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DE AAR'S GROUND-WATER SUPPLY: A DIGEST OF THE PAST AND AN OUTLOOK FOR THE FUTURE

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FOLDERS

INTRODUCTORY REMARKS

This comprehensive report - perhaps more aptly termed a memoir - is the final instalment in the fulfilment of a contract entered into between the Department of Water Affairs and the author to

1. assimilate and evaluate

(a) data and reports emanating from the 1987-89 ground- water investigations of the Directorate of Geohydrology at De Aar;

(b) earlier data and reports;

(c) historical water-level and pumpage data;

(d) findings of the Water Research Commission project : Exploitation potential of Karoo aquifers (De Aar section);

2. compile a scientific as well as an executive report on the locale, hydrogeology, supply potential and water quality of sources which are used or may be used for urban supply; and

3. provide guidelines for the operation of an integrated ground-water supply system for De Aar.

In partial fulfilment of these obligations, this report was preceded by

(i) a provisional estimate of ground-water potential (Vegter 1990a) which was required for a study of the technical feasilibity and cost of improving the quality of water for De Aar (Stewart, Sviridov and Oliver 1990).

(ii) a concise exposition of ground-water resources (Vegter 1990b) for the planning of supplementary supplies (Haasbroek 1991).

Further study subsequent to the submission of these reports, has necessitated a revision of the ground-water potential. Figures given in chapter 11 supersede previous estimates. For a description of the options for phased development of supplementary supplies Vegter (1990b) should still be consulted.

In response to criticism a new title has been given to this comprehensive report. In draft form it was "An evaluation of groundwater exploitation and its potential for urban use, De Aar." Some corrections and clarifications have been made to the text as well.

At the expense of being accused of long windedness, the author has nevertheless considered it fit to process and record as fully as possible, facts and perceptions about the investigation and exploration for ground water in the hopes of providing useful information not only to the hydrogeologist but also the planner, water development engineer and interested layman. The report is structured so as to allow selective reading.

ABSTRACT

The compilation and evaluation is based on numerous ground-water investigations by the Geological Survey and the Directorate of Geohydrology (Water Affairs), exploratory drilling, testpumping, development and performance of municipal borehole and Railway well fields over the past fifty years. De Aar has been dependent on ground-water supplies from the pioneer farming days in the previous century up to the present time. Although De Aar was proclaimed a municipality in 1904, the municipal Burgerville water supply scheme only came into operation in 1936. It was planned to yield about 800 m^3 per day. The S.A. Railways started earlier and had the Caroluspoort scheme instituted somewhere between the turn of the century and 1916. Shortly after World War II the total municipal and railway supply amounted to about 1 million m^3 per annum reaching a peak of 3.4 million m^3/a by the mid-eighties. The volume abstracted annually by the Railways doubled in the mid-sixties but eventually petered out by 1989 owing to a gradual switch from steam to diesel and electric haulage. Municipal abstraction on the other hand started to increase more rapidly in the early seventies when water-borne sewerage was introduced. Water shortages that have been experienced from time to time during droughts can be ascribed to a lack of timeous extensions to the ground water supply scheme rather than to a lack of resources albeit on private land.

The surroundings of De Aar from where its ground water supply is obtained, lie at an elevation of 1 200 to 1 500 metres above mean sea level in the Upper Karoo physiographic region, and are part of the catchment of the Brak River - quaternary drainage region D603.

The climate is semi-arid; rainfall averages about 290 mm per annum, the greater part of which falls during the months February and March. The vegetation changes from the Central Upper Karoo type in the west to False Upper Karoo east of De Aar (Acocks 1953).

The geology comprises Beaufort Group mudstone, siltstone and sandstone east and southeast of De Aar and Ecca Group shale and subordinate siltstone west and northwest of De Aar. The beds have been intruded by undulating and furcating dolerite sheets on two horizons and by dolerite and kimberlite dykes. Superficial deposits consist of calcrete forming extensive terraces in certain parts, of colluvium around the base of hills and of alluvium along river courses.

Three aquifer types may be distinguished

(1) the basal section of alluvial deposits which is usually coarse grained.

(2) weathered and fractured Beaufort and Ecca strata and dolerite; optimal fracturing in the vicinity of intrusive contacts.

(3) a combination of (1) and (2).

The Karoo strata and dolerite owe their water-bearing properties to fracturing which is generally limited to the top 20-30 metres below the surface. Weathering processes play an essential role in opening up incipient fractures/joints and in converting the rocks into more porous media. Jointing/fracturing is enhanced in the vicinity of intrusive contacts. Statistical analyses of exploratory drilling results have provided the following information:

- *The probability of striking water is highest between depths of 5 and 15 metres (note that the statistical analysis was done in a manner not to bias in favour of the more numerous shallow holes).*

- *Individual strike yields are mostly less than 1.0 l/s.*

- *Strike yields and fracture permeability decrease with depth.*

- *Boreholes owe high yields to having struck a number of water-bearing fractures rather than to a single high yielding one.*

- *Ground-water levels in the valleys are very shallow - mostly less than 5 metres.*

- *There is no material difference in strike yields in the upper and lower contact zones of dipping dolerite intrusions.*

- *Although a very clear picture of the probability of striking water in intrusive contact zones at different depths could not be obtained owing to the small number of holes that penetrated upper and lower contact zones at different depths, results are not in conflict with the decreasing probability of striking water and decreasing fracture permeability, deduced from the analysis of all exploratory holes.*

- *Water is struck more readily in the sedimentary sections of both upper and lower intrusive contact zones than in the dolerite sections.*

- *Apart from vertical to inclined fracturing associated with dolerite dykes and dipping sheets, there are some indications that horizontal fracturing along bedding planes may also be an important water-bearing feature.*

Geophysical exploration methods have not been found particularly useful in ground-water exploration. Electrical resistivity and refraction seismic methods have been used in combination with exploration drilling to map the thickness and extent of alluvial deposits. Moving source and receiver electromagnetic systems may prove a faster but not necessarily a superior means of profiling alluvial deposits - the problem being overlapping resistivities of alluvium and bed-rock. Geophysical borehole logging should receive more attention. Hydraulic fracturing may be useful in limiting the number of exploratory holes that often have to be drilled in dolerite contact zones before obtaining a satisfactory yield as well as in improving yields of successful boreholes.

Pumping tests have been analysed by Vegter (1961), von Hoyer and

Rinkel (1976), Rinkel (1974a & b) and Kirchner et al (1991) for determining aquifer parameters. Results may be summarised as follows:

	Alluvium	*Fractured hard rock*	*Composite aquifers*
Transmissivity $T(m^2d)$	*212 - 347*	*7 - 1320*	*83 - 3797*
Coefficient of storage S	*0.062 - 0.11*	*$2x10^{-6}$ to 0.02*	*$3.6x10^{-5}$ to 0.074*

Composite and alluvial aquifers appear to be semi-confined (leaky) or semi-unconfined or unconfined with delayed yield. The behaviour of fractured hard-rock aquifers is not very clear. Noteworthy is, however, the similarity of response between composite and fractured rock aquifers. The response of water levels is in certain cases similar to that of unconfined delayed yield aquifers. This is in accordance with the model of a fractured medium consisting of porous or micro-fractured blocks (double porosity). In many instances log-log time-drawdown curves are quasi-linear - possibly corresponding to the theoretical response of a horizontal fracture. Without information on the permeable fracture pattern meaningful interpretation of the pumping test data is not possible.

Estimates of recharge by rainfall infiltration have been made by von Hoyer (1976) and Kirchner et al (1991). Von Hoyer suggested that recharge may amount to 7 percent of the annual rainfall in the Burgerville area. Kirchner et al's recharge formula for the area occupied by the dolerite ring structure west of De Aar results in a figure of 4.3 percent for the average rainfall year. The figure of 14.4 percent for the alluvium part of the area however seems unacceptable in the light of an uncompleted study of the effect of river flow on water levels in the vicinity of the river channel and also the ground-water balances of unit XXIB (part of the ring structure) discussed in chapter 9. It seems that the alluvium is only recharged occasionally during abnormal flooding as for instance during 1988.

A detailed study was made of ground-water unit XXIB, which occupies the southern half of the dolerite ring structure west of De Aar. It covers an area of about 80 square km and is traversed by the Elandsfontein Spruit. Excepting subsurface inflow and outflow (the latter presumably insignificant) where the Elandsfontein Spruit cuts through the surrounding dolerite hills, the unit is seen as an independent hydraulic entity.

Ground-water flow within the unit is from higher-lying ground towards the Elandsfontein Spruit where under natural (virgin) conditions it is discharged into the riverbed and lost through surface outflow from the unit and by evapotranspiration. Abstraction from municipal and farm boreholes has reduced the natural discharge.

Changes in the volumes of saturated hard rock (higher ground) and alluvium (occupying lower ground along the river) between October 1985 and June 1988 have been analysed in terms of ground-water abstraction and loss during periods of no recharge (rainfall less than 10 mm/d) and of recharge.

The first has yielded coefficients of storage for the alluvium and hard rock ranging between 0.049 and 0.10 and 0.0054 to 0.007 respectively.

Using coefficients of storage of 0.07 and 0.0058, recharge has been determined for the only three periods of replenishment available and expressed in terms of total rainfall, and rainfalls exceeding 9.9 and 14.9 mm/day. The recharge threshold for hard- rock areas after a dry spell is considered to be at least between 10 and 15 mm per shower or day. Apart from higher percentages recharge resulting from considering only the higher daily rainfalls, recharge as a percentage increases with increasing seasonal rainfalls. For seasonal rainfall comprising the component of 15 mm/day and more recharge percentages range from 5.4 for 0 - 49 mm/season tot 9.9 for 250 - 299 mm/seasonal rainfall of 15 mm/day and more.

The steady or assured yield of ground-water unit XXIB was determined by

(1) taking its "live" storage to be equivalent to a minimum water depth of 26.5 mm and a maximum of 39.5 mm over its area

(2) calculating seasonal recharge for the period 1913-1989 from the De Aar rainfall record (it is assumed that the worst rainfall conditions that may be expected are included in this period)

(3) determining by trial and error the maximum constant annual abstraction rate that can be maintained (storage at beginning of season plus recharge minus abstraction = end of season storage = storage beginning of next season).

Estimates of the assured yield vary between a minimum of 7.2 mm/a to a maximum of 9.5 mm/a.

Of the appproximately 600 chemical analyses made on ground water samples which have been collected between 1970 and 1989, 65 percent have a total dissolved solids content of less than 1 000 mg/l and 83 percent less than 1 500 mg/l.

There is a tendency for ground water quality to deteriorate with pumping. The phenomena may be ascribed to the so-called double porosity nature of the aquifers. On pumping, particularly strenuous pumping, water held in pores and micro-fractures and which is presumably more saline, is mobilized. The wide variation in quality and very localised hydrochemical facies along the Brak River must be ascribed to the very shallow nature of the aquifer.

To identify the different hydrochemical facies and understand the processes which are involved, localised three-dimensional studies of flow paths and hydrochemistry will be required.

To describe the potential of ground-water resources around De Aar, the area has been subdivided on the basis of surface catchment and cross-cutting dolerite intrusions into 33 ground- water units. Based on the above-mentioned determination of steady or assured yield of unit XXIB, the assured yields of another 21 units, some already being exploited by municipality, have been estimated. Discounting the Hennops Kraal area (unit XXIIIB) the total assured yield has been estimated at between 7.7 and 9.3 million m^3 per annum. (The previous estimate (Vegter 1990b) was between 5.8 to 8.2 million m^3).

To establish the effect of ground-water abstraction for urban supply on the ecology, monitoring of ground-water levels, rainfall and vegetation over a period of 10-20 years will be required. Ground-water levels in river valleys should in any case not be lowered so far below riverbed level, that permanent damage is done to reeds and other stabilizing growth.

Successful operation of a municipal ground-water supply scheme, timeous development and introduction of additional new sources, depends on the continuous observation of ground-water levels, the recording of volumes pumped from individual or groups of boreholes or obtained from springs, the periodic measurement of electrical conductivity of water and/or chemical analysis, recording of local rainfall and river flows. These data should be continually evaluated by a hydrogeologist, and the pumping regime adjusted accordingly. Development of a management model(s) is considered premature.

The large scale exploitation of ground water at De Aar (i.e. for the Karoo) presents excellent opportunities for geohydrological research. It is urged that these opportunities should be grasped.

1. HISTORICAL OVERVIEW

1.1 Nineteenth century

In 1839 a farm named De Aar was allocated to Jan Gabriel Vermeulen alias Swart Jan, one of a group of pioneers who, since a few years previously, had been taking up land in this part of the Upper Karoo. The farm owes its name to a source of fresh water which initially must have issued upstream of an eastwest trending dolerite dyke - "de aar" - southeast of the present day town, close to the junction of the Noupoort and Beaufort West railway lines. A well at this location subsequently served as a watering point for thousands of sheep. When Brounger Junction came into being with the completion of the two railway lines in 1884, the station was also supplied from this well which was known as "Samesuiping" because it served both subdivisions of the original farm.

Shortly after the Anglo Boer War, the brothers Wulf and Isaac Friedlander who were trading at the station, purchased the portion of De Aar farm belonging to D.F. Grundlingh and had a town laid out. Stands were sold in December 1902 by public auction. De Aar was proclaimed a municipality in 1904.

1.2 Early urban and railway supplies

Between 1902 and 1936 growth of the town was impeded by the lack of a municipal water supply. Residents had to provide water themselves. Stands were served by private boreholes. Serious water shortages were experienced. In 1925 one third of the town's 200 holes failed; in 1927 197 holes of a total of 310 failed - a state of affairs repeated in 1933.

An inadequate supply forced the Cape Government Railways shortly after the turn of the century to drill for water in the vicinity of the station. No record of the results is available except for that of a deep borehole about which B.W. Ritso, Inspector of Boring, Public Works Department reports as follows: "The site of the one (deep borehole) at De Aar was in the centre of a network of dolerite dykes and penetrated such a quantity of igneous rocks that it was considered useless to continue it beyond 1630 feet." No yield was reported.

The Railways subsequently (date unknown but earlier than 1916) obtained a portion of the farm Caroluspoort 3, 14 km east of De Aar (see folder 1B for location of farms), where the westward- draining Brak River cuts through a range of hills. Water, apparently both storm flow and effluent ground water from the alluvial deposits, was withdrawn from a weir at the lower end of the poort. At some time or other the weir was destroyed by a flood. In 1948 when the author visited Caroluspoort water was obtained by the Railways from the so-called Stofpoort springs which issued in a tributary donga east of the poort. The volume pumped from the donga immediately above its confluence with the Brak River amounted to 770 m^3/d. Seepage in the Brak River was not utilized. Apart from water supplied by the Municipality, the Railways also at that time obtained a volume of 360 to 450 m^3/d from wells where the Kimberley railway line crosses the Brak River north of De Aar. These wells remained in use up to the middle seventies.

1.3 Initial steps for a municipal scheme

Three water supply schemes were considered by the Town Council during the above-mentioned period of critical water shortages. Of two possible sites for a storage dam on the Elandsfontein Spruit, namely on Zwartekopjes 131 and Klein Brandfontein 87 (Renosterpoort), the former was surveyed in 1932 by consulting engineer T. Stromsoe. To avoid submergence of the farmstead the height of the dam had to be limited to 35 feet (8.7 m). The scheme was considered too costly by the Town Council as the S.A. Railways required only 50 000 gallons (227 m^3) per day from it. It is interesting to note that according to J.P. Kriel's analysis (1958) such a dam would have stored 50% of the mean annual runoff (corrected for soil conservationwork supstream) and would have had an assured yield of about 1 300 m^3/d. The assured yield of a dam with storage equal to the reduced MAR at either Zwartekopjes or Klein Brandfontein would have been approximately 2 000 m^3/d.

In 1927 the Town Council in principle had already accepted the third possibility namely the Burgerville scheme. This scheme entailed purchasing the small village of Burgerville, which was established in 1907 34 km east of De Aar, as well as the farm Zewe Fountain 9 on which it was situated. Because of prolonged negotiations nine years elapsed before the scheme became a reality. It cost £61 165 and was planned to yield 175 000 gallons (about 800 m^3) per day through a seven inch pipeline. Of this volume, the Railways were to receive 50 000 gallons (about 230m^3) per day.

1.4 The Burgerville scheme

The sources of supply of the Burgerville scheme were originally the Bloufontein and Rivier springs on northern Zewe Fountain and the Populierbos spring at Burgerville. According to consulting engineer W.C. Gibbons, the former two yielded about 140 000 gallons (640 m^3) per day with little variation. The latter varied from 20 000 (90 m^3) to 60 000 gallons (270 m^3) per day.

By 1945 the Railways were taking in addition to own sources of supply, 117 000 gallons (530m^3) per day from the Municipality. It was desired to increase this to 300 000 gallons (approx 1400m^3) per day. The town's requirements had also increased and were estimated by W.C. Gibbons in 1946 at roughly 233 000 gallons (1060m^3) per day. The Municipality accordingly embarked on a drilling programme and the Geological Survey was called upon to advise on sites (de Villiers 1945).

A total of 19 holes were drilled, two or three of which on sites recommended by the Geological Survey. Information on the drilling is scant and identification of the holes in the field is uncertain. J.F. van Eetveldt, chairman of the Council's water committee at that time, reported that four holes were dry; the yields of another five were too small to justify their use for urban supply although they could be equipped for stock watering. Ten of the holes had yields ranging between 3 000 and 11 000 gallons per hour (4 - 14 l/s).

Of the ten holes, five were to be equipped with diesel-engine driven turbine pumps and five with windpumps working 8 inch (200 mm) cylinders (W.C. Gibbons 1947). It was considered that these holes would be capable of supplying 504 000 gallons (2 300 m^3) per day, *in addition to the 244 000 gallons (1 100 m^3) per day yielded by the springs and a so called siphon borehole on northern Zewe Fountain. The 7 inch (178 mm) steel pipe line to De Aar which had become badly corroded where it crossed brack soil was to be replaced by a 12 inch (300 mm) mains capable of carrying 800 000 gallons (3 600 m^3) per day. (According to Ninham Shand (1973) the capacity under gravity is 4 700 m^3/d.) Although no written confirmation has come to hand all of this work was apparently carried out.*

The consulting engineer Gibbons report also contains recommendations for a storage dam on northern Zewe Fountain with a capacity of 414 million gallons (1.9 million m^3) and covering 103 hectares when full. It was thought capable of supplying 450 000 gallons (2 000 m^3) per day for at least 6 months per year. This would mean that boreholes equipped with turbines need only be pumped during droughts. The dam was not constructed - reason unknown, possibly not permitted.

1.5 <u>Ground-water investigation and development at Caroluspoort 1954</u>

In 1954 the Geological Survey was called upon to undertake ground-water investigations on behalf of the S.A. Railways at Caroluspoort and again for the Municipality on Zewe Fountain Burgerville. At that time De Aar station was supplied

(a) by the Municipality with 300 000 to 430 000 gallons (1 400 - 2 000 m^3 per day).

(b) from Caroluspoort with 150 000 gallons (680 m^3 per day).

(c) from the Railways Brak River wells with 50 000 gallons (230 m^3 per day).

The total amounted to 500 000 to 630 000 gallons (2 300 to 2 900 m^3) per day.

The only figure available for the town's consumption is that of December 1952 - about 1 600 m^3/d. When necessary the supply from Zewe Fountain Burgerville was supplemented by purchasing water from a Mr Jooste of the farm Bloemhof where two boreholes capable of yielding 15 000 gallons per hour (19 l/s) were pumped.

The S.A. Railways were advised of two possible solutions to the Caroluspoort water supply problem:

(a) a storage dam in Caroluspoort

(b) improved utilization of the ground water stored in the alluvium by abstraction from wells instead of collecting seepage in the Stofpoort donga.

The second alternative was taken up by the Railways. Six wells lined with porous concrete with a diameter of 3,4 m were constructed of which three had yields of about 10 l/s.

1.6 Ground-water investigation and development Zewe Fountain/Burgerville 1954

The 1954 investigation of the Geological Survey for the Municipality resulted in the selection of seven borehole sites on Zewe Fountain. The Municipality had five sites drilled of which one borehole G6787 ("In die dam") on the northern portion of the farm and two on the southern (Burgerville) portion G6783 ("Lekkerwater") and G6785 ("Bailer gat") were equipped with turbines.

At this time the Municipality was advised about the necessity of continued recording of ground-water levels and of volumes of water obtained from the springs and different boreholes. These recommendations were unfortunately not put into practice by the Municipality. Such data would have been of very great value for assessing the assured yield of Karoo aquifers. An automatic water level recorder was however supplied and erected by the Geological Survey in 1954 on borehole no. 5 (Northern Zewe Fountain see old plan Gph 747). The recorder, later numbered D6N501, was moved to borehole no. 2 in 1956 (old plan Ghp 747; on plan Ghp6903 the borehole is number ZN64) where it has been in operation up to the present. Its record clearly demonstrates that ground water is being recharged from time to time (folder 5). Coupled with a history of more than four decades of continuous ground water abstraction, it proves indisputably the validity of utilizing ground water for urban supply.

In the period 1955-57 the average volumes of water supplied by the Municipality were:

Town	216 000 gallons or	980 m^3/d
Railways	319 500 gallons or	1 450 m^3/d
Total	535 500 gallons or	2 430 m^3/d

This volume was obtained from the springs and municipal boreholes on Zewe Fountain/Burgerville.

1.7 Purchase of private water by De Aar

At about this time additional water became available from two private boreholes - on the Leeufontein portion of Zewe Fountain 9 (de Kock) and on Leuwe Fountain 27 (C.M. Oosthuizen). Pumpage from Leeufontein over the period 1962 to 1987 has averaged 133 500 m^3/a. In the hydrocensus tables compiled by A. Woodford it is stated that the Municipality had a contract with the owner of Leuwe Fountain to pump up to a maximum of 13 600 m^3/month from a pit numbered LN12 and shown on plan Ghp6903 (Woodford 1989). Water was pumped from here over the period 1957 to 1981. The maximum was 27 000 m^3 in a month. No record of pumpage exists.

1.8 S.A. Railways' quest for more water

In 1958 the Department of Water Affairs was approached by the S.A. Railways about finding an additional supply of half a million gallons per day (about 2 300 m^3/d) for the town and the Railways, within a distance of 48 km from De Aar. A supply from the Orange River was discounted by the Department of Water Affairs on the grounds of

(a) cost - 6/6 to 8/6 (shillings/pence) per 1 000 gallons (14.3 to

18.7 c/m^3) compared to the municipal tariff current at that time of 1/9 (or 3.8 c/m^3).

(b) future redundancy of the scheme in view of projected development of the Orange River.

Following on a reconnaisance visit by officials of the Department of Water Affairs, the S.A. Railways and the Geological Survey in February 1958, recommendations as to what should be done were made in reports by J.P. Kriel and by J.R. Vegter and F.W. Schumann viz.:

(a) Geohydrological investigations of

(i) Caroluspoort 3 (J.P.K. and J.R.V./F.W.S.)

(ii) Zewe Fountain 9 and adjoining farms (J.R.V./F.W.S.)

(iii) the valley of the Elandsfontein Spruit between Zwartekopjes 13 and Klein Brandfontein 87 (J.P.K. and J.R.V./F.W.S.)

(b) Regular gauging of the artesian boreholes and spring on the De Bad portion of Riet Fountain 39 (J.P.K. and J.R.V./F.W.S.)

(c) A reconnaisance hydrogeological and borehole survey to identify other possible groundwater sources (J.R.V./F.W.S.).

Arising from these recommendations and following previous promising results, an intensive investigation was undertaken by the Geological Survey in 1959-60 to determine the supply that could be developed on the Railway's Caroluspoort property (approx. 200 ha) and on adjoining land further to the southeast along the Brak River. From this investigation it was concluded that a steady supply of between 250 000 to 300 000 gallons (1 100 - 1400 m^3) per day could be obtained from Caroluspoort provided additional wells were sunk in the alluvial deposits outside Railway property. In 1963 the construction of 6 wells was undertaken. Based on long-term pumpage and water-level fluctuations Z.M. Dziembowski (1971), J.R. Vegter (1975) and Z.M. Dziembowski (1990) have reassessed the assured yield of the Caroluspoort wells at 2 000, 1 600 and 1 770 m^3/d respectively. If those wells which yield a poorer quality are discarded, the assured yield decreases to 740 m^3/d (Dziembowski 1990). The Caroluspoort scheme has now (1990) been taken over from the Railways by the De Aar Municipality.

During the period 1960 to 1988 annual abstraction at Caroluspoort by the S.A. Railways has varied between 274 000 and 822 000 m^3. Water-level fluctuation over this period was about 6 metres. More than a doubling of the supply from Caroluspoort was thus eventually achieved (248 000 m^3 in 1954) through the scientific siting of abstraction points.

Several areas southeast of De Aar also received attention of the Geological Survey during 1958/59. Firstly the possibility of obtaining a supply of 50 000 gallons (approx 230 m^3) per day for Burgerville Road was investigated in 1958 on behalf of the S.A. Railways (Schumann 1958a and b). Nine sites were selected along the railway line. There is no record that these sites were drilled. In addition the following properties in the vicinity of Burgerville Road were *identified as possible sources for a supply to the station as the owners were prepared to make certain boreholes available for that purpose:*

> *Leuwe Fountain 27 (Leeufontein, C.M. Oosthuizen) Sipreshof (portion of Zewe Fountain 9, B. Jooste - two areas where boreholes G38270 and G38269A were drilled in 1988) Bloemhof 145 (J. Boonzaaier) Taaibosch Fontein 41 (B. Oosthuizen)*

1.9 <u>Abortive attempts by De Aar at obtaining additional supplies 1959/69</u>

In 1959 the Geological Survey was requested by the Municipality to assess the potential yield of boreholes on Hartebeeshoek of Mr van Eetveldt. F.W. Schumann (1959) concluded that the boreholes were capable of yielding only one quarter of that required by the Municipality (120 000 gallons or about 550 m^3/d) and that further drilling and testpumping would be necesary to prove the potential of this farm.

Because of the disappointing test results on Hartebeeshoek, the Municipality requested the Geological Survey to investigate the possibilities of developing an additional supply on Leuwe Fountain 27 and other farms adjoining Zewe Fountain. Four drilling sites were selected on Leuwe Fountain 27 (Hauger 1959a and b) - three alongside dykes of which at least two were drilled and one in a weathered dyke. The result of a pumping test on an existing borehole on Leuwe Fountain was inconclusive. Hauger (1959 a) drew attention to the possibility of obtaining water from Sipreshof and Helderwater 10. Information on drilling results and follow up by the Municipality is lacking. There were apparently no further developments.

In 1968 the question arose whether the Municipality should purchase portion 3 of Hennops Kraal, 976 ha in extent and situated about 34 km north of De Aar. The owner of this farm which appeared to be well endowed with ground water, was prepared to sell it at a price of R85 000 to the Municipality. Renewed attention was also given at this time to the idea of supplying De Aar from the Orange River a long-nurtured ideal of the Town Council. Development of a supply from Hennops Kraal was seen as the first step in attaining this ideal by providing a pipeline part of the distance to the Orange River. At this point in time it was uncertain when construction of the P.K. le Roux dam and the proposed southern canal would commence, which would have shortened the distance to Orange River water considerably.

Two officials of the Department of Water Affairs and the Geological Survey undertook a reconnaisance of Hennops Kraal on the 22nd May 1968. The essence of a brief preliminary report by F.W. Schumann (1968) was:

(a) The combined yield of a group of wells could be 25 l/s.

(b) This rate might not be maintained during droughts.

(c) Extended simultaneous pumping tests should be conducted on four wells before deciding on the purchase of the farm.

For unknown reasons (possibly the high cost of the pipeline from

Hennops kraal) no further action appears to have been taken by the Municipality.

The Geological Survey was asked instead to site boreholes close to De Aar (and presumably also on Zewe Fountain) to obviate expenditure on lengthy pipelines. During the first half of 1969 sites for boreholes were selected as follows (Erasmus 1969a and b):

(a) On Zewe Fountain 9 seven sites. Full details of the drilling operations are not available. Considerable difficulty was experienced in drilling with an air drill through loose alluvium. Eventually holes were completed with a jumper rig at three of the sites. Several holes were drilled at the sites which were selected on dyke contacts. Boreholes at sites G23229 and G23232 have been equipped with turbines.

(b) On the townlands one site south of the reservoirs in the vicinity of the shooting range. It was drilled and its yield was inadequate for incorporation in the municipal supply.

(c) On Blaauw Krans 144 four sites on alluvial deposits along the Brak River. One hole only was drilled penetrating 15m of alluvium overlying dolerite. Reasons for discontinuing the drilling of a promising proposition are unknown.

(d) On Hillside three and Paarde Valley 145 one site. Two of the sites on Hillside were drilled but failed to strike strong yields. In addition the drilling contractor made three unsuccessful attempts at a guarantee hole. It is unknown whether the Paarde Valley site was drilled.

1.10 Regional reconnaissance 1970

A photogeological interpretation (Temperley 1971) and hydrocensus (de Bruin and Vegter 1971) was carried out by the Geological Survey in 1970 of an area of about 4 000 km^2 around De Aar, with the purpose of identifying favourable areas for developing urban groundwater supplies. The following target areas were identified:

(a) The Brak River valley
- *(i) between Roode Kraal 28 and Caroluspoort 3;*
- *(ii) on Paarde Valley 145 and Blaauw Krans 144;*
- *(iii) between Spioenkop (portion of Kalkfontein 85) and Tweefontein (portion of Spreeuwsfountain 88).*

(b) The valley of the Elandsfontein Spruit between Zwartekopjes 131 and Brandfontein 87 including a tributary on Smauspoort 130.

(c) Farms adjoining Zewe Fountain 9.

(d) The valley of the Wag 'n Bietjie spruit (Wagt en Bittje 5).

(e) The farms Nieuwejaars Fountain 137 and Ezels Fountain 65.

1.11 Groundwater investigations 1971-75

In pursuance of these recommendations detailed investigations comprising hydrogeological mapping, geophysical surveys, exploratory drilling and testpumping were undertaken in the period August 1971 to May 1975 in target areas (a)(i) South-eastern, (a)(ii) (Northern), (b) (Southwestern) as well as Zewe Fountain including privately owned portions. In total 477 boreholes (342 exploratory and 135 observation), with a summed depth of 8 136 metres were drilled. Depths of holes ranged from 1.5 to 64 metres; the majority being less than 20 metres deep. Fifty four pumping tests (step-drawdown and constant rate) were conducted on 30 boreholes. Forty-seven holes were recommended for production with pumping rates ranging between 5 and 22 l/s (von Hoyer 1972, 1974; 1975; 1976 and von Hoyer and Rinkel 1976).

In Smit's (1975) summary report on the 1971-75 investigations the safe yields of the different areas were stated to be as follows:

Northern area (target a(ii) and extended westwards) to include portions of Kappokpoort and Kalkfontein)		1.2 x 10^6 m^3/a
Southwestern area (target b comprising Zwartekopjes-Vaalbank-Renosterpoort	0.55 x 10^6 m^3/a)	
and Brandfontein	0.25 x 10^6 m^3/a)	0.8 x 10^6 m^3/a
Southeastern area (target a(i))		1.2 x 10^6 m^3/a
Caroluspoort proper (S.A. Railways)		0.5 x10 ^{6} m^3/a
Zewe Fountain (Burgerville)		0.6 x 10^6 m^3/a
Total		4.3 x 10^6 m^3/a

1.12 Southwestern and Southeastern Schemes

In anticipation that additional sources of supply would become available southeast and southwest of De Aar (target areas (a)(i) and (b) Ninham Shand and Partners (1973a and b) submitted two civil engineering reports to the Municipality in 1973 for:

(a) *increasing the flow rate through the Burgerville mains from the then existing capacity of 6 000 m^3/d (booster pump at De Aar installed in 1963) to 7 800 - 8 000m^3/d by means of a booster pump at either Zewe Fountain 9 or Wag en Bittje 5. This would allow introduction of water from boreholes along the Brak River (or the so called Southeastern borehole field).*

(b) *the exploitation of the newly established borehole field southwest of De Aar, based on pumping 12 boreholes on Renosterpoort and Vaalbank (portions of Brandfontein 87 and Zwartekopjes 131) and capable of delivering up to 3 000 m^3/d.*

In September 1978 the Southwestern scheme was brought on stream with the commissioning of eight production holes on Renosterpoort and Vaalbank. Another four holes situated on Zwartekopjes in the Vaal-

bankpoort were added in February 1980. Between 1980 and 1988 production from these holes varied between 0.65 to 1.14 million m^3/a.

Production boreholes on Brandfontein northwest of Renosterpoort were not connected to the scheme.

The Southeastern scheme consisting of boreholes in the Brak River valley upstream of Caroluspoort came into operation in 1981 with one borehole. From 1985 onwards up to seven holes were pumped at times and the volume pumped from 1985 to 88 ranged between 0.49 and 1.0 million m^3/a. In 1989, largely owing to the heavy rainfall in 1988 and 1989, only 0.14 million m^3 was abstracted. The Southeastern borehole field was however not developed to the extent that had been envisaged by the 1971-75 groundwater investigations.

1.13 Deterioration of water quality and rising demand

During the relatively dry middle eighties the quality of the municipal supply deteriorated. The suitability of ground water from the Northern area, the next to be incorporated in the municipal supply was also questioned. Quality was thought to have fallen off after the 1974 and 1976 floods. A hydrochemical study was accordingly undertaken in 1988/89 by R.P. Parsons (1989). Although it was ascertained that quality had declined after boreholes had been commissioned, ad-hoc sampling at widely scattered intervals does not allow firm conclusions as to whether there is a continuing trend of deterioration or whether a more or less stable but fluctuating condition obtains (author's observation). The latter appears to be the case in areas which have been subjected to pumping over many years e.g. Caroluspoort 3 and Zewe Fountain 9.

1.14 Investigations 1987 to 1989

To meet the expected rise in consumption for the next decade or two and following on renewed representations by the Town Council for a supply from the Orange River - a costly scheme at the present and projected rate of consumption - the Directorate of Geohydrology embarked on further groundwater investigations during the period 1987 to 1989. This comprised exploratory drilling, testpumping and establishment of additional production holes in the southeastern and Zewe Fountain (Burgerville) areas, the redrilling and/or redevelopment as well as testpumping of the 1971-75 proposed production holes in the northern and Brandfontein areas, and the investigation of further possibi-lities in the so-called extended northern and the Houtkraal-Hennops-kraal areas involving drilling and testpumping (for details consult Woodford 1989, 1990a, 1990b ; van Wyk 1989, 1990).

At the very beginning of this programme several exploratory boreholes were drilled with no success in the industrial area of De Aar.

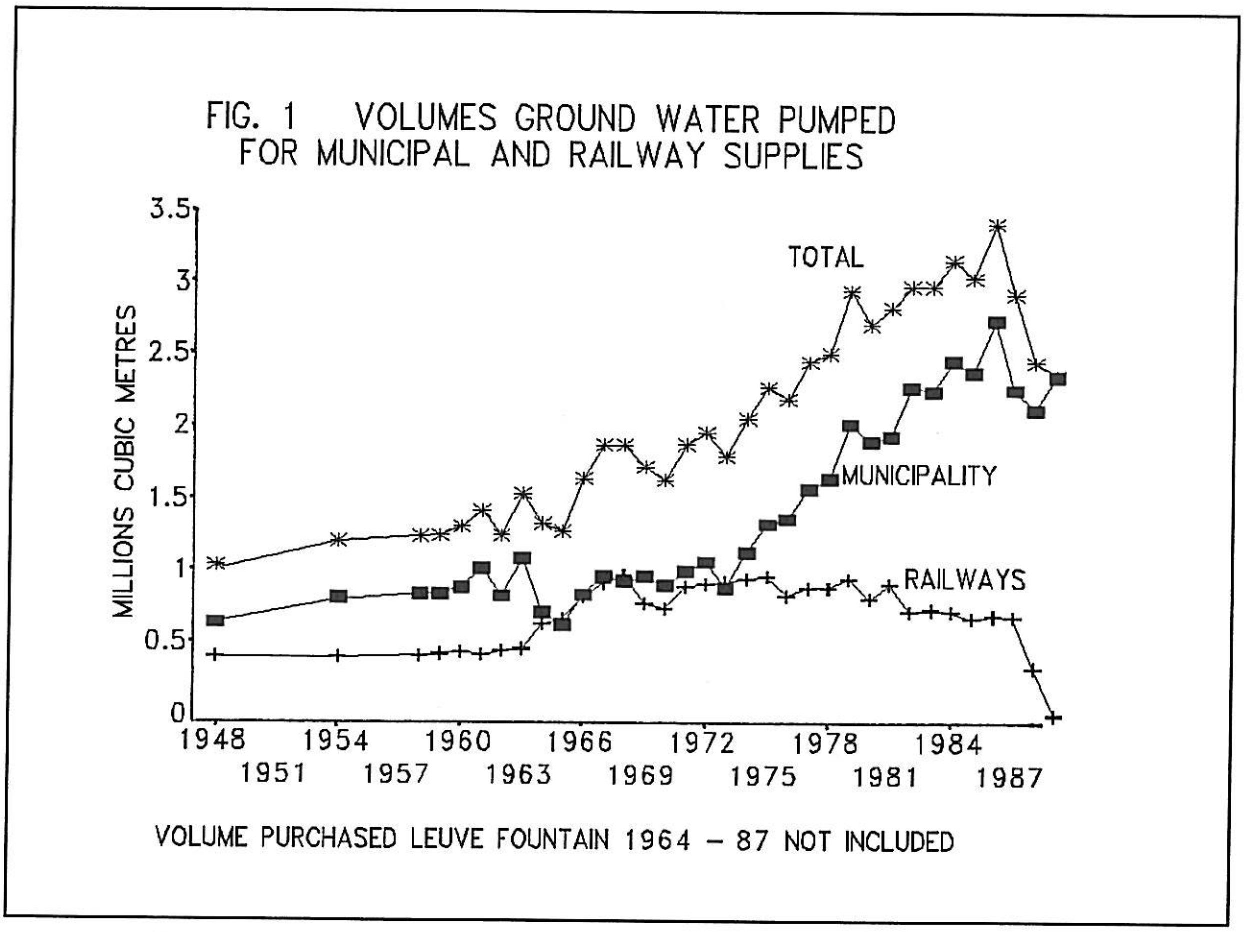
A total of 240 holes (about 9 000 m) were drilled of which seven are replacements for proposed production holes drilled during the 1971-75 investigations. Fifty-three step drawdown and forty-seven constant rate pumping tests were conducted as well as a 10 day test involving five boreholes on Hennops Kraal.

During 1987 the Town Council also had several holes of over 100 m *deep drilled on the townlands. These were failures.*

The 1987-89 investigations culminated in reports by Vegter (1990a, 1990b), Stewart Sviridov and Olivier (1990) and Haasbroek (1991). The latter report recommended that the growing demand should be met by expanding the existing groundwater supply.

*1.15 **Volumes pumped 1948-1989.***

Volumes of ground water abstracted for municipal and railway supplies for the period 1948-1989 are shown in table 1 (Appendix) and figure 1. Combined abstraction by the Municipality and the Railways increased from about 1 million cubic metres in 1948 to a peak of 3.4 million cubic metres in 1986. It dropped thereafter owing to the reduction and eventual cessation of pumping by the Railways at Caroluspoort.



2. *GENERAL FEATURES*

2.1 *Delimitation of area*

Folders 1A and 1B outline the area with which this report is concerned and of which a geological map has been compiled by the author and Mr J. Steyn.

The trapezoidally shaped geological map covers approximately 3545 km^2. It is bounded in the west and east by lines of longitude 23° 48' 8" and 24° 28' 24" E, and in the south by latitude 30° 53' S. Starting at a point on Diederiksput 19 (known as Brosdoornput), District Britstown at 23° 48' 8" E and 30° 17' S, the northern boundary runs to 24° 6' 22,5" and 30° 19' 3" S (on Baartmanskoppie 95, District Philipstown), and thence to 24° 28' 4" E and 30° 35' 9" S (on Trekpoort 163, District Philipstown). The southwestern and southeastern corners fall on Dassiesfontein 139 (District Britstown) and on the boundary between Franschman's Kop 42 and Grogblossom 43 (District Hanover).

2.2 *Topography*

The main features are also shown in folder 1A. Lying at an altitude of roughly between 1 200 and 1 500 a.m.s.l., the area is part of the Upper Karoo physiographic region (van Eeden 1972). On Kruger's (1983) terrain morphological map of Southern Africa, the area is designated as lowland with hills (Class C12).

Topographic relief is most subdued in the southeast i.e. east of the De Aar - Beaufort West railway line and south of the De Aar - Burgerville road. Here dolerite koppies, ridges and plateaux generally stand less than 50 m above the surrounding country. In the far east the watershed (elevation 1 400 - 1 450 m.a.m.s.l.) between the Seekoei River (drainage region D320) and tributaries of the Brak River is marked by pans and indistinct and discontinuous drainage lines.

The Renosterberg which lies about 20 km north of De Aar, and attains an altitude of 1633 m.a.m.s.l., is the most prominent topographic feature in the area. It rises 250 m above its immediate surroundings and stands more than 400 m above the bed of the Brak River about midway between it and De Aar.

Relatively more rugged topography is also encountered from about 13 km east of De Aar, in the form of two more or less northsouth trending ranges of dolerite-capped hills. The first is situated on Caroluspoort 3. A narrow gorge has been cut through it by the Brak River. The second is a westerly facing escarpment like feature running from Pienaarskloof 136 in the north to Zewe Fountain 9 in the south. The highest point in the area, 1 686 m.a.m.s.l., lies on Pienaarskloof 136.

Other prominent topographic features lie west and southwest of De Aar. There is a ring of dolerite hills, 12 km in diameter, directly west of the town. The Kasarmberge which form the southern side of the ring are part of a hilly terrain which extends southwards over an area of 50-60 km^2. It is built by a horizontally disposed dolerite sheet. The southwestern and southeastern extremities of the *hilly terrain are known as Maanhaarberg (1 667 m. a.m.s.l. and situated on Damfountain 138) and Platberg (1 523 m. a.m.s.l. and situated on Zwartekopjes 131). Southwest of Maanhaarberg the Swartrant, a north-south trending range of dolerite hills, is the eastern side of another ring structure.*

2.3 Drainage

The area under discussion constitutes a portion of the catchment of the Brak River (quaternary drainage region D603) which is a tributary of the Ongers River (drainage region D6). The upper Brak River has four main branches. The author has subdivided the upper Brak River catchment into the following quinary regions:

(1) the Hondeblafspruit D603/11 which joins the Brak about 10 km above the defunct Baverspoort gauging station D6H002A01.

(2) the Brak River proper with headwaters close to and some distance west of Hanover. Its catchment within the area of interest has been divided into the following:

- *(a) D603/3 Headwater tributaries and river downstream to Caroluspoort.*
- *(b) D603/4 Leuwe Fountain tributary.*
- *(c) D603/5 Bloemhof tributary.*
- *(d) D603/6 Maatjies Fontein or "Stofpoort" tributary.*
- *(e) D603/7 Paarde Valley tributaries.*
- *(f) D603/8 Vetlaagte tributary.*
- *(g) D603/9 Renosterberg tributaries.*
- *(h) D603/10 De Aar tributary.*

(3) the Elandsfontein Spruit D603/2 which rises along a southeasterly trending watershed between Deelfontein railway station and Bontebokfontein 97 18 km southwest of Hanover.

(4) the Kromme River - Dassiefontein leegte D603/1 rising in dolerite hills west of Deelfontein railway station. It joins the Elands-fontein Spruit west of Renosterpoort (Brandfontein 87). The confluence with the Brak is about 12 km downstream from this point on western Kalk Fontein 85.

Mean annual runoff figures as estimated by Sorour and Nel (1990) are given in table 2.

TABLE 2 MEAN ANNUAL RUNOFF BRAK RIVER TRIBUTARIES

Catchment	Area (km^2)	Mean annual precipi- tation (mm)	Mean[1] annual runoff million m^3/a
Brak River D603/3 - D603/6	1495	309	10,3
Brak River D603/3 - D603/10	2310	303	15,1
Elandsfontein Spruit at Renosterpoort D603/2	1478	290	8,9
Kromme R - Dassiefontein Leegte D603/1 (at confluence with Elandsfontein Spruit)	600		2,4[2]
Hondeblafspruit D603/11		no estimates	

(1) Uncorrected for upstream storage in dams and behind soil conservation embankments.

(2) Difference between MAR at railway bridge and MAR at Renosterpoort corrected for reduction in catchment area.

2.4 Climate

The area lies in the southern steppe, semi-arid climatic region Ss of Schulze (1986). De Aar's climate is characterised by

(a) large variations in diurnal and seasonal air temperature: monthly mean day temperatures range between 23.9°C in January and 8.6°C in July. The monthly mean diurnal variation ranges from 15.0°C in March/April to 17.6°C in September. Highest and lowest maxima and minima recorded are 40.7 (29/12/44) and 2.8° (21/5/82) and 26.4° (10/3/83) and -10.0°C (21/7/43).

(b) showers and thunderstorms which occur from October to March culminating in February/March. The mean annual precipitation at De Aar from the 1913/14 to 1987/88 seaons excluding 1922/23 and 23/24 (incomplete data) amounts to 284 mm. A maximum of 714.7 mm was recorded in the 1973/4 season and a minimum 106.4 mm in 1952/53.

(c) American class A pan evaporation averages 2 853 mm per annum (Table 19 Appendix). The mean maximum monthly rate is 405 mm (in December) and the mean mimimum monthly rate 91 mm (in June).

2.5 Soils

The following soil forms are present within the dolerite ring structure west of De Aar (Kirchner et al 1991) :

Mapping unit	Soil form	Soil series
0	Oakleaf	Letaba
S	Sterkspruit	Swaerskloof
H	Hutton	Shigalo
M	Mispah	Mispah
MK	Mispah	Kalkbank
SE	Sterkspruit	Swaerskloof (eroded phase)

Three broad soil patterns are distinguished in the surroundings of De Aar:

Ae : Red apedal freely drained soils
Fb : Mispah (lime rare or absent in upland areas but generally present in lowlying soils)
Ib : Rock areas
(See 1 : 250 000 Land type map Colesberg Soil and Irrigation Research Institute, Department of Agriculture and Water Supply 1987)

2.6 Vegetation

Acocks (1953) recognises two veld types: Central Upper Karoo in the west grading into False Upper Karoo east of De Aar.

Central Upper Karoo vegetation includes amongst numerous others, various species of Eriocephalus, Pentzia, Pteronia, Nestleria, Salsola, Aster, Lycium and Sutura. Rhus undulata var. burchelli is the characteristic shrub of the hills. Grasses are mainly represented by Eragrostis and Aristida species. The False Upper Karoo scarcely differs in appearance from the Central Upper Karoo except that it has more grassiness mainly Aristida curvata, A baslicollis and Eragrostis lehmanniana. The principal shrub in the hills is Rhus erosa.

3. GEOLOGY

3.1 Stratigraphic column

The geological map accompanying this report (folder 2A) was compiled from mapping of different parts of the area on scales of 1:20 000, 1:36 000 and 1:50 000 by A.C. Woodford during the course of the 1987/89 groundwater investigations, supplemented with information from provisional regional geological maps (scale 1:50 000) kindly supplied to the Directorate of Geohydrology by the Geological Survey (see folder 1A).

The following strata are present:

TABLE 3 STRATIGRAPHIC COLUMN

Period	Lithostratigraphic Designation	Rock types
Quaternary to Tertiary		Alluvium Colluvium Calcrete
Cretaceous		Kimberlite dykes
Jurassic		Dolerite sheets and dykes
Late Permian	Beaufort Group : Middleton Formation	Mudstone siltstone and sandstone
Lower Permian	Ecca Group : Tierberg Formation	shale, siltstone

The oldest strata are of Permian age and belong to the Ecca and Beaufort Groups. The former occupies the northwestern section of the map. The overlying Beaufort Group outcrops in the east and south-east.

3.2 Ecca Group

The Ecca Group is represented by the Tierberg Formation (Prinsloo 1989; Le Roux 1990). Its base is not exposed in the area. The Formation consists of a monotonous succession of thin bedded bluish grey shales with locally developed carbonate concretions on certain horizons and yielding a splintery product on weathering.

The succession of shales is interrupted on several horizons by layers and lenses of siltstone and fine-grained sandstone. These increase in number towards the top of the succession. Evidence points to a changing depositional environment of the Tierberg Formation - from its base upwards diminishing water depth and increasing energy conditions. Visser and Loock (1974) postulate a change in environment from deep marine (infraneritic) through prodelta to delta and delta *front. On the other hand as an alternative to the fluviodeltaic model for the Ecca-Beaufort transition, Smith and Zawada (1988) propose a shallow marine shelf which prograded over a basin shale.*

3.3 Beaufort Group

The position of the Ecca-Beaufort contact shown on folder 2A is open to question. In the explanation to the unpublished geological sheet 3022 (Britstown) Prinsloo (1989) states that strata typical of the Carnarvon formation (not yet formally recognised by SACS) are not recognisable east of longitude 23° 35', that is within the area covered by folder 2A. This formation which Prinsloo places at the top of the Ecca Group is seen as the transition between the predominant marine Ecca and the fluvial Beaufort Groups. On the provisional Geological Survey sheets 3022 BD (Montrose) 3022 DB (Brand) and 3022 DD (Deelfontein) which cover the western part of folder 2A, strata have however been assigned to the Carnarvon formation. In the compiled geological map (folder 2A) these strata have been included in the Middleton Formation (Beaufort Group). Should to the contrary the strata be taken as belonging to the Ecca Group, only a minor shift of the Ecca Beaufort boundary on the map would be involved, except in the far southwest where the boundary on Damfountain 138 would move eastwards to the adjoining Nieuwejaars Fountain 137.

The problem regarding the boundary between the Ecca and Beaufort in the vicinity of De Aar is however not fully resolved in this way.

