Detailed Geohydrological Investigations in the Poesjesnels River Catchment in the Breede River Valley with Special Reference to Mineralization.

Final Report to the Water Research Commission.

August 1990

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EXECUTIVE SUMMARY

DETAILED GEOHYDROLOGICAL INVESTIGATION IN THE POESJESNELS RIVER CATCHMENT IN THE BREEDE RIVER VALLEY WITH SPECIAL REFERENCE TO MINERALIZATION

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AIMS AND OBJECTIVES

The aims of the project were to:

1. determine the factors contributing to the mineralisation of South African rivers and the development of methods to alleviate it;

2. provide data for use in mathematical models to describe geohydrological and mineralisation patterns of the river systems under various operating and irrigation conditions;

3. reduce the dilution water demand on Brandvlei Dam by developing alternative irrigation and management strategies to keep salt concentrations in the river to a minimum.

4. provide the Department of Water Affairs, the Department of Agriculture, the local farming community and other interested parties with a suitable guideline for the purposeful control of mineralisation processes.

DETAILED GEOHYDROLOGICAL INVESTIGATION IN THE POESJESNELS RIVER CATCHMENT IN THE BREEDE RIVER VALLEY WITH SPECIAL REFERENCE TO MINERALIZATION

Section 1: The research emphasis is placed on:

1. determining the salinity potential of the soil and bedrock in the catchment.

2. gaining an understanding of the movement of groundwater.

3. presentation of data for a mathematical model of the catchment.

The water in the Breë River has been deteriorating over the past twenty years, and measurements have shown that tributaries such as the Poesjesnels River contribute increasingly heavy salt loads to this important Western Cape river as more areas are developed for irrigation in these catchments. This project was initiated to investigate the origin and movement of the salt, and to provide data for a model which is needed to control the whole Breë River irrigation system. Soil analyses by Dr. J.H. Moolman indicated a load of salt at 1 metre depth over much of the Poesjesnels River valley(1979), and water analyses by Dr. J.M. Fourie indicated high salt loads in the Poesjesnels River during summer months, causing damage to crops irrigated with Breë River canal water at Bonnievale. Previous borehole surveys indicated that the Bokkeveld shale formations contained a large amount of salt and produced mineralized groundwater.

The modelling concept is explained, with a view to the implementation of a hydrological working model for the Breë River valley and its tributaries so that future irrigation needs and return flow volumes may be effectively managed.

Section 2:

The geology, physiography and rainfall of the catchment are presented, so that the annual precipitation on the two major rock types i.e. shale and sandstone may be distinguished.

The annual rainfall volume averages are:

sandstone mountains - 50.87 million cubic metres
shale valley areas - 32.89 million cubic metres.

Evaporation figures for the valley are high, reaching 10 mm per day during summer.

Whole rock chemical analyses indicated that higher K_2O and Al_2O_3 content occurs in the black (carboniferous) micaceous shale, but no chloride values could be determined by the XRF technique. The marine origin of the sediments is proved by the minor or trace element content, and a correlation between sulphur and pyrite was established.

Section 3:

The total area under irrigation in the valley amounted to 1794.29 hectares; this has recently grown to 1820 hectares due to new development on the western side of the farm DE WILGEN and the adjacent eastern side of the farm WEL VAN PAS by the owner, Mr Wouter De Wet. (Section 7.2, p 146)

The average irrigation volume applied to the whole catchment amounts to ± 13 million cubic metres per annum, generally concentrated over an 8 month period (September to April.)

The total amount of water introduced by the Le Chasseur canal from the Brandvlei Dam amounts to 6.78 million cubic metres per annum according to figures supplied by the farmers.

The total input of water to the catchment from all sources amounts to 90.45 million cubic metres; only one tenth of this water i.e. 9.4 million cubic metres has been estimated to flow out of the catchment (Hasenjager, 1980) lending support to the high evapotranspiration figures.

Section 4:

The river sampling and analysis indicated a strong increase in salt load as the river flowed into the central part of the valley between sampling stations 15 and 34. The pH also rises from acidic to alkaline conditions and calcrete is precipitated in central valley soils. The southern tributaries (Rietvlei and Mosiesleegte rivers) brought in

heavy salt loads, mainly in the form of irrigation return flow seepage with salinities as high as 3 000 and 7 000 mg/l respectively.

Seasonally, an inverse relationship between flow and salinity was established, with salinity rising as flow diminishes after the winter months.

During the summer months (December - January) extensive irrigation on well established vineyards on alluvial soils at Le Chasseur produces a good quality return flow which restrains the trend of rising salinity to some degree.

The flow measuring device at H4M18 (Le Chasseur bridge) indicated an annual average of ± 8 million cubic metres, 1.4 million lower than the figure calculated by Hasenjager. According to the work by Flügel (1989), some water may be lost from the catchment through faults and fractures. He calculated the flow of groundwater through fractures into the Breë River to be 9.91 m^3/s along a 58 km stretch of the river. This amounts to 99.5% of the groundwater inflow while the other 0.5% flows in laterally through sandy alluvium (Flügel, 1989). A unit inflow of 0.085 m^3/s per kilometre of single riverbank was determined.

Based on daily average flow and conductivity, the average annual salt load passing the H4M18 measuring station at the lower end of the Poesjesnels River was calculated at 7674 tons.

A salt load model based on all possible increments contributing to this tonnage leads to an understanding of the salt contributed to the Poesjesnels River annually by inflow of groundwater, i.e. 609 tons and 203 000 m^3 respectively.

Based on the values used in the model, the annual rainfall together with the water applied to irrigated Bokkeveld shale soils releases 344.25 grams of salt per cubic metre, while irrigated alluvial soils produce only 77.16 grams per cubic metre. Leaching tests in Section 6 confirm that much heavier loads of salt are actually available in these materials, but the natural leaching process takes place more gradually over many years.

Principal component chemistry of the river water varies as follows: $NaCl > MgSO_4 > CaHCO_3$. There is also a seasonal change in the ionic character of the water, with

the ratio of NaCl : Mg/Ca + SO_4/HCO_3 increasing during winter and decreasing during summer.

Section 5:

Six areas were selected for the drilling of groups of boreholes to examine the lithology and groundwater of the valley. Geophysical logging and pumping tests were carried out. Groundwater salinity in most cases tended to increase with depth, especially where low permeability was encountered in black shales.

Transmissivity calculated on less than ideal borehole spacings amounted to 62 m^2/day. (An aquifer thickness of 62 metres is assumed because fractures and open joints occur to at least such a depth below the GWT in the bedrock). A storativity of 1.3×10^{-3} was also determined.

Section 6:

Leaching experiments on fresh and decomposed bedrock materials are described. Salinity as high as 5658 mg/l was encountered in leachates from some shallow auger borehole samples at the transition from soil to decomposed shale or clay.

Leaching of crushed diamond drill cores indicated that sericitic black shale contained more adsorbed salt than sandstone layers.

Oxidation of pyrite from percussion borehole cuttings produced some high salinities, indicating the very active chemical nature of the sediments, e.g. 4389 mg/l at a depth of 27 metres in borehole B1f in pyritic micaceous black shale; sandstone on the other hand gave values as low as 143 mg/l at a depth of 9 metres.

Section 7:

Natural leaching of soil materials by irrigation water and rainfall releases considerable loads of salt into drainage lines and the Poesjesnels River.

The average salinity of applied irrigation water is 312.2 mg/l, and that of the return flow seepage is 2965,6 mg/l (i.e. ± 3 000 mg/l.)

Change in the ratios of principal chemical components indicates that more $MgSO_4$ and $CaHCO_3$ are released from the soils of the upper part of the catchment with NaCl predominating in the soils of the lower part of the catchment.

New, deep ploughing development on 25ha of thinner soils overlying Bokkeveld shales allowed for the release of heavy salt loads when subjected to heavy rainfall and irrigation. Increase in salinity in the Mosiesleegte stream as a result of such development followed by 40 mm of rainfall on 27/28 August 1988 on the farm De Wilgen amounted to 7233 mg/l, the TDS of the stream increasing from 420 to 7653 mg/l due to seepage from the developed area. Most of the salt consisted of NaCl. Simultaneously the salinity at the Le Chasseur bridge in the Poesjesnels River rose to its highest level yet measured by project staff, namely 5026 mg/l (The flow was judged to be ± 100 l/s). HRI records show that the TDS on 29 August 1988 was measured at 5 405 mg/l, while the flow gauge registered 82 l/s.

Section 8:

Piper trilinear and Durov rectangular diagrams showed the changing trends of chemical constituents in the various water bodies sampled during the project.

The plots confirmed an increase of NaCl ratio in the river as it flowed through the central and lower reaches of the catchment. Below sampling station 28 the return flow from irrigation on alluvial soils opposed this trend and produced lower NaCl ratios.

Water from artesian boreholes in Bokkeveld bedrock reflected the same chemical characteristics as that flowing in the Poesjesnels River, suggesting that in interchange is taking place between the groundwater in the bedrock and the water in the river.

Plots of the chemical analyses of samples from borehole-piezometers show that the five main borehole groups can be differentiated by their cation and anion ratios, but they all show very high NaCl contents in relation to the other chemical constituents.

Only a few chemical trends with depth could be detected and these were not constant. An increase in Cl^- with depth was found in borehole B1, but a decrease in Na^+. By contrast, Cl^- decreases with depth in boreholes D1 and E1.

Plots of the auger hole leachate analyses show some $CaCO_3$ at surface but a very strong NaCl component in the decomposed layers below the soil. At line H in the upper part of the valley, $MgSO_4$ was found to increase with depth in auger holes near the river. However, hole H1 situated 400 metres from the river gave the same trend of NaCl increase with depth as found in auger holes elsewhere in the valley.

Trilinear plots of leachates from the percussion borehole cuttings and crushed diamond drill core samples all confirm a stronger NaCl concentration in the shallow, decomposed parts of the profile with Ca/Mg SO_4 increasing in the deeper, unaltered bedrock.

Changes in ionic ratios are also visible on trilinear plots of irrigation return flow seepage water, which comes from the leaching out of salts at shallow levels in the soil. $MgSO_4$ predominates in the upper valley soils, $Ca(HCO_3)_2$ in the central part and NaCl in the lower part of the valley, probably due to a long period of leaching out of the latter in the upper valley areas and its adsorption onto clay materials in the downstream areas.

Section 9:

Groundwater table gradients were determined at various borehole transects in the valley; the average gradient for the riverbank areas of the valley works out at 0.0116.

The flow of groundwater reaching the river through the uppermost intersected part of the groundwater table was calculated to be 203 232 m^3 per annum and consists mainly of saline lateral seepage. Additional amounts of low TDS water upwelling along fault zones, will not seriously affect the salt balance model.

Seasonal movements of the GWT in the various boreholes are sluggish in the central part of the valley but clearly visible in boreholes near the foot of the mountains (close to the Bokkeveld/TMS contact), such as at the E1 group and the boreholes on Vredenhof.

Section 10:

Fractures play an important role in the passage of groundwater through the impervious bedrock of Bokkeveld shale in the valley.

Measurements indicated that the main joint direction crosses the valley at right angles to the fold axes and the most important fault lines. They are well situated to allow groundwater migration under pressure from the elevated GWT in the Table Mountain aquifer, eventually welling up into the river from below.

Tracer tests provided evidence of some lateral movement of groundwater through same of the borehole arrays, i.e. 0.046 metres per hour in four boreholes where positive results were found. (If the sites where no movement was detected are brought into reckoning, the average flow rate reduces to 0.0018 metres per hour.)

Along fault zones the rate of groundwater flow will be much greater, but no such zone was intersected by two boreholes which could have been used for a tracer experiment.

Section 11:

Tritium analyses showed old water in the Table Mountain sandstone and younger water in the Bokkeveld shale. (Greeff, 1979)

Oxygen isotope studies revealed that ^{18}O-depleted groundwater exists in the Table Mountain sandstone layers which underlie the Bokkeveld formations in the valley, and that thus type of water is finding its way into the Poesjesnels River, probably by moving upwards along fault zones in the vicinity of the river, under pressure from the hydraulic head of elevated groundwater in the mountainous parts of the catchment.

The volume or flow rate of this water could not be measured or calculated, and its chemistry is unknown.

Although the effect of this ^{18}O depleted water may not be detected during the winter high flow period, its presence in summer is clearly indicated.

CONCLUSIONS

Bearing in mind the aims of the research project (page 3), the following conclusions may be drawn from all the analytical and geological data:

1 Salinity potential of the bedrock formations:

This was the most important requirement of the whole project, given the fact that salinity levels in the Breë River during the summer months when irrigation water is required from the river had risen to very disturbing proportions, and information about a typical tributary draining Bokkeveld shale was required to assist future planning.

Early on, the chemical analyses of water sampled along the full length of the Poesjesnels River gave a clear signal that some heavy mineralization was taking place in the valley. Hydrographs of the flow and salinity clearly indicated that heavy salt loads were being introduced to the water along the middle reaches of the river particularly at the onset of the first rains during autumn. During periods of strong flow after periods of heavy rainfall in winter and spring, the salinities naturally were reduced.

The percussion, diamond-core and auger boreholes which were drilled in the riverbank areas adjacent to the stretches of river with the highest salinity, revealed the distribution of salts in the vertical profile.

Leaching tests on samples of soil obtained from the auger boreholes showed that the uppermost layers were relatively free of salt, but that the materials from depths between 1 on 4 metres contained strong salt accumulations (App. FIGS 6.2 - 6.8.) The alluvial sandy soils tended to have less salt, particularly in the areas where irrigation had been practiced for more than forty years near the Le Chasseur bridge. Clays and decomposed shales encountered below a thin covering of soil a little further from the river contained much greater quantities of salt, for example more than 2 800 mg/l in 1:1 leachates in auger holes B13, C4, D6, more than 3 000 mg/l in auger hole H1 and a value in excess of 4 000 mg/l at a depth of 4 metres in auger hole B11. (1:1 leachate = 1 kg. sample taken up in 1 litre H_2O)

Unfortunately the trend of rising salinity with depth could not be followed effectively because the auger penetration was limited to 4 metres.

Samples from these deeper levels were supplied by diamond core boreholes and percussion boreholes, and leaching tests carried out on them indicated that the fresh, deeper lying bedrock could also release significant amounts of salt; the maximum salinity achieved by 1:1 leaching of crushed diamond core was 799 mg/l from a decomposed shale at a depth of 6.3 metres in borehole D1. Other high values were 741 mg/l from fresh black graphitic shale carrying sericite mica at 22.2 metres in borehole B1 and 734 mg/l from fresh black graphitic silty shale at 51 metres in borehole A1. (p 112)

The leaching of cuttings from percussion boreholes produced higher salinity values, even though material similar to that obtained from diamond core holes was tested. The high values have resulted from the oxidation of pyrite within the shales and the chemical activity which followed (TABLE 6.5A) as well as a high sericite mica content. High values in borehole A1e for example are seen in samples from depths between 2 and 7 metres, in C2 between 4 and 6 metres and in F3 at 5 metres, all within the lower part of the zone of decomposition.

The high values at depths of 20 metres in borehole C2 and at 21 metres in D4 and E1 are clearly related to a prominent black micaceous shale layer.

Taking all the leach tests into account, it appears that most of the chemical activity is concentrated near the surface of the soil, between depths of 1 and 7 metres, in the zone of decomposition, particularly if pyritic micaceous black shale layers are present. However, under natural conditions an equilibrium has been established between rainfall, runoff, infiltration, leaching of salts at the contact between soil and decomposed shale, seepage into natural drainage lines and the precipitation of substances such as calcrete and ferricrete in the soil profile. The salt content of natural seepage entering drainage lines is probably similar to that measured in the Mosiesleegte stream after rainfall in the subcatchment described in Section 7, i.e. 474 mg/l. Further downstream in the main river, prior to irrigation development, salinity was probably higher, possibly reaching 1 000 mg/l during low flow periods, but never as high as values being recorded in the Poesjesnels River at present (5 000 mg/l).

Analytical comparison of applied irrigation water and the return flow appearing in drainage lines gives a very good impression of the difference in salt leaching or mobilization as a result of the development activities by farmers, particularly recent development such as on De Wilgen, where deep ripping of 25 hectares to a depth of 1 metre produced drainage water containing more than 7 grams per litre in a stream which had been carrying less than 1/2 gram per litre only 300 metres further upstream.

The groundwater below this area on De Wilgen, encountered by boreholes A1 and A2 contained ± 4 300 and 5 500 mg/l respectively during the drilling process. Piezometer samples drawn from borehole A2 gave even higher TDS values in excess of 6 000 mg/l. It is therefore not surprising that the accumulation of salt in the decomposed bedrock materials at the top of the profile has produced such highly saline water after its first big rainfall event.

Other irrigation areas do not produce return flows with quite such high salinities; TABLE 7.3 shows that eight of the ten areas tested produce return flow with TDS between 871.6 and 2974 mg/l; the average TDS of return flow for all ten areas tested works out at 2965.6 mg/l.

2 Groundwater table and groundwater movement

Too few boreholes were available in the valley for the construction of a good groundwater contour map, but the borehole traverse lines running at right angles to the river made it possible to determine a groundwater table gradient of 0.0116. Together with a transmissivity figure of 62 m^2/day this value was used to calculate a flow of 203 232 m^3 of groundwater at an average TDS of 3 000 mg/l into a 16 km length of the river.

This figure of 3 000 mg/l for groundwater is a reasonable estimate, not only because of the TDS of irrigation return flow, but also if the salinity of water drawn from borehole piezometers is taken into account:

Borehole	Lowest TDS mg/l	Highest TDS mg/l	Pumpage yield l/s
A1	3 502	7 776	13
B1	1 535	3 288	14
C2	7 209	9 325	12.5
D1	1 951	2 970	7.2
E1	3 709	4 748	12

Boreholes not fitted with piezometers, but sampled during drilling:

Borehole	Lowest TDS mg/l	Highest TDS mg/l	Pumpage yield l/s
A1	4 247	4 515	4
B2	3 478	5 740	23.5
B4	2 196	2 844	4.4
B5	-	3 540	17.5
C1	6 174	7 660	4.4
D2	1 083	2 145	3.5
D4	4 389	4 779	-

The artesian water encountered at B2 and B4 confirms the fact that groundwater is under pressure in the central part of the valley; the TDS of this artesian water is very high, namely ± 5 800 mg/l (B2) and ± 2 700 mg/l (B4), indicating long migration paths through Bokkeveld shales and siltstones, during which extended leaching occurred.

Tracer tests produced results which indicated a very low average flow rate for groundwater through the Bokkeveld shale, i.e. 0.0018 metres per hour. At the four positive test sites where the tracers were identified in monitor holes by virtue of some joints or fractures linking them to the injection borehole, an average groundwater migration rate of 0.046 metres per hour was determined; even this is a very slow rate of movement, but it does give a figure to work with.

The average yield of the boreholes which were used in the tracer tests is 12 l/s or 43.2 m^3/h.

If the total area of the open joints through which fracture flow takes place across a given cross section of bedrock can be determined, another approach can be made to finding the volume of groundwater entering the river laterally and from below.

Many of the siltstone outcrop areas showed a pattern of joints cutting across the valley, with an average of 2 open vertical joints per metre (App. FIG 2.5c). Given that each joint is 0.25 mm wide, this gives a total area of openings of 2 metres x 0.25 mm = 500 mm^2 or 0.0005 m^2 for every vertical square metre of bedrock.

Using a GW migration rate half way between 0.0018 m/h and 0.046 m/h, ie 0.0239 m/h, a volume of flow through each square metre of rock can be calculted by multiplying the area of the openings by this migration rate,

i.e. 0.0005 x 0.0239 = .0000 1195 m^3/h.

Across a valley length of 16 km, and assuming that only 100 metres of aquifer depth is involved, we find the following volume of flow:

= 16 000 m x 100 m x .0000 1195 m^3/h
= 19.12 m^3/h
= 458.88 m^3/day
= <u>167 491.2</u> m^3 per annum

The less elevated northern watershed which consists mainly of Bokkeveld formations is not able to transmit the same volume of groundwater to the central valley bedrock. If the abovementioned flow is cut by half, i.e. 83 745.6 m^3 per annum, both valley sides would together produce 251 236.8 m^3 of groundwater flow according to this model. (Any excess figure determined in Section 9 (page 179) would constitute deep

percolation of low TDS water from the underlying TMS along faults.) A depth of 100 m for an aquifer of this nature is also very conservative, as open fractures were encountered at that depth in some of the boreholes. One should probably calculate down to 300 metres, but the flow will diminish with increasing depth.

The ^{18}O isotope studies gave clear evidence that movement of groundwater is taking place at deeper levels in the valley, and that groundwater from the Table Mountain sandstone layers eventually finds it's way into the Poesjesnels River, probably by way of the main fault zones. The ^{3}H content of the artesian boreholes B2 and B4 indicate water which is older than that usually encountered in the Bokkeveld bedrock, and is suggestive of some input from the underlying TMS. However, the ^{18}O content of this artesian water is not particularly depleted and it cannot therefore be directly linked to the underlying strongly depleted TMS groundwater, unless a mixing process can be proved. (The TDS content of B2 and B4 is very high.)

3 Alluvial salt concentrations

Although the main emphasis was placed on an examination of the bedrock formations, a number of shallow auger boreholes were sunk into alluvial sand and/or gravel during the course of the project, and some areas of high salinity were found (i.e. > 1 000 mg/l) These are the following:

Borehole	Leachate TDS mg/l	Depth m.
B9	1 844	2.4
B10	3 087	0.4
B11	5 658	1.0
B11	5 557	2.8
D6	2 974	1.0
F6	2 690	2.0
H1	3 557	1.8
H3	1 984	0.6
H4	1 145	0.2

Most of these areas lie below irrigated fields and therefore receive some irrigation return flow seepage. F6 is an exception, and has probably received its salinity from natural runoff draining a terrace slope cut into decomposed shale and topped by thin Bokkeveld soil in the vicinity of position F4. (App. FIG 6.8) Evapotranspiration in low lying areas without effective drainage naturally increases the salt buildup in these soils, but their effects are rather localized and do not pose the same threat as the decomposed shale salt reservoirs.

The leachates from the alluvial samples taken near the Le Chasseur bridge (P1 - P6) showed very little salinity, and bear testimony to the effective drainage and application of low TDS irrigation water in this well developed area.

4 Soil characteristics at levels deeper than 1.5 metres have indeed been studied and analyzed by means of auger, percussion and diamond core-drill boreholes and leaching tests, and are presented in many figures and sections.

5 The data from this project are hereby submitted for integration into mathematical models for the Breë River catchments and for calibration and testing of such models by modellers of the Department of Agriculture and Fisheries, the HRI the WRC and the CSIR.

We trust that they will be of much use for future planning.

RECOMMENDATIONS

1 A deep borehole (± 500 m) should be drilled down into one of the fault zones and sampled at its maximum depth by means of a sealed off packer, to test the possible upwelling of TMS water.

2 A time series of water sampling of seepage in a drainage stream below untouched veld should be carried out on an hourly basis during a heavy rainfall event in the catchment, and continued until all water has disappeared from the stream. Ripping should then be carried out to different depths over accurately measured areas alongside the drainage stream, and a second set of hourly sampling of seepage carried out following subsequent rainfall events. Analyses of the flow in the stream and the chemistry of the samples will give clearer indication of the release of salts per hectare following agricultural development.

3 The volume of high quality water stored in the Sandstone mountain watershed and its exploitation by means of horizontal boreholes should be assessed, as such water could be added to irrigation canals in the catchment. The untapped potential of very high quality water within the Table Mountain sandstone must be explored. Some vertical boreholes have been sunk into sandstone in the area, and yields in excess of $10m^3$ per hour realized. Having seen what Prof. Issar has achieved with horizontal adits into sandstone in Israel, and remembering the enormous flows of water encountered in the tunnels put through the Cape mountains for the Theewaterskloof scheme and the Huguenot Road Tunnel, we should consider at least an attempt to drive horizontal boreholes into the sandstone with a view to intersecting vertical or subvertical brecciated fault zones (such as the one exploited at DJB) at depths not greater than 200 metres. The high quality water so produced, could be used for low-TDS irrigation as well as dilution of return flow runoff and beneficiation of the Breë River water quality.

Ten boreholes in a valley such as the Poesjesnels, intersecting a number of fault zones along their length, could then flow under their own piezometric pressure at 20 to 25 m^3 per hour, giving a total of ± 150 000 m^3 per month. This could be allowed to flow in summer and sealed off during winter for recharge.

4 Uncontrolled development of new irrigation areas which entail the deep ripping of thin Bokkeveld soils must be restricted if the salinity levels in the catchment drainage are to be kept within present limits, which are already putting pressure on the Brandvlei - Kwaggaskloof water supply system.

5 A high level canal would open up large new areas for irrigation and agricultural production, and the Breë River would have to become the drainage for all the irrigation return flow.

Statistics of
Capital Equip + A/F/R.
Extract from Enclosures.

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DETAILED GEOHYDROLOGICAL INVESTIGATIONS IN THE POESJESNELS RIVER CATCHMENT, BREë RIVER VALLEY, WITH SPECIAL REFERENCE TO MINERALIZATION.

1. INTRODUCTION

This report presents the results of a program of research carried out between 1983 and 1986 with intensive data processing during 1987, to determine the origin and movement of salts in the soil profile and bedrock of a typical valley in the South Western Cape namely the Poesjesnels River, a tributary of the Breë River. The report is presented in two volumes: the first contains the main body of research results in A4 format, while the second contains photographic prints, maps and diagrams as an Appendix in A3 format. Figures referred to in the text of Volume I have the preface "App." to indicate that they are to be found in Volume II.

The Breë River valley constitutes an important agricultural region of the Cape, and a large part is cultivated under irrigation from the Brandvlei Dam. The valley extends from the Tulbach-Wolseley area in a south-easterly direction to the Indian Ocean at Witsand (St. Sebastian's Bay), and includes the Worcester, Robertson, Bonnievale and Swellendam districts.

The work was initiated and financed by the Water Research Commission, and forms part of a much larger research effort involving the Commission, the Council for Scientific and Industrial Research, the Department of Agriculture and the Department of Water Affairs, with a view to providing data for a mathematical model which would assist the planning of irrigation development and the control of saline return flow in the Breë River valley and similar areas in South Africa. The need for an operational hydrological model to control irrigation arose when salinity levels in the Breë River showed a sharp increase in the 1960's and 1970's particularly in parts of the river upstream from canals such as the Robertson, Angora and Sanddrift which serve the Klaasvoogds and Bonnievale agricultural areas. (Fig. 1.1)
Increased salinity has prompted similar research along the Berg River, the Orange-Fish-Sundays River Scheme and at the Vaal-Hartz scheme.

The following aims were proposed for the research program, and accepted by the WRC:

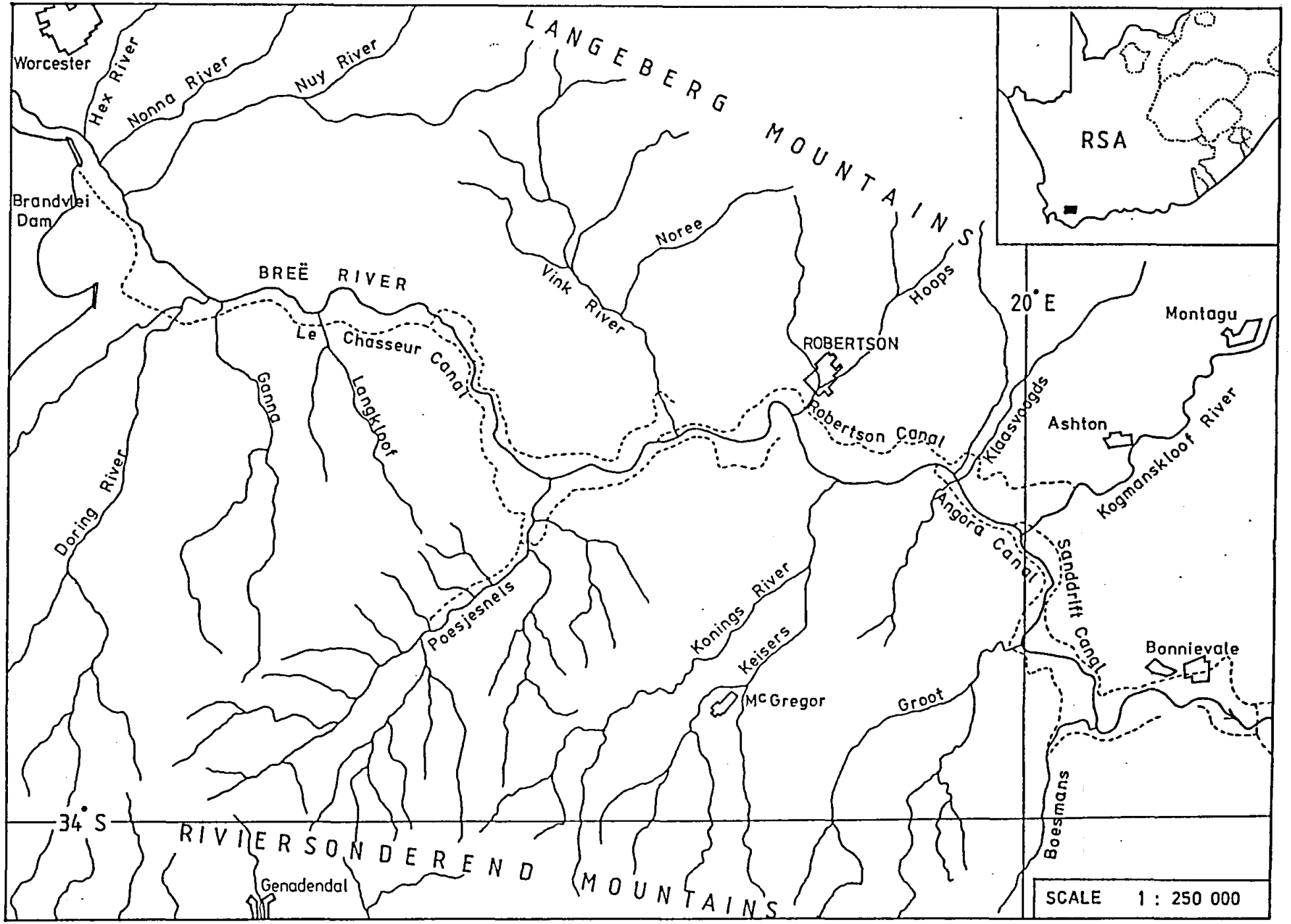

FIG. 1.1 The Rivers and Canals of the Breë River Valley between Worcester and Bonnievale.

1. Determination of the salinity potential of the bedrock formations along 5 selected profiles in the Poesjesnels River Valley; these profiles were to extend from the alluvial deposits alongside the river channel to the thinner soils of the more elevated valley sides. (The profiles were planned to investigate undisturbed as well as cultivated areas of the catchment.)

2. Determination of the groundwater table and migration speed of groundwater through the different formations in the valley, along the 5 profiles.

3. Determination of the position and relative importance of alluvial salt concentrations in contrast to deepseated sources through which groundwater percolates before reaching the river channel.

4. Determination of the soil characteristics at depths greater than 1.5 metres along the profiles, particularly where an impervious barrier exists below irrigated areas, and tests to assess the mobilization of salts.

5. Integration of results and conclusions from abovementioned work with the mathematical modelling program of the Poesjesnels River Catchment as implemented by the Department of Agriculture and Fisheries (Moolman en Weber, 1979).

These research objectives were submitted after:

1. An initial survey of the chemical and isotopic nature of the water from most of the boreholes in the central part of the Breë River catchment between the Brandvlei Dam and Robertson had been carried out between 1977 and 1979. (G.J. Greeff 1978 and 1979).

2. Valuable discussions and thought provoking questions were considered at the Workshop on Understanding Mineralization Processes held in Pretoria in August 1980, under the auspices of the National Institute for Water Research of the C.S.I.R.

(The papers read at this workshop by eminent water scientists such as Prof. Joel Gat of the Weizmann Institute of Science served both to inspire further research

and to give valuable guidance for addressing the complexities of the mineralization and admixture of surface and groundwater, particularly as this affects the Breë River.)

A Steering Committee was appointed to guide the research work and assist the project leadership. This committee consisted of:

Mr. H.C. Chapman	Water Research Commission (Chairman)
Mr. G. R. Botha	National Institute for Water Research
Mr. E. Braune	Hydrological Research Institute
Mr. H.M. du Plessis	Soils and Irrigation Research Institute
Dr. A.H.M. Görgens	Ninham Shand Inc., Cape Town
Dr. G.C. Green	Water Research Commission
Mr. G.J. Greeff	Stellenbosch University
Prof. I.W. Hälbich	Stellenbosch University
Prof. L. Hiemstra	Stellenbosch University
Dr. J.L. Hutson	Soils and Irrigation Research Institute
Mr. J.G. Kriel	Breë River Water Conservation Board
Mr. H. Maaren	Hydrological Research Institute
Dr. J.H. Moolman	Stellenbosch University
Dr. P.J.T. Roberts	Water Research Commission
Mr. J.R. Vegter	Department of Water Affairs
Mr. P. W. Weideman	Water Research Commission (Committee Secretary)

Without the experience and guidance of these eminent scientists it would not have been possible to tackle and complete the project; the value of their advice, constructive criticism and encouragement cannot be overemphasized.

