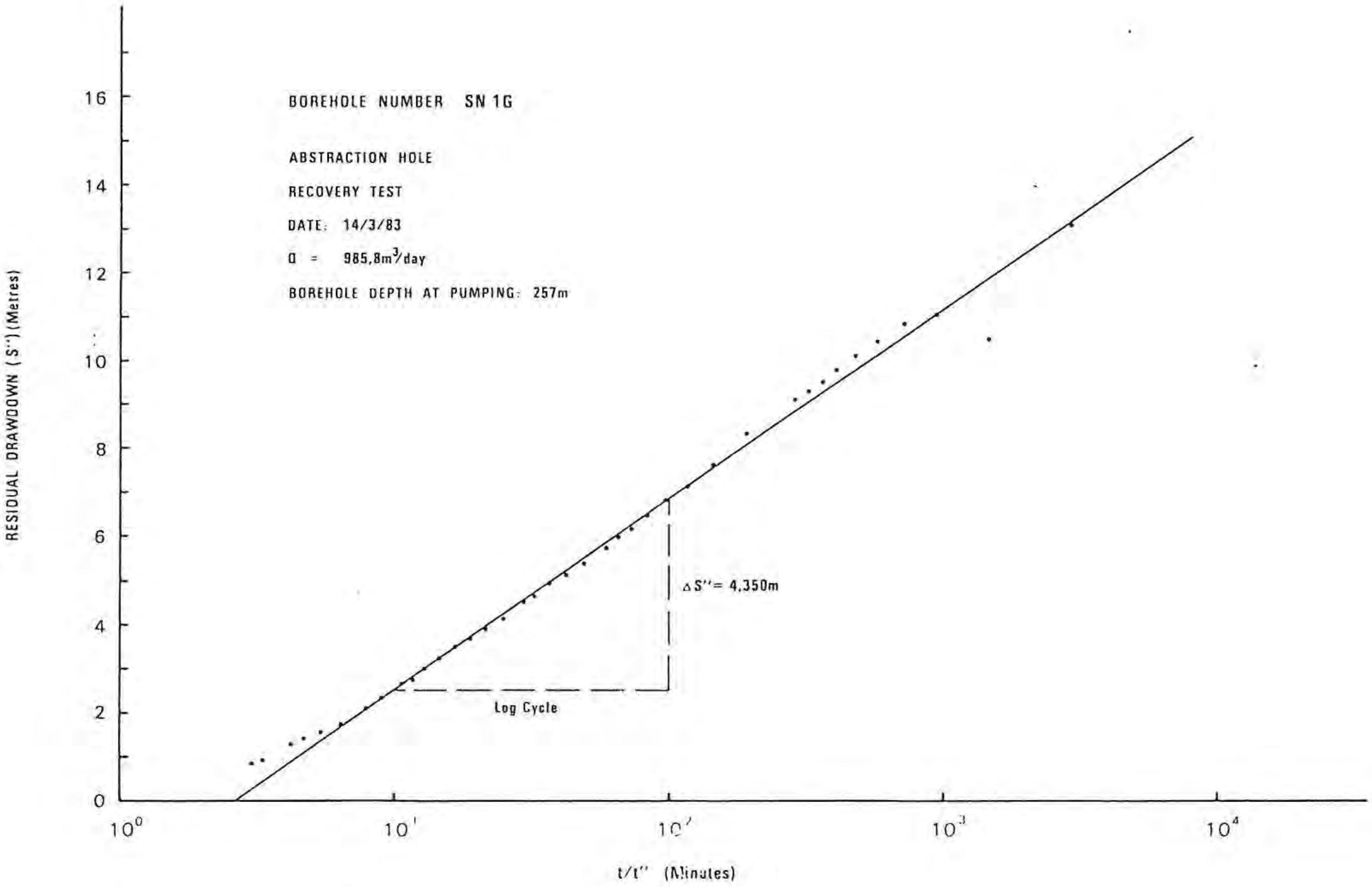

8
7
6
5
4
3
2
1
0
DRAWDOWN (S) (Metres)
ΔS_A = 4,890m
$\Delta S'$ = 4,890m
A
S_A = 6,910m
BOREHOLE NUMBER MW 3A
OBSERVATION HOLE (To MW 4B)
CONSTANT RATE TEST
r = 24,030m
Q - 852,0m³/day
ABSTRACTION BOREHOLE DEPTH AT PUMPING: 126m
t° = 9,5min = 9,5/144° days
t_A = 250min = 0,174 day
10^0
10^1
10^2
10^3
10^4
TIME (t) (Minutes)


BOREHOLE NUMBER MW 3A
OBSERVATION HOLE (To MW 4B)
RECOVERY TEST
r = 24,030m
Q = 852,0m/day
ABSTRACTION BOREHOLE DEPTH AT PUMPING: 126m
Δ S' = 2,160m
Log Cycle
RESIDUAL DRAWDOWN (S'') (Metres)
0
1
2
3
4
5
6
7
8
10⁰
10¹
10²
10³
10⁴
t/t'' (Minutes)


DRAWDOWN (S) (Metres)
29
27
25
23
21
19
17
15
13
TIME (t) (Minutes)
10^0
10^1
10^2
10^3
10^4
A
S_A = 27,075 m
ΔS_A = 2,80m
ΔS = 2,80m
t_A = 50min
BOREHOLE NUMBER SN 1G
ABSTRACTION HOLE
CONSTANT RATE TEST
DATE: 25/1/83
Q 397,4m³/day
BOREHOLE DEPTH AT PUMPING: 109m


BOREHOLE NUMBER SN 1G
ABSTRACTION HOLE
RECOVERY TEST
DATE: 25/1/83
Q = 397,4m³/day
BOREHOLE DEPTH AT PUMPING: 109m
△ S'' = 4,47m
Log Cycle
RESIDUAL DRAWDOWN (S'') (Metres)
0
1
2
3
4
5
6
7
8
10⁰
10¹
10²
10³
10⁴
t/t'' (Minutes)


BOREHOLE NUMBER SN 1G
ABSTRACTION HOLE
CONSTANT RATE TEST
DATE: 14/3/83
Q = 985,8m^3/day
BOREHOLE DEPTH AT PUMPING: 257m
Log Cycle
Δ S$_A$ = 5,20m
Δ S = 5,20m
A
S$_A$= 34,480
t$_A$ = 70min
DRAWDOWN (S) (Metres)
44
40
36
32
28
24
20
16
12
10^0
10^1
10^2
10^3
10^4
TIME (t) (Minutes)