Von Hoyer (1975) describes the occurrence of sandstone, mudstone and shale in higher-lying terrain on Kalkfontein 85 and Kappokpoort 82; on Blaauwkrans 144 thick layers of sandstone fine-grained light grey to greenish white in colour alternating with sandy shale have been found in boreholes; and on Paardevlei 145 and Du Plessisdam 179 fine-grained sandstone and brightly coloured mudstone greyish green, light green and bluish grey are present. On folder 2A these farms are indicated as being occupied by Tierberg Formation. Is this correct? Or do these beds belong to either the Beaufort Group or the Carnarvon formation? On the other hand Woodford states that boreholes drilled in the Brak River valley on Caroluspoort 3 and Rietfontein 6 generally penetrated blue to dark grey to black shale with minor discontinuous bands of siltstone i.e. typically Tierberg Formation.

According to Prinsloo (1989) and le Roux (?1990), the Ecca Beaufort boundary has been mapped at the base of the first prominent sandstone following on the Tierberg Formation. (Note that in its type area, the contact between the relatively arenaceous Carnarvon formation and the underlying Tierberg Formation is also taken at the base of the most prominent sandstone or siltstone.)

The Beaufort marker sandstone is fine grained and has a light grey to brownish colour. It is overlain by upward fining cycles, each consisting of lighter coloured medium-grained sandstone at the base, followed by siltstone grading into blue grey and maroon mudstone.

3.4 *Intrusives*

Apart from steeper transgressive intrusions which acted as feeder channels, undulating sheet-like dolerite intrusions appear mainly on two horizons as is evident in the Renosterberg, the Pienaarskloof escarpment north-east of De Aar as well as Platberg west of De Put siding. The structure is illustrated in broad outline by means of south-north section DB and west-east section DE (folder 2B). East-west section ABC shows in greater detail the irregular undulatory nature of the lower dolerite sheet as disclosed by exploratory drilling in the Houtkraal area, 28 km north of De Aar. The dolerite intrusions on the two horizons are not single continuous tabular bodies; apart from undulation, furcation is evident in places e.g. von Hoyer (1975) describes the existence of separate sheetlike bodies on Paardevlei 145. The maximum thickness of the sheets appears to be about 60 metres.

Directly west of De Aar is the well-known ring-shaped dolerite structure. Other apparently similar though not as conspicuous features may be distinguished. The Swartrant on the southwestern edge of folder 2A is the eastern side of a ring structure. Another basin-like feature is present between De Aar and Caroluspoort. The northern half of Zewe Fountain 9 occupies the southern end of an oval-shaped basin. For a discussion on the origin of ring-shaped dolerite outcrops the reader is referred to Meyboom and Wallace (1978). Their explanation of the formation of ring structures is open to argument.

Most transgressive intrusions up to 30 metres wide have arcuate or sinuous outcrops. Their form and dip is variable and changes to virtually horizontal sheet-like bodies have been noted. Regular straight dykes are more or less restricted to the Middleton Formation southeast of De Aar. They vary in width from one to more than 10 metres, and in length from one to about 6 or 7 km an exception being a dyke in the southwestern corner of folder 2A which can be followed beyond the confines of the map over a distance of 30 km. It appears to coincide with the continuation underneath the Karoo of the Doringberg fault. In the close vicinity of dolerite intrusions sandstone has been converted to quartzite, shale to splintery hornfels with conchoidal fracture (lydian stone).

Kimberlite dykes are found east and southeast of De Aar on farms such as Pienaarskloof 136, Du Plessisdam 179, Vetlaagte 4, Slingershoek 2, Roodekraal 28, Zewe Fountain 9, Helder Water 10, Riet Fountain 39, Leuwe Fountain 27, Palmiet Fountain 24, Goede Hoop 26 (le Roux 1990). On aerial photographs the dykes can be recognised as lines of denser vegetation.

3.5 *Superficial deposits*

Calcrete is present as incrustation on or replacement of shale and decomposed dolerite. An extensive calcrete plateau is present north of the Renosterberg and on Sandilands Vlakte 86 to the north of as well as inside the dolerite ring structure directly west of De Aar. On Hennops Kraal 104 and Houd Kraal 105 massive calcrete with overlying calcified sand and silt up to 11 metres thick occurs. These plateaux as well as other smaller occurrences are indicative of an older erosion surface.

Alluvial deposits consisting of silt, fine-grained sand, grit and pebbles in part calcified are found along the Brak River, the Elandsfontein Spruit, the Hondeblafspruit and their tributaries. The maximum thickness is about 18 metres.

3.6 Structure

The Karoo sedimentary rocks lie practically horizontal. The dip of not more than a few degrees is to the southeast. Local deviations are caused by dolerite intrusions. Apart from more intensive fracturing associated with dolerite and kimberlite intrusions, no evidence of major fracture zones was found during the course of the 1987-89 and earlier field work.

On the analogy of the large flow of warm water struck in a major fracture zone in the Orange Fish River Tunnel (believed to be associated with the Doornberg fracture zone) borehole water temperatures were measured in the De Aar area. Temperature variations that were encountered however appear to be related to differences in the thermal conductivity of the sedimentary rocks and dolerite.

Although many lineaments have lately been identified by the Hydrological Research Institute on satellite imagery of the surroundings of De Aar, it has at the time of writing not yet been established whether these lineaments feature structures other than dolerite and kimberlite intrusions. A comparison of the interpreted satellite imagery with the photogeological interpretation of Temperley (1971) should be a worthwhile exercise.

4. HYDROGEOLOGY

4.1 Intergranular porosity and permeability

No determinations of the intergranular porosity and permeability of Karoo sedimentary rocks in the De Aar area have been undertaken. Petroleum exploration drilling during the sixties has however provided basin-wide poroperm data on the Karoo sedimentary rocks (Rowsell and de Swardt 1976). South of latitude 29°, (De Aar latitude 30° 44') porosity and permeability of Beaufort and Ecca sandstone is very low.

The porosity of Beaufort sandstone in borehole AB1/65 between 283 and 746 m below the surface, ranges between 0.3 and 3.7 percent averaging 1.3 percent. Permeability varies between 0.0-2.0 millidarcy ($0-2x10^{-8}$ m/s). In borehole QU1/65 porosity ranges between 0.1 and 6.3 percent (average 1.8 percent) over a depth range of 7 to 778 metres, and permeability between 0.0 and 0.44 millidarcy. Porosity of upper Ecca sandstone in borehole KL1/65 varies between 0.13 and 1.89 percent, averaging 0.75%; permeability 0-0.1 millidarcy.

Porosity appears to be higher close to the surface as a result of weathering; supporting data are however few. The porosity of Middleton/Lower Beaufort sandstone between 7-20 m below the surface in borehole QU1/65 averages 2.8 percent and between 21 and 94 m 1.7 percent.

The bulk density of Ecca and Beaufort shale of southern Karoo is high. It varies between 2 600 and 2 750 kg/m^3, which indicates that the sediments south of 29° latitude have reached a stage of maximum compaction. The porosity of a small number of samples ranges between 0.4 and 0.9 percent. Intergranular permeability of shale has not been measured, but can be taken as very low to zero.

Fresh dolerite may be assumed to have zero porosity and permeability. According to von Hoyer and Rinkel (1976) and von Hoyer (1974) the fine to medium-grained varieties of dolerite are highly resistant to weathering. In many boreholes fresh and solid dolerite directly underlies alluvium although in some holes 4 to 8 metres of weathered dolerite has been encountered. Coarse-grained dolerite decomposes to a friable mass intermixed with surface limestone and clay. This zone which is between 4 and 18 m thick is underlain by weathered and jointed but hard dolerite between 2 and 8 metres thick which gradually passes into fresh solid rock.

Woodford (1992) states that leucocratic dolerite which is mainly coarse grained, appears to be more susceptible to weathering than mesocratic/melanocratic varieties. Leucocratic dolerite was encountered along the Brak River between Riet Fountain 6 and Weltevreden (portion Leuwe Fountain 27).

4.2 Fractures

Karoo sedimentary rocks and dolerite clearly owe their aquiferous properties to permeable fractures which are largely restricted to the shallow zone of weathering which generally does not extend deeper than between 10 to 15 metres. In two exceptional instances (boreholes on Kalkfontein 85 and Kappokpoort 82) weathered shale was en-

countered to depths of 24 and 34 metres below the surface. The overlying alluvium is 11 and 6.8 metres thick respectively. Weathering tends to reach deeper alongside dykes than away from them.

Oxide-stained joints extend into fresh rock for variable distances, from a mere few metres to depths of more than 30 metres below the surface. Von Hoyer and Rinkel (1976) state that in the southwestern area (Zwartekopjes 131 - Brandfontein 87) open joints in shale change deeper down into clay- and calcite-filled ones or become tightly closed. These conditions are also encountered elsewhere e.g. in the valley of the Brak River north of De Aar. Open joints are not necessarily solely associated with weathered rocks. On Du Plessisdam 179 north of De Aar well-jointed but unweathered sedimentary rocks 10-15 metres thick overlie a dolerite sheet which covers a large part of the Brak River valley north of De Aar. Jointing extends between 2 and 9 m from the lower sheet contact into the underlying sandstone, mudstone and shale layers. However where the sheet exceeds 30 m in thickness, jointing does not exist (von Hoyer 1975).

To summarize : Excepting possible master fracture zones of which no evidence was found in the surroundings of De Aar, Karoo aquifers are the product of fracturing and weathering processes. Most intense fracturing and deepest weathering occur in the vicinity of dolerite intrusions (and kimberlite where present). As a result of the shallow depth of weathering and the low intergranular porosity of the Karoo sedimentary rocks aquifer storage is very limited. Typical examples of water strikes in the vicinity of dolerite intrusions are shown in figures 2 and 3.
Note the tendency for strikes to occur on more or less the same level in different boreholes (see also 4.4.10)

*4.3 **Alluvial and composite aquifers***

The coefficient of storage of alluvial deposits is about one order larger than that of the fractured and weathered sedimentary rocks. Although these deposits are chiefly fine grained, coarser sand and gravel are present locally in deeper sections of buried valleys.

The most prolific aquifers are evidently composite consisting of a primary (porous and permeable sand and gravel) and a underlying secondary (weathered fractured rock) component. This is the case in the Zwartekopjes-Brandfontein area where coarse grained alluvium is underlain either by weathered and jointed shale associated with a dolerite sheet or by weathered and jointed coarse grained dolerite. Similar conditions pertain to the Brak River valley north of De Aar.

East and southeast of De Aar, the target of high yielding boreholes is mainly the weathered fractured contact zone of dolerite intrusions. The reason being that except for a few kms along the Brak River upstream of Caroluspoort, alluvial deposits either lack a significant coarse component or are too thin.

Along the Hondeblafspruit on Hennops Kraal 104, the alluvium is highly calcified varying in thickness between 6 and 13 metres.

FIGURE 2 SECTION ACROSS DOLERITE INTRUSION RIET FOUNTAIN 6

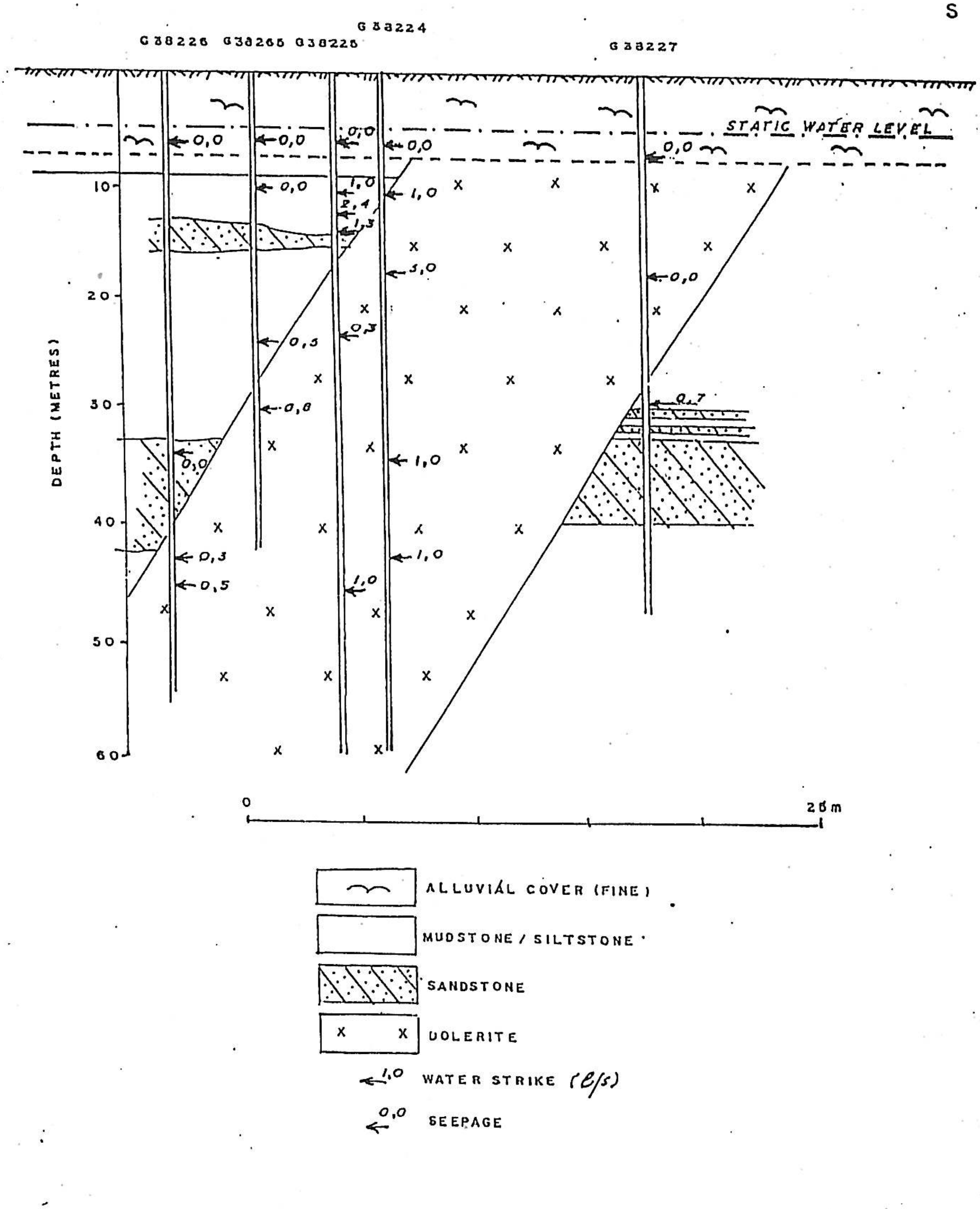


FIGURE 3 SECTION ACROSS DOLERITE INTRUSION ON ROODEKRAAL 28

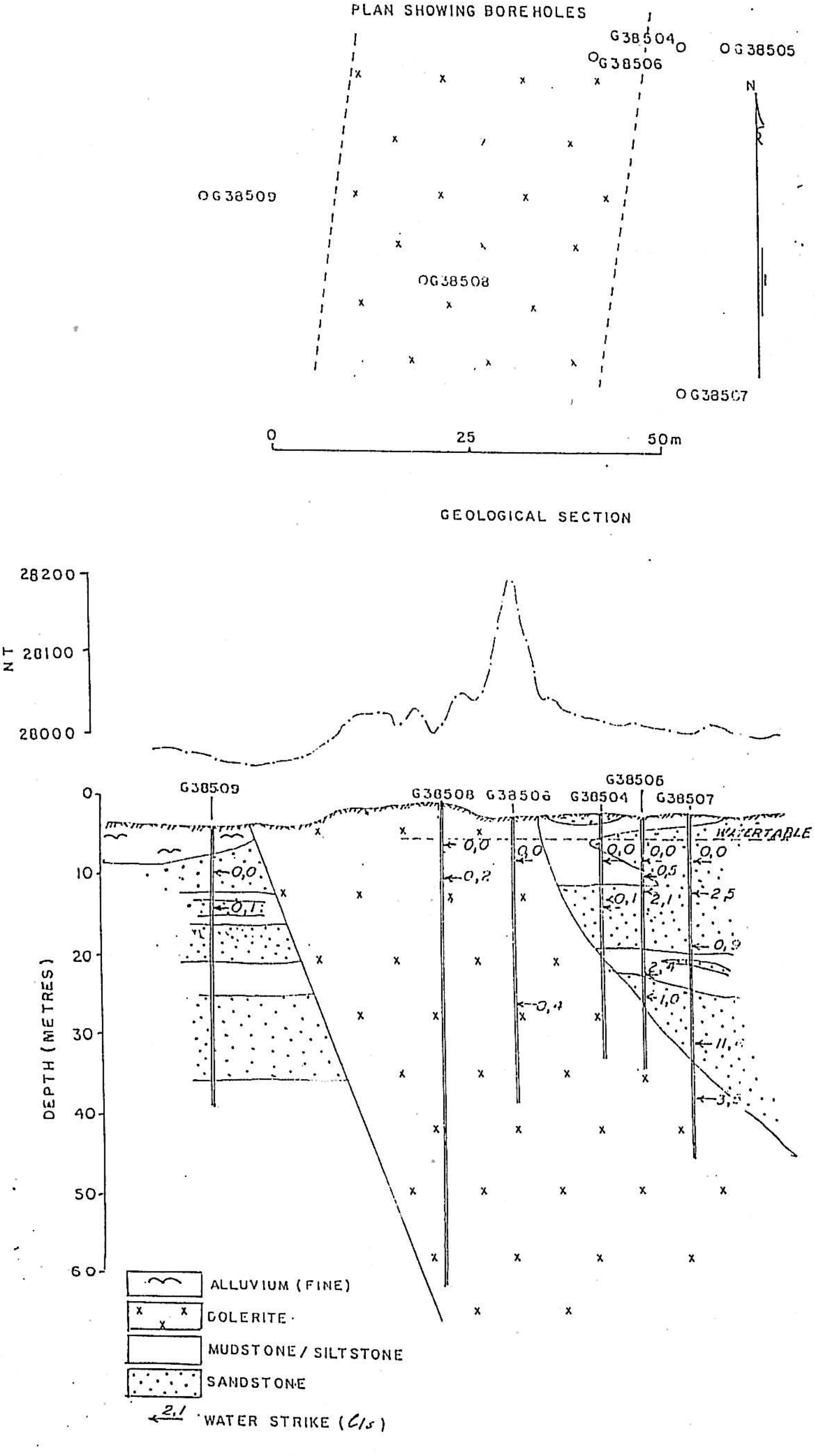
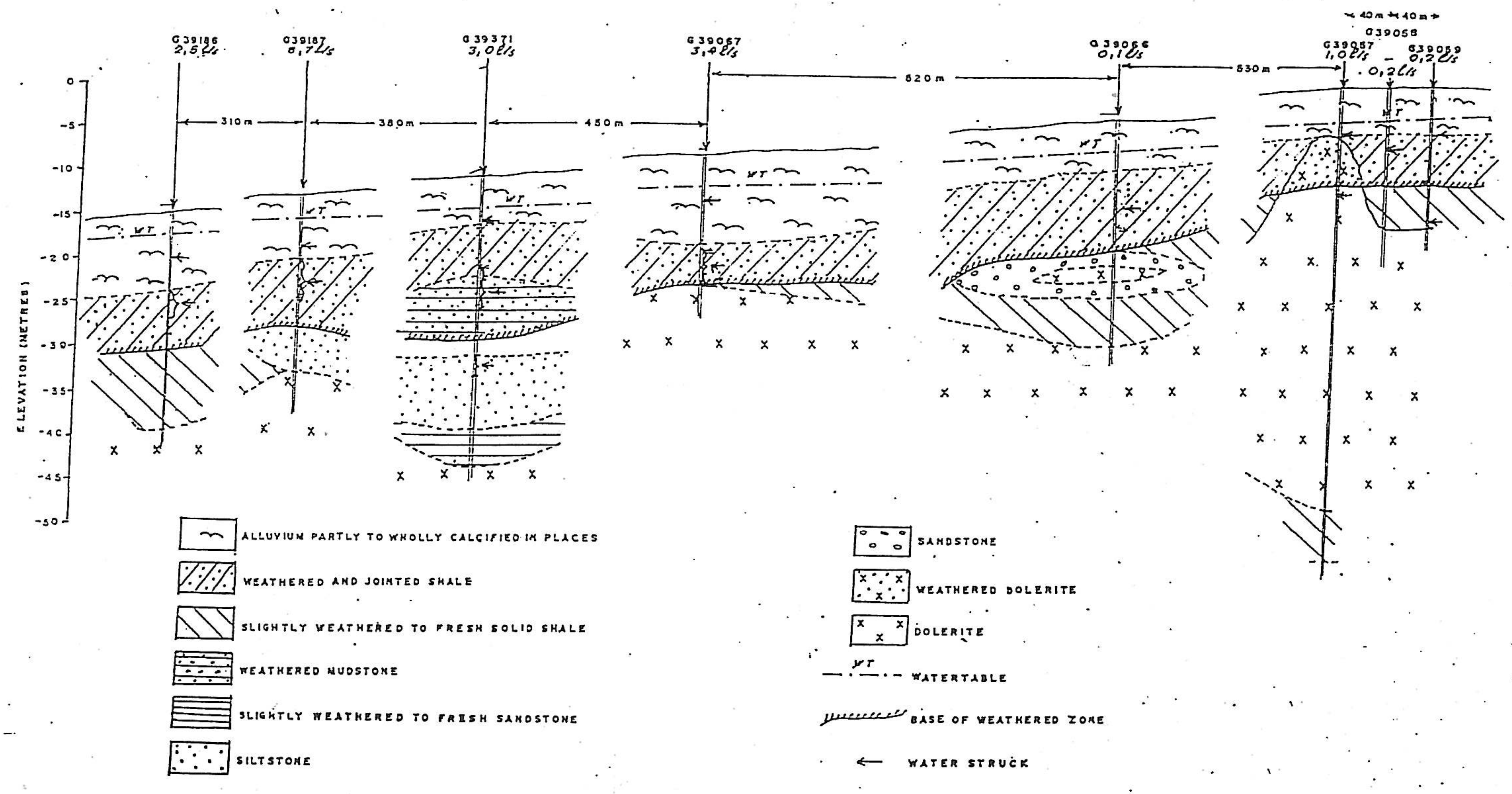


FIGURE 4 SECTION ILLUSTRATING OCCURRENCE OF GROUND WATER IN TIERBERG SHALE INTRUDED BY DOLERITE SHEET HENNOPS KRAAL 104



Yields in excess of 5 l/s have been struck in the weathered and fractured shale underlying the alluvium especially where almost total calcification has taken place (Woodford 1990a). The contact zone of an underlying dolerite sheet is only significant as an aquifer where weathering extends down to it. Figure 4 illustrates conditions along the Hondeblafspruit.

4.4 Statistical Analysis

Data of the 1987-89 exploratory drilling programme and of the 1971-75 investigation in as far as the required information has been provided, were analysed statistically. The results are given in tables 4-15 and figures 5-11.

The following may be deduced of the analysis:

4.4.1. Table 4 and figures 5, 6, 7 and 8

TABLE 4: FREQUENCY DISTRIBUTION OF EXPLORATION BOREHOLE DEPTHS AND WATER STRIKES

DEPTH RANGE (m)	NUMBER OF HOLES PASSING THROUGH DEPTH RANGE	NUMBER OF WATER STRIKES	PROBABILITY OF A WATER STRIKE	NUMBER OF WATER STRIKES WITH KNOWN YIELDS	SUM OF YIELDS (L/S)	MEAN YIELD OF WATER STRIKES L\S	MEAN YIELD PER UNIT HEAD (1) L\S
0 - 4.9	323	30	0.093	9	4.1	0.5	(0.5)
5 - 9.9	323	193	0.598	107	85.65	0.8	0.20
10 - 14.9	323	205	0.635	111	231.0	2.1	0.23
15 - 19.9	312	89	0.285	51	96.1	1.9	0.14
20 - 24.9	272	68	0.250	50	89.75	1.8	0.09
25 - 29.9	206	31	0.151	58	36.15	0.6	0.025
30 - 34.9	185	39	0.211	32	37.3	1.2	0.041
35 - 39.9	150	18	0.120	15	17.6	1.2	0.035
40 - 44.9	117	13	0.111	10	10.4	1.0	0.026
45 - 49.9	85	5	0.059	5	15.1	3.0	0.068
50 - 54.9	52	2	0.039	1	0.7	0.7	0.014
55 - 59.9	36	2	0.056	2	1.1	0.6	0.011
60 - 64.9	35	0	0.000	0	0.0	-	-
65 - 69.9	19	1	0.053	1	0.2	-	-
70 - 74.9	13	1	0.077	1	0.1	-	-
75 - 79.9	10	1	0.100	1	0.1	-	-
80 - 84.9	10	0	0.000	0	0.0	-	-
85 - 89.9	5	1		1	0.5	-	-
90 - 94.9	5	0	-	0	0.0	-	-
95 - 99.9	4	1	-	1	0.5	-	-
100-104.9	3	1	-	1	0.3	-	-
105-109.9	1	0	-	0	0.0	-	-
110-114.9	1	0	-	0	0.0	-	-

(1) Strike yield divided by depth of strike below water level, based on an assumed water-level depth of 3,5 metres below the surface

FIG. 5 DEPTH OF 323 EXPLORATION BOREHOLES

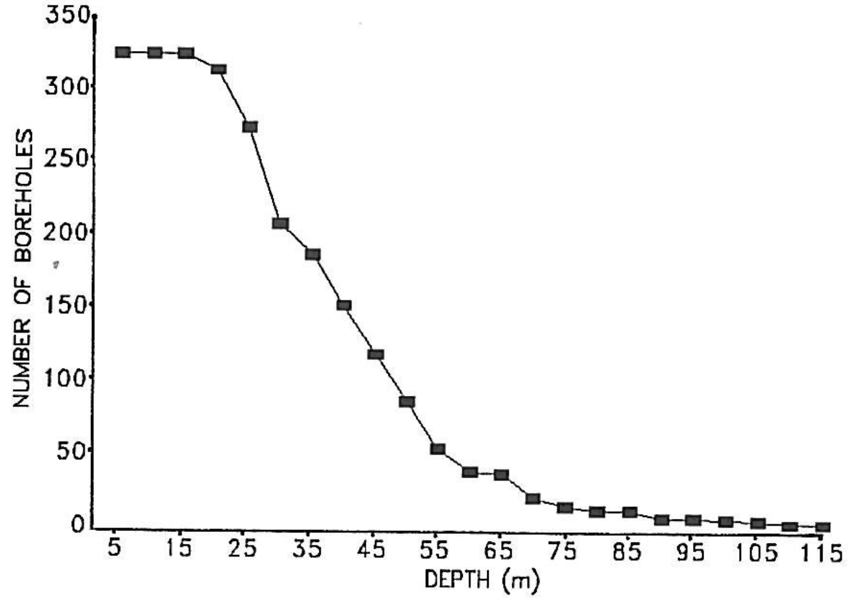


FIG. 6 FREQUENCY DISTRIBUTION OF DEPTH OF EXPLORATION BOREHOLES AND STRIKES

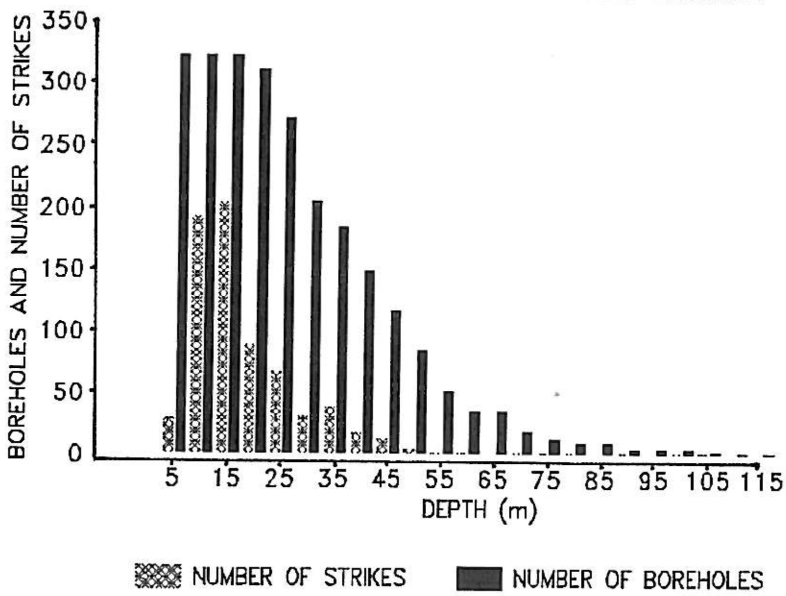


FIG. 7 PROBABILITY OF A WATER STRIKE

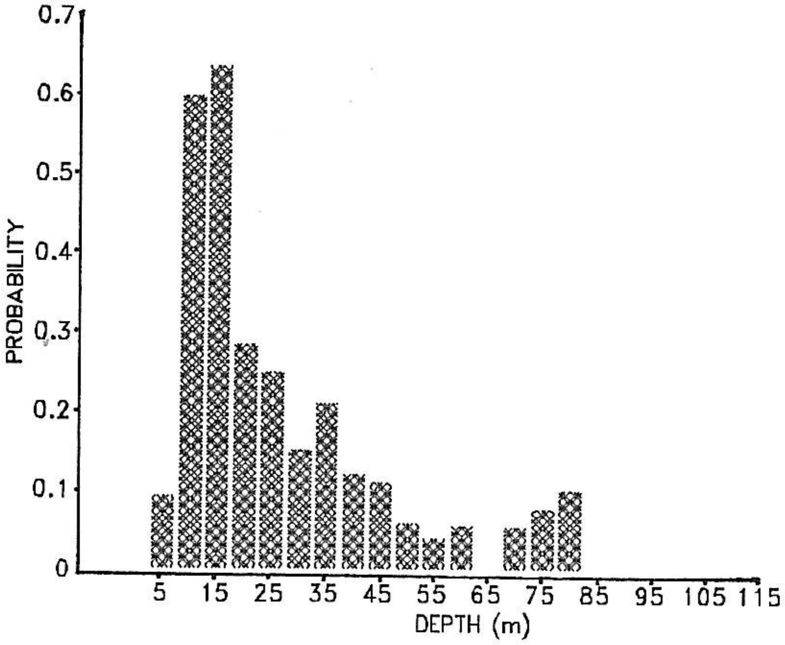
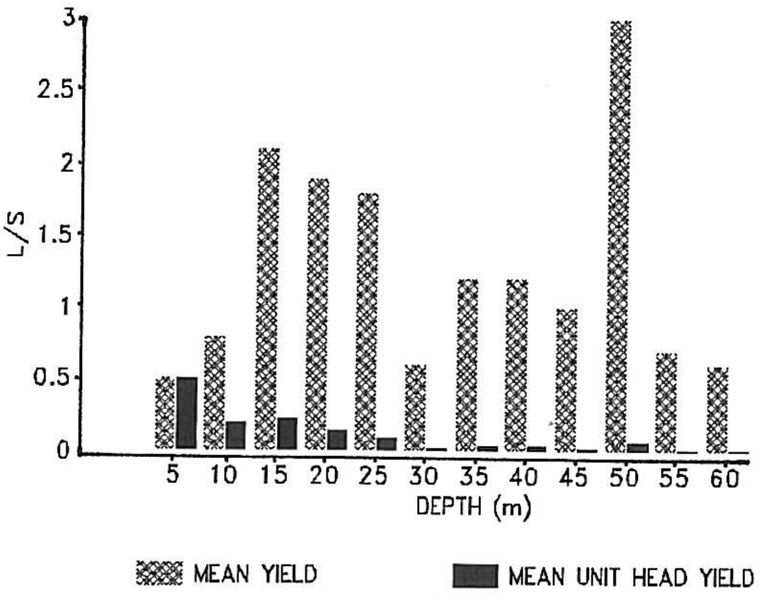


FIG. 8 MEAN YIELD AND MEAN UNIT HEAD YIELD OF WATER STRIKES



Few holes have been drilled deeper than 60 metres (fig. 5). Generally speaking it is needless to drill deeper than 40 metres. The probability of striking water is highest between 5 and 15 metres (fig. 6 and 7). It drops sharply with increasing depth. Particularly take note that bias in favour of shallow depths has been obviated by calculating probability of strikes in terms of the number of holes which passed through a particular depth range and not in terms of the total number of holes. Strike yields also decrease with depth (fig. 8). The decrease is pronounced when the mean strike yields are expressed in terms of mean yield per unit head. Fracture permeability therefore decreases sharply with depth. (Yield per unit head is strike yield divided by depth of strike below water level in borehole).

4.4.2. Table 5

About 2/3rds of the strike yields lie in the range of 1.0 to less than 0.1 l/s. Boreholes owe high yields to multiple strikes rather than a single fracture.

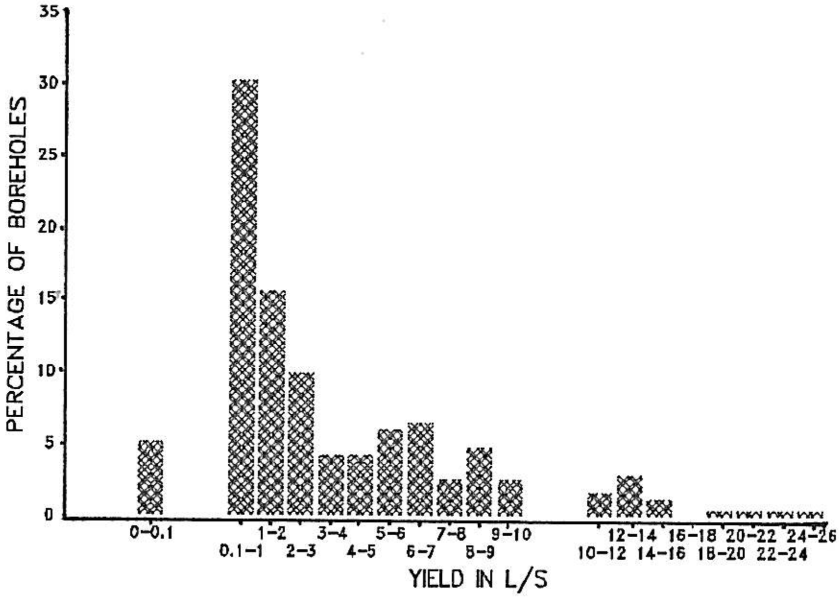
TABLE 5 FREQUENCY DISTRIBUTION OF INDIVIDUAL STRIKE YIELDS

Blow-out Yield per individual strike l/s	Percentage of total number of strikes (422)
less than 0.1	2.8
0.1 - 1.0	65.2
1.1 - 2.0	12.0
2.1 - 3.0	5.4
3.1 - 4.0	3.6
4.1 - 5.0	3.8
5.1 - 6.0	1.7
6.1 - 7.0	1.2
7.1 - 8.0	0.7
8.1 - 9.0	0.5
9.1 - 10.0	0.5
10.1 - 11.0	0.7
12.1 - 14.0	1.2
14.1 - 16.0	0
16.1 - 18.0	0
18.1 - 20.0	0
20.1 - 22.0	0.7

4.4.3. Figure 9

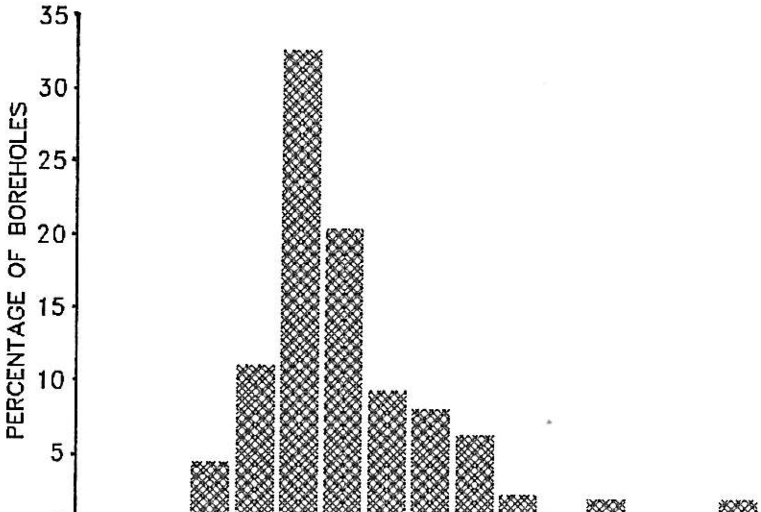
More than 50 percent of the boreholes have blow-out yields of 2.0 l/s and less. Assuming that it is not possible to improve on the siting of high yielding production holes, and setting 5.0 l/s as the minimum target for a municipal production hole, it is evident that on average 10 holes will have to be drilled in order to obtain three production holes. High-yielding boreholes are generally associated with vertical or dipping dolerite contact zones. Because the more intensive fracturing occurs within a narrow zone along the contact and intrusions often tend to be irregular in form and dip, it appears extremely doubtful whether prospection drilling can be ruled out. It is doubted that in general this problem can be resolved completely and effectively by geophysical methods.

FIG. 9 BLOW-OUT YIELD OF 231
EXPLORATION BOREHOLES



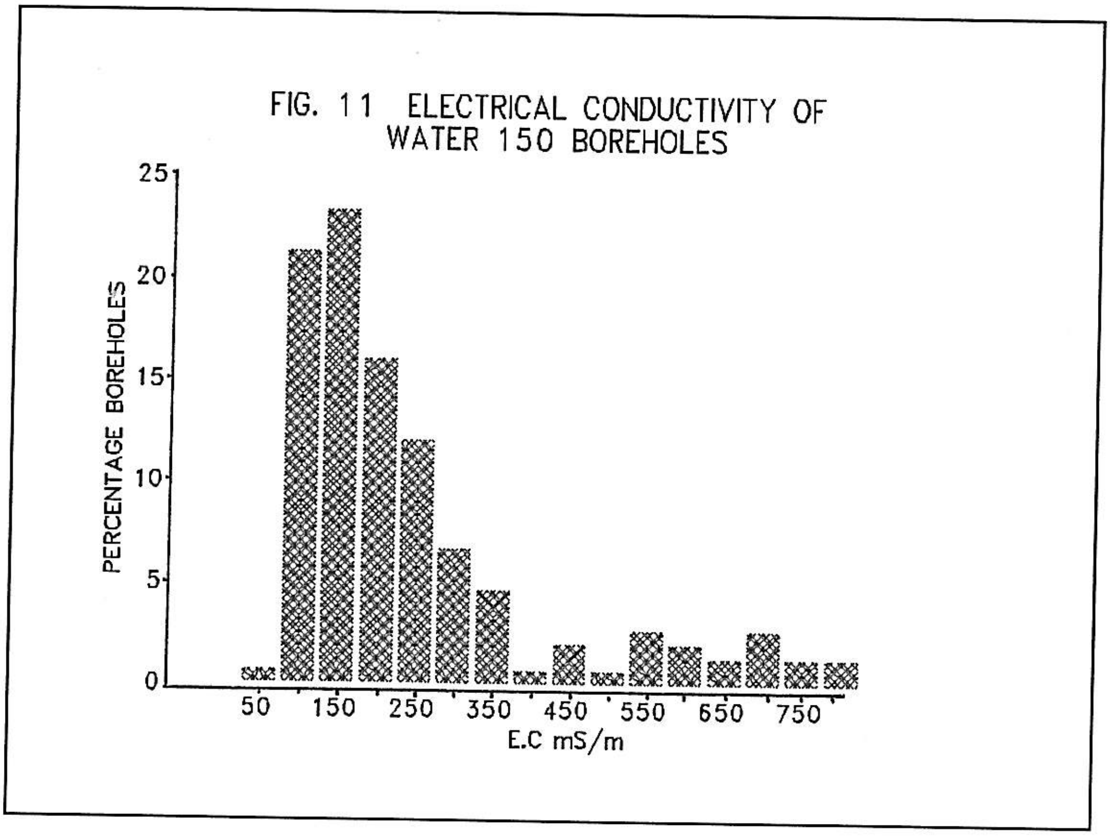
4.4.4 Figure 10
Groundwater levels are very shallow in accordance with the superficial nature of the aquifer. The shallowness is however somewhat exaggerated by the fact that exploration holes have been drilled in the valleys.

FIG. 10 WATER LEVEL DEPTH OF 270
EXPLORATION BOREHOLES



4.4.5. *Figure 11*

Few holes yielded water during the drilling process with electrical conductivity in excess of 250 m S/m (about 1 650 mg/l dissolved solids). Forty-five percent of the holes yielded water with an EC of less than 150 m S/m (about 1 025 mg/l TDS).



4.4.6. *Tables 6 and 7*

There appears to be no significant differences in water-bearing properties of hard rock strata whether they are overlain by water-saturated alluvium or not. However, the probability of a strike drops to less than 0.1 below 35 metres in the case of overlying saturated alluvium whereas this happens from 45 metres onwards in the absence of such a cover.

TABLE 6 STATISTICS OF WATER STRIKES IN KAROO STRATA AND DOLERITE OVERLAIN BY SATURATED ALLUVIUM

Depth range (m)	Number of boreholes passing through range	Number of water strikes in range	Sum of strike yields l/s	Probability of striking water	Mean yield per strike l/s	Mean strike yield per unit head l/s/m
0 - 4.9	117	-	-	-	-	-
5 - 9.9	117	24	21.2	0.17	0.9	0.2
10 - 14.9	117	50	101.7	0.36	2.0	0.2
15 - 19.9	96	24	37.7	0.22	1.6	0.1
20 - 24.9	92	23	43.4	0.25	1.9	0.1
25 - 29.9	73	11	8.9	0.15	0.8	0.03
30 - 34.9	62	16	20.1	0.25	1.3	0.04
35 - 39.9	44	3	2.9	0.06	1.0	0.03
40 - 44.9	31	1	1.0	0.02	-	-
45 - 49.9	20	0	0	0.00	-	-
50 - 54.9	20	0	0	0.00	-	-
55 - 59.9	15	1	1	0.07	-	-

Water was also struck at depth of 71.5 m 0.1 l/s; 79 m 0.1 l/s and 102 m 0.3 l/s.

TABLE 7 STATISTICS OF WATER STRIKES IN KAROO STRATA AND DOLERITE (NO SATURATED ALLUVIUM COVER)

Depth range (m)	Number of boreholes passing through range	Number of water strikes in range	Probability of striking water	Mean yield per strike l/s	Mean strike yield per unit head l/s/m
0 - 4.9	110	4	0.04	-	-
5 - 9.9	110	40	0.36	0.5	0.1
10 - 14.9	109	60	0.55	1.0	0.1
15 - 19.9	99	32	0.31	3.3	0.2
20 - 24.9	89	30	0.32	1.8	0.1
25 - 29.9	70	11	0.15	0.8	0.03
30 - 34.9	58	14	0.23	1.7	0.06
35 - 39.9	51	10	0.18	0.9	0.03
40 - 44.9	40	9	0.19	0.7	0.02
45 - 49.9	25	3	0.08	-	-
50 - 54.9	24	1	0.04	-	-
55 - 59.9	18	0	0.00	-	-
60 - 64.9	10	1	(0.10)	-	-
65 - 69.9	6	1	(0.16)	-	-
70 - 74.9	5	0	(0.00)	-	-

4.4.7. Table 8

A greater saturated thickness is not the only factor responsible for higher yields in alluvium. In the deeper parts of river channels coarser sediments are present.

TABLE 8 SATURATED ALLUVIUM AS AQUIFER

Saturated thickness (m)	Number of boreholes	Number of holes with water	Sum of yields (l/s)	Range of yields (l/s)
0 - 0.9	20	0	0	-
1 - 1.9	20	3	0.6	0.1 - 0.4
2 - 2.9	18	8	1.85	0.1 - 0.5
3 - 3.9	8	3	1.1	0.1 - 0.5
4 - 4.9	8	1	0.5	-
5 - 5.9	6	4	3.5	0.2 - 2.6
6 - 6.9	6	5	4.6	0.1 - 3.4
7 - 7.9	4	4	12.2	0.2 - 5.6
8 - 8.9	5	4	36.2	4.7 - 13.0
9 - 9.9	2	2	25.2	3.5 - 22

4.4.8. Tables 9 and 10 Upper and lower dolerite contact zones.

TABLE 9 UPPER CONTACT OF DOLERITE INTRUSION AS WATER-BEARING ZONES

DEPTH RANGE (m)	NO. OF TIMES INTRUSIVE CONTACT WAS PENETRATED	NO. OF WATER STRIKES WITHIN 1m ABOVE/ BELOW CONTACT	NO. OF WATER STRIKES WITHIN 5m ABOVE/ BELOW CONTACT	SUM OF BLOW-OUT YIELDS OF WATER STRIKES WITHIN 5m ABOVE/ BELOW CONTACT (L/S)	MEAN BLOW-OUT YIELD OF WATER STRIKES (L/S)	RANGE L/S	PROBABILITY OF STRIKING WATER WITHIN 5m OF CONTACT
0- 4.9	11	0	4	0,7	0,18	0,1-0,3	0,36
5- 9.9	13	4	11	13,6	1.24	0,1-10	0,85
10-14.9	20	8	13	11,6	0,89	0,1-3,5	0,65
15-19.9	21	5	15	37,7	2,51	0,1-6,4	0,71
20-24.9	13	7	13	22,2	1,71	0,1-6,7	1,00
25-29.9	11	3	6	3,9	0,65	0,1-1,6	0,55
30-34.9	11	6	9	17,7	1,97	0,1-11,6	0,82
35-39.9	3	2	3	2,1	0,7	0,4-0,9	(1,00)
40-44.9	6	0	0	0	0	-	(0.00)
45-49.9	4	1	2	0,8	0,4	0,3-0,5	(0,04)
50-54.9	4	0	0	0	0	-	(0,00)

To cater for steeply dipping intrusions, water strikes within both 1 and 5 metres on both sides of the contact have been considered. The small number of holes which penetrate the upper and lower contacts of dolerite intrusions at different depths, do not provide a very clear picture of the probability of striking water in contact zones.

The results are however not in conflict with a decreasing probability of water strikes and decreasing permeability of fractures with depth as found in figures 6 and 7. Strike yields in the lower and upper contact zones are not materially different from each other or from water strikes away from contact zones.

TABLE 10: LOWER CONTACT OF DOLERITE INTRUSIONS AS A WATER-BEARING ZONE

DEPTH RANGE m	NO. OF TIMES CONTACT WAS PENETRATED	NO. OF WATER STRIKES WITHIN 1m ABOVE/BELOW CONTACT	NO. OF WATER STRIKES WITHIN 5m ABOVE/BELOW CONTACT	SUM OF BLOW-OUT YIELDS OF WATER STRIKES WITHIN 5m ABOVE/BELOW CONTACT (L\S)	MEAN BLOW-OUT YIELD OF WATER STRIKES L\S	RANGE L\S	PROBABILITY OF STRIKING WATER WITHIN 5m OF CONTACT
0 - 4.9	1	0	1	0,3	-	-	-
5 - 9.9	3	0	2	3,9	1,95	0,5 - 3,4	(0,67)
10 - 14.9	12	7	15	24,3	1,62	0,1 - 4,4	1,25
15 - 19.9	7	3	6	3,2	0,53	0,1 - 1,0	0,86
20 - 24.9	10	5	9	11,3	1,25	0,2 - 4,0	0,09
25 - 29.9	10	1	7	8,0	1.14	0,1 - 4,3	0,7
30 - 34.9	9	4	6	3,0	0,44	0,1 - 1,2	0,67
35 - 39.9	9	6	7	6,9	0,99	0,1 - 5,0	0,78
40 - 44.9	9	0	3	6,0	2,0	0,5 - 4,5	0,33
45 - 49.9	1	0	0	0	0	-	-
50 - 54.9	2	0	0	0	0	-	-
55 - 59.9	1	0	1	1,0	-	-	-
60 - 64.9	0	0	0	0	-	-	-
65 - 69.9	0	0	0	0	-	-	-
70 - 74.9	2	0	1	0,1	-	-	-
75 - 79.9	0	0	0	0	-	-	-
80 - 84.9	0	0	0	0	-	-	-
95 - 89.9	2	1	1	0,5	-	-	-
90 - 94.9	0	0	0	0	-	-	-
95 - 99.9	0	0	0	0	-	-	-
100 - 104.9	1	1	1	0,3	-	-	-

4.4.9. *Table 11*

Water is more often struck in the sedimentary section of both the upper and lower contact zones than in the dolerite section. Strike yields in sedimentary strata directly overlying dolerite are considerably higher than in the underlying dolerite. The same does not apply to the lower contact where mean strike yields in the sedimentary and dolerite sections of the contact zone are about the same.

TABLE 11 FRACTURED SEDIMENTARY ROCK AND FRACTURED DOLERITE OF INTRUSIVE CONTACT ZONES AS AQUIFERS

I.	**Upper contact zone**	
	Total number of water strikes in zone	76
	Sum of strike yields l/s	110.8
	Mean strike yield l/s	1.5
	Number of water strikes in sedimentary rocks	
	Percentage of total number of strikes	68.4
	Sum of strike yields l/s	86.1
	Mean strike yield l/s	1.7
	Number of water strikes in dolerite	24
	Percentage of total number of strikes	31.6
	Sum of strike yields l/s	12.1
	Mean strike yield l/s	0.5
II.	**Lower contact zone**	
	Total number of water strikes in zone	60
	Sum of strike yields l/s	68.7
	Mean strike yield l/s	1.2
	Number of strikes in dolerite	22
	Percentage of total number of strikes	36.7
	Sum of strike yields l/s	23.8
	Mean strike yield l/s	1.1
	Number of strikes in sedimentary rocks	38
	Percentage of total number of strikes	63.3
	Sum of strike yields l/s	44.9
	Mean strike yield l/s	1.2

4.4.10. *Table 12*

Drilling east and southeast of De Aar has been in the Middleton Formation of the Beaufort Group. A few holes have penetrated into Ecca shale. Nearly half of the distance drilled has been in dolerite. The Middleton Group is composed of about equal thicknesses of sandstone and mudstone with subordinate siltstone and some shale(?) Water is struck more frequently in fractures in sandstone than in other sedimentary strata and dolerite. Strike yields are also higher.