In the years preceding the commencement of the project, officials of the Department of Water Affairs, the CSIR and Irrigation Boards had been monitoring the salinity levels in the Breë River and irrigation return flow drainage lines; they reported that during the period 1970 to 1979 steadily increasing volumes of saline return flow were entering the river. This increase of salinity seemed to be taking place concomitant with the development of new irrigation areas (orchards and vineyards) on thinner, shaly soils upslope from the previously developed areas on alluvial riverbank soils. This increased return flow naturally increased the salinity of the water in the Breë River and its canals, resulting in a critical situation during hot summers when farmers in the Bonnievale area found

that many of their crops, including lucerne, showed signs of distress, and some areas had died. (Fourie, 1977 p. 47)

The water inspector at Bonnievale confirmed that during 1979 - 1980:

1. Mr. P. Zaaiman of the farm TEVERA had lost large patches of lucerne;

2. Mr. F. Matthee of MERWESPONT had suffered damage of R10 000 to a plantation of newly grafted vine cuttings;

3. Mr. L. van der Merwe of MERWESPONT had suffered extensive loss of leaves on his vines after overhead irrigation.

In all three abovementioned cases, the salinity levels in the water from the Sanddrift Canal had increased to ± 400 mg/l. (Mr. J.H. Fabricius, pers. comm. 1988)

As an immediate response to this serious situation, an additional large volume of high quality water was released from the Brandvlei Dam to reduce the salinity. (This procedure is being followed every year during the summer months.) A program of daily sampling and analysis in the Breë River and its tributaries was started, and by 30th October 1980 Dr. J.M. Fourie of the CSIR Water Laboratory in Bellville was able to report to the seventh meeting of the Task Group for Mineralization of Water in the Western Cape: "Lacking suitable weirs, the Breë River has been sampled on a daily basis since August 1975 at five points along the irrigation area supplied with water from the Brandvlei Dam. Daily sampling has also been carried out at the weir on the Sonder-End River just before its confluence with the Breë River, and at the weir on the Breë River at Swellendam. In 1978 this program was extended to include the following tributaries: Hex, Nuy and Poesjesnels and in 1980, the Vink. (Fig. 1.1)
.....along the Breë River conditions are typical of those to be expected along a river serving an extensive irrigation area. Winter flows are generally of good quality, excepting during the very dry winter of 1978, as they are largely derived from high quality run-off from TMS watersheds. Summer flows are extensively mineralized by irrigation return flow to the river.
.....Wide fluctuations in quality can occur over very short time intervals along the river, and experience has shown that such variations are associated with rainfall

accompanied by an increase in flow volume. The general pattern along a major river is an initial rise in salinity associated with the arrival of saline run-off from adjacent sources, followed by a marked drop in salinity due to the arrival of large volumes of low-saline run-off from its upper reaches. In tributaries the saline peak has a shorter duration."

The salinity levels at the lower ends of a number of tributaries of the Breë River were measured by Dr. Fourie, and on the strength of these results a particular valley, the Poesjesnels, was selected for further, more detailed analysis.

The first analytical research work in this catchment was done by Dr. J.H. Moolman of the Department of Soil Science at the University of Stellenbosch. In 1978-1979 he carried out a thorough soil survey and chemical analyses, which showed that alluvial sandy soil alongside the river, particularly where irrigation has been practiced for 40 years or more, carried little salt while shallower soils overlying clay and shale upslope from the alluvial strip along the river had a much greater salt content.

At the same time the writer carried out a borehole survey of the Breë River valley and all its tributary valleys between the Brandvlei Dam and Robertson to determine which, if any, of the bedrock formations carry deep-seated saline groundwater which could contribute to the mineralization of the tributaries and eventually the Breë River itself. Borehole samples were analyzed for principal chemical components, and samples were also sent to the Nuclear Research Institute for Tritium analysis to determine the ages of different bodies of groundwater. The results of this work showed that the Bokkeveld Shale Formation produced highly saline water, and that many of the boreholes that have been sunk are unsuitable for irrigation. (G.J. Greeff, 1978).

Strong folding and faulting of crustal rocks prior to the plate movements which led to the breakup of Gondwanaland (A.L. du Toit, 1954) followed by uplift and erosion, have resulted in the prominent fold-mountain ranges of the South Western Cape. Sandstone formations of the Table Mountain Group are exposed along anticlinal ridges and softer shale formations of the Bokkeveld Group are generally preserved along synclinal or down-faulted valleys. (App. FIG 2.4) The Poesjesnels River valley is one such fault controlled valley, and as measurements of river and soil salinities had already been taken here since the early 1970's the

Water Research Commission selected this valley for an intensive geohydrological study, the results of which are to be used in the development of an irrigation return flow model as part of a full hydrological model for the Breë River catchment.

Such mathematical models have been used for more than two decades in various parts of the world to manage water resource systems and to predict how changes within the system would affect important parameters such as runoff, salinity and agricultural development. The following background to the application of modeling techniques was given at the 1975 Seminar on the Colorado River Basin, Modeling Studies: "The problems of managing water resource systems are basically those of decision making based upon considerations of the physical, biological, economic, sociological and other processes involved. These processes are strongly interrelated and constitute a dynamic and continuous system. Any combination of these interrelated system variables yields a management solution. In essence, the model is intended to reproduce the behaviour of the important system variables of the prototype under study.

Once a prototype system is identified, the various processes in the system may be represented by either physical or mathematical models, the latter consisting either of simulation or programming.

Simulation is an attempt to represent as realistically as possible, the processes of the real world; mathematical programming is an optimizing procedure whereby a solution is sought in terms of a specific objective function frequently requiring considerable simplification of the real system.

For complex systems such as those encountered in water resource management, mathematical simulation often proves to be the only feasible tool for predicting the system behaviour. Mathematical simulation is achieved by using algebraic relationships to represent the various processes and functions of the prototype systems, and by linking these equations into a systems model.

Hopefully, simulation models have three basic properties: realism, precision and generality. Thus, computer simulation is basically a technique of analysis whereby a model is developed for investigating the behaviour or performance of a dynamic prototype system subject to particular constraints and input functions. The model

behaves like the prototype system with regard to certain selected variables, and can be used to predict probable responses when some of the system parameters or input functions are altered.

It is possible to employ either stochastic or deterministic techniques, or various combinations of both, in the representation of a system. The approach which is adopted is dependent upon a number of conditions including availability of information about the system, and the kinds of problems which the model is required to solve. The predictive power of the model within the system response space will usually vary with the degree to which the model is stochastic or deterministic." (Riley, 1976).

In his paper, this writer goes on to explain the advantages of simulation modeling and the process by which such a model is developed i.e. the expression of verbal symbols into mathematical ones for use in a computer program by means of a stepping stone in the form of a conceptual model based on known information and hypotheses concerning the various elements of the system. The conceptual model with its real world data is then translated into mathematical form for computer programming and thus becomes a working model. As more data are gathered from the system, the conceptual and the working model are improved. South African hydrologists, engineers and agronomists have examined a number of such models and tested them under local conditions with a view to predictive applications to some of our water resource development problems such as water supply, rainfall runoff, infiltration, irrigation return flow and river salinity.

The work done by Pitman (1973, 1976), Herold (1980), Moolman and Beukes (1980), Hall, du Plessis and Hutson (1980), Moolman (1982), Görgens (1983) Flemming (1984), Roberts (1984) Schulze (1984, 1986) Hughes and Herold (1987), Pitman and McKenzie (1987) and Schultz (1987) is of particular note and has made a valuable contribution to our understanding of the complex hydrological processes active in catchments and irrigated areas, even though many of the models are still being calibrated and tested to greater refinement. Management alternatives and predictions have already been produced by some of the models.

In their development of the FLOSAL model for river flow and salinity, Hall and du Plessis (1984) show how the characteristics of semi-arid South African

catchments call for adjustment of some of the American model assumptions and structures (section 4.3 p 60 - 72). They have leaned strongly on the work by Thomas et al. (1971), Pitman (1973, 1976), Schaffer (1976), Hall and Görgens (1979) and Herold (1980, 1981) in their choice of a model type for:

(i) catchment runoff and salinity,
(ii) irrigation return flow,
(iii) simulation of river flow manipulations.

They clearly explain the main functions of the various subroutines; groundwater discharge is simulated in the subroutine CATCH, while runoff and salt transport are simulated by the closely associated subroutines HYDRO and RETFLO (p 75 - 81). A formula for the groundwater storage balance is then derived (5.18 on p. 107). Care is also taken to show the difference in the parameters for the monthly and daily time-base models $FLOSAL_m$ and $FLOSAL_d$

The FLOSAL model was then calibrated on flow and salinity data from measuring stations in both the Sundays River and the Great Fish River catchments, so that planning options and operational rules for the system could be tested.

The inclusion of the THOMAS subroutine which predicts chemical changes in the system is particularly useful because six ionic species are handled simultaneously together with the TDS. (RETFLO simulates loads for only one constituent at a time). The same ions were monitored during the Poesjesnels River examination.

With the construction during 1980 of measuring station H4M18 below the bridge over the lower end of the Poesjesnels River at Le Chasseur (See App. Fig. 2.2a Photo 3 and App. Fig. 2.2d Photo 4), the daily salinity and flow rate of the river could be accurately measured (when the intakes and registering devices had been properly serviced), the total salt load produced by the catchment could be determined and previous estimates (Fig. 1.2) could be corrected.

Dr. Moolman completed his Ph D studies on irrigation return flow in the Poesjesnels River catchment before the measuring station was constructed (Moolman, 1982). In follow-up work he planned to use the flow and quality data

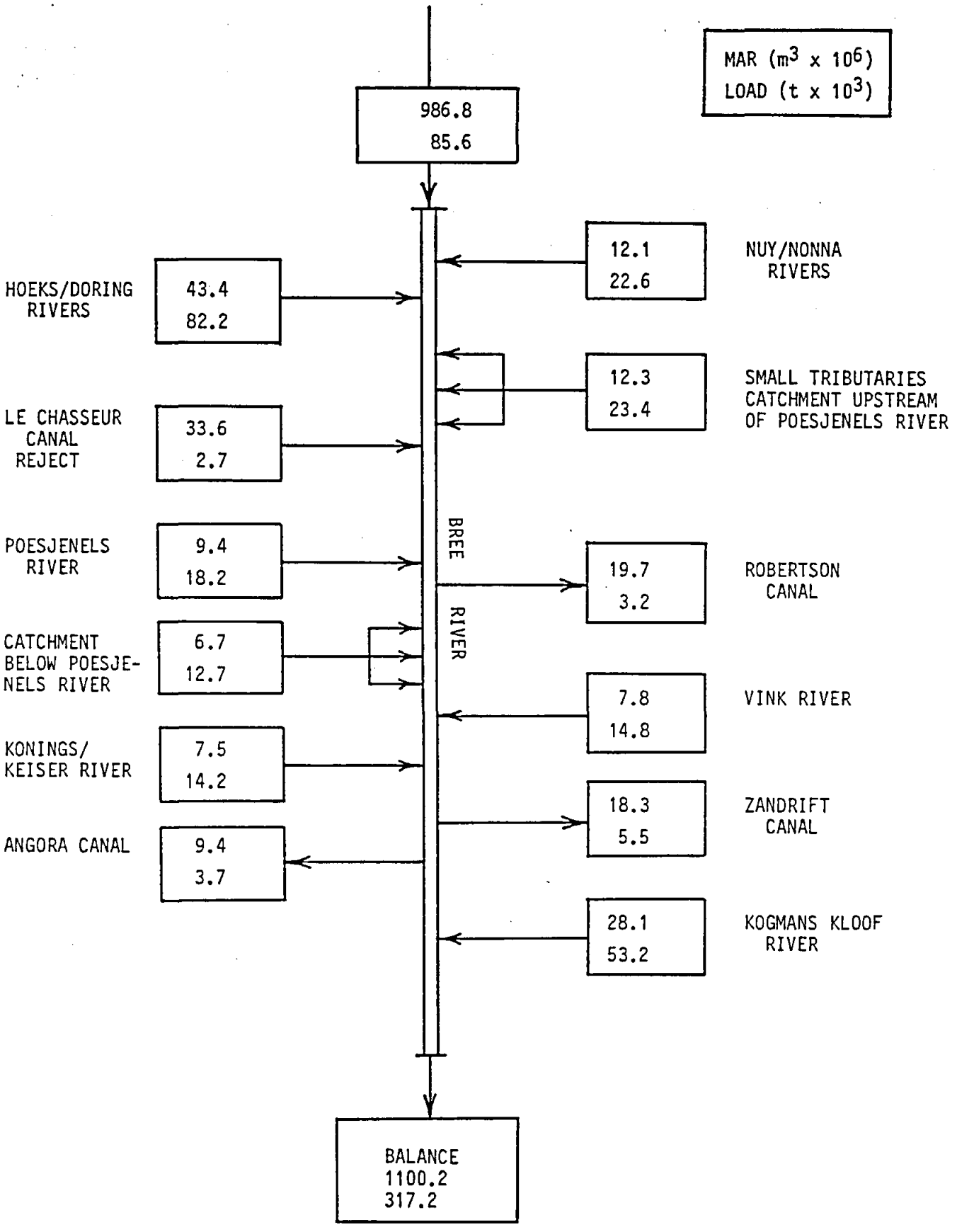

FIG. 1.2 ESTIMATED MEAN ANNUAL RUNOFFS AND SALT LOADS FOR THE BREË RIVER CATCHMENT BELOW THE LE CHASSEUR CANAL, THE HEX RIVER AND THE BRANDVLEI DAM. (After Hasenjager, 1980)

to obtain a better validation of the model used for his thesis, because the mean annual salt load for 1981 and 1982 as measured at H4M18 was about 7000 tons, very much higher than the 1500 tons he had calculated as arising from irrigation return flow alone. This figure indicates a considerable contribution from other sources, and emphasizes one of the original objectives of the work in the Poesjesnels area i.e. the development of a hydrological model to which the irrigation return flow model would have to be coupled to completely explain flow and salinity trends in the river.

Against this background then, one sees the need for more information from the Poesjesnels River catchment on the following:

A: Study of the Physiography, Climate, Vegetation and Geology of the catchment.

B: Determination of total area under irrigation, irrigation water volume and distribution during the year.

C: Salinity profile of the river and its seasonal or monthly fluctuations during the year.

D: Selection of borehole profile positions for bedrock examination; drilling, logging and equipping boreholes with piezometers and conductivity devices.

E: Determination of vertical distribution of salt in the soil, decomposed layers and fresh bedrock of all types present.

F: Groundwater table contours and groundwater response to rainfall, irrigation and dry spells.

G: Rate of migration of groundwater through the bedrock formations and paths followed.

H: Determination of Transmissivity and Storativity of the bedrock by test pumping.

I: The potential for salt leaching of soils, clays, decomposed- and fresh bedrock by the seepage or migration of groundwater.

J: Whole rock analyses of main and trace elements before and after leaching.

K: Measurement of change in salinity of irrigation water as it moves through the soil and into return flow drainage lines.

L: Construction of soil salinity contour maps to indicate salt concentrations.

M: Characterization ("fingerprinting") of different bodies of water on the basis of chemistry or isotopes (^{3}H or ^{18}O) in an attempt to determine how each contributes to the water mixture passing H4M18 at different times of the year.

N: Salt mobilization and movement.

Most of these aspects were included in the project proposals accepted by the Water Research Commission in 1982, and guided through the past five years by the Task Group for Mineralization and the Project Steering Committee.

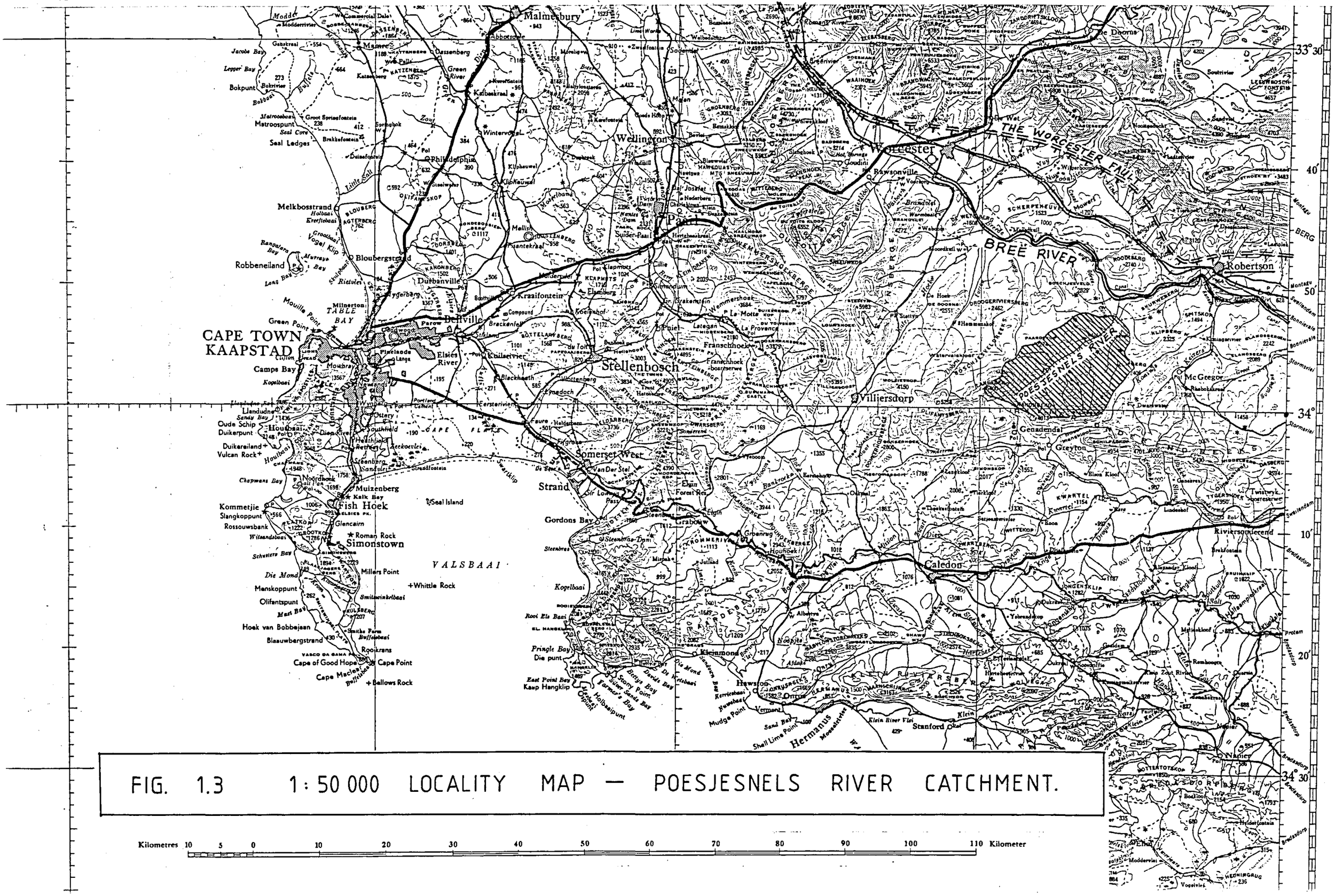

FIG. 1.3 1 : 50 000 LOCALITY MAP — POESJESNELS RIVER CATCHMENT.

2. DESCRIPTION OF THE POESJESNELS RIVER VALLEY (PRV)

2.1 Physiography (App. Fig. 2.1)

The clearly defined, roughly D-shaped Poesjesnels River catchment is situated between 19 30' and 19 45'E and 33 52' and 34 01'S and has a total surface area of 227 km^2. The highest point, Jonaskop in the Suurberg Mountain on the west, rises to 1646m, and the lowest point at hydrologic measuring station H4M18 just below the bridge over the Poesjesnels River at Le Chasseur is at an elevation of 169m.

The northern boundary of the catchment generally has a lower elevation (500-900m) than that on the south which is formed by the Riversonderend Mountains (700-1400m).

The river, which originates on the southern slopes of the Suurberg, flows in a north easterly direction to its confluence with the Breë River 14 km upstream from Robertson. It follows a remarkably linear path over its length of 25 km, and is joined by three smaller tributaries, the Poespasvlei, the Rietvlei, and the Mosiesleegte Rivers which drain the mountains along the southern side of the catchment. The valley sides are steeper on the northern flank than on the south, where a much larger area is drained. Most of the watershed is formed by rugged, resistant ridges of Table Mountain sandstone forming the Suurberg and the Riviersonderend Mountains. (App. Fig. 2.2a Photo 1, and Fig. 2.2b Photos 1 and 2). Other views of the valley and its mountainous watershed are presented in App. Figs. 2.2 a-e (Photo N°3 of Fig 2.2a presents a view of the Le Chasseur area at the lower end of the Poesjesnels River, with Robertson and the Langeberg Mountain Range in the distance. It shows the bridge over the river at station H4M18, and beyond that the Sandberg Mountain with the cleft cut by the Breë River below the arrow.) The lower watershed on the north side (App. Fig. 2.2b Photo N° 3 and Fig. 2.2c Photo N° 1) consists of shale and siltstone beds of the Bokkeveld Group which have been more easily eroded.

The central part of the valley is undulating as a result of the weathering of shale formations which are separated by an occasional resistant ridge of folded sandstone or siltstone. (App. Fig. 2.2b Photo N° 4) Alluvial sands and gravels have been deposited alongside the river channels to form flatter surfaces (App. Fig. 2.2 a-d); most of the agricultural development is concentrated here.

2.2 Climate

The valley has a rather dry Mediterranean climate with most rain falling in winter, driven in by northwesterly winds from the Atlantic Ocean producing precipitation mainly on the Riversonderend Mountains on the south. Mean annual rainfall is 277mm, (1981-1985) with a greater volume falling on the mountains and the upper half of the catchment than on the downstream end. Temperatures vary from ±5 °C in winter, when light snowfalls occur on the highest peaks, to ±40 °C in summer, usually in the period January to March. Class A pan evaporation in the central part of the valley lay between 9.0 and 11.7 mm/day during the summer months of 1979 but dropped to values between 1.7 and 2.9 mm/day in the winter months.

2.2.1 Rainfall

Moolman (1982) discussed rainfall in the PRV, pointing out that in 1979 a lot more rain was measured at Mountain View that at Agterkliphoogte Wine Cellar (301.6mm and 163.4mm) resp.) while 209.7mm was measured at Robertson in 1979. The long term mean annual rainfall for Robertson is 272.7mm.

During this study daily rainfall figures were obtained from the Cellarmaster at the Agterkliphoogte Wine Cellar and the farmers on Wansbek and Kasra, for the period 1980 to 1986. The automatic rainfall measuring device installed on the farm Watwo correlated well (when not plagued by battery failure or malfunction of the logging device) with the figures from Kasra, the adjoining farm. The measurements from these three positions are compared in TABLE 2.1a and are used to calculate monthly averages for the central part of the valley, underlain by Bokkeveld Group sediments and alluvial deposits. From these figures a total was obtained for each year. The average annual rainfall for the central valley over the 1980 to 1986 period amounted to 256.9 mm.

These figures do not, however, give the full rainfall picture over the entire catchment. Raingauges on the farms Mountain View and De Hoek at the uppermost end of the valley registered significantly higher rainfall. Moolman (1982) mentions this in his discussion of the figures for 1979 (a relatively dry year) when 163.4 mm were registered at Agterkliphoogte and 301.6 mm at Mountain View - an increase by a factor of 1,84. The official raingauge on Mountain View was removed in 1981, but the farmer's raingauge continued to supply results. Comparison of these figures

TABLE 2.1a RAINFALL COMPARISON FOR THREE CENTRES IN THE POESJESNELS RIVER VALLEY.

(Official figures for Mountain View not recorded after 1980) *

DATE	RAINFALL IN mm			AVERAGE MONTHLY TOTAL	Mountain View. *
	Agterkliphoogte Wine Cellar	Farm Wansbek	Farm Kasra		
1980 JAN 4		4	2.5	2.1667	16.5
FEB 6	0.8	-	-	.366	2.8
13	0.3	-	-		
MAR 12		25	11.5	12.166	0.0
APR 10	9.5		7	11.19	20.3
18	2.9		3		
MAY 6-8	2.8	4	7.5	25.366	36.1
14	6.5	8	-		
17	1.1	-	-		
24	18.7	14	13.5		
JUN 16	2.3	-	-	29.93	53.5
27	11	-	-		
28	20	22	26.5		
29	8	-	-		
JUL 12	3.5	7.5	2	8.533	20.2
30	5.1	3	4.5		
AUG 13	3.7	19	15.5	15.9	23.0
26	3.9	-	5.5		
SEP 7	5.3	-	6.5	9.5	23.0
26	1.8	-	9.5		
OCT 8	-	9	-	9.6	7.0
15-16	4	4	4.5		
22	4.7	-	2.5		
NOV 4	1.1	4.5	25	53.5	62.7
6	7	7.5	9.5		
13	2.4	2	2		
19	19	17.5	13.5		
20	5.9			16.6	
29-30	9.4	17	17.5		
DEC 1	16.8	5.5	5.5	16.9	16.0
7	1.3	1.5	-		
21	7.6	6.5	6		
(ROBERTSON TOTAL = 264mm MOUNTAIN VIEW TOTAL = 281.1mm)			TOTAL	195.2	281.1

DATE	RAINFALL IN MM			Average monthly TOTAL
	Agterkliphoogte Wine Cellar	Wansbek	Kasra	
1981 JAN 25-26	110.4	124	107	113.7
FEB 2	2.5	25	18.5	22.3
3	21			
MAR 25	15.8	19.5	21.5	18.9
APR 6	2.4	4		24.3
27-29	20.5	18	28	
MAY 28	9	5	7	7
JUN 22	9.7	9	5	7.9
JUL 7	13.5	13.5	14.5	43.9
11	1.4	11	19	
13	9.5	5.5	-	
19	17.2	13.5	13.5	
26	1.2	12	-	
AUG 1-2	6.8	-	6.5	46.2
8	5.2	-	5.5	
10	22.2	19.5	13.5	
27-28	15.5	-	29	
29	3.4	-		
SEP 7	4.2	2	-	37.3
9	10.4	10	7	
14	3.8	4	2.5	
16	6.5	20	22.5	
17	17.4			
OCT 16	7.8	15	9.5	23.6
20	3.4	5	3	
NOV 8	10.1	6	-	
DEC 7	8.4	3	-	
(ROBERTSON TOTAL = 543mm MOUNTAIN VIEW TOTAL = 474mm)			TOTAL	345.1

TABLE 2.1a (continued)

DATE 1982	RAINFALL IN MM			
	Agterkliphoogte Wine Cellar	Wansbek	Kasra	Average Monthly TOTAL
JAN 16	2.5	4	-	2.2
FEB	-	-	-	0
MAR 10	3.2	4	2.5	5.5
20	1.0	6	-	
APR 7	80.5	70	70	140.2
8	13	6	10	
9-10	14.1	5	10	
17	5.3	17	20	
18	2.7		7.5	
19	3.5			
27-29	21	31	24	
MAY 17	4	5	3	4
JUN 1	8.5	15	10	22.4
2	4.2			
15	4	3.5	5	
22-23				
AUG 21	6.2	7.5	4	5.9
SEP 1	7.2	-	9.5	30.1
4	1.7	2	4.5	
13	1.0	4.5	-	
16	1.6	-	2.5	
OCT 12	19.8	18	18	18.6
NOV 15	7.4	8	9.5	8.3
DEC 6	1.0	2.5	1	1.5

(ROBERTSON TOTAL = 328.2mm MOUNTAIN VIEW TOTAL = 302.3mm) TOTAL 232.4

DATE 1983	RAINFALL IN MM			
	Agterkliphoote Wine Cellar	Wansbek	Kasra	Average Monthly TOTAL
JAN	-	-	-	-
FEB 2	6.2	5	-	5.7
12	1.5	-	-	
27	2.0	-	2.5	
MAR 2	1.4	5	3	21.3
8	20.2	20	14.5	
APR 18	1.0	-	2.5	1.2
MAY 2	4.8	-	2	42.5
11	1.3			
15	12.7	10	11	
20	22.5	28	24.5	
21	12.0			
JUN 6	1.5			62.7
12	3.0	14	5.5	
23	22.1	23	21	
24	24.7	28	17	
25				
27	9.9	7.2	11.5	
JUL 5	12	11	13.5	46.9
6	3.1			
14-15	10.3	8.2	5.5	
22	7.6	17.5	8	
25	8.0	12	12	
27	1.3	7	4	
AUG 6	6.7	5	7.5	9.4
18	2.5	-	6.5	
SEP 1	4.5	5	3	35.4
7	6.5	7.5	-	
8	3.3			
22	3.5	11	34	
23	25.8	-	2	
OCT 2	4.8		2	2.3
NOV 4	1.4			25.9
20	9.9	17.2	49	
DEC	-	-	-	-

(ROBERTSON TOTAL = 294.9mm MOUNTAIN VIEW TOTAL = 402.9mm) TOTAL 253.3

TABLE 2.1a (continued)

DATE 1984		RAINFALL IN MM			
		Agterkliphoogte Wine Cellar	Wansbek	Kasra	Average Monthly TOTAL
JAN		-	-	-	-
FEB		-	-	-	-
MAR	11	22.8	40	32	40.2
	12	14.0			
APR	8	-	5	5	11.6
	26	13.5	11.5		
MAY	6	2.4			59
	14	1.7		7.5	
	15	12.8	12.5	18.5	
	16	18.2	35.0	11.5	
	17	22.5	8.5		
	18	8.3		3.0	
	27	5.3	5	4	
JUN	20	3.5	-	-	1.2
JUL	20	8.5	4.5	10.5	7.8
AUG	4	5.2	-	6.5	3.9
SEP	3	8.2	12	8	39.3
	4	15.8	22	13	
	5	12.6		6.5	
	6	4.3	4	4	
	26	2.6	2.5	2.5	
OCT	5	37.5	32.5	25	42.1
	6	8.5	10	5	
	7	3.3		4.5	
NOV	7	5.2	12.5	15.5	11.1
DEC	4	8.3	15	10.5	14.7
	5	6.2			
	24	4.0			
(ROBERTSON TOTAL = 236mm MOUNTAIN VIEW TOTAL = 323.5mm)				TOTAL	230.9

DATE 1985		RAINFALL IN MM			
		Agterkliphoogte Wine Cellar	Wansbek	Kasra	Average Monthly TOTAL
JAN	14	23	22.5	23.5	24
	30	2.2	-	-	
FEB	8	6.7	13	13	13.4
	11	7.5			
MAR	2	11.6	17.5	15	28.3
	3	9.4			
	15	6.8	7	10.5	
	16	7.3			
APR	6	8.5	9	12	15
	23	6.2	5	4.5	
MAY	23	2.9	-	-	5.2
	27	4.1	5	3.5	
JUN	12	19.2	15	15	33.7
	13	16.7	16	17	
	25	2.2	-	-	
JUL	5	2.2			72.2
	6	56.7	56	58	
	7	4.0			
	10	8.0	16	6	
	11	9.0		10	
AUG	1	4.1	3	3	33.4
	3	13.5	12	11	
	7	9.0	10	8	
	9	6.5	14	6	
SEP	12	10.5	9.5	8	10.1
	19	1.2			
	25	1.2			
OCT	14	26.5	16.5	23	39.6
	15	2.7		4.5	
	30	16.0	15.5	14	
NOV	2	14		9	13.7
	4	11			
	8	3	3		
DEC	2	8.5	14	12	18.8
	3	2.5		2.5	
	6	4.8		12	
(ROBERTSON TOTAL = 361.7mm MOUNTAIN VIEW TOTAL = 435mm)				TOTAL	307.4

TABLE 2.1a (continued)

DATE 1986		RAINFALL IN MM			
		Agterkliphoogte Wine Cellar	Wansbek	Kasra	Average Monthly TOTAL
JAN		-	-	-	-
FEB	22	7	11	8.5	11.43
	23	6	-	1.8	
MAR	23	3.9	6	4.8	8.97
	24	3.3	-	2.7	
	30	3.2	3	-	
APR	14	1.8	-	-	10
	19	5.2	13	10	
MAY	9	2.3	-	3.5	4.43
	28	0.5	-	7	
JUN	2	4.2	7	4.8	27.6
	3	4.8	8	3.5	
	17	12.5	12	12	
	18	5.5	4	4.5	
JUL	4	9.8	4	5.8	24.37
	8	0.8	3	2.7	
	14	16.5	16	12.5	
	23	2	-	-	
AUG	4-5	28.5	30	21.8	89.57
	6	2.7	3	3.5	
	14	13.5	19	13	
	15	5.5	7	5	
	16	4.2	7	5	
	24	-	-	2.5	
	25	5.5	4	3.7	
	26	1.0	2	-	
	27	3.0	4	-	
	28	8.2	6	-	
	29	-	2	5.5	
	30	15.8	16	20.8	
SEP	6	1.6	-	-	25.13
	11-12	21.5	24	20	
	24	-	5	3.3	
OCT	5	-	5	8.7	17.47
	6	8.5	-	7.0	
	13	-	11	12.2	
NOV	3	5.1	7	8.7	15.23
	4	1.5	-	-	
	8	7.4	11	5	
DEC		-	-	-	-
(ROBERTSON TOTAL = 256mm MOUNTAIN VIEW TOTAL = 387mm)				TOTAL	234.2 mm

with those from the central valley (App. FIG. 2.1) showed the following increase factors of rainfall at the upper end of the valley relative to that registered in the central part:

(rainfall in mm)

Year	Central Valley Rainfall	Mountain View		De Hoek	
		Rainfall	Factor of Increase	Rainfall	Factor of Increase
1979	163.4	301.6	1.84		
1980	195.2	281.1	1.44		
1981	345.1	474	1.37		
1982	232.4	302.3	1.30		
1983	253.3	402.9	1.59	504	1.98
1984	230.9	323.5	1.40	476	2.06
1985	307.4	435	1.42	535	1.74
1986	234.2	387	1.65	497	2.12

Clearly, much higher rainfall is induced by the topographic effect of the high sandstone mountains. Based on the figures from these upper farms, one can assume a value twice that of the central valley. This water runs off the mountain slopes without being mineralized, and must play a significant role in reducing salinity levels in the river lower down the valley, particularly when the soils have become saturated.