BOREHOLE NUMBER SN 1G
ABSTRACTION HOLE
RECOVERY TEST
DATE: 14/3/83
Q = 985,8m³/day
BOREHOLE DEPTH AT PUMPING: 257m
ΔS'' = 4,350m
Log Cycle
RESIDUAL DRAWDOWN (S'')(Metres)
0
2
4
6
8
10
12
14
16
10⁰
10¹
10²
10³
10⁴
t/t'' (Minutes)

APPENDIX 5
HYDROCHEMICAL ANALYSES

APPENDIX 5 A
HYDROCHEMICAL ANALYSES FROM THE HYDROCENSUS

CHEMICAL ANALYSES OF BOREHOLE WATERS (MG/L) FROM BOREHOLE SURVEY

B/H NUMBER	DATE	pH	TDS	TAL	NH_4	Ca	Cl	NO_3	Na	Mg	F	Si	K	SO_4	P	REMARKS
KR 2A	27.2.82	6,6	117	24	0,03	4	41	0,21	23	4	0,55	4,0	4,0	5	0,009	
	4.3.83	6,9	136	37	0,04	7	32	0,38	22	5	0,8	4,0	3,9	14	0,026	
KR 3B	27.2.82	6,2	180	18	0,025	5	73,5	0,04	38	5	0,3	3,9	3,4	10	0,005	
	8.3.83	5,9	92	13	0,04	0	33	0,09	19	3	0,3	3,7	1,5	14	0,007	
KR 4	22.2.82	5,5	314	12	0,025	6	130	0,08	70,5	9	0,2	4,0	1,9	21	0,001	
KR 7A	27.2.82	6,6	203	24	0,04	3,5	84	0,05	52	4	0,2	3,9	2,7	5	0,007	
	8.3.83	5,6	252	12	0,05	4	121	0,08	72	9	0,2	4,4	1,8	25	0,006	
KR 10A	22.2.82	6,4	290	19	0,02	5	109	0,05	67,5	9	0,4	4,0	1,6	26	0,003	
	8.3.83	5,7	210	12	0,04	3	101	0,03	59	7	0,2	4,0	1,6	18	0,006	
KR 11A	22.2.82	6,1	322	15	0,03	7	132	0,05	72	10,5	0,01	4,1	1,7	26	0,000	
KR 16	27.2.82	5,3	205	11	0,025	4	82	0,28	47	6	0,4	4,1	1,4	18	0,003	
	8.3.83	4,7	174	12	0,05	3	78	0,08	47	6	0,1	4,2	1,1	20	0,003	
KR 18A	22.2.82	6,5	413	28	0,035	10,5	171	0,04	91	14	0,07	4,0	3,1	23	0,003	
KR 19A	22.2.82	7,3	1238	161	0,02	21	466	0,10	329	37,5	0,7	3,9	9,6	167	0,003	
KR 21	1.4.82	3,5	2298	0	0,04	55,5	986,5	0,01	516	106	0,25	5,5	4,9	271	0,005	
KR 22	25.2.82	5,0	230	11,5	0,02	5	100,5	0,04	52,5	7	0,6	3,9	1,9	13,5	0,002	
	8.3.83	4,5	193	10	0,05	3	96	0,06	52	7	0,4	4,1	1,6	17	0,008	
KR 23	27.2.82	6,4	191	11	0,05	4	81	0,35	45	5	0,1	0,6	1,6	4	0,016	
KR 32	8.3.83	3,7	145	10	0,04	2	66	0,08	38	7	0,3	2,1	1,0	16	0,005	
KR 34	27.2.82	7,7	3929	84	0,06	112	1883,5	0,695	907	145	4,9	1,1	49,0	195	0,015	

CHEMICAL ANALYSES OF BOREHOLE WATERS (MG/L) FROM BOREHOLE SURVEY

B/H NUMBER	DATE	pH	TDS	TAL	NH_4	Ca	Cl	NO_3	Na	Mg	F	Si	K	SO_4	P	REMARKS
KR 38	27.2.82	4,9	820	6,5	0,03	18	364	0,05	185	31	0,08	4,3	2,3	72	0,001	
KR 45	22.8.83	7,2	914	293		15	365		180	33			28,0			
KR 47	22.2.82	6,3	273	22	0,02	6	113	0,06	63	8	0,1	3,7	2,0	12,5	0,001	
KR 48A	22.2.82	5,6	275	11	0,03	6	113	0,22	61	9	0,4	4,2	1,75	22	0,006	
KR 49	22.2.82	6,8	623	33	0,03	16	268	0,10	133	26	0,7	1,6	3,0	37	0,006	
	8.3.83	6,0	171	14	0,05	2	78	0,06	42	7	0,4	4,0	2,5	17	0,012	
KR 50	27.2.82	6,4	202	24	0,03	5	80	0,04	47	5,5	0,3	3,9	3,0	9	0,001	
	8.3.83	6,7	127	22	0,04	1	44	0,37	31	3	0,4	4,1	1,5	13	0,009	
KR 52	27.2.82	5,8	250	11	0,03	5	107	0,05	57,5	7	0,1	4,3	1,8	15	0,002	
	9.6.82	7,3	563	53	0,05	13	198	0,91	129	20	0,1	2,8	2,2	38	0,000	
KR 52A	25.1.83	7,4	3884	87	0,11	227	2146	0,75	1086	116	0,4	1,9	28,0	168	0,005	
	8.3.83	7,2	159	31	0,06	12	54	0,06	31	4	0,4	3,9	0,9	14	0,011	
KR 53A	22.2.82	4,7	476	9	0,03	7	203	0,06	112	16	0,1	2,8	1,5	39	0,003	
	10.6.82	7,9	10872	116	0,04	278	6166	0,05	3204	429	0,4	0,35	107,7	436	0,069	TAKEN AT START OF PUMPING
	8.3.83	5,7	214	14	0,05	3	100	0,03	64	7	0,1	4,0	1,1	18	0,004	
KR 54	22.2.82	7,7	2951	297	0,02	76,5	1067	13,26	651	128	1,1	11,1	3,6	359,5	0,002	
	10.6.82	7,1	135	22	0,2	2	49	0,11	30	3	0,3	2,8	0,9	1	0,011	
KR 55	22.8.83	5,8	251	37		1	146		62	4			2,0			
KR 57	22.8.83	7,1	287	73		4	143		55	9			3,0			
KR 60	23.2.82	6,0	202	13	0,03	5	85,5	0,05	46	6	0,0	4,1	1,3	16	0,000	