Excluding strikes within 1 metre (vertically) of intrusive contacts and including 17 strikes within successions of rapidly alterating sedimentary layers, 75.7% of the strikes in the sedimentary rocks appear to be closely associated with bedding planes. The rather small fraction of strikes within 1 metre of dolerite contacts cannot be taken as a true reflection of the importance of intrusive contacts as aquifers. Most of the drilling has been done on steeply dipping *contacts. Strikes more than one metre vertically from dolerite contacts may be within one metre horizontally from the contacts.*

TABLE 12 WATERBEARING FRACTURES IN MIDDLETON FORMATION AND IN DOLERITE E AND SE OF DE AAR (1)

TYPE	PERCENTAGE OF METRES DRILLED 1987-1989 PROGRAMME	PERCENTAGE OF DISTANCE DRILLED IN SEDIMENTARY STRATA ONLY 5102m	NUMBER OF WATER STRIKES (2)	PERCENTAGE OF TOTAL NUMBER OF STRIKES	SUM OF STRIKE YIELDS L/S	RANGE OF STRIKE YIELDS L/S	MEAN STRIKE YIELD	AVERAGE NUMBER OF METRES DRILLED PER STRIKE	NUMBER OF STRIKES WITHIN 1 METRE (VERTICALLY) OF SEDIMENTARY/ INTRUSIVE CONTACT
Sandstone	21.7	39.0	68	33.7	208.4	0.1-22	3.1	16.3	48
Siltstone	8.1	14.5	19	9.4	36	0.1-6.5	1.9	21.7	18
Mudstone	23.5	42.1	45	22.2	102.7	0.1-7	2.3	26.7	30
Shale	2.4	4.4	2	1.0	1.2	0.4-0.8	0.6	62.5	2
Dolerite	44.2	-	68	33.7	170.3	0.1-18.5	2.5	33.5	14

Notes
(1) Farms Caroluspoort 3, Wagt en Bitje 5, Riet Fountain 6, Cyfferkuil 7, Zewe Fountain 9, Leuve Fountein 27, Roode Kraal 28, Bloemhof 145
(2) In an additional 17 instances water was struck in a zone straddling the contact between different strata or comprising a rapid alternation of strata types - strike yields range from 1-14 l/s

4.4.11. Table 13
The modal thickness of the sedimentary beds is from 1 to 2 metres. In less than one quarter of the cases does bed thickness exceed 4 metres.

TABLE 13 THICKNESS OF SEDIMENTARY BEDS SOUTHEAST OF DE AAR

Thickness of bed (metres)	Percentage of beds with specified thickness			
	Sandstone (222)	Siltstone (146)	Mudstone (230)	Shale (29)
0 - 0.9	4.1	0,0	6.1	3.5
1 - 1.9	36.0	39,7	29.1	44.8
2 - 2.9	24.8	25,3	24.8	27.6
3 - 3.9	10.8	19,9	14.8	10.3
4 - 4.9	6.8	6,2	5.7	-
5 - 5.9	5.4	6,2	4.8	6.9
6 - 6.9	1.4	0,7	3.5	3.5
7 - 7.9	4.1	1,4	3.0	-
8 - 8.9	2.3	0,7	1.7	-
9 - 9.9	0.9	-	2.2	-
10 - 10.9	1.8	-	0.9	3.5
11 - 11.9	0.5	-	0.4	-
12 - 12.9	0.5	-	0.4	-
13 - 13.9	-	-	1.3	-
14 - 14.9	-	-	0.4	-
15 - 15.9	-	-	0.9	-
16 - 16.9	0.5	-	-	-
22 - 22.9	0.5	-	-	-

4.4.12. Table 14

Considering that weathering generally does not extend deeper than 20 metres and that the stated thicknesses of dolerite in the table were drilled into or through at different depths below the surface, it would appear by hindsight that a considerable amount of unnecessary drilling in dolerite may have been undertaken.

TABLE 14 THICKNESSES OF DOLERITE ENCOUNTERED IN EXPLORATION BOREHOLES SOUTH-EAST OF DE AAR

Thickness of dolerite metres	Percentage of boreholes (79) penetrating specified thickness of dolerite	Percentage of boreholes (62) stopped in specified thickness of dolerite
0 - 4.9	29.1	21.0
5 - 9.9	13.9	29.0
10 - 10.9	17.7	19.4
15 - 15.9	8.9	3.2
20 - 20.9	10.1	3.2
25 - 29.9	7.6	4.8
30 - 34.9	3.8	3.2
35 - 39.9	1.3	3.2
40 - 44.9	2.5	4.8
45 - 49.9	-	1.6
50 - 54.9	1.3	1.6
55 - 59.9	-	-
60 - 64.9	2.5	1.6
65 - 69.9	1.3	1.6
70 - 74.9	1.3	1.6

4.4.13. Table 15

Although perhaps not fully representative of the occurrence of groundwater in Tierberg shale, the most complete data set is presented by the exploration drilling conducted on Hennops Kraal 104, Houd Kraal 105 and Roode Kraal 106 north of De Aar.

The probability of striking water was found to be the highest between 5 and 15 metres below the surface. The highest mean yield is between 10 to 15 metres. Fracture permeability decreases with depth.

Dolerite contact zones were not highly productive. The upper contact was cut 20 times at depths varying between 8 and 54 metres. Water was struck in only 8 instances in shale near the contact strike yields 0.1 - 1.0 l/s. The lower contact was penetrated between depths of 9 and 79 metres in 14 instances. Water was struck in 10 cases chiefly within the underlying shale. Yields ranged between 0.1 and 1.2 l/s.

TABLE 15 : FRACTURING IN TIERBERG SHALE CONTAINING AN UNDULATING DOLERITE SHEET ON HENNOPS KRAAL 104, HOUD KRAAL 105 AND ROODE KRAAL 106

DEPTH RANGE (m)	NO OF HOLES		NUMBER OF STRIKES	PROBABILITY OF STRIKING WATER	SUM OF STRIKE YIELDS L\S	RANGE OF STRIKE YIELDS L\S	MEAN STRIKE YIELD L\S
	ENTERING DEPTH RANGE	EXITING DEPTH RANGE					
0-4.9	38	38	1	0.03	0.2	-	-
5-9.9	38	38	34	0.93	16.7	0.1 - 2.4	0,5
10-14.9	38	37	28	0.74	84.2	0.1 - 12	3,0
15-19.9	37	34	8	0.22	10.6	0.1 - 7	1,3
20-24.9	34	30	6	0.17	9.0	0.1 - 4.5	1,5
25-29.9	30	24	4	0.16	2.1	0.1 - 1.0	0,5
30-34.9	24	22	9	0.40	16.2	0.1 - 8.0	1,8
35-39.9	22	17	4	0.21	4.3	0.1 - 1.7	1,1
40-44.9	17	16	2	0.12	0.3	0.1 - 0.2	-

5. *ROLE OF GEOPHYSICAL EXPLORATION METHODS IN THE SITING OF BOREHOLES*

5.1 *Ground magnetics*

Ground magnetics may be employed for tracing dolerite intrusions under soil and alluvial cover. It has however been found that some intrusions have very weak or no anomalies.

5.2 *Electrical resistivity*

Electrical resistivity has been used on Caroluspoort and in the so-called Southwestern area (Renosterpoort, Vaalbank Zwartekopjes) for determining the configuration of alluvial deposits. At Caroluspoort the alluvium is characterised by resistivities of between 20 and 50 ohm metres. The resistivity of the underlying shale ranges from 50 to more than 100 ohm metres. Electrical depth determinations empirically interpreted have been found to be in error by as much as 3 metres that is about 20% of the alluvium thickness.

Burvenich (1973) found Wenner depth probe curves of the Southwestern area difficult to interpret. They are of the A type. Because near surface resistivity inhomogeneities are recognised more readily on Schlumberger curves these by contrast, were interpreted easily by means of two layer master curves using the Ebert method of auxiliary point and three layer standard curves. Bedrock underlying the alluvium is weathered in places. Resistivities of alluvium and weathered bedrock overlap. The usefulness of the resistivity method in locating the deeper sections with coarser alluvium is therefore severely curtailed.

Von Hoyer found the resistivity method of little use in studying the thickness of the alluvium along the Brak River on Wagt en Bittje, Rusoord and Riet for the same reason. Problems were also experienced with lateral effects caused by surface limestone and heterogeneity of the alluvium.

Electrical resistivity borehole logging has provided the following data.

TABLE 16 ELECTRICAL RESISTIVITIES

Alluvium	1.5	-	15	ohm metre
Calcilfied alluvium	50	-	100	" "
Middleton mudstone			15	" "
Tierberg shale and sandstone	30	-	150	" "
Weathered Tierberg shale	20	-	60	" "
Weathered dolerite	10	-	100	" "
Fresh dolerite			1 000	" "

Because electrical depth probing proved unreliable, experimental shallow seismic refraction surveys were undertaken in the Southwestern area and on Caroluspoort.

In the case of Caroluspoort (Vegter 1961) contours of the floor of the alluvial deposits were based on a combination of borehole data, electrical depth probing and seismic refraction lines.

Without borehole control only a general but not accurate idea of the extent and thickness of the alluvium is obtained.

5.3 Refraction Seismics

In the Southwestern area, thin shallow high velocity calcified layers attenuate refractions from deeper horizons. This causes considerable problems in profiling the base of the alluvium. There is also a considerable overlap in seismic velocities of different strata. This is illustrated in the following table (Botha 1972):

TABLE 17 SEISMIC VELOCITIES AND INTERPRETED LITHOLOGY

Seismic velocity m/s	*Interpreted as*
200	*loose soil and sand*
304 - 1308	*dry to moist sand moist sand and gravel*
704 - 1825	*moist to saturated gravel and pebbles*
918 - 1289	*moist gravel, sandstone and jointed shale*
1025 - 2840	*moist to saturated gravel, pebbles and weathered dolerite*
2160 - 4791	*shale*
3077 - 8089	*sligthly weathered to fresh dolerite*

Depth calculations by the critical distance and intercept time methods compared with each other fairly well to very poor - in the extreme a 100 percent difference has been found. Comparison with borehole depths also ranged from good to poor.

5.4 Geophysical borehole logging

To date virtually no use has been made of geophysical logging in the De Aar area. It is surmised that as has been found elsewhere, geophysical logging may be a useful method in directing drilling operations.

5.5 Conclusion

In view of

(a) the small thickness of the alluvium (maximally 18 m), of which the depth and nature can be probed rapidly by drilling

(b) the time and cost involved in seismic refraction survey and in electrical depth probing and the rather indifferent results and

(c) the necessity of a considerable amount of borehole control in order to obtain a fairly reliable picture

employment of these two geophysical methods in the Karoo is not considered worthwhile.

It is suggested that the use of the Geonics EM34-3, a moving source - moving receiver electromagnetic system be investigated. It may be a rapid though not accurate means of profiling alluvial deposits, owing to overlapping resistivities of alluvium and weathered, jointed bedrock. In other words it may be useful as a reconnaissance technique whereby exploratory drilling can be directed and limited.

Precise location of permeable water-bearing fractures within dolerite contact zones by means of geophysical methods is thought to be unattainable.

6. HYDRAULIC FRACTURING AND THE DEVELOPMENT OF HIGH-YIELDING PRODUCTION HOLES IN ALLUVIUM

The irregular form and dip of dolerite intrusions and the vagaries of the associated fracturing, usually require the drilling of several exploratory holes before the desired yield is obtained. It is doubtful whether geophysical methods can resolve the uncertainty of borehole siting within narrow dolerite contact zones. It is therefore suggested that the necessity of drilling several holes may be obviated if hydraulic fracturing is done. Hydraulic fracturing should be tested experimentally using a double packer system. Successive opening up of individual fractures in short borehole sections should be attempted rather than trying to open up a number over a long section in one shot. The objection that the capacity of the hydraulic fracturing equipment is limited may be largely discounted by the fact that individual strike yields are mostly less than 1 l/s and that boreholes owe high yields to having struck a number of water-bearing fractures rather than a single high yielding one.

Van Wyk (1989) reports that production boreholes have been developed successfully in alluvial deposits by the use of properly sized PVC screens and the installation of a sand sump which is closed at the bottom of the borehole. Development was done by means of surging and air-lifting.

7. DETERMINATION OF AQUIFER PARAMETERS

7.1 Alluvium Caroluspoort

The first determinations of the storage coefficient and permeability of the alluvial aquifer on S.A.R. land on Caroluspoort 3 were made in 1959-60 (Vegter 1961). Several methods were employed: Laboratory determinations of permeability were done on 41 undisturbed samples of alluvium obtained from boreholes. Values range from 1.5×10^{-7} to 4.8×10^{-4} m/s. The majority of values lies between 1.5×10^{-6} and 7.5×10^{-6} m/s with a median value of 3.3×10^{-6} m/s.

Six laboratory determinations on samples of coarse sediments exposed near the bottom of donga's yielded values of 7.5×10^{-6} to 1.1×10^{-4} m/s. All these values with the exception of the last one, are however one and more orders too low to account for the yields of wells constructed by the S.A. Railways in the alluvium.

Moisture desorption determinations by the Soils Mechanics Laboratory of the National Building Research Institute on disturbed samples of alluvium taken at different depths from auger holes, have been used to estimate effective porosity. Under the estimated suction conditions prevailing at Caroluspoort the effective porosity appears to vary between 0.092 and 0.189.

Data of two 5 day pumping tests on Caroluspoort conducted on a fully penetrating well in alluvium with 15 observation boreholes along 4 radiating lines were evaluated in several different ways. Results obtained were as follows

Specific yield	*Sy*	*0.062 to 0.11*
Permeability	*P*	*6.6×10^{-4} to 12.7×10^{-4} m/s*
Transmissivity	*T*	*212 to 347 m^2/d.*

7.2 Composite alluvium-fractured bedrock aquifers: 1971-75 investigations

The last figures of the previous paragraph may be compared to those derived from a pumping test on borehole G27927 on Wagt en Bittje upstream of Caroluspoort (von Hoyer 1974 and Rinkel 1974b). The borehole was drilled through saturated alluvium into weathered and fractured shale. Analysis according to Hantush's method for semi-confined (leaky) aquifers yielded

Transmissivity	T	155 - 773 m^2/d; mean 330 m^2/d
Storage coefficient	S	0.004 - 0.0143; mean 0.0094.

Based on the reaction to testpumping, von Hoyer and Rinkel (1976) recognised two hydraulic conditions in the Southwestern area (Zwartekopjes, Vaalbank, Renosterpoort). The eleven pumptested holes of which the data could be evaluated, all penetrated saturated alluvium overlying weathered and fractured bedrock. The aquifer consists of coarse-grained alluvium, or underlying fractured bedrock or a combination of both. It was found that the water-level response in pumped and observation holes could be evaluated in terms of either semi-confined (leaky) or semi unconfined or unconfined delayed yield conditions.

For the former the Hantush (1964) method for non-steady state leaky artesian or semi-confined aquifers was used. The latter required application of the Boulton (1964) method for non-steady state semi-unconfined or unconfined with delayed yield conditions. T was also evaluated from the residual drawdown. The reliability of these computations is doubted by the authors von Hoyer and Rinkel.

Typical conditions are illustrated by the section and the log time drawdown curves (folder 3). The T and S values obtained from the different tests with their sets of observation holes range as follows

TABLE 18 : T AND S VALUES SOUTHWESTERN AREA (VON HOYER AND RINKEL 1976)

	$T(m^2/d$	S
Hantush method	83 to 3797	3.6×10^{-6} to 0.074
Boulton method	167 to 923	0.0025 - 0.17 (specific yield of alluvium)
Residual drawdown	119 to 917	

The more acceptable values would seem to be between 250 - 1 000 m^2/d for T and 0.014 to 0.10 for the specific yield Sy of the alluvium. The median Sy is 0.03 and the median S for the semi-confined aquifer 0.0025. In the so-called northern area, two boreholes G29632 and G29642 on Blaauwkrans 144 and one G29652 on Kalkfontein 85 were pumptested (von Hoyer 1975). These holes tap semi-confined aquifers composed of coarse-grained basal alluvium and underlying fractured dolerite (first two holes) and shale (last hole). These tests were also analysed with the

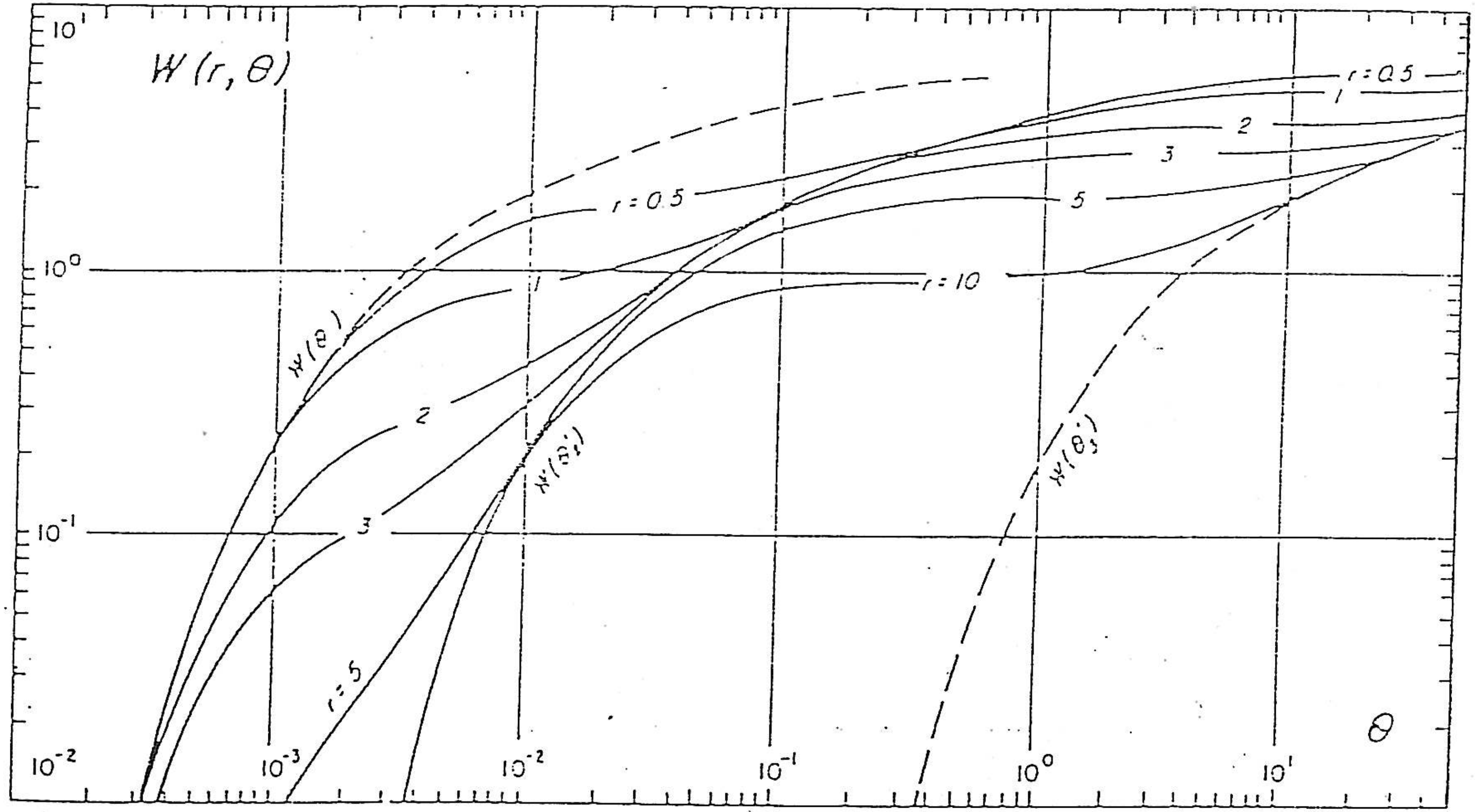
Hantush method for leaky aquifers. The results were T values ranging from 117 to 395 m^2/d; mean 210 m^2/d. S values range from 6.6 x 10^{-5} to 5.65 x 10^{-3}.

7.3 __Fractured rock aquifers: 1971-75 investigations__

In reports by von Hoyer (1974) and Rinkel (1974b) it is stated that the response of water levels in observation boreholes to the pumptesting of boreholes G28301 and G27918C on Riet Fountain 6 (Southeastern area) follows Boulton type curves for delayed yield. The same applies to tested borehole G24617 and observation holes on Du Plessisdam north of De Aar. The response was considered surprising because a saturated alluvial cover is missing. No explanation for this unexpected phenomenon was offered by the authors. The pumptested holes are located in dyke contact zones. This state of affairs is illustrated in folder 4 - a sketch plan of borehole G28301 and observation holes and double logarithmic time drawdown plots of G28301 and observation holes. Note that of the 16 observation holes involved in the three constant yield tests, only six curves could be evaluated. The near linear log water level response in the pumped holes appears to conform to Gringarten and Witherspoon (1972) theoretical curves for horizontal and vertical fractures (figures 12B and 12C).

Boulton type response is however in accordance with theoretical development based on considering fracture type aquifers as double porosity media with delayed yields from blocks to fissures. According to Streltsova-Adams (1978) the initial portion of a time drawdown curve for an unconfined fracture type aquifer, represents a fissure elastic response which approximates the exponential Theis function for very early times. As delayed elastic response of the porous blocks contributes to fissure flow, the time drawdown curve will deviate with time from the first Theis curve and will approach a second Theis-like curve based on the elastic properties of the porous blocks. With advancement of time the effect of watertable change will supersede the aquifer elastic response and the final segments of the time drawdown curve will merge with a third Theis type curve (see figure 12A, a reprint of Streltsova-Adams' figure 17, 1978). Each time drawdown curve has thus two inflection points: the first resulting from the delayed elastic contribution of the porous blocks and the second corresponding to a temporary steady state flow preceding accelerated watertable drop. The curves shown in fig 12A have been calculated for aquifer parameters that are very different from those presumed to be characteristic of Karoo sedimentary rocks. Writer is of the opinion that the different drawdown phases need not be evident in all cases. This will be dependent on the physical dimensions of the aquifer, its hydraulic properties, in particular whether the contribution of the blocks is significant and is maintained during pumping. As the writer is not equipped to calculate theoretical curves covering the possible range of values applicable to the De Aar area, no interpretation based on the Streltsova-Adams exposition was possible. In so far as the Boulton interpretation may be considered realistic it is interesting to note that the specific yield Sy of the fractured hard rock determined from the three tests mentioned above ranges between 0.0008 and 0.00548 (6 values). The mean and median is 0.0031 (compare this with figures given in 9.13) T values range between 397 and 1126 m^2d.

Figure 12A: Type curves for unconfined flow to a pumped borehole in a fissured formation according to Streltsova-Adams (1978)



Type curves for the drawdown function $W_1 = 4\pi T_1 s_1/Q$, calculated from Eq. (57) for the aquifer parameters $S_1 = 0.0001$, $S_2 = 0.001$, $S' = 0.1$, $x_1 = 1000$, and $x_2 = 0.1$.

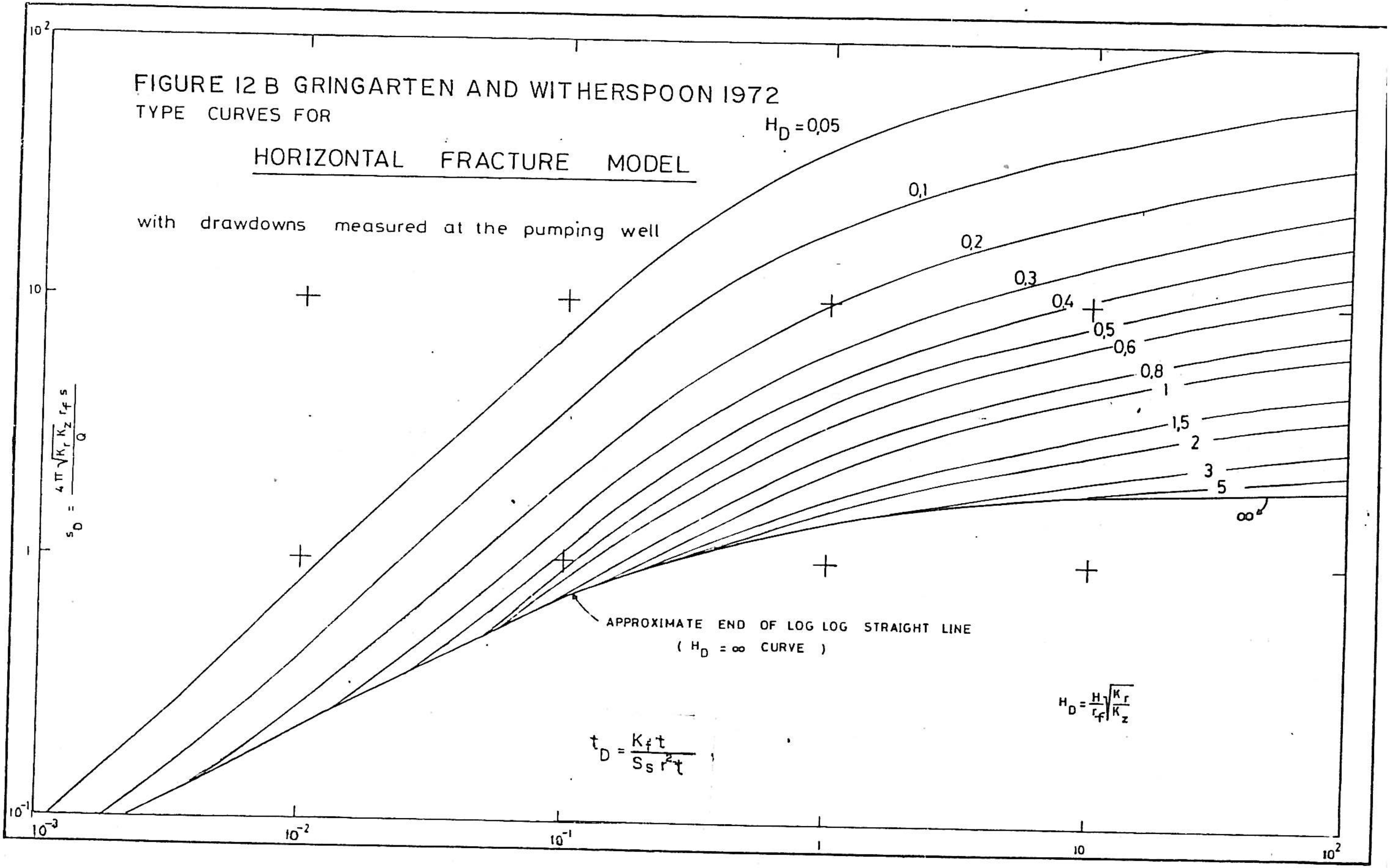


FIGURE 12 B GRINGARTEN AND WITHERSPOON 1972
TYPE CURVES FOR

HORIZONTAL FRACTURE MODEL

with drawdowns measured at the pumping well

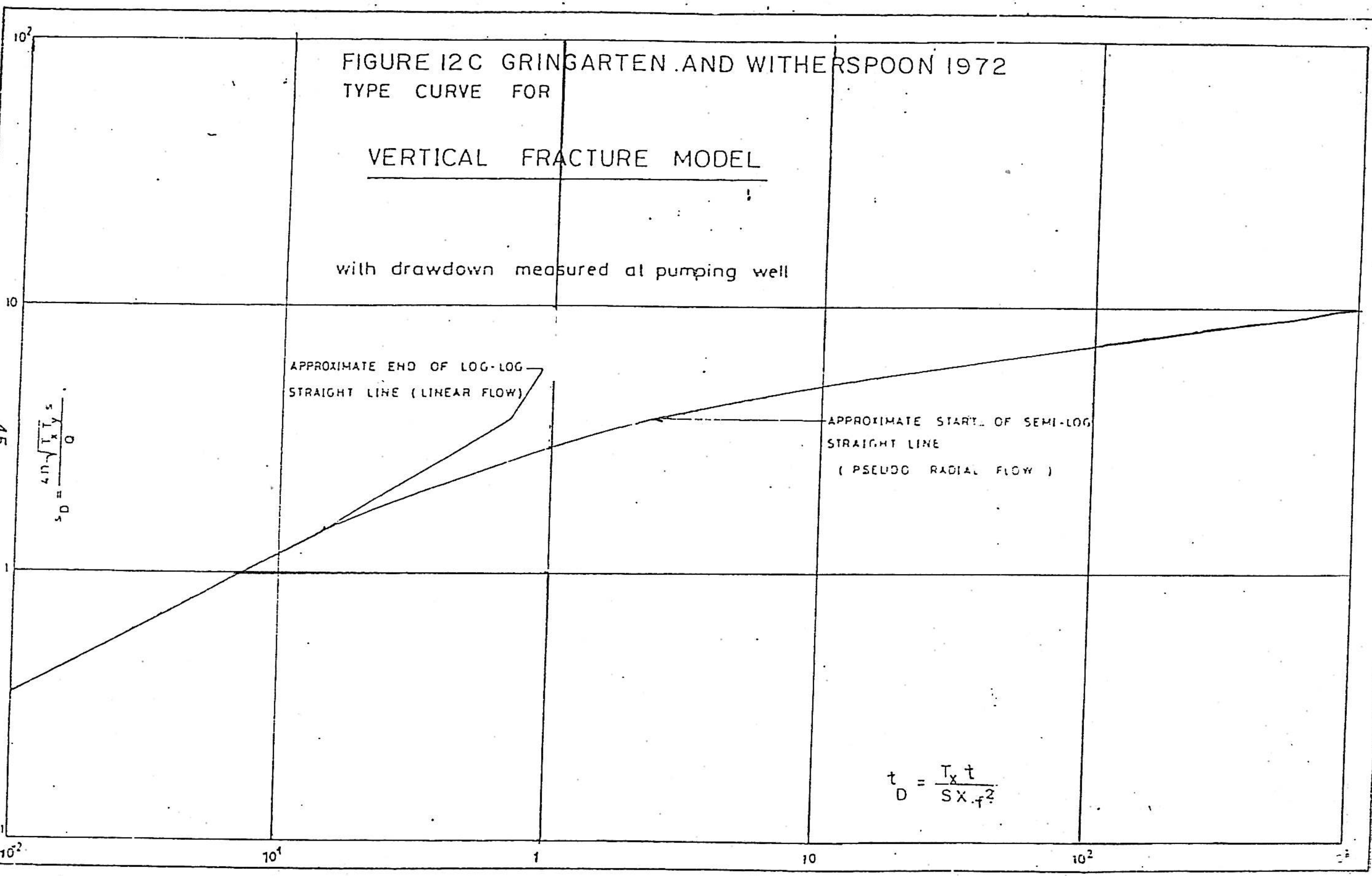


FIGURE 12C GRINGARTEN AND WITHERSPOON 1972
TYPE CURVE FOR

VERTICAL FRACTURE MODEL

with drawdown measured at pumping well

7.4 Pumping tests of 1988-89 excluding the Hennops Kraal area

Between January and August 1989 step drawdown and constant yield tests were conducted on 20 boreholes southeast of De Aar as follows:

(a) **Hard rock overlain by saturated alluvium**

Carolusspoort 3	one borehole G39037 3024CA00078
Wagt en Bittje 5	one borehole G39029 3024CA00419
Riet Fountain 6	two boreholes G38459, G38224 3024CA76
Bloemhof 145	one borehole G38455 3024CA382
Cyfferkuil 7	one borehole G38537 3024CB99
Total	6 boreholes

(b) **Hard rock only**

Riet Fountain 6	four boreholes G28307, G28313B, G38473, G38468 (3024CC27, 3024CA281, 3024CA395)
Leuwe Fountain 27	two boreholes G38491, G38478A 3024CD9 | 3024CD6
Bloemhof 145	three boreholes G38517, G38520, G38531 3024CA405 | 3024CA408, 3024CB74
Cyfferkuil 7	two boreholes G39024, G39025 3024CB113 | 3024CB114
Zewe Fountain 9	two boreholes G38269A, G38270 3024CB115 | 3024CD22
Roode Kraal 28	one borehole G38507 3024CC17
Total	14 boreholes.

Between August 1988 and September 1989 step drawdown and constant yield tests were conducted as follows:

(a) on 16 boreholes north of De Aar, hard rock overlain by saturated alluvium.

Paarde Valley 145	one borehole G39145 (originally G29619) 3024CA80
Du Plessisdam 139	one borehole G29644 3024CA88
Blaauw Kranz 144	eight boreholes G29630B, G29632, 3023DB208 | 3023DB131 G29633 G39146 (originally G29636) 3023DB224 G29637A, G29639, G29641 and G39147 originally G29642) 3023DB117
Kappok Poort 82	three boreholes G29647A, G39148 (originally G29648) and G39149 (originally G29650).
Kalkfontein 85	three boreholes G39150 (originally G29649), G29652 and G29654.

(b) In April 1989 and September 1989 boreholes G28402, G28405 and G39151 (originally G28403; step drawdown only) on Brandfontein 87, were tested. All were drilled through water-bearing alluvium.

Although waterlevels were recorded in many cases in neighbouring open exploration and observation holes, no attempt was made at determining aquifer parameters T and S. In fact the pumping tests were intended only as borehole yield tests not as aquifer tests. Moreover many of the exploration holes which served or could have served as observation holes are too close to the pumptested holes.

7.5 *Quasi-linear drawdown curves*

Woodford (1989) states that owing to the complex nature of the fractured aquifers, standard methods of interpretation cannot be applied. He draws attention to quasi-linear curves when the square root of time is plotted against drawdown on arithmetic graph paper a feature described by Jenkins and Prentice (1982) and Sen (1986) as resulting from linear flow in a vertical fracture. The linearity of the curves plotted by Woodford is questionable.

According to Sen (1986) straight lines with a slope of 0.5 should be obtained for large values of time (small "u") when plotting drawdown versus time on double logarithmic paper. This is contrary to Gringarten and Witherspoon (1972) who state that a log-log plot of drawdown in a pumped hole penetrating a vertical fracture, versus time, is characterised by a half unit slope for early times. At later times drawdown versus time approximates a semilog straight line.

Inspection of figures 13 and 14A (14B is a site plan) shows that quasi-linear curves are obtained for pumped boreholes and observation holes close to the pumped hole. The quasi-linearity, starts from about 1 minute after commencement of pumping. Although drawdown data for less than 1 minute are available in a few instances, they have not been plotted. The accuracy of drawdown data for less than 1 minute is questionable owing to the uncertainty of an instantaneous water-level measurement. The initial very rapid drawdown during the first minute as is evident from the graphs, appears to be in accordance with a response for low S values e.g. 0.003. The similarity between the curves of fig. 13 and in particular fig. 14A with those of figure 15 which applies to a composite alluvium fractured rock aquifer should be noted.

In as far as the curves of pumped holes in fractured rock (no cover of water-bearing alluvium) may be taken as linear their slopes vary from 0.017 to 0.18 per log cycle. Slopes of observation holes close to the pumped hole are steeper than further away.

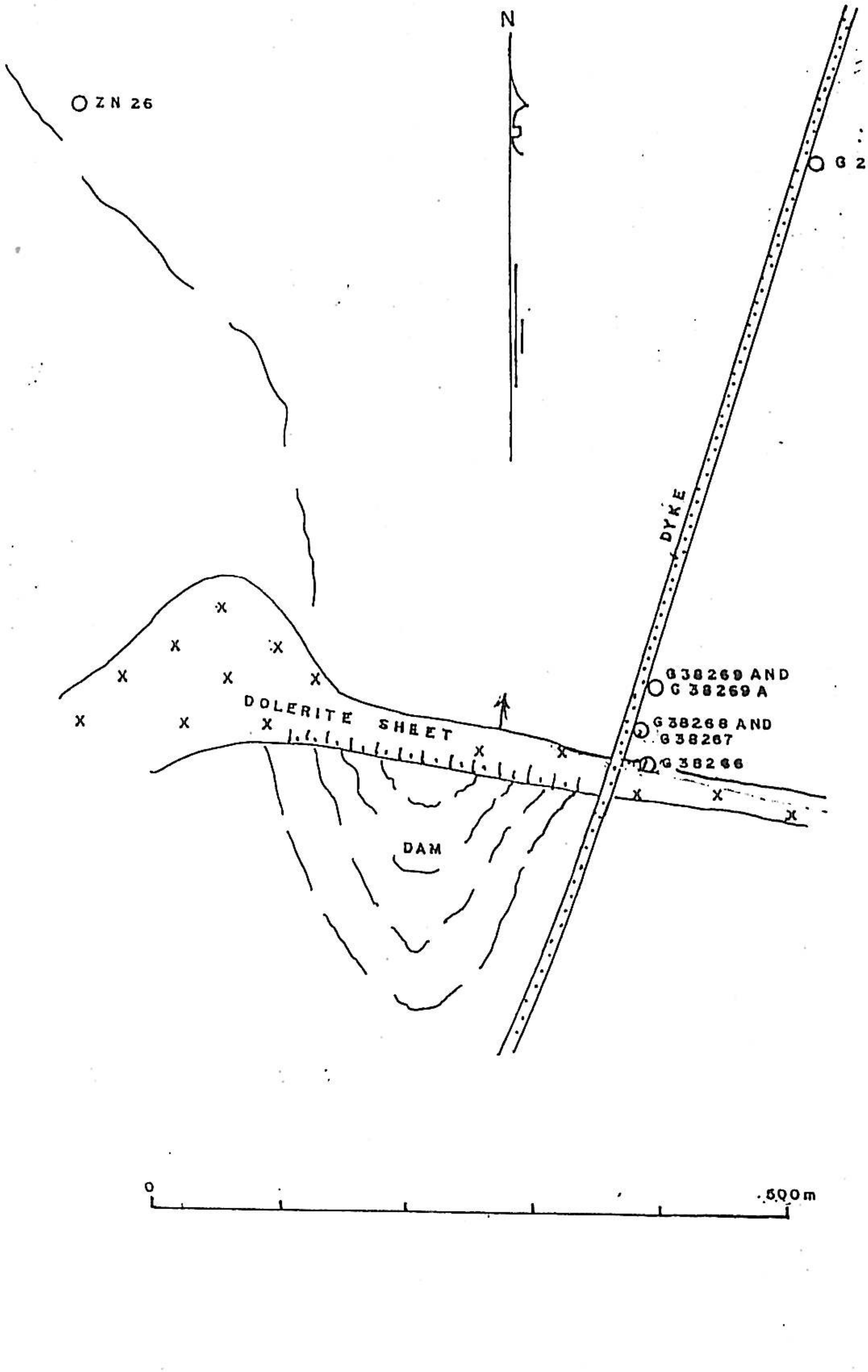
These low slopes are not in accordance with Jenkins and Prentice (1982) and Sen (1986), but could be in agreement with Gringarten and Witherspoon (1972) response for a horizontal fracture with vertical permeability several orders smaller than the fracture permeability.

In most cases it is nevertheless possible to visualise inflection points on the quasi-linear graphs which appear to be analogous to Boulton's delayed yield and Bourdet-Gringarten's double porosity fractured aquifer graphs. The lack of or uncertain accuracy of water-level drawdown during the first minute (including the effect of borehole storage) as well as the slight curvature of the graphs makes the fitting of Theis curves (if applicable) to either the early or the later part impossible or very uncertain. Consequently no attempt at determining T (fracture) and S (fracture plus matrix) has been made by this author.

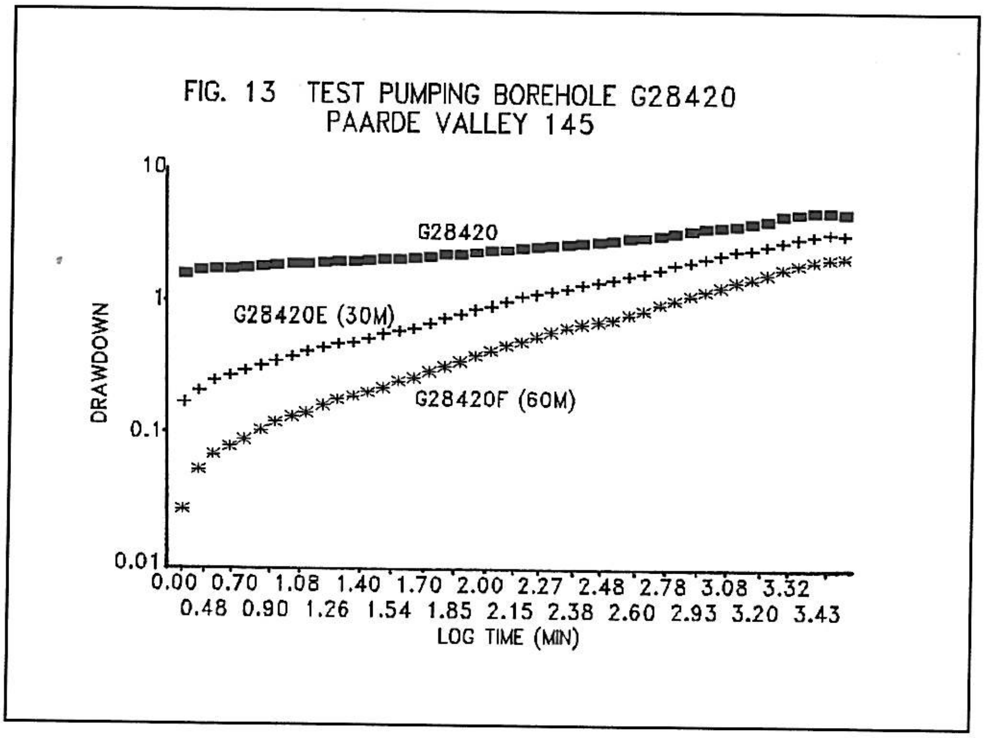
Interpretation of pumping tests on boreholes in fractured rock aquifers requires selection of the correct conceptual model and therefore information on the distribution and attitude of water-bearing fractures (Kruseman and de Ridder 1990). Is the fracturing mainly inclined or vertical; is it horizontal, parallel to the bedding or is it three-dimensional orthogonal? As discussed in 4.4.10 there is some evidence for more or less horizontal fracturing associated with bedding in

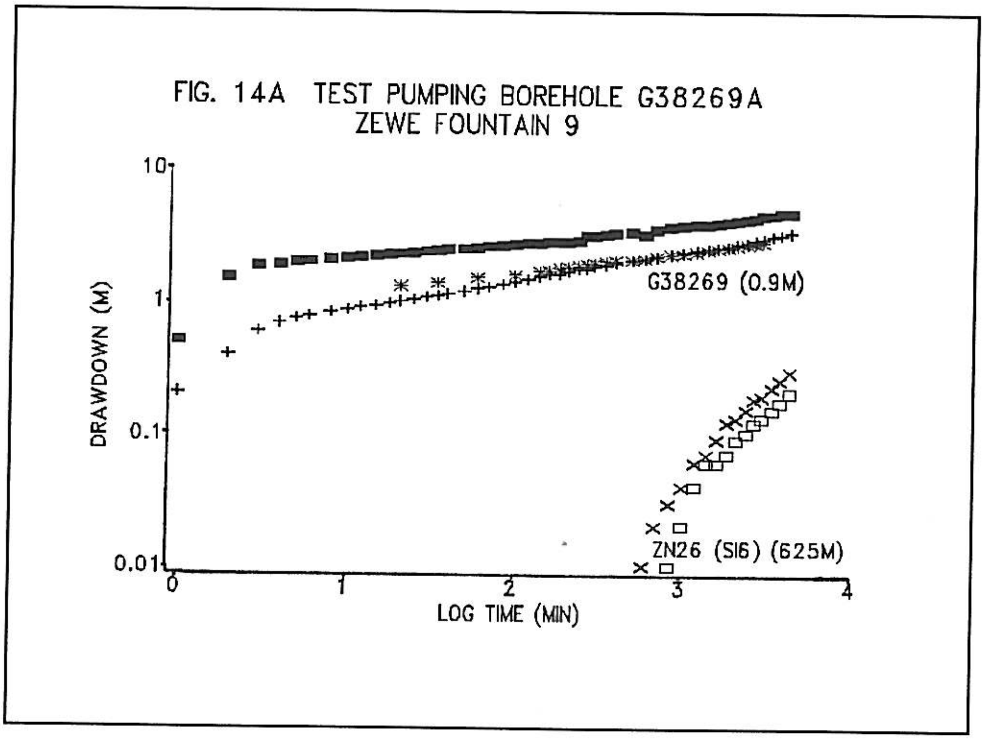
FIGURE 14B SITE PLAN OF PUMPING TEST ON BOREHOLE G38269 A

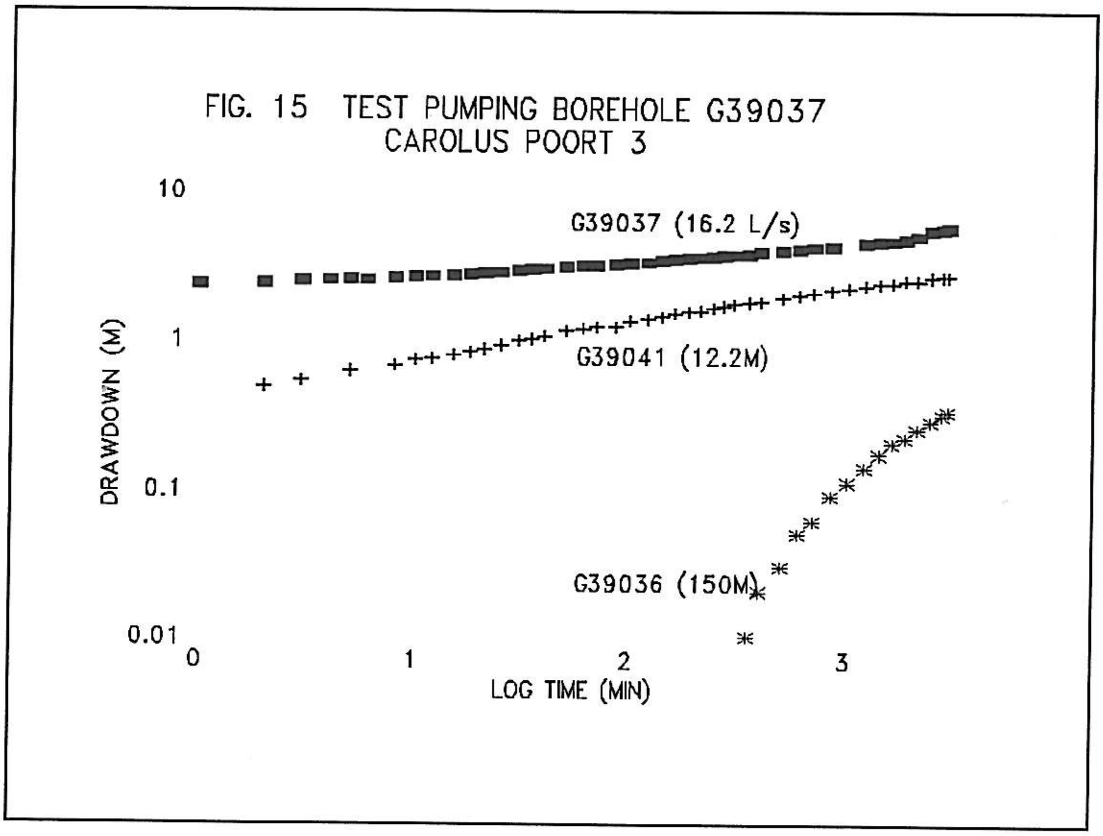
SIPRESHOF PORTION OF ZEWE FOUNTAIN 9



addition to the vertical or inclined fracturing in the vicinity of dolerite contacts. Without knowledge about the fracture pattern interpretation of pumping tests becomes meaningless.







It is therefore imperative that the distribution and attitude of fractures is ascertained from outcrops and boreholes (if available, through both geological and geophysical logging) before a pumping test is designed for determining aquifer characteristics. In many cases this condition may be difficult and/or too costly to satisfy, particularly if a spread of boreholes has to be tested to obtain a picture of the areal variation of aquifer parameters. Observation boreholes will have to be sited according to the fracture pattern to distances of at least 150 metres from the pumped hole.

Another aspect that has to be considered is whether the theoretical models that have been developed for regular fracture systems including dyke/dyke contact aquifers are generally applicable to Karoo fractured strata (see for instance Kruseman and De Ridder 1990).

To gain an understanding of groundwater movement and storage in fractured Karoo strata, cognizance has to be taken of the striking resemblance between log-log plots of pumping tests conducted on holes tapping alluvium and underlying fractured bedrock and those tapping fractured hard rock only, (Compare folder 3 and figure 15 - saturated alluvium cover; with folder 4 and figures 13 and 14A - hard rock only). The quasi-linear sections of log-log plots of pumptested holes tapping the composite alluvium hard rock aquifer have slopes varying between 0.058 and 0.23, i.e. similar to fractured hard rock.

One may perhaps speculate whether hydraulic conditions in a composite alluvium hardrock aquifer could vary laterally between that of an Hantush leaky, a Boulton delayed yield and a Gringarten and Witherspoon horizontal fracture model the fractured zone underlying the alluvium approaching equivalence in effect to that of a horizontal fracture. However no simple solution to the interpretation of aquifer tests in Karoo fractured rock appears to be in sight.

7.6 Composite alluvium - fractured rock aquifers - Hennops Kraal

Eight step drawdown tests and five one day constant yield tests were run during September/October 1989. A ten day test was conducted in December 1989. With the exception of one hole, the remaining seven tested holes were drilled through saturated alluvium into the underlying weathered shale/mudstone of the Tierberg Formation. In view of the preceding comments, the author did not request field data or graphs; consequently no evaluation of drawdown graph was made. T-values determined from the step drawdown, one-day constant yield and ten-day pumping test, range from 109 to 390 m^2/d (Woodford 1990). With exception of two values (1.5 x 10^{-2} and 6.4 x 10^{-2} S ranges from 9.0 x 10^{-5} to 8.2 x 10^{-3}, which is indicative of confined conditions (Woodford 1990).