An assessment of the rainfall input on the sandstone mountain area of the upper catchment is necessary in order to understand the water balance of the valley.

Assuming a precipitation of twice that of the central valley, and multiplying with the area underlain by Table Mountain Sandstone (99km^2), one can arrive at an approximate volume for this rainfall:

e.g. for 1980:

Mountain area = 99 m^2 x 10^6

Precipitation = 2 x 195.2 mm

Volume of water = 99 x 0.3904 m^3 x 10^6

thus the 1980 volume = 38.65 m^3 x 10^6

The volume of water falling on the central or Bokkeveld part of the valley (128 km^2) calculated in a similar way for 1980, gives:

Bokkeveld and alluvial area = 128 m^2 x 10^6

precipitation = 195.2 mm

thus the volume for 1980 = 24.98 m^3 x 10^6

Calculations of rainfall water volumes for the period 1980-1986 are shown in Table 2.1 b.

TABLE 2.1 b: ANNUAL RAINFALL VOLUMES

YEAR	MOUNTAIN AREAS x 10^6 m^3	CENTRAL VALLEY x 10^6 m^3	TOTAL x $10^6 m^3$
1980	38.65	24.98	63.63
1981	68.32	44.17	112.49
1982	46.02	29.75	75.77
1983	50.15	32.42	82.57
1984	45.72	29.56	75.27
1985	60.87	39.35	100.22
1986	46.37	29.98	76.35
AVERAGE:	50.87	32.89	83.76

These values are used later in section 4.2 (page 46) when a comparison is made between total input and outflow from the valley (TABLE 4.2 B). Moolman (1982) pointed out that a number of rainfall events in the valley during 1979 registered less than 5 mm, and questioned the effectivity of the higher rainfall recorded at Mountain View.

Although the smaller rainfall events are not effective in producing runoff which will significantly alter the salinity of the river, they do have an effect on the infiltration of water into particularly the fissured and jointed sandstone rocks in the mountain areas. In some cases light rain will produce zero runoff, but appreciable infiltration; studies of the oxygen isotopes in rain and borehole water confirm the entrapment of highly ^{18}O depleted water in the sandstone mountains (section 11.2, page).

In modelling the geohydrology of a valley such as the Poesjesnels, the most difficult parameter to simulate is the infiltration rate over given area. If the total input of water is known (rainfall and irrigation canals), and the total water loss (river outflow plus evaporation and evapotranspiration) is subtracted from this figure, one could begin to approach a figure for total infiltration over the whole catchment. Naturally some of the infiltrated water does leave the groundwater zone by seepage, artesion flow or pumpage, and joins the river outflow; in this way it becomes part of the total water loss which is subtracted from input, resulting in a more conservative value of the total infiltration into the groundwater zone within the bedrock of the catchment. (These aspects are addressed in section 4.2)

Although Moolman (1982) also questioned the validity of the very high evaporation measurements from Agterkliphoogte and Mountain View relative to those from Robertson during 1979, subsequent measurements during the period 1980 to 1984 confirmed the very high summer values of ±10 mm per day, with the annual mean over the five year period being:

Agterkliphoogte	= 2 130 mm/y
Mountain View	= 1 954 mm/y.

(Data supplied by the Agricultural Research Centre of the Winter Rainfall Region, Elsenburg.)

2.3 GEOLOGY

The area was initially mapped in 1906 by the Geological Commission, Cape of Good Hope, prior to the establishment of the Union of South Africa. More recently, mapping of the valley has been carried out by geologists of the Western Cape office of the Geological Survey of South Africa, but the maps have not yet been finalized and published.

Provisional maps were however made available to the project by Dr. J.N. Theron, Director of the Western Cape Division. Ground control surveys and aerial photographic study revealed additional information about the catchment, particularly with regard to faulting and jointing of the bedrock. (App. Fig. 2.4)

The following salient features are described:

2.3.1 Geomorphology. (App. Figs. 2.3 and 2.4)

The valley and catchment have developed by headward erosion of the Poesjesnels River from the Breë River valley, which originated by downfaulting on the south side of the Worcester Fault (Fig. 1.3); the Poesjesnels and its tributaries exploited the synclinally folded sedimentary rocks of the Cape Supergroup and were assisted by cataclastic deformation along some faults, the most prominent being the Sewefontein Fault (App. Fig. 2.5a) which exends the full length of the valley. This is a wrench fault with downthrow to the south in the upper part of the valley, and to the north in the lower part; massive breccia in the fault zone is exposed on the farms De Hoek, Mountain View and Sewefontein, the latter having a strong spring flowing from the fault zone. Photo 1 of App. Fig. 2.5b shows a similar breccia zone on the Jordaan Fault at borehole DJB on the farm Vredenhof. Drilling here produced a small artesian flow (photo 2) and a strong yield of 30 litres/sec. upon pumpage.

The sandstone layers of the Table Mountain Group form the resistant flanks of the major syncline, while the softer shale and siltstone beds of the Bokkeveld Group occupy the core of the syncline in the central part of the valley.

Resistant, steeply folded beds of siltstone or quartzite within the Bokkeveld sedimentary group have formed sharp hogsback ridges, V-ridges at the noses of

plunging synclines and anticlines, and elongate, dissected basins and domes, especially in the southern half of the catchment. These all trend ENE, more or less parallel to the main river valley.

Along the Poesjesnels Valley river erosion is at present cutting back into the alluvial deposits forming new sand and gravel terraces, particularly along the southern bank of the river (App. Fig. 2.2c Photo N°2)

2.3.2 Bedrock Types (App. Fig. 2.4)

The areas underlain by the main bedrock groups in the catchment are as follows:

Table Mountain Group:	99km^2
Bokkeveld Group:	128km^2 (including alluvial cover)
TOTAL:	227km^2

The alluvial cover of sand and gravel has an area of approximately 40 km^2; most of this has been developed for irrigation.

a) Table Mountain Group (App. Fig. 2.2b Photo N°1 and 2):

This group consists mainly of well sorted, monomict, medium to coarse massively bedded sandstone showing deltaic cross bedding with very hard, siliceous orthoquartzite developed in many places. These rocks are responsible for most of the boulders, cobbles, pebbles and sand layers found in the alluvial deposits of the valley. They constitute a reasonably porous, well jointed aquifer, with all vestiges of marine salt leached out by centuries of rainfall, and produce high quality groundwater outflows. Although slightly porous in some zones where diagenesis has not caused complete cementation (particularly in the Nardouw Formation), groundwater flow is mainly controlled by secondary fractures produced during the tectogenesis associated with the Cape folding and the fault geodynamics of the Mesozoic Era in the southern part of South Africa.

b) Bokkeveld Group:

In the catchment four shale and four sandstone formations of the Bokkeveld Group may be recognized. The shales are dark grey to black, with a high carbon content seen as graphite flakes in cleavage zones, contain a high percentage of iron sulphide in the form of pyrite crystals and nodules and have sericite flakes developed throughout.

Water obtained from these formations by boreholes is highly mineralized, with the TDS values of some samples exceeding 9000mg/litre. A large amount of black foam is produced by the compressed air during percussion drilling in the shale; samples of this were leached in ether, and an extract of petroleum separated by distillation (App. Fig 2.5d Photo N° 3) Mass spectrometer analyses showed the oil to be long chain hydrocarbons. It is assumed that the oil is a residue left among the graphite grains in the shale after high temperature organic breakdown during the metamorphism associated with the folding. Although the shale formations have a thickness of ±200m, outcrops of shale formations of the Bokkeveld are not often encountered, as these have weathered away more easily than the siltstone or quartzite formation to form low lying, soil covered areas between resistant ridges of the latter. (A stratigraphic column is provided in App. Fig. 2.4).

The sandstone formations (App. Fig. 2.5c) have a pale grey colour and are for the most part fine grained enough to be called siltstones (App. Fig. 2.5d photo N° 4). They contain much sericite mica and some feldspar in the highly quartzitic material.

These sandstone outcrops show well developed jointing, which provides the channels for groundwater movement through Bokkeveld bedrock and also contain many oxidized pseudomorphs of limonite after pyrite (App. Fig. 2.5c photo N°4 and Fig. 2.5d photo N° 5). The sandstone formations are much thinner than the shales, varying in thickness from about 10m (Gydo Sandstone - C2Q1) to about 100m.

The shale formations occurring in the valley are generally very impervious to the passage of groundwater, but some openings along fault zones and joints with quartz crystallization do exist, as can be seen in the photos in App. Fig. 2.5e.

The cyclic nature of the sedimentary processes responsible for the formation of the Bokkeveld Group is evident in the banded nature of the bedrock; in most of the

drill cores it can be seen that the shale formations contain many interbedded sandstone or siltstone layers, and also that shale bands are encountered at various places in the predominantly sandstone formations. An example is shown in App. Fig. 2.5d photo N°6.

2.3.3 Whole Rock Chemical Analyses.

In order to examine the possibility of the occurrence of highly saline horizons within the bedrock formations, and check on the graphite and sulphur content by examination of the LOI (loss on ignition) figures, XRF whole rock analyses were carried out on drill cores by the Geochemistry Section of the Geology Department at the University of Stellenbosch. The results for both percussion borehole cuttings (P) and diamond drill cores (D) are presented in App. TABLE 2.2 a to g, together with the descriptions of the rock materials (App. pages 7 to 12).

The analytical results on App. Table 2.2 do not reveal any particularly saline horizons. The highest Na_2O values are found in A2 at 9 m and 10 m depth, B1 at 50 m depth and D2 at 10 m depth, an lie between 2.12 and 2.58%, not uncommon for micaceous siltstone or shale containing a little feldspar. K_2O values reach a maximum of 4.79% in B1 at 22 m depth where a micaceous, graphitic shale was encountered. (K_2O forms part of the structure of sericite or muscovite mica.)

Comparison of the chemical analyses with the bedrock materials shows that Silica (SiO_2) varies from 57 to 66% in the shales, from 67 to 77% in siltstones and is >77% in quartzite. A clear correlation may also be seen with alumina (Al_2O_3) which varies from ± 10% in fresh quartzite (B2-54m) to 21% in black micaceous shale (B1-22m), and also with potash (K_2O) which increases with the mica content of the bedrock. The extreme SiO_2 values in B1-3m, B2-3m, C2-3m and D2-3m indicate a high quartz and/or quartzite content in these river-washed sandy gravels.

Geochemical analyses of marine sediments both ancient and recent show significant concentrations of major and minor elements such as B, Li, Nb, Ga, Y, Sr and Rb when compared with fresh water deposits. (Degens, 1965; Manheim and Sayles, 1974; Rieke and Chilingarian , 1974; Chilingarian, 1983).

The exchange affinity series Li<Na<K<Rb<Cs and Mg<Ca<Sr<Ba have been found to exist in a clay mineral medium, and may partially account for the retention of potassium on the continents and the transportation of sodium to the sea. (Degens, 1965). The series also show that Rb replaces K and that Sr replaces Ca on the surfaces of the clay minerals.

A very strong correlation also exists between high values of Sulphur (occurring as pyrite) and Carbon in marine sediments (p. 601, Goldhaber and Kaplan, 1974). Analyses of some of these elements in the bedrock samples confirmed the marine character of the Bokkeveld sediments; the high Sr values confirm the enrichment of the interstitial water of biogenic sediments due to recrystallization of calcite during diagenesis, while high Rb concentrations in the micaceous sedimentary layers confirm the substitution of this minor element for K. (App. TABLE 2.3)

In this table one can also see that the highest S values coincide with high Fe_2O_3 values from App. Table 2.2, particularly in the following samples:

Borehole	Depth (m)	S (%)	Fe_2O_3 (%)	LOI (%)
A1	1	0.545	7.65	4.21
A1	51	0.607	5.97	3.76
A2	20	0.196	6.14	3.88
A2	99	0.201	6.43	3.73
B1	14	0.492	4.97	3.43
B1	22	0.129	6.75	5.44
B1	42	0.322	5.07	3.41
C1	99	0.391	5.41	3.58
C2	42	0.250	7.32	4.51
D1	99	0.198	6.71	3.61

This is in agreement with the work by Berner, (1970) and Goldhaber and Kaplan (1974), who found that the amount of pyrite formed in sediments appears to be dependant on the extent of organic carbon deposition.

With the exception of the soil sample at 1 metre depth from borehole A1, (which shows anomalously high Cu, Ni and Zn values and probably contains some oxidized sulphide mineral grains including limonitized pyrite), the other samples in this list are all carbonaceous shale carrying fresh pyrite grains, explaining the high Fe and S content. (Fresh and oxidized pyrite nodules were clearly seen in drill core samples from borehole A2 (App. Figs. 2.5d and 5.3). Sulphur and Carbon are driven off during ignition, giving the substantial LOI values. There are however a number of samples with low sulphur content showing LOI values in excess of 4%; these include A1-5 m, A2-18 m and 51 m, B2-10 m, C2-20 m, D1-10 m and E1-20 m and 99 m which have been logged as carbonaceous or graphitic shales. The high LOI values for these samples indicate the vapourization of carbon, whereas shallower samples like B1-3m, A2-3m, C1-3m, D1-3 m and E1-3m have high L.O.I. figures due to the breakdown of calcite and loss of CO_2 from the calcareous material.

Chloride could not be analyzed by the XRF method, but chemical analyses were carried out on leachates obtained from crushed borehole samples; these indicate that the highest Cl^- values are associated with micaceous shales which carry the highest carbon or graphite content.

There is no immediate indication of the role (if any) played by graphite in retaining chloride in marine sediments after deposition. However, saline waters are associated with many petroleum deposits, and the large amount of carbon in the Bokkeveld appears to be a residue of earlier biogenic oozes rich in hydrocarbons. The evidence points to a connate marine origin for the salt in the Bokkeveld sediments, with Na^+, K^+ and Cl^- ions being adsorbed onto the large amount of clay mineral and sericite mica platelets. (Degens, 1965).

In a study of an alternating sequence of clay shales and sandstones in a petroleum basin, Chilingarian and Rieke (1976) clearly showed that compaction actually squeezes most of the connate salt from the shale into the interstices of the sandstone. (Chloride concentrations in the shales vary from 1 500 to 20 000 mg/l and in the sandstones from 11 000 to 200 000 mg/l.). One reason postulated is that

the innerlayer water of swelling clay minerals is fresher than the interstitial free water (Chilingarian, 1983, p 148).

The sediments of the Bokkeveld cannot be classified as a petroleum basin deposit, nor is a clear distinction to be drawn between clay shales and sandstones. The shales in the Bokkeveld tend to be rather silty, with much sericite; the sandstones are in most cases fine enough to be termed siltstones and also carry a large proportion of sericite mica flakes.

Nevertheless some analogy is possible, even though the work by Chilingarian and Rieke was carried out on drill cores from depths between 1 000 and 5 000 metres. The interstitial saline fluids are trapped in their deep sediments, while at the shallow depths examined in this investigation, much groundwater movement and leaching has already taken place, particularly under the head of groundwater pressure within the encircling sandstone mountains.

The greater permeability of the Bokkeveld siltstone and sandstone layers has clearly permitted a much more extensive leaching out of salt than the micaceous black shales, thus explaining the greater salinity of the latter (in contrast to the results of Chilingarian and Rieke.)

Oxidization of sulphide minerals such as pyrite in the zone of decomposition will naturally produce a large amount of sulphate which would be available for leaching by percolating groundwater. Many other elements strongly held in fresh bedrock could also be released by weathering in the zone of decomposition. Leaching tests on fresh and decomposed bedrock were carried out to evaluate this release; results are discussed in section 6. (Page 102)

2.3.4 Structure

The Poesjesnels River valley lies in a longitudinally faulted syncline, as can be seen by examination of the vertical sections in App. Figs. 2.6 - 2.9. (see also App. Fig. 2.4 (t)) The wrench faulting of the Sewefontein Fault caused the upthrusting of the Suurberg Mountain mass to its prominent position in the northwest, clearly seen in section Q-Q" (App. Fig. 2.8) and in section R-R" (App. Fig. 2.9).

App. FIGS 2.6 and 2.7 show that the deformation of the Bokkeveld sediments is more intense south of the Sewefontein Fault than to the north, as evidenced by steeply dipping and even overfolded strata having strongly developed cleavage (App. Fig. 2.5c). North of the fault the Bokkeveld beds are folded into a gentle anticline which plunges at a low angle to the east, eventually becoming horizontal in the northeast corner of the catchment where the Wuppertal Sandstone (C2S5) forms the mesa-like crest of the Platberg at the northern end of profile line J-J".

Because of this general eastward dip of the formations north of the Sewefontein Fault, the whole sequence of sediments from the Peninsula Formation of the Table Mountain Group (C1Q1) to the Wuppertal Sandstone of the Bokkeveld (C2Q4) is exposed (App. Fig 2.9 A). A further consequence of this regional dip of sandstone formations below the Bokkeveld shales is the presence of a number of fountains and artesian boreholes on the farms De Fontein, Sewefontein and Wansbek Oos 1 (circled on App. FIG 2.1) due to the development of a piezometric groundwater head in the Suurberg sandstone mountain. This water has a low TDS of ± 100 mg/1 and is used for irrigation on the abovementioned farms as well as on Bellevue, De Wetshof and Rabiesdal in the vicinity of the Agterkliphoogte Wine Cellar.

2.4 Vegetation

The natural vegetation in the central part of the valley consists of low bushes and succulent plants adapted to hot, dry environments (App. Fig. 2.2c) and is similar to that found in the Karoo. On the elevated sandstone mountains much of the famed Kaapse fynbos is to be found together with proteaceae. In and along the riverbanks, thicker bush, thorn scrub, soutbos and reeds grow in profusion.

3. IRRIGATION

3.1 Area under irrigation:

Every farmer in the valley was approached and asked to complete a questionnaire relating to the areas on his farm used for irrigated cultivation of three categories of crops:

a. vines, fruit and lucerne
b. grain
c. vegetables and feedlots.

They were also asked to report on the period and volume of irrigation applied. They gave excellent co-operation, and the survey results are shown in App. TABLE 3.1. Area totals for the three categories are:

vines, fruit and lucerne	1286.76 ha
grain crops	450.00 ha
vegetables and feedlots.	57.50 ha
TOTAL area under irrigation	1794.29 ha

In comparison with this survey, the total area determined by Arnold (1980) for the Soil and Irrigation Research Institute was 1900 ha, that determined by Stickler (1983) of the Hydrological Research Institute using LANDSAT imagery was 1496 ha and that reported by Moolman (1982) for vines and fruit alone was 769 ha.

3.2 Irrigation volume and distribution

Irrigation water which is applied to crops in the valley comes from four main sources:

1. The Brandvlei Dam (indicates as BV on App. TABLE 3.1) by means of the Le Chasseur canal. This water reaches a point halfway up the valley, on the farm Wansbek B, where the tailwater overflow is retained in an earth dam. (TDS ±50 mg/l).

2. A canal leading from a weir on the Poesjesnels River on the farm Sewefontein (TDS ±200 mg/l) to which water flowing from fountains and an

artesian borehole on the farm De Fontein is added. (TDS ±100 mg/l). This water serves the farms between Sewefontein and Wansbek B on the northern bank of the river, i.e. De Fontein; Bellevue, De Wetshof, Rabiesdal and Wansbek A.

3. A canal leading from the Rietvleikloof to De Wilgen, along the southern part of the valley (TDS ±90 mg/l) and serving the farms Vredenhof, Werk en Rus, Kasra, Rietvlei and Watwo (incorporated with Vredenhof), the southern portions of Wansbek, Wansbek A and Wansbek B and eventually the southern portion of De Wilgen.

4. Earth dams which store rainfall runoff flowing in streams in the valley (TDS varies from 50 mg/l to 300 mg/l). Most of the farms have at least one such reservoir.

In addition to the four categories already mentioned, a number of boreholes are pumped to assist with irrigation during the hottest months of the year when most mountain streams stop flowing, and dams are empty. These are situated on the following farms:

Vredenhof: drilled into Table Mountain Sandstone and producing 40 m^3/h for 3 months of the year at a TDS of ±350 mg/l.

Kasra: drilled into Bokkeveld Siltstone and producing 30 m^3/h for 3 months of the year at a TDS of ±2 050 mg/l.

It was not possible to find out exactly how these various water resources were applied to the various crop types, nor was it possible to compile a map which would show the distribution of different crop types on each farm; such a map would show a rather complicated pattern of agricultural developments.

The distribution figures for irrigation in the valley as supplied by the farmers (App. TABLE 3.1) were added together and are as follows:

a.	vines, fruit and lucerne:		Total volume
	1371 552 m^3 per month for 8 months (September to April)	=	10 972 416 m^3
b.	grain crops:		
	382 942 m^3 per month for 3 months (September to November)	=	1 148 826 m^3
c.	vegetables and feedlots:		
	39 792 m^3 per month for 12 months (January to December)	=	477 504 m^3
	∴ Total annual irrigation volume	=	12 598 746 m^3

The distribution of irrigation during the year is graphically shown at the top of App. Fig 4.1 (a - e).

Division of the total volume by the total area shows that annually, an average of 7022 m^3 is applied to each hectare giving coverage of 702 mm. This correlates well with the figures quoted by Moolman (1982) in his thesis on p.70.

According to figures supplied by the farmers an average total of 6 776 880 m^3 comes in annually from the Brandvlei Dam via the Le Chasseur canal. The balance of the irrigation water (5 821 866 m^3) comes from rainfall runoff stored in dams, mountain streams fed into canals, outflow from artesian boreholes and fountains or pumped borehole water.

In addition to the 702 mm of applied irrigation, rainfall adds an average of 257 mm of water (p. 15) to developed orchard areas in the central part of the valley. A total of ± 960 mm is therefore available in these areas for leaching of soil and subsoil layers, partially into drainage lines as return flow and partially into the underlying decomposed and fresh bedrock, eventually reaching the groundwater table mainly by means of flow along fractures.

It should be noted that in addition to the irrigated areas, a further ±1000 hectares have been ploughed and cultivated for dry land grain crops, bringing the total area under agricultural development to ±28 km^2 (shaded areas in App. Fig. 2.3A).

As shown in section 2.2.1 the mean annual rainfall volume for the valley is approximately 83.76 $m^3 \times 10^6$, i.e. about 12 times as much as the irrigation water brought in by the Le Chasseur canal from the Brandvlei Dam.

The total average annual water input into the Poesjesnels catchment is as follows:

rainfall	83.76	
Le Chasseur canal	6.78	
TOTAL	90.45	$m^3 \times 10^6$

The MAR (mean annual runoff) for the Poesjesnels catchment was estimated by I. Hasenjager of the Hydrology Division (Directorate of Water Affairs) and included in the Annual Runoff and Salt Load diagram for the Breë River catchment by R.W. Arnold (1980) (see Fig. 1.2 of this report). The figure he submitted was 9.4 $m^3 \times 10^6$, which is one tenth of the total water input.

This figure is due to a high degree of evapotranspiration in the valley particularly during the summer months. (USWB class-A pan evaporation in the central part of the catchment is in excess of 2 000 mm per annum - Mr. J. Myburgh, Elsenburg, pers. comm. 1988). High winds and high temperatures are mainly responsible for the extremely high evaporation. Some rainfall events during the summer months are so light and the surface so dry that no infiltration takes place, and all the precipitation is lost to the atmosphere soon afterwards. Runoff only begins when more than 5 mm of rain has fallen in less than 30 minutes - (J.H. Moolman, pers. comm. 1988). During winter, 5 mm rainfall events, which occur after good rainfall has saturated the soil on the previous day, will produce considerable runoff; these aspects are at present being studied by scientists of the Hydrological Research Institute at Rhodes University, Grahamstown, in similar arid environments.

The work by Moolman (1982) has clearly shown the greater effect of irrigation on the wetting-up of the soil profile, particularly during the summer months. Both irrigation and rainfall produce runoff on the surface as well as return flow through the subsoil and decomposed bedrock which enter drainage lines and streams, and

eventually reach the river. Quantification of these amounts and differentiation between them is a difficult task, and although beyond the scope of this project, are being researched by hydrologists in the Robertson irrigation area at present. Measurements of the flow in the Poesjesnels River, the salt load and the changes in salinity along the length of the river are presented in the next section.

4. POESJESNELS RIVER SURVEY

4.1 Daily Flow Volume

The hydrological gauging station H4M18 which was constructed in 1980, began recording daily measurements of the flow passing over the V-notch weir on the 14th June of that year having given electrical conductivity data since November 1977. A few months later, on 25th and 26th of January 1981, the very high rainfall in the southern Cape which led to the Laingsburg floods, caused a very high flow a water at H4M18, beyond the capacity of the measuring device, and interfered with the conductivity measurements. Daily flow and E.C. measurements for the period 1981 to 1986 are graphically illustrated in App. Figs. 4.1 to 4.6, using data supplied by Mr. E. Braune of the Hydrological Research Institute. Irrigation input is shown at the top of the diagrams.

The flow measurements are carried out continuously by means of a graphic recorder, but the salinity data are recorded at 24 hour intervals by means of conductivity readings in a sampling pipe in the stream. Significant changes in the flow volume resulting from heavy rains can be monitored, but salinity fluctuations cannot be as closely followed. Calculation of the salt load carried past the measuring station using the flow and salinity data do not therefore give an exact tonnage. The positive and negative errors however tend to cancel each other out and give a result, especially if daily data are used, which lies within a few percent of the true value if monthly totals are considered. These variations are handled by two versions of the hydrological model for the mineralization of rivers i.e. $FLOSAL_d$ and $FLOSAL_m$ (Hall and du Plessis, 1981).

Some observations: (NB. FIGS 4.1 to 4.6 are included in the Appendix)

FIG 4.1 (1981):

Rainfall in excess of 113 mm in the C.C.A. (central catchment area) on 25th and 26th January caused the flow past H4M18 to increase from 0.03 m^3/s to more than 10.94 m^3/s. The level of water in the intake of the conductivity device seems to have affected the instrument in some way because it ceased to register salinity data for 23 days, until the 16th February. A similar long break occurred on the last

day of June, and continued right through July - a pity, because of the good rainfall of 44 mm registered during the month.

In trying to find the correlation between rainfall and river flow, one sees that rainfall events occurring after a dry spell cause an initial runoff response within 24 hours, peaking about 3 to 4 days afterwards. The response is initially small, but increases with succeeding rainfall events, indicating increased saturation of soil layers together with rising of the groundwater table.

The graphic records for the months June to September 1981 clearly demonstrate this increase of runoff even though rainfall events were not spectacular, as can be seen in the following listing of rain and river flow peaks:

	DATE -	RAIN mm	FLOW m^3/s -	DATE
1.	25 March	18.0	0.33	27 March
2.	27 April	22.0	0.2	28 April
3.	22 June	7.9	0.51	22 June
4.	13 July	7.5	1.02	14 July
5.	19 July	14.7	1.293	20 July
6.	1 August	6,7	0.661	2 August
7.	10 August	18.4	0.873	11 August
8.	28 August	15.5	3.695	31 August
9.	9 September	10.2	0.896	10 September
10.	14 September	4.0	1.41	14 September
11.	17 September	20.0	2.959	18 September

In addition to these flow peaks, other runoff peaks were registered even though no rainfall was recorded in the CCA*, e.g. a peak of 0.37 m^3/S on the 5th of May. Initially it was assumed that some rain probably fell in the mountains to cause this runoff; confirmation of this was given by examination of recently accessed rainfall records from De Hoek, the uppermost farm in the valley, which show 18 mm of

(CCA = Central Catchment Area.)*

rain on the 4th of May, even though no rain was registered on the adjoining farm, Mountain View, or any of the other farms in the catchment. Runoff from such mountain rainfall would be very fresh, and cause a decline in the salinity of the river - as was in fact registered on the daily conductivity graph (FIG 4.1) when very high values at the end of April (600 m S/m) declined sharply to ±150 m S/m during the first half of May.

Rainfall events occurring within the valley during late Autumn tend to have the opposite effect: salts which have accumulated in the soil during the hot summer months are flushed out by these early rains, causing increased salinity in the river water as may be seen from the salinity peaks at the end of April, May and June.

As heavier rains fall and the river flow increases during the period July to September, the salinity decreases, only to increase again as the river flow decreases during the hot summer months of October, November and December. There conditions reflect a normal, predominantly writer rainfall distribution pattern. Occasionally, heavy rainfalls have occurred during the summer months and caused unseasonal runoff with lowered salinities (e.g. October, November and December of 1985, App. Fig. 4.5).

Snowfalls on the mountain peaks may also affect the hydrographs, by virtue of the slow release of fresh water into the catchment during their period of melting. Although no rain was recorded, the flow hydrograph shows plateau-like peaks during mid-May and the first half of June, associated with low river water salinities. Cross checking against data supplied by the Weather Bureau in Pretoria i.e. maximum and minimum daily temperatures, rainfall, past and present weather, cloud ceilings and elevation of freezing levels at D.F. Malan airport as well as information from farmers and newspapers, has given the following correlations between hydrographic plateaux and snow melt runoff in the six year period 1981 to 1986 (Table 4.1):

TABLE 4.1 Assessment of possible snowfalls in the catchment; temperatures at Robertson near or below freezing point; freezing level at D.F. Malan airport below 1 500 metres; weather reports in Cape Town newspapers.

YEAR	MONTH	DAY	MINIMUM TEMP°C
1981	JUNE	9	-0.6
		16	-0.9
		17	-1.6
		22	-0.2
		23	-0.3
	JULY	7/8	-0.1
		20/21	-1.0
	Aug	3	-0.4
1982	JUNE	13	-0.3
		18	-0.4
		20	-0.5
	JULY	17	-0.4
		30	-0.2
	AUG	6	-1.6
		16	-0.1
		17	-0.2
1983	JUNE	11	-0.3
	JUL	18	-0.6
1984	JUN	7	-0.1
	AUG	26	-1.6
	SEPT	2	1.7
	OCT	5	0.6
1985	APR	13	-0.5
	MAY	25	-0.1
	JUN	9	-1.6
	JUL	13	-0.2
		14	-0.5
	AUG	23	1.0
1986	JUN	24	0.6
	JUL	3	-2.8
		6	-0.4
		28	-0.4

FIG 4.2 (1982):

The flow and salinity graphs in this diagram show a very clear inverse relationship, with high flow periods matched almost exactly by strongly reduced salinities in response to rainfall events in the period April to July. However the 18.6 mm precipitation on 12th October had very little effect and must have been restricted to the C.C.A.

After a dry summer, a significant rain event of 74 mm on 7th April caused the low flow condition to increase to a peak of 1.135 m^3/s on the same day; subsequent rainfalls on 17th and 18th April of ±15 mm and on 27th of ±25 mm caused increased runoffs of 1.942 and 5.777 m^3/s. The reduced salinities during these latter runoff periods indicate a strong contribution from runoff in the mountains, followed by seepage from the soil with rising salinity. The rains in early June and July can clearly be correlated with higher runoffs on 7th June and 3rd July which are associated with lower salinities; the peaks are broad, and as in the previous example, are probably related to snowfalls and melting (TABLE 4.1).

As the rainfall lessened after the winter, flow diminished and salinity of the runoff increased to more than 450 mS/m by October. The rising salinity in the early part of October is turned into a slight decrease by the 18.6 rain in the C.C.A. on the 12th. This salinity level was maintained throughout most of the summer months, and began to drop at the end of December and into January of 1983 notwithstanding the fact that no rainfall was recorded.

This improvement in river water quality during the hottest part of the summer must be related to the return flow from irrigation (Le Chasseur canal water), because the flow in the upper part of the river had by this time ceased. Although salts are leached from newly developed shallow soils upon irrigation, a much greater volume of return flow is derived from the older, wider, sandy alluvial terraces in the lower reaches of the river. The better quality of this return flow appears to lower the salinity of the river at the measuring station during summer - a trend noted on all the hydrographs. (Based on figures from the farmers, 2 million cubic metres of irrigation water with an average TDS of ±100 mg/l is applied monthly during December and January.

FIG. 4.3 (1983):

The first important rain event of 21.3 mm occurred on 8th March; it must have been very localized because no change in flow or salinity was registered. The 25 mm event on 20th May caused a small increase in flow from 0.026 to 0.222 m^3/s and a sudden decrease in salinity from 358 to 90 mS/m. By the 21st May this again increased to 468 mS/m with decreased runoff.

The increase in runoff at the end of May, and the plateau extending into June is inexplicable; no rainfall was recorded, and temperatures were well above zero, eliminating the possibility of snowfalls. (The measuring device may have been faulty).