CHEMICAL ANALYSES OF BOREHOLE WATERS (MG/L) FROM BOREHOLE SURVEY

B/H NUMBER	DATE	pH	TDS	TAL	NH_4	Ca	Cl	NO_3	Na	Mg	F	Si	K	SO_4	P	REMARKS
KR 61	27.2.82	6,1	339	15	0,03	5	135	0,06	83	8	0,09	2,2	1,5	32	0,003	
	9.3.83	4,0	346	5	0,05	4	157	1,18	108	10	0,6	4,2	2,3	47	0,008	
KR 63	27.2.82	6,3	250	17	0,03	6	107	0,05	58	7	0,07	4,5	2,1	15,5	0,000	
KR 66	27.2.82	7,1	306	44	0,03	7	116	0,04	73	9	0,1	4,1	2,9	23	0,000	
LH 1	3.11.82	6,2	541	5	0,03	17	326	0,00	148	23	0,4	3,3	0,8	17	0,010	
MD 7	22.8.83	6,1	1534	134		7	939		400	43			11,0			
MW 4B	7.3.83	7,3	1554	142	0,04	10	612	11,44	461	50	0,3	2,9	14,5	179	0,010	
MW 6	4.5.82	6,8	410	13	0,04	8	154	0,07	87	12	0,06	3,4	1,3	25	0,002	
	9.3.83	6,9	294	17	0,05	5	144	0,03	90	9	0,1	4,0	1,1	20	0,006	
MW 8	11.5.82	7,8	3604	150	0,05	662	1586	0,11	810	159	0,15	1,2	72,9	1815	0,001	TAKEN AT START OF PUMPING
	11.5.82	7,3	416	25,5	0,02	6	169	0,11	96	11	0,2	5,55	4,6	22	0,012	

APPENDIX 5 B
HYDROCHEMICAL ANALYSES DURING DRILLING

CHEMICAL ANALYSES OF BOREHOLE WATERS (MG/L) DURING DRILLING

B/H NUMBER	DEPTH (M)	pH	TDS	TAL	NH_4	Ca	Cl	NO_3	Na	Mg	F	Si	K	SO_4	P
KR 71G	44	6,8	550	36	0,05	9	222	0,04	142	7	0,6	3,1	10,0	25	0,029
	49	7,1	493	50	0,04	10	190,5	0,01	122	9	0,3	4,7	7,3	24	0,013
	54	7,1	467	41	0,05	9	176	0,80	117	9	0,1	3,3	5,5	25	0,008
	58	6,9	442	36	0,05	9	172,5	0,045	111	6	0,2	2,7	6,8	27	0,027
	62	6,8	410	20	0,06	6,5	147	0,52	93	7	0,1	3,4	6,6	31	0,015
	67	6,4	383	10	0,04	6,5	142,5	0,07	88	6	0,1	3,2	6,3	28	0,021
	70	6,9	1126	42,5	0,04	18	446,5	0,12	270	35	0,5	3,5	5,0	115	0,006
	71	7,1	554	71	0,04	11	213	0,04	144	9	0,4	3,6	5,9	23	0,005
	73	6,9	358	20	0,02	2	142	0,06	93	8	0,2	4,3	6,5	27	0,007
	75	6,9	1114	46	0,04	19	453	0,01	266	36	0,3	3,4	4,9	114	0,002
	78	6,8	365	24	0,05	6	129	0,07	79	7	0,1	4,1	5,3	24	0,026
	83	6,9	377	23	0,06	6	133	0,07	85	7	0,1	3,9	6,3	26	0,042
	85	6,9	356	28	0,04	7	125	0,06	79	7	0,2	3,5	4,1	24	0,028
	88	6,7	358	30	0,05	9	132	0,00	79	7,5	0,1	3,8	4,9	23,5	0,014
	92	7,1	402	77	0,04	26	131	0,01	79	10	0,4	3,3	5,15	26	0,006
	99	6,7	359	36	0,04	9	131	0,01	80	7	0,2	4,3	5,5	22	0,000
	105	6,8	369	37	0,04	8	137	0,02	82	8	0,3	4,4	5,3	25	0,008
	110	5,9	435	1	0,04	9,5	173	0,12	95	15	0,4	4,65	1,9	39	0,017
	116	6,7	347	33	0,04	8	129	0,10	76	7,5	0,25	4,0	4,0	25	0,009
	123	6,4	351	30	0,02	8	130	0,03	83	8	0,04	4,3	4,2	25	0,011
	127	6,4	358	29	0,03	8	123	0,05	83	8	0,15	4,2	4,4	27,5	0,010
	132	6,4	358	20	0,06	9	121	0,11	82	8	0,4	4,4	4,3	37,5	0,024
	137	6,4	346	38	0,03	9	118	0,05	80	8	0,2	5,0	4,8	19	0,013
	142	7,2	358	44	0,03	7	127	0,14	82	8	0,2	3,5	4,3	23	0,009
	147	6,9	356	46	0,07	11	118	0,11	82	8	0,3	4,5	4,3	20	0,035
	152	6,4	326	30	0,03	7	116	0,03	79	6	0,1	3,6	3,9	15,5	0,010
	157	5,9	189	13	0,04	5	69	0,08	40	5	0,03	5,05	1,1	9	0,028
	162	6,5	401	54	0,03	9	141	0,05	99	9	0,3	4,0	4,8	17	0,009