Woodford states that after recovery from the ten day test the water-level stood about 0.1 m lower as a result of the abstraction of 36281 m^3 during the test. The test was run in December 1989 when 5 holes were pumped simultaneously. The area over which the drop occurred is not stated but may be assumed to be no greater than that enclosed by the zero depth to dolerite contour shown in figure 1 of Woodford (1990). This area is about 7.5 square km. Assuming a drop of 0.1 m over 7.5 square km through abstraction of 36 281 m^3 of water, a storage coefficient of 0.048 is obtained. A smaller area would result in a higher value.This seems to be in keeping with de-watering of the alluvium. It is ac-cordingly surmised that log-log pumping test graphs may either indicate leaky aquifer or delayed yield conditions, as has been found elsewhere in the De Aar area.

The saturated alluvium occupies at least an area of 2.8 square km within the basin-like dolerite feature. Its average thickness is estimated at 3.6 m. The volume of water stored in the alluvium is thus of the order of 0.5 million m^3. Assuming further a storage coefficient of 0.0058 for the underlying weathered shale (see 9.13) and an average thickness of 5 metres of saturated weathered rock over the area of 7.5 square km, a volume of about 0.2 million m^3 of water is obtained. This means that a total of about 0.7 million m^3 is held within the basin-like feature (figure 1 Woodford 1990). This estimate is of the same order as that of Woodford's. However, his estimate is based on a storage coefficient which is too low for the alluvium and one which is much too high for the weathered zone of well fractured rock.

7.7 IGS study "Exploitation potential of Karoo Aquifers"

During the course of this project step drawdown and constant yield tests were conducted on 6 boreholes tapping fractured hard rock only. The results were analysed using Theis and Cooper Jacob I methods. These yielded T and S values ranging respectively from 7 to 286 m^2/d and from 0.000002 to 0.02. The relevancy of these determinations is seriously doubted. In many, if not all instances the data points do not fit the Theis curve and straight lines. Some log-log curves resemble those encountered by von Hoyer and Rinkel and by Woodford which were discussed above.

7.8 Summary

In as far as reliance may be placed on the various determinations the transmissivity of weathered and fractured hard rock as well as of composite alluvium fractured hard rock aquifers generally lies in the range of 200 to 400 m^2/d - that is in the vicinity of boreholes yielding 5 l/s and more. The specific yield of alluvium varies most probably between 0.02 and 0.10 whilst that of the weathered and fractured Karoo strata is one order smaller i.e. around 0.005. Confined fractured strata have lower S values.

T and S values may be expected to vary widely areally. Taking borehole yield as a measure of transmissivity and considering that a yield of about 1 l/s is the general rule, T values about 1/5 to 1/10 of that quoted above, would seem to apply generally.

As weathering is an important factor in the formation of water-bearing openings, not only T but S as well will be strongly dependent on the position of the groundwater level.

In view of the spatial variability of fracturing, microfracturing and secondary intergranular porosity resulting from weathering processes within an horizontally disposed alternating sedimentary succession, further complicated by dolerite intrusions, it is a moot point as to how much more effort and finances should be expended in developing and refining interpretive models for determining aquifer characteristics. Whereas T values derived with currently available techniques appear fairly reliable, S values are dependent on duration of pumping. (Kirchner et al 1991). An alternative approach is necessary e.g. determinations by means of groundwater balances over extended periods of recharge.

8. RECHARGE

8.1 Rainfall infiltration

There can be no question about the reality of groundwater recharge in the De Aar region and for that matter in the Karoo. This is clearly demonstrated in folder 5 a record (D6N501) of waterlevel fluctuations since 1956 in a borehole on northern Zewe Fountain. At this locality ground water has been and still is being abstracted since the fifties by the Municipality of De Aar as well as the farmer (for irrigation). There is no evidence of a permanent gradual decline.

The question to be answered is under which circumstances of rainfall, evapotranspiration, soil cover, soil characteristics and moisture content, run off and river flow conditions does recharge take place and how much?

Kirchner et al (1991) have attempted to estimate recharge at Dewetsdorp and De Aar directly i.e. by looking at water movement through the unsaturated zone. They found that none of the techniques soil water balance, zero flux plane, the Darcian approach or the soil water flow model provided meaningful results. Indications are that recharge mainly takes place along preferred pathways so called macro-pores rather than through the soil matrix. During rainfall showers of high intensity, water moves through macro-pores in the unsaturated zone. During rainfall events of low intensity, the water in the macro-pores is forced into the adjacent soil matrix, because of the higher negative moisture potential in the soil matrix (Kirchner et al 1991).

The first estimation of recharge in the De Aar area was done by von Hoyer (1976). He compared the volume of water pumped in the Burgerville Zewe Fountain area (about 85 km^2) by the Municipality of De Aar and by farmers with rainfall during the period 1958-73. During this period abstraction varied between 0.71 and 1.17 million m^3/a, which is about equal to 4.3 percent of the average annual rainfall (287 mm). Considering that the spread of boreholes does not allow full exploitation and that consequently ground water is also being lost through seepage and evapotranspiration, von Hoyer suggests that the recharge rate may be 7 percent or even more of the annual rainfall (maximum abstracted through boreholes during a year amounted to 5.5 percent of the rainfall during that year). As no water-level data were available for this period, this estimate implicitly assumes no reduction in storage at the end of the period.

The so called indirect method of groundwater balance was used by Kirchner et at (1991) to determine recharge in the dolerite ring structure west of De Aar. The study period was October 1985 to July 1988. Both the saturated volume fluctuation (SVF) and ground-water level fluctuation (GLF) methods were used. Marked differences in recharge between a northern and southern hard rock and an alluvial aquifer were found. For an average rainfall year of 287 mm the recharge percentages according to the SVF method will possibly be 1.4; 2.8 and 14.4 percent respectively. The calculated recharge for the whole aquifer (ring structure) is

Recharge = 0.048 (precipitation - 27) mm

or 4.3 percent during the average rainfall year. The GLF method yielded a figure of 3.1 percent for the average rainfall year.

The high percentage recharge of the alluvium conflicts directly with the *geohydrological analysis of chapter 9. According to that analysis recharge is mainly effected over the hard rock areas with shallow soil cover. Recharge of the alluvium by infiltration is limited to times of heavy rainfall and of river flow (flooding?). The alluvium is as a matter of course continuously replenished by groundwater flow from higher lying hard rock areas.*

Kirchner et al (1991, p 265) state the estimates are for net recharge i.e. recharge remaining after evapotranspiration (and seepage loss). Under natural (virgin) conditions ground water is discharged solely by spring flow, seepage and through evapotranspiration. By pumping from boreholes part or all of this discharge may be recovered, depending on the effectiveness of the borehole field in diverting groundwater flow away from natural discharge areas. Unless it can be shown that further reduction of natural groundwater losses by abstraction from boreholes is not feasible, the value of net recharge figures for the estimation of groundwater potential is highly questionable.

8.2 Recharge by river flow

De Aar's municipal boreholes have mostly been sited along valleys where saturated alluvium provides about ten times the storage per unit volume available in weathered fractured hard rock. Consequently it is important to know what role flows in the Brak River and Elandsfontein Spruit play in groundwater recharge, as opposed to rainfall infiltration.

Two lines of observation boreholes were accordingly drilled in 1989: one across the Elandsfontein Spruit on Vaalbank; the other on the alluvial plain west of the Brak River on Carolus Poort 3, several kilometres upstream of the poort. River stage and borehole water-level recorders were installed. Hydrogeological sections are shown in figures 16A and B and 17A and B.

The Vaalbank line is unfortunately not well located, as a number of windpumps on the site cause short term fluctuations of water levels which interfere with the observation of possible river recharge effects. It is doubted whether removal of the nearest windpump will solve this problem.

The river has been scoured where the river stage recorder is located with the result that a pool of water persists for a considerable period after flow has ceased. The puzzling hydrograph (see folder 6) was understood only after a personal visit to the site.

Note that the eastern bank and riverbed is composed of shale. The western bank consists of alluvium.

The lack of observation holes east of the Brak River on Carolus Poort 3 is also considered a serious shortcoming. Such observation holes would have indicated whether the greatest groundwater level rise after river flow occurs at the river channel or further east, away from the channel. The latter would be indicative of a pressure effect arising from recharge of fractured hard rock under shallow cover by infiltrating rainfall, rather than from flow in the river. At present a firm conclusion about the effect of river flow cannot be reached. The possibility of a pressure response, for which there is some evidence, cannot be ruled out.

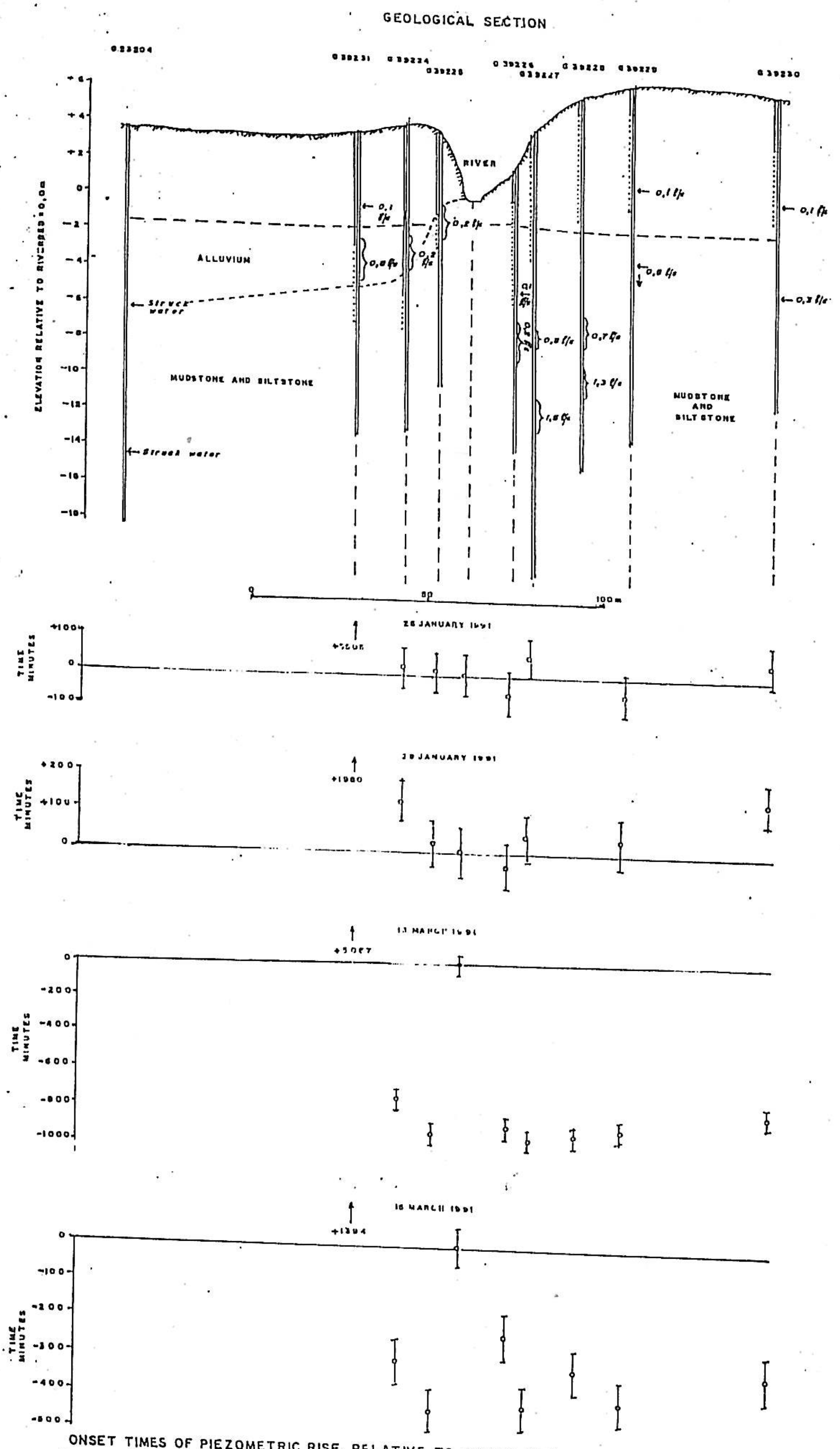


FIGURE 16 A ONSET OF RIVERFLOW AND GROUND-WATER FLUCTUATION: SECTION ACROSS ELANDSFONTEIN SPRUIT VAALBANK

(SEE ALSO FOLDER 6)

Further drawbacks affecting the interpretation of the observations are

(a) the lack of local rainfall recorders.

(b) onset times of groundwater level rise and river flow are accurate only to within about plus or minus 30 minutes.

Ground-water level and river flow hydrographs for the periods when flows occurred in the period December 1990 to March 1991 are depicted in folders 6 and 7. Onset times of ground water rise relative to the start of flow in the rivers and water-level profiles across the rivers at different times after onset of river flows, are shown in figures 16A and 17A.

At this stage unambiguous interpretation of the results is not possible. Larger flows and floods need also to be observed. These river sections are also not necessarily representative of conditions along rivers. The almost synchronous response of observation boreholes on Caroluspoort, and of boreholes G39224, G39225 and G39230 on Vaalbank points to pressure effects rather than local replenishment. This is corroborated by the leaky and delayed yield phenomena that have been observed during pumping tests. In a number of instances groundwater rises also commenced before river flow and continued for days after river flow had stopped. The pressure effect appears to be propagated from areas of hard rock outcrop or shallow soil cover where recharge by rainfall takes place.

Further evidence of lack of infiltration of river flow is provided by the pool in the Elandsfontein Spruit which did not dissipate through infiltration but dried up during April 1991 as a result of evaporation.

It is provisionally concluded that no significant recharge is effected by flows of the magnitude recorded from December 1990 to April 1991. The flood of February 1988 appears to have recharged the alluvium of ground-water unit XXIB (see 9.14).

9. GEOHYDROLOGY OF Ground-Water UNIT XXIB

9.1 Introduction

Ground-water unit XXIB is part of the dolerite ring structure which is situated directly west of De Aar. It contains part of the so called southwestern borehole field of the De Aar municipality namely eight of the twelve production boreholes comprising this field. It is the most intensely studied area and has the most complete set of data of the borehole fields exploited by the municipality. (De Bruin and Vegter 1971; von Hoyer 1972; Botha 1972; Burvenich 1973; Rinkel 1974b; von Hoyer and Rinkel 1976; Vegter 1990; Kirchner et al 1991). Water levels have been recorded in 6 boreholes situated along the river course since 1974. Monthly pumpage figures are available for each production borehole from the start.

The unit was therefore selected for detailed analysis as the results are needed for assessing the development potential of all the other ground-water units which are to be exploited for urban supply.

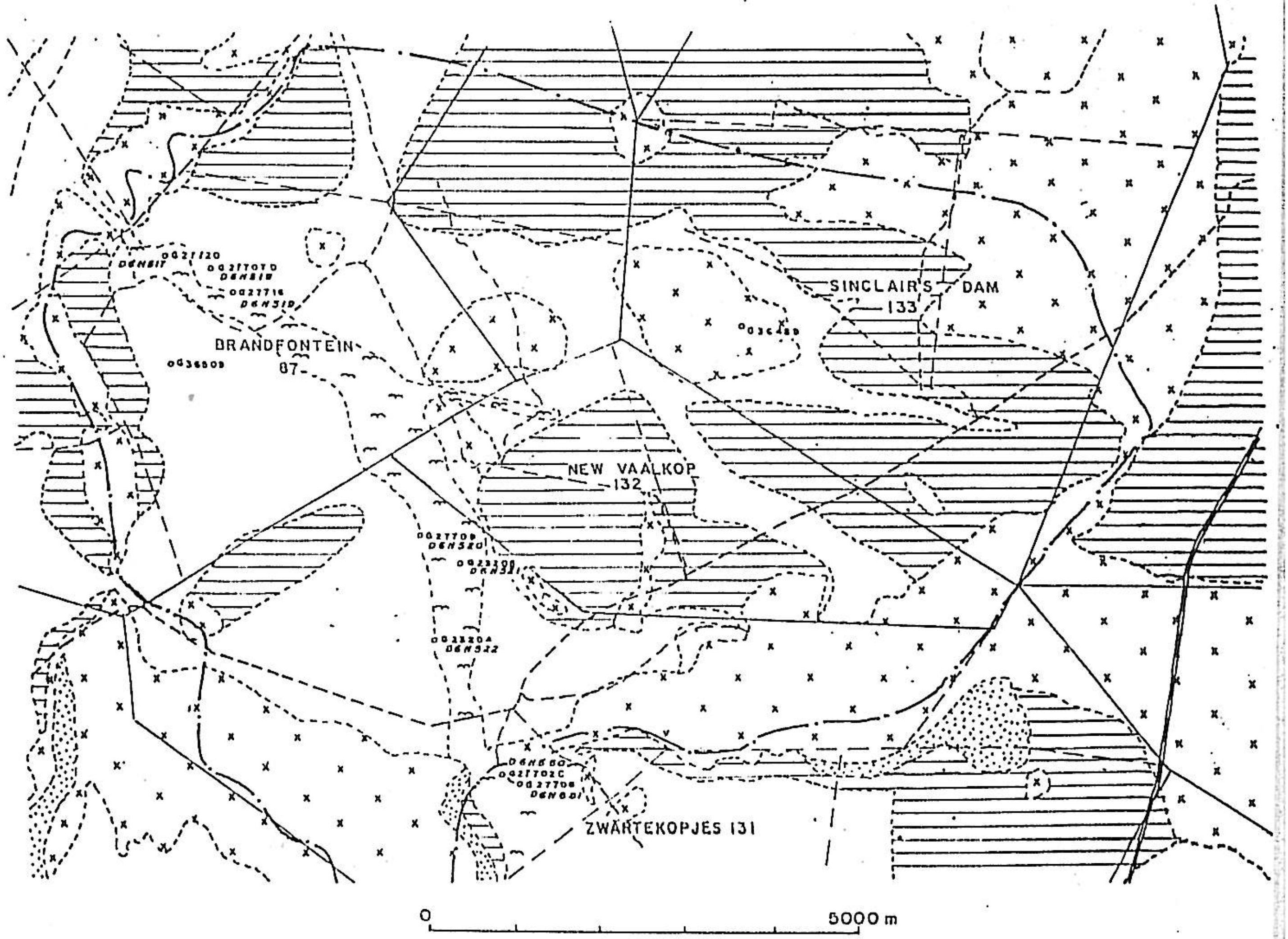
9.2 Features

Ground-water unit XXIB is bounded by subsurface divides except for two gaps where the Elandsfontein Spruit enters and exits the unit. Ground-water divides are assumed to coincide with surface watersheds. In the east, south and west the boundary is the crest of dolerite hills forming part of the ring structure. The northern boundary is an east-west trending topographic high which bisects the ring structure. The unit is traversed by the Elandsfontein Spruit which enters the ring structure in the southeast through a poort which has been cut through the dolerite hills on Zwartekopjes 131. It similarly exits the unit through a dolerite poort Renosterpoort on Brandfontein 87, in the northwest.

The outline of unit XXIB and its geology (adapted from Kirchner et al figure 4.104 1991) are depicted in figure 18. Its total area is 81.7 km^2. The hills occupy 12.9 km^2; the area underlain by saturated alluvium covers 5.0 km^2. The remainder which is relatively flat, is underlain by Tierberg Formation shale and dolerite under shallow soil cover. The encircling dolerite dips inwards. Within the basin like feature dolerite is present in the form of one or two undulating sheets. Apart from dolerite outcrops within the basin, many of the exploration boreholes drilled along the Elandsfontein Spruit have encountered dolerite or baked sediments below the alluvium.

Coarse sand and gravel deposits of the buried valley is the main aquifer. A composite aquifer is formed where the sand and gravel are underlain by weathered jointed shale (as on Renosterpoort) or by weathered coarse grained dolerite (as on Vaalbank). Yields of the 13 holes that were tested by von Hoyer and Rinkel (1976) vary between 5.5 and 14.2 l/s.

FIGURE 18 GEOLOGY OF GROUND-WATER UNIT XXIB (AFTER KIRCHNER ET AL 1991)



COLLUVIUM / SOIL

ALLUVIUM

DOLERITE

CARNARVON FORMATION

TIERBERG FORMATION

BOREHOLE WITH WATER LEVEL RECORDER

BOUNDARY OF GROUND-WATER UNIT

No boreholes were drilled outside the valley during the investigation of the seventies. This serious deficiency as far as waterbalance studies are concerned, was rectified only during 1985 when the research project on the exploitation potential of Karoo aquifers (Kirchner et al 1991) got underway. Water-level measurements and recording in these holes during the period October 1985 to middle 1988 has provided the data necessary for the production of water-level contour maps and ground-water balance determinations.

Of the 56 boreholes drilled in 1985 outside the alluvial fill, forty were successful with a median yield of 0.34 l/s. The composite alluvium hard-rock aquifers appear to be more prolific than the weathered fractured hard rock.

9.3 Ground-water contour maps

Contour maps were constructed of ground-water levels at the following times: July 1974, October 1985, February 1986, April 1986, July 1986, December 1986, March 1987, July 1987, September 1987, February 1988 and June 1988. Three of these July 1974, September 1987 and June 1988 are included in this report as folders 8, 9 and 10. As no water levels outside the valley are available for July 1974 it was assumed that these and those of June 1988 are identical, both having been preceded by an abnormally high rainfall season. Water levels in the alluvium were lower in June 1988 than in July 1974 - a result of municipal abstraction which had started in 1978.

These contour maps imply a flow of ground water from the higher-lying weathered and fractured hard rock areas to the alluvial deposits along the Elandsfontein Spruit. Ground water which is not abstracted from boreholes before reaching the river, is discharged as seepage into the riverbed, or is lost through evaporation from moist riverbanks and transpired by a dense growth of reeds. Open water in the river is either lost through evaporation or outflow from the ground-water unit. No information exists on outflow. It is assumed that evapotranspiration accounts currently for the loss.

9.4 Evapotranspiration

Conditions along the riverbed from Zwartekopjes to Renosterpoort were inspected by H.W. Moller of Geohydrology in June 1990 . The elevations of ground-water levels relative to the riverbed were determined at eight localities.

For about 3.5 km upstream of Renosterpoort to approximately borehole G23206A the riverbed is overgrown with reeds. Two stretches of water 1 000 and 500 metres long were present - the first directly upstream of Renosterpoort and the second at the top end of the reeds. Within the Renosterpoort, reeds occur along a stretch of about 1 km. Ground-water levels stand above the riverbed.

In the seventies pools of water also existed further upstream on Vaalbank over a stretch of about 2 000 metres. Municipal abstraction from boreholes G27715, G23205, G23205F and G23204D since 1979 has lowered the water level in this section to below the riverbed.

In the upper poort on Zwartekopjes the riverbed is overgrown with reeds. Pools of water are present here at times.

An attempt has been made in table 19 at estimating the evapotranspiration losses from ground-water unit XXIB. The mean monthly evaporation loss at De Aar from an American Class A pan over the period 1957 to 1980, has been converted first to equivalent Symon's pan figures and thence to evaporation loss from bodies of water. Lucerne irrigation requirements at De Aar have been interpolated from figures for surrounding localities as given in the joint Agricultural Technical Services and Water Affairs publication (1973). These figures are more conservative than the evaporation rates for water bodies. They have been used at estimating the possible evapotranspiration loss in the Renosterpoort area and the loss along the river on Vaalbank prior to municipal pumping. Evapotranspiration loss of ground water was reduced to zero by 1982 in the Vaalbank section, when the ground-water level dropped below river bed level.

Apart from a climatic fluctuation, evapotranspiration will also vary according to the position of the watertable - it will wane during droughts and wax after recharge. However in the following ground-water balance determinations (9.14) it is taken that the monthly figures remain the same from year to year.

It will be realised that a great deal of uncertainty is attached to these estimates. For this reason a lower figure of about 1/3 has also been introduced as a minimum estimate and used in the subsequent calculations (last column of table 19).

9.5 Water consumption for farming

Von Hoyer and Rinkel (1976) estimated consumption for farming as follows:-

	Million m^3/a
41.13 ha lucerne under irrigation requiring 915mm/a	0.3764
3068 head of sheep	0.0025
51 head of cattle	0.0008
Total	0.3797
	say 0.38 million m^3/a

In 1989 J.M.N. Calitz of Geohydrology found only 7.9 ha of lucerne and 1.6 ha of vegetables under irrigation. Consumption is estimated at 0.123 million m^3/a (see table 20). Requirements of households and stock are shown in table 21. The total monthly requirements of farming are given in table 22. These figures have been taken to apply for the period 1985-1988. It should however be evident that actual consumption may fluctuate and deviate considerably from these figures that have had of necessity to be used in the succeeding sections of the report.

9.6 Abstraction by the Municipality

Based on water-level behaviour, two groups of production holes may be distinguished, namely a Renosterpoort group boreholes G27707, G27719I, G27704 and G23604A; and a Vaalbank group G27715G, G23205B, G23205F and G23204D. Monthly pumpage figures for the period October 1985 to September 1988 for these two groups are listed in table 23. In addition *the table also includes abstraction figures of the Zwartekopjes group of holes G23203A, G27702G, G27703 and G23202. Abstraction from these holes affects underground flow from ground-water unit XX to unit XXIB.*

9.7 Fluctuation of the ground-water level

Water levels in hard rock have been measured and recorded only from October 1985 to July 1988. South-west of Elandsfontein Spruit water-level fluctuations in the different observation holes ranged between 0.5 and 2.0 m during this period. See for example the hydrograph of borehole G36509 on folder 11. In this part the ground-water flow direction is more or less parallel to the river. The amplitude is consequently similar to that of ground-water levels in boreholes penetrating saturated alluvium, i.e. along the river. See for example hydrographs of boreholes G27716 (D6N 519) and G23205 (D6N 521) on folders 12 and 13.

Folder 14 depicts water-level fluctuations in borehole G27708C (D6N 550) on Zwartekopjes in Vaalbankpoort (ground-water unit XX). Municipal abstraction is taking place in the vicinity of these three water-level recorders.

East of Elandsfontein Spruit and at considerable greater distances from the river, fluctuations in different holes are much larger - from 5.4 to 10.3 metres. The hydrograph of borehole G36489 (folder 11) is an example. This borehole is situated 4 000 metres away from the river.

The differing long-term behaviour of ground-water levels in boreholes penetrating saturated alluvium is shown in folders 15, 16 and 17. Levels reached a peak in 1976/77 after copious rains and a low in the second half of 1987. Municipal pumping commenced on Renosterpoort and on Vaalbank in September 1978 and in the Vaalbankpoort further upstream (in ground-water unit XX) in February 1980. Whereas levels on Renosterpoort and Zwartekopjes recovered in 1989 to those before municipal pumping started, those on Vaalbank fall far short. The alluvium has been dewatered here to below riverbed level. The situation is summed up in the following table:

TABLE 24 : LOWEST AND HIGHEST GROUND-WATER LEVELS IN ALLUVIUM Ground-water UNIT XXIB

AREA	Number of water-level recorders	Mean lowest water level (1987) relative to that in			Mean highest water level (1989) relative to that in		
		Beginning 1974 (m)	1976/77 (m)	Middle 1978 (m)	Beginning 1974 (m)	1976/77 (m)	Middle 1978 (m)
Renosterpoort	3	-1.9	-3.1	-2.1	+0.1	-0.9	-0.1
Vaalbank	3	-10.7	-12.4	-11.1	-5.6	-7.3	-6.0
Vaalbankpoort	2	n.d.	n.d.	-3.7	n.d.	n.d.	+1.1

n.d. - no data

9.8 *Fluctuations in the volumes of saturated hard rock and alluvium*

Volumetric changes of saturated hard rock and alluvium have been determined separately. Attempts at determining volume changes between different dates by planimetering contour maps drawn for these dates had to be abandoned. Volume changes were found to be of similar magnitude than the inaccuracies introduced by hand contouring and planimetering. Computer contouring and calculation of volume changes was not attempted. Hand contouring was favoured as lack of data points particularly along the margins of unit XXIB and an uneven spread elsewhere necessitated a considerable degree of hydrogeologic discretion.

Volume changes were accordingly determined by

(a) dividing the hard rock and saturated alluvium areas into sub-areas having as far as possible similar water-level responses - five in the case of the hard rock area and three for the alluvium.

(b) calculating for the periods under consideration the mean change in water-level for each sub-area from borehole measurements.

(c) multiplying mean change with area and adding up the results of the sub-areas.

Water-levels were initially not observed by IGS in some of the hard rock boreholes. By correlating fluctuations subsequently observed in these holes, with those in boreholes measured from the start, it has been possible to extrapolate with a fair degree of reliability the missing data.

Volumetric changes of saturated hard rock and of alluvium over the period October 1985 to July 1988 are given in tables 25 and 26 respectively. The data are also shown graphically in folder 18, figure 19 and figures 20A, B and C.

It should be noted that the tables 25 and 26(Appendix) are more extensive (after further refinement)and the values somewhat different to those previously used by the author (Vegter 1990b). The latter figures were not included in the 1990b report. They were used for the determination of the coefficient of storage of hard rock strata. Ground-water balances and recharge estimates were based on them. Revision and refinement has resulted in differing estimates of the coefficient of storage and recharge (see following sections).

9.9 *Storage coefficient of hard-rock strata*

Lack of noticeable recharge is evident from the smooth linear decline of the hard rock storage of ground-water unit XXIB between April 1986 and January 1987 (see folder 18, figure 19). During this period rainfall was mostly less than 5 mm/day; on four occasions, rainfall of between 10.2 and 19 mm was measured. In each case however only at one of the three IGS recorders situated within ground-water unit XXIB. The De Aar station likewise recorded 19 mm on one occasion only; the next highest being 6.5 mm. (See table 27 Appendix).

Between May and September 1986 there was little or no change in the apparent volume of saturated alluvium (figure 20A, B and C). The term "apparent" is used as the recorded water levels are considered to be *pressure heads rather than coincident with the watertable. As recharge is thought to occur more readily in the hard-rock areas than through fine-grained alluvial deposits, there was certainly no recharge of the alluvium by rainfall or from river flow between May and September 1986.*

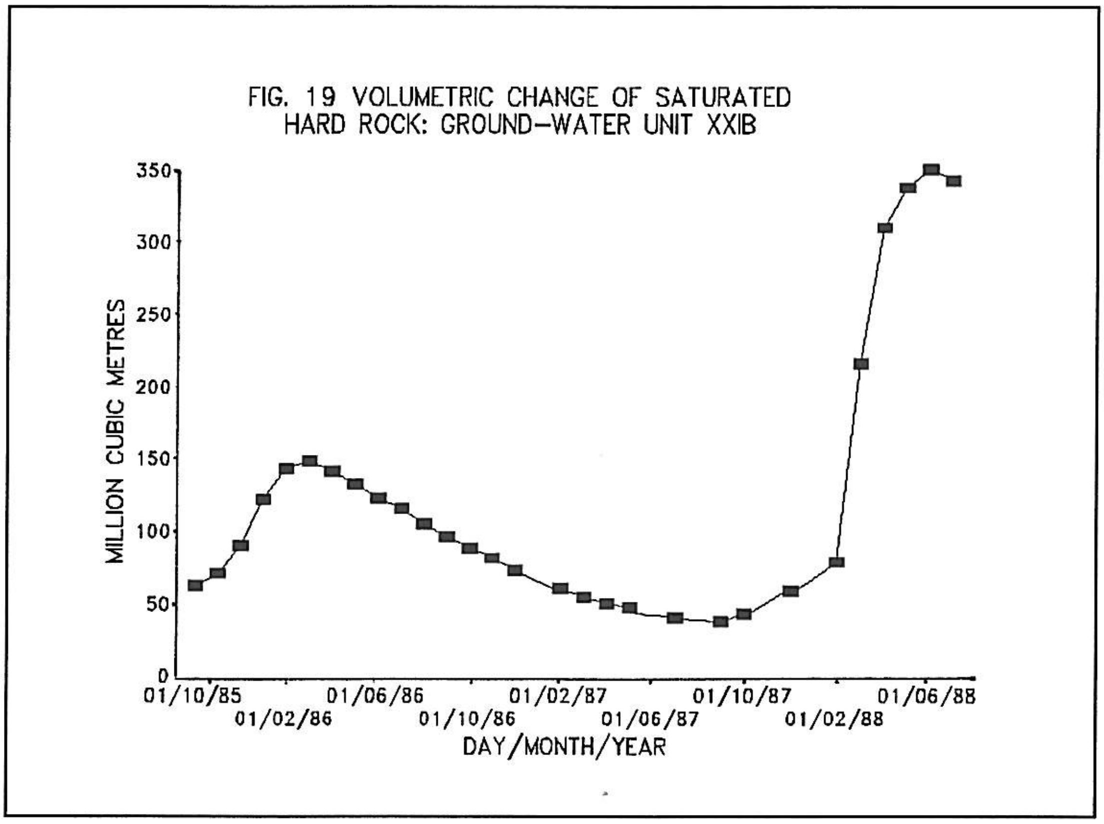
Loss of ground-water from the alluvium through municipal abstraction, farm consumption and evapotranspiration must therefore have been compensated by subsurface flow of ground-water from the hard-rock areas to the alluvium.

Municipal abstraction amounted to 173 000 m^3 (table 23 Appendix). Evapotranspiration loss and farm consumption is estimated at a lower value of 21 000 m^3 and a higher of 63 000 m^3 (see tables 19 and 22 Appendix). A volume of 36 million m^3 of hard-rock strata was dewatered (Appendix table 25). By equating hard-rock outflow to ground-water discharge from the alluvium and setting the latter equal to

(a) municipal abstraction only (0.173 million m^3)

(b) municipal abstraction plus the lower values for evapotranspiration and farm consumption (0.194 million m^3)

(c) municipal abstraction plus the higher values for evapotranspiration and farm consumption (0.236 million m^3)



the figures 0.0048, 0.0054 and 0.0066 are obtained for the storage coefficient of the hard-rock strata.

The values corresponding to (b) and (c) which were used in the Vegter (1990b) report are 0.0073 and 0.01. The difference may be ascribed to the following factors:

(a) *the 1990 storage coefficients are the mean of three periods of assumed zero recharge*

(b) *previous figures for volumetric change differ somewhat from those used in this report*

(c) *the storage coefficient of the alluvium was assumed to be 0.1.*

9.10 __Flow rate ex hard-rock strata to alluvium__

The mean flow rates corresponding to total discharges of 0.173, 0.194 and 0.236 million m^3 ((a), (b), (c) above) are 1407, 1577 and 1919 m^3/d respectively.

Flow rate will vary according to changes in

(a) *saturated thickness of hard-rock strata which implies changes in transmissivity*

(b) *hydraulic gradient*

By making use of the statistically determined characteristics of Karoo strata (see 4.4) the change in transmissivity has been estimated as follows:

$$\text{Percentage change in T} = \frac{\left(\sum_{n=1}^{n=8} \frac{q_n}{h_n} . P_n\right) + \frac{q_c h_c}{h_1} . P_1}{\left(\sum_{n=1}^{n=8} \frac{q_n}{h_n} . P_n\right)} \times 100$$

where q_n is the mean yield (l/s) of water strikes in the nth 5 metre borehole section. Sections commence from 5.5 m depth

q_c is taken as 1.0 l/s per 5 metre section and is used as a means of measuring the increase/decrease in transmissitivity owing to water-level fluctuation

h_n is the head from the centre of nth section to the water-level which is assumed to be at a mean depth of 3.0 m below the surface.
P_n is the probability of striking water in the nth 5 metre borehole section
h_c is the mean rise or drop of the ground-water level.

It was found that compared to the period 1/5/86 - 1/9/86, transmissivity would have been about 13% higher in June 1988 and about 10% lower in August 1987.

Corresponding changes in the hydraulic gradient have been estimated from water-level contour maps at about + 4% and - 5%.

The flow rate may therefore be taken to have been 17% higher in June 1988 and 15% lower in August 1987 than the mean rate of the period May to September 1986.

9.11 Storage coefficient of alluvium

Apart from rain recorded on 8-9 February and 19 July 1987 the period April 1986 to September 1987 appears to have been characterised by isolated light showers over parts of the ground- water unit XXIB (see table 27 Appendix). These showers as well as the really more extensive but also relatively light rainfall of 8-9 February and 19 July 1987 appear to have been insufficient to have either recharged the alluvium directly or to have produced significant flow in the river.

The alluvium is however continuously being recharged by ground-water flow from the higher lying hard-rock areas. If the assumption of zero recharge of the alluvium from rainfall and/or river flow is correct, then changes in the volume of saturated alluvium will depend on the difference - positive or negative - between subsurface flow to the alluvium and discharge through municipal boreholes, evapotranspiration loss and farm consumption. Although some farm boreholes are situated on higher ground, no serious error will be made by assuming that the total discharge of ground-water takes place from within the alluvial strip only.

Apart from flow originating within ground-water unit XXIB, the rate of municipal abstraction upstream on Zwartekopjes determines whether sub-surface flow to the unit takes place through Vaalbankpoort or not. Von Hoyer (1976) estimated the undisturbed subsurface flow at Zwartekopjes in 1974 at 750 m^3/d. This figure may be on the low side. Municipal abstraction on Zwartekopjes averaged about 32 000 m^3/month during the period October 1985 to February 1987. From March 1987 municipal abstraction from Zwartekopjes dropped sharply, mainly because of complaints by the landowner that reeds in the riverbed would die and a pump that was sucking air.

Sets of cumulative curves have been constructed by summing on a monthly basis the deficiencies/surpluses arising from:

Case I — *total discharge or loss in unit XXIB exceeding/falling short of the flow to the alluvium which originates from within the unit.*

Case II — *total discharge or loss in unit XXIB exceeding/falling short of the sum of*

(i) the flow to the alluvium which originates from within the unit and

(ii) the deficit (negative) or surplus (positive) depending on whether municipal pumpage on Zwartekopje exceeds/falls short of 32 000 m^3/month.

For each of cases I and II three values have been assumed for discharge or loss in unit XXIB:

A municipal abstraction only (see table 23 Appendix)

B municipal abstraction plus the lower estimate of evapotranspiration loss and farm consumption (Tables 19, 22 and 23 Appendix)

C municipal abstraction plus the higher estimate of evapotranspiration loss and farm consumption (Tables 19, 22 and 23)

In 9.9 the situation was considered where the flow to the alluvium equals discharge. The three figures for the discharge or loss rate given there are taken to apply to July 1986. The flow rates ex hard-rock to alluvium for June 1988 and August 1987 are assumed to be respectively about 17 percent higher and about 15 percent lower than in July 1986. Flow rates for the remaining months were interpolated from these figures (see table 28).

The results are depicted in figures 20A, B and C as follows:

Fig 20A	*Graph*	*V Volumetric change of saturated alluvium (table 25 Appendix)*
	"	*IA Case I combined with discharge A*
	"	*IIA Case II combined with discharge A*
Fig 20B	*Graph*	*V Volumetric change of saturated alluvium (table 25 Appendix)*
	"	*IB Case I combined with discharge B*
	"	*IIB Case II combined with discharge B*
Fig 20C	*Graph*	*V Volumetric change of saturated alluvium (table 25 Appendix)*
	"	*IC Case combined with discharge C*
	"	*IIC Case combined with discharge C*

For the period May 1986 to about May 1987 there is a fair degree of conformity between cumulative curves IA, IB, IC and the curve of saturated volume of alluvium. Beyond the latter month the downward trend of these curves continues till February 1988 when heavy rainfall occurred.

Curves IIA, IIB, IIC (in which allowance has also been made for reduced municipal pumpage on Zwartekoppies) conform more closely to the saturated volume curve (V) for the whole period up to the beginning of September 1987. During this period there was evidently no direct recharge to the alluvium from rainfall or from river flow. Curve IIA actually appears to match the volume curve up to February 1988.

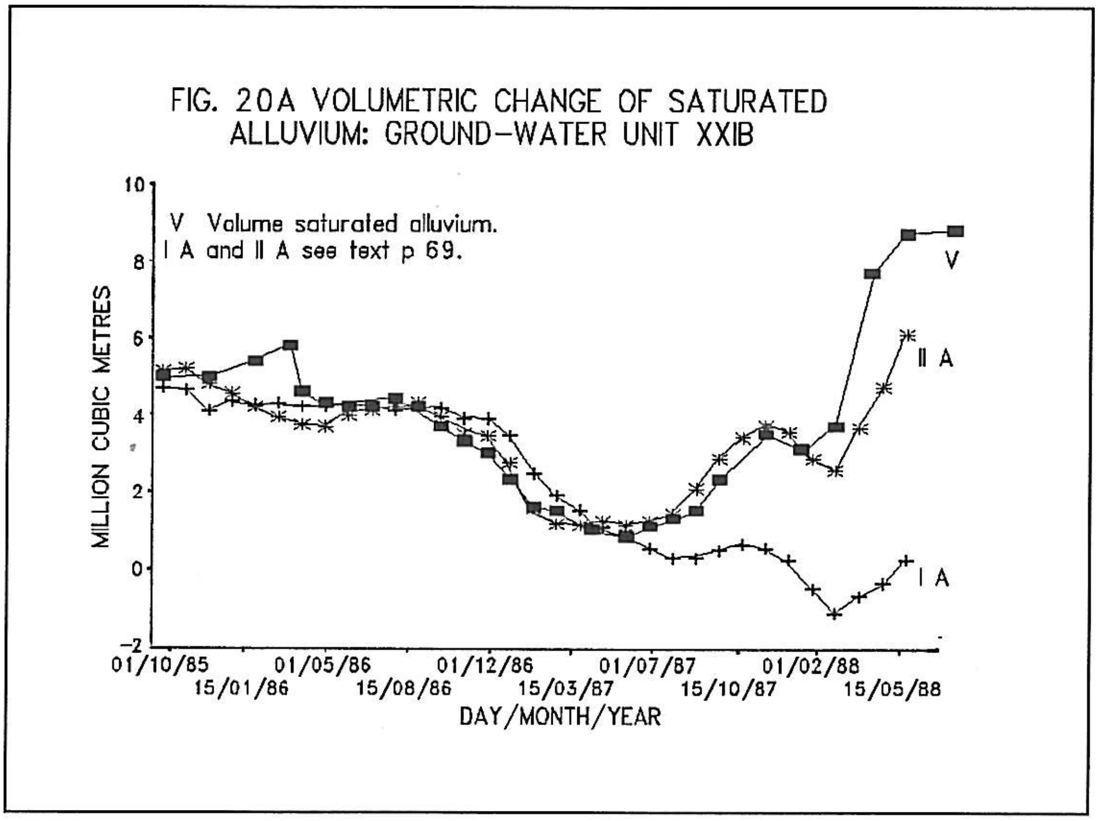


FIG. 20A VOLUMETRIC CHANGE OF SATURATED ALLUVIUM: GROUND-WATER UNIT XXIB
V Volume saturated alluvium.
I A and II A see text p 69.
MILLION CUBIC METRES
10
8
6
4
2
0
-2
V
II A
I A
01/10/85
15/01/86
01/05/86
15/08/86
01/12/86
15/03/87
01/07/87
15/10/87
01/02/88
15/05/88
DAY/MONTH/YEAR

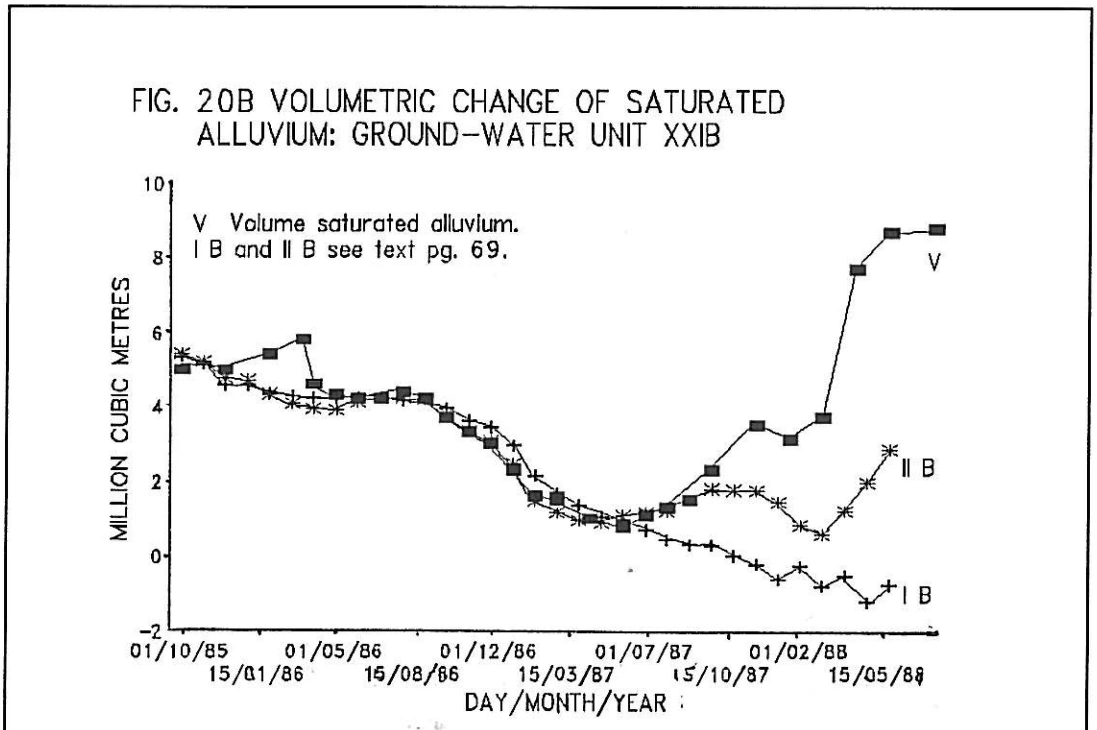
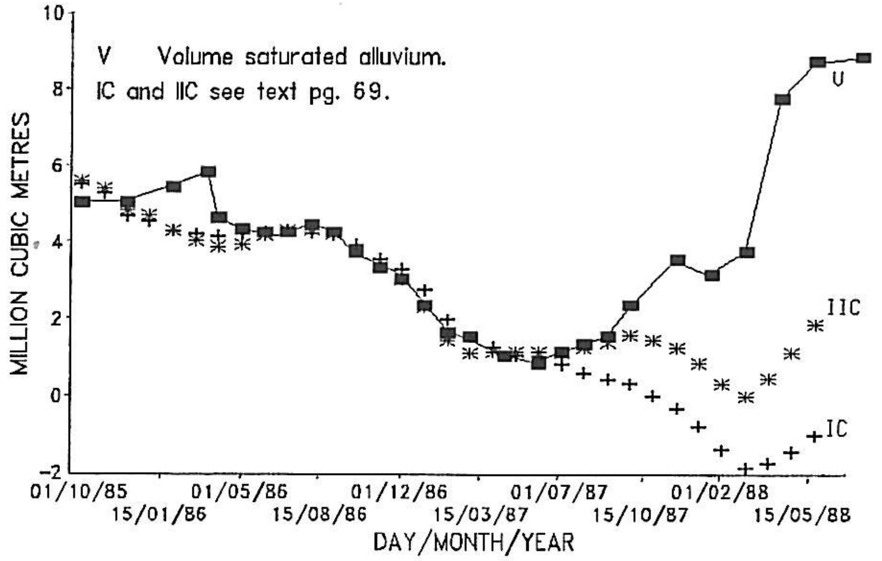


FIG. 20B VOLUMETRIC CHANGE OF SATURATED ALLUVIUM: GROUND-WATER UNIT XXIB
V Volume saturated alluvium.
I B and II B see text pg. 69.
MILLION CUBIC METRES
10
8
6
4
2
0
-2
V
II B
I B
01/10/85
15/01/86
01/05/86
15/08/86
01/12/86
15/03/87
01/07/87
15/10/87
01/02/88
15/05/88
DAY/MONTH/YEAR

FIG. 20C VOLUMETRIC CHANGE OF SATURATED ALLUVIUM: GROUND-WATER UNIT XXIB



The saturated volume curve (V) deviates from all six cumulative curves over the period December 1985 to March 1986 and with the exception of curve IIA also over the period September to June 1988. During both periods significant rain fell. The rise and subsequent rapid drop of the storage curve in April 1986 appears to be largely a pressure effect arising from recharge of fractured hard-rock strata outside the river valley (ground-water levels within the alluvial strip were recorded in boreholes that penetrate into the bedrock underlying the alluvium).

The fair degree of conformity between the saturated volume and cumulative IIA curves from September 1987 to February 1988 apparently indicates the lack of a similar pressure response to hard-rock recharge by comparable and even higher rainfall over the period September to December 1987 than that of December 1985 to March 1986. This discrepancy may be ascribed to the underestimation of ground-water discharge/loss (taken as municipal abstraction only) rather than the poor or zero hard-rock recharge. This is evident from the deviations of curves IIB and IIC over this period.

The matching of the cumulative and saturated volume curves is otherwise not sensitive to assumed magnitudes of evapotranspiration loss and farm consumption. A fair match is still possible assuming double the higher estimates of evapotranspiration loss and farm consumption (graphs not included). The reason for this is probably the synchronous variation of evapotranspiration loss and farm consumption on the one hand and municipal abstraction on the other.

From the foregoing the following is concluded:

(i) *Natural undisturbed ground-water flow through Vaalbankpoort (Zwartekopjes) to ground-water unit XXIB amounts to about 1 000 m^3/d.*

The storage coefficient and recharge volume based on IIA are considered underestimations, whilst those based on IIC may be too high. The IIB figures are deemed the best.

(ii) *Municipal (and other) abstraction on Zwartekopjes has therefore to be taken into consideration in drawing up a ground-water balance for unit XXIB.*

(iii) *The storage coefficients of the alluvium deduced from the matching of cumulative and saturated volume curves are*

Curve IIA	*0.043*
Curve IIB	*0.066*
Curve IIC	*0.082.*

(iv) *The difference between the cumulative and saturated volume curves at the beginning of October 1985 is indicative of recharge of the alluvium by rainfall/riverflow during the period October 85 to March 86.*

Volumes recharged according to

Curve IIA 0.2 million m^3 x 0.043 = 0.009 million m^3
Curve IIB 0.4 million m^3 x 0.066 = 0.026 million m^3
Curve IIC 0.6 million m^3 x 0.082 = 0.049 million m^3

(v) *The maintenance of higher ground-water levels in the alluvium beyond June 1988, is indicative of recharge and not merely a pressure response to recharge of the hard-rock strata.*

The difference between the cumulative and saturated volume curves on 1 June 1988 is a measure of the volumes recharge in the alluvium by rainfall/riverflow.