However, the 7.5mm C.C.A. average on 12th June (associated with snowfalls) brought a sharp drop in salinity. The rainfall events commencing on the 23rd June caused an ever increasing runoff response with peaks getting higher and higher in a similar way to that described in Fig 4.1, even though the volume of precipitation in each event declined as the winter progressed. The gradual decline of runoff through the first half of August was clearly associated with an increase in salinity of the water showing a good inverse correlation. From mid-August until 22nd September the graph gradually increases in salinity, being interrupted by decreases of short duration caused by small rainfall events such as that on 7th September.

Then on 22nd September, 34 mm was registered at Kasra in the southern part of the catchment, and the flow went from 0.093 to 11.11 m^3/s on the 23rd, causing a drop in salinity from 505 mS/m to 41 mS/m! This runoff declined rapidly, and on 3rd October was down to 0,505 m^3/s, when rainfall produced a new peak of 1.339 m^3/s and a drop in salinity. After this the salinity increased as runoff decreased again. A strong rainfall event (49 mm on Kasra) on 20th November brought little change in runoff, but a rise in salinity which later decreased again during December.

FIG. 4.4 (1984)

This was a year of exceptions. The salinity of the river water was low in the summer, rose to a high level in the winter, and fell again in the following summer months, contrary to the normal pattern.

The flow graph shows signs of malfunction in the logging device, as substantial rain events cause only small flow peaks to appear. (Compare the 62.7 mm of June 1983 causing a peak flow of 1.251 m^3/s and a total run-off for the month of 0.855 million cubic metres with the 59 mm of May 1984 causing a peak flow of 0.28 m^3/s and a total run-off for the month of 0.115 million cubic metres). The sluggishness of the measuring device is further demonstrated by the annual totals:

1983 rainfall	= 253.3 mm
1983 total runoff	= 7.229 $m^3 \times 10^6$
1984 rainfall	= 230.9 mm
1984 total runoff	= 1.184 $m^3 \times 10^6$

Runoff is naturally dependant not only on the total volume of rainfall but also on the intensity of the precipitation events. However, the decline in runoff during 1984 reflected on the measuring devices is too great to have been caused by variance in the nature of the precipitation, i.e. soft soaking drizzle instead of a few heavy storms. Rainfall was registered on 34 days in 1983 and on 26 days in 1984 giving totals of 253.3 and 230.9 mm respectively. The runoff of 1.184 $m^3 \times 10^6$ for 1984 clearly indicates a malfunction in the flow-measuring device at H4M18.

However, some peaks do appear, mostly associated with C.C.A. rainfalls events which increased the salinity. The sharp drop from 710 to 53 mS/m on 6th June occurred with no rain being recorded in the C.C.A., but a temperature of -0.1° C below freezing point and other factors indicate snow on the mountains at this time.

Lowering of the salinity between the 24th and 26th August occurred without any rainfall being measured in the C.C.A. The temperature dropped to -1.6 ° C, and snow was confirmed on records kept by Mr. Johannes Rabie of the farm Kasra. A further pronounced lowering of the runoff salinity took place between 5th and 7th October, when 42.1 mm rainfall was measured; snow was recorded, and the

salinity of the runoff remained low (± 120 mS/m) until the 17th, after which it increased to the normal summer level of ± 600 mS/m, before slowly declining through the rest of October, November and December with rainfall events having little effect on flow or salinity.

FIG 4.5 (1985)

The flow measuring device seems to have been repaired, and the salinity graph shows the normal pattern of high values in the summer months with a lowering during winter. The sharp decline from 478 to 139 mS/m on 20th August co-incides with a snow event in the mountains without rainfall recorded in the C.C.A.

The rainfall events in the summer months from January to the 6th April had little effect on the runoff and its salinity. Then, on 13th April an increase in flow and sharp decrease of salinity was recorded, without any rainfall in the C.C.A. Such a set of circumstances could be caused by a cessation of irrigation by farmers with a resulting strong flow of canal reject before the water was closed off at Brandvlei or Le Chasseur, or by mountain rain or snowfalls. The temperature of -0.5 ° C and other climatic factors such as cloud cover and freezing levels below 1 500 metres point to the latter. Similar situations developed on 7th May, 25th May and 23rd August.

Whenever strong rain events occurred in the C.C.A. during June, July, August, October and November, the runoff increased immediately and generally declined in salinity. A notable exception was seen on 5th July when the salinity rose from 60 to 244 mS/m after 57 mm of rain, probably restricted to the C.C.A., which caused strong flushing of soils in the catchment with limited runoff from the mountains. August and September are the months during which irrigation is commenced in the valley, and nearly 16 million cubic metres of water are applied per month. On figures 4.2, 4.3 and 4.5 the rising trend of runoff salinity at H4M18 can clearly be seen during these months. There seems to be an increase in salt load even though the runoff remains constant, which suggests that subsoil salts are dissolved by the irrigation water and flushed into drainage lines and eventually the river. Chemical analyses of irrigation and irrigation return flow are presented in Section 8 of this report.

FIG. 4.6 (1986)

Unfortunately a break in flow data occurred in July and August.

Nevertheless a number of features are still evident: the very sharp drop in salinity from 388 to 53 mS/m on 28th April when no rain fell in the C.C.A., and the minimum temperatures remained well above O°C; this coincided with an increase in runoff far in excess of that caused by rain events in February, March and mid-April. The reason for this probably lies in a large flow of canal reject from the end of the Le Chasseur canal, similar to that identified in April 1985.

Snow and rainfall in June, July and August (TABLE 4.1) kept bringing the salinity down, but the rainfall events at the end of August seem to have caused sharp increases probably as a result of soil flushing in the C.C.A.

Nevertheless, 22 mm rainfall on 11th September lowered the salinity levels because the rain was concentrated in the southern part of the catchment (Riviersonderend Mountains); similar events occurred later in September and in October.

A graph showing weekly TDS measurements is included at the bottom of Fig. 4.6. Although there is some correlation, many important salinity fluctuations are totally absent, underlining the value of a program of daily salinity measurements.

4.2 Cumulative flow volumes passing H4M18

Total monthly and annual flow volumes were determined from the daily data supplied by the H.R.I., and are shown in TABLE 4.2A.

TABLE 4.2A MONTHLY AND ANNUAL FLOWS ($m^3 \times 10^6$)

MONTH	YEAR:						
	1980	1981	1982	1983	1984	1985	1986
JAN	- *	2.013+	0.105	0.056*	0.07x	0.060x	0.072
FEB	- *	1.305	0.061	0.070	0.055x	0.048x	0.047
MAR	- *	0.241	0.067	0.071	0.148x	0.054x	0.060
APR	- *	0.388	1.705+	0.072	0.116x	0.111	0.130
MAY	- *	0.509	0.917	0.115	0.147x	0.177	0.518
JUN	0.269	0.962	0.855	0.772	0.151x	0.567	0.812
JUL	0.293	1.198	1.286	2.142	0.091x	1.316	- *
AUG	0.265	2.207	0.271	0.876	0.139x	0.878	0.726
SEPT	0.123	3.718	0.268	2.387+	0.155x	0.158	0.590
OCT	0.102	0.436	0.188	0.816	0.532x	0.885	- *
NOV	0.100	0.212	0.127	0.076*	0.086x	0.651	- *
DEC	0.113	0.118	0.095	0.075*	0.061x	0.228	- *
TOTAL:	1.265*	13.307	5.945+	7.528*	1.751x	5.133x	2.955*

* = Break in data.
+ = Measuring capacity of station exceeded.
x = Measuring device suspected to be faulty.

Unfortunately gaps in the data record and faulty measurements affect the totals in most years, but a comparison of input from rainfall and the Le Chasseur canal may be compared with the flow figures:

TABLE 4.2B ANNUAL INPUT AND OUTFLOW OF WATER IN MILLIONS OF CUBIC METRES

YEAR	TOTAL RAIN (TABLE 2.2)	IRRIGATION WATER	TOTAL INPUT	TOTAL OUTFLOW	$\frac{\text{TOTAL OUTFLOW}}{\text{TOTAL INPUT}} \times \frac{100}{1}$
1980	63.63	6.78	70.417	1.265*	not calculated
1981	112.49	6.78	119.27	13.307	11.16
1982	75.77	6.78	82.55	5.945	7.2
1983	82.57	6.78	89.35	7.528	8.42
1984	75.27	6.78	82.05	1.751*	not calculated
1985	100.22	6.78	107.00	5.133	(4.79)
1986	76.35	6.78	83.13	2.955*	not calculated
AVERAGE	83.76	6.78	90.54	7.978	8.93

* = DATA LARGELY INACCURATE OR INCOMPLETE

The flow measuring device appears to have been faulty during the first 3½ months of 1985, because substantial rainfall events made almost no impression on the graph. The total of 5.133 $m^3 \times 10^6$ therefore appears to be too low, being only 4.79% of the total input of 107 $m^3 \times 10^6$. (This figure is therefore discarded.)

Using the three years when the device seems to have been working properly, i.e. 1981, 1982 and 1983, the average percentage of outflow to input works out at 8.93% which is similar to, but still lower than that calculated from the figures of Hasenjager (9.4 $m^3 \times 10^6$) in section 3.2:

i.e.: $\frac{9.4}{90.54} \times 100 = 10.38\%$

These calculations indicate that ± 9 to 10% of the total input to the catchment appears to flow over the measuring weir at H4M18, on its way to the Breë River.

It would be most useful to have accurate values for the total infiltration of rainfall into the subsoil and bedrock of all parts of the catchment, but such volumes are not directly measurable. The shape of the groundwater table within the fractured and faulted mountainous part of the catchment is not known either, and the assessment of losses of water by lateral movement to areas outside the catchment can only be guessed at. Very little infiltration takes place when rain falls on areas of shale outcrop, since these are decomposed to a dense, clay-rich mass below the soil, which causes lateral runoff. Where sandstone and siltstone formations are exposed, a fair proportion actually enters the bedrock through fractures and joints, particularly during periods of light, extended rainfall. The well-jointed and sometimes coarse sandstone of the mountain watershed are responsible for most of the infiltration which recharges the groundwater reservoir of the valley. The fact that most of the sandstone beds dip inwards towards the valley suggests that very little infiltrated water escapes from the catchment through the mountain areas, but that water may actually be added to the groundwater of the valley during the summer months when southeasterly winds drive rainclouds onto the Riviersonderend Mountains along the southern boundary of the catchment, and infiltration into the jointed sandstone takes place.

Losses of water from the catchment through faults and fractures in the bedrock are more likely to occur through the lowermost, eastern end of the valley. The Sewefontein Fault is an example of such a permeable, subsurface aquifer.

Fracturing of bedrock quartzites in association with faulting, as found in borehole A2, provides many smaller, open passageways for the escape of water through this end of the valley below the groundwater table. To quantify this subsurface outflow one needs to subtract the total surface outflow and evapotranspiration from the total input (rainfall and canal water). Complicating factors are naturally provided by springs, artesian boreholes and pumped boreholes. Class A pan evaporation values for the central part of the catchment are in excess of 2 000 mm per annum, far in excess of the total water input to the valley. Since most of the variables are difficult to measure, a model to simulate the quantities can be very useful, especially since the measuring weir at Le Chasseur gives a good value for the total outflow.

Work by W. Flügel in the central part of the Breë River (1989) shows that a significant volume of 52 l/s flows into the river through shallow alluvial gravel and sand layers on both banks along a 58 kilometre stretch of river between two weirs (H4M17 and H5MO4), but that this is only 0.5% of the total groundwater flow; the other 99.5% moves mainly through the fractured Bokkeveld Bedrock at a rate of 9.91 m^3/S.

This flow rate, calculated for a total riverbank length of 116 kilometres, gives a unit inflow of 0.085 m^3/S per kilometre of riverbank at an average groundwater table gradient of 0.1% (Flügel, 1989).

In the abovementioned investigation the groundwater contribution by individual fault zones which cross the Breë River channel below the alluvium have not been evaluated, and the results give an integrated assessment of groundwater inflow from all possible sources. Drilling on farms such as Highlands, Madeba and De Wilgen which adjoin the Breë River has produced groundwater yields in excess of 30 l/s (108 m^3 per hour) from individual fault zones which strike NW-SE and cross the river.

One of these, the Sewefontein Fault, is capable of carrying a considerable volume of outflow from the PRC* through its northeastern end, assisted by a large group of NE striking fracture-zones which run parallel to the Poesjesnels River. This is a water volume component which must be included in any geohydrolgic flow model for such a catchment. (Confirmed by Prof. A . Herrmann, 1989, Pers. comm.). More about this in Section 10.

4.3 Salt Load passing H4M18

The salt load in the Poesjesnels River passing the gauging station H4M18 is made up of:

a. dissolved salt in Le Chasseur canal water used for irrigation
b. salts dissolved from the soils and underlying materials within the catchment by rainfall and irrigation.

The salt load contributed by the Le Chasseur canal running at a mean TDS of 100

* PRC = Poesjesnels River Catchment

mg/l, amounts to an average of 678 tons per annum.

Monthly and annual figures for the total salt load in the runoff passing H4M18 were calculated from the HRI measurements of average daily flow (m^3/s) and daily conductivity (mS/m). Unfortunately instrument malfunction caused some poor results and even total absence of data in places, and these had to be patched (by linear interpolation) when trying to ascertain the total movement of dissolved salt in the river. Results are given in TABLE 4.3:

TABLE 4.3 Monthly and Annual Salt Loads passing H4M18 in metric tons

MONTH	YEAR:					
	1981	1982	1983	1984	1985	1986
JANUARY	(920)	176	136	103+	155+	142
FEBRUARY	(1220)	92	128	87+	124+	101
MARCH	406	117	136	139+	150+	136
APRIL	391	1669	139	132+	195	262
MAY	607	1362	191	314+	195	228
JUNE	743	923	789	425+	242	266
JULY	(800)	1108	1494	376+	1268	(1500)
AUGUST	1595	535	827	478+	769	1686
SEPTEMBER	1766	660	1652	591+	562	1062
OCTOBER	850	493	1241	894+	1840	(800)
NOVEMBER	416	329	390	241+	962	(300)
DECEMBER	174	228	195	159+	326	(200)
TOTAL:	9888	7692	7318	3939+	6788+	6683
MINUS SALT CONTRIBUTED BY IRRIGATION	-678	-678	-678	-678	-678	-678
PRODUCED BY CATCHMENT =	9210	7014	6640	3261+	6110+	6005
TOTAL CCA RAINFALL:	345.1 mm	232.4 mm	253.3 mm	230.9 mm	307.4 mm	234.2 mm

( ) = estimated figures, patched data.

+ tonnage too low because daily flow data incorrect

NB. Total rainfall 1979 = 163.4 mm and 1980 = 195.2 mm (i.e. very dry years)

The average annual salt load passing H4M18 between 1981 and 1986 (disregarding 1984) amounts to 7674 tons, according to the HRI daily flow and salinity data.

This salt load is made up of the following increments:

A. Salt dissolved from the atmosphere by rain water which falls in the catchment.

B. Dissolved salt in the Le Chasseur canal water entering the valley for irrigation.

C. Leaching of humic acids, connate salts and the ions produced by weathering of feldspars by runoff and unsaturated seepage in the Table Mountain Sandstone areas after rainfall. (area = 99 km^2)

D. Leaching of salts by runoff and seepage, after rainfall on virgin soils overlying Bokkeveld shales and siltstones. (area = 88 km^2)

E. Salts leached from cultivated soils on Bokkeveld bedrock (no irrigation) in response to rainfall, by runoff and unsaturated seepage. (area = 10 km^2 or) 1 000 ha

F. Salts leached from irrigated soils on Bokkeveld bedrock in response to rainfall and irrigation by runoff, seepage and return flow. (area = 400 ha)

G. Salts leached from irrigated soils on alluvium alongside the rivers and streams of the valley in response to rainfall and irrigation by runoff, seepage and return flow. (area = 1 400 ha)

H. Salts leached from uncultivated soils on alluvium in response to rainfall by runoff and seepage. (area = 1 200 ha)

I. Salts dissolved in groundwater seepage entering the river from the saturated zone in decomposed and fresh bedrock. The groundwater movement has lateral as well as upward vectors, utilizing faults and fractures incised by the river.

Each of these increments produce different amounts of salt due to differences in water applied, materials leached and runoff and seepage characteristics. The following tonnages of salt are determined for each increment, using lumped parameters and making use of the best possible assumptions based on research done in the valley and adjoining areas in order to assist in the establishment of a proposed geohydrologic model for the valley:

A = 837.6 tons (The mean annual rainfall volume of 83.76 m^3 x 10^6 multiplied by the average TDS which is taken as 10 mg/l following Van Wyk, 1988)

B = 678 tons (6.78 m^3 x 10^6 of canal water at an average TDS of 100 mg/l)

C = 396 tons (based on 20% runoff and seepage from this 99 km^2 area after 500 mm mean annual rainfall, deduced from the 1:250 000 Isohyetal Map for the area 3319 Worcester (1988) and the discussion in Section 2.2; the average TDS gain of this water is 40 mg/l.)

D = 652.3 tons (257 mm rainfall on 88 km^2 area with 5% runoff and seepage and a gain in TDS of 500 mg/l.)

E = 514 tons (257 mm rainfall on 1 000 ha area with 10 % runoff and seepage and a gain in TDS of 2 000 mg/l.)

F = 554 tons (257 mm rainfall on 400 ha area with 10 % runoff and seepage and a gain of in TDS of 5 390 mg/l.*)

plus 1 513.5 tons (702 mm irrigation applied to 400 ha with 10 % runoff and seepage and a gain in TDS of 5 390 mg/l.*)

* *(This TDS value concentration is the mean of the two values:*

(i) the average salinity increase in irrigation return flow over initially applied irrigation at stations IR4, IR5, IR9 and IR10 over a 15-month period, i.e. 5 600 mg/l, and

(ii) the average salinity increase in the seepage at points 3, 4, 6, 7 and 8 after the 40 mm rainfall event at De Wilgen described in Section 7.2, i.e. 5180 mg/l.)

G. = 431.8 tons (257 mm rainfall on 1 400 ha area with 10% runoff and seepage and a gain in TDS of 1 200 mg/l)

plus 1 179.4 tons (702 mm irrigation on 1 400 ha area with 10% runoff and seepage and a gain in TDS of 1 200 mg/l)

H = 308.4 tons (257 mm rainfall on 1 200 ha area with 10% runoff and seepage and a gain in TDS of 1 000 mg/l)

I = 609 tons (slow seepage through faults and fractures along the length of the Poesjesnels River of 203 000 m^3 of groundwater per annum with an average TDS of 3 000 mg/l. This includes lateral movement towards the river of groundwater in the riverbank areas under the influence of the GWT in the immediate vicinity of the river (± 1 - 2 km), and also water welling up along faults under the influence of a head of pressure produced by the elevated GWT in the encircling mountains)

TOTAL = 7674 tons per annum

The volume of groundwater inflow is determined from the salt mass balance after the increments A to H are subtracted from the total salt tonnage per annum. This volume will be compared with groundwater flow volumes determined by other methods in sections 5, 9, 10 and 11.

Results in Section 6 show that different amounts of salt are produced by the various soil and bedrock types in the valley. Based on the tonnages listed above, the weight in grams of salt produced per annum by leaching of the soil to an average depth of 1.5 m (below which depth more impervious layers of clay or decomposed bedrock exist) in response to the mean annual rainfall of 257 mm is as follows:

Increments:	Area (ha)	kg/ha	g/m^3 of soil
C (mountain soils)	9 900	40.00	2.67
D (Bokkeveld natural)	8 800	74.13	4.94
E (Bokkeveld cultivated)	1 000	514.00	34.00
F (Bokkeveld irrigated)	400	1 385.00	92.00
G (Alluvial irrigated)	1 400	308.00	21.00
H (Alluvial uncultivated)	1 200	257.00	17.13

Leaching by 702 mm irrigation water gives the following results:

Increments:	Area (ha)	kg/ha	g/m^3 of soil
F (Bokkeveld irrigated)	400	3 783.75	252.25
G (Alluvial irrigated)	1 400	842.42	56.16

Bokkeveld soils (F) are clearly the most saline, producing 92 grams and 252.25 grams to give a total of 344.25 grams of salt per cubic metre in irrigated areas per annum while irrigated alluvial areas (G) produce 21 grams and 56.16 grams for a total of 77.16 grams of salt per cubic metre.

4.4 Salinity profile in the Poesjesnels River

During the initial stage of the research, 41 sampling stations were selected at ±500 metre intervals extending from Mountain View farm downstream to the confluence with the Breë River (App. Fig. 2.4t). River water samples were taken at these stations at the beginning of every month, over a period of three years (1983 to 1985) and analyzed for their total salt content. Some were selected for principal chemical component analysis. This sampling program was carried out in order to identify the parts of the valley producing the greatest amount of saline

runoff, so that a borehole investigation of subsurface materials could be concentrated in the more critical areas.

The total dissolved salt content of the river water showed very large seasonal variations, with high TDS values in summer when the river ceased to flow and pools had to be sampled or holes had to be dug through the sandy bed to reach some water. These results are of academic interest only and cannot be used for salt load or balance calculations.

Two typical salinity profiles from Mountain View to the measuring weir H4M18 at the Le Chasseur bridge are shown in App. Fig. 2.9; one was sampled during August 1983 after good winter rainfall, the other during February 1984 in the following summer. In both cases low TDS values are present in the upper part of the valley between stations 0 and 10. Below station 10, a weir in the river deflects water into an irrigation canal which also feeds a number of dams. During the summer months very little water is encountered at the sampling stations immediately below this weir; a few isolated pools exist, and a small amount of subsurface flow takes place within the sandy, alluvial deposits on the riverbed. Conditions and materials which were encountered at the sampling points during February 1984 are described in TABLE 4.4 and explain the extremely high TDS values measured in the laboratory:

TABEL 4.4 CONDITIONS (FEBRUARY 1984) IN THE POESJESNELS RIVER DURING A TYPICAL SAMPLING RUN FROM MOUNTAIN VIEW TO THE JUNCTIONS WITH THE BREE RIVER. (500 m intervals)

SAMPLING STATION	DESCRIPTION OF RIVER FLOW AND MATERIALS
0.	Clean water flowing at ±150 per minute over a bed of TMS cobbles and boulders.
1.	Same as above. Flow volume ±200 litres per minute.
2.	Fast flowing steam over TMS cobbles ±200 litres per minute.
3.	±200 l/min. flowing over sand and gravel. Many plants encroaching into stream.
4.	Clean water flowing at 100 - 150 l/min over TMS gravel.
5.	Clear water flowing more slowly at ±120 l/min over sand and TMS gravel.
6.	Same as above.
7.	Clear water flowing at 150 - 200 l/min over sandy bed. Banks covered with grass and reeds.
8.	Clear water flowing at 150 - 200 l/min over algae covered sandy bed. Grass and reeds on banks.
9.	Stronger flow of ±250 l/min over sandy bed covered with algae.
10.	Slightly muddy water flowing slowly at 100 l/min over sand bed.
11.	No flow discerned. Pools of water are standing in a sandy bed with TMS gravel.
12.	No water seen in sand covered bed. Water sample taken in isolated hole full of reeds and reedgrass.
13.	Shallow pools of water in sandy bed. Many reeds.
14.	Sandy riverbed. Had to dig 0.8 m in order to sample water.
15.	Sandy riverbed. Had to dig in dry water hole to obtain sample.
16.	Water standing amongst reeds. No flow discerned.
17.	Riverbed dry. Sample taken in waterhole.
18.	Water standing between cobbles and silt banks, which show white salt deposits.
19.	Dry riverbed. Excavated 0.5 m for sample.
20.	Dry riverbed. Excavated 0.3 m in sand for sample.
21.	Standing water amongst reeds covered with algae.
22.	Dry riverbed with many reeds. Dug through a layer of clay into sand for sample at 0.5m.
23.	Same as above.
24.	Dry riverbed covered with reeds. Sample taken in waterhole.
25.	Same as above.
26.	Same as above.
27.	Clayey riverbed covered with reeds. Water seen flowing at ±20 l/min.
28.	Muddy bed covered with reeds. Sample taken at depth of ±0.25m.
29.	Riverbed covered by reeds. TMS covered by 0.4m of silt provide flow medium for water.
30.	Dry channel covered by reeds. Excavate 0.5m.
31.	Waterhole in muddy riverbed covered by reeds.
32.	Riverbed of sand and boulders, with standing water covered by algae.
33.	Sand and boulder bed with water flowing at 10 l/min. Much algae.
34.	Weir in river; water flow ±30 l/min. Reeds on bank.
35.	Sandy riverbed with flow of ±70 l/min. Reeds on bank.
36.	At H4M18 gauging station. Flow ±150 l/min.
37.	Sandy bottom with reed covered banks between vineyards. Flow ±200 l/min.
38.	Same as above.
39.	Reeds in riverbed. Slow flow of water ±100 l/min.
40.	Standing water amongst reeds at junction with Breë River.

Below sampling station 32 the floodplain begins to widen, a larger area is under irrigation and the increased volume of return flow reaches the river to be seen as a stream of water again, becoming stronger as it approaches the Breë River.

The pH values also show a well defined increase from acidic conditions in the upper part of the valley (close to sandstone slopes) becoming neutral between sampling stations 10 and 12, and then becoming more and more alkaline as the water flows downstream.

The pH increase from ± 6.00 to 8.65 generally coincides with an increase in the TDS of the river particularly well seen in the August 1983 profile. The reduction of TDS from 1835 mg/l at S.St.* 23 to 456 mg/l at S.St. 24 coincides with a pH drop from 8.03 to 7.95; a similar situation is seen at S.St. 31 and 32. (App. Fig. 2.9B). The fluctuations in TDS and pH values along the river profile probably stem from inflow of rainfall runoff along tributary streams during winter and spring, especially if these drain Table Mountain Sandstone areas. In summer the values fluctuate between high salinities caused by base-flow seepage, irrigation return flow and evaporation from static pools. A further variation is introduced by the periodic overflow of low salinity excess water from the Le Chasseur canal with a pH of ± 6.5 in the vicinity of S.St. 22 and 23.

The bedrock which is traversed by the river may exert some influence as well. The gently eastward-dipping Hex River sandstone (C2Q2) of the Bokkeveld Group, cut by the De Fontein and Bellevue faults (possibly connected to the Sewefontein fault) lies below and alongside S.St. 22-24 (in the vicinity of section line L-L") and could be responsible for upward seepage of low- pH water under artesian pressure following the period of winter recharge.

The main tributary of the Poesjesnels River is the Poespasvlei River which is joined by the Rietvlei River before it enters the Poesjesnels from the south between S.St. 20 and 21. The water in this river has a low salinity (average TDS over a two-year period = 550 mg/l at an average pH of 7.34) as measured at the sampling station PPV (see App. TABLE 4.5)

*S.St. = sampling station

The water in the Rietvlei River is more saline, particularly during the summer months (with a two-year average TDS of 2718.3 mg/l and pH of 8.2), reflecting the presence of much calcrete and lime in the shaly topsoil of this subcatchment, and the salinity of a borehole on the farm Kasra (2044 mg/l) which is pumped at a rate of 30 m^3 per hour for irrigation purposes. The alkaline nature of this mineralized water is particularly evident in irrigation return flow analyses which show abnormally high $Ca(HCO_3)_2$ and $CaSO_4$ figures, and suggest gypsum applications by farmers. (This latter aspect was not investigated).

The result of this inflow to the main stream is seen on App. Fig. 2.9 (section C) as a drop in salinity together with a rise in pH, but during the summer conditions are highly variable along the river which is reduced to a series of pools of water with very little flow taking place.

4.5 Principal Component Chemistry

In order to evaluate the possible variation in chemistry of the Poesjesnels River during the year, 22 samples were selected from the 40 mentioned above and analyzed for the principal components Ca^{++}, Mg^{++}, Na^{+} and K^{+} (by atomic absorption) and HCO_3^-, Cl^-, $SO_4^=$ and NO_3^- (by specific electrode ionalyzer). Samples taken each month from the Rietvlei, Poespasvlei and Mosiesleegte Rivers and artesian boreholes B2 and B4 were included as they become available.

The results of this long term analytical program are given in App. TABLE 4.5, together with the pH and TDS values and the percentage error in the balance between cation and anion milli-equivalent totals. Lists of milli-equivalents are not included in this report, but these figures were calculated and used to plot Piper and Durov trilinear and rectilinear diagrams by means of the Data General computer at Steffen, Robertson and Kirsten in Johannesburg. (See Section 8).

Monthly variations in the milli-equivalent percentages of cations, anions and related salt groups in the river water at H4M18 during the period 1983 to 1985 may be seen on a histogram (App. Fig. 4.7). The histogram shows that:

a. $Na^{+} >> Mg^{++} > Ca^{++} > K^{+}$

b. $Cl^{-} >> SO_4^{=} > HCO_3^{-} > NO_3^{-}$

A seasonal variation in ionic percentages is also noticeable:

c. Na^+ appears to increase at the cost of Mg^{++} and Ca^{++} during and after the winter rainfall (from June to November) and has lower percentages during the period December to May.

d. Cl^- shows a similar trend, having higher percentages relative to $SO_4^=$ and HCO_3^- during the winter and spring months and lower percentages during late summer and autumn.

These trends are enhanced if the milli-equivalent percentages of the ions are combined into related salt groups such as NaCl, Mg SO_4 and Ca $(HCO)_3$ or Ca CO_3 (see the third histogram). It appears that $MgSO_4$ remains more or less constant but that NaCl varies inversely with $CaCO_3$. Strong post-winter river flows carry higher NaCl percentages and lower $CaCO_3$, with the opposite being true in summer during the irrigation phase.

The higher calcium content of the runoff water during the summer irrigation months is probably produced by:

1. the dissolution at higher summer temperatures of a small part of the calcrete in the soils overlying Bokkeveld shales during irrigation,
2. the application of gypsum by farmers to the more sandy, acidic alluvial soils along the river,
3. a small amount of dissolution of calcium from the concrete lining of the Le Chasseur canal by low-pH water as it moves from the Brandvlei Dam to the Wansbek Farms in the Poesjesnels catchment and
4. more substantial leaching of NaCl by the larger volume of water falling on the soils of the catchment during the wet winter months. (NaCl has a higher solubility coefficient and greater mobility in the soil profile).

5. THE DRILLING PROGRAM

In order to gain insight into the possible sources of salinity in the subsurface materials in the valley and to examine the chemistry and movements of groundwater, a number of boreholes were sunk into the bedrock on pre-determined profile lines (App. Fig. 2.3 A to F, App. FIG 2.4 t and FIG 5.1A - E).

Three types of boreholes were used to give as much information as possible:

(a) 150 mm diameter percussion boreholes drilled to 100m (deep holes) or to ±35m (observation holes).

(b) 50 mm diameter (NX) diamond core boreholes drilled to a depth of 50m at five of the profile areas.

(c) 300 mm auger holes drilled to a maximum depth of 4m, giving soil samples at 20 cm intervals.

Some trenches were also excavated, and attempts made to investigate lateral flow of water through the soil after irrigation, but without much success due to anomalous flows along termite tunnels in the soil, followed by collapse of the sidewalls.

5.1 Selection of areas for borehole investigation

Six areas in the valley were selected after discussions with research colleagues such as Dr J.H. Moolman, and Messrs A.H.M. Görgens and A. Stone. The six areas were chosen in order to sample the greatest variety of situations regarding soil type, slope, agricultural development and position along the length of the valley, while at the same time investigating river bank areas immediately adjacent to those parts of the river where sampling had shown strongly increased salinity in the water.

AREA OR LINE A (on profile section J-J", App. Figs. 2.3 F; 2.4 t)

This area was chosen because it contained undeveloped land hitherto used only for grazing, and the owner had indicated that he would be ploughing it in a few years time and using it for the cultivation of vines under irrigation. It was felt that this area would provide a chance to investigate the distribution of salt in the undisturbed soil column and the salinity of the seepage/runoff into the Mosiesleegte River before the ploughing and compare these with the situation after the ploughing.

A transect through this area would furthermore be situated in the lower formations of the Bokkeveld Group, near the TMS contact, and provide data on the eastern part of the catchment, south of the Poesjesnels River.

AREA OR LINE B (on profile section K'-K", App. Figs. 2.3 E; 2.4t)

Having found a strong increase in the salinity of the river in the vicinity of sst 26 and 27, and noting the well developed cultivation, a transect was planned immediately above these sampling stations, in close proximity to some fruit orchards.

Furthermore, the upper formations of the Bokkeveld Group would be intersected. This line was later extended to the right bank on the southern side of the river.

AREAS OR LINES C AND D (on profile section L-L", App. Figs. 2.3 D; 2.4t)

These areas were chosen to investigate the left and right banks of the river above stations 22 and 23 where high salinities were registered during the early part of 1983, irrigation of lucerne was being practiced and a marked difference in morphology existed. (The left bank is low-lying and covered in alluvial gravel and sand, while the right bank consists of an elevated terrace with shallow soil and gravel overlying shale formations from the middle of the Bokkeveld Group.)

AREA OR LINE E: (East of hill M', App. Figs. 2.3C; 2.4t)

This area adjacent to the Rietvlei River was selected because earlier research (Greeff, 1978) had shown the Rietvlei Valley to be a source of much salinity, with

boreholes in the Bokkeveld bedrock producing water containing nearly 3 000 mg/l. While the profile lines in the other areas were set out perpendicular to the Poesjesnels River and thus at right angles to the strike of the folded Bokkeveld formations, the profile line in this areas was set out perpendicular to the north flowing Rietvlei River and therefore more or less parallel to the strike. This orientation would make it possible to investigate any flow of groundwater along bedding plane joints or flexure hollows associated with folding of an interlayered sequence of shale and sandstone beds which vary in competence.