CHEMICAL ANALYSES OF BOREHOLE WATERS (MG/L) DURING DRILLING

B/H NUMBER	DEPTH (M)	pH	TDS	TAL	NH_4	Ca	Cl	NO_3	Na	Mg	F	Si	K	SO_4	P
KR 71G	167	7,4	411	50	0,02	7	152	0,015	103	8	0,3	5,6	5,0	23,5	0,012
CONTINUED	172	6,7	428	55	0,02	9	152	0,05	110	8	0,2	4,25	4,7	18	0,007
	177	6,6	447	58	0,085	11	160,5	0,05	112	10	0,3	4,9	5,3	20	0,008
	182	6,7	413	51	0,035	9	149	0,05	103	8	0,1	3,7	4,8	16	0,010
	187	7,4	377	46	0,02	9	130	0,035	86	7	0,3	6,9	5,6	19	0,012
	192	7,2	396	46	0,02	7	147	0,14	92	8	0,3	5,3	5,3	19	0,012
	197	6,5	387	40	0,03	9	137	0,05	94	7,5	0,1	5,1	4,7	20	0,010
KR 72	60	7,4	1512	51	0,03	23	636	0,06	372	49,5	0,5	3,0	6,9	170	0,000
	65	7,3	1516	46	0,04	22,2	628	0,06	384	50	0,5	2,6	6,3	176	0,018
	80	7,0	1178	57	0,05	18,5	474	0,02	290,5	37,5	0,4	2,9	4,8	123	0,010
	85	7,0	1190	52	0,14	18,5	469	0,02	292	39	0,5	3,1	4,7	123	0,054
	90	6,5	397	28	0,04	7	154,5	0,02	87	11,5	0,2	4,6	5,3	33	0,003
	95	6,9	377	19	0,03	6	147,5	0,03	82	12	0,2	3,8	4,9	34	0,004
	100	7,1	410	28	0,04	7	152	0,04	92	14	0,2	3,75	3,15	33	0,015
	105	6,6	371	30	0,04	7	147	0,00	84	12	0,2	4,2	2,7	30	0,005
	130	7,0	369	23	0,04	6	135	0,045	78	11	0,1	3,7	2,6	26	0,007
	135	7,0	386	36	0,04	10	135	0,05	79	12	0,1	3,9	2,5	25	0,007
	140	7,5	1229	69	0,04	16	478	0,05	299	41	0,2	3,2	3,6	128	0,006
	150	7,2	1482	58	0,03	16	614	0,04	375	51	0,3	5,3	7,4	172	0,006
	155	7,2	1496	63	0,04	18	614	0,14	387	53	0,4	5,5	7,1	138	0,016
	160	7,4	1474	64	0,04	18	592	0,02	372	52	0,3	5,3	7,2	171	0,009
	165	6,8	1743	67	0,035	19,5	697	0,05	444	59	0,45	5,1	6,7	181	0,026
	170	7,2	1747	68	0,40	20	699	0,00	446	59	0,4	5,1	7,0	175,5	0,021
	185	7,2	1457	50	0,04	17	614	0,025	364	50	0,4	4,3	5,1	166	0,019
	190	7,2	1379	51	0,04	17	578	0,055	338	47	0,5	5,0	6,8	155	0,010
	195	7,3	1375	48,5	0,03	23	571	0,04	339	46	0,4	5,4	7,5	157	0,007
	200	7,4	1281	54	0,04	18	529	0,06	326	45	0,6	3,4	3,6	134	0,043

CHEMICAL ANALYSES OF BOREHOLE WATERS (MG/L) DURING DRILLING

B/H NUMBER	DEPTH (M)	pH	TDS	TAL	NH_4	Ca	Cl	NO_3	Na	Mg	F	Si	K	SO_4	P
KR 75G	29	7,5	16384	0	0,85	1096	9286	1,57	3439	760	0,5	6,0	38,3	676	0,053
	34	7,5	16466	0,4	1,09	1135	9222	1,40	3439	755	0,4	6,1	30,4	675	0,059
	36	8,0	4589	274	0,05	85	1713	44,58	1295	129	1,1	5,2	31,2	797	0,010
	40	8,1	4517	292	0,18	94	1608	44,11	1270	143	1,1	5,0	37,9	806	0,008
	88	7,9	794	158	0,03	27	280	0,11	205	11	0,6	2,6	18,9	56	0,011
	93	8,0	818	154	0,18	25	286	0,11	219	9	0,5	2,4	21,1	66	0,009
	98	8,2	984	196	0,04	37	324	0,11	254	14	0,7	2,4	21,1	91	0,016
	105	8,2	877	180	0,04	28	319	0,05	247	11	0,8	1,6	10,4	40	0,009
	110	8,0	3365	220	0,03	101	1203	55,73	893	103	0,9	2,6	22,2	524	0,006
	115	8,0	3297	157	1,12	82	1083	36,09	862	126	0,9	2,7	30,8	758	0,001
	120	7,9	3068	197	1,25	117	1145	27,62	776	89	0,8	3,5	25,0	547	0,004
	125	8,0	2660	201	0,03	90	1042	23,22	710	63	0,9	3,1	21,3	382	0,008
	130	7,9	2475	188	0,19	80	976	19,49	675	56	0,9	2,9	19,9	349	0,011
	135	8,0	2418	194	0,35	76	955	19,02	649	56	0,8	2,9	20,0	337	0,009
	140	7,8	2094	179	0,04	63	800	21,60	581	44	0,8	3,0	16,5	271	0,008
	145	7,9	1891	168	0,04	59	737	12,77	527	40	0,8	3,7	17,7	243	0,008
	150	7,8	1742	151	0,03	52	679	9,98	509	34	0,8	2,4	17,7	218	0,008
	155	7,9	1108	136	0,90	27	394	3,83	311	24	0,6	1,6	9,4	158	0,010
KM 1G	15	7,6	15974	14	1,03	1047	9394	1,38	3379	828	0,4	5,1	53,6	722	0,020
	55	7,5	9466	0	0,15	574	5484	0,30	2441	251	0,7	3,7	33,8	481	0,000
	60	7,4	11520	0	0,26	801	6366	0,09	2828	295	0,4	4,1	16,7	508	0,015
	65	7,3	11325	0	1,07	835	6426	0,07	3163	355	0,6	3,7	54,5	1027	0,011
	70	7,4	12442	6	1,16	806	6299	0,44	2858	311	0,6	4,1	19,5	493	0,013
	80	7,2	9818	0	0,44	571	5331	0,34	2657	196	0,8	2,7	28,2	438	0,002
	85	7,5	9756	0	0,44	599	5528	0,41	2894	238	0,8	2,5	45,3	745	0,003
	100	7,1	8355	79		362	5512		2230	155			17,0		
	145	7,1	7459	49		260	4852		2180	107			11,0		