Curve IIA	*2.6 million m^3 x 0.043 = 0.11 million m^3*
Curve IIB	*5.8 million m^3 x 0.066 = 0.38 million m^3*
Curve IIC	*6.9 million m^3 x 0.082 = 0.57 million m^3*

9.12 Alternative estimates of storage coefficient of alluvium

In the period 1 April 1986 to 31 December 1986 during which presumably neither the hard-rock strata nor the alluvium was recharged, the volume of saturated hard-rock strata decreased by 69 million m^3 (table 25 Appendix). Based on the three values (0.0048, 0.0054, 0.0066) given in 9.9 this is equivalent to volumes of 0.331; 0.373; and 0.455 million m^3 of water, which were lost through subsurface flow to alluvium.

Ground-water discharge from the alluvium amounted to

Municipal abstraction only	*0.485 million m^3*
Municipal abstraction plus lower estimate of evapotranspiration loss and farm consumption	*0.564 million m^3*
Municipal abstraction plus higher estimate of evapotranspiration loss and farm consumption	*0.723 million m^3*

Taking corresponding estimates of volumes lost from hard-rock strata, it is found that discharges exceed subsurface inflow from hard-rock strata by 0.154, 0.191 and 0.268 million m^3. The saturated volume of alluvium decreased by 1 million m^3 (table 26 Appendix). Coefficients of storage are therefore 0.067. 0.083 and 0.117 according to the figure assumed for discharge of ground-water.

A slightly different approach is that of using the estimated flow from hard-rock to alluvium (table 28 Appendix). These estimates range from 0.398 through 0.425 to 0.479 million m^3 for the period 1 April to 31 December 1986 depending on the estimated discharge or loss of ground-water. Excess discharges over flows to the alluvium are 0.087, 0.139 and 0.244 million m^3. Corresponding coefficients of storage are 0.083, 0.060 and 0.106.

To summarise, depending on the discharge figure assumed, estimates of the storage coefficient of the alluvium range as follows:

Discharge equal to		*Mean*
Municipal abstraction only	*0.043; 0.067 and 0.038*	*0.049*
Municipal abstraction plus lower estimate of ET and farm use	*0.066, 0.083 and 0.060*	*0.07*
Municipal abstraction plus higher estimate of ET and farm use	*0.082, 0.117 and 0.106*	*0.10*

Adopting these mean values for alluvium, corresponding adjusted storage coefficients for the hard-rock strata change to 0.0054, 0.0058 and 0.007, depending on discharge assumed (compare with 9.9).

9.13 Coefficients of storage of alluvium and hard-rock strata adopted for further assessments

Ground-water discharge in unit XXIB certainly exceeds municipal discharge. On the other hand, a large degree of uncertainty is attached to the higher estimates of evapotranspiration and farm consumption (tables 19 and 22). At this juncture it therefore appears prudent to be conservative and to accept the lower estimates of evapotranspiration loss and farm consumption in further assessments.

This implies coefficients of storage of 0.0058 and 0.07 respectively for hard-rock strata and alluvium.

9.14 Replenishment

The hard-rock storage curve for ground-water unit XXIB (folder 18 and figure 19) for the period that ground-water levels were observed by IGS outside the alluvial strip, consist of five legs: a recharge phase October 1985 to March 1986; followed by a linear decline up to January 1987; there after a reduced rate of decline up to August 1987; then a rising leg up to January 1988, where after storage increases sharply until the beginning of June 1988. Ground-water balances were drawn up for three recharge periods.

In the estimation of recharge set out in table 29 the last two legs are treated as one recharge period because a proper estimate of the change in alluvium storage cannot be made at the beginning of February 1988 owing to the pressure response of water levels recorded by the boreholes drilled through the alluvium.

It is interesting to note that the inference of alluvium recharge made from a comparison between cumulative pumpage effect and saturated alluvium volume curve for the period October 85 - March 86 is corroborated (see 9.11) by the analysis in table 29. That the figures should agree 100% is however too much to be hoped for (0.038 against 0.080 million m^3).

Recharge of the alluvium by 0.1 million m^3 during the period 1/2/87 - 31/8/87 has to be ascribed (as already discussed in the 9.11) to the reduction of municipal pumpage on Zwartekopjes (Vaalbankpoort). The volume pumped during this period falls 0.111 million m^3 short of the previously maintained average of 32 000 m^3/month (0.224 million m^3 over 7 months).

Part of the recharge of 0.596 million m^3 to the alluvium in the period 1/9/87 - 31/5/88 must be attributed to the reduced municipal abstraction on Zwartekopjes which was 0.156 million m^3 short of the 0.288 million m^3 (32 000 m^3/month) presumably necessary to intercept all of the flow through Vaalbankpoort. This seems to indicate that recharge of the alluvium by rainfall and more likely by flooding amounted to 0.440 million m^3.

According to the difference between the cumulative and saturated volume curves alluvium recharge was 0.38 million m^3 (see 9.11). This fairly close correspondence gives confidence that the interpretation of the geohydrology is correct and that the estimations of recharge, and storage coefficients are not far off the mark.

Estimation of recharge in terms of rainfall is problematic because daily and monthly figures diverge greatly from each other over short distances within ground-water unit XXIB (see folder 18 and table 27 Appendix). The three IGS stations which were in operation from end October 1985 to April 1988 appear definitely insufficient for reliable estimates of the volume of rain per shower on the ground-water unit.

By looking at replenishment events of several months duration at least some of the variability in rainfall should be smoothed out. Under the circumstances of inadequate coverage with rain gauges the only option for calculating volume of rain on unit XXIB is that of averaging the rainfall as recorded at the three IGS stations. As all three IGS recorders were not in operation for the whole period October 1985 to June 1988 rainfall figures of the Weather Bureau station at De Aar had also to be used to fill gaps.

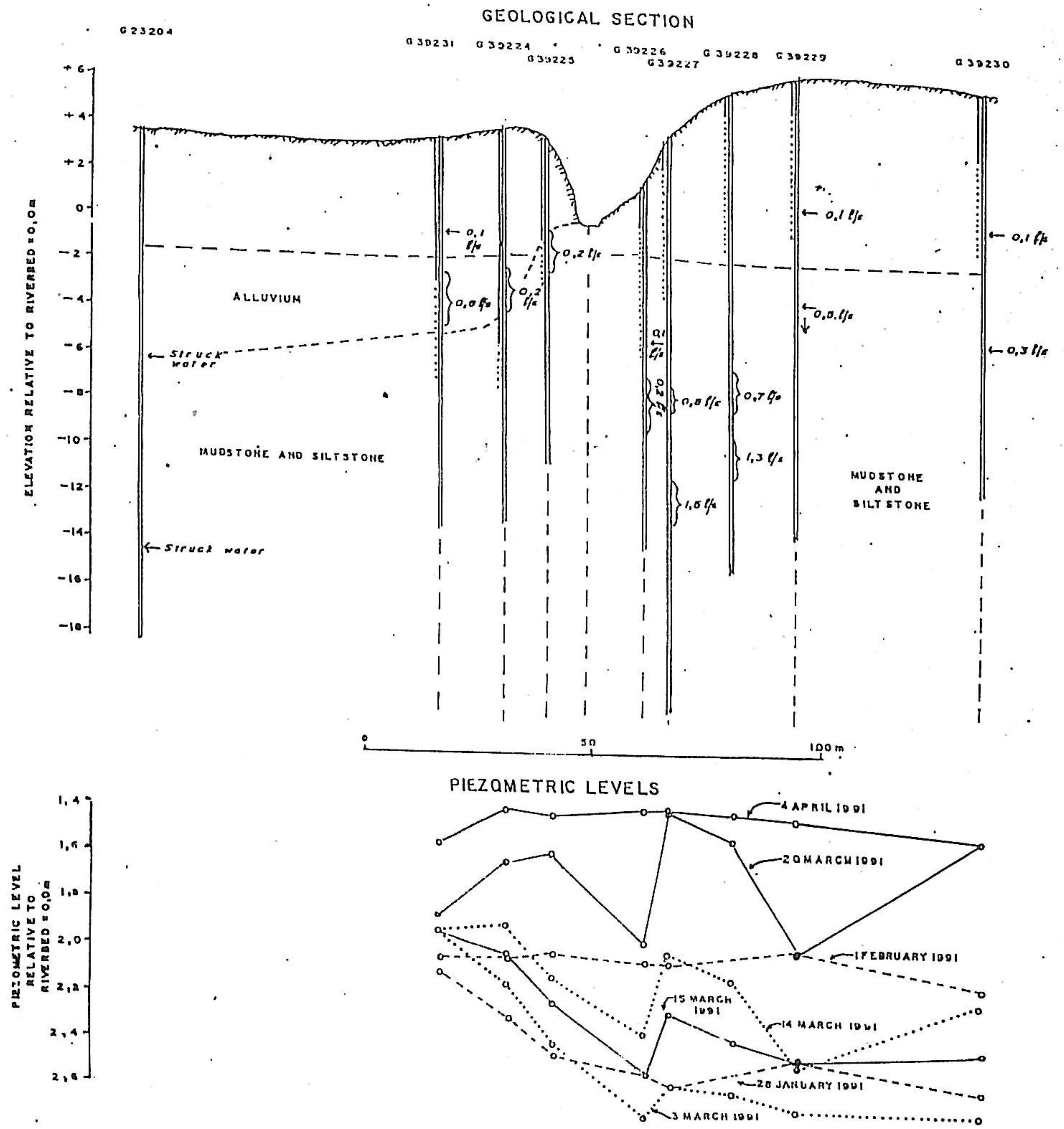
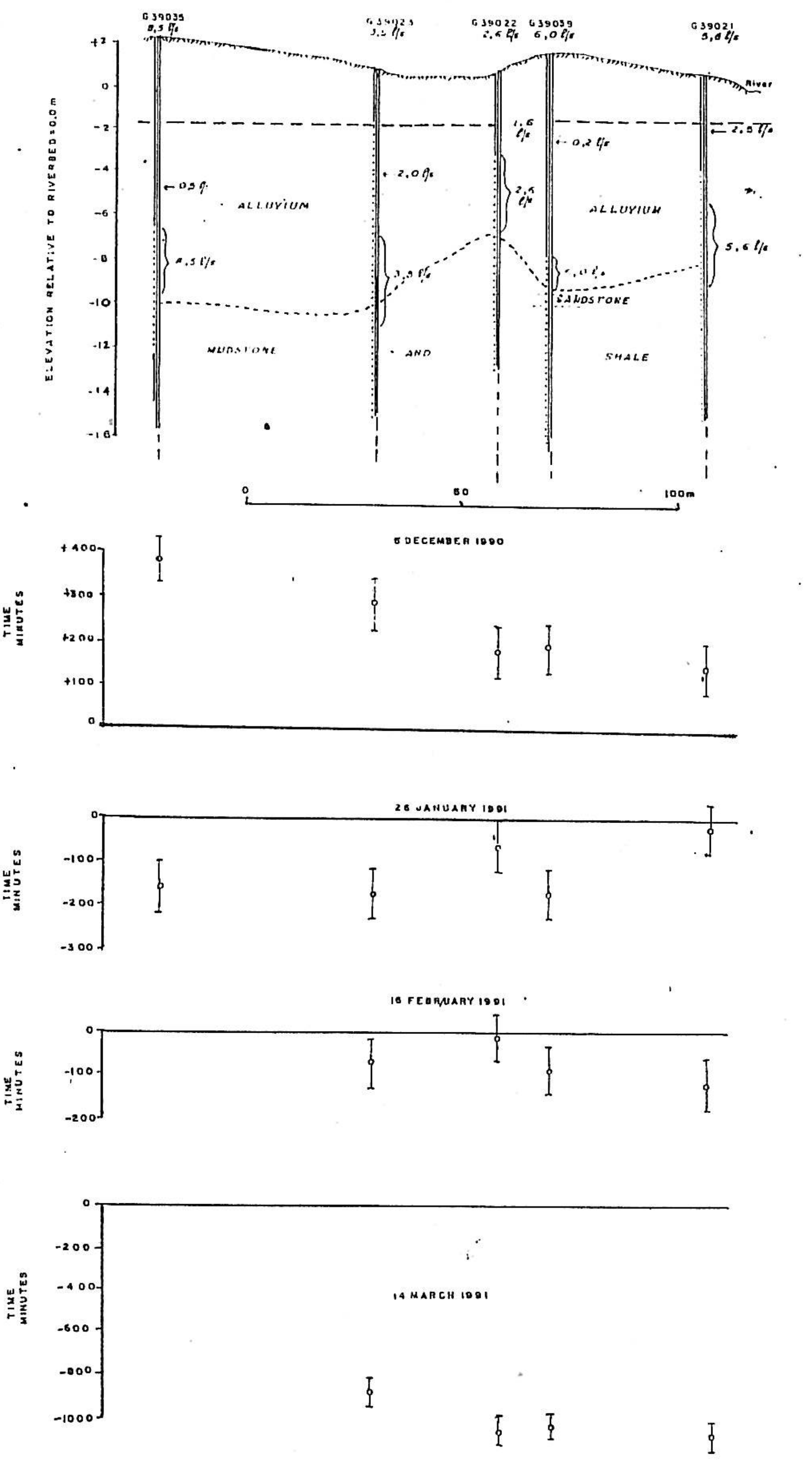


FIGURE 16B PIEZOMETRIC LEVELS ON DIFFERENT DATES
VAALBANK RIVER SECTION

(SEE ALSO FOLDER 6)

GEOLOGICAL SECTION

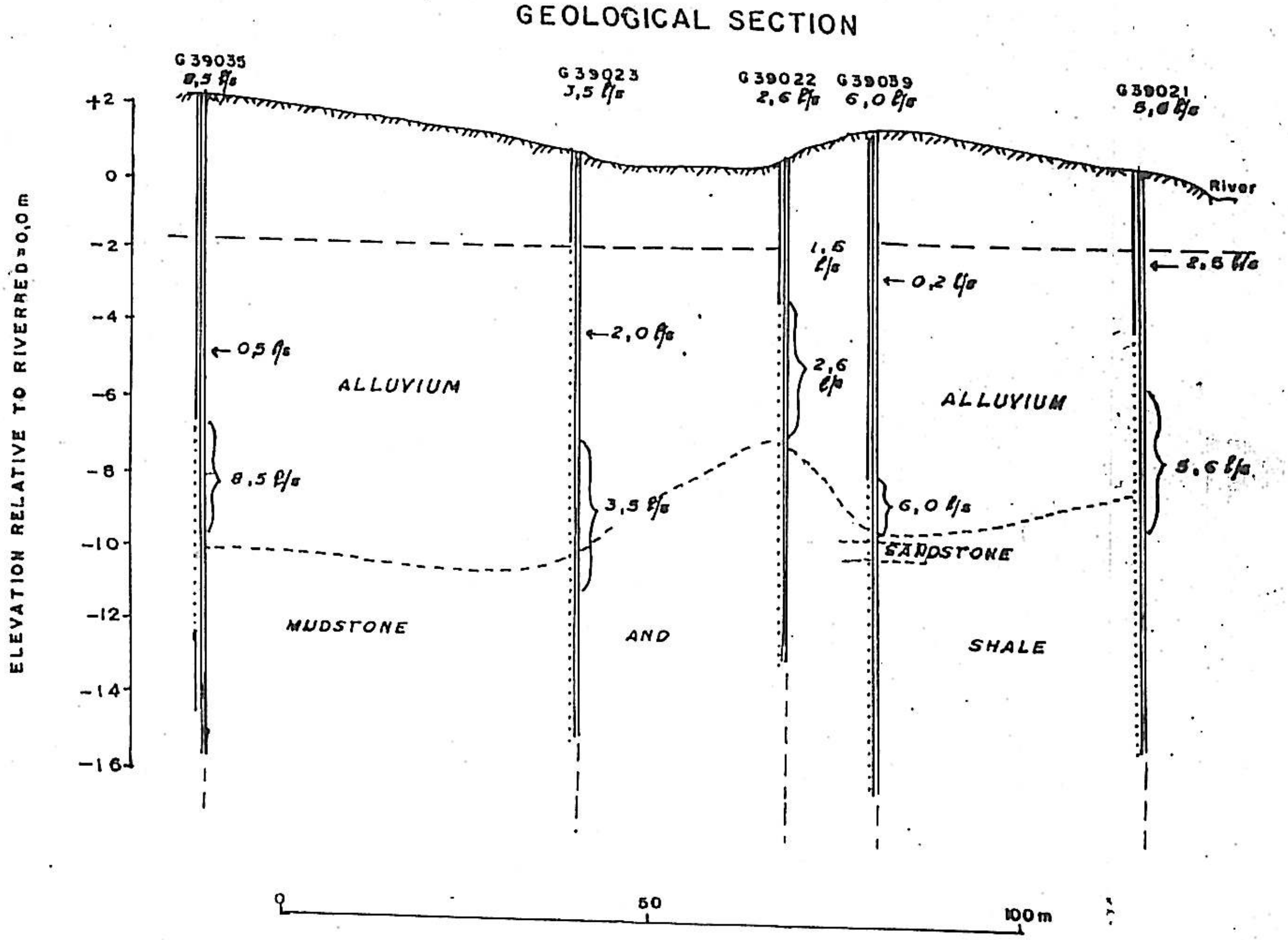


ONSET TIMES OF PIEZOMETRIC RISE RELATIVE TO ONSET RIVERFLOW = ZERO MINUTES

UNCERTAINTY RANGE OF ONSET TIME

FIGURE 17A ONSET OF RIVERFLOW AND GROUND WATER FLUCTUATION: SECTION ACROSS BRAK RIVER CAROLUSPOORT

(SEE ALSO FOLDER 7)



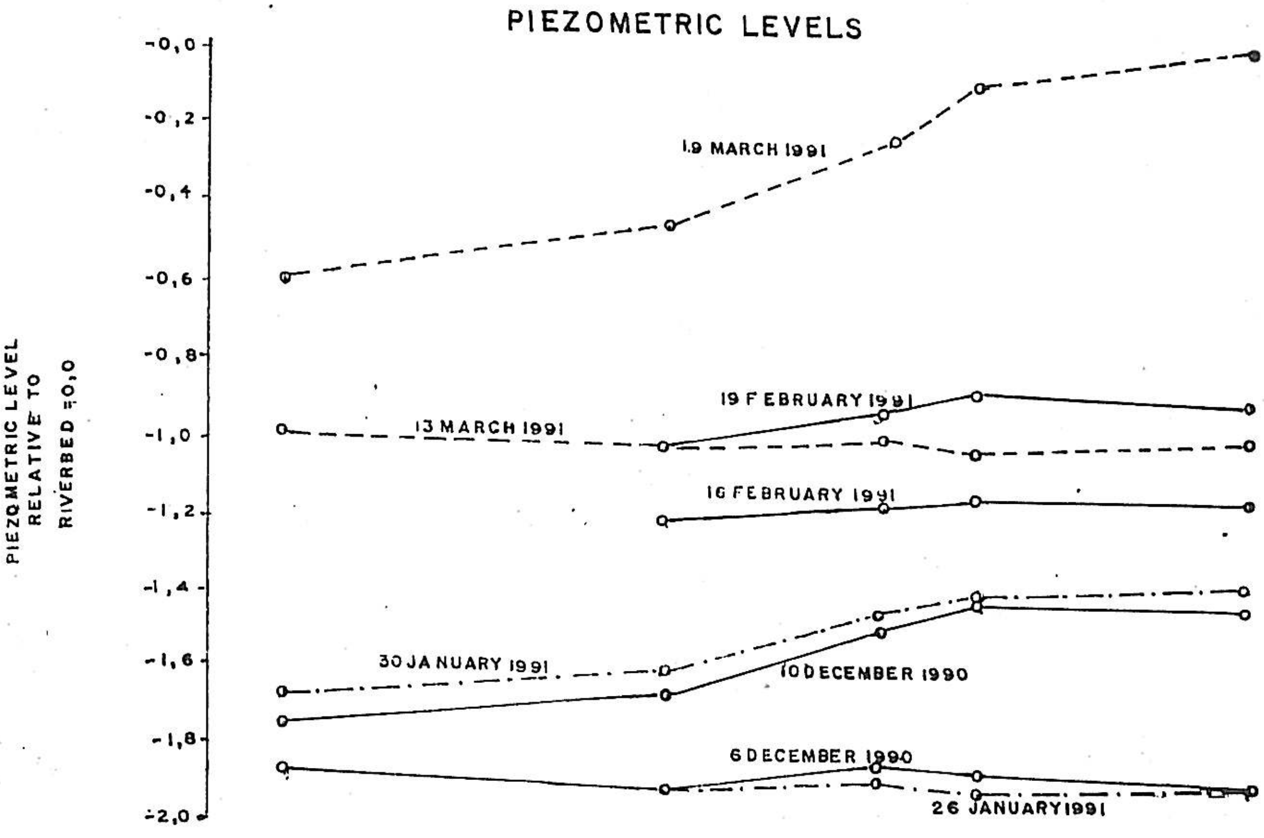


FIGURE 17 B PIEZOMETRIC LEVELS ON DIFFERENT DATES
CAROLUSPOORT RIVER SECTION

(SEE ALSO FOLDER 7)

TABLE 29 ESTIMATION OF RECHARGE GROUND WATER UNIT XXIB

LINE		REMARKS			
1	Period		1/10/85 - 31/3/86	1/2/87 - 31/8/87	1/9/87 - 31/5/88
2	Mean areal rainfall (mm) 3 IGS recorders; incomplete record supplemented with De Aar 0170/009	Appendix table	215	74	417
3 a	Mean areal rainfall 10 mm/day and more (percentage of total areal mean)		166 (66%)	47 (63.5%)	323 (77.5%)
b	Mean areal rainfall 15 mm/day and more (percentage of total areal mean)		129 (60%)	36 (48,6%)	292 (70%)
4	Evapotranspiration loss (million cubic m) conservative figure	Appendix table	0.060	0.029	0.072
5	Farm consumption (million cubic m) conservative figure	Appendix table	0.031	0.014	0.036
6	Municipal abstraction (million cubic m)	Appendix table	0.294	0.344	0.409
7	Total ground-water discharge (million cubic m)		0.385	0.387	0.517
8	Change in volume of saturated alluvium (million cubic metres)	Appendix table	-0.4	-0.1	+7.2
9	Equivalent change in volume of water held in alluvium (million cubic m)	Storage coefficient 0.070	-0.028	-0.007	+0.504
10	Change in volume of saturated hard-rock strata (million cubic metres)	Appendix table	+79.5	-22.5	+312.7
11	Equivalent change in volume of water held in hard-rock strata (million cubic m)	Storage coefficient 0.0058	0.461	-0.131	+1.814
12	Outflow volume from hard-rock strata to alluvium (million cubic m)	Appendix table	0.277	0.281	0.425
13	Volume of water recharged to hard-rock strata - areal extent 76,7 million square m (million cubic m)	Lines 11 + 12 figures	0.738	0.150	2.239
14	Recharge as percentage of rainfall	E-5 (line 13 fig) 76,6 (Line 2 fig)	4.5	2.6	7.0
15 a	Recharge as percentage of rainfall 10 mm/day and more	E-5 (Line 13 fig) 76,6 (Line 3a fig)	5.8	4.2	9.0
b	Recharge as percentage of rainfall 15 mm/day and more	E-5 (Line 13 fig) 76,6 (Line 3b fig)	7.5	5.4	10.0
16	Alluvium rechared (million cubic m)	Lines 7 +9 - 12 figures	0.080	0.100	0.596

The threshold rainfall for recharge is uncertain. It is variable depending on moisture deficits that have developed since the previous rainfall. This depends on the length of the intervening period and the evapotranspiration rate. Rainfall during the winter may effect more recharge than in summer. Apart from magnitude, intensity and duration of showers obviously also play a role. Judging from the water-level response, it would appear that after a dry spell at least 10 to 15 mm of rain are required to effect noticeable recharge of hard-rock strata with a soil cover of one metre and less.

An analysis of rainfall recorded at De Aar since 1913 (see table 30 Appendix) shows that the percentage of the seasonal rainfall that equals and exceeds 10 and 15 mm per day varies as follows:

A Rainfall 10 mm and more per day

Range as a percentage of total seasonal rainfall)	Total seasonal rainfall (mm)	Season recorded	Corresponding % of rainfall equalling/exceeding 15 mm/d
21.1 (25.2 mm)	119.4	1944/45	0.0
93.3 (223.8 mm)	240	1920/21	62.5

B Rainfall 15 mm and more per day

Range as a percentage of total seasonal rainfall)	Total seasonal rainfall (mm)	Season recorded	Corresponding % of rainfall equalling/exceeding 10 mm/d
0.0 (0 mm)	120.2; 107.2; 119.4	1918/19; 1932/33; 1944/45	56.1; 35.5; 21.1
81.0 (170.5 mm)	210.6	1968/69	81.0

The lowest and highest seasonal rainfalls of 10 mm and more per day and of 15 mm and more per day are respectively:

10 mm/d and more :

25.2 mm 1944/45 and 656.4 mm 1973/74 (91.9% of total)

15 mm/d and more

0.0 mm [1918/19, 1932/33, 1944/45] and 561.4 mm 1973/74 (78.6% of total)

These figures illustrate the highly variable composition of rainfall. Expressing recharge as a percentage of total rainfall is untenable if the threshold concept is correct. For example replenishment will be overestimated if the recharge percentages of total rainfall given in table 29 are applied to situations where the 10 or 15 mm/day and more components comprise smaller fractions of total rainfall than were analysed in that table.

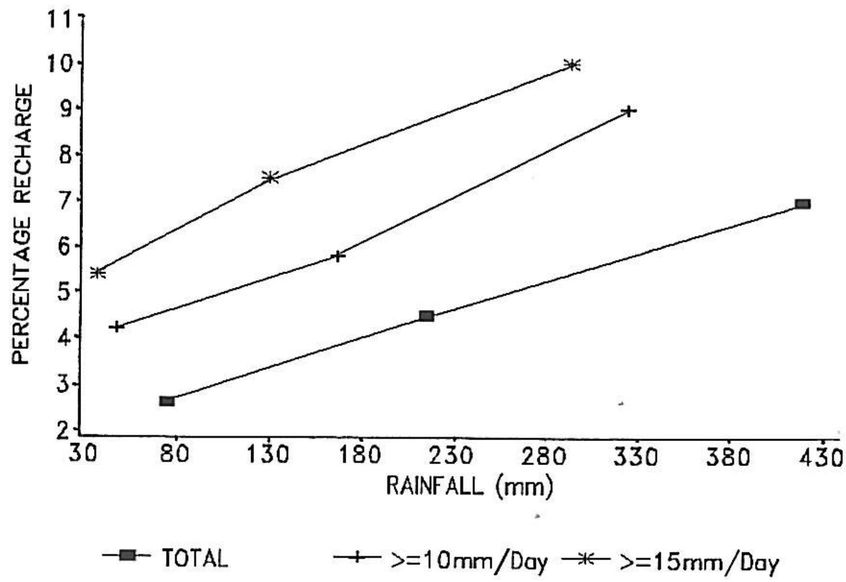
Recharge percentage increases with increasing seasonal rainfall. In order to estimate recharge for different seasonal rainfalls, recharge percentages of the 10 and 15 mm/day and more components were linearly interpolated for 50 mm intervals as follows (see also figure 21)

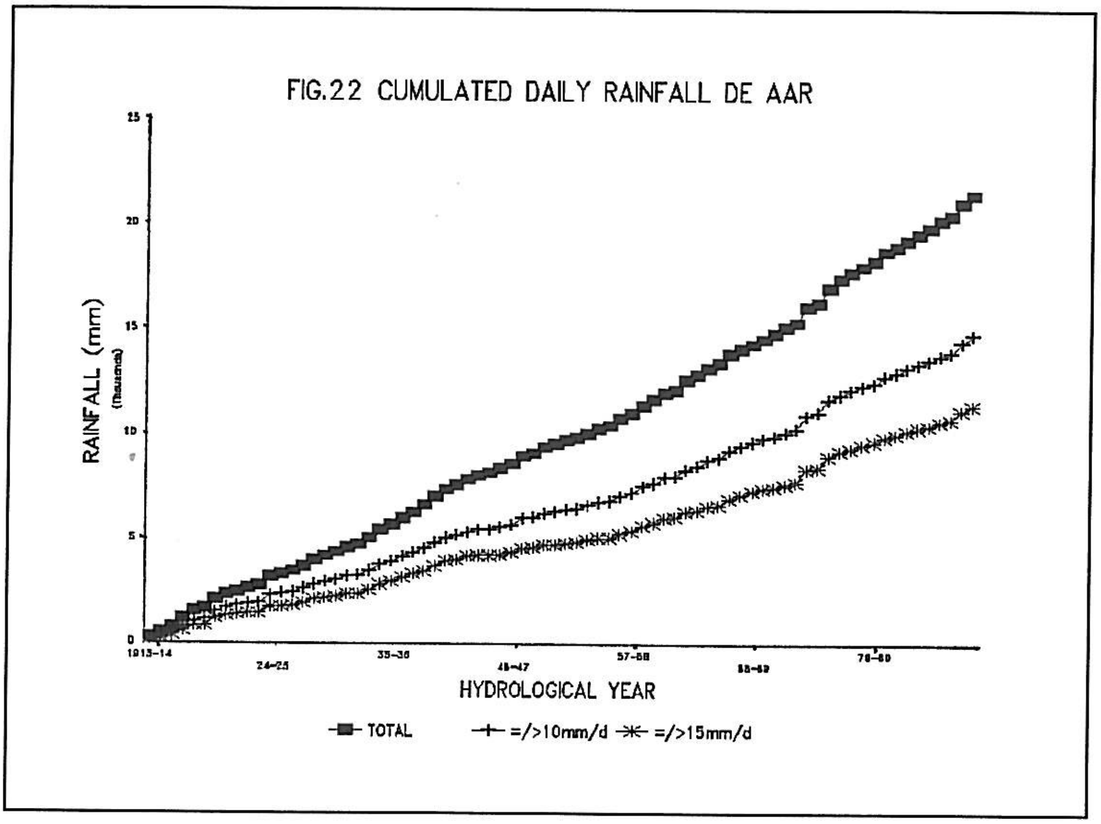
TABLE 31 RECHARGE AS A PERCENTAGE OF RAINFALL

Seasonal Rainfall (mm)*	*Recharge Percentage for*	
	10 mm/day and more component	*15 mm/day and more component*
0 - 49	*3.6*	*5.4*
50 - 99	*4.5*	*6.3*
100 - 149	*5.4*	*7.2*
150 - 199	*6.3*	*8.1*
200 - 249	*7.2*	*9.0*
250 - 299	*8.1*	*9.9*
300 - 349	*9.0*	*10.8*
350 - 399	*9.9*	*11.7*

** 10 mm/day and more and 15 mm/day and more component.*

FIG. 21 RECHARGE AS PERCENTAGE OF RAINFALL





Recharge calculated according to Table 31 from the De Aar rainfall records 1913-1989 (table 30 Appendix), yields a total for the 15 mm/day and over component that is about 14% less than that for 10 mm/day and over rainfall. Total recharge for the 1913-89 period based on the recharge percentages of total rainfall is about 34% higher than that of the 15 mm/day and over component. Curves of cumulated total daily rainfall, daily rainfall exceeding 9.9 and 14.9 mm are shown in fig. 22.

9.15 Long-term steady or assured yield

The long-term steady or assured yield of ground-water unit XXIB may be determined from the historical rainfall record of De Aar in a manner analogous to that used for dams.

The "live" volume of hard-rock strata is conservatively put at 350 million m^3. With a storage coefficient of 0.0058 (see 9.13) this is equivalent to just over 2 million m^3 of water or a depth of 26.5 mm water over the 76.6 km^2 occupied by hard-rock strata (a saturated volume change of 312.7 million m^3 occurred between September 1987 and June 1988).

Since municipal pumping commenced in 1978, the saturated volume of alluvium decreased by 19.5 million m^3 which is equivalent to nearly 1.4 million m^3 of water (storage coefficient 0.07 see 9.13). The extraordinary heavy rains and flooding of early 1988 accompanied by reduced pumpage on Zwartekopjes effected recharge of the alluvium of about 0.6 million m^3. This is probably a fair estimate of the maximum recharge (and "live" storage) that may be expected for the alluvium *(the balance of 0.8 million m^3 withdrawn since municipal pumping started in 1978 must be viewed as "mined" water). Considering that ground-water flow ex hard-rock strata to the alluvium has been estimated to have dropped only about 15 percent below its value of July 1986 by September 1987 (corroborated by matching with alluvium storage curve - see 9.10 and 9.11) - and taking the "live" alluvium storage into account, an upper safe limit to the total "live" storage of ground-water unit XXIB may be put at 3.0 million m^3 of water which is equivalent to a water depth of 39.5 mm over the hard-rock area.*

The final result of the trial and error determinations of steady yield for "live" storages of 26.5 and 39.5 mm using both sets of recharge percentages (table 31) are given in tables 32 and 33 (Appendix)

The results are also presented graphically in figures 23-26. An area of 76.6 km^2 is implied.

TABLE 34 STEADY OR ASSURED YIELD OF Ground-water UNIT XXIB

Figure	*Assumed full storage mm*	*Recharge based on daily rain=fall exceeding mm/d*	*Steady/Assured yield mm/annum*
23	*26.5*	*9.9*	*8.6*
24	*26.5*	*14.9*	*7.2*
25	*39.5*	*9.9*	*9.5*
26	*39.5*	*14.9*	*8.2*

FIG. 23 G–W UNIT XXIB: END OF SEASON STORAGE: ABSTRACTION RATE 8.6 mm/a

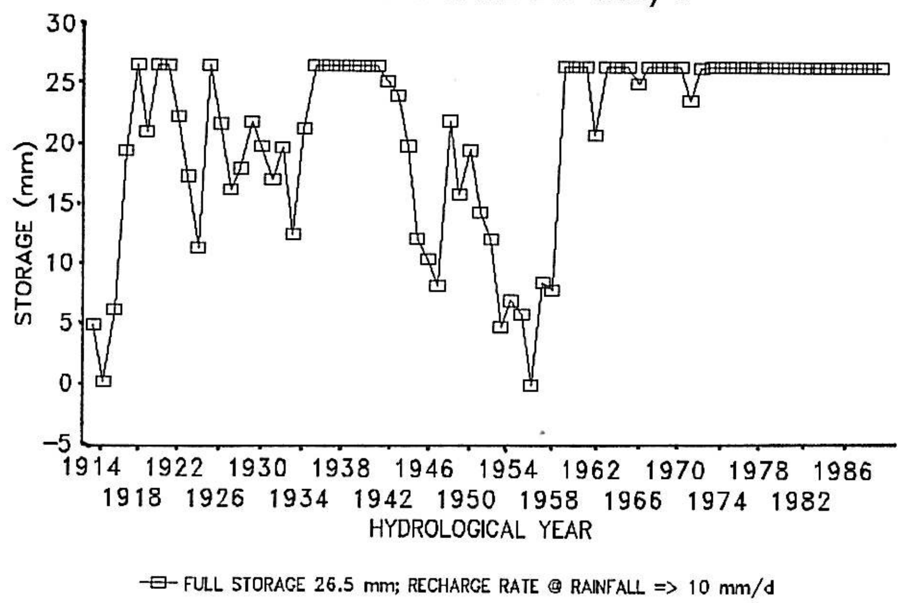


FIG. 24 G-W UNIT XXIB: END OF SEASON STORAGE: ABSTRACTION RATE 7.2 mm/a

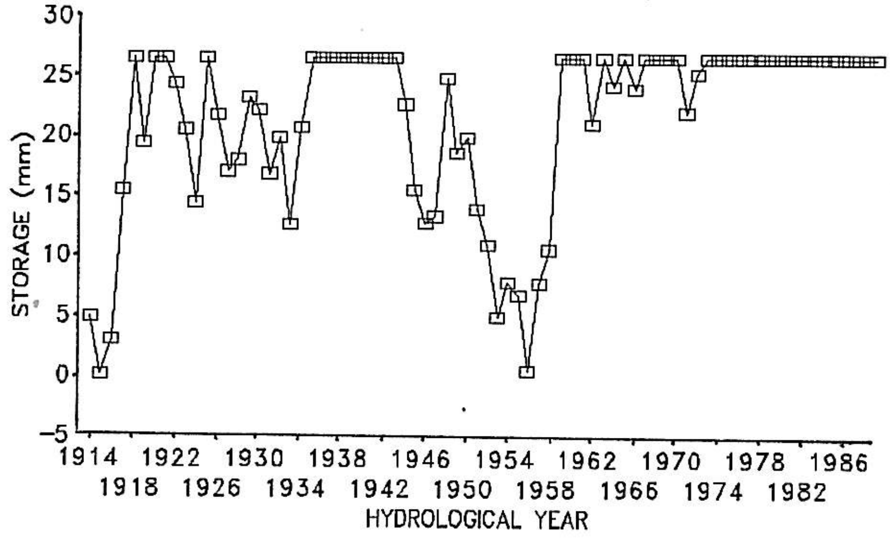


FIG. 25 G-W UNIT XXIB: END OF SEASON STORAGE: ABSTRACTION RATE 9.5 mm/a

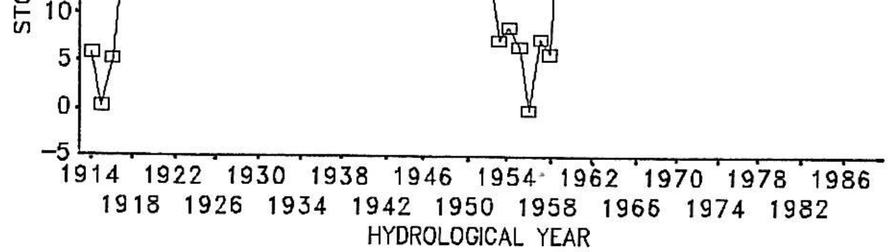
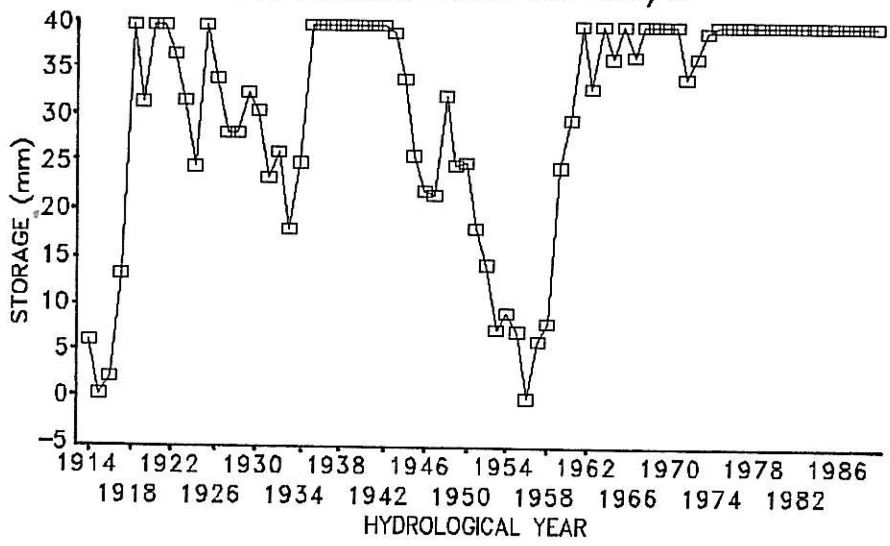


FIG. 26 G-W UNIT XXIB: END OF SEASON STORAGE: ABSTRACTION RATE 8.2 mm/a



The steady yields are determined by the worst recharge period from 1943/44 to 1955/56. Between 1934/35 and 1941/42 and from 1960/61 onwards the estimated recharge exceeds the steady yield practically uninterruptedly leaving storage at full capacity. In fact between 1973/74 and 1988/89 steady yields about double that of 1943 to 1955/56 i.e. 15.1 mm/annum (storage 26.5 mm recharge based on rainfall exceeding 14.9 mm/day mm) and 17.7 mm/annum (corresponding figures 39.5 mm and and rainfall exceeding 9.9 mm/day) appear possible with storage at full capacity at the end of the period.

How do these high steady yields compare with municipal abstraction and estimated evapotranspiration loss and farm consumption from 1978/79 to 1988/89? Municipal abstraction amounted to 6.5 million m^3. Evapotranspiration loss is estimated at a maximum of 3.9 and minimum of 1.3 million m^3 taking into account that up to 1982 open groundwater must have also been present on Vaalbank, and not only Renosterpoort (table 19 Appendix). Farm consumption is put at a maximum of 1.4 and a minimum of 0.45 million m^3 (see table 22).

The total discharge over the 11 year period appears to lie between 8.25 and 11.8 million m^3. The higher steady yields possible during this period of between 15.1 and 17.7 mm/annum (see columns C2, F2 table 32 and C2, F2 table 33), amount to 12.7 -14.9 million m^3 for the 11 year period.

The difference between these two sets of figures may be ascribed to one or more reasons:

(1) under-estimation of evapotranspiration loss and discounting the possibility of surface outflow during the earlier part of period when the ground-water level was considerably higher especially in the Vaalbank area.

(2) over-estimation of recharge. De Aar rainfall figures have been used. Rainfall recorded by IGS during 1985-88 in ground-water unit XXIB appear to be somewhat lower than at De Aar.

(3) the higher of the two "live" storage figures (39,5 mm) may be an over-estimation.

10. HYDROCHEMISTRY

10.1 Range in quality

Between 1971 and 1989 ground-water in the surroundings of De Aar has been sampled and analysed on various occasions. About 600 analyses have been listed by Parsons (1989), Woodford (1990a), van Wyk (1989) and Kirchner et al (1991). This number not only comprises different holes but also repetitions. Parsons (1989) has evaluated the data to determine the suitability of ground-water for urban supply and whether water quality tends to deteriorate with time. Stewart, Sviridov and Oliver (1990) have investigated the technical feasibility and cost of improving the quality of water for De Aar.

Quality ranges widely:

	mg/l
Total dissolved solids	210 - 5 700
Na	15 - 1 750
Mg	0.0 - 320
Ca	4 - 600
Cl	6 - 1 925
SO_4	0.0 - 1 600
Total alkalinity	40 - 730

Figure 27 is a frequency plot of total dissolved solids:

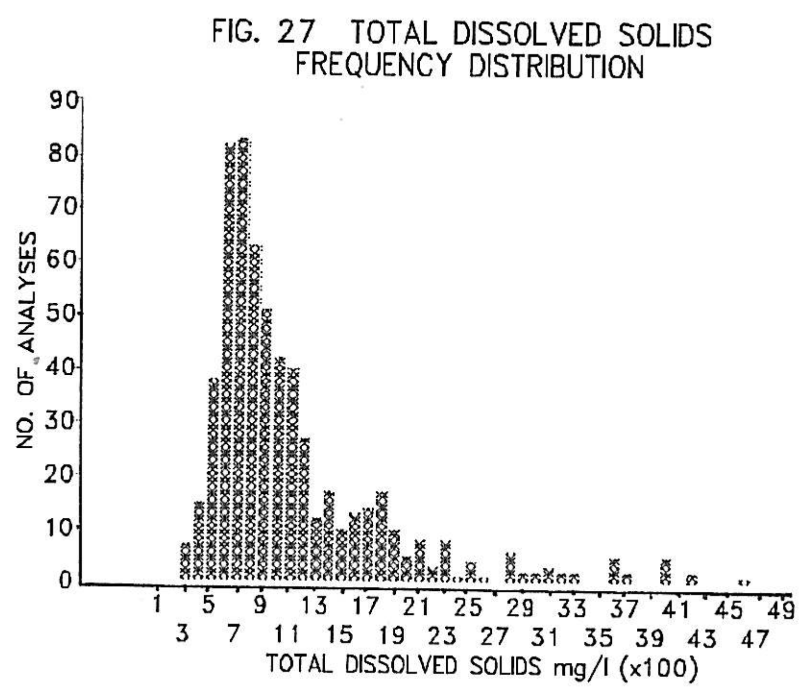
65 percent of the water samples contain less than 1 000 mg/l total dissolved solids
83 percent of the water samples contain less than 1 500 mg/l total dissolved solids
93 percent of the water samples contain less than 2 000 mg/l total dissolved solids

River valleys are characterised by higher salinities. Ground-water with a total dissolved solids content of more than 4 000 mg/l is found in places along the Brak River on Carolus Poort 3, some distance upstream of the poort; as well as higher up on the southernmost part of Riet Fountain 6; on Barends Kuilen 38, Riet Fontein 39 and Leuwe Fountain 27. Upstream of Caroluspoort towards the watershed, the Brak River valley is wide and flat - its gradient about 1:500.

10.2 Quality deterioration

There is evidence that the quality initially found when a borehole has been drilled tends to deteriorate somewhat after it has been put to use. This is possibly due to mobilization of saline water contained in pores and micro-fractures. Droughts aggravate the situation. Lack of recharge, the heavier extraction necessitated by droughts and the greater hydraulic gradients which are consequently created, mobilise more of the higher salinity water which is held in micropores / microfractures (double porosity medium).

Although water quality of the municipal supply has deteriorated during the eighties, sampling of boreholes has been too infrequent to establish under which conditions - hydrogeological, rainfall, pumping and water level regimes - where, when and over what course of time it has taken place. Parson's (1989) hydrochemical bar charts show fluctuations (all of which are not in phase) rather than a continuous worsening trend.



10.3 Characterization in terms of lithology

Parsons (1989) has attempted by means of Durov diagrams to characterize ground water abstracted from alluvial, sedimentary and dolerite related aquifers. It is not surprising that no characteristic hydrochemistry was found. The reason is that the sampled boreholes are located in the river valleys. Ground-water flow from differing lithological terrains contribute to the ground-water bodies in the valleys as is illustrated by the ground-water contour maps of unit XXIB (folders 8, 9 and 10). The varying hydrochemistry is further enhanced by heterogeneous hydraulic properties, influxes from tributary valleys and localised evapotranspiration losses along the rivers. The variable hydrochemical nature of ground water along the Brak River is illustrated in figures 28A and B. The shallowness of the aquifers is responsible for very localised hydrochemical facies.

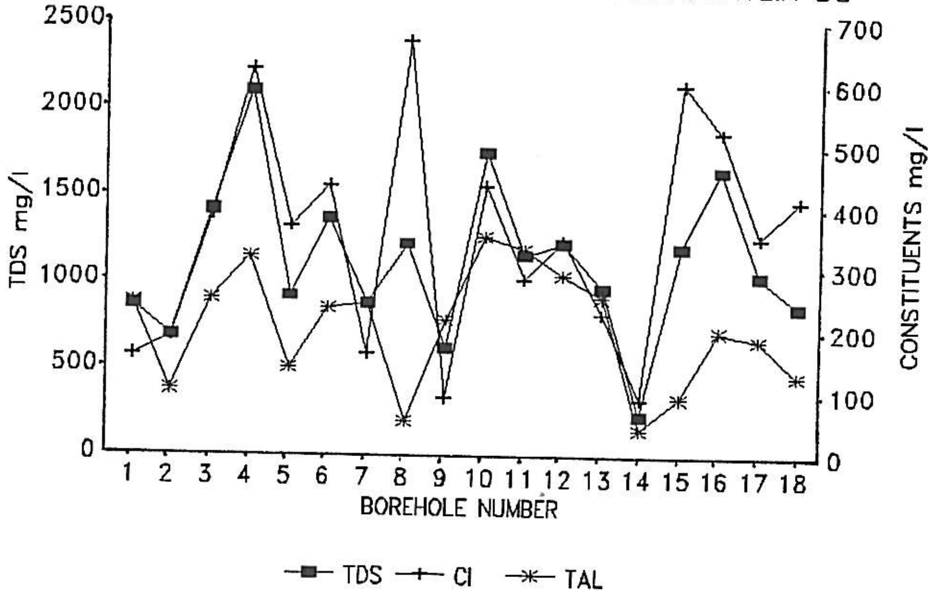
10.4 Hydrochemical trends

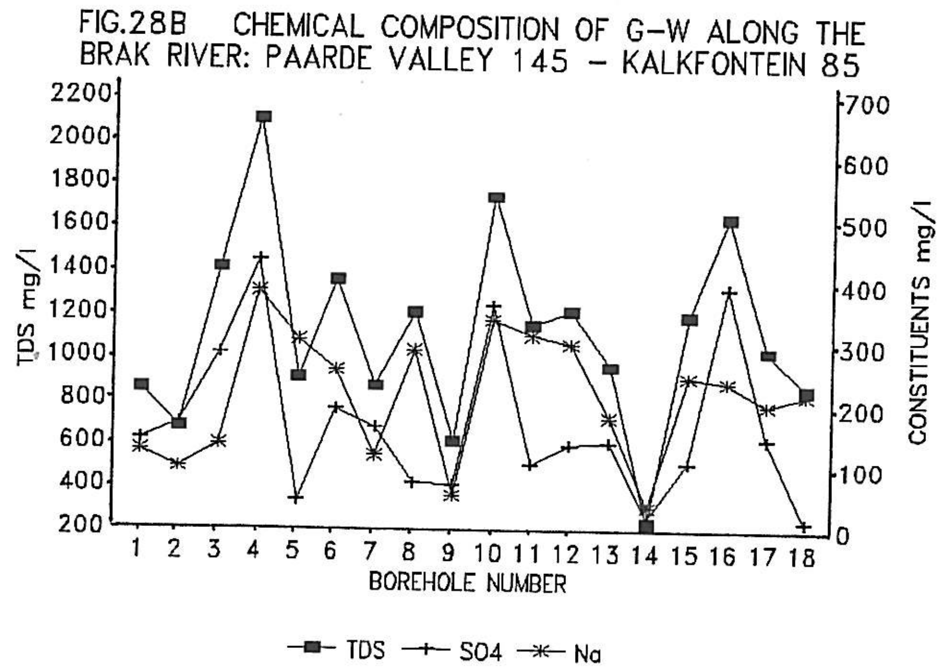
To study hydrochemical trends, major cations and anions have been plotted against total dissolved solids (TDS) content and also as a percentage of TDS against TDS (see figures 29 to 40). The 0 - 2 000 mg/l TDS field is shown in enlarged form in the equivalently numbered "A" figures.