These flexure hollows, longitudinally associated with crests or troughs of folds, are known to carry substantial amounts of water in Bokkeveld bedrock of this area.

AREAS OR LINE F: (on profile section M-M", App. Figs. 2.3 B; 2.4t)

This area was selected after discussions with Mr. M. Vandoolhaege of the Dept. of Water Affairs in Cape Town, who agreed that we should try to place boreholes into Bokkeveld rocks where these have been disturbed by major faults. The presence of the Sewefontein Fault through the upper part of the valley was roughly known, and the boreholes on this transect were sited in an attempt to intersect some faulted material. In the event, the boreholes penetrated extremely dense unfractured shale with very poor water deliveries in a wedge of bedrock between the Sewefontein and Rabie Faults.

5.2 The percussion borehole investigation (App. Fig. 5)

Two transects (groups of boreholes) were planned for each profile line passing through areas A to E.

5.2.1 Pattern of drilling on each transect (Fig. 5.1 and FIG 5.1A - E)

a. One deep hole was drilled down to 100 metres at the lower end of the transect.

b. Six shallower holes were then drilled upslope from the deep borehole to depths of ± 35 metres (i.e. at least 15 m below the groundwater table). These would be used as monitor holes during pump tests, and also for tracer experiments to measure the natural migration velocities of ground-

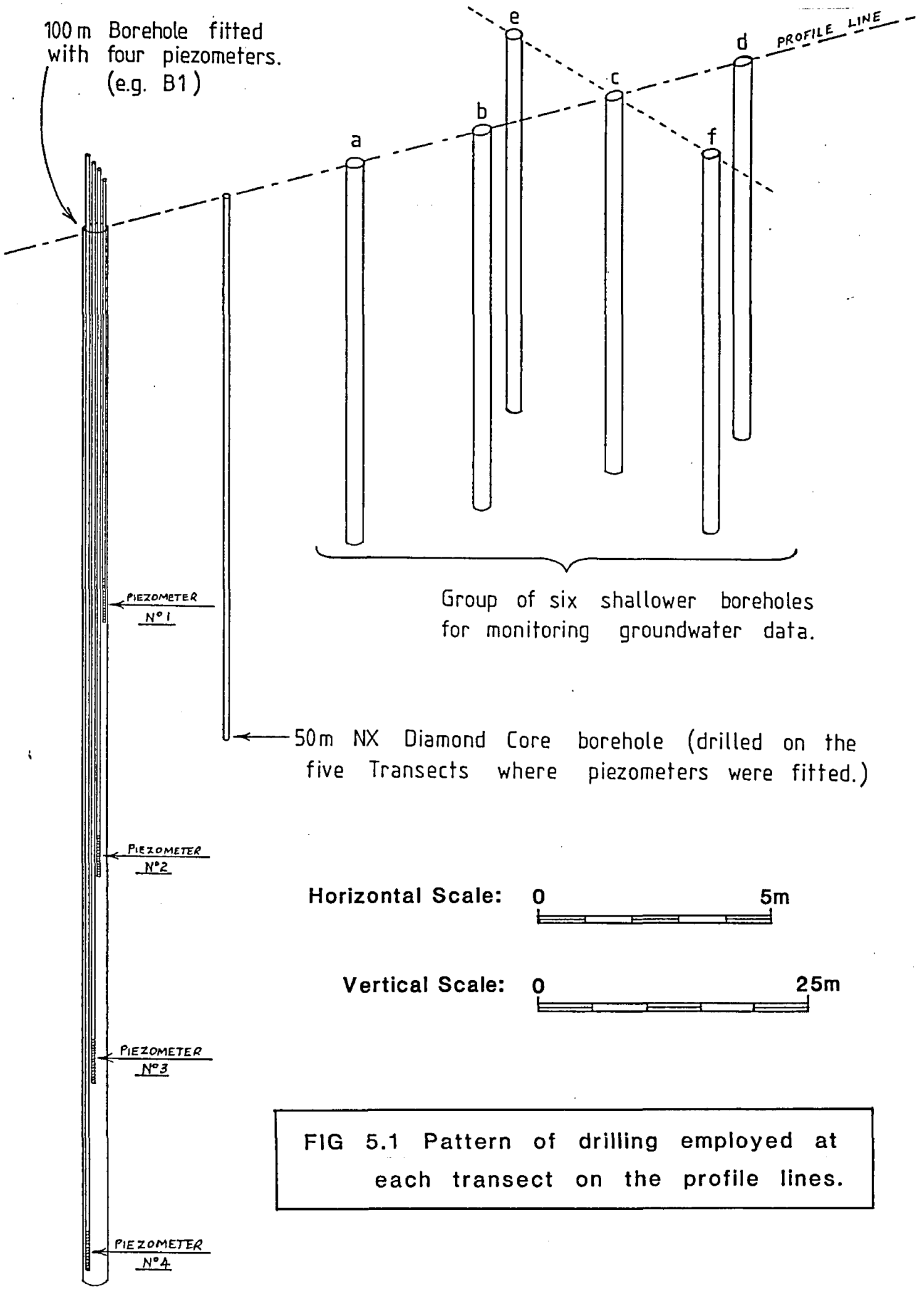

FIG 5.1 Pattern of drilling employed at each transect on the profile lines.

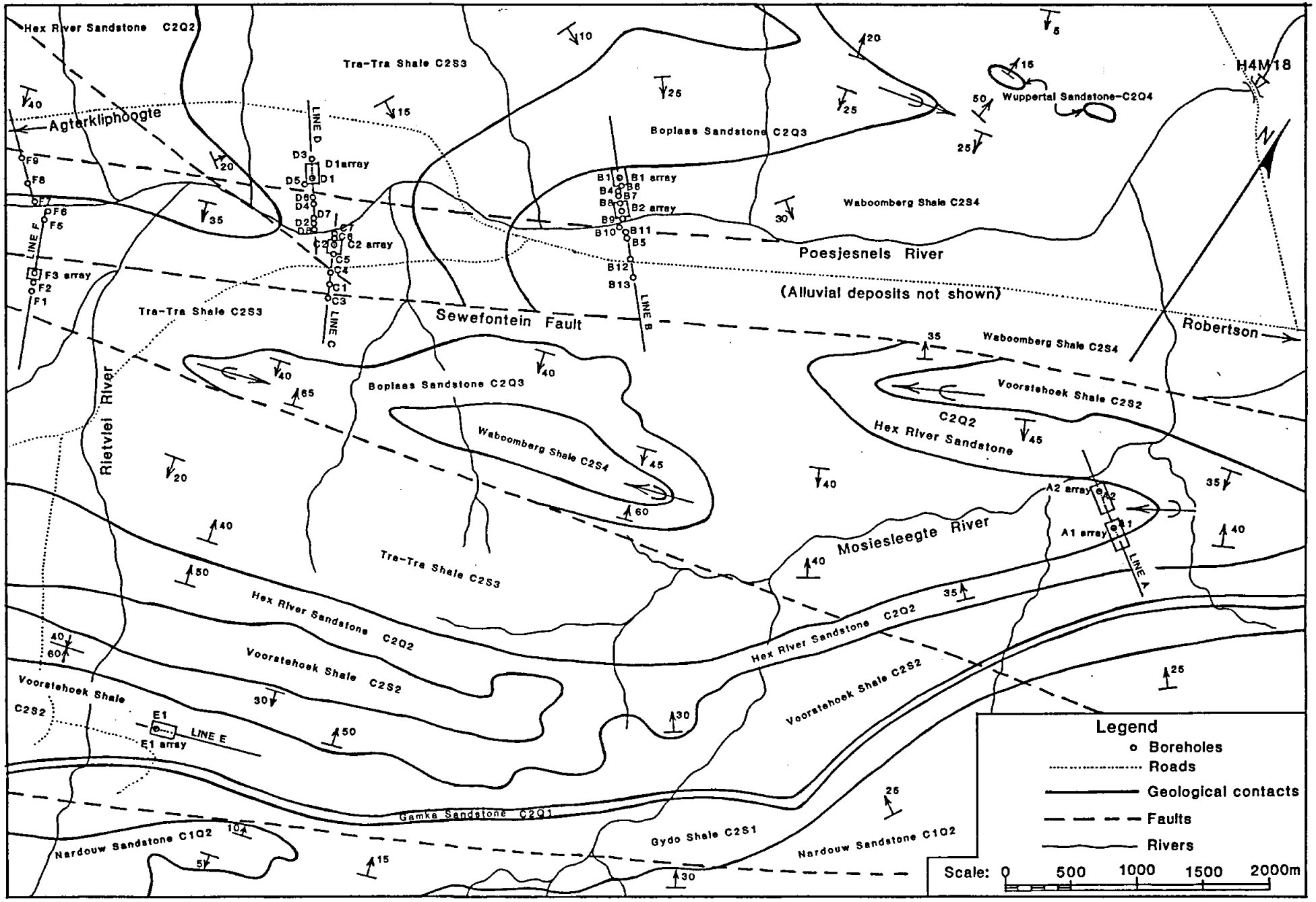

FIG 5.1A Map showing positions of the Borehole Transect Lines and Geological Formations in the lower Poesjesnels River Valley.

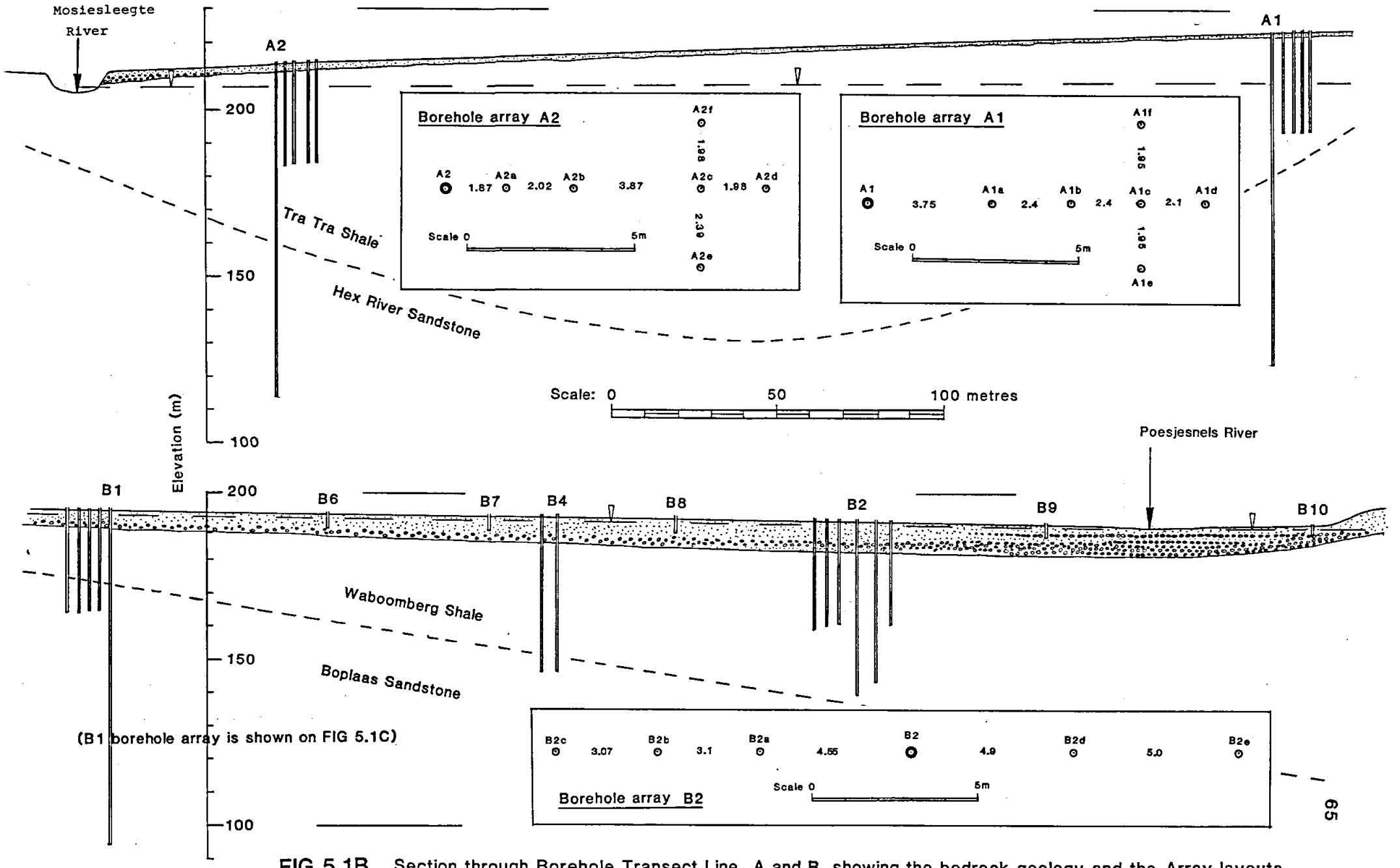

FIG 5.1B Section through Borehole Transect Line A and B showing the bedrock geology and the Array layouts

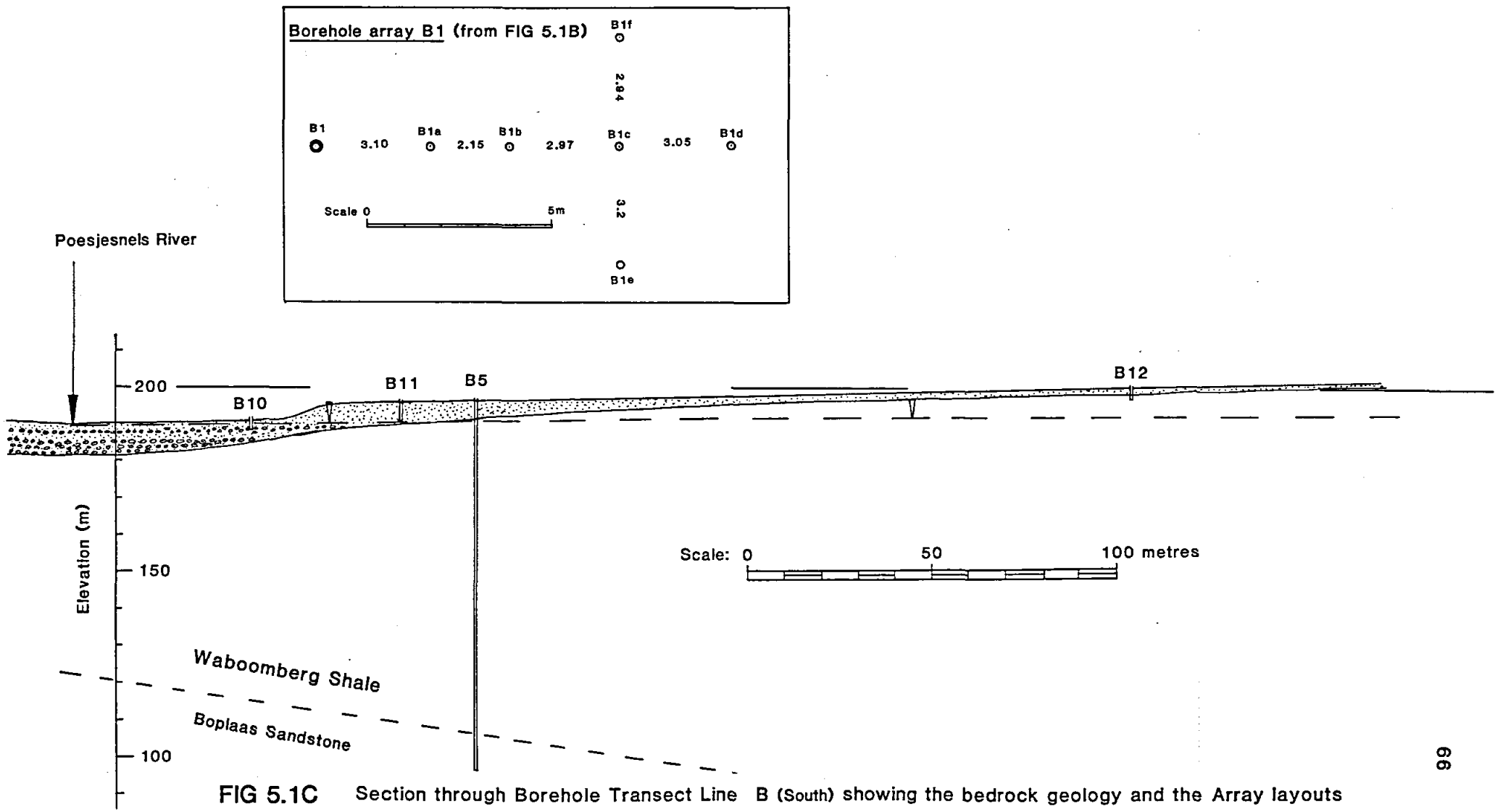

FIG 5.1C Section through Borehole Transect Line B (South) showing the bedrock geology and the Array layouts

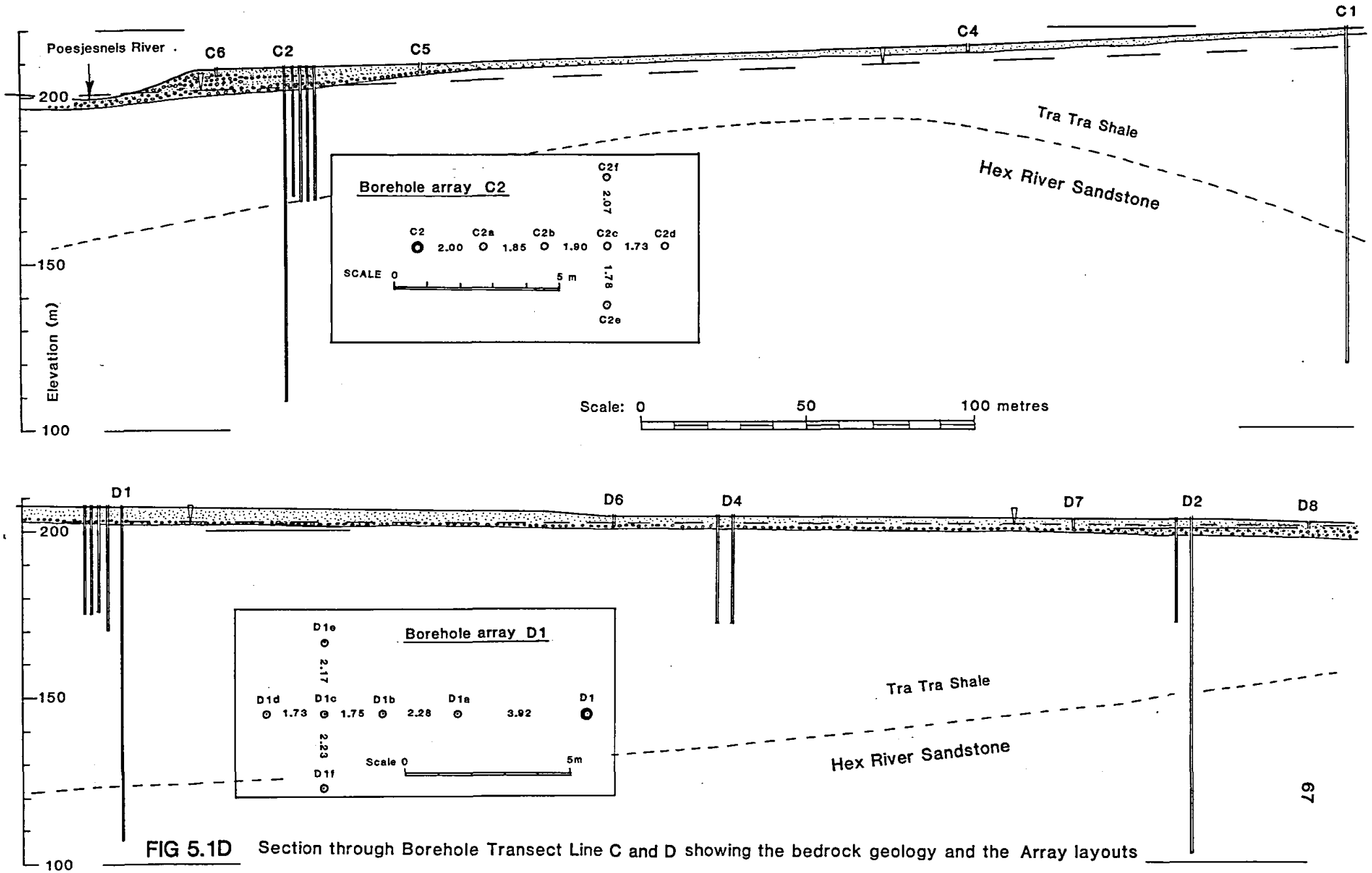

FIG 5.1D Section through Borehole Transect Line C and D showing the bedrock geology and the Array layouts

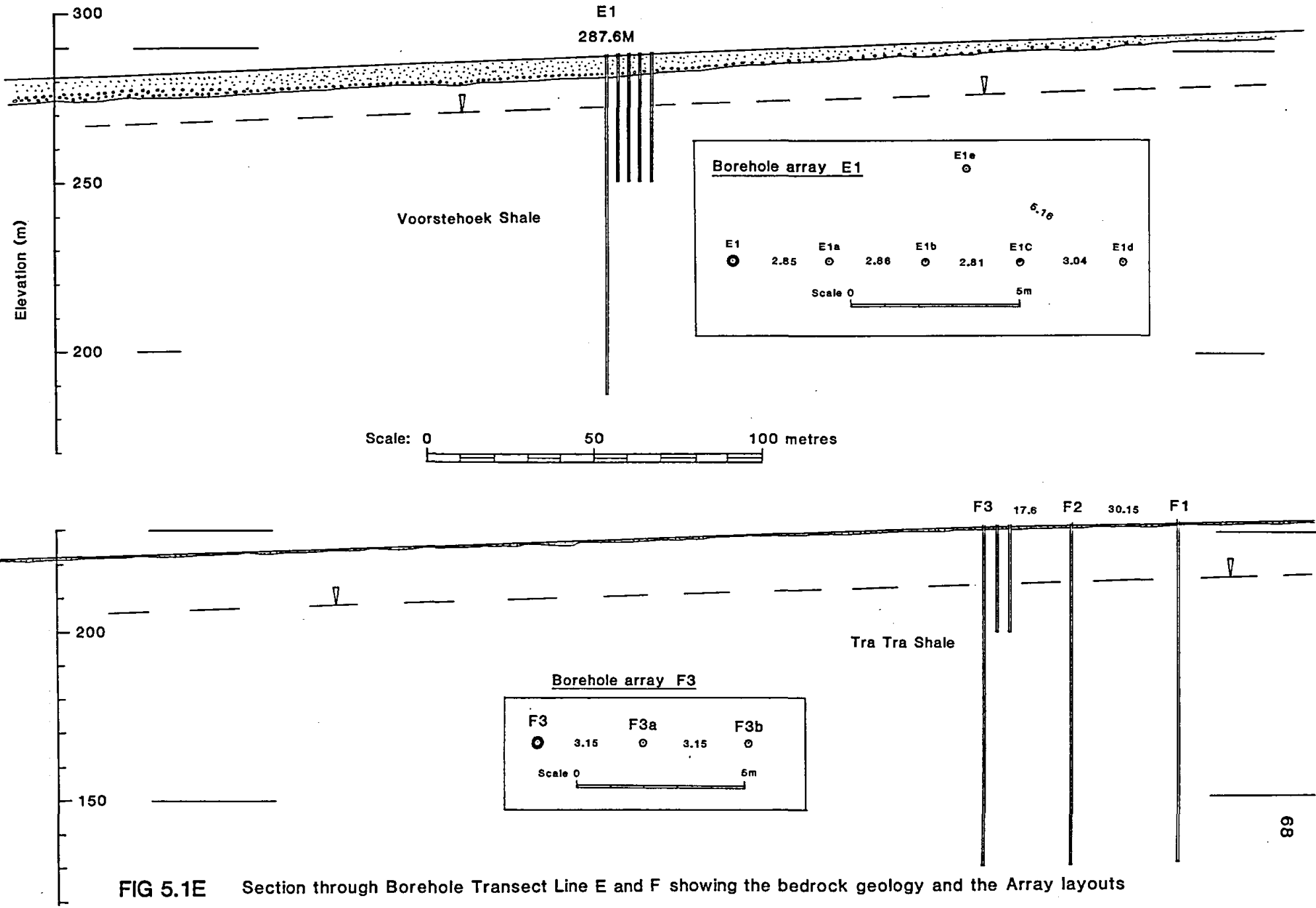

FIG 5.1E Section through Borehole Transect Line E and F showing the bedrock geology and the Array layouts

water through the bedrock. These holes were drilled on a cross-shaped pattern of four holes in line, with two on either side (Fig. 5.1 and App. Fig. 5.13) so that groundwater migration could be detected even if it was not taking place directly downslope towards the river, but diagonally or even laterally across the profile line. A close spacing of 2 to 3 metres was adopted because work by Andrew Stone at Middleton in the Eastern Cape showed extremely slow migration velocities for groundwater through similar shale bedrock. (In one case no flow was detected between boreholes 5 metres apart even after a two year period! - A. Stone, pers. comm. 1982)

Although two transects were initially planned on each of the profile lines A to E, some changes were introduced due to the conditions and research needs we encountered during the program; only one transect was drilled on line E, and no monitor holes were sunk above deep borehole C1.

However, a number of holes were added to profile lines B and D, and five holes were drilled in the profile area F after consultation with project advisors. The information gained from these boreholes is presented in the following sections.

5.2.2 Bedrock lithology and geophysics

Bedrock chips or cuttings were airlifted continuously during drilling and these were sampled at 1 metre intervals at each of the deep boreholes, and ± 1 kg samples then brought to Stellenbosch in plastic containers for logging and further testing. The shallow boreholes were sampled at selected depths and also brought to Stellenbosch, with a view to providing lithological correlation across each transect. This proved to be very difficult in most cases due to the alternating sequence of shale and siltstone beds; where thicker siltstone marker horizons occurred, these could be followed across the transects, and the dip of the bedding planes determined. (Figs. 5 to 14, Progress Report N°4 to the WRC, 1984).

Lithological logs based on examination of cuttings from the most important boreholes on each transect are presented in App. Figs. 5.2 - 5.12. The most important rock types in order of predominance are Black Shale, Siltstone and Sandstone.

Geophysical logging was carried out on all the borehole transects by the Department of Water Affairs. The results enhanced lithological and structural interpretation (App. Figs. 5.2 - 5.8). Also included on these logs are the maximum airlift yield of each hole and the decline in yield after one hour of pumpage. Zones where water inflows were struck by the drill are also indicated; these generally occur within layers of siltstone or sandstone, or where quartz veins are traversed.

Geophysical logging was not carried out on boreholes C2, D2, E1 and B5 (App. Figs. 5.9 - 5.12), as piezometers had already been fitted, or due to the absence of shallow monitor holes.

Geophysical logging included (reading from left to right on the graphic areas of these figures):

a. Caliper log of borehole diameter (20mm per division). This log is useful to show the overbreak which occurs when the drill penetrates faulted or fractured bedrock and/or quartz veins, usually zones where flows of groundwater are encountered, for example:
   A1 - 53m.
   A2 - 27m, 44m and 67m.
   B2 - 17m, 41m and 49m.
   C1 - 13m, 26m, 46m, 83m and 85m.
   D1 - 16m, 61m.
   F1 - no caliper indication of fracturing; no groundwater flows encountered.

b. Short normal Resistivity (in ohm-metres) using a four-electrode arrangement. One electrode is earthed at the surface, one is provided by the suspending cable which has a one metre section cleared of insulation nine metres above the probe, and two are set a short distance apart on the probe itself.

   Zones of high resistance are formed by sandstone and siltstone layers or veins filled with secondary quartz; these zones sometimes produce groundwater flows, as follows:

A1 at 21 and 86m.
A2 at 55 and 85m.
B1 at 27, 40, 47-55 and 67m.
B2 at 31, 37 and 49m.
C1 at 75 and 81m.
D1 at 39, 50, 68, 73, 78, 85, 91 and 95m.
F1 at 35, 44, 54, 85 and 91m.

c. Single Point Resistance (in ohms) using only a single down-the-hole electrode coupled to a surface electrode. The same anomalies are recorded, but the graph has a lower sensitivity to changes in rock formation.

d. Water Resistivity (in ohm-metres)

This measurement was done on two electrodes spaced at 40 mm on the probe and gave a rapidly fluctuating graph without very large anomalies, as the water in the borehole had reached a measure of uniformity due to mixing. Sharp reductions in resistance due to influx of saline water are evident in borehole A1 at 41 - 42m and 52 - 55m where fractures in siltstone and shale are indicated by the caliper log. Similarly in:

A2 at 19, 27.5, 53 and 67m
B2 at 16 and 41m.
C1 at 25 and 83 - 100m.
D1 at 16, 44, 55 and 62m.

Higher resistivity values, probably due to the influx of low-salinity water, were recorded in:

B1 at 26 - 30, 35 - 37, 39 - 42, 45 - 56 and 66 - 68m
C1 at 74 - 77m
D1 at 36 - 43m

These are associated with sandstone or siltstone layers.

e. Water temperature (°C)

This parameter increases in all the boreholes measured. Examination of results showed the following temperature gradients:

A1	2.19 °C per 100m,	20.8 °C at GWT	
A2	2.04	"	20.6 °C " "
B1	0.73	"	21.4 °C " "
B2	0.43	"	20.0 °C " "
C1	1.49	"	21.6 °C " "
D1	2.73	"	19.0 °C " "

It appears that the artesian conditions in boreholes B1 and B2 cause dissipation of heat from the bedrock which results in the low temperature gradients.

f. Spontaneous Potential (in millivolt)

This is the simplest electrical log, obtained by reading a voltmeter set between an earthed surface electrode and a single down-the-hole electrode. It provides a measure of the naturally occurring potential differences between the surface electrode and the borehole electrode as the latter is drawn upwards. "The origin of these natural electric potentials is not well understood, but they are apparently related to electrochemical interactions that take place between the borehole fluid and the in situ rock-water complex." (Freeze and Cherry, 1979).

Examination of the logs in App. Figs. 5.2 to 5.8 shows that the SP increases in those holes which produce poor groundwater flows, A1, C1 and F1) and decreases where stronger groundwater is struck (A2, B1, B2, D1). In the latter hole very sharp decreases in SP values occur at 24, 33, 44 and 70m coinciding with black graphitic shale layers. This correlation is noticeable also in A2 at 21m and 46m and B1 at 20m, and may be due to the electrical conductivity of the graphite zones.

g. Natural Gamma radiation (counts per second.) This gamma log is used to distinguish units having a high clay content which would cause a low

effective porosity relative to the total porosity (W. Scott Keys, 1968).

In the present study, differentiation between shale and sandstone on the basis of gamma readings is limited. A few good examples occur as follows (lower readings in siltstone or sandstone, higher in shale):

A1 - sandstone at 21, 26, 52 and 66m;
shale at 37, 49, 53, 63, 91 and 97m.
A2 - sandstone at 28, 42 and 58m;
shale at 17, 32, and 51m.
B1 - sandstone at 27, 35, 41, 45-53 and 68m;
shale at 23, 33, 43, and 57m.
B2 - sandstone at 13, 16, 25, 36 and 46m;
shale at 12 and 20m.
C1 - sandstone at 74 and 83m;
shale at 34, 48, 76 and 90m.
F1 - sandstone at 16, 20, 35 and 59m;
shale at 23 and 49m.

h. Gamma-gamma measurements (counts per second)

A gamma radiation source (100 milli Curie) is passed through the borehole, followed by a counter. It is thought that some softer rock types give a higher reading or reflection, whereas more dense rock types give low readings due to absorption of the radiation. Differentiation of bedrock types on this basis proved very difficult, but higher values were encountered wherever the caliper logs indicated fracturing or shattering of the sidewalls of the boreholes.

i. Neutron-neutron log (counts per second)

A neutron source (1 Curie) is passed through the borehole with a counter. The neutrons are moderated by hydrogen, with the result that water-bearing zones in bedrock give a lower reading than dry formations, or formations with a low porosity.
Examination of results on the logs of this test shows a trend which is reciprocal to the gamma-gamma logs mentioned above. Where high

gamma-gamma values occur, lower anomalies are found in the neutron graphs, and vice versa. Although neutron logs are most effective in the evaluation of moist areas in the unsaturated zone, application in the zone below the groundwater table seems tenuous. The lower anomalies nevertheless seem to be associated with shale formations and/or fractured areas in the bedrock, while high anomalies are associated with sandstone or siltstone in boreholes A1, A2, B1, B2 and C1.