CHEMICAL ANALYSES OF BOREHOLE WATERS (MG/L) DURING DRILLING

B/H NUMBER	DEPTH (M)	pH	TDS	TAL	NH_4	Ca	Cl	NO_3	Na	Mg	F	Si	K	SO_4	P
KM 1G	195	6,8	7497	37		259	5112		1950	117			12,0		
CONTINUED	252	6,9	8823	98		427	5651		2440	192			15,0		
	305	6,9	7962	55		310	5217		2230	137			13,0		
MD 20G	30	8,2	4658	116	0,04	97	2524	0,02	1361	169	0,9	4,7	71,0	289	0,011
	44	8,3	4432	120	0,04	92	2387	0,02	1284	171	1,0	4,6	75,9	271	0,006
	50	8,2	5080	151	0,04	119	2703	0,01	1501	173	1,1	4,0	86,8	308	0,008
	60	8,2	4600	143	0,05	102	2446	0,06	1352	157	1,0	4,9	71,8	291	0,069
	65	8,3	4607	111	0,05	89	2490	0,03	1352	175	0,9	4,7	73,4	287	0,008
	70	8,5	4679	118	0,07	93	2563	0,07	1356	156	1,0	4,1	68,6	293	0,015
	75	8,3	4711	152	0,04	91	2504	0,03	1386	176	0,9	4,5	71,8	292	0,008
	85	8,3	4523	117	0,04	115	2432	0,02	1282	170	0,9	4,8	64,1	314	0,000
	90	8,1	4499	129	0,04	117	2406	0,01	1275	169	1,0	4,4	65,1	304	0,000
	95	8,0	4157	70	0,05	107	2280	0,01	1181	164	0,8	3,3	66,2	267	0,008
	100	8,2	4459	92	0,05	88	2416	0,03	1314	172	0,8	4,5	60,7	291	0,008
	105	8,6	4738	89	0,04	99	2610	0,03	1387	167	0,8	4,6	67,8	294	0,009
	110	8,4	4713	69	0,04	94	2590	0,03	1414	167	0,8	4,1	74,3	294	0,008
	115	8,2	4668	72	0,03	96	2571	0,02	1382	167	0,8	4,1	73,4	285	0,011
	120	8,2	4732	67	0,04	92	2585	0,01	1413	177	0,8	3,9	76,7	302	0,008
	130	8,0	4597	69	0,03	89	2527	0,03	1369	160	1,1	3,1	71,8	291	0,012
	135	8,0	4546	69	0,05	85	2527	0,03	1335	164	1,1	3,4	67,8	279	0,011
	140	8,0	4732	96	0,04	95	2536	0,06	1431	184	0,9	1,6	60,1	307	0,008
	145	8,1	4699	71	0,04	108	2568	0,02	1352	175	1,1	2,7	66,2	340	0,006
	150	8,0	4651	56	0,04	85	2556	0,03	1391	189	1,0	2,6	66,2	292	0,006
MD 21G	131	6,7	1075	14	0,53	28	490	0,15	292	16	0,3	5,2	17,1	68	0,029
	136	6,8	1098	21	0,05	20	487	0,12	265	24	0,5	2,4	10,0	42	0,024
	141	6,7	1094	14	0,41	20	484	0,16	267	24	0,5	0,9	9,0	44	0,011
	146	6,8	1094	17	0,25	24	475	0,35	272	20	0,3	1,3	8,3	46	0,014

CHEMICAL ANALYSES OF BOREHOLE WATERS (MG/L) DURING DRILLING

B/H NUMBER	DEPTH (M)	pH	TDS	TAL	NH_4	Ca	Cl	NO_3	Na	Mg	F	Si	K	SO_4	P
MD 21G	151	6,8	1114	20	0,43	21	491	0,02	287	22	0,6	1,4	9,5	42	0,010
CONTINUED	156	6,7	1133	12	0,27	23	495	0,31	282	21	0,3	0,9	9,7	50	0,008
	161	6,7	1139	14	0,42	20	520	0,27	291	20	0,7	0,5	9,4	45	0,013
	167	6,4	1096	14	0,22	21	514	0,32	282	19	0,5	0,7	9,5	50	0,004
SN 1G	22	7,9	29503	0	1,77	579	16534	0,08	8020	1729	0,8	2,2	73,2	2562	0,013
	24	7,6	25375	121	0,36	621	15729	0,13	7440	1628	1,4	2,2	27,9	2318	0,011
	50	6,9	1511	17	0,04	27	649	0,06	356	42	0,6	7,3	15,9	100	0,007
	60	6,5	1056	6	0,97	17	461	0,00	253	30	0,7	9,6	14,3	71	0,021
	65	5,8	1032	0	2,45	20	445	0,13	241	29	0,5	11,5	16,0	72	0,028
	70	7,3	1911	33	0,53	39	1029	0,04	571	76	0,5	4,4	9,7	138	0,018
	75	5,4	634	7	0,53	10	264	0,00	147	16	0,4	3,7	9,7	38	0,009
	80	6,0	573	7	0,39	11	234	0,00	133	15	0,4	7,7	7,9	34	0,009
	85	6,7	1384	22	0,45	27	616	0,00	321	43	0,4	3,5	6,0	79	0,012
	90	5,9	642	1	0,65	10	268	0,00	148	18	0,3	4,0	4,1	37	0,021
	95	5,1	266	2	0,85	5	105	0,00	60	7	0,1	4,2	2,2	21	0,016
	100	4,7	198	0	0,80	3	78	0,06	43	5	0,2	4,4	1,6	16	0,022
	108	6,4	191	8	0,72	7	72	0,00	40	4	0,2	4,4	1,4	14	0,020
	115	6,9	817	20	0,02	16	434	0,04	231	34	0,5	4,7	4,7	67	0,013
	125	6,3	427	18	0,01	8	219	0,06	122	17	0,3	2,8	3,1	32	0,005
	135	7,2	816	28	0,02	14	426	0,03	234	34	0,3	3,9	5,2	64	0,004
	145	6,8	848	26	0,02	15	451	0,03	239	33	0,4	4,6	7,7	65	0,004
	155	6,6	379	15	0,01	7	194	0,03	108	15	0,3	3,4	3,2	31	0,004
	165	6,8	846	20	0,02	17	449	0,05	244	32	0,5	4,3	7,6	67	0,006
	175	5,9	798	5	0,02	16	445	0,03	224	27	0,9	5,0	16,5	57	0,005
	185	6,2	521	15	0,04	9	272	0,03	152	18	0,9	3,3	9,9	37	0,007
	195	6,6	794	14	0,02	15	422	0,03	228	29	0,9	4,4	14,7	62	0,004
	215	7,4	819	49		5	504		220	32			9,0		
	225	7 2	915	61		6	574		230	41			3,0		