The behaviour of the cations is as follows:

Na (mg/l) versus TDS (mg/l):	*Linear increase with increasing TDS*
Percentage Na versus TDS	*: Maximum of 35% at 300 mg/l TDS Trends towards a narrower bandwidth of between 15 to 30% of TDS with increasing TDS.*
Mg (mg/l) versus TDS (mg/l):	*Initial steeper increase changing to lesser linear increase with increasing TDS*
Percentage Mg versus TDS	*: Maximum of nearly 11% at about 1 800 mg/l TDS Trends towards a bandwidth of about 3% to 6% of TDS with increasing TDS.*
Ca (mg/l) versus TDS (mg/l):	*Points lie below an inverted parabola with maximum of about 600 mg/l Ca at about 4 500 mg/l TDS*
Percentage Ca versus TDS	*: Maximum of 16 to 14% from 0 to about 4 000 mg/l TDS. Drops sharply thereafter to 2% at 7 000 mg/l TDS.*

FIG.28A CHEMICAL COMPOSITION OF G-W ALONG THE BRAK RIVER: PAARDE VALLEY 145 - KALKFONTEIN 85





The behaviour of the anions is as follows:

Cl (mg/l) versus TDS (mg/l): Linear increase with increasing TDS
Percentage Cl versus TDS : Maximum of 55% at 1 200 mg/l TDS Trends towards a narrow bandwidth of about 26 to 38% of TDS with increasing TDS.

SO_4 (mg/l) versus TDS (mg /l): Increases with TDS. Steeper rate from 2 000 to 4 000 TDS (mg/l)

Percentage SO_4 versus TDS : Maximum of 39% at about 3 250 mg/l TDS Trends towards a bandwidth of about 20% to 30% of TDS with increasing TDS

Total alkalinity (mg/l) versus TD S : The range of alkalinity values decreases with increasing TDS
Percentage TAL versus TDS : Maximum 55 at about 400 mg/l TDS decreases asymptotically towards between 0 and 10% at TDS values of more than 5 000 mg/l.

From figures 29 to 40 the ranges of variation of cations and anions (TAL was converted to HCO_3) have been read off at TDS values of 500, 1 000, 2 000 and 4 000 mg/l. These have been converted to milli-equivalents per litre and are shown in table 35. The percentages that each cation (and anion) comprise of the mean total cation (and anion) content for the four TDS concentrations have been calculated and are also included in the table 35. It is interesting to note the behaviour of the mean percentage which may be taken as indicative of hydrochemical changes:

The mean Sodium percentage remains constant between 500 and 2 000 mg/l TDS increasing thereafter.

The mean Magnesium percentage increases up to 2 000 mg/l of TDS, drops thereafter.

The mean Calcium percentage drops from a high of 34.1% to a constant of about 20% at 2 000 - 4 000 mg/l TDS.

The mean Bicarbonate percentage decreases all the way with increasing TDS whilst both sulphate and chloride increase. The latter's percentage stabilises at 2 000 mg/l TDS.

In comparison with the eight-fold increase in TDS content - 500 to 4 000 mg/l - calcium and bicarbonate are apparently lost through precipitation whilst Na, Mg, Cl and SO_4 become concentrated on average respectively 8,8, 11, 13,5 and 19 times. In view of the chemical variability of the ground water as evinced by the scattering in the abovementioned figures and the changeable lithology - sedimentary and igneous - it appears unlikely that a single succession and path of hydrochemical and physical processes is responsible for the nature of the ground water.

10.5 <u>Hydrochemical variability within ground-water unit XXIB</u>

Ground-water unit XXIB is the only area where sampling has been done away from the river valleys and where borehole data are available. The drilling and sampling of exploration boreholes was however not designed for hydrochemical studies.

The hydrochemical variability of ground water in this unit is illustrated in figure 41. It was found possible to group boreholes according to hydrochemical composition and to calculate the mean major ion compositions.

A distinct difference is evident between the ground water along the Elandsfontein Spruit within unit XXIB (designated 3 figure 41) and that from boreholes in Zwartekopjespoort upstream along the same river (designated 2). Sodium and bicarbonate are clearly preponderant in the Zwartekopjespoort. Downstream in unit XXIB, sodium although still predominating has lost ground to magnesium whilst chloride has become the most abundant anion. The difference between the anions is smaller in unit XXIB whilst TDS has increased.

FIGURE 29 AND FIGURE 29A
Na VERSUS TDS

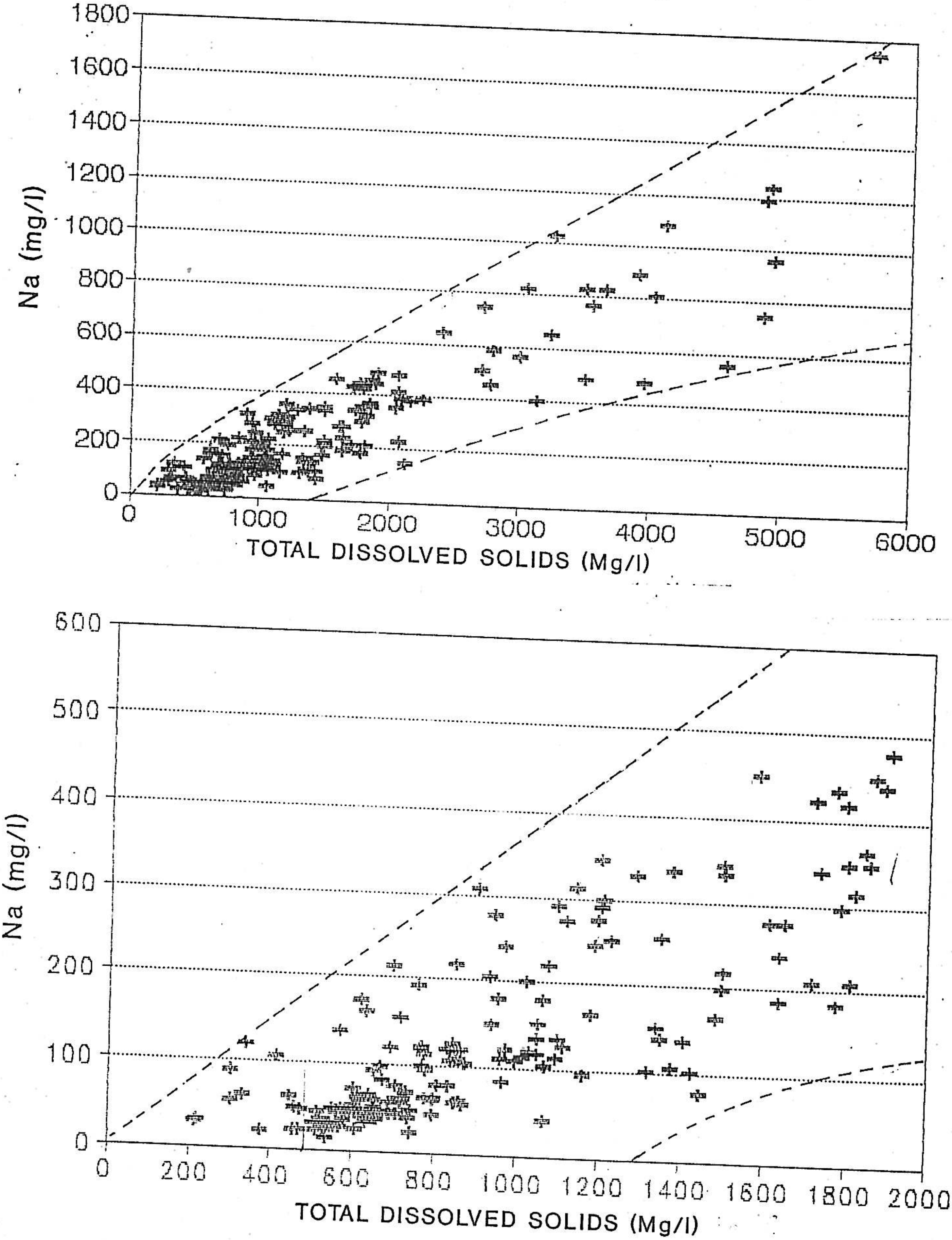
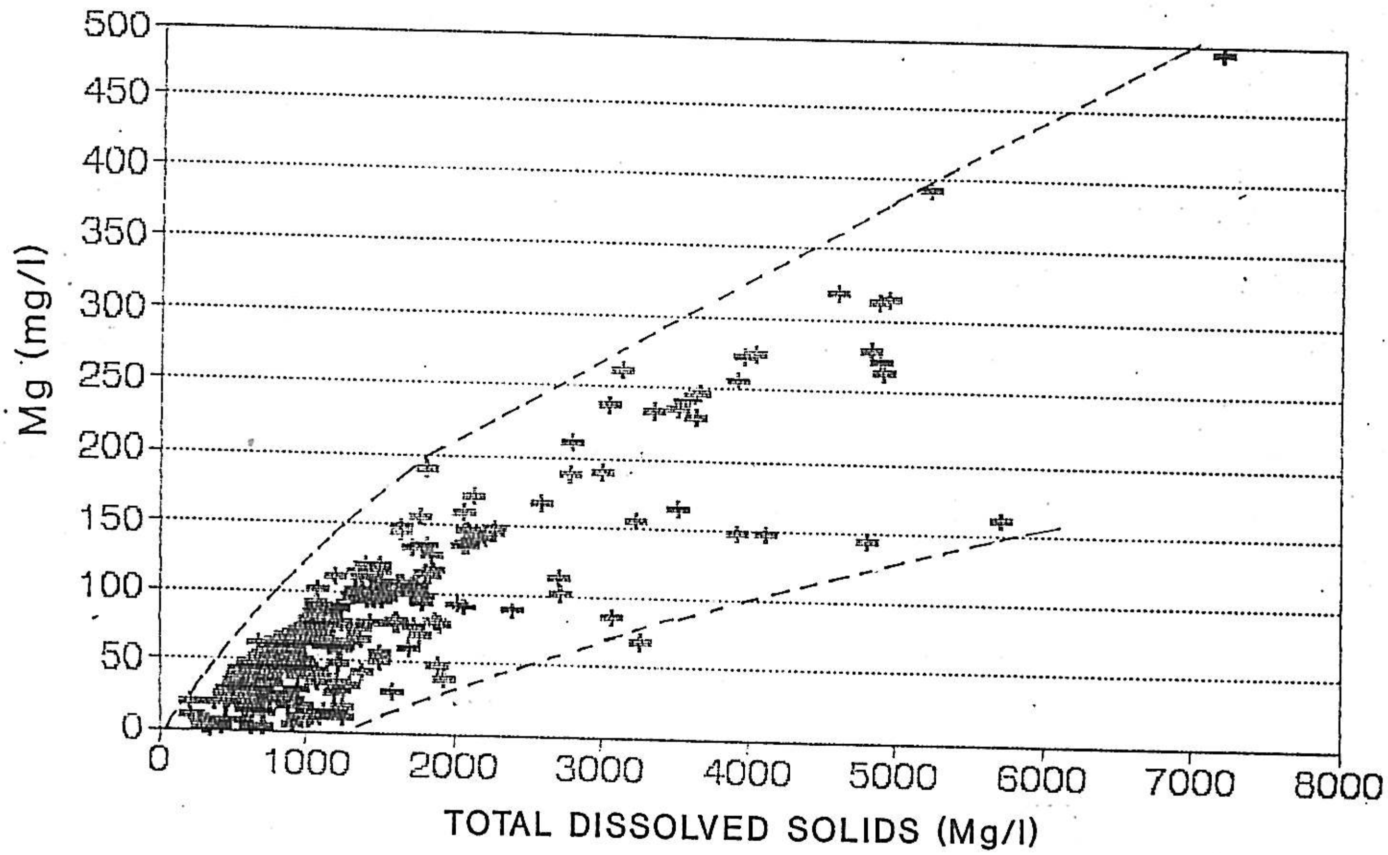


FIGURE 31 AND FIGURE 31A
Mg VERSUS TDS



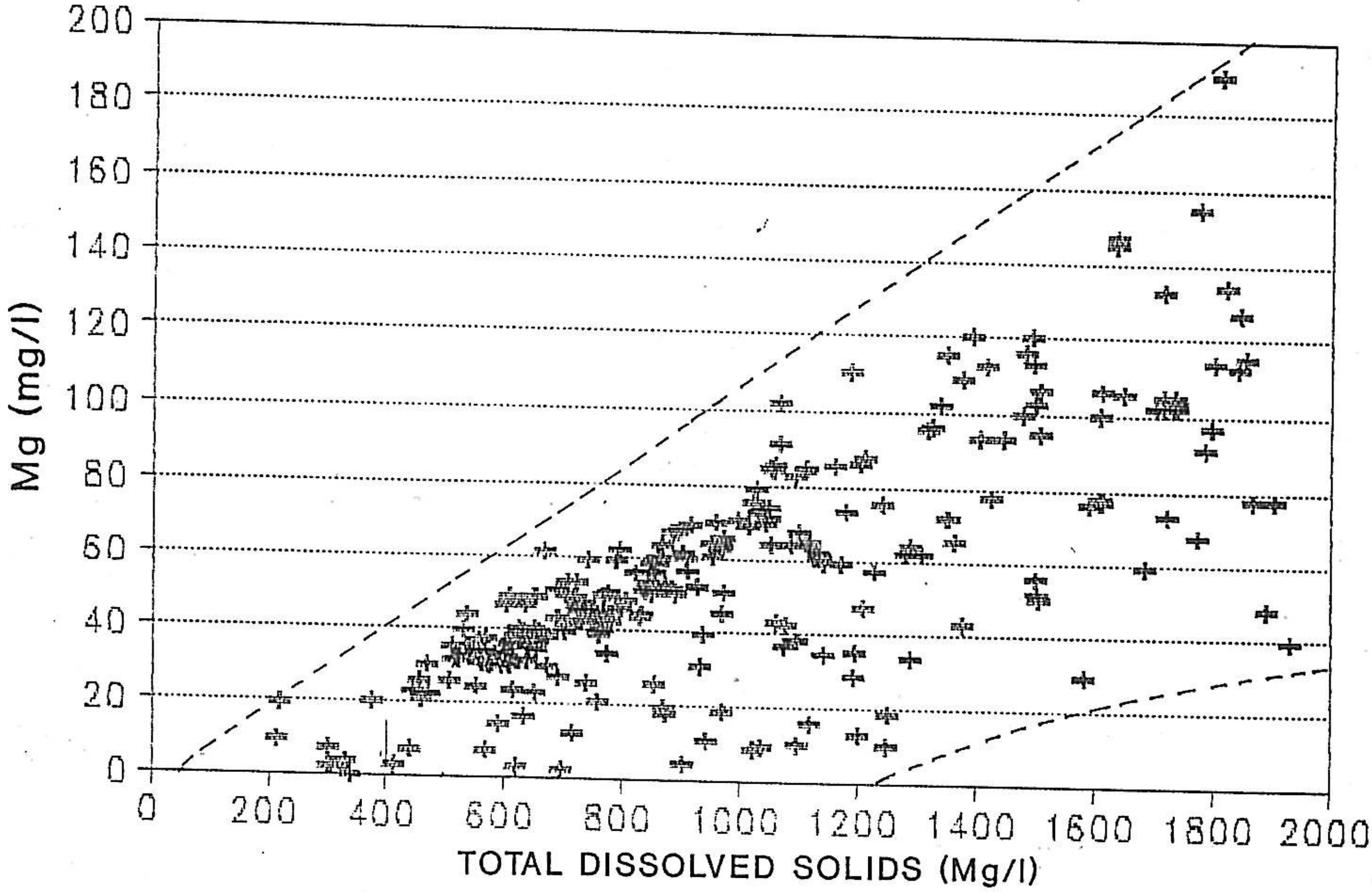
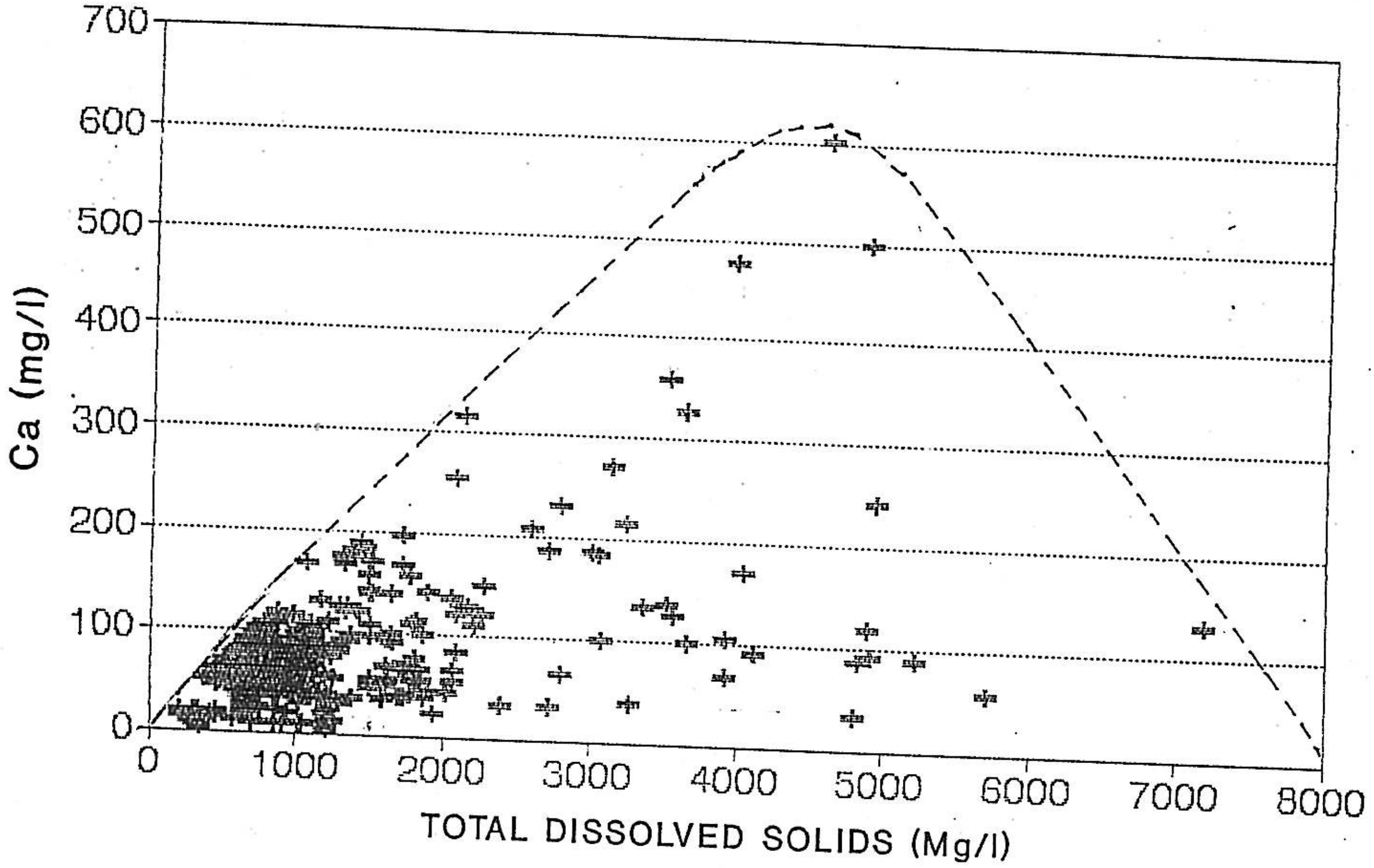


FIGURE 33 AND FIGURE 33A
Ca VERSUS TDS



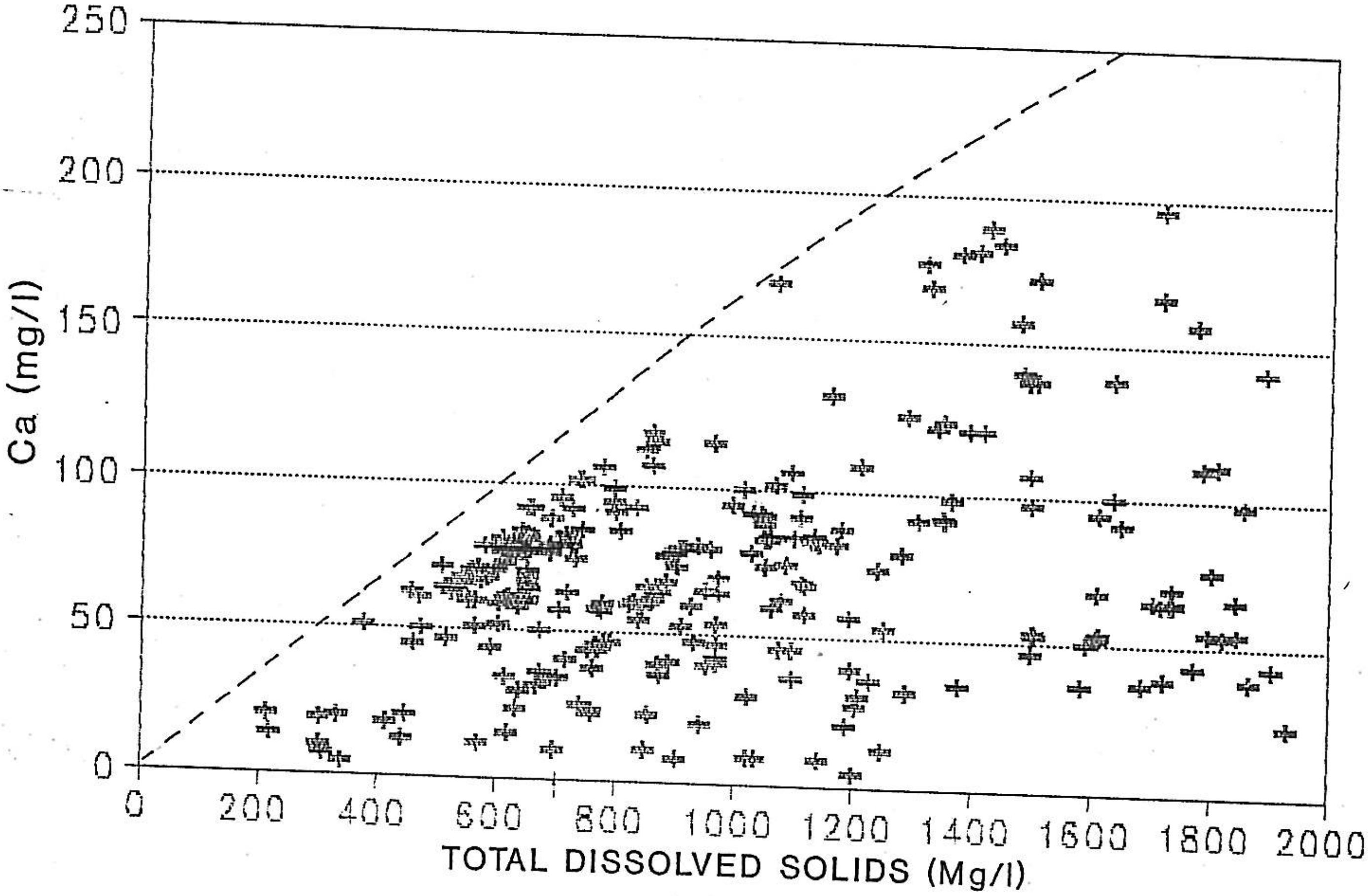


FIGURE 35 AND FIGURE 35A
Cl VERSUS TDS

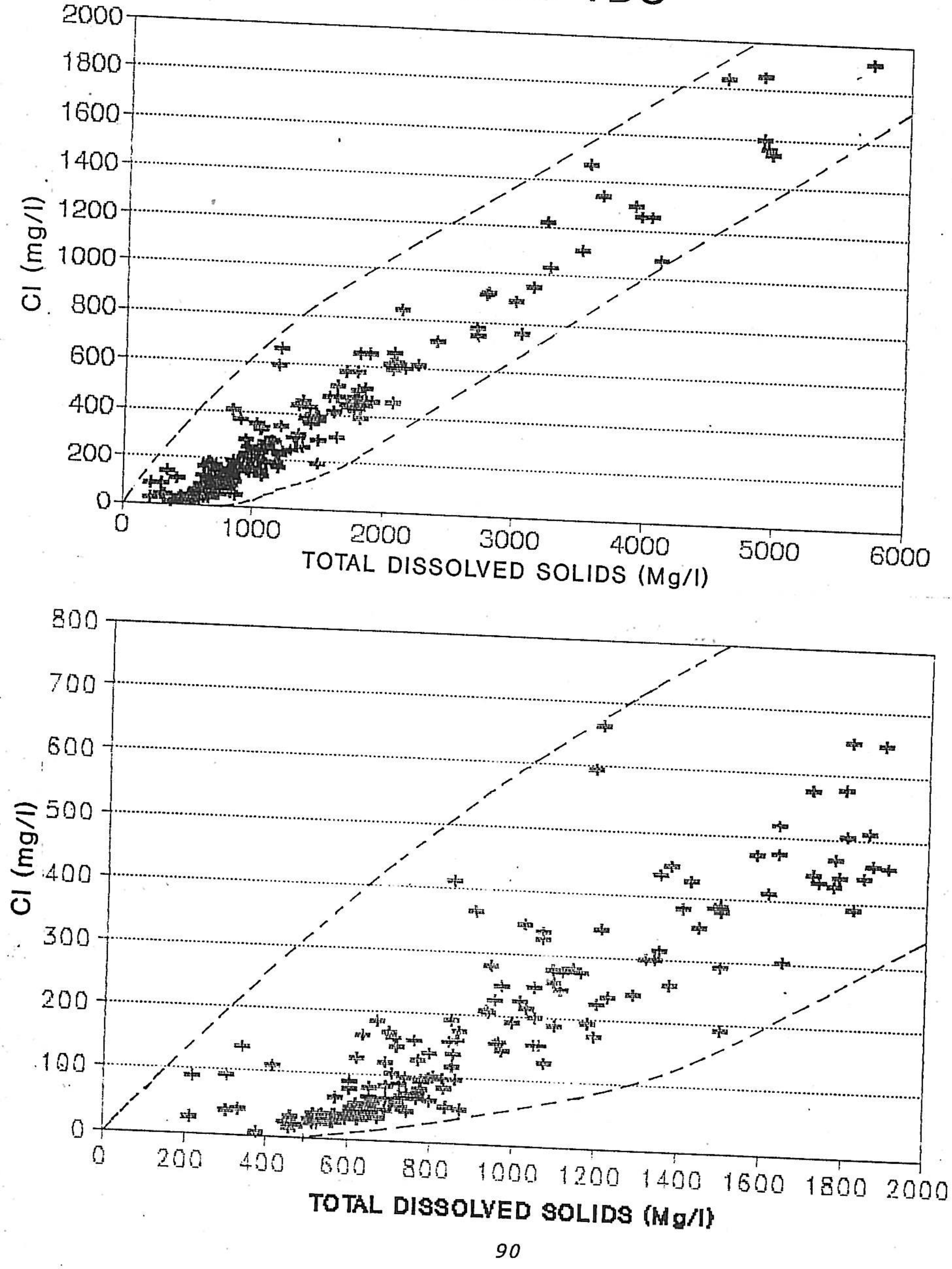
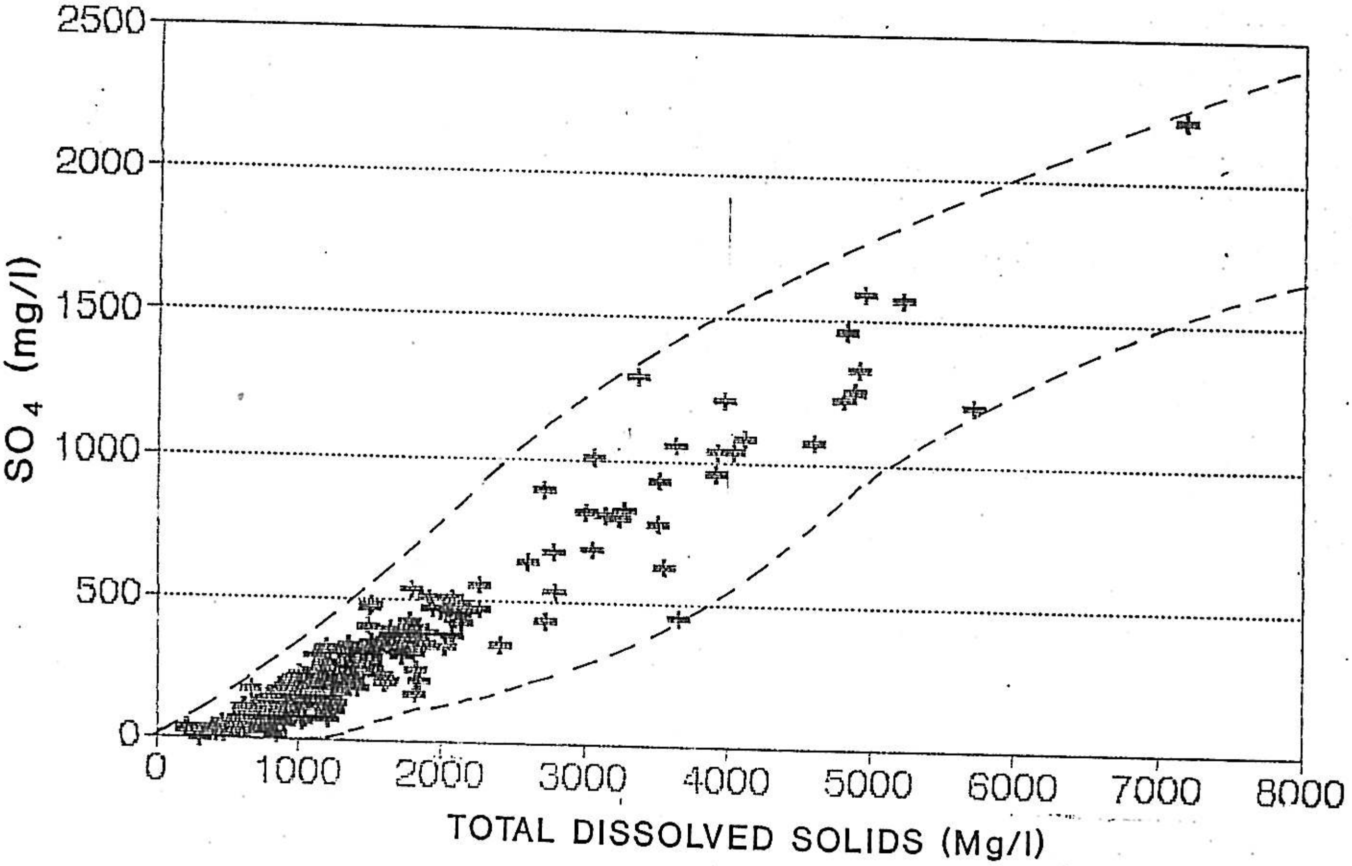


FIGURE 37 AND FIGURE 37A
SO_4 VERSUS TDS



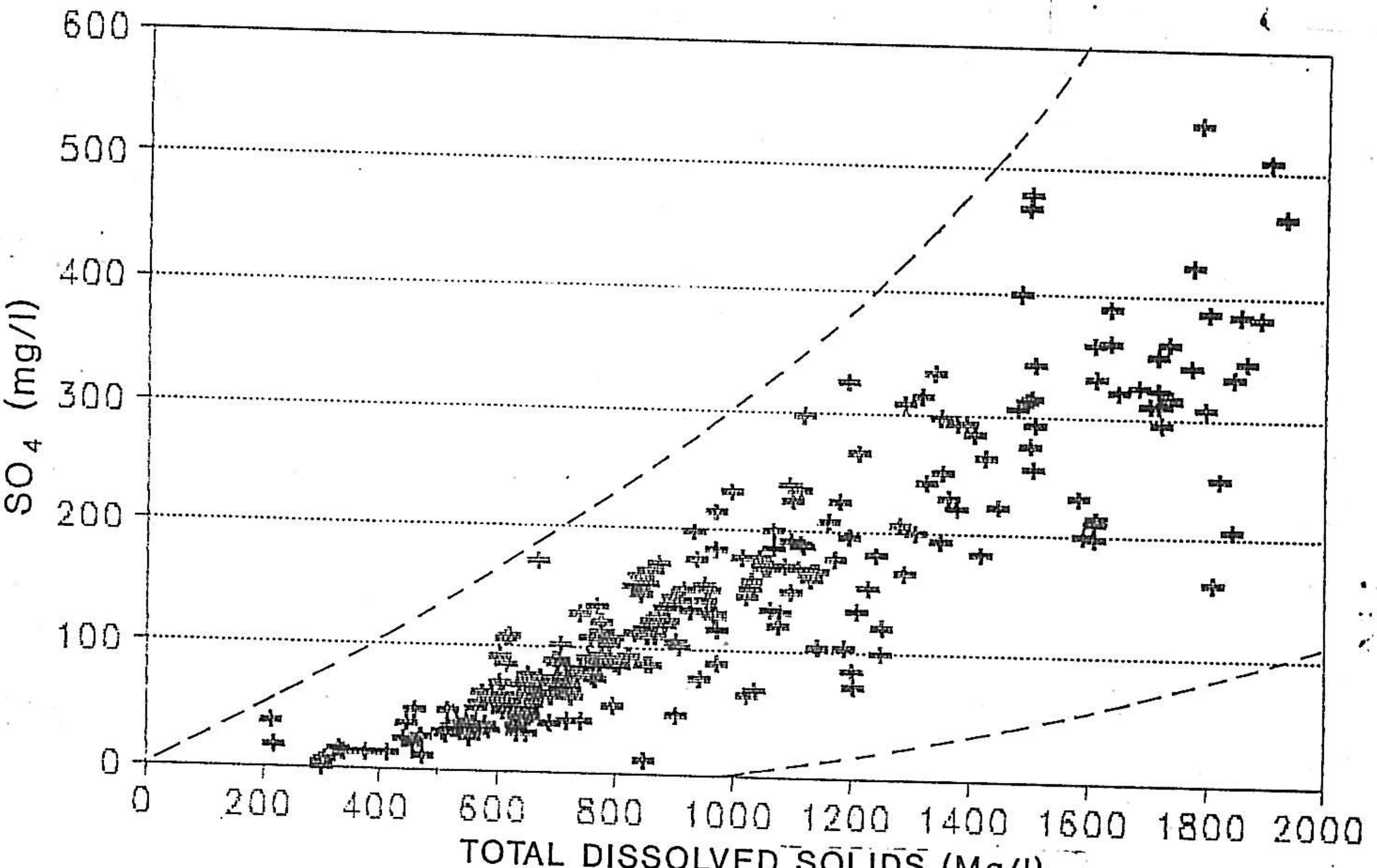
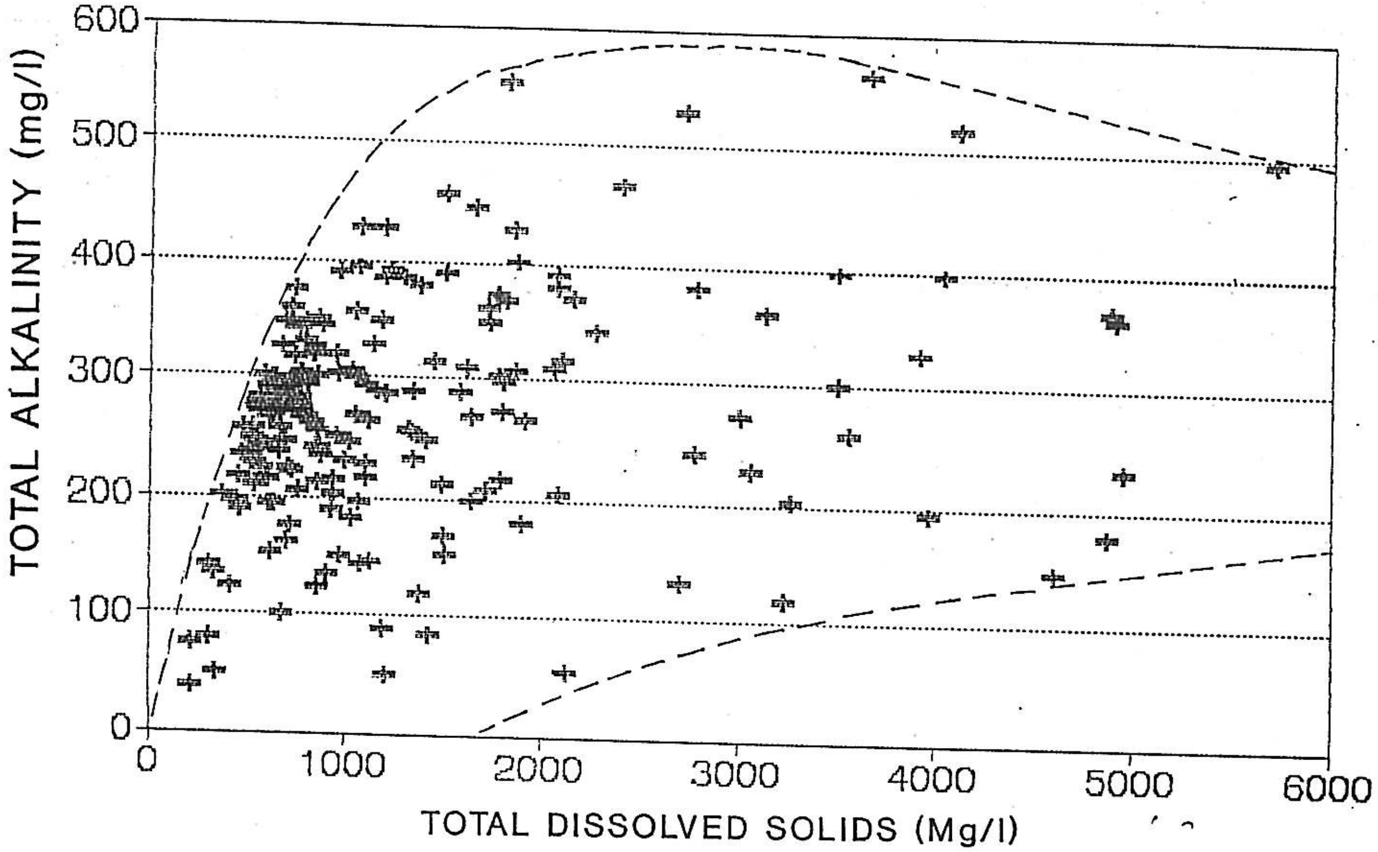


FIGURE 39 AND FIGURE 39A
TAL VERSUS TDS



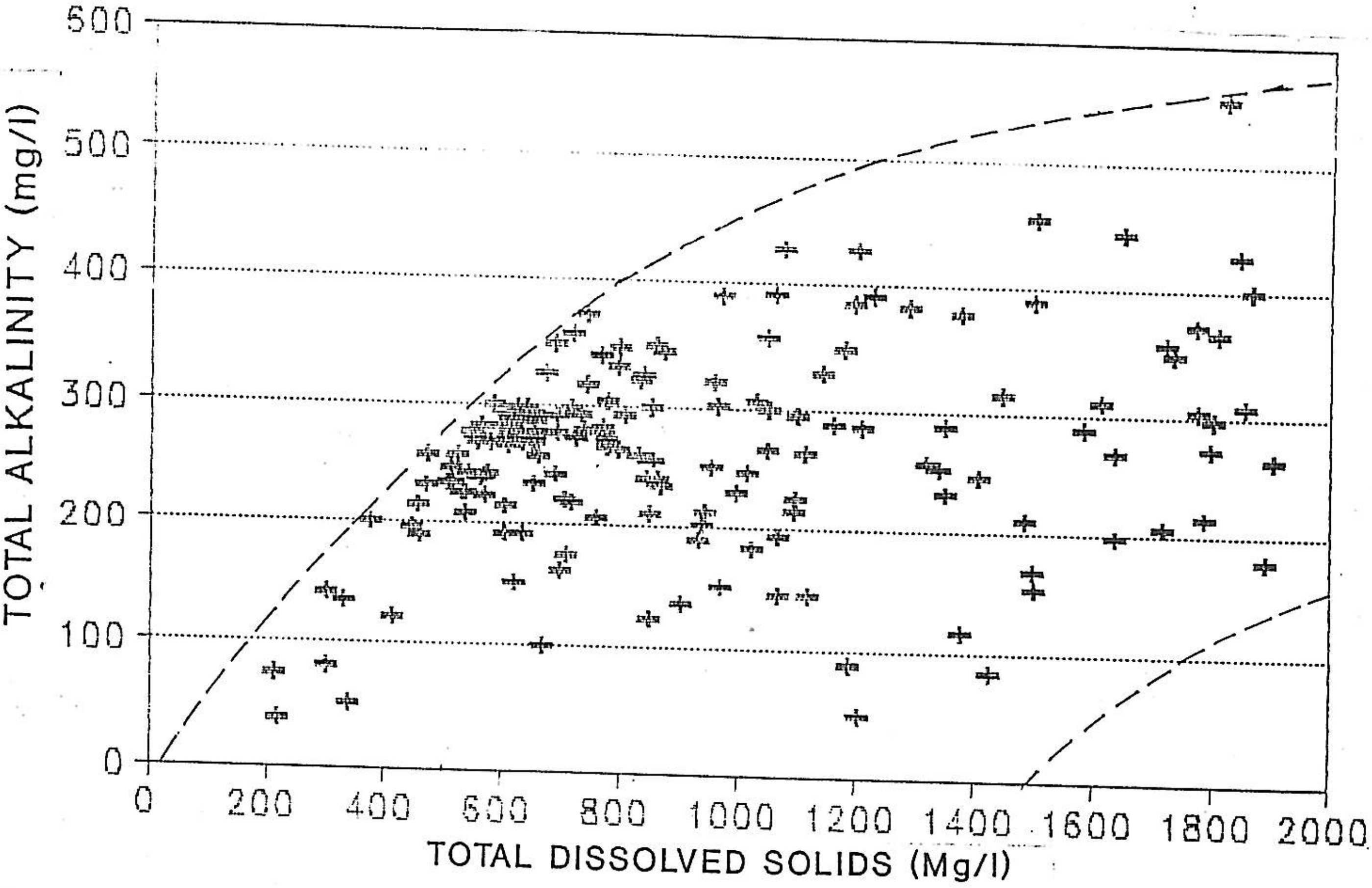
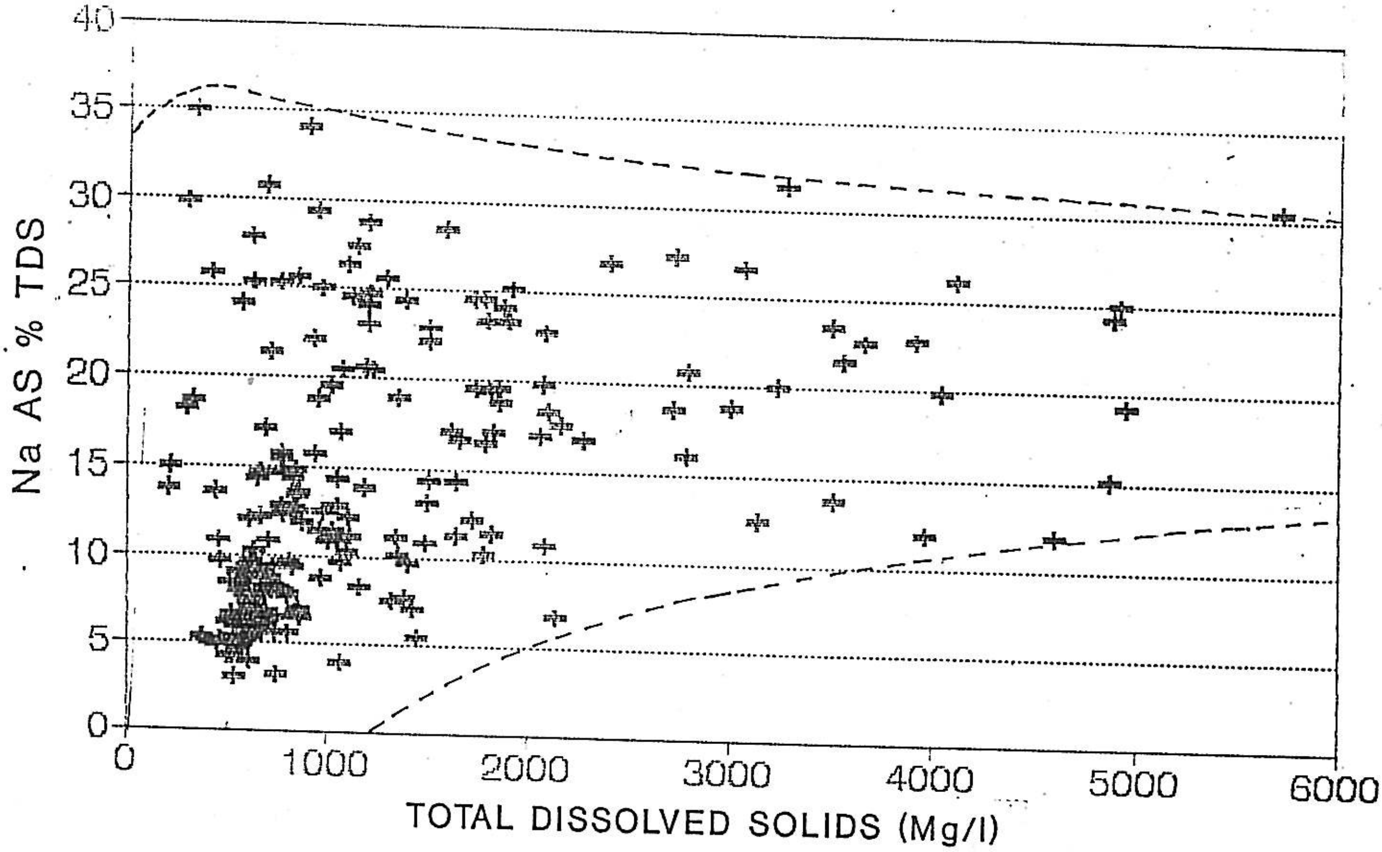