The lithological and hydrological features of each borehole are summarized in the following table:

TABLE 5.1 SUMMARY OF MAIN FEATURES OF THE BOREHOLES

Borehole	PROBABLE GEOLOGICAL FORMATION/S	LITHOLOGY	WATER yield(l/s)	Conductivity (mS/m)
A1	Tra-Tra Shale and Hex River Sandstone. (contact at ±20m)	Decomposed shale down to 20m; siltstone and sandstone predominant from 20 to 100m. Almost devoid of quartz veins.	4.0	602
A2	Tra-Tra Shale and Hex River Sandstone (contact at ±55m)	Calcrete near surface, decomposed siltstone and shale down to 16m; alternating shale and siltstone/sandstone. Many quartz veins.	13.0	1006
B1	Waboomberg Shale and Boplaas Sandstone	Decomposed bedrock down to 18m Shale predominant, but sandstone/siltstone layers very common in central part of borehole. (35-70m) Strong water in sandstone at 54m.	14	273
B2	Waboomberg Shale and Boplaas Sandstone	Alluvial gravel and sand lies directly on fresh bedrock at 9m. Siltstone and sandstone predominant over shale. Many quartz veins. Strong artesian flow at 49m.	23.5	956
B5	Waboomberg Shale and Boplaas Sandstone	5.5 metres of alluvial sand overlies decomposed shale which extends down to 15m. Alternating sequence of shale and sand-stone becomes predomi-nantly sandstone below 46m. Strong water struck at 98m.	17.5	590
C1	Tra-Tra Shale and Hex River Sandstone. (contact at ±73m)	Decomposed bedrock to 14m. Alternating sequence of shale and siltstone passing into sandstone.	4.4	939

Borehole	PROBABLE GEOLOGICAL FORMATION/S	LITHOLOGY	WATER yield(l/s	Conductivity (mS/m)
C2	Tra-Tra Shale and Hex River Sandstone. (contact at ±47m)	Gravel at 6m overlies decomposed bedrock down to 17m. Pyritic and graphitic siltstone and shale passing into siltstone layers.	12.5	1250
D1	Tra-Tra Shale and Hex River Sandstone. (contact at ±86m)	Decomposed shale below hillwash gravel, extends down to 14 m. Shale and siltstone layers alternating, with sandstone at depth.	7.2	440
D2	Tra-Tra Shale and Hex River Sandstone. (contact at ±76m)	Alluvial gravel at 5m overlies siltstone decomposed down to 12m. Black pyritic shale and siltstone passing down into sandstone with quartz veins.	3.45	320
E1	Voorstehoek Shale	Decomposed shale down to 19m. Bedrock mainly pyritic, graphitic, micaceous shale alternating with siltstone. Quartz veins seen between 45 and 70m.	12.0	690
F1	Tra-Tra Shale and Hex River Sandstone. (contact at ±91m)	Decomposed bedrock down to 12m. Bedrock is black shale alternating with siltstone until sandstone is struck at 91m.	<0.01	356

During the percussion drilling of most of the boreholes, a large amount of black carbonaceous foam or scum was produced at the surface, particularly when the drill was penetrating graphitic shale layers. Samples of this material were submitted to the Department of Chemistry for testing. After ether extractions were done on the samples, coloured petroleum fluids were obtained (App. Fig. 2.5d). These were then analyzed and found to be long-chain hydrocarbons falling within the category of natural petroleum. It is thought that some petroleum was formed within the carbonaceous Bokkeveld shale formations after deposition, but that regional low-grade metamorphism due to tectonic pressure associated with the Cape Fold Belt destroyed most of this material. Some residues are however retained, probably within the graphite streaks and cleavages within the folded shale horizons.

Whole rock chemical analyses were carried out on a number of percussion borehole cuttings (App. TABLE 2.2 a-g).

5.2.3 Structure of the bedrock below the transects

Most of the profile lines and transects were chosen at right angles to the strike of the folded bedrock formations, and it was therefore possible to use the geophysical logs of the borehole sets such as A1, A1a, A1b, A1c and A1d or B2, B2a, B2b, B2c etc to determine the dips of the sedimentary layers below the profile lines, making use of the collar elevations of the boreholes and the distances between borehole centres which had been accurately measured by the Control Industrial Technician of the Department of Water Affairs at Worcester.

For lithological correlation the logs for resistance, gamma radiation and neutron-neutron response proved to be most useful; as an example, geophysical logs from the B2 transect are shown in Fig. 5.1 F. Carbonaceous shale is indicated by a high peak in the gamma log, and a trough in the neutron - neutron log. Siltstone and Quartzite are indicated as high peaks in the resistance log. Using this method, the following angles of dip were determined (direction of dip in parentheses):

A1:	18°	(NW)	C1:	no monitor holes	
A2:	8.6°	(SE)	C2:	19.6°	(NW)
B1:	4°	(SE)	D1:	8.6°	(NW)
B2:	36°	(SE)	D4:	17°	(NW)
B4:	24°	(SE)	E1:	0°	(parallel to the strike)

N.B. These angles of dip must be classified as apparent dips as the transect lines are not exactly perpendicular to the strike of the sedimentary beds.

Some joint orientation measurements were made in the diamond core boreholes, and are listed in section 5.3.

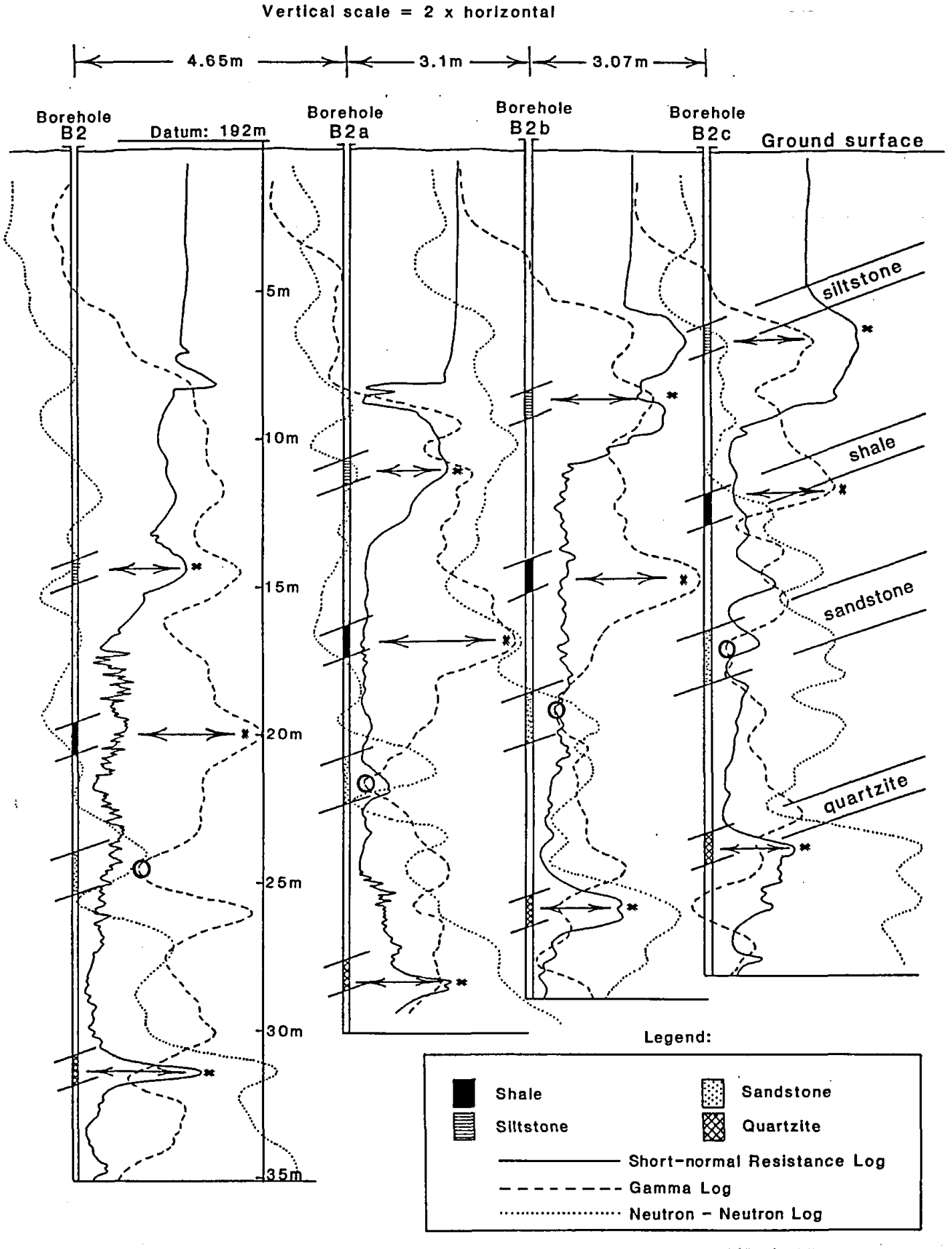

FIG 5.1F Lithological correlation by means of Geophysical Logs - Borehole Transect B2.

(Detailed Geology is shown on the Log of Borehole B2 in App. Fig. 5.5)

5.2.4 The piezometer program

Five boreholes were selected for the emplacement of piezometers by means of which water samples could be extracted from different levels to evaluate changes in groundwater quality with depth in the bedrock. Each piezometer consisted of a 1 metre length of plastic well-screen bonded to a length of 50 mm PVC piping; the screen was then embedded in coarse filter sand.

Four piezometers were emplaced in each borehole, (Fig. 5.1, p. 65) and separated from those above and below by a two metre seal of Bentonite clay held within a filling of normal river sand.

Groundwater elevations in the standpipes were regularly monitored and samples drawn (by nitrogen airlift technique) for chemical and isotopic analyses. Details of peizometer emplacement are given in TABLE 5.2.

TABLE 5.2 PIEZOMETER LEVELS IN BOREHOLES

BOREHOLES FITTED WITH PIEZOMETERS:	A2	B1	C2	D1	E1
Surface elevation (m):	213.89	194.67	208.45	206.89	287.60
Depth to the base of:					
Piezometer N° 1	20	41	40	36	37
Bentonite Seal	23	49.5	46	44	43
Piezometer N° 2	54.8	55	60	53	53
Bentonite Seal	57.8	65.5	64.5	57	57
Piezometer N° 3	76	73	81	73	74
Bentonite Seal	85	86.5	88	86	85
Piezometer N° 4	90.5	99 *	98	98	96

* Borehole B1 provided an interesting example of induced artesian flow; on

completion of drilling down to 100 m, this borehole gave a maximum airlift yield of 14 litres per second, after which the groundwater level rose in the borehole to stand at a depth of only 2 metres below surface.

After the first piezometer had been introduced to its 99m depth and the coarse sand had been placed around the screen, finer river sand was being introduced prior to the placement of the Bentonite seal at the 85 m depth. Suddenly artesian water began flowing from the top of the 99m standpipe, 0.7 metres above ground level, at a rate of 0.4 litre per second indicating that upward flow from this deep level in the borehole to a shallower horizon had been interrupted. (App. Fig 5.13 photo N° 4). This flow continued for the duration of the project, but was plugged to prevent spillage and pollution on the farm land and drainage lines. (The salt content of this water flowing from the standpipe was measured at 3200 mg/l during 1984, considerably less than the 5 740 mg/l measured during drilling in 1983.)

The water levels in the remaining three piezometer standpipes of B1 did not vary significantly from the groundwater levels in the other boreholes on this transect. Similarly, water levels in the standpipes of boreholes A2, C2, D1 and E1 showed minimal variation when monitored. These levels certainly moved upwards or downwards seasonally with the groundwater table, but the difference in water levels in the four piezometers never exceeded 1 cm.

5.2.5 Chemical analyses of the groundwater

Analyses were made of the groundwater airlifted during the drilling process, but mixing and pollution of the samples tended to produce a uniform salinity, generally lower than values obtained later when samples were drawn from piezometers. Values of T.D.S. for the boreholes during drilling in 1983 are as follows:

TABLE 5.3 : Salinity of groundwater during drilling (May to October 1983)

Borehole	Depth (m)	TDS mg/l
A1	25	4515
	63	4247
	78	4370
	89	4283
	93	4370
A2	30	5876
	42	5203
	53	5537
	78	5537
	100	5494
B1	13	1546
	36	1794
	50	1711
	100	1780
B2	19	3478
	37	4292
(artesian)-	48	5740
B4	20	2196
	35	2432
(artesian)-	47	2844

Borehole	Depth (m)	TDS mg/l
C1	36	7660
	74	6174
	100	6372
C2	32	5749
	42	6704
	78	6089
	98	6740
D1	20	1644
	36	2148
	49	2274
	53	2282
	81	2794
	98	3271
D2	15	1083
	43	1310
	65	1473
	83	1756
	96	2145
D4	22	4779
	29	4389
	35	4390
E1	35	3564
	53	4026
	71	3729
	96	3904

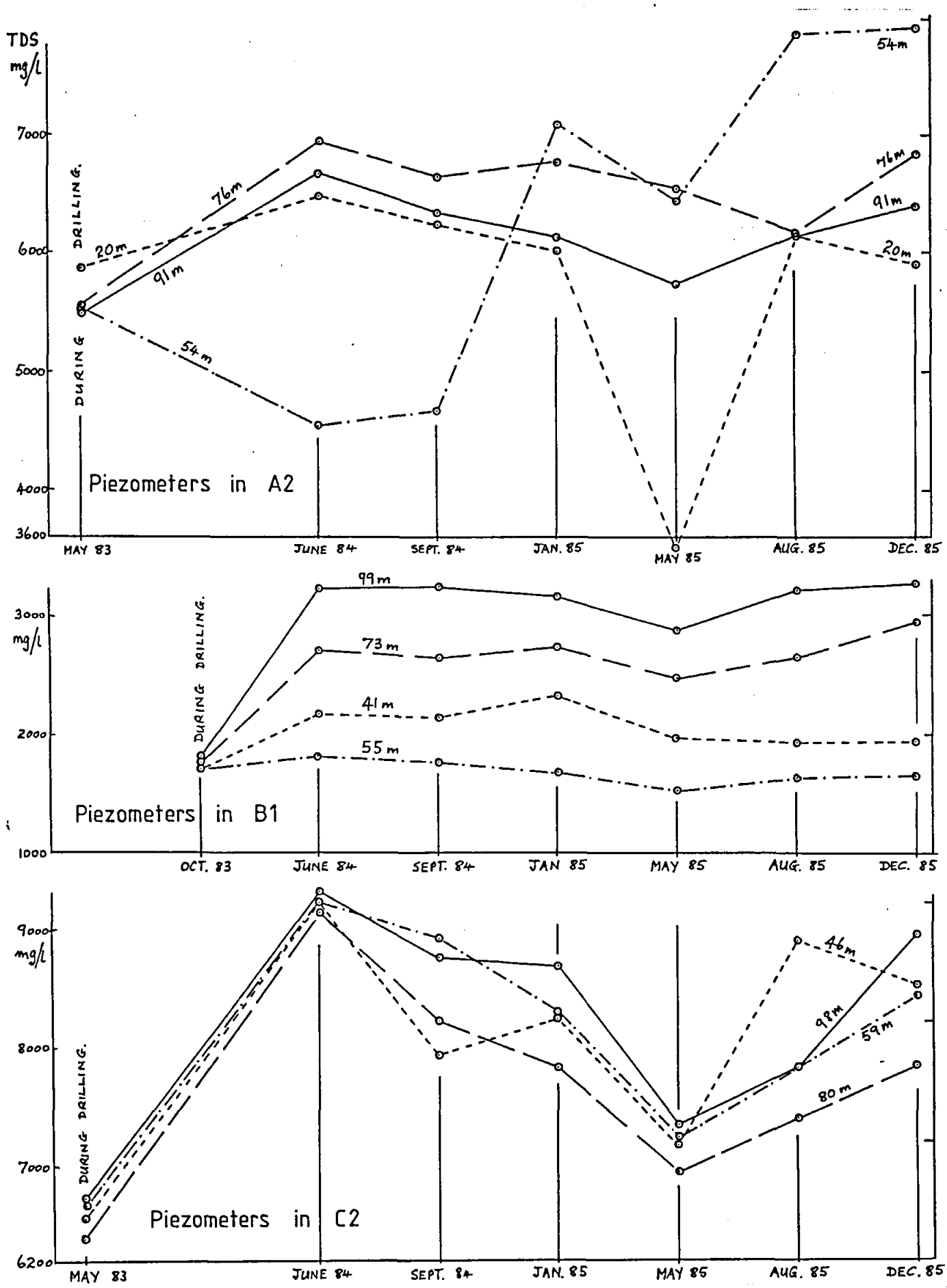

FIG. 5.17A Salinity changes in boreholes with time.

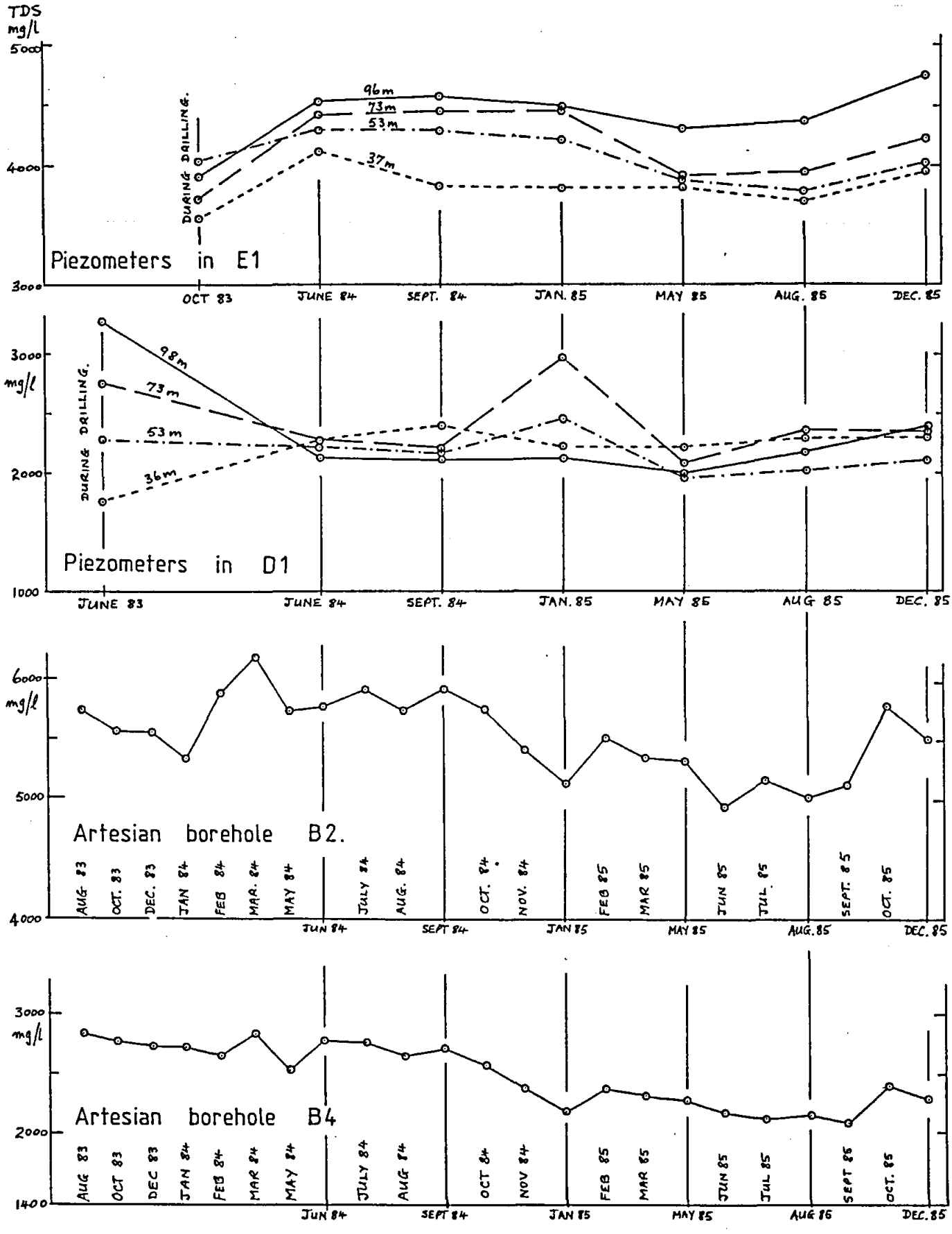

FIG. 5.17 B Salinity changes in boreholes with time.

Water samples were drawn from the piezometers seasonally and analyzed for the principal chemical components. Results are presented in App. TABLE 5.4. Graphic plots of the total dissolved salts in piezometer samples and in artesian water from B2 and B4 show the lowering of salinity during the winter rainfall months and the rise during the hot summer months (Fig 5.17A + B). Many other variations of salinity are however imposed on this general trend.

From the graphs it appears that the salinity of the groundwater generally increased from the time of drilling during the period May to October 1983 to the first sampling of piezometers during June 1984. (The only exceptions were at 54m in A2 and at the 53m, 73m, and 98m levels in D1).

The drilling period coincided with the onset of good rainfall during the winter and spring of 1983 (May to September), when the daily flow in the river reached some high peaks (hydrographs in App. FIG 4.) In contrast, the initial part of the piezometer sampling program (June 1984 to January 1985) coincided with below average flow and high salinity in the river (hydrographs in App. FIGS 4.4 and 4.5), and the analyses also showed increased salinity in the boreholes.

Good rains in 1985, particularly during April, June and July resulted in stronger river flow with sharply reduced salinity. Water drawn from the borehole piezometers during May and August also registered a lower salinity. These results need to be carefully assessed. Infiltration of fresh rainwater into the boreholes themselves must be considered. Although the piezometer pipes were covered to deny access to any rainfall, the open spaces between the 50 mm PVC pipes standing within the borehole casing could have provided access for direct rainfall infiltration inside the casing. This could have percolated through the uppermost part of the sand filling and reached the groundwater table 7 meters below surface in borehole A2, and affected the shallowest piezometer set at a depth of 20 meters, producing the very sharp drop in salinity on the graph (Fig 5.17A). In addition, a slight basin surrounding the casing at borehole A2 probably acted as a rainfall collector, the fresh water leaking down between the outer wall of the 6 metres of casing and the borehole annulus.

The very sharp reduction in salinity in the piezometers of borehole C2 during May 1985 cannot be explained; possibly the plastic covers of the piezometer pipes were

not replaced after the January sampling run, allowing rain water to cause some dilution prior to the drawing of samples during May.

Nevertheless, the boreholes closest to the river (A2 and C2) showed the greatest fluctuations while those further away or associated with artesian conditions changed more slowly or showed a greater lag period.

The artesian water of boreholes B2 and B4 showed a steadily declining salinity trend, punctuated by some isolated increases, e.g. February and October 1985. The low salinities in B2 and B4 during the January - February period in 1984 are probably derived from the infiltration of rainwater which fell in September and November 1983. By contrast, the salinity rose again in March 1984, probably due to the dry hot period from December 1983 to February 1984, and then dropped during May 1984 in response to heavy rains in March. (These correlations indicate a 2 to 3 month lag period between rainfall events and their effect on groundwater salinity.)

The situation in borehole D1 differed somewhat from the other boreholes. With the exception of the 36m level, the June 1984 piezometer samples had lower salinities than the initial groundwater, particularly in the deeper part of the hole.

In D1 the salinity of water airlifted during drilling rose steadily form 2752 to 3370 mg/l as the drill penetrated the black siltstone and shale below 73m (TABLE 5.5). During the piezometer sampling of June 1984 one year later, water from the 73m and 98m levels had much lower salinities namely 2210.7 and 2129.5 mg/l.

It appears that some zones such as the quartz veins at 69m and the sandstone at 90m which were intersected during drilling could be responsible for the introduction of lower salinity water to the 73m and 98m piezometer zones below the bentonite seal at 57m. Strong water flows of 1,4 l/s at 59m, 1,9 l/s at 77m and 1,2 l/s at 90m were encountered. The resistivity graphs (App. Fig. 5.7) show strong variations, and sharp decreases can also be seen on the spontaneous potential recording. Analyses of the full set of water samples taken at D1 during drilling and afterwards (TABLE 5.5) show the following salinity changes:

TABLE 5.5 DETAILS OF WATER FROM BOREHOLE D1

DEPTH (m)	Airlift yield (litres/sec.)	JUNE 1983, DURING DRILLING		PIEZOMETER SAMPLE, JUNE 1984	
		TDS mg/l	EC mS/m	TDS mg/l	EC mS/m
17	0.2	1573	262		
20 *	0.44	1644	274		
24	0.463	1755	293		
28	0.781	1994	332		
31 *	1.667	2394	399		
34	2.597	2134	356	2260.7	377
36	2.667	2148	358		
40 *	2.857	2092	349		
43	2.941	2057	343		
46	3.077	2176	363		
49 *	3.636	2274	379		
OVERNIGHT STOP IN DRILLING					
51	4.44	2106	351		
53	5.263	2282	380	2227.9	371
56	5.263	2303	384		
59 *	6.667	2029	338		
63	6.061	2064	344		
65	5.376	2134	356		
67	5.51	2134	356		
69	4.651	2148	358		
71	5.00	2218	370		
73	5.089	2752	459	2210.7	368
75	5.00	2829	472		
77 *	6.06	2578	430		

OVERNIGHT STOP IN DRILLING					
79	5.618	2534	422		
81	6.667	2794	466		
83	6.25	2962	494		
85	6.45	2998	500		
88	6.06	3047	508		
90 *	7.273	3131	522		
92	6.06	3194	532		
94	5.263	3271	545		
96	5.714	3370	562		
98	5.5	3271	545	2129.5	355

The asterisks indicate depths at which groundwater inflows were encountered. Decreased salinities are associated with the inflows at 40m, 59m and 77m. The other inflows caused increased salinity, particularly in the deepest part of the borehole between 79 and 98 metres, where black shale and siltstone were penetrated.

Comparison of results in Figs. 5.17 A and B shows that the bedrock salinity (as sampled by the piezometers) increases with depth, particularly in B1, D1 and E1; a similar trend was encountered during the drilling of boreholes B2, B4 and D2 (TABLES 5.3 and 5.5).

Salinity of the groundwater in boreholes A1 and C2 remained nearly constant with increase in depth, but in A2, C1 and D4 the salinity decreased with depth as drilling proceeded. Subsequent piezometer sampling in A2 and C2 gave a rather mixed result, with the salinity fluctuating; however, all the piezometer graphs showed their lowest salinities during May 1985, following a period of above-average rainfall during the summer months of January to April of that year. More rain probably fell in the mountains, accounting for the lower salinity in the river at H4M18 (App. Fig. 4.5) particularly during April.

This rainfall and the resulting infiltration of water to the bedrock was probably responsible for the lowering of the groundwater salinity over most of the valley, particularly if the rise in groundwater table at this time is taken into account. (Section 9).

Comparison of the principal chemical components with those in river and irrigation return flows will be made in Section 8.

5.3 The Diamond Core boreholes

Five 50 mm diameter (NX) boreholes were drilled alongside the percussion boreholes which had been selected for piezometer emplacement. Bedrock structure and lithology were clearly visible in the cores which were brought to Stellenbosch for closer examination, and these details were incorporated into the main borehole logs presented in the previous section (App. Figs. 5.3, 5.4, 5.7, 5.9 and 5.11) and are shown in the photographic examples (Fig. 5.18 and App. Figs. 5.14, 5.15, 5.16, and 5.19).
Features clearly seen in the cores include:

a. Three rock types namely shale, siltstone and sandstone, alternating with each other sometimes over short distances.
b. Highly carbonaceous nature and black colour of especially the shales and siltstones.
c. Abundance of sericite mica flakes, pyrite nodules and crystals; also graphite on cleavages or in disordered streaks.
d. Soft sediment deformation of bedding planes, often with siltstone or fine sandstone veinlets traversing shale.
e. Strongly developed secondary cleavage.
f. Oxidation zones, with limonite replacing pyrite nodules.
g. Depth of alteration of bedrock, and the thickness of soil and gravel layers.
h. Occurrence of joints and fault zones with clay filling, quartz or calcite veins or signs of chemical leaching or staining.
i. Fossil remains.

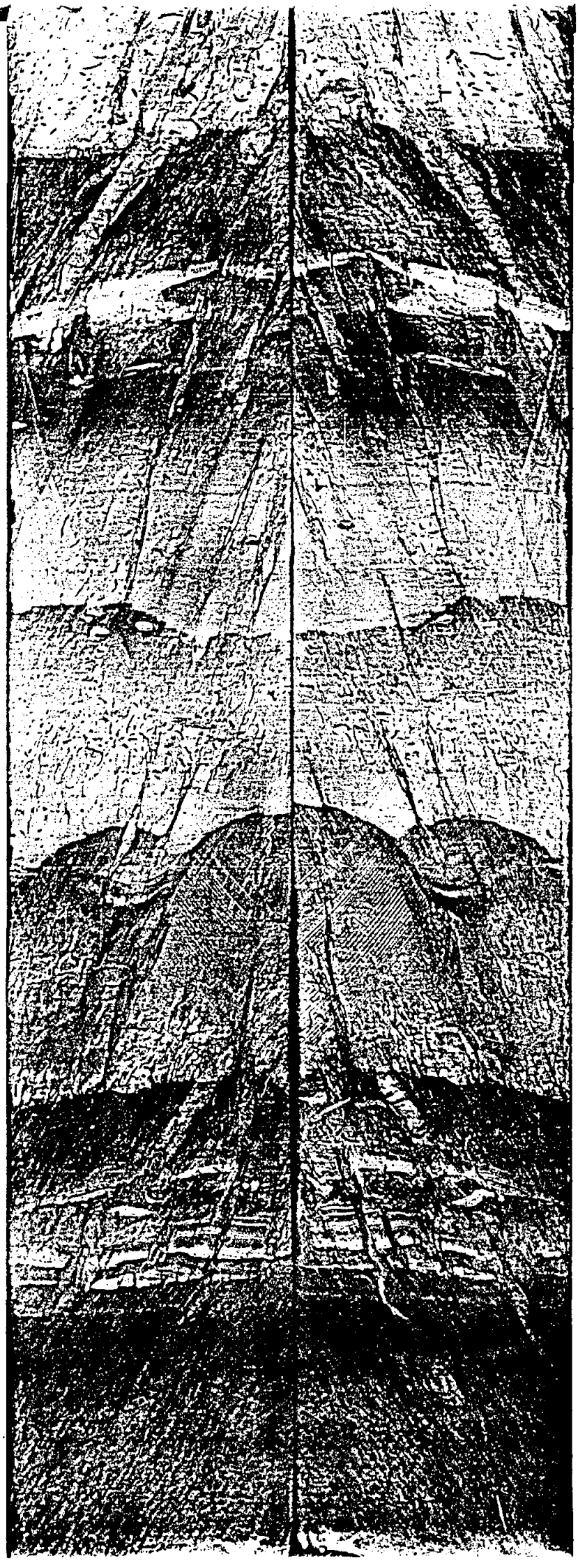

FIG 5.18

Sliced Diamond Core
from Borehole D1
at 22.5m

(Actual size)

It was possible to make down-the-hole measurements of the dip and strike of joint planes where the core had broken off cleanly during drilling, eg.:

TABLE 5.6 ORIENTED JOINT MEASUREMENTS

BOREHOLE	DEPTH	DIP	STRIKE
A2	26 m	41°SE	70°
C2	27 m	30°SW	150°
C2	42 m	15°SW	105°
E1	20 m	45°NW	88°
E1	27 m	36°N	92°
E1	40 m	28 NE	122°

The dip of the sedimentary layers could also be measured and compared with the attitudes determined from the geophysical logs (section 5.2.3).

Sections of core were crushed and used for whole rock chemical analyses (TABLE 2.2 b-e), leaching tests and permeability experiments.

5.3.1 Permeability tests on core samples

Three 10 cm sections of NX diamond core were selected from each of the holes and submitted to the Department of Civil Engineering at Stellenbosch University for determination of the permeability along the core axis (more or less perpendicular to the bedding planes) under hydraulic pressure. Their efforts, even under a maximum pressure of 600 KPa returned a zero result, not only in the case of shale samples but also when siltstone and quartzite were tested.

Following this, 30 mm cores were drilled at right angles to the core axes, approximately parallel to the bedding planes and cleavage of the rock. A total of 63 of these smaller cores were then tested in a similar way, and once again it was reported that the samples of rock gave a permeability of K = O for all samples of

unbroken, fresh bedrock encountered by the diamond drill. (Cores of decomposed bedrock could not be obtained as these crumbled during drilling, particularly the 30 mm cross-cores).

It must therefore be accepted that the Bokkeveld bedrock has zero permeability in its fresh, unbroken state. The induration and density of the rock is high, and pore spaces appear to have been effectively sealed, probably due to secondary crystallization during periods of dynamic metamorphism. The presence of well developed micaceous cleavage and graphite in many bedrock samples suggests that high tectonic pressures were active in this area in the past. The permeability that is present in the rock is of a secondary nature, due to fracturing.

5.4 The shallow auger boreholes

The Worcester Depot of Escom assisted the project a great deal by making available a powerful auger drilling machine, normally used for the excavation of holes for the planting of power line poles. During the early part of 1986 this machine drilled 36 holes, lifting out soil and decomposed bedrock samples at 20 cm intervals to a maximum depth of 4 meters, where conditions permitted. Boulders or hard bedrock were often encountered, causing refusal before full depth was reached, but a great number of good samples were obtained and used for leaching tests. While sinking auger hole F5, the drilling rig suffered a hydraulic valve seizure, reared up on its auger and toppled sideways nearly pinning the operator, who sprained his ankle while leaping clear of the rig. The square steel drilling stem was bent through 90°, and took many months of costly repairs before it could be returned to service on Escom power lines, precluding the return of the machine to the project.

Auger holes were drilled along existing profile lines, as well as in areas not previously investigated. Dr. J.H. Moolman in particular requested that the alluvial terraces along the lower reaches of the river be examined, because irrigation had been applied here for more than 40 years, and salts in the upper soil profile would have been leached out to a large extent. He was also interested to know what salinities existed at levels below 1.5 metres (the depth to which his soil sampling had been done).