CHEMICAL ANALYSES OF BOREHOLE WATERS (MG/L) DURING DRILLING

B/H NUMBER	DEPTH (M)	pH	TDS	TAL	NH_4	Ca	Cl	NO_3	Na	Mg	F	Si	K	SO_4	P
SN 1G	235	7,1	921	37		5	609		230	30			11,0		
CONTINUED	245	7,3	931	37		6	626		220	35			7,0		

APPENDIX 5 C
HYDROCHEMICAL ANALYSES DURING CONSTANT YIELD TESTS

CHEMICAL ANALYSES OF BOREHOLE WATERS (MG/L) PUMPING AT CONSTANT YIELD

B/H NUMBER	TIME (MINUTES)	pH	TDS	TAL	NH_4	Ca	Cl	NO_3	Na	Mg	F	Si	K	SO_4	P	REMARKS
KR 71G	70	5,2	155	0	0,04	2	76	0,03	40	6	0,0	4,6	0,8	25	0,021	YIELD = 13,0 L/S
	140	5,6	159	4	0,04	2	77	0,03	40	6	0,0	4,7	0,8	22	0,013	AT 200 M DEPTH
	300	6,1	161	4	0,03	2	79	0,00	42	6	0,0	4,7	0,9	23	0,009	
	480	5,6	159	2	0,04	2	78	0,00	43	6	0,0	4,8	0,9	23	0,009	
	720	5,7	159	1	0,04	2	78	0,00	42	6	0,0	4,8	0,8	24	0,008	
	870	5,4	168	6	0,04	2	81	0,00	43	6	0,0	4,8	0,8	22	0,000	
KR 72	8	6,8	639	37	0,05	19	241	0,05	148	19	0,1	5,5	2,0	60	0,044	YIELD = 12,9 L/S
	18	6,6	663	27	0,04	13	251	0,05	157	21	0,1	4,9	1,9	62	0,050	AT 200 M DEPTH
	30	6,5	631	20	0,05	11	249	0,03	151	19	0,1	4,6	1,8	59	0,034	
	65	6,8	506	35	0,03	18	187	0,03	114	15	0,1	4,7	1,5	43	0,014	
	80	6,4	476	21	0,04	11	181	0,00	108	14	0,1	4,8	1,4	42	0,010	
	125	6,4	415	24	0,03	12	156	0,03	94	12	0,1	4,6	1,6	34	0,004	
	195	6,1	357	10	0,03	7	135	0,27	81	10	0,2	4,6	1,3	27	0,012	
	300	5,9	314	8	0,03	6	121	0,03	72	9	0,0	4,9	1,1	24	0,014	
	420	5,7	296	9	0,05	5	114	0,03	68	8	0,0	4,8	1,2	23	0,006	
	575	5,6	280	6	0,03	5	114	0,04	64	8	0,1	4,6	1,2	24	0,012	
	660	5,9	274	7	0,04	6	105	0,03	62	8	0,1	4,8	1,0	19	0,013	
	780	6,5	285	17	0,04	11	104	0,03	60	8	0,1	4,8	1,1	18	0,011	
	840	5,7	269	6	0,04	4	105	0,13	60	7	0,4	4,9	1,1	18	0,023	
	900	5,3	264	5	0,03	4	103	0,03	60	7	0,0	3,2	1,0	18	0,003	
	1005	5,7	262	6	0,04	5	99	0,03	59	7	0,0	4,9	0,9	20	0,009	
	1120	5,5	259	7	0,03	5	100	0,04	60	6	0,0	4,9	1,0	18	0,004	
	1245	5,3	260	7	0,02	4	105	0,04	59	7	0,1	5,0	1,0	21	0,018	
	1350	5,4	259	11	0,02	5	105	0,04	59	7	0,2	4,8	1,1	20	0,014	
	1440	5,5	260	10	0,03	5	105	0,07	59	7	0,5	4,8	1,0	21	0,021	

CHEMICAL ANALYSES OF BOREHOLE WATERS (MG/L) PUMPING AT CONSTANT YIELD

B/H NUMBER	TIME (MINUTES)	pH	TDS	TAL	NH_4	Ca	Cl	NO_3	Na	Mg	F	Si	K	SO_4	P	REMARKS
KR 75 G	110	5,9	183	4	0,04	3	81	0,00	53	6	0,2	4,2	2,1	28	0,012	YIELD = 10,4 L/S
	180	7,3	200	26	0,04	3	84	0,00	53	5	0,3	4,2	2,3	16	0,027	AT DEPTH 164 M
	300	7,9	272	69	0,03	23	83	0,00	52	6	0,3	4,1	2,1	17	0,029	
	350	7,2	195	24	0,03	2	83	0,00	52	5	0,2	4,2	2,7	16	0,026	
	420	7,2	195	23	0,03	3	82	0,00	53	5	0,3	4,2	2,1	17	0,018	
	485	7,3	190	21	0,04	3	82	0,02	51	6	0,2	4,2	2,0	16	0,020	
	600	7,3	196	26	0,04	2	82	0,00	54	5	0,3	4,2	2,2	16	0,025	
	680	7,2	190	20	0,04	2	82	0,00	52	7	0,2	4,2	2,1	17	0,019	
	725	7,2	198	25	0,04	3	82	0,00	55	5	0,4	4,2	1,9	16	0,015	
	785	7,3	197	25	0,04	3	83	0,00	52	5	0,2	4,2	2,3	17	0,016	
	845	7,2	191	21	0,04	2	83	0,00	53	5	0,2	4,2	2,2	16	0,014	
	905	7,1	192	22	0,03	2	83	0,00	53	5	0,2	4,2	2,2	17	0,013	
	1020	7,1	198	27	0,04	3	83	0,00	52	5	0,2	4,2	2,0	16	0,015	
	1105	7,1	196	25	0,04	2	83	0,00	52	5	0,2	4,2	2,3	17	0,014	
	1235	7,2	191	22	0,05	3	83	0,00	51	5	0,2	4,2	2,1	16	0,015	
	1385	7,1	185	20	0,04	2	81	0,00	50	5	0,2	4,2	2,0	17	0,018	
	1435	6,9	191	21	0,04	2	81	0,00	51	5	0,2	4,2	2,0	18	0,011	
KM 1G	START	6,8	9436	0	0,30	547	5119	0,16	2595	108	0,7	2,2	5,7	441	0,002	YIELD = 0,325 L/S
	END	6,8	8092	0	0,65	456	4458	0,02	2598	55	0,7	3,1	42,0	527	0,000	AT 88 M DEPTH
MD 20G	30	8,3	4711	152	0,04	91	2504	0,03	1386	176	0,9	4,1	68,6	292	0,000	YIELD = 5,1 L/S
	50	8,3	4523	118	0,04	115	2432	0,02	1282	170	0,9	4,4	66,2	267	0,008	AT DEPTH 98 M