FIGURE 30 AND FIGURE 30A
Na AS % TDS VERSUS TDS



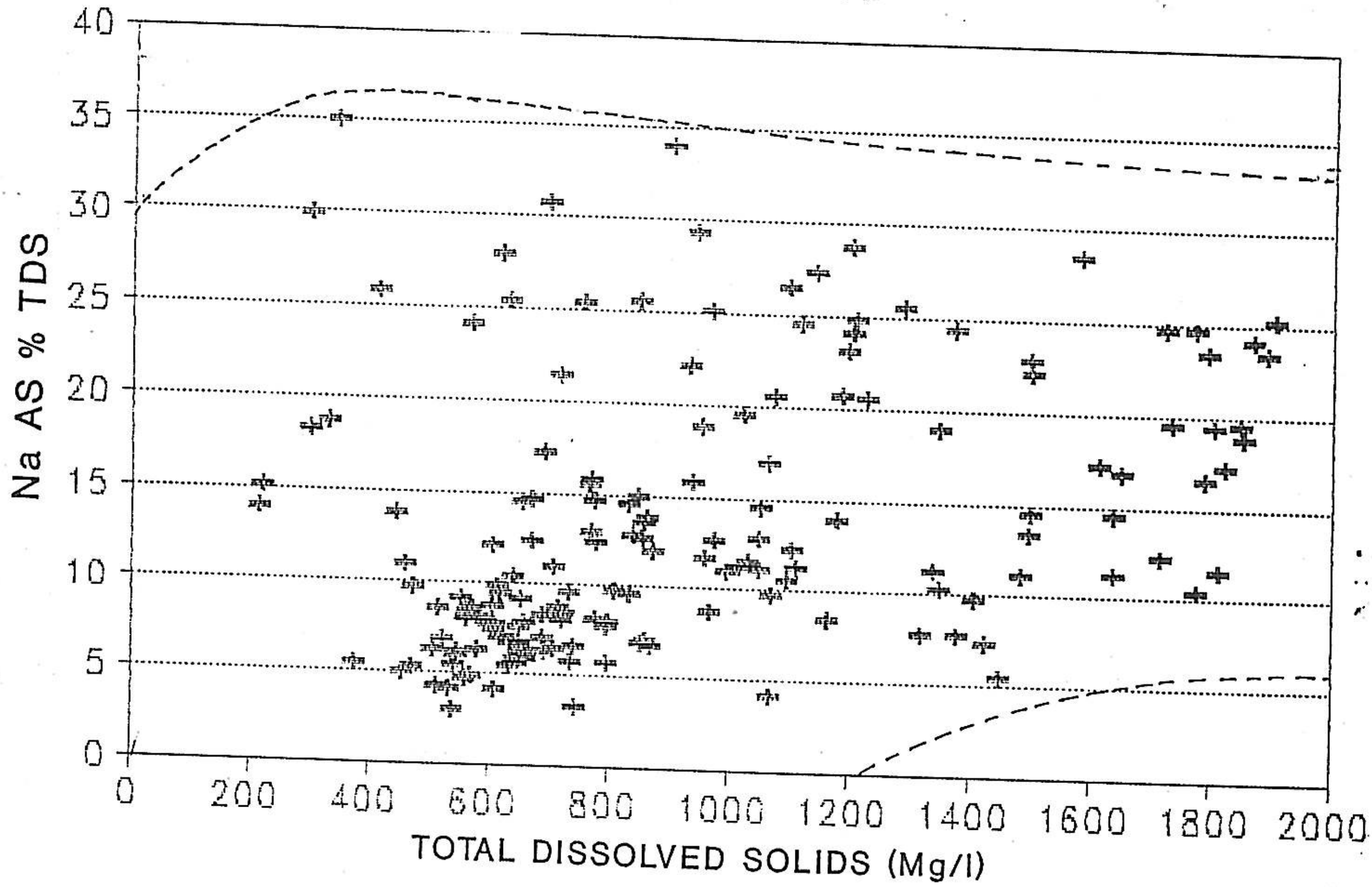
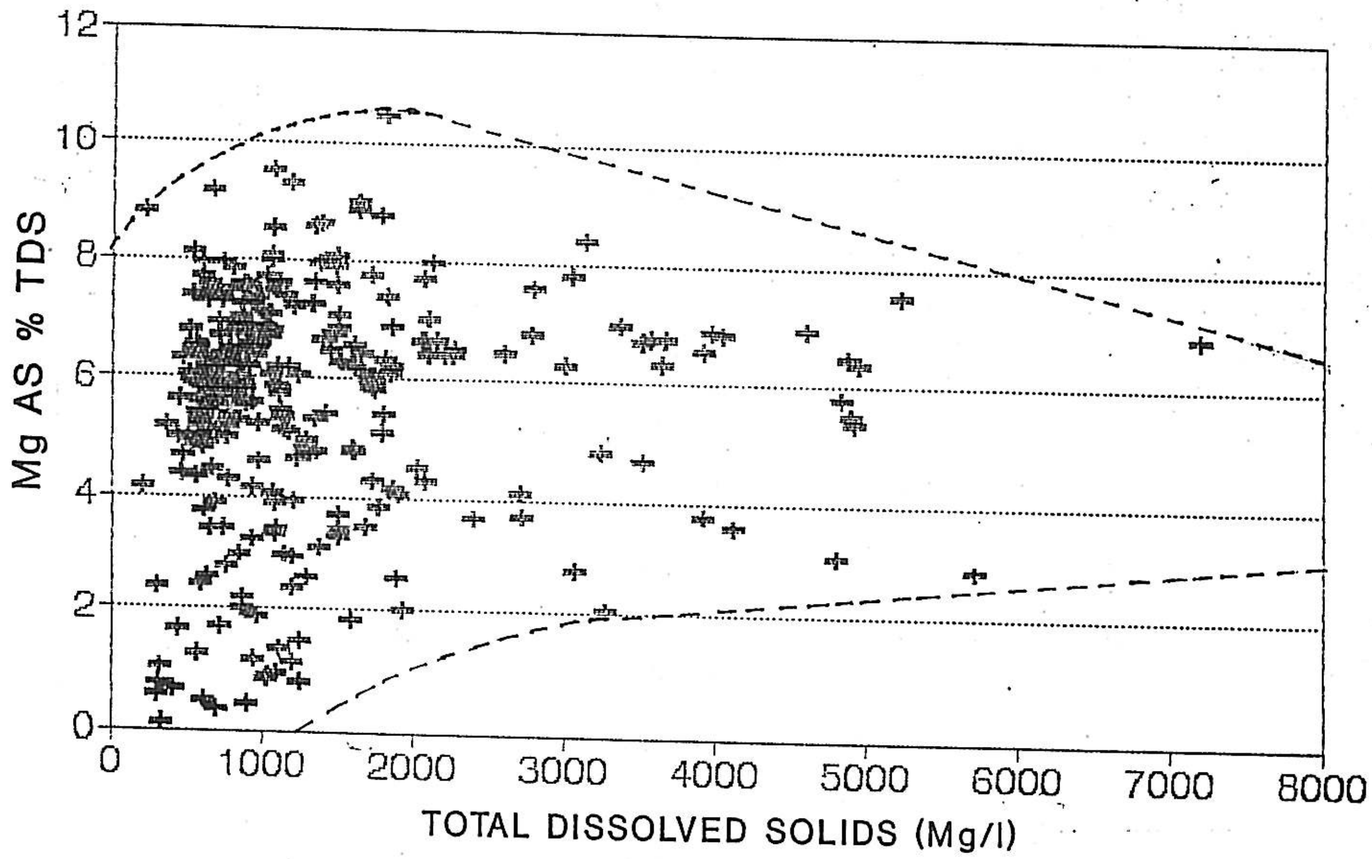


FIGURE 32 AND FIGURE 32A
Mg AS % TDS VERSUS TDS



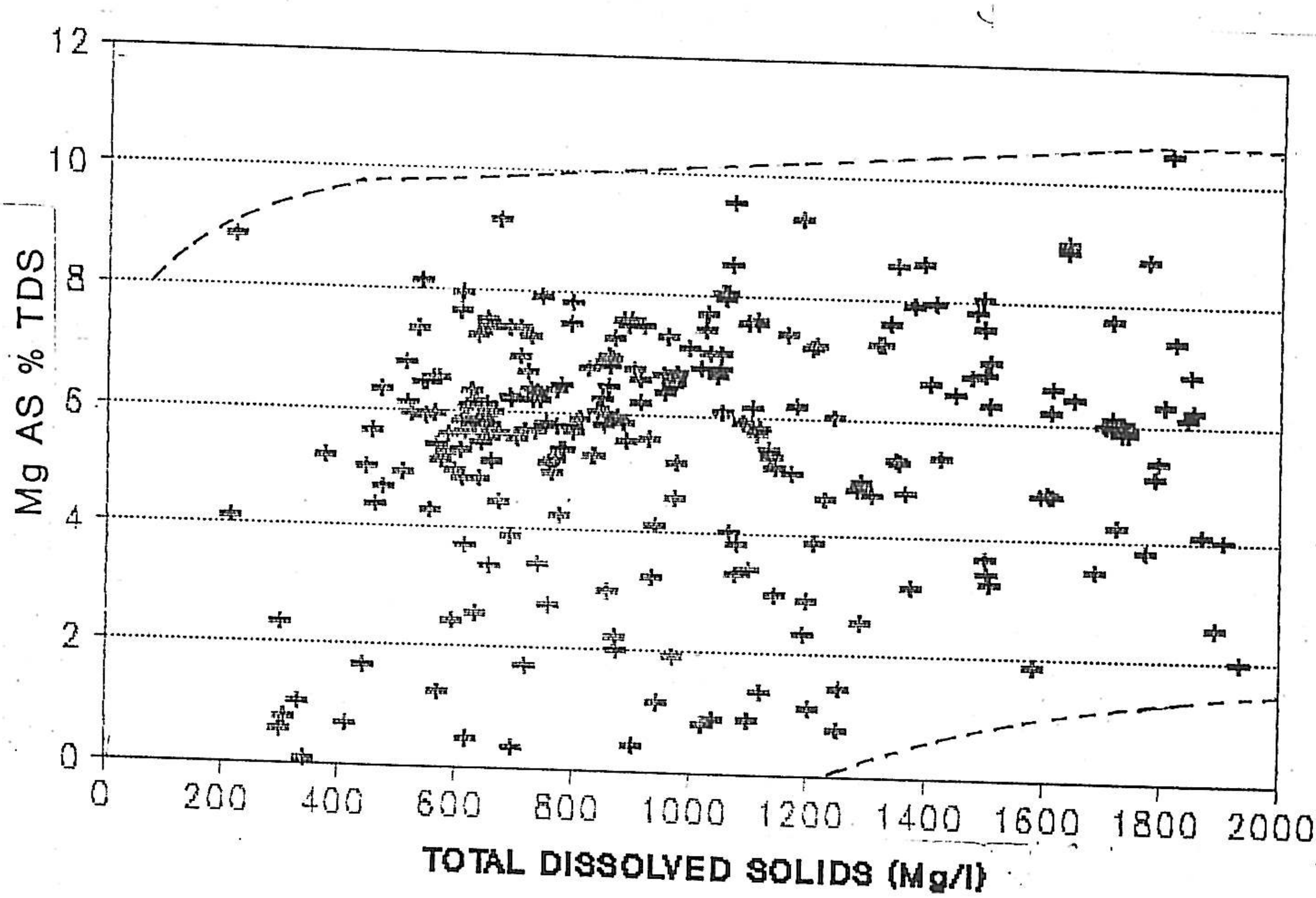


FIGURE 34 AND FIGURE 34A
Ca AS % TDS VERSUS TDS

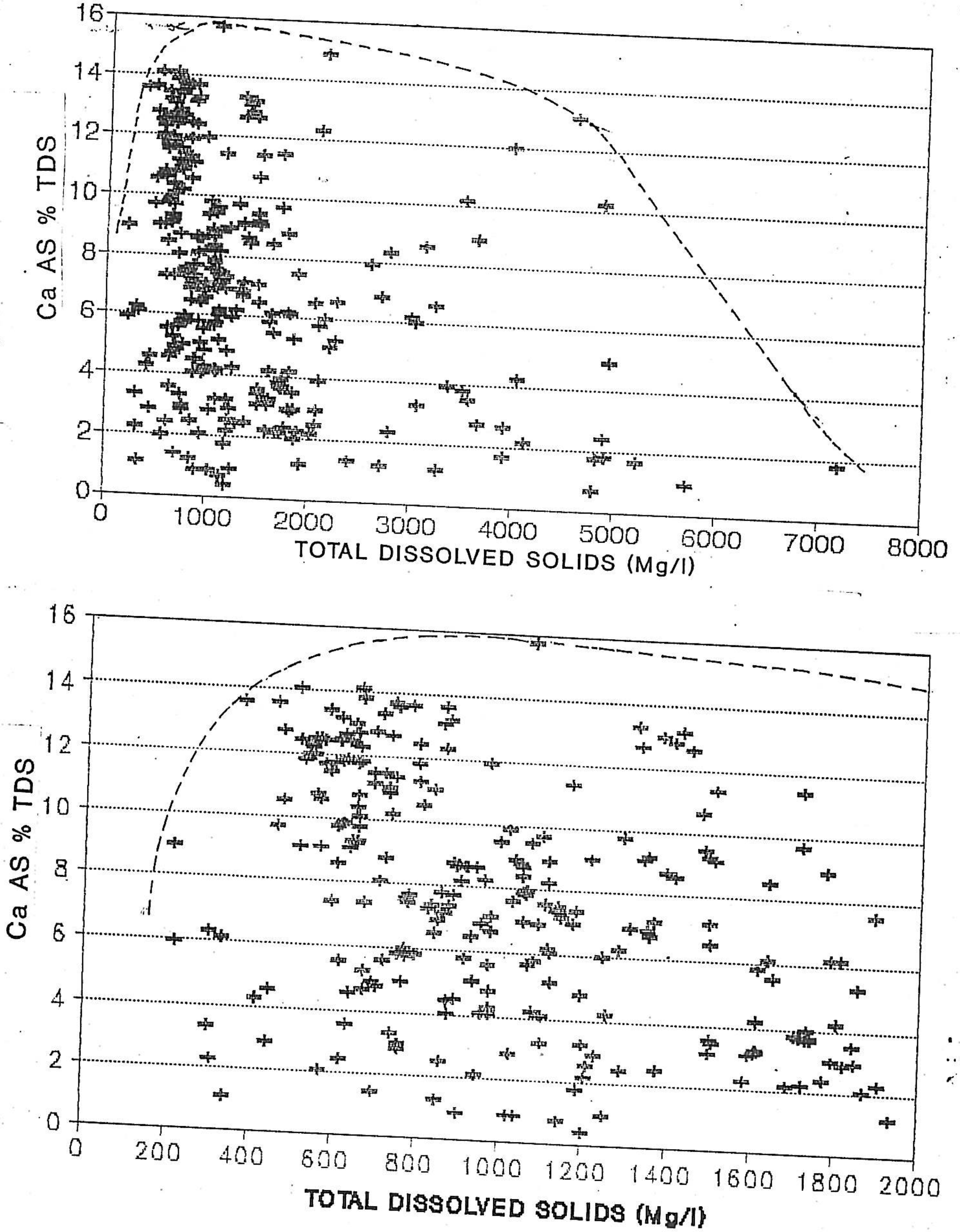
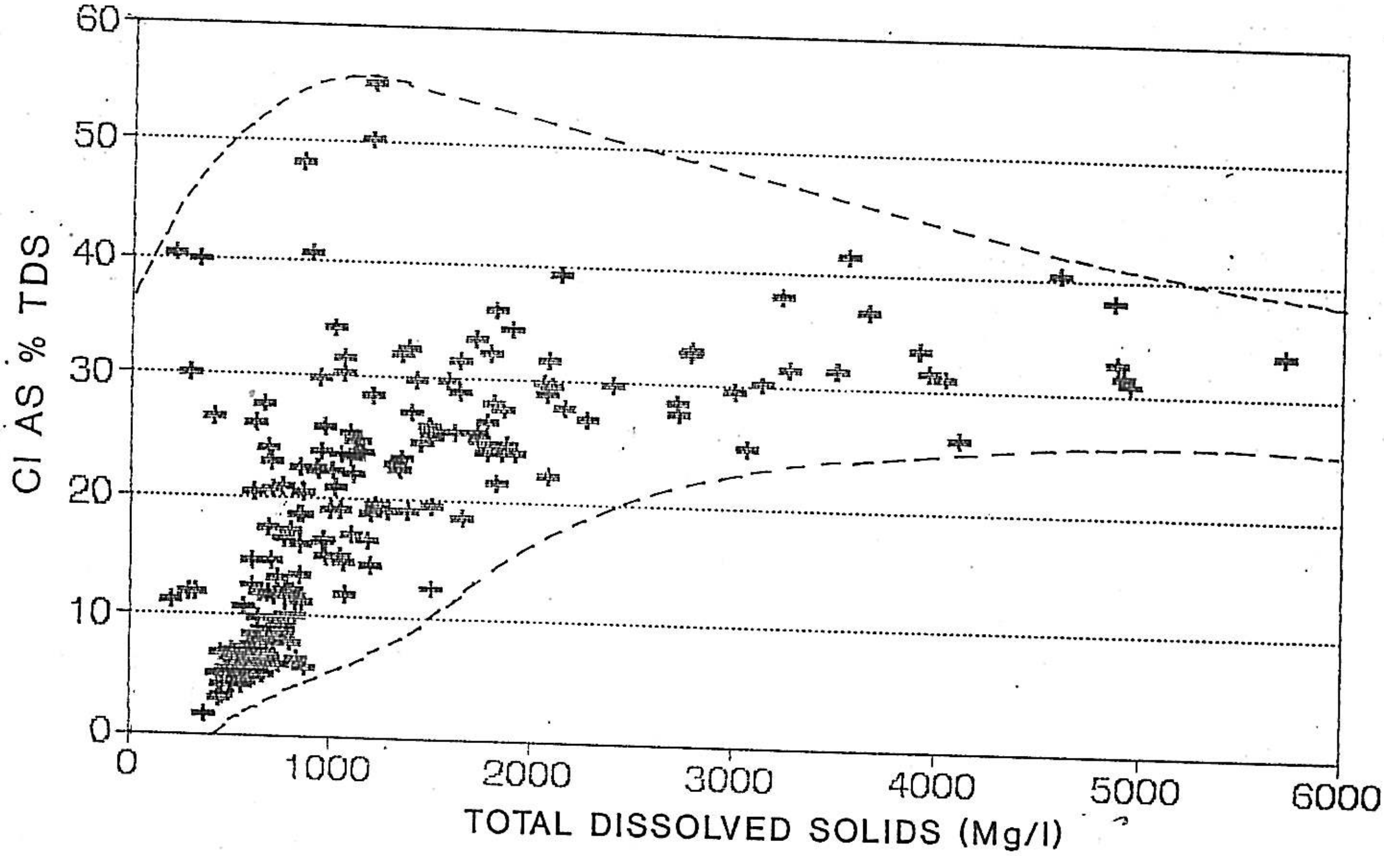


FIGURE 36 AND FIGURE 36A
Cl AS % TDS VERSUS TDS



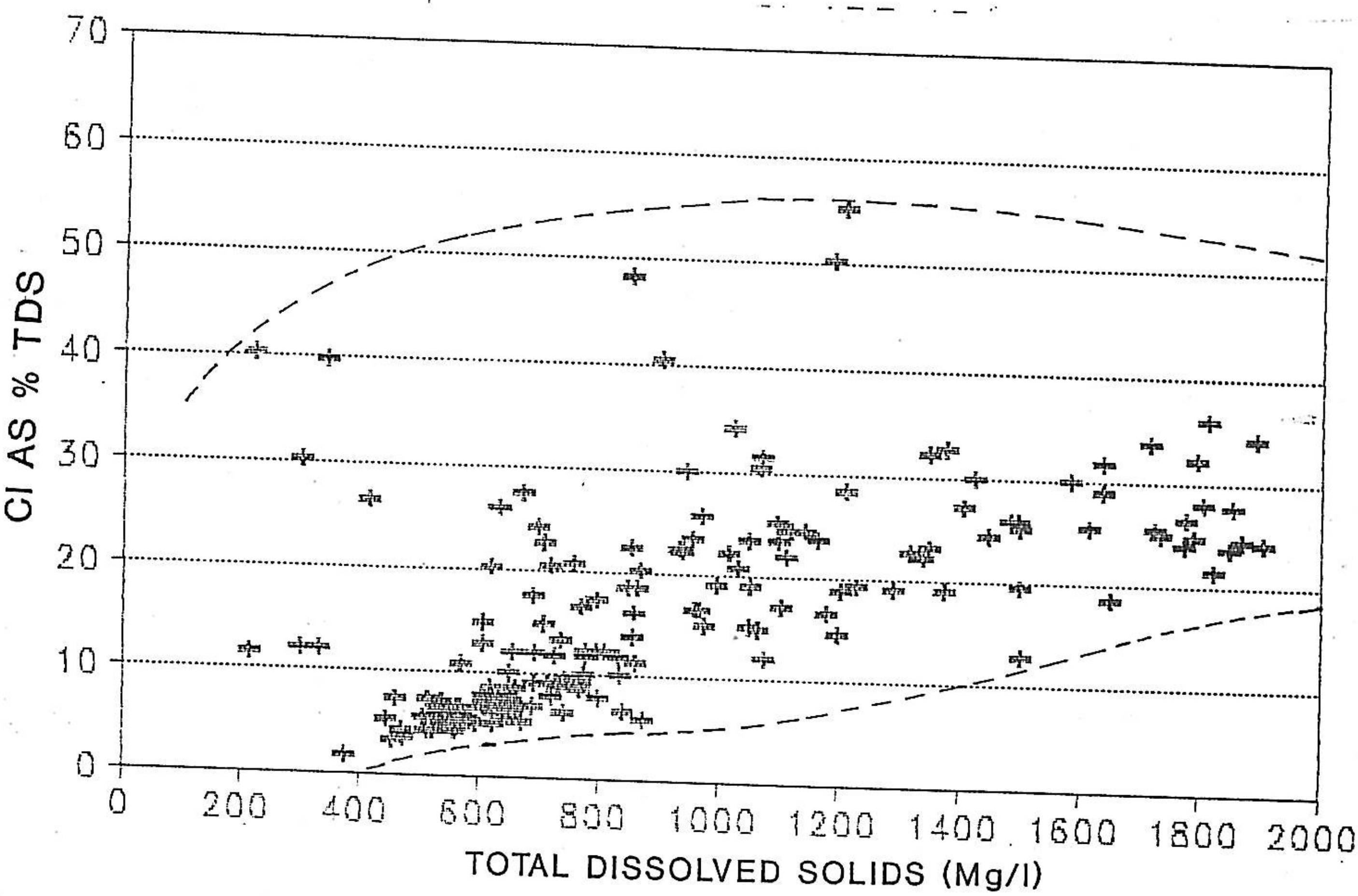
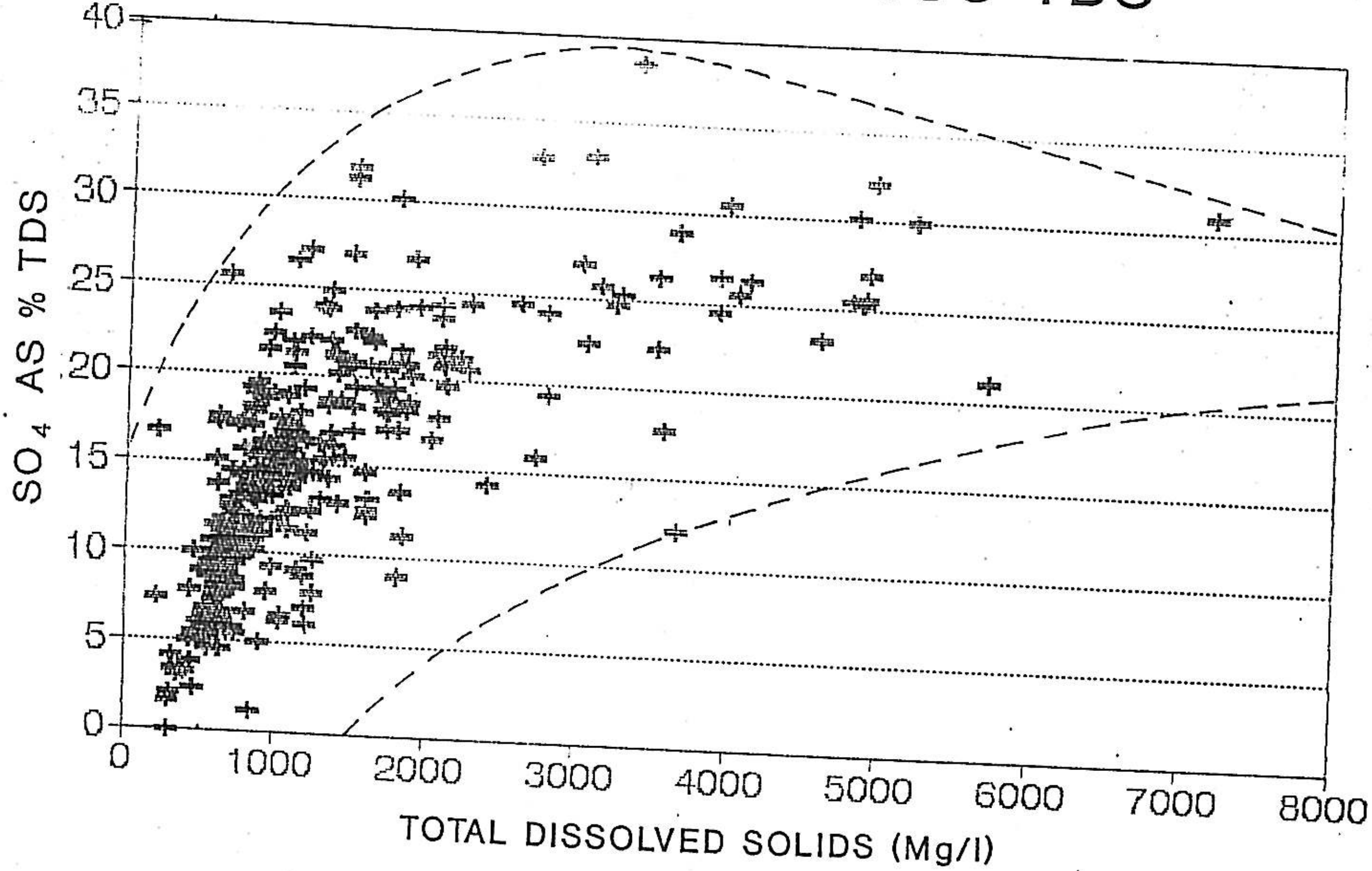


FIGURE 38 AND FIGURE 38A
SO_4 AS % TDS VERSUS TDS



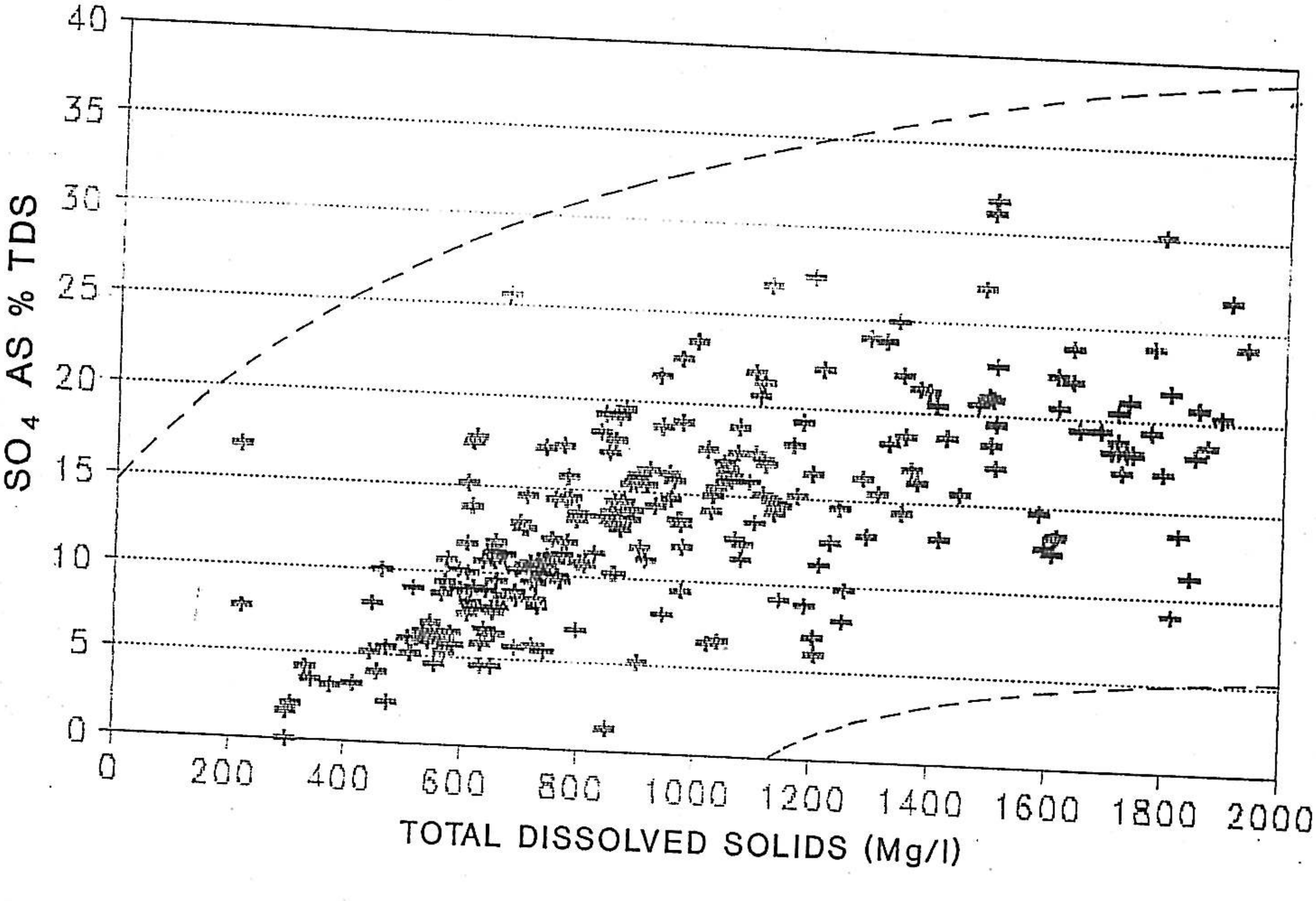
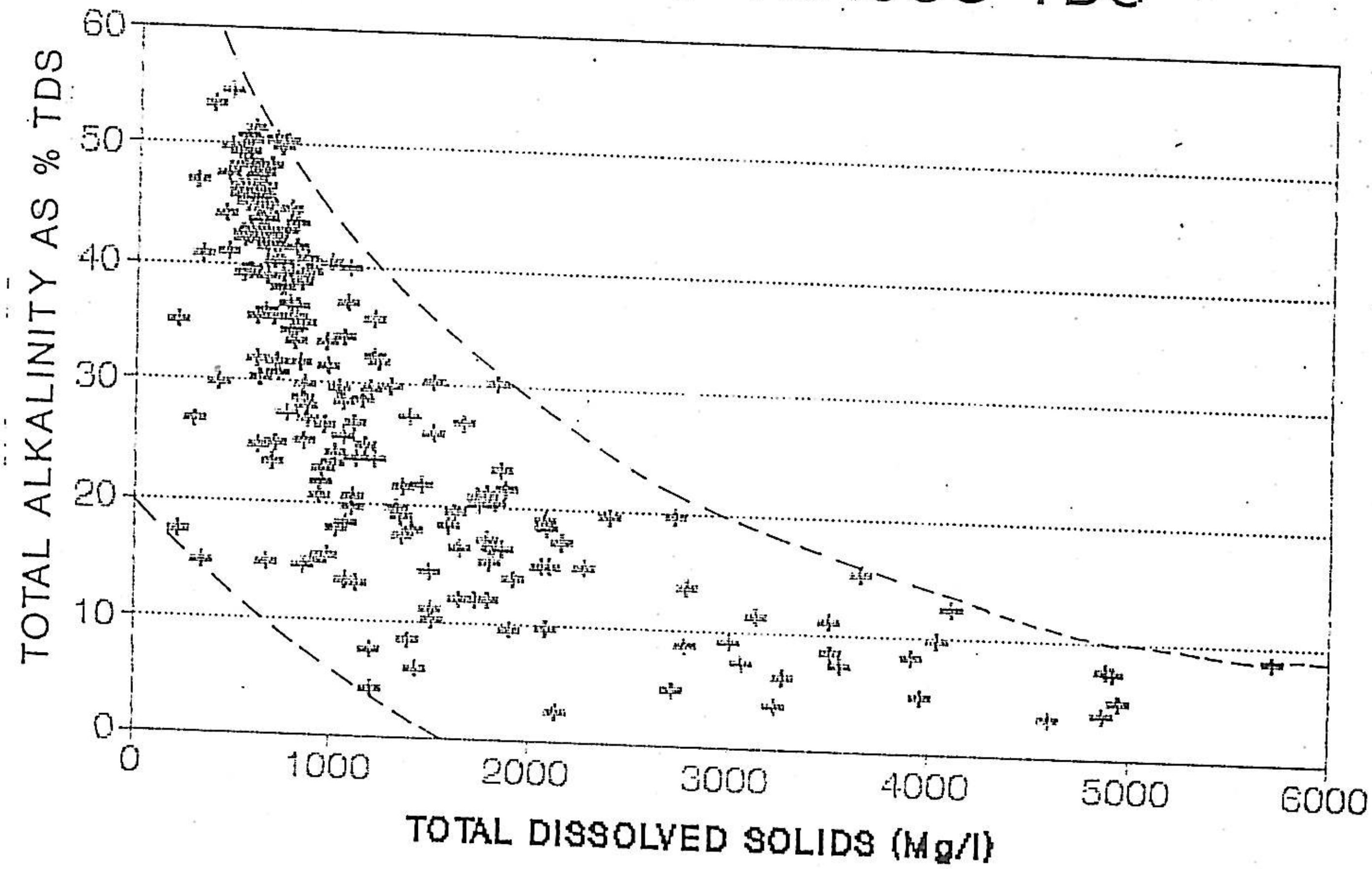


FIGURE 40 AND FIGURE 40A
TAL AS % TDS VERSUS TDS



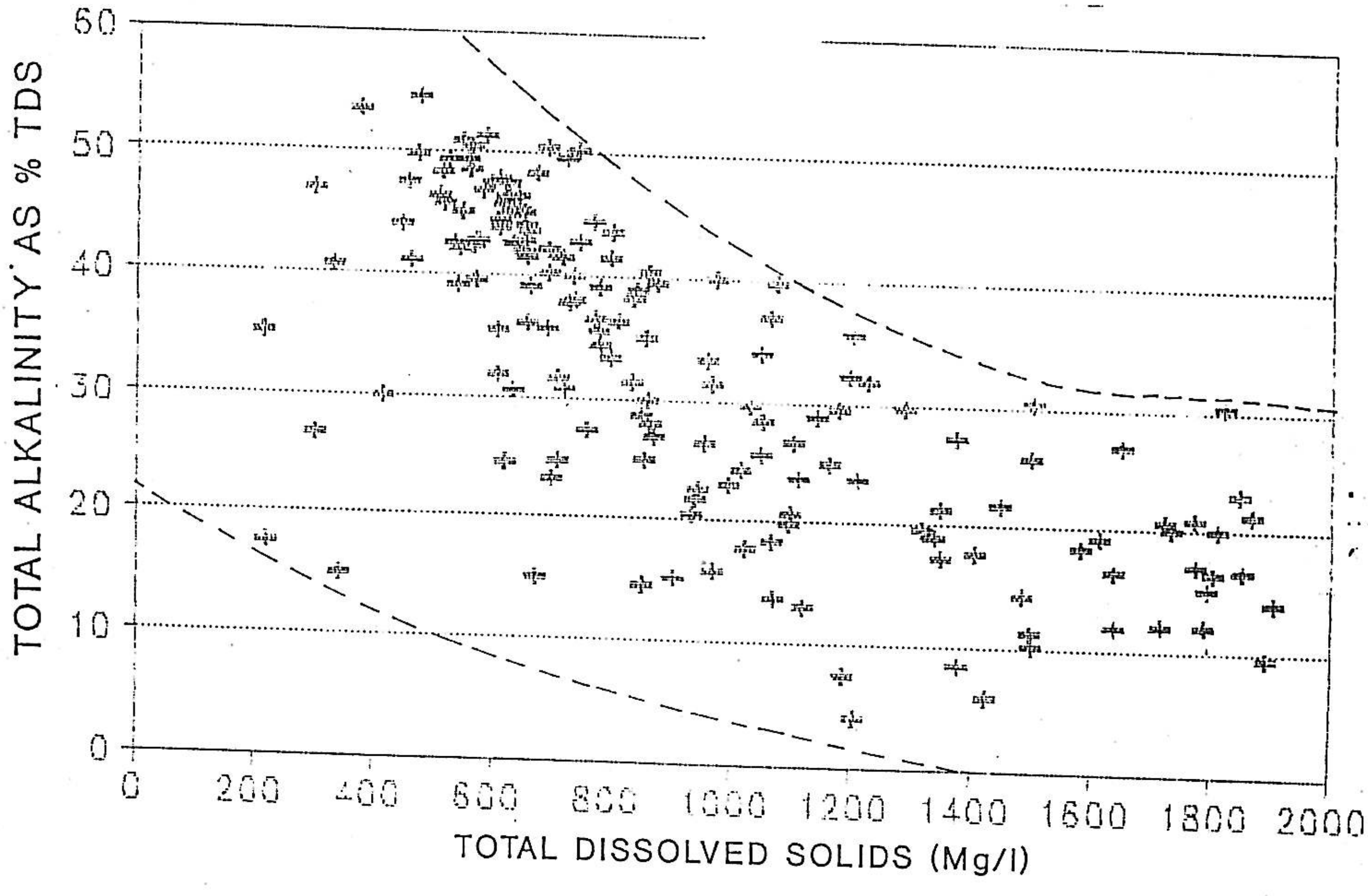


TABLE 35 CHANGES IN PERCENTAGE CATION AND AMION CONTENT (MEQ/L) WITH INCREASING TOTAL DISSOLVED SOLIDS

TDS	Na			Mg			Ca			HCO3			SO			Cl		
	meq/l		Mean	meq/l		Mean	meq/l		Mean	meq/l		Mean	meq/l		Mean	meq/l		Mean
mg/l	Range	Mean	%	Range	Mean	%	Range	Mean	%	Range	Mean	%	Range	Mean	%	Range	Mean	%
500	0.1 - 7.4	4.3	48.3	0.0 - 3.1	1.6	17.6	0.3 - 5.5	3.0	34.1	0.3 - 5.6	3.0	41.5	0.2 - 2.5	1.4	19.0	0.4 - 5.2	2.8	39.4
1000	2.2 - 13.0	7.6	48.1	0.4 - 8.2	4.3	27.2	0.3 - 7.5	3.9	24.6	1.0 - 0.5	4.8	32.6	1.0 - 5.1	3.1	21.1	2.3 - 11.3	6.8	46.3
2000	5.6 - 20.9	13.3	47.0	3.3 - 15.6	9.5	33.6	1.2 - 9.8	5.5	19.4	3.4 - 7.0	5.2	19.1	3.4 - 11.0	7.2	26.5	11 - 18.6	14.3	54.4
4000	20.9 - 54.8	37.9	53.9	8.2 - 27.1	17.7	25.1	2.0 - 27.4	14.7	20.9	2.4 - 11.0	6.7	9.4	12.5 - 40.6	26.6	37.4	29.1 - 46.3	37.7	53.1

Bicarbonate predominates on the higher ground north-east of Elandsfontein Spruit (designated 1 figure 41); Mg is the most abundant cation whilst Ca has gained considerably in importance compared to the river valley. The result is that the difference between the cations' content is rather small. The preponderance of Mg is discordant with the general dominance of sodium.

West of Elandsfontein Spruit two types of ground water are recognisable. The areally more representative type has been designated 4a in figure 41. It is typified by an even higher Mg-content than northeast of the river. However instead of bicarbonate, chloride surprisingly preponderates.

An amazing feature is the very localised group of boreholes also west of the river designated 4b in figure 41, of which the ground water is characterised by a very high sodium and chloride content and low TDS.

It is thought that the high content of Mg and elevated Ca, coupled with a preponderance of bicarbonate might be ascribed to dolerite which was encountered in some of the boreholes northeast of the Elandsfontein Spruit as well as the surrounding dolerite hills to the southwest. A high sodium and chloride content would then be indicative of a sedimentary origin. If this deduction is correct, then the preponderance of Mg coupled with chloride as found west of the river, seems peculiar.

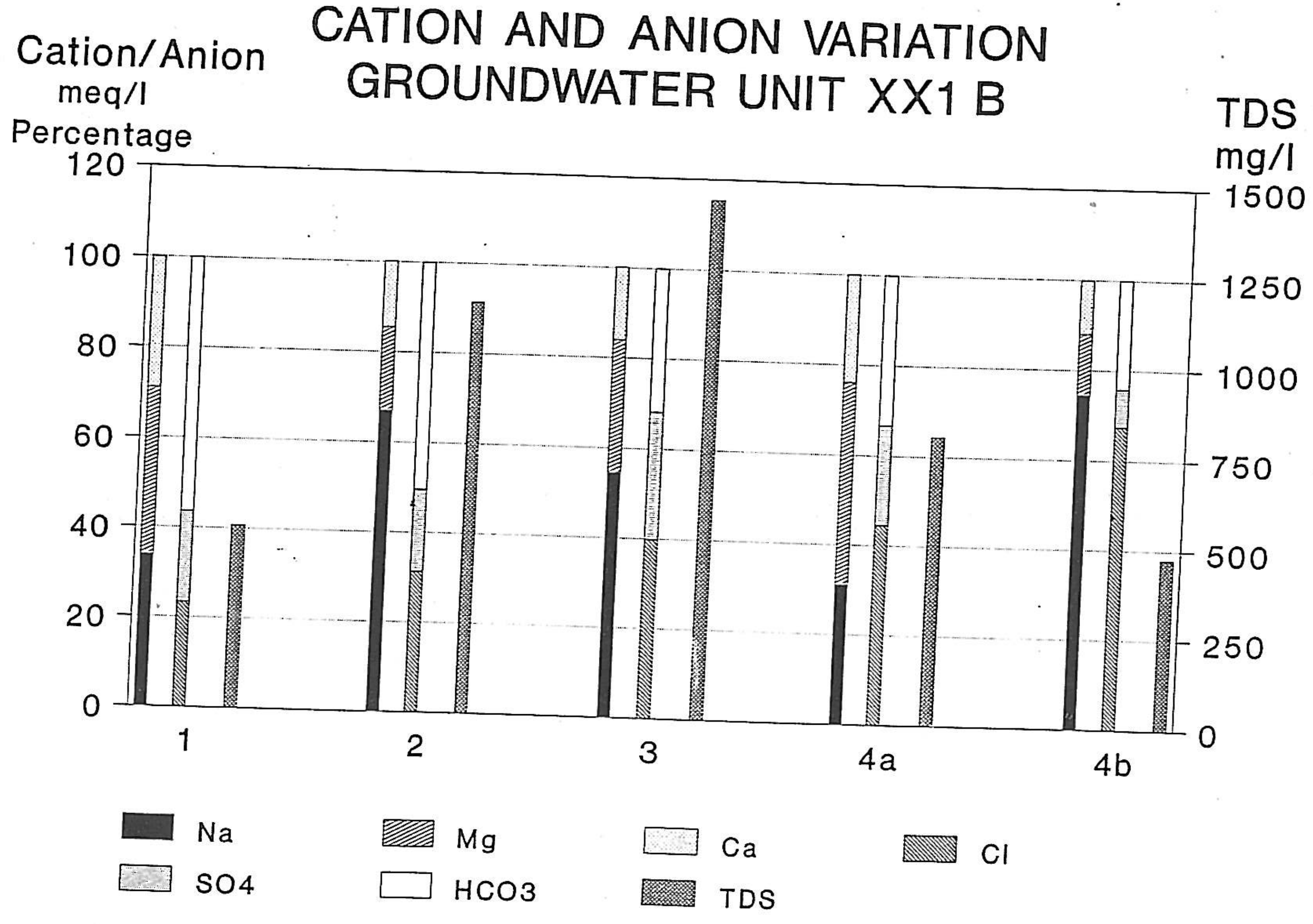


FIG. 41

(see text for explanation 1, 2, 3, 4a, 4b)

11 EXISTING AND POTENTIAL SOURCES OF GROUND-WATER SUPPLY FOR DE AAR

11.1 Existing schemes

De Aar is currently (1992) supplied by the following ground-water schemes:

Zewe Fountain (Burgerville)
Southwestern (Zwartekopjes, Vaalbank, Renosterpoort)
Southeastern (Riet Fountain 6 - Wagt en Bittje 5)
Caroluspoort

as well as private boreholes on

Leeufontein and Sipreshof (both portions of Zewe Fountain 9)
Kaffersdam (Cyffer Kuil 7)

Except for ground-water unit XXIB which is part of the Southwestern scheme and which has been the subject of a detailed study (chapter 9) and the well field on Caroluspoort formerly exploited by the Railways and subject of several assessments (Dziembowski 1971 and 1990; Vegter 1961 and 1975) data on Zewe Fountain (Burgerville) and the Southeastern area are completely inadequate to attempt similar evaluations.

In the case of Zewe Fountain (Burgerville) including the private holes on Leeufontein, Sipreshof and Kaffersdam, abstraction is from three different ground-water units (III, IV and VA). The water-level is recorded only in one borehole (unit IV). Its record is depicted in folder 5. Until recently no reliable figures of abstraction from the different units and boreholes have been available. Information on the areal distribution of rainfall, river flow, water content in dams and spring flows are lacking.

The Southeastern scheme involves units XI and XII. Water is being abstracted from three groups of boreholes - 2 in unit XI and one in XII. Volumes abstracted from the three groups of holes and the water-level response thereto are depicted in folders 19, 20 and 21. Heavy localised abstraction from two areas during 1985-87 in unit XI resulted in excessive drawdown and the weakening of boreholes. The copious rain and flood of 1988 restored water levels to their pre-pumping positions. These data are however totally inadequate for an evaluation of the assured yields of units XI and XII on similar lines as that of unit XXIB.

The only option for assessment of steady or assured yields is applying the results of the analysis of XXIB to units III, IV, VA, XI and XII on the assumption that storage and recharge conditions are comparable.

11.2 Additional sources

An additional potential source the so-called Northern area was identified by the investigations of the seventies (von Hoyer 1975).
In the period 1987-1989 further hydrogeological work was done by the Directorate of Geohydrology as well as drilling and pumptesting under its direction. Potential production holes were indicated in the following areas:

East and Southeast of De Aar (Woodford 1989)
Northern (van Wyk 1989)
Extended Northern (Woodford 1990b)
Far Northern (Woodford 1990a)
Brandfontein (van Wyk 1990)

Besides the above, exploitation possibilities exist in other areas which have not been investigated or fully explored.

11.3 Ground-water units and their estimated potential

To describe these possibilities and to evaluate potentially assured yields the surroundings of De Aar have been subdivided into 33 ground-water units. The division was made firstly on the basis of surface catchments and secondly using dolerite intrusions which intersect drainage lines (see folder 22 and table 35). The results of unit XXIB have been used as a basis.

The assured yield of ground-water unit XXIB has been estimated as follows (see 9.14):

		Assured yield per unit area	
		Lower estimate	Higher estimate
(a)	"Live" hard rock storage only (26.5 mm)	7.2 mm/a	8.6 mm/a
(b)	"Live" hard rock plus alluvium storage (39.5 mm)	8.2 mm/a	9.5 mm/a

Table 37 has been compiled assuming that

(i) depending on the absence or presence of meaningful volumes of water-bearing alluvium, either set of these estimates may be applied for the estimation of steady yields of the remaining ground-water units;

(ii) all non-productive losses of ground water can be obviated by the judicious siting of production boreholes and by maintaining a steady rate of abstraction;

(iii) boreholes meeting the minimum yield specification of 5 l/s for urban use can be established where presently non-existent, (unexplored units).

TABLE 37 ESTIMATES OF SUPPLIES AVAILABLE FOR URBAN USE FROM DIFFERENT GROUND-WATER UNITS DE AAR

Ground-water unit	Area sq. km	Steady Yield assuming zero effluent seepage / evapotranspiration loss: Lower Recharge Rate based on rainfall 15 mm/d and more (1)		Higher Recharge Rate based on rainfall 10 mm/d and more (1)		Farm Use (See Table IIA) Vegter 1990b	Estimates(2) for: Lower recharge rate: Urban abstraction from all currently available production boreholes	Lower recharge rate: Remaining undeveloped potential	Higher recharge rate: Urban abstruction from all currently available production boreholes	Higher recharge rate: Remaining undeveloped potential	Remarks (Consult text also)
		mm/annum	Volume E-6m3	mm/annum	Volume E-6m3	E-6m3	E-6m3	E-6m3	E-6m3	E-6m3	
I	21.8	7.2	0.157	8.6	0.187	0.002	-	0.155	-	0.185	
II	18.0	7.2	0.130	8.6	0.155	0.002	-	0.128	-	0.153	
III	46.4	7.2	0.334	8.6	0.399	0.095+?	0.15	0.089	0.15	0.154	Improve bh. distribution
IV	63.3	8.2	0.519	9.5	0.601	0.056	0.34	0.123	0.34	0.204	Improve bh. distribution
V A	48.9	7.2	0.352	8.6	0.421	0.005	0.35	0.0	0.35	0.069	
V B	41	-	-	-	-	-	-	-	-	-	Unfavourable low relief watershed
VI	39.2	7.2	0.282	8.6	0.337	0.044	-	0.238	-	0.293	
VII	17.7	7.2	0.127	8.6	0.152	0.002	-	0.125	-	0.150	
VIII B	72.3	8.2	0.593	9.5	0.687	0.007	0.28	0.306	0.28	0.400	
IX	92.1	7.2	0.663	8.6	0.792	0.079+(?)	0.05	0.534	0.05	0.663	
X	37.7	7.2	0.271	8.6	0.324	0.004	0.15	0.122	0.15	0.175	
XI	122.5	8.2	1.005	9.5	1.164	0.362+(?)	0.60	0.043	0.60	0.202	
XII	14.8	8.2	0.121	9.5	0.141	0.001	0.12(3)	0.0	0.14(3)	0.0	
XIII B	47.2	7.2	0.340	8.6	0.406	0.005	0.06	0.275	0.06	0.341	
XIV A	39.9	7.2	0.287	8.6	0.343	0.004	-	0.283	-	0.339	
XIV B	117.6	-	-	-	-	-	-	-	-	-	Mainly De Aar Townlands; not considered favourable
XV	151	-	-	-	-	-	-	-	-	-	Too remote
XVI A	13.1	-	-	-	-	-	-	-	-	-	Too remote
XVI B	123.7	8.2	1.014	9.5	1.175	0.362	0.28	0.377	0.28	0.538	
XVII	29.6	7.2	0.213	8.6	0.255	0.153	0.06(3)	0.0	0.10(3)	0.0	
XVIII A	56.3	-	-	-	-	-	-	-	-		Poor prospects
XVIII B	32.9	7.2	0.237	8.6	0.283	0.083	0.06	0.099	0.06	0.145	
XIX	78.3	8.2	0.642	9.5	0.744	0.048	0.53	0.069	0.53	0.171	Improve bh. spread
XX	126.9	8.2	1.041	9.5	1.206	0.013	0.30	0.728	0.30	0.893	
XXI A	22.2	-	-	-	-	-	-	-	-	-	Potential too limited
XXI B	81.7	8.2	0.670	9.5	0.776	0.128	0.44	0.107	0.44	0.213	
XXI C	40.2	-	-	-	-	-	-	-	-	-	
XXII	30.3	8.2	0.248	9.5	0.288	0.133	0.12(3)	0.0	0.16(3)	0.0	Limited potential; supplies in farming needs of unit XXII? Development feasible only if farming needs are at least partially met by unit XXIC
TOTAL	1626.6	..	9.2	-	10.8	1.588+(?)	3.86	3.80	3.96	5.29	
XXIII A	approx 80	-	-	-	-	-	-	-	-	-	)Not considered viable
XXIII B	75	8.2	0.615	9.5	0.712	0.238+?	0.37	0.0	0.37	0.101	)at present because
XXIII C	approx 60	-	-	-	-	-	-	-	-	-	)of distance from De Aar)

(1) See text (2) Allowing for farm needs as estimated
(3) Annual abstraction less than proposed pumpage as stated in tables X, XIII and XVIII Vegter 1990b estimated

This table is a revised version of table II of Vegter (1990b). The table lists lower and higher estimates of assured yields of twenty two ground-water units, estimated farming requirements, the annual volumes abstractable with all the presently available production holes (i.e. those currently in use as well as proposed) and the remaining undeveloped potential.

Table 38 (below) compares these estimates of the total assured yield of 21 ground-water units (currently being exploited and those worthy of consideration) and of ground-water unit XXIIIB (separately) with those previously given in the author's 1990b report. Farming requirements have been discounted (table IIA Vegter 1990b).