Consequently the auger program was started in the Le Chasseur area north and south of the river immediately upstream from the bridge and measuring station H4 M18.

The following auger holes were drilled:

a.	H1 to H5	on section N - N"	(App. Fig 2.3 B)
b.	P1 to P6	near H4M18	(App. Fig 2.3 F)
c.	B6 to B13	on borehole line B	(App. Fig 2.3 E)
d.	C3 to C6	on borehole line C	(App. Fig 2.3 D)
e.	D5 to D8	on borehole line D	(App. Fig 2.3 D)
f.	F5 to F9	on section M - M"	(App. Fig 2.3 B)

Auger holes could not be drilled on the A or E borehole lines due to the machine breakdown. Fortunately enough samples were obtained from the other lines for leaching tests which gave a good understanding of the distribution of salts in the soil and upper decomposed bedrock zones in the valley.

5.5 Test pumping of boreholes

Even though a zero permeability was encountered in fresh, unbroken bedrock in the valley, the percussion drilling program clearly showed that groundwater did flow through the bedrock, in some cases producing large yields. This flow must therefore be taking place along discontinuities such as bedding planes, joints, fractures or faults.

To try to assess the fracture flow or secondary permeability of the bedrock, test pumping of the borehole arrays was requested, and then carried out by staff and equipment from the Department of Water Affairs. This work was done during February 1985 by Mr. Schmidt and his assistants.

The results were submitted to Messrs M. Vandoolaeghe and P. Seward of the Dept of Water Affairs in Cape Town, who submitted the following report based on the findings:

"The boreholes used for pumping tests had been drilled primarily for tracer tests, in arrays not ideal for determining aquifer characteristics. This report therefore

attempts to describe what information can be gained from the tests, and suggests options that could be pursued if more information is desired.

Since no observation borehole is more than 12 m from a pumped hole it was suspected that the observation holes might be too close to the pumped holes to allow meaningful estimates of transmisivity (T) and storativity (S) to be made.

The following method was used to guard against erroneous results:

(a) The step-drawdown test data were analysed using linear regression techniques on the Jacob equation to obtain an estimate of the well loss component of drawdown at the constant rate test yield.

(b) The pumped hole drawdown was corrected for well losses and compared with drawdowns in the observation boreholes (Table 1).

(c) If the drawdown in the observation holes were less than the corrected pump hole drawdown they were used to calculate T and S values, otherwise they were discarded (Section 4, Example).

The logic used in (c) is that an observation borehole with a drawdown greater than the corrected pump well drawdown is so close that it is also affected by well losses, and an observation borehole with a drawdown equal to that of the corrected pumped well indicates that it lies on the same fracture or fractured zone thereby forming an "extended well" (Fig. 1). In either case attempting to calculate aquifer characteristics would lead to totally misleading results.

TABLE 1: ANALYSIS OF STEP DRAWDOWN TESTS

Pumped Borehole	B ($d/_{m^2}$)	C ($d^2/_{m^5}$)	Q (l/s)	Well efficiency	Corrected drawdown after 24 hours (m)	Observation borehole	Oberservation borehole drawdown after 24 hours (m)
A1	0,0287	$4,5x10^{-5}$	4,5	62%	14,1	A1d	12,1
B2	0,0010	$5,0x10^{-6}$	6,2	65%	3,5	B2e	5,86
B2c	0,0142	$2,51x10^{-5}$	4,8	58%	6,0	B2e	4,63
C2b	0,0486	$7,5x10^{-4}$	0,72	51%	7,7	C2f	7,00
D1a	0,0243	$1,73x10^{-4}$	1,98	45%	no drawdown measurement	D1e	5,76
D1d	0,0155	$5,8x10^{-5}$	2,71	53%	4,7	D1b	8,37
E1e	0,0044	$9,67x10^{-6}$	6,08	46%	3,17	E1e	3,97

Where B = aquifer loss coefficient

C = well loss coefficient

Q = constant rate test yield in l/s

$$\text{well efficiency} = \frac{BQ}{(BQ+CQ^2)} \times 100\%$$

$$\text{corrected drawdown} = \frac{\text{well efficiency}}{100} \times \text{actual drawdown}$$

Corrected drawdowns from the pumped hole, together with any suitable observation hole drawdowns were then plotted against time on log-log paper. Drawdown-time curves that could be matched to a Theis curve were deemed to indicate pseudo-radial flow, while a straight line was assumed to be due to linear fracture flow.

The pseudo-radial flow cases were analysed using normal Theis curve matching techniques or the Jacob method to give values for aquifer characteristics. Purely linear flow is governed by the equation:

drawdown = (a constant) x yield x (square root of time)

A graph of drawdown versus the square root of time allows the constant to be determined, but unfortunately aquifer parameters cannot be calculated if the flow is purely linear. T and S values can be calculated if the observation boreholes are far enough away and flow becomes radial or pseudo-radial.

Only one boundary effect was noted on the drawdown-time curves and was interpreted as a semi-impermeable boundary. It is suspected that had the constant rate tests lasted more than 24 hours more boundary effects would have been apparent.

RESULTS

The methods discussed in the previous section yielded the following results:

Borehole	Flow conditions	Method of interpretation	T (m^2/day)	S	Comments
A1 *	radial	Jacob	15,5		
A1d	radial	Jacob	15,8	$1,3x10^{-3}$	
B2 *	linear	)	($L\sqrt{TS}$ = 68 where		T and S cannot be be determined with this method
		) Jenkins & Prentice	L = fracture length)		
B2e	linear	)			
B2c *	linear	)	($L\sqrt{TS}$ = 00)		T and S cannot be determined with this method.
		)			
		) Jenkins & Prentice			
		)			
B2e	linear	)			
C2b*	radial	Theis	8,0		
D1a*					data missing
D1e	radial	Theis	15,0		
D1d	radial	Theis	27		
E1e	radial plus semi-impermeable boundary	Theis and Seward departure method for boundary	Tp=209 Ts=145		Tp=transmissivity of zone in which pumped hole is situated. Ts=transmissivity of zone beyond the semi-impermeable boundary.
	F3	?	(waterlevel dropped to below pump intake after 10 minutes of pumping)		

(A representative graph of drawdown against time for each test site has been included to illustrate the effect of the flow conditions and the method of interpretation; Figures 2 to 6 - Seward Report).

EXAMPLE

Pumping tests on D1d

1. Step drawdown test.

The drawdown in a pumped borehole is made up of two components: aquifer loss and well loss. The relationship between the two components is given approximately by $S_W = BQ + CQ^2$

where: Q = yield
BQ = aquifer loss
CQ^2 = well loss

The coefficient B and C were determined using the methods outlined in "The Analysis and Planning of Step Drawdown Tests", Lewis & Clark, Q.J. . Engng. Geol. 1977 Vol. 10, except that graphical methods were replaced by linear regression techniques - in effect, a semi-automatic version of "A method for interpreting step drawdown pumping test data using the T159 programmable calculater", P. Seward, Report no. Gh3200, 1982.

In this case B was found to be 0,015 and C $5{,}8 \times 10^{-5}$.

Well efficiency was then calculated using the equation:

$$\text{well efficiency} \quad \frac{BQ}{(BQ+CQ^2)} \times 100\%$$

The pumped well drawdown was then corrected for well losses:

$$\text{corrected drawdown} = \frac{\text{well efficiency}}{100} \times \text{actual drawdown}$$

In other words the corrected drawdown is an estimate of the well loss component of actual drawdown, whereas BQ gives the theoretical drawdown when conditions

are approaching steady-state. Thus the corrected drawdown varies with time while BQ does not.

A value of 4,7 m was obtained for the corrected drawdown after 24 hours of pumping. This was then compared with the observation borehole drawdowns after 24 hours. The waterlevel in observation borehole D1b was 8,4 m and in the shallow (36 m) piezometer in borehole D1 was 7,1 m. Since these drawdowns are greater than the corrected pumped hole drawdown it is argued that linear fracture flow and/or turbulent flow in the vicinity of the pumped well have distorted the observation borehole drawdowns. Thus only the pumped well can be used.

The drawdown for the pumped hole was corrected for well losses and them plotted against time on log-log paper. Since the drawdown-time plot could be matched to a Theis curve, radial flow was postulated. The Theis curve matching technique was then used to obtain a value of 27 m^2/day for transmissivity.

To obtain a figure for storativity, observation boreholes are needed outside the turbulent flow and linear flow zones.

DISCUSSION

Besides the problem of observation boreholes which are situated too close to the pumped hole, a second problem was encountered in that the majority of pumped and observation boreholes did not fully penetrate the aquifer.

Each test site consisted of one 100m deep borehole usually equipped with multiple piezometers, while the remaining observation boreholes and pumped hole were usually only about 30m deep. The 100m boreholes usually have water strikes throughout, while no records were made of water strikes in the shallow holes. Thus it is clear that aquifer parameters calculated only apply to the top of the aquifer. To obtain more representative values the pump hole and at least one of the observation boreholes should fully penetrate the aquifer.

Furthermore, the constant rate tests should have lasted at least 3 days to properly establish the full range of aquifer conditions.

POSSIBLE FURTHER WORK

The following options might be considered:

(1) no further work to be carried out unless it is certain that reliable local T and S values are fundamental to the understanding of the role of groundwater in the mineralization process.

(2) Additional boreholes could be drilled and further pumping tests carried out using procedures normally employed by the Directorate of Geohydrology. For fractured rock aquifers a minimum of 3 observation boreholes are usually required. Thus for the 5 pumping test sites where 24 hour tests were completed, a total of 15 observation boreholes would be required. Since the borehole logs indicate that water interceptions occur as deep as 85m the boreholes should be at least 90m deep. Obviously, the observation boreholes should be in different directions and at different distances from the pumped hole. Initially, it is suggested that no observation borehole should be drilled closer than 25m to the pumped hole. However, water levels should be monitored while the drilling of observation boreholes is in progress so that the optimum sites for the remaining observation boreholes can be constantly re-assessed. The result constant rate test should last at least 3 days.

However, even if all the above procedures are carried out, there is no guarantee that representative T and S values will be obtained. Since more than one water interception is often present the possibility exists that a multi-aquifer system is being tested and that analysing it as a single aquifer gives totally misleading results. To overcome this problem each water-bearing fracture needs to be tested as a discrete unit using packer tests or alternative procedure using multiple piezometer layouts.

On the other hand, the multi-level piezometers installed in some of the 100 m boreholes do seem to show that even the deepest fracture is affected when interceptions at less than 30m are pumped so it may well be that the set of fractures behaves as a single aquifer and thus can be analysed as such.

CONCLUSIONS

1. An average transmissivity of $62m^2/day$ and a single storativity value of $1,3x10^{-3}$ were obtained.

2. These values are probably too high to be representative for the area as a whole because of distortions introduced as a result of observation boreholes being much too close to the pumped holes, and because the pumped holes apparently did not fully penetrate the aquifer.

3. Options for further work include (i) abandoning as irrelevant the pursuit of reliable T and S values, (ii) obtaining T and S values from pumping tests carried out in similar areas, (iii) drilling additional boreholes and carrying out additional pumping tests".

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The value of the transmissivity as determined by Mr. Seward coupled with tracer migration experiments can be used to give some understanding of the flow of groundwater through the bedrock fractures; these parameters will be combined for this purpose in a later section.

6. LEACHING TESTS ON SOIL AND BEDROCK SAMPLES

No survey of salinity in a river draining a catchment with a view to finding the origin of the salt would be complete without a thorough examination of all the possible materials which could contribute salt to the drainage system, part of which entails leaching experiments using distilled or low-salinity water of known T.D.S.

A number of such experiments were carried out:

6.1 Leaching of a sample of black silty shale taken from the riverbed

The final sampling run of the P.R. Valley was done on 4th and 5th December 1985 immediately following two days of rain. It was particularly good to see the river flowing along its whole length as rainfall runoff and seepage were being carried downstream towards the Breë River.

In the vicinity of sampling station 18 where the salinity levels of the river show a dramatic increase, the alluvial gravels and sands in which the river had flowed up to that point make way for Bokkeveld Shales and siltstones into which the river has cut itself a channel. A sample of this material was taken from the riverbed to see what salts could be leached from it; it had probably been in the riverbed, washed by winter rainfall runoff for many years, and had given up some of its superficial salt already. (photograph N°2, App. Fig. 2.2e)

The intact sample weighing 3,6729kg and having a volume of 1429cm^3 was immersed in 2 litres of distilled water and agitated at one minute intervals in order to leach any surface salts from the ±2400cm^2 area; the change in T.D.S. of the leachate with time is shown by the curve on the graph in App. Fig. 6.1.

After the first leachate was removed, the process was repeated giving curves 2 and 3 of the graph (App. Fig. 6.1). The sample was allowed to dry for 24 hours, and the process repeated once more, producing double the amount of salt in the previous leach - compare curves 3 and 4.

The sample was again dried for 24 hours and then put through a jaw crusher and again leached with 2 litres of distilled water which was agitated by flushing back and forth at one minute intervals. This produced ten times the amount of salt

initially leached from the surface, with a very rapid release of salt from the fresh, broken fragments (varying in size from 5 x 3 x 1cm to dust particles), reaching a concentration of 30mg/l in 10 minutes with a back and forth flushing every minute (see curve 5, App. Fig. 6.1). The chemical analyses of leachates from the surface and the crushed sample are included at the end of TABLE 6.5B.

When the test was terminated at 2450 minutes, the salt concentration had reached 1050mg/l and was still being released.

This 3,6729kg specimen of bedrock, already leached by the river, had produced in surface leaching and leaching of a crushed aggregate a total of 1,175 grams of salt (i.e. 0,32 grams per kilogram of rock). The specimen showed the familiar black streaks of graphite and grey-white specks of sericite mica in its dark grey shale matrix. The impervious nature of this shale rules out the possibility that salts were taken up by the rock from the river water. This is the bedrock material producing much of the salt in the Poesjenels River valley, particularly at stations 18, 19 and 20.

In nature, bedrock is not always available to such effective leaching, and we have noted the low permeability of the rock material. Nevertheless, fracture flow of groundwater must leach a substantial amount of salt from the bedrock after each rain event, and introduce this to the river through fractures under the influence of piezometric pressure developed by the head of groundwater in the elevated valley sides, or by simple seepage under gravity.

6.2 Leaching of soil samples from sidewall of a trench

An attempt was firstly made to determine lateral movement of water through the soil by digging a trench to a depth of 2 metres on the B borehole transect line, subjecting the surface to heavy infiltration of water by means of ponding, and monitoring sidewall inflow by means of steel sheets forced horizontally into the trench walls and gutters, fitted to catch any water flowing out of the soil.

Secondly a continuous sampling of the sidewall material provided alluvial sandy soil for leaching and analysis to determine the salinity variation with depth.

The former process was terminated soon after its initiation because termite burrows and tunnels in the soil provided conduits for the ponded water which

flowed through the soil and the sidewall in uncontrollable streams, flooding the trench.

The second investigation was carried out successfully, and 15 soil zones from the surface to a depth of 195 cm were leached and the leachates analyzed:

TABLE 6.2 SALT DISTRIBUTION IN THE SOIL COLUMN AT A TRENCH BETWEEN B6 AND B7 ON BOREHOLE LINE B.

(1 Kg sample taken up in 1 litre H_2O)

Sample depth (cm)	Leachate T.D.S. (mg/l)
0-15	404
15-28	228
28-37	365
37-53	186
53-66	275
66-78	363
78-87	823
87-99	827
99-107	859
107-115	846
115-134	449
134-145	444
145-160	394
160-173	593
173-195	438

The column consisted of alluvial sand, slightly clayey in places. One such clay rich zone existed between 0.75 and 1.15 m, and had the highest soluble salt content.

Because of the problems encountered with this method of testing and sampling, it was decided to concentrate on a program of auger drilling which would provide a more comprehensive sampling of soil and subsoil layers over a larger part of the valley.

6.3 Leaching of auger samples

At the sampling positions where the auger drill had penetrated a full 4 metres, a total of 20 samples were obtained at 0.2m intervals (20 cm). In many holes, auger refusal precluded the sampling of the full profile, resulting in a smaller number of samples for logging, leaching and analysis. The samples were returned to Stellenbosch, dried, screened to pass 1 mm and weighed off into 500 gram batches. These were then each taken up in 500 ml distilled water, shaken repeatedly over a period of four to six days until maximum concentration or constant salinity had been reached (less than a 1% increase in the T.D.S. over a 24 hour period) and then decanted through filter paper. Stoppered glass containers were used for storage, and good leachate clarity obtained by normal gravity settlement. A number of samples had to be put through a centrifuge to separate the clay particles.

These soil layer leachates derived from the auger samples were then analyzed for their principal chemical components; results are listed in TABLE 6.3.

The materials are described and the total dissolved salts in the leachates graphically presented in App. Figs. 6.2 - 6.8. Vertical sections through the borehole lines showing the groundwater table and the contact between alluvial deposits or soil and the Bokkeveld bedrock are included on these figures.

6.3.1 Auger line H (App. FIG. 2.3B and FIG. 6.2)

The results show a remarkable variation in materials and salinity between holes H1 which has a maximum leachate salinity of 3557 mg/l and H2 which has a maximum of 442 mg/l. Sandy clay hillwash predominates in H1 while clean alluvial sand was found in H2, showing a profound change in subsurface materials even though the holes are only 190 metres apart, and have a difference in

TABLE 6.3 CHEMICAL ANALYSES OF SATURATED LEACHATES DERIVED FROM SOIL AND DECOMPOSED BEDROCK OBTAINED FROM THE AUGER SAMPLING PROGRAM.

Sample number	pH	Ca	Mg	Na	K		HCO3	Cl	SO4	NO3	T. D. S.	ERROR
		mg/l	mg/l	mg/l	mg/l		mg/l	mg/l	mg/l	mg/l	mg/l	%
H1 2	8.30	47.4	55.1	170.1	19.5		7.3	390.0	174.6	10.0	945.0	.4
H1 8	8.00	33.0	59.8	338.8	8.6		3.4	656.0	118.8	11.0	1297.0	.7
H1 14	7.60	61.7	171.1	879.6	42.9		1.8	1880.0	184.1	14.0	3091.0	.5
H1 20	7.60	51.1	161.9	881.6	56.2		1.1	1880.0	142.8	20.0	3381.0	.6
H1 26	7.80	25.0	81.7	650.8	23.4		1.3	1240.0	126.5	15.0	2242.0	1.4
H1 32	7.80	20.3	65.0	581.3	26.1		1.5	1050.0	120.7	12.0	1966.0	.1
H1 38	7.90	12.9	40.9	486.0	15.2		2.0	815.0	95.5	6.0	1490.0	.8
H2 2	8.40	11.0	5.7	29.4	45.5		.7	105.5	21.8	5.0	285.0	.9
H2 8	8.20	9.8	3.5	10.2	4.4		1.0	37.6	11.6	2.6	103.0	1.0
H2 14	8.50	3.1	1.1	9.9	8.5		.9	15.8	18.0	4.0	69.0	.4
H2 20	8.50	3.2	6.3	29.5	10.1		.7	64.5	19.2	3.0	161.0	1.3
H2 26	7.90	6.9	8.7	52.7	10.0		1.1	100.0	34.4	4.0	229.0	.2
H2 32	7.10	8.9	12.6	51.9	13.6		.6	71.5	96.3	3.0	301.0	.1
H2 36	7.50	13.8	25.1	62.3	18.1		.6	103.0	152.3	2.0	442.0	1.6
H3 2	8.20	25.2	22.0	85.2	22.3		4.1	204.0	69.9	3.0	540.0	.1
H3 8	8.00	46.3	69.4	428.1	9.2		3.5	755.0	316.7	2.0	1621.0	2.0
H3 14	8.00	22.8	57.1	315.3	10.9		4.8	555.0	194.3	4.0	1180.0	.0
H3 20	8.00	22.6	41.1	215.3	6.5		5.3	382.0	150.8	3.0	842.0	0.0
H3 28	7.90	23.4	52.0	209.2	7.0		3.9	395.0	160.0	2.6	925.0	.5
H4 2	6.40	53.2	51.4	178.4	106.6		.8	480.0	178.5	20.0	1145.0	.6
H4 8	7.00	11.3	27.8	154.6	46.1		.8	266.0	144.3	14.0	690.0	.0
H4 14	7.50	2.0	9.2	35.2	4.6		.7	62.5	41.8	5.0	217.0	4.2
H4 20	7.90	4.8	10.2	46.8	4.5		.8	79.7	44.8	6.0	220.0	.9
H4 26	7.60	4.0	8.3	47.6	2.5		1.1	52.8	71.7	5.0	228.0	1.1
H5 2	8.20	66.8	30.0	123.7	10.2		15.0	346.8	47.7	12.0	669.0	1.0
H5 8	8.50	5.3	10.2	41.2	.9		2.0	55.5	59.7	8.0	196.0	.9
H5 14	7.80	2.1	6.4	34.2	.1		2.3	43.6	44.2	6.0	156.0	3.7
P1 3	8.50	22.3	7.8	43.1	4.1		19.8	94.5	23.5	2.0	214.0	3.1
P1 9	8.60	26.9	11.0	36.8	3.8		18.9	91.3	46.3	3.0	260.0	.6
P1 15	8.70	18.6	6.0	46.0	1.5		19.4	69.0	53.5	2.6	214.0	.6
P1 21	8.80	12.8	5.5	58.8	1.7		19.0	60.8	71.0	1.0	223.0	2.4
P1 29	8.80	9.0	7.7	83.7	3.0		19.1	92.0	92.4	2.0	280.0	.7
P2 2	8.70	33.5	12.8	9.0	24.5		20.9	74.5	46.7	3.0	243.0	3.9
P2 8	8.80	23.4	8.7	25.0	10.5		14.5	76.0	38.5	4.0	232.0	.1
P2 14	8.60	27.9	6.5	14.5	3.6		13.7	67.9	23.4	2.5	179.0	.3
P2 20	8.40	13.0	5.3	12.3	3.7		7.8	46.4	13.6	2.0	123.0	1.1
P2 26	8.20	10.4	8.4	16.8	6.4		3.8	16.0	76.9	2.0	172.0	1.0
P2 30	8.20	19.8	17.0	27.8	8.1		4.5	52.0	111.2	2.6	298.0	-.9
P3 2	8.40	9.3	4.8	3.9	5.3		4.9	25.0	15.2	1.0	73.0	2.0
P3 8	8.40	41.9	9.4	7.4	12.5		15.9	92.0	25.6	1.6	207.0	1.3
P3 14	8.30	13.7	5.1	43.3	2.2		13.0	86.0	15.1	2.0	201.0	.9
P3 20	8.30	6.0	4.3	39.0	1.9		12.5	60.2	19.8	2.6	160.0	.9
P3 26	8.20	9.6	5.7	50.8	1.4		30.1	80.0	16.4	3.0	204.0	.8
P3 32	8.30	9.7	5.5	51.6	1.6		26.0	93.5	19.4	2.0	205.0	4.1
P3 38	8.20	9.0	6.6	80.9	5.3		24.6	100.0	78.1	2.0	290.0	1.6
P4 2	8.20	17.8	15.4	18.8	32.9		2.9	65.0	89.1	3.0	307.0	.4
P4 8	8.40	13.4	9.1	14.8	15.0		7.3	66.0	21.6	2.6	166.0	.6
P4 14	8.50	23.9	13.1	16.4	11.4		16.4	92.0	23.3	2.0	207.0	1.6
P4 20	8.60	9.4	7.2	9.5	5.4		8.7	45.0	5.7	1.0	104.0	2.1
P4 26	8.40	14.2	10.1	11.2	6.6		12.6	68.0	7.0	2.0	137.0	2.4
P4 32	8.50	11.4	9.5	11.9	5.9		13.2	56.0	7.0	1.6	133.0	1.3
P4 36	8.40	15.1	11.4	13.4	6.9		11.4	68.0	9.2	2.0	158.0	2.5
P5 2	7.90	34.7	11.6	20.2	30.2		14.9	38.0	138.3	5.0	295.0	.7
P5 8	8.30	27.2	21.4	95.9	5.0		13.7	100.0	207.7	2.0	520.0	.1
P5 14	8.40	24.8	24.0	39.5	4.5		7.9	95.0	111.8	2.0	365.0	1.2
P5 20	8.50	12.4	8.4	21.6	5.4		11.1	43.0	48.7	1.6	183.0	1.0
P5 26	8.20	11.4	9.5	30.0	7.2		14.5	68.8	27.6	1.0	183.0	1.3
P5 34	8.40	8.3	5.8	28.9	5.1		14.0	60.0	11.2	1.0	154.0	2.4
P6 2	7.10	22.5	7.2	5.4	52.1		1.5	58.4	66.7	6.0	267.0	1.9
P6 8	7.20	23.6	9.5	19.1	17.5		6.7	58.7	71.3	3.0	253.0	.9
P6 14	7.50	16.9	18.1	23.5	36.6		5.7	81.2	98.4	4.0	351.0	2.4
P6 20	7.80	13.2	10.1	9.6	12.1		20.4	41.0	37.5	3.0	154.0	2.3
P6 26	8.20	9.8	7.1	8.4	6.9		14.5	20.3	28.6	2.0	109.0	5.8
P6 32	8.20	10.5	7.4	8.8	5.8		12.4	30.8	28.0	1.5	112.0	.5
P6 36	8.20	10.2	7.1	10.0	5.2		13.1	30.2	26.4	1.0	109.0	3.7

TABLE 6.3 CHEMICAL ANALYSES OF SATURATED LEACHATES DERIVED FROM SOIL AND DECOMPOSED BEDROCK OBTAINED FROM THE AUGER SAMPLING PROGRAM.

Sample number	pH	Ca	Mg	Na	K	HCO3	Cl	SO4	NO3	T. D. S.	ERROR
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	%
B6 2	9.90	9.0	3.6	3871.5	35.9	280.0	4860.0	1061.5	60.0	9782.0	1.6
B6 8	8.80	6.2	4.0	140.0	2.8	20.5	200.0	36.2	10.0	428.0	.7
B6 14	8.60	5.1	5.6	173.1	2.5	10.7	222.0	88.7	11.0	643.0	.9
B6 20	8.50	9.3	10.8	133.2	4.1	15.1	203.0	69.6	9.0	500.0	2.1
B6 26	8.50	5.7	6.9	169.8	1.8	16.1	220.0	86.3	8.0	578.0	.7
B6 34	8.60	4.7	5.6	214.7	.1	17.8	266.0	113.2	9.0	735.0	1.3
B7 2	8.80	20.3	20.2	225.1	20.7	25.0	394.0	78.7	8.0	821.0	1.1
B7 8	8.60	8.6	20.4	273.5	19.5	20.2	421.0	136.2	9.0	821.0	2.3
B7 14	8.50	3.3	6.5	201.9	25.9	20.2	236.0	142.2	7.0	701.0	.4
B7 20	8.40	6.4	12.1	106.4	6.9	12.5	157.0	53.2	5.0	311.0	2.5
B7 26	9.00	3.1	15.1	116.6	10.0	11.6	196.0	54.0	4.5	382.0	1.4
B7 32	8.90	3.9	22.4	100.5	16.1	10.0	181.0	50.7	4.0	311.0	3.0
B7 40	8.90	6.0	26.2	141.4	4.0	23.0	240.0	66.5	5.0	450.0	.6
B8 2	8.20	17.9	15.1	90.4	19.4	19.7	199.0	36.9	6.0	382.0	1.8
B8 8	8.40	12.8	11.3	422.8	7.3	11.0	628.0	172.8	17.0	1345.0	3.9
B8 14	8.10	15.7	26.9	422.9	3.9	6.7	680.0	126.8	14.0	1331.0	1.5
B8 20	8.00	13.2	23.5	346.5	3.8	5.7	592.0	120.7	13.0	1175.0	4.7
B8 26	7.80	10.3	22.3	319.0	2.0	2.9	500.0	101.3	12.0	1019.0	.5
B8 30	7.90	13.1	30.1	335.7	2.1	4.4	580.0	118.8	13.0	1168.0	3.6
B9 2	8.00	59.4	78.1	365.7	8.9	3.6	840.0	162.7	12.0	1657.0	3.4
B9 8	8.50	26.7	59.2	551.1	6.1	2.9	964.0	163.0	11.0	1777.0	.8
B9 14	8.10	25.1	27.5	367.6	3.9	5.1	585.0	134.1	7.0	1154.0	.3
B9 20	8.00	26.3	48.8	441.7	4.0	5.4	765.0	166.7	7.0	1484.0	1.2
B9 24	8.00	45.9	69.4	582.5	3.0	4.1	1000.0	260.0	14.0	1876.0	.7
B10 2	8.50	114.8	75.4	924.5	7.6	19.6	1480.0	421.5	14.0	3048.0	1.2
B10 8	8.40	52.6	68.2	563.3	3.2	8.3	950.0	306.1	12.0	2025.0	1.0
B10 14	8.20	40.1	63.6	565.0	3.7	6.9	1000.0	240.8	12.0	1907.0	2.5
B10 20	8.50	45.4	65.0	569.7	.5	5.8	1010.0	267.6	11.0	2018.0	2.9
B11 2	8.80	92.2	30.9	571.4	24.7	12.7	1090.0	204.6	20.0	2097.0	4.3
B11 8	8.60	286.9	126.4	1306.6	59.8	7.1	2060.0	1278.5	18.0	4796.0	1.2
B11 14	8.60	41.3	65.4	1883.4	54.8	8.8	2700.0	691.8	17.0	5347.0	.1
B11 20	8.80	29.8	38.3	1593.0	41.4	11.5	2320.0	692.0	14.0	4641.0	3.4
B11 26	8.80	22.7	31.3	1277.0	29.9	9.2	1800.0	475.0	12.0	3789.0	.8
B11 32	8.20	46.1	51.9	833.4	33.2	3.9	1310.0	376.2	8.0	2586.0	1.5
B11 40	8.40	177.8	156.7	1364.5	1.1	5.4	2400.0	818.8	10.0	4823.0	2.3
B12 2	9.10	23.6	8.5	91.1	13.9	14.2	187.0	21.4	10.0	404.0	.7
B12 8	8.90	2.6	3.0	202.8	11.5	34.7	197.6	134.8	11.0	578.0	2.0
B12 14	8.80	5.2	10.6	430.4	24.3	21.8	550.0	279.0	8.0	1336.0	3.2
B12 20	8.60	16.3	39.1	769.2	.5	13.4	1080.0	435.6	3.0	2415.0	3.0
B13 2	8.50	21.5	15.7	102.5	8.3	17.2	204.0	25.8	2.0	404.0	3.1
B13 8	8.40	4.1	30.4	102.4	9.5	3.4	195.0	79.7	4.0	404.0	.8
B13 16	8.60	46.2	83.7	891.7	1.1	8.5	1430.0	406.0	10.0	2868.0	1.1
C3 2	8.40	20.4	14.0	69.6	4.4	17.2	166.4	22.7	2.0	320.0	1.6
C3 8	8.60	5.2	19.2	246.1	6.4	20.7	378.0	52.5	3.0	693.0	2.3
C3 14	8.80	3.6	6.3	354.8	6.0	23.1	448.0	153.3	2.5	966.0	.1
C3 20	8.70	2.7	4.4	304.3	8.2	23.8	350.0	140.2	3.0	829.0	2.6
C3 26	8.60	3.8	4.8	263.7	8.0	18.1	346.0	99.8	3.0	772.0	.3
C3 30	8.60	4.1	5.3	248.4	7.0	18.3	330.0	89.8	2.0	746.0	.5
C4 2	8.60	25.5	12.3	133.7	2.7	25.4	251.6	32.1	2.0	536.0	.3
C4 8	8.70	30.0	17.1	371.8	1.1	24.4	560.0	138.2	4.0	1159.0	.1
C4 14	8.60	129.2	105.8	820.5	16.1	16.7	1630.0	252.6	8.0	2844.0	.4
C4 20	8.50	112.1	89.8	563.3	5.0	10.6	878.0	608.6	3.0	2198.0	.1
C4 24	8.40	119.7	111.9	789.8	1.1	8.5	1540.0	304.6	4.0	2797.0	.4
C5 2	9.20	28.1	12.0	73.8	5.9	23.1	173.5	24.1	2.0	333.0	.5
C5 8	8.90	21.5	10.8	180.0	8.3	33.8	273.0	70.2	3.0	535.0	1.2
C5 14	8.80	11.2	18.3	164.6	3.9	26.2	251.0	30.4	4.0	479.0	6.4
C5 20	8.90	3.6	4.5	143.0	3.5	17.1	203.0	62.2	4.0	442.0	3.6
C5 24	9.00	3.0	2.6	159.9	3.4	32.7	220.0	28.5	5.0	465.0	.1
C6 2	8.80	35.5	21.5	76.5	2.9	32.0	206.0	21.9	2.5	436.0	.8
C6 8	8.70	64.3	11.5	67.9	1.5	28.0	192.0	50.3	2.0	396.0	1.4
D5 2	8.40	29.1	11.8	17.3	1.6	15.7	90.0	12.6	1.5	209.0	2.1
D5 8	8.50	12.9	11.7	159.9	1.4	24.9	196.0	132.7	2.0	593.0	.8
D5 14	8.60	.5	1.9	180.2	2.4	5.9	150.0	191.0	2.0	600.0	1.6
D5 20	8.50	.2	1.5	139.2	1.8	8.9	134.0	105.7	1.5	455.0	.7
D5 26	8.60	.4	1.3	140.1	6.1	15.2	158.0	95.8	1.0	449.0	2.6
D5 30	8.70	.4	3.4	138.5	.1	17.2	152.0	89.8	1.0	428.0	1.0
D6 2	8.70	19.2	14.4	54.2	2.2	13.2	130.0	24.6	2.0	355.0	1.4
D6 8	8.30	82.4	120.3	592.5	2.0	6.4	1200.0	375.2	14.0	2580.0	2.6
D6 14	8.80	7.3	63.1	680.5	2.1	1.7	1050.0	304.6	5.0	2166.0	1.2
D6 20	8.80	3.4	35.9	486.0	2.6	2.9	709.0	238.0	6.0	1573.0	1.6
D6 24	8.90	3.2	7.0	529.5	.3	21.6	600.0	291.1	3.0	1338.0	.8

TABLE 6.3 CHEMICAL ANALYSES OF SATURATED LEACHATES DERIVED FROM SOIL AND DECOMPOSED BEDROCK OBTAINED FROM THE AUGER SAMPLING PROGRAM.