CHEMICAL ANALYSES OF BOREHOLE WATERS (MG/L) PUMPING AT CONSTANT YIELD

B/H NUMBER	TIME (MINUTES)	pH	TDS	TAL	NH_4	Ca	Cl	NO_3	Na	Mg	F	Si	K	SO_4	P	REMARKS
MD 21G	180	6,4	983	40	0,03	24	524	0,06	295	27	0,2	5,6	5,6	53	0,009	YIELD = 0,34 L/S
	390	6,3	961	39	0,03	21	514	0,00	285	27	0,1	6,0	5,7	54	0,006	AT 167 M DEPTH
	540	6,3	963	40	0,03	22	519	0,03	283	27	0,1	5,9	5,1	53	0,005	
	720	6,5	955	38	0,03	21	514	0,06	281	27	0,4	5,9	5,0	54	0,003	
SN 1G	START	7,1	2363	16	0,14	53	1287	0,02	673	120	0,2	1,6	5,5	201	0,008	YIELD = 4,6 L/S
	180	5,9	449	6	0,03	10	244	0,02	125	22	0,2	1,8	1,6	37	0,006	AT 109 M DEPTH
	360	6,4	811	7	0,01	19	448	0,05	223	38	0,2	3,6	2,8	67	0,005	
SN 1G	START	6,4	880	11	0,01	17	466	0,10	254	40	0,2	4,1	2,7	81	0,008	YIELD = 11,4 L/S
	490	6,2	287	11	0,01	9	201	0,10	111	16	0,2	4,2	2,4	29	0,003	AT 258 M DEPTH
	1240	6,1	252	11	0,01	6	124	0,08	71	9	0,2	4,6	2,1	20	0,003	
	2880	6,1	153	10	0,01	5	86	0,07	50	6	0,3	4,5	2,1	16	0,004	

CHEMICAL ANALYSES OF BOREHOLE WATERS (MG/L) DURING STEP TESTS

B/H NUMBER	STEP & TIME	pH	TDS	TAL	NH_4	Ca	Cl	NO_3	Na	Mg	F	Si	K	SO_4	P
KR 71G	1/15 MIN	5,8	166	9	0,02	4	73	0,03	41	6	0,1	4,6	1,3	24	0,016
	2/70 MIN	4,5	154	1	0,03	3	72	0,00	39	6	0,0	4,8	1,4	27	0,016
	2/113 MIN	5,3	149	1	0,04	2	72	0,00	39	5	0,0	4,6	1,0	23	0,020
	3/125 MIN	5,6	154	3	0,03	3	74	0,03	38	5	0,0	4,7	1,0	24	0,012
	4/215 MIN	5,3	147	1	0,03	2	73	0,03	38	6	0,0	4,6	0,7	23	0,012
MD 21G	1	6,9	4620	73	0,04	87	2624	0,03	1402	137	0,6	0,0	19,7	260	0,017
	3	6,9	1972	88	0,04	27	1007	0,00	599	54	0,4	1,3	8,5	166	1,232

APPENDIX 6
ABSTRACTION DATA

ANNUAL WATER ABSTRACTION FROM THE KRUIS-RIVER AREA

DATE	BORE-HOLE NUMBER	OWNER	FARM NAME	RATE OF PUMPING ℓ/s	NUMBER OF HOURS PUMPED		YIELD PER ANNUM M³
28.9.82	KR 2A	HUMAN	BRANDSKLOOF	7,5	18 HOURS/DAY	ALL YEAR	177390
28.9.82	KR 3B	HUMAN	BRANDSKLOOF	8,8	18 HOURS/DAY	ALL YEAR	208138
8.3.83				8,0	18 HOURS/DAY	ALL YEAR	189216
28.9.82	KR 4	HUMAN	BRANDSKLOOF	7,5	24 HOURS/DAY	ALL YEAR	236520
28,9.82	KR 7A	DE KLERK	DIE EIKE	10,0	6 HOURS/DAY	ALL YEAR	78840
28.9.82	KR 10A	LAURENCE	LEBANON	3,8	12 HOURS/DAY	ALL YEAR	59918
8.3.83				4,65	12 HOURS/DAY	ALL YEAR	73321
22.8.83	KR 11A	S.A. KOÖPERATIEWE SITRUSBEURS B.P.K.	PORTION 52 OF K.R.	2,7	1 HOUR /DAY	ALL YEAR	3549
7.11.83	KR 13A	CLAASEN, J.	HIGHLANDS	8,0	4,8 HOURS/DAY	ALL YEAR	50458
28.9.82	KR 16	VAN VUUREN	LANGLAAGTE	6,5	12 HOURS/DAY	ALL YEAR	102492
22.8.82	KR 18A	CLAASEN	ROOIPADSBRAND	6 750 ℓ/week			352
28.9.82	KR 19A	CLAASEN	ROOIPADSBRAND	8,0	0,14 HOURS/DAY	ALL YEAR	1472
22.8.83				6,2	20 MIN/DAY	ALL YEAR	2716