TABLE 38 COMPARISON OF ASSURED YIELDS AS ESTIMATED BY VEGTER 1990b AND THIS REPORT

Ground-water units	Report	Lower estimate million m^3/a		Higher estimate million m^3/a	
		All available production[1] holes	Remaining undeveloped potential	All available production[1] holes	Remaining undeveloped potential
I-VA; VI; VII; VIIIB; XIVA; XVII - XXII (21 units)	Current 1990b	3.9 3.3	3.8 2.5	4.0 3.9	5.3 4.3[2]
XXIIIB	Current 1990b	0.37 0.26	0.0 0.0	0.37 0.41	0.1 0.0

(1) Consult Vegter (1990 b) Tables III - XIX for abbreviated borehole data

(2) Note that some corrections have had to be made to Table II of Vegter's 1990 b report. A corrected version is available.

The total assured yield excluding Hennops Kraal is estimated between 7,7 and 9.3 million m^3 per annum provided all 21 ground-water units are exploited by the municipality.

12. EFFECT OF LARGE SCALE GROUND-WATER EXPLOITATION ON THE KAROO ECOLOGY

12.1 Long term monitoring

Farmer's associations and Agricultural Unions have repeatedly expressed concern about the generally believed deleterious effect of ground-water exploitation for irrigation and urban use on Karoo veld.

A scientific taskgroup (1989) under chairmanship of the author and consisting of two representatives of the Department of Agriculture and Water Supply, one of the Water Research Commission and a second of the Department of Water Affairs, however found no conclusive evidence proving such detrimental effect. Neither could its possibility be irrefutably be denied.

The likelihood of a detrimental effect on the vegetation appears greatest on deep loamy soils flanking water courses where larger shrubs grow and where the ground-water level lies within one metre off the surface. Root depth of Karoo vegetation has been found seldom more than 1200 mm; root formation and penetration are generally limited to a depth of 600 mm.

As there appears to be no other way of proving or disproving an injurious effect, the taskgroup recommended that the situation should be monitored over a number of years (10 - 20 yrs) in at least three areas where the ground-water level is affected by pumping as well as three comparable and unaffected control areas. The monitoring action is to comprise of

(a) water-level recording
(b) local rainfall measurement
(c) periodic plant surveys of grazed and ungrazed plots.

12.2 Regulating watertable drawdown

The channels of the Brak River and the Elandsfontein Spruit are overgrown with reeds in certain sections and contain open water bodies either periodically or throughout the year. These are fed by ground water. The reeds stabilize the alluvial soils against erosion.

Although ground-water losses through evapotranspiration should be salvaged as far as possible, it appears prudent not to lower the ground-water level to such an extent that permanent damage be done to the reeds.

Ground-water unit XXIB may be quoted as an example. Here Vegter (p17 1990b; XXIB erroneously indicated as XXIC) has advised salvaging as much as possible of ground-water losses by heavier abstraction on Renosterpoort and less on Vaalbank. Abstraction should obviously be regulated in such a way that the reeds are not killed off by excessive lowering of the water-table. What a tolerable lowering is will need to be determined by an agriculturist.

13. GUIDELINES FOR OPERATION AND RESEARCH

13.1 Phased development

Vegter (1990b) has grouped the 21 ground-water units recommended for exploitation (tables 36 and 37 this report) into 7 sets, each of which has been discussed in some detail. For these details sections XI-XX and tables II-XIV of that report should be consulted. To ensure an adequate supply at all times phased extensions to the existing schemes will be necessary. Phased development may follow any one of several different programmes. Choice has to be based on engineering, financial and political considerations. The water treatment option (Stewart Sviridov and Oliver 1990) that is selected, may also affect the route followed by phased development.

As indicated by Vegter (1990b) phased development options range from

(a) bringing into production as a first phase the northern borehole field and linking up the additional available boreholes in the Southeastern area.

to

(b) first developing and adding certain new ground-water units in the Eastern (Zewe Fountain/Burgerville) and Southeastern areas which will yield better quality water and are also favourably situated with respect to existing pipeline routes.

to

(c) various intermediate possibilities.

Timeously phased additional hydrogeological investigation, exploratory drilling and testpumping may therefore be required at an early date.

13.2 Operational data

To keep track of the performance of borehole(s)/borehole fields and to identify at an earlier stage problems that may arise, the following data should be collected regularly:

(a) Quantities pumped per month from individual holes or groups of holes if grouping is justified on a geohydrological basis.

(b) Spring flow as per (a).

(c) Monthly measurement of electrical conductivity of water from individual or groups of holes as per (a).

(d) Water-level recording in the vicinity of abstraction localities. A locality may consist of a single or a group of holes.

(e) Rainfall measurement in the exploited ground-water unit.

(f) Qualitative information on river flow i.e. maximum stage and duration; dam levels in the exploited ground-water unit.

(g) Yearly estimation of farm consumption of ground water especially where irrigation is practised.

These data should be processed and evaluated on a continual basis by a hydrogeologist, who should direct/advise the municipality on adjustments to the pumping regime. Insufficient data and knowledge place the development of a predictive model for management of the ground-water resources beyond reach at this stage.

13.3 Research

Exploitation of ground water for De Aar and the likelyhood of further exploratory drilling and pumptesting present excellent opportunities for pursuing research on aspects that have as yet not been resolved satisfactory and are of considerable importance to the progress of local hydrogeology/geohydrology:

(a) hydraulic fracturing for reducing exploration drilling effort (see 4.4.3) and for increasing borehole yield.

(b) pumping tests - designed and conducted to understand and interpret hydraulic conditions : double porosity, horizontal/vertical fracture models (see 7.3 - 7.5).

(c) effect of large scale ground-water abstraction on Karoo ecology.

(d) ground-water development potential:

  (i) reliable storage figures for fractured Karoo rocks from lengthy periods of abstraction without recharge.

  (ii) rainfall and surface conditions that determine recharge by infiltration by observing local ground-water level fluctuations in relation to local precipitation events and by means of ground-water balances.

  (iii) conditions for and the magnitude of recharge effected by river flow.

  (iv) estimation of potential - IGS results (Kirchner et al 1991) are disputable, because recharge of the alluvium has been overestimated and the limitation posed by limited storage has not been taken into account.

(e) identification of different hydrochemical facies and understanding operative processes.

It is recommended that geohydrological research should at least be resumed in ground-water unit XXIB. This would in addition to aspects mentioned under 13.2 entail inter alia:

(a) Re-institution of water-level recording on boreholes in hard rock areas i.e. away from the river valley (also improvement to I.G.S. coverage of holes) and retaining existing water-level recorders.

(b) Rainfall recording and measurement at a number of points in order to obtain a fair picture of rainfall distribution areally as well as temporally.

(c) Recording of pumping times of municipal boreholes (computerised recording?).

(d) *River stage recording.*

(e) *Addition of another observation borehole section across the Elandsfontein Spruit (see 8.2 about drawbacks of present section on Vaalbank).*

(f) *Obtaining more reliable estimates of evapotranspiration loss and groundwater runoff and subsurface outflow through Renosterpoort by regularly keeping track of open water bodies and reeds growth; erection of weir for ground-water outflow measurement.*

(g) *Obtaining more reliable estimates of the temporally variable ground-water inflow through Vaalbankpoort and the effect of municipal pumping on Zwartekopjes on subsurface inflow (additional water-level recording downstream).*

Ideally, in order to judge whether the results obtained from XXIB are generally applicable, similar but more modest studies should be staged in ground-water units IV and XI. These two units differ from XXIB in the following respects:

(a) *Unit IV*

(i) *Situated higher up in drainage region 603; in a smaller catchment*

(ii) *Underlain by sandstone, siltstone and mudstone of the Middleton Formation and dolerite (unit XXIB Tierberg shale and dolerite)*

(iii) *Smaller volume of alluvium; not known whether water-bearing*

(iv) *Ground-water quality of the best in the De Aar area.*

(b) *Unit XI*

(i) *Catchment above Caroluspoort comparable to that above Renosterpoort (ground-water unit XXIB)*

(ii) *Wide flat valley with low gradient*

(iii) *Underlain by sandstone, siltstone and mudstone of the Middleton Formation and dolerite*

(iv) *Alluvial deposits thinner and more silty than in XXIB.*

(v) *Ground-water quality very poor in places.*

(vi) *Recharge by floods may be studied in adjoining downstream unit XII. Borehole section line on Caroluspoort should be extended to the east of the Brak River.*

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APPENDIX

TABLE 1 VOLUMES OF GROUNDWATER PUMPED FOR MUNICIPAL AND RAILWAY SUPPLIES

YEAR	MUNICIPAL SOURCES ON BURGERVILLE / ZEWE FOUNTAIN AND PURCHASED FROM FARMERS (1) MILLION CUBIC m	SOUTHWESTERN MUNICIPAL BOREHOLE FIELD MILLION CUBIC m	SOUTHEASTERN MUNICIPAL BOREHOLE FIELD MILLION CUBIC m	TOTAL BY MUNICIPALITY MILLION CUBIC m	S.A.R CAROLUSPOORT MILLION CUBIC m	S.A.R BRAK RIVER WELLS (3) MILLION CUBIC m	TOTAL BY RAILWAY (4) MILLION CUBIC m	TOTAL MUNICIPALITY AND RAILWAYS MILLION CUBIC m
1948	0.63	-	-	0.63	0.26	(0.13)	0.39	1.02
1954	0.80	-	-	0.80	0.26	(0.13)	0.39	1.19
1958	0.83	-	-	0.83	0.27	(0.13)	0.40	1.23
1959	0.83	-	-	0.08	0.28	(0.13)	0.41	1.24
1960	0.875	-	-	0.875	0.296	(0.13)	0.426	1.30
1961	1.005	-	-	1.005	0.274	(0.13)	0.404	1.41
1962	0.81	-	-	0.81	0.304	(0.13)	0.434	1.24
1963	1.075	-	-	1.075	0.32	(0.13)	0.45	1.53
1964	0.70	-	-	0.70	0.488	(0.13)	0.618	1.32
1965	0.615	-	-	0.615	0.528	(0.13)	0.658	1.27
1966	0.82	-	-	0.82	0.675	(0.13)	0.805	1.63
1967	0.955	-	-	0.955	0.774	(0.13)	0.904	1.86
1968	0.91	-	-	0.91	0.882	(0.13)	0.952	1.86
1969	0.95	-	-	0.95	0.633	(0.13)	0.763	1.71
1970	0.89	-	-	0.89	0.602	(0.13)	0.732	1.62
1971	0.985	-	-	0.985	(0.75) (2)	(0.13)	0.88	1.87
1972	1.05	-	-	1.05	(0.765) (2)	(0.13)	0.895	1.95
1973	0.875	-	-	0.875	(0.780) (2)	(0.13)	0.91	1.79
1974	1.119	-	-	1.119	(0.800) (2)	(0.13)	0.93	2.05
1975	1.316	-	-	1.316	(0.815) (2)	(0.13)	0.945	2.26
1976	1.357	-	-	1.357	0.824		0.824	2.18
1977	1.562	-	-	1.562	0.876		0.876	2.44
1978	1.301	0.329	-	1.630	0.872		0.872	2.50
1979	1.436	0.576	-	2.012	0.932		0.932	2.94
1980	1.104	0.790	-	1.894	0.801		0.801	2.70
1981	1.106	0.757	0.064	1.927	0.894		0.894	2.82
1982	1.152	1.011	0.097	2.260	0.713		0.713	2.97
1983	0.936	1.049	0.255	2.240	0.727		0.727	2.97
1984	1.067	1.146	0.233	2.446	0.708		0.708	3.15
1985	0.758	1.101	0.507	2.366	0.664		0.664	3.03
1986	0.848	0.998	0.884	2.730	0.679		0.679	3.41
1987	0.387	0.850	1.008	2.245	0.674		0.674	2.92
1988	0.966	0.656	0.492	2.114	0.326		0.326	2.44
1989	0.970	0.964	0.413	2.347				2.35

Footnotes:

(1) Volume purchased from Leuve Fountain between 1964 to 1987 not supplied by Municipality. Contract allowed for maximum of 13 600 million cubic meters/month

(2) Interpolated figures - gap in records

(3) Estimated mean volume

(4) Estimated 1948-1975

TABLE 19 ESTIMATED EVAPOTRANSPIRATION LOSS OF GROUNWATER FROM UNIT XXIB

MONTH	MEAN MONTHLY EVAPORATION DE AAR AMERICAN CLASS A PAN (mm)	DAILY EVAPORATION RATE FROM BODIES OF WATER (mm/DAY)	IRRIGATION REQUIREMENTS OF LUCERNE mm/DAY	ESTIMATED EVAPOTRANS-PIRATION LOSS RENOSTERPOORT SECTION OF RIVER (CUBIC m/MONTH)	ESTIMATED EVAPOTRANS-PIRATION LOSS VAALBANK SECTION OF RIVER PRIOR TO 1979 (CUBIC m/MONTH)	CONSERVATIVELY ESTIMATED LOWER EVAPOTRANSPIRA-TION LOSS RENOSTERPOORT SECTION OF RIVER (CUBIC m/MONTH)
January	393	6,7	6,5	35 000	20 000	12 000
February	300	5,1	5,7	28 000	16 000	9 000
March	247	4,9	3,5	19 250	11 000	6 500
April	158	3,3	2,3	12 250	7 000	4 000
May	121	2,6	1,0	5 250	3 000	2 000
June	91	2,1	1,0	5 250	3 000	2 000
July	109	2,2	1,0	5 250	3 000	2 000
August	158	3,2	2,6	14 000	8 000	4 000
September	234	4,2	4,2	21 750	12 500	6 500
October	294	5,2	4,7	25 500	14 500	9 000
November	343	7,5	5,7	29 750	17 000	11 000
December	405	7,6	6,6	35 750	20 500	12 000
Total for year	2 853		13,55	237 000	135 500	80 000

TABLE 20 ESTIMATED IRRIGATION REQUIREMENTS 1989

Ground-water UNIT XXIB

(RENOSTERPOORT, VAALBANK AREA)

Areas irrigated (Calitz survey Nov. 1988 - Feb. 1989)

Lucerne 7.9 ha
Vegetables 1.6 ha

Month	m^3 for lucerne	m^3 for vegetables	Total m^3
January	15 800	2 368	18 618
February	12 640	1 888	14 528
March	8 690	1 296	9 986
April	5 530	832	6 362
May	2 370	352	2 722
June	2 370	352	2 722
July	2 370	352	2 722
August	6 320	944	7 264
September	9 876	1 472	11 348
October	11 456	1 712	13 168
November	13 430	2 001	15 431
December	16 196	2 432	18 628
Year	107 048	16 001	123 049
	(say 107 000	16 001	123 000)

N.B. Area under irrigation in the seventies 41.13 ha lucerne
(von Hoyer report Gh2895)
Estimated water consumption 376 000 m^3/a

TABLE 21 ESTIMATED HOUSEHOLD AND STOCKWATERING REQUIREMENTS 1985-1988

GROUND-WATER UNIT XXIB

(RENOSTERPOORT-VAALBANK AREA)

		m^3/annum
2 farmsteads	50 m^3/month	1 200
*3 000 head of sheep	1.14 - 3.42 l/day	2 529
*50 head of cattle	45 l/day	821
	Total	4 550

*Figures given by von Hoyer (1976) report Gh 2895

TABLE 22 ESTIMATED WATER CONSUMPTION FOR FARMING DURING 1989 (APPLIED TO PERIOD 1985-1989)

GROUND-WATER UNIT XXIB

(RENOSTERPOORT-VAALBANK AREA)

Month	Estimated 1989	Conservative* minimum 1985-1988
	m^3	
January	18 500	6 000
February	14 900	4 550
March	10 400	3 000
April	6 700	2 000
May	3 100	1 000
June	3 100	1 000
July	3 100	1 000
August	7 600	2 500
September	11 600	3 500
October	13 500	4 500
November	15 800	5 000
December	18 900	6 000
Year	127 000	40 000

* Arbitrarily taken as about 1/3rd.

TABLE 23 MUNICIPAL PUMPAGE SOUTHWESTERN AREA

Month/ Year	Ground-water Unit XXIB		Ground-water unit XX
	Renosterpoort*	Vaalbank*	Zwartekopjes*
10/85	19	26	34
11/85	24	50	28
12/85	17	13	18
1/86	29	22	35
2/86	28	17	42
3/86	34	15	44
4/86	28	17	37
5/86	26	19	34
6/86	25	19	19
7/86	30	18	27
8/86	21	15	24
9/86	33	17	35
10/86	34	21	41
11/86	24	18	37
12/86	40	24	36
1/87	56	37	38
2/87	34	34	32
3/87	37	24	19
4/87	40	21	20
5/87	24	20	14
6/87	39	19	12
7/87	36	16	7
8/87	26	13	9
9/87	19	10	2
10/87	31	14	10
11/87	27	17	14
12/87	38	21	14
1/88	42	39	23
2/88	51	28	23
3/88	14	9	8
4/88	25	5	10
5/88	13	6	6
6/88	25	15	7
7/88	16	7	10
8/88	21	13	17
9/88	21	14	19

*Renosterpoort : Boreholes G27707, 27719I, 27704, 23206A
*Vaalbank : Boreholes G27715G, 23205B, 23205F, 23204D
*Zwartekopjes : Boreholes G23203A, 27702G, 27703, 23202

TABLE 25 VOLUMETRIC CHANGE OF SATURATED KAROO BEDS AND DOLERITE IN GROUND-WATER UNIT XXIB (RENOSTERPOORT-VAALBANK AREA)

Volume on 1 June 1988 arbitrarily assigned a value of 350 million m^3

Date	million m^3
1 Oct 1985	61.6
1 Nov 1985	70.4
1 Dec 1985	89.6
1 Jan 1986	120.9
1 Feb 1986	142.3
1 Mar 1986	147.9
1 Apr 1986	141.1
1 May 1986	131.5
1 Jun 1986	121.9
1 Jul 1986	115.3
1 Aug 1986	104.3
1 Sep 1986	95.5
1 Oct 1986	87.4
1 Nov 1986	80.8
1 Dec 1986	72.1
1 Feb 1987	59.8
1 Mar 1987	53.8
1 Apr 1987	49.0
1 May 1987	46.8
1 Jul 1987	40.2
1 Sep 1987	37.3
1 Oct 1987	42.9
1 Dec 1987	58.6
1 Feb 1988	78.3
1 Mar 1988	214.7
1 Apr 1988	309.3
1 May 1988	337.4
1 Jun 1988	350.0
1 Jul 1988	342.0

TABLE 26 VOLUMETRIC CHANGE OF SATURATED ALLUVIUM IN GROUND-WATER UNIT XXIB (RENOSTERPOORT-VAALBANK AREA)

Volume on 1/10/85 arbitrarily assigned a value of 5.0 million m^3

Date	million m^3
1/07/74	19.7
1/08/84	20.3
1/02/80	20.2
1/10/85	5.0
1/12/85	5.0
1/02/86	5.4
15/03/86	5.8
1/04/86	4.6
1/05/86	4.3
1/06/86	4.2
1/07/86	4.2
1/08/86	4.4
1/09/86	4.2
1/10/86	3.7
1/11/86	3.3
1/12/86	3.0
1/01/87	2.3
1/02/87	1.6
1/03/87	1.5
15/04/87	1.0
1/06/87	0.8
1/07/87	1.1
1/08/87	1.3
1/09/87	1.5
1/10/87	2.3
1/12/87	3.5
15/01/88	3.1
1/03/88	3.7
15/04/88	7.7
1/06/88	8.7
1/08/88	8.8

TABLE 27

DAILY RAINFALL (mm) RECORDED AT WEATHER BUREAU STATION DE AAR AND TEMPORARY INSTITUTE FOR GROUND WATER STUDIES RAINFALL RECORDERS IN GROUND-WATER UNIT XXIB (RENOSTERPOORT-VAALBANK AREA) - SEPTEMBER 85 - MAY 1988

A = Date
B = Day Number
C = Weather Bureau Station De Aar 170009A
D = Weather station (I.G.S.)
E = Recorder No 2 (I.G.S.)
F = Recorder No 1 (I.G.S.)

A			B	C	D	E	F
1985	09	01	1	–			
		03	3	3.1			
		07	7	1.7			
		08	8	1.3			
1985	10	07	37	19.5			
		12	42	2.7			
		14	44	9.1			
		28	58	0.5			
		30	60	16.5			
		31	61	23.2			
1985	11	01	62	1.4	1.4		
		02	63	–	0.2		
		03	64	–	0.2		
		04	65	1.5	–		
		07	68	–	0.2		
		27	88	2.5	2.4		
		28	89	5.7	3.2		
		29	90	0.7	–		
		30	91	2.6	–		
1985	12	01	92	10.7	–	–	
		02	93	1.5	–	2.3	
		03	94	6.3	–	–	
		04	95	0.2	–	–	
		05	96	10.4	6.6	–	
		06	97	–	1.2	–	
		18	09	2.1	3.0	–	
		19	110	48.9	40.2	–	
		23	114	–	–	1.3	
		24	115	–	–	7.7	
		25	116	–	–	1.0	
1986	01	02	124	–	–	8.7	
		03	125	–	–	0.1	
		04	126	–	–	0.6	
		10	132	–	–	0.2	
		11	133	–	–	0.2	
		17	139	19.1	3.4	5.7	6.8
		18	140	–	–	24.3	–
		19	141	14.4	13.6	33.4	12.4
		20	142	4.1	1.2	0.2	2.1
		21	143	–	–	1.8	–
		23	145	0.3	–	5.1	–
		24	146	3.5	–	–	7.8

Table 27 (continued)

A			B	C	D	E	F
1986	01	26	148	6.1	–	–	8.2
		27	149	–	–	–	–
		28	150	4.4	–	0.9	–
		30	152	3.5	–	–	1.6
		31	153	–	–	0.8	–
1986	02	01	154	–	–	0.1	–
		02	155	1.2	–	14.0	0.4
		03	156	10.9	–	0.7	2.2
		04	157	–	–	10.2	–
		05	158	–	–	–	–
		16	169	3.3	–	–	–
		21	174	–	–	0.4	–
1986	03	04	186	6.0	1.4	4.8	–
		05	187	–	–	20.4	–
		07	189	3.0	6.4	4.4	7.8
		08	190	7.5	1.8	34.7	1.6
		09	191	0.1	–	0.3	–
		10	192	6.0	10.0	9.7	–
		11	193	–	–	15.7	–
		14	196	–	–	0.8	–
		15	197	–	–	9.8	–
		16	198	–	–	0.2	–
		18	200	–	–	0.3	–
		22	204	7.0	–	–	–
		28	210	–	–	0.1	–
1986	04	08	220	0.8	–	0.5	–
		09	221	–	–	3.8	–
		10	222	–	–	0.4	–
		11	223	–	–	–	–
		12	224	–	–	–	–
		13	225	–	–	7.1	–
		14	226	–	–	3.5	–
		22	234	0.3	1.6	–	7.0
		23	235	0.5	0.4	–	–
		25	237	0.6	0.2	–	–
		26	238	1.2	0.2	0.6	–
		27	239	0.5	1.8	0.7	–
		28	240	–	–	5.8	–
1986	05	12	254	–	–	–	10.2
	06	01	273	6.0	5.8	–	5.8
		02	274	0.5	2.6	6.5	3.2
1986	06	03	275	4.3	0.4	3.5	–
		04	276	0.2	–	–	1.0
		13	285	–	–	–	4.2
		17	289	–	0.2	–	–
1986	07	07	310	1.2	–	–	–
		18	321	–	–	–	1.2
		19	322	–	–	–	17.6
		23	326	–	–	0.8	–
1986	08	10	344	2.9	–	–	–
		11	345	6.1	–	2.2	–
		13	347	–	5.2	–	–
		14	348	–	2.6	–	–
		28	362	5.6	–	–	2.4
		29	363	0.3	–	–	–

Table 27 (continued)

A			B	C	D	E	F
1986	08	31	365	–	5.2	–	–
1986	09	14	379	0.8	–	–	–
1986	10	01	396	–	–	0.2	–
		02	397	2.8	–	3.1	2.4
		03	398	6.5	–	0.1	2.0
		04	399	1.7	–	3.7	3.8
		05	400	–	4.8	3.7	–
		06	401	–	2.4	–	–
		07	402	–	1.0	–	–
		19	414	–	–	–	–
		21	416	–	–	–	–
		25	420	5.9	–	2.9	3.6
		28	423	3.3	1.0	–	–
		30	425	–	–	5.2	–
		31	426	–	–	–	2.5
1986	11	02	428	–	1.8	–	–
		06	432	0.8	–	–	–
		07	433	0.6	–	0.2	2.4
		08	434	0.1	–	–	2.0
		10	436	–	0.2	–	–
		11	437	–	–	–	–
		12	438	–	–	–	–
		13	439	–	–	–	–
		20	446	0.4	–	0.6	0.4
		21	447	19.0	–	8.9	4.9
		23	449	–	0.6	–	–
		24	450	0.4	10.2	–	–
		25	451	1.5	–	–	–
		26	452	–	–	2.1	–
		28	454	–	–	–	–
		29	455	–	1.4	–	–
1986	12	02	458	2.2	–	–	–
		21	477	–	–	–	–
		22	478	–	–	–	–
		28	484	4.0	–	5.3	16.6
		29	485	0.4	–	–	–
		31	487	–	1.4	–	–
1987	01	11	498	0.4	0.4	0.3	–
		14	501	–	–	–	9.0
1987	02	05	523	–	–	–	0.8
		07	525	–	–	–	–
		08	526	15.6	20.4	19.9	–
		09	527	4.9	9.6	14.1	–
1987	02	10	528	0.6	0.2	–	–
		11	529	6.2	1.8	0.9	–
		12	530	7.6	7.0	7.7	–
		15	533	–	–	–	–
		25	543	–	–	0.6	–
		27	545	1.0	1.6	2.2	–
1987	03	14	560	0.6	–	–	–
		16	562	0.5	0.8	–	–
		18	564	7.9	4.0	5.3	–
		20	566	0.8	–	–	–
		22	568	0.4	–	–	–
		29	575	3.0	6.8	3.7	–

Table 27 (continued)

A			B	C	D	E	F
1987	03	30	576	1.3	–	–	–
1987	04	09	587	–	2.8	–	–
		08	586	4.0	–	–	–
		11	589	–	–	–	6.0
		12	590	18.5	7.4	–	0.8
		13	591	2.5	2.0	–	1.0
1987	04	14	592	0.9	1.6	–	–
		20	598	6.0	1.8	–	–
1987	05	08	615	–	–	0.6	–
		11	618	12.0	11.0	–	–
		12	619	–	–	–	10.2
1987	06	04	642	2.0	1.4	–	1.0
		12	650	13.6	8.0	–	–
		13	651	–	–	–	4.2
		24	662	0.2	–	–	–
		25	663	0.1	–	–	–
1987	07	02	670	–	–	–	–
		16	684	–	–	1.6	–
		17	685	–	–	14.0	–
		18	686	3.0	2.8	–	1.2
		19	687	16.0	17.4	–	17.6
		20	688	1.5	2.6	–	–
1987	08	11	710	0.7	–	–	–
1987	09	06	736	–	1.0	–	2.2
		07	737	16.6	20.2	–	–
		11	741	–	–	15.6	–
		12	742	0.6	0.4	–	–
		18	748	1.6	2.0	–	0.8
		19	749	8.2	6.6	–	4.4
		20	750	–	–	17.4	–
		21	751	27.7	16.4	25.7	12.0
		22	752	32.0	18.4	–	35.4
1987	10	06	766	0.5	–	–	–
		07	767	–	–	0.4	–
		08	768	1.7	–	–	–
		12	772	–	–	0.3	–
		17	777	–	–	1.5	–
		18	778	0.6	–	8.7	–
		19	779	0.1	2.6	4.5	6.0
		21	781	4.3	4.4	4.8	4.0
		24	784	0.4	–	–	–
		30	790	0.6	2.2	1.8	0.2
1987	11	08	799	0.9	0.2	0.5	–
		11	802	10.5	7.0	8.1	6.4
		12	803	22.5	32.0	38.3	40.6
		13	804	19.5	7.2	5.0	7.0
		23	814	0.2	–	–	–
		28	819	23.6	17.2	13.4	17.2
		29	820	7.6	5.8	8.8	7.4
1987	12	11	832	0.5	–	–	–
		21	842	12.5		16.7	40.2
		22	843	10.0		–	5.6
1988	01	11	863	0.6		–	–
		14	866	6.0		10.2	8.0
		15	867	1.2		–	–

Table 27 (continued)

A			B	C	D	E	F
1988	02	05	888	–		–	0.8
		07	890	7.6		–	3.6
		09	892	1.5		–	–
1988	02	15	898	2.6		2.7	2.4
		16	899	20.0		7.5	6.2
		17	900	12.0		2.0	0.8
		18	901	48.0		29.4	53.0
		19	902	80.2		–	80.0
		20	903	0.6		–	4.0
1988	02	21	904	1.7		–	1.6
		22	905	13.6		–	14.6
		26	909	29.0		–	8.8
		27	910	15.0		–	12.0
		28	911	4.3		–	–
		29	912	1.6		–	–
1988	03	01	913	4.5		–	–
		04	916	3.5		1.9	7.0
		05	917	8.6		6.8	3.0
		09	921	25.4		18.9	37.6
		10	922	3.0		2.3	0.4
		11	923	12.0		1.9	0.8
		12	924	0.5		14.1	–
		13	925	–		–	1.6
		23	935	4.0		3.2	8.0
		25	937	2.7		–	–
		26	938	–		–	2.0
		29	941	0.6		2.3	7.8
1988	04	02	945	1.2		–	–
		03	946	5.5		0.6	2.6
		04	947	–		0.5	–
		05	948	4.5		20.5	18.2
		14	957	18.6		14.6	22.4
		17	960	25.5		19.1	
		18	961	0.5		–	
		19	962	0.4		–	
		20	963	1.0		–	
1988	05	07	980	0.4		–	
		08	981	0.9		–	
		16	989	3.0		0.2	
		26	999	0.3		–	
		27	1000	6.0		–	
		28	1001	3.7		–	
1988	06	06	1010	0.4		0.2	

TABLE 28 ASSUMED FLOW RATES EX HARD-ROCK STRATA TO ALLUVIUM GROUND-WATER UNIT XXIB

Month /year	Based on assumption of total ground-water discharge equalling: I Municipal abstraction only $m^3 \times 10^3$	II I + lower estimates of farm use + evapotranspiration $m^3 \times 10^3$	III I + higher estimates of farm use + evapotranspiration $m^3 \times 10^3$
10/85	40	43	48
11/85	41	44	50
12/85	44	47	53
1/86	45	48	54
2/86	47	50	56
3/86	47	50	56
4/86	47	50	56
5/86	46	49	55
6/86	45	48	54
7/86	45	48	54
8/86	44	47	53
9/86	44	47	53
10/86	43	46	52
11/86	42	45	51
12/86	42	45	51
1/87	41	44	50
2/87	40	43	48
3/87	39	42	47
4/87	38	41	46
5/87	37	40	45
6/87	37	40	45
7/87	37	40	45
8/87	37	39	44
9/87	37	39	44
10/87	37	39	44
11/87	37	40	45
12/87	37	40	45
1/88	38	41	46
2/88	39	42	47
3/88	48	51	57
4/88	53	57	64
5/88	53	57	64
6/88	54	58	65

TABLE 30 RAINFALL DE AAR 1913/14 TO 1988/89

Season	Total precipitation (mm)	Precipitation equalling/exceeding 10 mm/d (mm)	Precipitation equalling/exceeding 15 mm/d (mm)
1913-14	243.3	152,9	131.3
14-15	189.3	85.6	43.2
15-16	253.0	201.7	137.9
16-17	409.8	271.7	215.9
17-18	384.0	282.4	251.1
18-19	120.2	67.4	0.0
19-20	434.6	356.4	312.0
20-21	240.0	223.8	150.0
21-22	145.2	94.0	79.0
22-23	172.9	78.5	50.0
23-24	99.1	56.2	20.1
24-25	470.4	363.2	282.4
25-26	115.1	80.0	44.7
26-27	117.8	67.5	45.2
27-28	242.6	164.7	114.2
28-29	291.3	198.3	151.8
29-30	192.3	121.1	95.7
30-31	197.2	109.7	21.6
31-32	247.8	177.1	148.0
32-33	107.2	38.1	0.0
33-34	334.0	241.7	187.1
34-35	402.1	265.5	242.1
35-36	224.1	186.9	165.0
36-37	301.9	205.8	182.0
37-38	263.2	181.1	156.5
38-39	364.5	212.9	161.2
39-40	417.5	307.1	258.6
40-41	311.5	220.2	209.1
41-42	222.1	136.1	122.4
42-43	274.4	137.6	101.3
43-44	199.3	94.9	50.5
44-45	119.4	25.2	0.0
45-46	221.2	125.7	68.3
46-47	180.9	117.8	107.1
47-48	357.5	277.1	208.4
48-49	135.3	53.3	14.2
49-50	317.3	194.5	116.6
50-51	148.8	74.9	21.1
51-52	202.7	118.5	66.8
52-53	106.4	31	21.0
53-54	193.8	171..0	138.5
54-55	225.7	139.0	93.5
55-56	160.4	59.5	16.0
56-57	318.3	237.8	176.0
57-58	270.8	147.5	138.0
58-59	361.3	311.5	252
59-60	273.1	162.5	162.5
60-61	344.1	255.2	221.7
61-62	145.1	65	29
62-63	459.9	318.0	252

Table 30 (continued)

Season	Total precipitation (mm)	Precipitation equalling/exceeding 10 mm/d (mm)	Precipitation equalling/exceeding 15 mm/d (mm)
63-64	247.9	169.0	74.5
64-65	327.0	254.4	198.5
65-66	229.7	132.1	71
66-67	402.0	335.0	279.5
67-68	249.5	214.5	180.5
68-69	210.6	170.5	170.5
69-70	250.8	195.3	128.3
70-71	252.9	107.5	47
71-72	309.8	178.6	144.1
72-73	247.2	158.1	148.1
73-74	714.4	656.4	561.4
74-75	254.5	170.1	122
75-76	711.3	576.7	519.4
76-77	399.8	248.7	217.6
77-78	299.6	215.5	158.4
78-79	274.5	170.3	170.3
79-80	292.2	158.6	123.7
80-81	424.0	310.1	254.3
81-82	252.0	184.2	132.3
82-83	298.5	197.0	131.4
83-84	326.1	219.1	164.5
84-85	293.4	169.7	120.8
85-86	334.3	197.1	151.8
86-87	266.7	171.0	145.4
87-88	611.2	498.0	417.4
88-89	412.8	326.6	277
Mean	281.9	192.8	149.2

TABLE 32 ESTIMATION OF LONG-TERM STEADY YIELD BASED ON AN ASSUMED "LIVE" STORAGE OF 26.5 mm (HARD-ROCK) AND RECHARGE PERCENTAGE OF RAINFALL EXCEEDING 9.9 AND 14.9 mm/DAY

Season : October - September

- *A* — *Rainfall exceeding 9.9mm/day*
- *B* — *Recharge mm (see table 31)*
- C_1 — *End of season storage with steady abstraction of 8.6 mm/annum*
- C_2 — *End of season storage with steady abstraction of 16.4 mm/annum - period 1973/74 to 1988/89 only*
- *D* — *Rainfall exceeding 14.9 mm/day*
- *E* — *Recharge mm (see table 31)*
- F_1 — *End of season storage with steady abstraction of 7.2 mm/annum*
- F_2 — *End of season storage with steady abstraction of 15.1 mm/annum - period 1973/74 to 1988/89 only*

Season	A	B	C_1	C_2	D	E	F_1	F_2
1913-14	152.9	9.6	4.7		131.3	9.6	4.8	
14-15	85.6	3.9	0.0		43.2	2.4	0.0	
15-16	201.7	14.5	5.9		137.9	10.0	2.8	
16-17	271.7	22.0	19.3		215.9	19.4	15.4	
17-18	282.4	22.9	26.5		251.0	24.8	26.5	
18-19	67.4	3.0	20.9		0.0	0.0	19.3	
19-20	356.4	35.6	26.3		312.0	33.7	26.5	
1920-21	223.8	16.1	26.5		150.0	12.3	26.5	
21-22	94.0	4.3	22.2		79.0	5.1	24.3	
22-23	78.5	3.6	17.2		50.0	3.3	20.4	
23-24	56.2	2.6	11.2		20.1	1.1	14.3	
24-25	363.4	36.3	26.5		282.4	28.0	26.5	
25-26	80.0	3.7	21.6		44.7	2.5	21.7	
26-27	67.5	3.1	16.1		45.2	2.5	16.9	
27-28	164.7	10.4	17.9		114.2	8.2	17.9	
28-29	198.3	12.5	21.8		151.8	12.4	23.1	
1929-30	121.1	6.5	19.7		95.7	6.2	22.1	
30-31	109.7	5.9	17.0		21.6	1.2	16.7	
31-32	177.1	11.2	19.6		148.0	10.8	19.7	
32-33	38.1	1.4	12.4		0.0	0.0	12.5	
33-34	241.7	17.4	21.2		187.1	15.3	20.6	
34-35	265.5	21.5	26.5		242.1	21.8	26.5	
35-36	186.9	11.8	26.5		165.0	13.5	26.5	
36-37	205.8	14.8	26.5		182.0	14.9	26.5	
37-38	181.1	11.4	26.5		156.5	12.8	26.5	
38-39	212.9	15.3	26.5		161.2	13.2	26.5	
1939-40	307.1	27.6	26.5		258.6	25.6	26.5	
40-41	220.2	15.9	26.5		209.1	18.8	26.5	
41-42	136.1	7.3	25.2		122.4	8.9	26.5	
42-43	137.6	7.4	24.0		101.3	7.4	26.5	
43-44	94.9	4.4	19.8		50.5	3.3	22.6	
44-45	25.2	0.9	12.1		0.0	0.0	15.4	

Table 32 (continued)

Season	A	B	C_1	C_2	D	E	F_1	F_2
45-46	125.7	6.8	10.3		68.3	4.4	12.6	
46-47	117.8	6.4	8.1		107.1	7.8	13.2	
47-48	277.1	22.4	21.9		208.4	18.8	24.8	
48-49	53.3	2.5	15.8		14.2	0.8	18.4	
1949-50	194.5	12.3	19.5		116.6	8.5	19.7	
50-51	74.9	3.4	14.3		21.1	1.2	13.7	
51-52	118.5	6.4	12.1		66.8	4.3	10.8	
52-53	31	1.2	4.7		21.0	1.2	4.8	
53-54	171.0	10.8	6.9		138.5	10.1	7.7	
54-55	139.0	7.5	5.8		93.5	6.1	6.6	
55-56	59.5	2.7	-0.1		16.0	0.9	0.3	
56-57	237.8	17.1	8.4		17.6	14.4	7.5	
57-58	147.5	8.0	7.8		138.0	10.1	10.4	
58-59	311.5	28.0	26.5		252.0	24.9	26.5	
1959-60	162.5	10.2	26.5		262.5	13.3	26.5	
60-61	255.2	20.7	26.5		221.7	20.0	26.5	
61-62	65.0	2.9	20.8		29.0	1.6	20.9	
62-63	318.0	28.6	26.5		252.0	24.9	26.5	
63-64	169.0	10.6	26.5		74.5	4.8	24.1	
64-65	254.5	20.6	26.5		198.5	16.3	26.5	
65-66	132.1	7.1	25.0		71.0	4.6	23.9	
66-67	335.0	30.1	26.5		279.5	27.7	26.5	
67-68	214.5	15.4	26.5		180.5	14.8	26.5	
68-69	170.5	10.7	26.5		170.5	14.0	26.5	
1969-70	195.3	12.3	26.5		128.3	9.4	26.5	
70-71	107.5	5.8	23.7		47.0	2.6	21.9	
71-72	178.6	11.3	26.4		144.1	10.5	25.2	
72-73	158.1	10.0	26.5		148.1	10.8	26.5	
73-74	656.4	100.4?	26.5	26.5	561.4	85.9?	26.5	26.5
74-75	170.1	10.7	26.5	20.8	122.0	8.9	26.5	20.3
75-76	576.7	77.9?	26.5	26.5	519.4	74.7?	26.5	26.5
76-77	248.7	17.9	26.5	26.5	217.6	19.6	26.5	26.5
77-78	215.5	15.5	26.5	25.6	158.4	12.8	26.5	24.2
78-79	170.3	10.7	26.5	19.9	170.3	13.8	26.5	22.9
1979-80	158.6	10.0	26.5	13.5	123.7	8.9	26.5	16.7
80-81	310.1	27.9	26.5	25.0	254.3	25.2	26.5	26.5
81-82	184.2	11.6	26.5	20.2	132.3	9.5	26.5	20.9
82-83	197.0	12.4	26.5	16.2	131.4	9.5	26.5	15.3
83-84	219.1	15.8	26.5	15.6	164.5	13.3	26.5	13.5
84-85	169.7	10.7	26.5	9.9	120.8	8.7	26.5	7.1
85-86	197.1	12.4	26.5	5.9	151.8	12.3	26.5	4.3
86-87	171.0	10.8	26.5	0.3	145.4	10.5	26.5	-0.3
87-88	498.0	58.3?	26.5	26.5	417.4	52.6?	26.5	26.5
88-89	326.6	23.5	26.5	26.5	277.0	27.4	26.5	26.5

TABLE 33 ESTIMATION OF LONG-TERM STEADY YIELD BASED ON AN ASSUMED "LIVE" STORAGE OF 39.5 mm (HARD-ROCK PLUS ALLUVIUM) AND RECHARGE PERCENTAGES RAINFALL EXCEEDING 9.9 AND 14.9 mm/DAY

Season : October - September
A Rainfall exceeding 9.9 mm/day
B Recharge mm (see table 31)
C_1 End of season storage with steady abstraction of 9.5 mm/annum
C_2 End of season storage with steady abstraction of 17.7 mm/annum - period 1973/74 to 1988/89 only
D Rainfall exceeding 14.9 mm/day
E Recharge mm (see table 31)
F_1 End of season storage with steady abstraction of 8.2 mm/annum
F_2 End of season storage with steady abstraction of 16.4 mm/annum - period 1973/74 to 1988/89 only.

Season	A	B	C_1	C_2	D	E	F_1	F_2
1913-14	152.9	9.6	5.6		131.3	9.6	5.8	
14-15	85.6	3.9	0.0		43.2	2.4	0.0	
15-16	201.7	14.5	5.0		137.9	10.0	1.8	
16-17	271.7	22.0	17.5		215.9	19.4	13.0	
17-18	282.4	22.9	30.9		251.0	24.8	39.5	
18-19	67.4	3.0	24.4		0.0	0.0	31.3	
1919-20	356.4	35.6	39.5		312.0	33.7	39.5	
20-21	223,8	16.1	39.5		150.0	12.3	39.5	
21-22	94.0	4.3	34.3		79.0	5.1	36.4	
22-23	78.5	3.6	28.4		50.0	3.3	31.5	
23-24	56.2	2.6	21.5		20.1	1.1	24.4	
24-25	363.4	36.3	39.5		282.4	28.0	39.5	
25-26	80.0	3.7	33.7		44.7	2.5	33.8	
26-27	67.5	3.1	27.3		45.2	2.5	28.1	
27-28	164.7	10.4	28.2		114.2	8.2	28.1	
28-29	198.3	12.5	31.2		151.8	12.4	32.3	
29-30	121.1	6.5	28.2		95.7	6.2	30.3	
1930-31	109.7	5.9	24.6		21.6	1.2	23.3	
31-32	177.1	11.2	26.3		148.0	10.8	25.9	
32-33	38.1	1.4	18.2		0.0	0.0	17.8	
33-34	241.7	17.4	27.1		187.1	15.3	24.8	
34-35	265.5	21.5	39.1		242.1	21.8	39.5	
35-36	186.9	11.8	39.5		165.0	13.5	39.5	
36-37	205.8	14.8	39.5		182.0	14.9	39.5	
37-38	181.1	11.4	39.5		156.5	12.8	39.5	
38-39	212.9	15.3	39.5		161.2	13.2	39.5	
1939-40	307.1	27.6	39.5		258.6	25.6	39.5	
40-41	220.2	15.9	39.5		209.1	18.8	39.5	
41-42	136.1	7.3	37.3		122.4	8.9	39.5	
42-43	137.6	7.4	35.2		101.3	7.4	38.7	
43-44	94.9	4.4	30.1		50.5	3.3	33.8	

Table 33 (continued)

Season	A	B	C_1	C_2	D	E	F_1	F_2
44-45	25.2	0.9	21.5		0.0	0.0	25.6	
45-46	125.7	6.8	18.8		68.3	4.4	21.8	
46-47	117.8	6.4	15.7		107.1	7.8	21.4	
47-48	277.1	22.4	28.6		208.4	18.8	32.0	
48-49	53.3	2.5	21.6		14.2	0.8	24.6	
1949-50	194.5	12.3	24.4		116.6	8.5	24.9	
50-51	74.9	3.4	18.3		21.1	1.2	17.9	
51-52	118.5	6.4	15.2		66.8	4.3	14.0	
52-53	31	1.2	6.9		21.0	1.2	7.0	
53-54	171.0	10.8	8.2		138.5	10.1	8.9	
54-55	139.0	7.5	6.2		93.5	6.1	6.8	
55-56	59.5	2.7	-0.6		16.0	0.9	-0.4	
56-57	237.8	17.1	7.0		17.6	14.4	5.8	
57-58	147.5	8.0	5.5		138.0	10.1	7.7	
58-59	311.5	28.0	25.0		252.0	24.9	24.4	
1959-60	162.5	10.2	25.7		262.5	13.3	29.5	
60-61	255.2	20.7	37.9		221.7	20.0	39.5	
61-62	65.0	2.9	31.3		29.0	1.6	32.9	
62-63	318.0	28.6	39.5		252.0	24.9	39.5	
63-64	169.0	10.6	39.5		74.5	4.8	36.1	
64-65	254.5	20.6	39.5		198.5	16.3	39.5	
65-66	132.1	7.1	37.1		71.0	4,6	36.3	
66-67	335.0	30.1	39.5		279.5	27.7	39.5	
67-68	214.5	15.4	39.5		180.5	14.8	39.5	
68-69	170.5	10.7	39.5		170.5	14.0	39.5	
1969-70	195.3	12.3	39.5		128.3	9.4	39.5	
70-71	107.5	5.8	35.8		47.0	2.6	33.9	
71-72	178.6	11.3	37.6		144.1	10.5	36.2	
72-73	158.1	10.0	38.1		148.1	10.8	38.8	
73-74	656.4	100.4?	39.5	39.5	561.4	85.9?	39.5	39.5
74-75	170.1	10.7	39.5	32.5	122.0	8.9	39.5	32.0
75-76	576.7	77.9?	39.5	39.5	519.4	74.7?	39.5	39.5
76-77	248.7	17.9	39.5	39.5	217.6	19.6	39.5	39.5
77-78	215.5	15.5	39.5	37.3	158.4	12.8	39.5	35.9
78-79	170.3	10.7	39.5	30.3	170.3	13.8	39.5	33.3
1979-80	158.6	10.0	39.5	22.6	123.7	8.9	39.5	25.8
80-81	310.1	27.9	39.5	32.8	254.3	25.2	39.5	34.6
81-82	184.2	11.6	39.5	26.7	132.3	9.5	39.5	27.7
82-83	197.0	12.4	39.5	21.4	131.4	9.5	39.5	20.8
83-84	219.1	15.8	39.5	19.5	164.5	13.3	39.5	17.7
84-85	169.7	10.7	39.5	12.5	120.8	8.7	39.5	10.0
85-86	197.1	12.4	39.5	7.2	151.8	12.3	39.5	5.9
86-87	171.0	10.8	39.5	0.3	145.4	10.5	39.5	0.0
87-88	498.0	58.3?	39.5	39.5	417.4	52.6?	39.5	39.5
88-89	326.6	23.5	39.5	39.5	277.0	27.4	39.5	39.5

TABLE 36 LOCATION OF GROUND-WATER UNITS IN QUINARY DRAINAGE REGIONS
(see folders 1A and 22)

Ground-water Unit	Quinary catchment
I	D603/5
II	D603/5
III	D603/5
IV	D603/5
VA	D603/5
VB	D603/5
VI	D603/6
VII	D603/6
VIIIA	D603/6
VIIIB	D603/6
IX	D603/4
X	D603/4
XI	D603/3
XII	D603/3
XIIIA	D603/8
XIIIB	D603/8
XIVA	D603/8
XIVB	D603/10
XV	D603/7
XVIA	D603/7
XVIB	D603/7
XVII	D603/9
XVIIIA	D603/9
XVIIIB	D603/9
XIX	D603/9, D603/10
XX	D603/2
XXIA	D603/10
XXIB	D603/2
XXIC	D603/12
XXII	D603/1, D603/12
XXIIIA	D603/11
XXIIIB	D603/11
XXIIIC	D603/11

GH VERSLAG ROTERING

TITEL De Aar's Ground-Water Supply: A Digest of the Past and an Outlook for the Future .... GH 3775

OUTEUR J. R. Vegter .... Datum June 1992

DATUM ONTVANG DEUR DOELWITLEIER ....

DATUM ONTVANG DEUR ADJUNK-DIREKTEUR ....

VERSLAGBESKIKBAARSTELLING
(Slegs vir interne gebruik/vir beskikbaarstelling na buite
(skraap wat nie van toepassing is nie)

VERSPREIDINGSLYS

Die volgende persone/instansies moet van 'n kopie van die verslag voorsien word.

...... Mnr. J. R. Vegter
...... Mnr. Z.M. Dziembowski
...... Beplanning en Munisipaliteit
...... Prof. Kirchner - GIS
...... E. v. Wyk - Kuruman
...... P. Seward - Kaapstad
...... 2 - Inligting (Geo)
....
....
....

ADJUNK-DIREKTEUR HANDTEKENING ....

DATUM ....

VERSLAG ONTVANG DEUR SEKSIE INLIGTING ....

VERSLAG VERSPREI ..... L Cronje