DATE	BORE-HOLE NUMBER	OWNER	FARM NAME	RATE OF PUMPING ℓ/s	NUMBER OF HOURS PUMPED		YIELD PER ANNUM M^3
28.9.82	KR 21	LE ROUX	GROOTKLOOF	2,7	1,1 HOURS/DAY	ALL YEAR	3903
30.8.83				1,7	1,1 HOURS/DAY	ALL YEAR	2457
28.9.82	KR 22	COOKE	PORTION 54 OF K.R.	7,0	20,5 HOURS/DAY	ALL YEAR	188559
7.11.82	KR 23	COOKE	PORTION 54 OF K.R.	5,0	24 HOURS/DAY	ALL YEAR	157680
28.9.82	KR 32	VAN HEERDEN	PORTION 97 OF K.R.	1,3	12 HOURS/DAY	ALL YEAR	204 98
28.9.82	KR 38	HARRIS	BONNIEVALE	3,0	4 HOURS/DAY	ALL YEAR	15768
28.9.82	KR 45	SCHEEPERS	RETREAT	1,0	4 HOURS/DAY	ALL YEAR	5256
28.9.82	KR 47	BARDARD	HOPEDALE	0,36	2 HOURS/DAY	ALL YEAR	946
30.8.83				1,25	2 HOURS/DAY	ALL YEAR	3285
28.9.82	KR 48A	HUMAN	PORTION 89 OF K.R.	2,5	18 HOURS/DAY	ALL YEAR	59130
8.3.83				3,08	18 HOURS/DAY	ALL YEAR	72848
28.9.82	KR 49	RENS	AVONDSRUS	5,0	12 HOURS/DAY	ALL YEAR	78840
5.9.83				10,0	12 HOURS/DAY	ALL YEAR	157680
28.9.82	KR 50	FERREIRA	PORTION 113 OF K.R.	0,9	2 HOURS/DAY	ALL YEAR	2365
8.3.83				0,8	2 HOURS/DAY	ALL YEAR	2102

DATE	BORE-HOLE NUMBER	OWNER	FARM NAME	RATE OF PUMPING ℓ/s	NUMBER OF HOURS PUMPED		YIELD PER ANNUM M^3
28.9.82	KR 52	HUMAN	PORTION 38 OF K.R.	6,7 CLOSED IN 1982	18 HOURS/DAY	ALL YEAR	158468
8.3.83	KR 52A	HUMAN	PORTION 38 OF K.R.	5,0	18 HOURS/DAY	ALL YEAR	118260
22.8.83				5,7	18 HOURS/DAY	ALL YEAR	134816
28.9.82	KR 53A	HUMAN J.N.	FONTEINSHOEK	3,7	12 HOURS/DAY	ALL YEAR	58342
30.8.83				3,3	12 HOURS/DAY	ALL YEAR	52034
28.9.82	KR 55	HANCKE	KWEPERLANDE	0,5	1 HOUR/DAY	ALL YEAR	657
8.3.83				0,28	1 HOUR/DAY	ALL YEAR	368
5.9.83				0,39	1 HOUR/DAY	ALL YEAR	512
8.3.83	KR 57	RUDMAN	PORTION 70 OF K.R.	1,1	20 MIN/DAY	ALL YEAR	482
28.9.82	KR 60	MULLER	FONTEINSHOEK	1,2	5 HOURS/DAY	ALL YEAR	7884
30.8.83				1,0	2,6 HOURS/DAY	ALL YEAR	3377
28.9.82	KR 61	GERBER	PORTION 104	16,7	10 HOURS/DAY	ALL YEAR	219438
8.3.83				10,0	10 HOURS/DAY	ALL YEAR	131400
28.9.82	KR 63	BOTHA	OLIVIA NOT CURRENTLY IN USE 8.3.83	1386 ℓ/day CARTED			506

DATE	BORE-HOLE NUMBER	OWNER	FARM NAME	RATE OF PUMPING ℓ/s	NUMBER OF HOURS PUMPED		YIELD PER ANNUM M^3
28.9.82	KR 66	THOMPSON	GREENACRES	2,1	1,3 HOURS/DAY	ALL YEAR	3587
30.8.83				0,9	1,3 HOURS/DAY	ALL YEAR	1537
22.8.83	KR 72	S.A. KOÖPERATIEWE SITRUSBEURS B.P.K.	PORTION 52 OF K.R.	2,6	1 HOUR/DAY	ALL YEAR	3432
16.9.83	BH 1	BLOM	NUWEPLAAS	0,5	1 HOUR/DAY	ALL YEAR	657
28.9.82	LH 1	SEARLE	WINCANTON ESTATES	1,26	8 HOURS/DAY	ALL YEAR	13245
28.9.82	MD 2	SEARLE	WINCANTON ESTATES	0,7	4,5 HOURS/DAY	ALL YEAR	4139
8.3.83	MW 4B	GERBER	PORTION 3 OF MAMOSADALE WEST	8,7	12 HOURS/DAY	SUMMER	105987
5.9.83				10,7	24 HOURS/DAY	ALL YEAR	337435
28.9.82	MW 6	FROST	ECHODALE	0,5	5 HOURS/DAY	ALL YEAR	3285
28.9.82	MW 8	FROST	ECHODALE	0,4	6 HOURS/DAY	ALL YEAR	3154
5.9.83	KR 17	SEADY	RHODECOURT	10,25	24 HOURS/MONTH	ALL YEAR	10627

APPENDIX 7
PIEZOMETRIC SURVEY

PIEZOMETRIC SURVEY

BOREHOLE NO.	DATE OF SURVEY	PIEZOMETRIC LEVEL (METRES ABOVE SEA LEVEL)
BH1	5-9-83	67,010
KM1G	13-3-84	48,350
KR4	30-8-83	55,125
KR11A	30-8-83	47,190
KR19A	30-8-83	54,550
KR21	18-3-83	42,915
KR37	5-9-83	46,350
KR38	2-2-82	48,700
KR39	5-9-83	46,410
KR45	5-9-83	46,660
KR50	5-9-83	43,000
KR54	30-8-83	46,725
KR57	30-8-83	40,105
KR61	27-2-83	62,856
KR63	23-6-80	48,800
KR64	5-9-83	49,790
KR66	30-8-83	31,658
KR70	30-8-83	60,375
KR71G	30-5-83	40,574
KR72	30-8-83	51,435
KR75G	5-9-83	48,210
MD4A	18-3-83	69,320
MD6	5-9-83	82,675
MD7	5-9-83	57,420
MD20G	5-9-83	74,290
MD21G	5-9-83	58,735
MW4B	3-2-83	36,550
MW6	30-8-83	±75,0
MW7	11-5-82	69,099
MW8	5-9-83	68,220
MW20G	5-9-83	-9,140
SN1G	30-8-83	66,160