Sample number	pH	Ca	Mg	Na	K		HCO3	Cl	SO4	NO3	T. D. S.	ERROR
		mg/l	mg/l	mg/l	mg/l		mg/l	mg/l	mg/l	mg/l	mg/l	%
D7 2	8.20	6.8	3.5	3.6	14.1		11.8	26.9	12.2	1.0	84.0	3.3
D7 8	8.50	7.9	7.7	25.9	9.8		7.9	64.5	17.4	8.0	185.0	.7
D7 14	8.40	7.0	12.7	122.8	.1		4.4	169.2	73.2	3.0	462.0	2.4
D8 2	8.30	11.0	10.9	50.9	14.4		1.1	105.5	51.8	4.0	234.0	.4
D8 8	8.40	38.9	26.7	137.4	16.4		1.2	300.0	96.5	5.0	697.0	.2
D8 16	8.50	11.5	16.2	89.6	.1		3.8	177.0	38.0	2.5	448.0	.7
F5 2	7.90	11.7	12.7	40.4	2.8		20.2	86.5	22.0	2.5	211.0	2.8
F5 8	8.30	5.0	5.2	83.3	2.7		10.8	130.0	20.4	3.0	266.0	.6
F5 14	8.40	4.9	4.3	29.4	1.6		9.6	55.0	9.0	2.0	132.0	.3
F5 20	8.50	3.0	2.8	16.9	3.9		8.6	34.3	7.0	1.0	79.0	2.2
F5 26	8.20	5.8	3.4	41.3	.1		3.7	70.8	16.5	2.0	148.0	1.3
F6 2	8.30	17.7	23.9	79.2	20.3		3.3	190.0	69.0	2.0	485.0	.5
F6 8	8.00	14.2	44.0	468.6	3.5		5.1	764.0	180.0	3.0	1522.0	1.3
F6 14	7.90	8.7	37.1	803.7	1.4		1.8	1055.0	353.0	5.0	2301.0	1.7
F6 20	8.20	19.0	48.9	824.8	1.4		4.2	1205.0	425.0	6.0	2690.0	2.5
F6 26	8.30	11.0	24.9	543.9	1.0		3.5	785.0	180.0	5.0	1657.0	.5
F6 32	8.10	9.6	18.2	343.0	1.4		2.9	500.0	115.0	4.0	1076.0	1.0
F6 38	8.00	29.6	48.4	499.0	2.3		2.9	775.0	253.0	4.0	1664.0	.0
F7 2	8.50	32.2	31.2	163.5	65.5		.5	402.0	83.0	4.0	804.0	.7
F7 8	8.40	11.6	20.3	85.7	17.4		1.4	168.8	72.0	2.5	375.0	.8
F7 14	8.40	11.7	16.2	70.6	7.6		.5	147.0	40.0	2.0	336.0	1.6
F7 20	8.30	13.1	16.3	93.1	5.6		.5	167.0	76.0	1.6	418.0	1.1
F7 26	8.20	10.6	15.2	139.0	2.9		3.4	183.6	107.0	1.0	496.0	2.8
F7 32	8.40	9.5	15.3	131.1	1.6		5.1	168.2	113.0	2.0	453.0	1.8
F7 38	8.40	3.8	20.3	83.7	1.7		5.2	126.3	103.0	1.0	336.0	2.3
F8 2	8.60	42.3	12.5	16.0	8.9		21.2	87.0	52.0	2.0	269.0	3.4
F8 8	8.50	46.7	22.1	58.7	3.5		22.9	178.0	52.0	3.0	470.0	2.0
F8 14	8.50	17.5	10.2	42.9	5.9		26.3	93.4	26.0	2.0	234.0	1.0
F8 20	8.40	9.9	6.5	26.2	7.3		16.2	60.2	14.0	1.6	170.0	1.6
F8 26	8.50	12.2	10.7	33.8	11.3		10.4	98.7	14.0	2.0	235.0	.5
F8 32	8.60	13.7	19.0	51.5	15.6		10.7	134.0	45.0	4.0	361.0	.7
F8 36	8.70	13.1	25.1	81.4	17.0		13.4	169.0	85.0	4.0	400.0	.9
F9 2	7.90	35.8	25.7	32.7	19.5		1.2	154.8	58.0	2.0	390.0	1.7
F9 8	7.80	3.5	14.4	24.4	8.5		3.4	64.9	28.5	2.0	123.0	2.4
F9 14	8.00	15.4	13.7	74.0	.4		3.0	125.0	75.8	1.0	266.0	.4
G1 2	3.60	10.9	14.0	88.7	3.3		1.6	101.8	129.2	2.0	368.0	.2
G1 4	5.70	8.6	9.7	66.2	2.9		.5	84.0	88.2	2.0	290.0	.8
G1 6	5.40	5.9	6.3	40.4	2.4		.4	52.4	55.5	1.0	191.0	.5
G1 8	5.70	5.2	5.5	29.4	2.4		.4	42.5	43.6	1.0	163.0	1.8

TABLE 6.4B CHEMICAL ANALYSES OF LEACHATES DERIVED FROM CRUSHED DIAMOND DRILL CORES. THE LOWER TABLE SHOWS THE ANALYSES FOR A SECOND LEACHATE EXTRACTION OF THE SAME SAMPLES.

Sample number	pH	Ca	Mg	Na	K		HCO3	Cl	SO4	NO3	T. D. S.	ERROR
		mg/l	mg/l	mg/l	mg/l		mg/l	mg/l	mg/l	mg/l	mg/l	%
A1 9	8.20	7.1	9.8	152.4	25.9		9.5	280.0	20.0	.5	610.0	.2
A1 18	8.30	2.6	3.0	62.4	65.2		11.0	150.0	15.0	.6	225.0	.3
A1 51	7.70	17.7	67.6	90.2	37.6		2.5	25.8	520.0	.7	734.0	1.2
B1 6	8.20	2.1	20.3	40.5	5.4		43.5	76.0	38.0	.6	213.0	3.9
B1 10	8.00	2.0	18.9	30.6	17.3		20.6	79.5	48.0	.8	200.0	.9
B1 14	8.40	11.4	39.1	82.0	48.8		6.0	14.4	400.0	.7	654.0	1.4
B1 22	6.80	19.1	56.4	69.3	80.4		1.2	33.8	505.0	.6	741.0	3.8
B1 42	7.80	7.8	37.0	74.1	67.8		2.7	14.9	376.0	.5	639.0	.5
B1 49	6.80	1.4	26.6	65.2	1.3		1.1	10.7	225.0	.5	360.0	1.1
C2 9	8.00	1.6	2.4	127.0	27.7		6.2	202.0	33.0	.8	450.0	.1
C2 42	8.00	.9	9.1	29.4	.5		10.0	38.8	38.0	.7	135.0	.6
D1 6	8.90	5.0	6.3	285.1	3.0		35.0	380.0	68.0	.8	799.0	2.0
D1 45	7.50	2.2	4.9	91.5	6.5		2.3	83.0	109.0	.4	350.0	.0
A1 9X	7.60	2.0	3.0	39.0	4.2		4.2	62.5	6.0	.2	141.0	4.6
A1 18X	7.70	3.0	4.9	11.3	21.8		5.2	41.5	15.0	.1	77.0	.8
A1 51X	7.30	4.5	16.5	17.4	38.1		1.4	7.3	152.0	.2	245.0	1.3
B1 6X	7.90	10.3	16.9	37.4	3.5		16.3	106.8	18.0	.2	59.0	.5
B1 10X	7.70	10.8	10.1	28.6	9.6		7.4	57.6	29.0	.2	63.0	3.6
B1 14X	6.70	2.8	8.0	19.1	24.0		.4	3.2	115.0	.1	186.0	5.3
B1 22X	7.10	4.0	11.1	18.0	27.0		1.1	7.5	123.0	.1	211.0	3.8
B1 42X	7.30	1.9	6.3	9.7	32.0		1.1	1.9	88.0	.1	159.0	1.4
B1 49X	7.30	1.0	4.0	15.6	26.9		1.3	1.9	82.0	.1	109.0	1.1
C2 9X	7.80	2.2	3.5	34.4	2.1		5.1	61.7	15.0	.2	111.0	4.7
C2 42X	7.80	1.3	2.9	11.0	10.9		4.9	24.1	14.0	.2	62.0	2.0
D1 6X	8.50	1.2	1.1	84.3	.3		17.7	109.0	16.0	.3	276.0	2.5

elevation of only 3.58 metres. H2 and H3 are similarly disposed and have the same sedimentary materials, but H3 has higher salinity, as does H4. The reason for the low salinity in H2 is difficult to explain, but must be related to the large volume of clean sand, free of clay layers. A canal bearing high quality water from a weir 1km upstream crosses the line just above H2, and provides irrigation water which seepage from this could have leached out the salts. The presence of the Sewefontein Fault which carries low T.D.S. water from the Suurberg mountain and crosses the auger line somewhere near H2, may also have contributed to the lowering of the salinity of these sediments.

H5 shows a decline in leachable salt as one moves downwards from the topsoil into decomposed bedrock, which becomes harder and less saline with depth.

6.3.2 Auger line P (App. FIG. 2.3F and App. FIG. 6.3)

Although boreholes P2 and P3 are not in the same line as P1, P4, P5 and P6, they were drilled in the same area i.e. vineyards which have been irrigated for over 40 years. The results show a low overall salinity in both alluvial deposits and the decomposed bedrock (Waboomberg Shale Formation). Values over 300 mg/l are seldom attained, notable exceptions being at 1.4 m in P6 where clay was encountered and at ± 1 m in P5 where calcareous sandy hillwash gave 534 mg/l when leached.

6.3.3 Auger line B. (App. FIG 2.3E, 6.4 and 6.5)

Eight boreholes were drilled by auger on this line, 4.5km upstream from line P.

Once again the materials change from hillwash sand and clay to cleaner alluvial sands and gravel as the boreholes get closer to the river (i.e. from B6 to B9 and B10 - App. Fig. 6.4). However, the salinity of the sediments in B6 and B7 is lower than 800mg/l (excluding the upper samples which have been contaminated by saline irrigation return flow and artesian outflow from borehole B1) while B8 and B9 show values generally in excess of 1000 mg/l, reaching a maximum of 1847 mg/l.

On the southern side of the river (App. Fig. 6.5) even higher values are found, i.e. ± 2000mg/l in B10, with a maximum of 3078. In B11, where a thick deposit alluvial and hillwash sand was sampled, extremely high values were encountered, i.e.

between 3000 and 5658mg/l. In B12 and B13 where shallow soil overlies decomposed Bokkeveld bedrock, a very strong increase in salinity occurs with depth. In B12 it rises from 300mg/l to 2451mg/l at 2.00 metres and in B13, from 200 to 2868mg/l at 1.6 metres. It is thought that natural leaching of these salts from the bedrock and movement downslope towards the river caused the concentration of the salt in the sandy material at B11, possibly by evaporation of seepage water at the side of the alluvial terrace. The highly variable salinity in B11 certainly indicates a layering of sediments with different permeabilities and porosities. (well sorted, medium sand at 3.2m has a distinctly lower salinity than more clay-rich materials above and below).

Saline outflow from the sandy terrace in which B11 was drilled probably caused the high salinity of the samples taken on the riverbank at B10.

6.3.4 Transect C on Auger line C - D (App. FIG 2.3D and App. FIG. 6.6)

On borehole transect C a thin layer of stony soil overlies decomposed siltstone and shale of the Boplaas and Tra Tra Formations forming a gently sloping alluvial terrace recently undercut by the river to produce an eight metre scarp.

At the upper end of the line (boreholes C3 and C4) the salt distribution is similar to that encounterred at boreholes B12 and B13, i.e. an increase of salinity as one passes downwards through the thin soil layer into the decomposed shale and siltstone. A maximum leachate salinity of 2857 mg/l was determined at a depth of 1.4m in C4 and 1123 mg/l at a depth of 1.8m in C3.

Downslope at C5 an C6 the soil and gravel appears to have been leached (possibly by irrigation) and gave a maximum of only 574 mg/l. In this area, the overburden appears more pebbly, with less clay that at the upper end of the line.

6.3.5 Transect D on Auger Line C - D (App. FIG. 2.3D and App. FIG 6.7)

In D5, 3 metres of sandy hillwash containing fragments of shale and siltstone overlies an alluvial gravel in which the auger refused further penetration. The highest leachate salinity was 759 mg/l at 1.2m. In the underlying decomposed micaceous siltstone, the salinity of leachate obtained from diamond core at a depth of 6m rose to 799 mg/l.

In D6 the salinity of the clay-rich soil rose to 2974 mg/l at a depth of 1m. Closer to the river, D7 and D8 were drilled in alluvial sand and salinities dropped to values below 700 mg/l .

In this transect, the hillwash soils contain more salt than the alluvial sand.

6.3.6 Auger line F (App. FIG 2.3B and App. FIG. 6.8)

Moving downslope from F9 to F7, the overburden increases in thickness from 0.7m to 3.2m, and shows only moderate leachate salinity, with a maximum of 804mg/l at F7. The decomposed siltstone and sandstone bedrock material shows a similar lack of salinity with a maximum value of 524 mg/l.

At F6, the alluvial deposits consist mainly of sand with pebbles and occasional clay layers; much higher salinities were found, with a maximum of 2690 mg/l at a depth of 2 metres in sandy clay.

These values are in sharp contrast with the very low salinities encountered in F5 only 60 metres away. Unfortunately severe damage to the drilling rig occurred during drilling of F5, and no samples could be obtained on top of the alluvial terrace at F4.

Full chemical analyses were carried out on leachates from selected depths, and will be discussed later. (section 8)

6.4 Leaching of crushed Diamond Core samples

The same twelve samples of diamond core which were crushed for XRF whole rock chemical analyses (Section 2.3.3, Table 2.2) were also used for leaching tests.

The twelve samples were chosen to give the widest possible variety of sedimentary rock types from the Bokkeveld Group, i.e. sandstone, micaceous siltstone and shale in various stages decomposition. Each sample was washed in distilled water and dried before being crushed to a powder by Siebtechnik. 500 grams of this powder was then taken up in 500 cc distilled water and shaken up regularly over a period of 5 days until constant salinity had been reached. Solids were separated, and T.D.S. determined. The leaching process was repeated a second and third time with 1000cc distilled water. The results are shown in Table 6.4A.

TABLE 6.4A

LEACHATE SALINITIES OF CRUSHED DIAMOND CORES

ADJACENT TO BORE-HOLE:	DEPTH in meters	MATERIALS	TDS of LEACHATES: (mg/l)		
			1st	2nd*	3rd*
A1	9.00	Yellow-brown fine decomposed siltstone.	610	141	28 (21.8)
A1	18.25	Khaki-brown graphitic shale.	225	77	37 (6)
A1	51.00	Grey-black graphitic silty shale.	734	245	88 (8.3)
B1	6.15	Grey-green micaceous decomposed siltstone	218	59	20 (10.9)
B1	10.25	Yellow-grey micaceous silty shale with brown stains.	200	63	27 (7.4)
B1	14.60	Dark grey micaceous graphitic shaly siltstone	654	186	82 (7.9)
B1	22.20	Black graphitic shale with sericite mica	741	211	160 (4.7)
B1	42.20	Black graphitic micaceous shaly siltstone.	639	159	68 (9.3)
B1	49.50	Grey sandstone with mica and graphite on cleavages	360	109	65 (5.5)
C2	9.25	Pale yellow-brown clayey siltstone.	450	111	35 (12.8)
C2	42.50	Black graphitic micaceous silty shale	135	62	44 (3.1)
D1	6.30	Green-brown clayey micaceous decomposed shale	799	276	31 (25.7)

* These leachings were done in 1000cc H_2O.

Examination of these results show that the decomposed, clay-rich materials give off their salts readily, with the result that much lower results are obtained with the second and third leaches. (The figures in parentheses show the ratios obtained by dividing the T.D.S. of the 1st leachate by the TDS of the 3rd leachate.) The less altered bedrock samples appear to retain the adsorbed salt longer, giving off appreciable amounts in the 2nd and 3rd leaches (with smaller ratios for the 1st divided by the 3rd leachates.)

Results of principal component chemical analyses of the twelve leachates mentioned above are shown in Table 6.4B (p. 108), together with results from the second leach test. Also included on the table is the chemical analysis of a leachate obtained from a finely crushed sample of sliced diamond core (depth 45m in borehole D1) shown in Fig. 5.18 and App. Fig. 5.19).

The diamond core samples had been stored dry, and less oxidation of the pyrite had been able to take place, resulting in lower chemical activity; less altered, deeper bedrock samples nevertheless gave high $SO_4^=$ values.

After the triple leaching had been done, the leached residue was dried and again submitted to XRF analyses for major and trace elements, to investigate changes in the chemical properties of the rocks. The results are presented in TABLE 6.4C. The chemical characterization of bedrock types is clearly shown in the variation of silica and alumina percentages: siltstone or fine sandstone layers run at SiO_2 values between 70 and 80% with Al_2O_3 below 12%, while shales have between 56 and 70% SiO_2 with Al_2O_3 above 12%.

Comparison of the weight percentages before and after leaching shows that in most cases SiO_2 increases while Al_2O_3 and Fe_2O_3 are reduced; the reasons for this are physical rather than chemical: clay minerals and iron hydroxide tend to remain in suspension, and small amounts are lost during decantation and filtration (when they pass through the filter paper) during the separation of leachate from its residue, rather than by solution (because their solubilities are low). Quartz tends to separate more readily from a suspension of rock powder and water by settlement and filtration, leading to the higher SiO_2 levels.

Looking at the trace elements, it is interesting to see that Rb (and to a lesser extent Sr) follow the trend of Al_2O_3. Where Al_2O_3 is greatly reduced, Rb follows

TABLE 6.4 C

Comparison of Chemical Analyses of finely crushed diamond-drill core materials before and after triple leaching to saturation in distilled water.

(500g sample in 500ml H_2O) (P = Powdered Sample / L = Leached residue)

SAMPLE	A1 - 9m		A1 - 18m		A1 - 51m		B1 - 6m		B1 - 10m		B1 - 14m	
DESCRIPTION OF MATERIAL	Yellow brown fine decomp. siltstone.		Grey-black carbonaceous shale.		Grey-black carbonaceous silty shale.		Greenish brown decomposed micaceous siltstone.		Yellow-grey semi decomp. micaceous siltstone.		Grey micaceous silty shale.	
Oxide Weight %	P	L	P	L	P	L	P	L	P	L	P	L
SiO_2	72.43	79.629	59.939	62.953	61.156	63.776	67.483	75.005	72.747	81.260	70.468	80.532
TiO_2	0.693	0.642	0.911	0.843	0.950	0.888	0.898	0.933	0.853	0.901	0.903	0.878
Al_2O_3	12.072	9.197	18.757	16.986	16.742	14.707	13.365	10.414	12.335	8.344	13.701	8.203
Fe_2O_3	4.735	2.666	6.320	6.054	8.163	8.201	6.041	3.961	4.636	2.335	4.977	3.207
MnO	0.046	0.023	0.036	0.043	0.044	0.058	0.747	0.692	0.038	0.022	0.031	0.022
MgO	1.192	0.633	2.269	1.873	2.511	2.181	1.470	0.993	1.219	0.510	1.591	0.814
CaO	0.275	0.249	0.207	0.204	0.277	0.290	0.139	0.090	0.239	0.221	0.150	0.152
Na_2O	2.586	2.789	1.081	1.293	1.140	1.149	0.980	1.293	1.267	1.745	1.097	1.393
K_2O	1.565	0.882	3.917	3.363	2.807	2.333	2.307	1.668	2.178	1.168	2.581	1.240
P_2O_5	0.174	0.159	0.136	0.156	0.174	0.190	0.08	0.066	0.158	0.159	0.109	0.105
L.O.I.	2.125	1.240	4.274	3.677	4.683	4.366	3.444	2.203	2.759	1.411	3.438	2.063
H_2O-	0.467	0.269	0.374	0.410	0.626	0.315	1.503	0.824	0.814	0.399	0.356	0.235
TOTAL	98.36	98.377	98.221	97.855	98.908	98.452	98.458	98.142	99.244	98.474	98.745	98.842
TRACE ELEMENTS (p.p.m.)												
Nb	14.99	13.93	20.24	18.42	18.74	17.38	19.32	19.40	17.91	18.70	18.96	19.50
Zr	350.44	444.39	240.58	240.04	210.90	223.17	385.07	469.39	404.39	488.77	367.28	585.44
Y	39.70	36.89	42.56	42.07	38.49	35.36	44.98	49.02	37.29	43.50	38.21	47.24
Sr	105.95	96.40	80.90	84.66	98.84	90.17	183.38	160.59	75.98	69.75	55.96	47.46
Rb	83.24	46.64	199.24	175.82	155.93	129.47	106.53	78.84	100.88	62.99	120.39	61.79
S%	<0.002		<0.002		0.607	0.746	<0.002		<0.002		0.492	0.576

TABLE 6.4C (continued)

SAMPLE	B1 - 22m		B1 - 42m		B1 - 50m		C2 - 9m		C2 - 42m		D1 - 6m	
DESCRIPTION OF MATERIAL	Black carbonaceous micaceous shale.		Dark grey micaceous shaly siltstone.		Grey hard micaceous siltstone.		Pale yellow-brown semi decomposed silty shale.		Black micaceous carbonaceous shale with some silt.		Yellow-brown semi decomposed micaceous shaly siltstone.	
Oxide Weight %	P	L	P	L	P	L	P	L	P	L	P	L
SiO_2	56.723	56.528	68.397	75.882	75.943	80.808	73.475	73.152	61.195	57.005	75.913	86.944
TiO_2	1.024	1.022	0.963	0.908	0.819	0.799	0.854	0.862	1.002	1.289	0.623	0.538
Al_2O_3	20.769	20.635	14.948	10.629	11.430	8.903	12.262	12.995	17.737	19.551	11.289	5.538
Fe_2O_3	6.751	6.748	5.079	3.797	3.144	2.187	3.813	3.623	7.326	8.379	4.090	1.724
MnO	0.047	0.059	0.029	0.029	0.025	0.028	0.028	0.03	0.045	0.054	0.011	0.013
MgO	2.349	2.200	1.700	1.226	1.081	0.752	1.111	1.089	2.327	2.512	1.126	0.433
CaO	0.134	0.137	0.167	0.147	0.167	0.159	0.098	0.087	0.236	0.211	.191	0.290
Na_2O	0.299	0.296	1.186	1.426	2.126	2.275	1.092	0.997	0.982	0.876	1.556	1.631
K_2O	4.792	4.763	2.889	1.806	1.789	1.076	2.274	2.485	3.388	3.857	1.367	0.526
P_2O_5	0.106	0.130	0.116	0.123	0.140	0.152	0.094	0.077	0.155	0.156	0.065	0.032
L.O.I.	5.448	5.329	3.415	2.287	2.073	1.575	2.726	2.739	4.518	4.738	2.696	1.283
H_2O-	0.493	0.609	0.235	0.150	0.159	0.104	0.574	0.624	0.274	0.419	0.745	0.360
TOTAL	98.936	98.456	99.123	98.409	98.897	99.448	98.401	98.758	99.187	99.048	98.945	99.313
TRACE ELEMENTS (p.p.m.)												
Nb	21.52	21.82	19.74	19.86	17.18	15.70	17.31	18.77	19.86	25.98	12.38	11.54
Zr	229.39	232.00	364.07	516.46	518.21	562.69	378.47	371.25	224.89	194.40	316.58	403.13
Y	43.24	41.35	38.75	45.18	39.64	38.89	34.44	32.06	40.39	35.22	35.33	37.78
Sr	52.64	51.24	66.99	58.76	74.43	69.77	94.85	93.91	70.57	69.05	70.19	45.58
Rb	222.15	222.10	137.49	88.11	88.86	55.18	115.03	122.31	173.02	194.96	74.79	34.74
S%	0.129	0.046	0.322	0.212	0.186	0.194	< 0.002		< 0.002		< 0.002	

suit, but remains at the same level when Al_2O_3 stays constant as in samples B1-22m and C2 - 9m. Nb and Y stay much more constant, but Zr increases in most cases, due to the resistance of the mineral grains of Zircon in the sediments which behave in the same way as Quartz grains.

The sulphur results show that in some samples the content was too low for analysis (<0.002%), while in others it rose to 0.75%. The latter contained pyrite. Where the pyrite was fresh and unaltered, it remained in the residue after leaching, and gave higher S values; where some oxidation had occurred forming soluble $SO_4^=$, the leached residues showed reduced S%.

In all the tests, the values for the alkali and alkali earth compounds K_2O, MgO and CaO were reduced by the leaching process, but the Na_2O values increased. This shows that some of the K, Mg and Ca may have been lost along with some clay. (Where Al_2O_3 remained constant as in B1-22m, the K,Ca and Mg followed suit).

It also shows that the Na is not present in clay minerals or in soluble ionic form, but that it occurs in mineral grains which are unaffected by the leaching process, such as albite, a mineral commonly occurring in marine sediments.

The L.O.I. (Loss on ignition) figures which rise as high as 5.448% are caused by the burning off of the carbon occurring as graphite in the black shales or as hydrocarbon molecules in the carbonaceous rock, CO_2 from carbonate minerals and SO_2 from sulphide minerals.

These figures also show a decline after leaching possibly due to the loss of carbon during the filtration process.

Finally, the phosphate content of the samples remained relatively constant.

It is unfortunate that whole rock analytical procedures could not be used to detect chloride, one of the major constituents of the salts in the bedrock, soils and rivers of the region. We have to assume that chloride ions are adsorbed onto mica, clay mineral or even graphite platelets in the marine sedimentary bedrock layers of the valley, and are released by decomposition and mobilized by precipitation or irrigation.

6.5 Leaching of percussion borehole cuttings

The borehole cuttings were sampled at 1 metre intervals at the drilling rig as they were airlifted to the surface, and brought back to Stellenbosch in plastic screw-cap containers for lithological logging and whole rock chemical analysis. These analyses were carried out with the minimum of delay. (Section 2.3.3)

The leaching experiments were carried out two years later after consultations with the Project Steering Committee; a measure of oxidation and weathering had taken place particularly in the pyritic shales. This served to enhance the chemically active nature of the Bokkeveld sedimentary rocks and their potential for the mineralization of groundwater.

In the event, samples from selected boreholes were crushed and screened to pass 5 mm. 500 grams of these "fines" were then taken up into 500cc of distilled water and leached to maximum salinity with regular agitation over a period of four to five days.

Decantation and filtration then produced leachate solutions which were made up to 500 cc to compensate for evaporation and adsorption losses before being analyzed. T.D.S. results of these tests are given in TABLE 6.5A.

TABLE 6.5A LEACHATE SALINITY OF PERCUSSION BOREHOLE CUTTINGS FROM SELECTED DEPTHS
(in mg/l)

DEPTH IN METRES	DEPTH	BOREHOLES				
	A1e	B1f	C2	D4	E1	F3
1	549	5820	849	98	3002	127
2	1972	5342	648	64	2174	139
3	3257	668	564	570	1317	963
4	2902	306	972	651	836	899
5	3370	293	1387	583	312	1345
6	2746	304	817	575	366	878
7	2496	465	480	570	312	857
8	-	188	408	502	271	736
9	-	143	551	454	244	835
10	-	185	622	508	244	765
11	-	213	532	678	129	651
12	1280	929	467	664	217	524
13	-	770	454	-	231	623
14	-	496	726	-	132	651
15	-	509	648	766	178	6095
16	-	2570	648	-	258	424
17	406	3435	804	-	461	-
18	-	2875	842	-	380	343
19	-	2068	940	-	153	-
20	-	1673	1296	-	-	-
21	-	1940	842	1342	1356	-
22	408	2512	1426	-	-	212
23	-	1018	428	-	-	-

(TABLE 6.5A Continued)

DEPTH IN METRES	DEPTH	BOREHOLES				
	A1e	B1f	C2	D4	E1	F3
24	-	1520	331	-	-	244
25	-	2544	343	1607	-	-
26	-	3785	-	-	1133	-
27	593	4389	-	-	-	382
28	-	3340	-	-	-	-
29	-	1794	-	-	-	-
30	-	2734	1854	630	2177	319
31	-	1527	-	-	-	-
32	1635		-	-	-	-
34			-	-	2983	-
35			2407	800		342
40			1360	-	153	219
45			1664	-	-	-
50			1628	-	-	280
55			1161	630	2177	-
60			1225	-	-	255
65			1487	-	-	-
70			1947	-	2983	202
75			1304	800		-
80			-			538
90			-			202
100						228

Full chemical analyses of the leachates were also carried out to determine the principal components; the results are given in Table 6.5 B, and will be discussed in Section 8.

6.5.1 Discussion of leachate salinities from percussion borehole cuttings

Leachate salinity values below 1000 mg/l tend to be associated with quartzite or unaltered siltstone layers, while values greater than this figure are produced by shales.

Decomposed shales in the upper part of boreholes and pyritic shales (which were moist when stored and underwent oxidation) produced the very high values in excess of 3 000 mg/l per kilogram of rock. These results may be contrasted with the analyses of leachates from diamond drill core samples which were stored dry and were therefore fresh and unaltered when crushed and leached; many pyrite crystal fragments could be seen shining brightly during the crushing process. (Section 6.4)

In borehole A1e, the sandy topsoil is clearly well leached by rainfall down to a depth of 1 metre. Between 2 and 7 metres depth, a pale brown decomposed siltstone with interlayered shale produced values between 1972 and 3370 mg/l in the leaching tests. (NB: these samples were all from above the GWT.)

Deeper down at 12 metres, the effect of decomposition is lower, giving 1280 mg/l; at 17,22 and 27 metres where slight alteration has produced olive green siltstone, the values reduce to below 600 mg/l. At 32 metres, where black shale was encountered, the leachate salininty rose to 1635 mg/l due to the oxidation of pyrite in the sample, and release of ions absorbed on sericite grains and clay minerals.

In borehole B1f the upper two metres of sandy clay soil show extremely high leachate salinities. The groundwater table is shallow, fluctuating between 2 and 3 metres below the surface. This transect is situated below a fruit orchard where much irrigation has been applied, and where return flow has been allowed to seep through and even run over the soil Evaporation of this seepage water has concentrated many leached salts in the soil, affecting only the upper two metres of the soil profile, where values in excess of 5000 mg/l were measured; at 3 metres the values drops to 668 mg/l and reduces further to 293 mg/l in gravelly sand at 5 metres. From this depth down to 15 metres, decomposed siltstone samples gave only moderate salinities varying from 143 to 929 mg/l.

TABLE 6.5B CHEMICAL ANALYSES OF LEACHATES DERIVED FROM PERCUSSION BOREHOLE CUTTINGS.
(THE SECOND PART OF THE SAMPLE NUMBER INDICATES SAMPLE DEPTH IN METERS.)

Sample number	pH	Ca	Mg	Na	K		HCO3	Cl	SO4	NO3	T. D. S.	ERROR
		mg/l	mg/l	mg/l	mg/l		mg/l	mg/l	mg/l	mg/l	mg/l	%
A1E 1	8.50	30.4	17.7	104.0	15.0		10.2	245.0	66.2	4.0	549.0	3.9
A1E 2	8.50	20.3	18.0	649.2	11.4		17.7	860.0	224.3	5.0	1972.0	2.9
A1E 3	8.60	31.9	35.2	1091.8	26.6		8.7	1360.0	599.8	17.0	3257.0	1.3
A1E 4	8.70	37.3	28.7	996.3	26.8		10.9	1260.0	440.5	16.0	2902.0	3.3
A1E 5	8.60	63.2	56.6	1061.2	38.9		6.1	1570.0	486.1	18.0	3370.0	.2
A1E 6	8.40	65.4	48.6	828.2	27.5		7.2	1120.0	660.4	16.0	2746.0	1.9
A1E 7	8.50	24.8	33.1	790.1	17.9		10.8	1170.0	265.1	14.0	2496.0	.2
A1E 12	8.40	3.8	5.9	421.5	2.6		7.7	525.0	132.8	8.0	1280.0	3.4
A1E 17	8.30	2.1	2.2	111.7	1.7		2.6	154.0	56.2	3.0	406.0	3.9
A1E 22	7.80	2.5	13.0	115.2	3.0		2.3	149.0	94.6	2.5	418.0	.2
A1E 27	7.60	10.2	22.0	143.9	16.4		2.4	252.0	94.6	2.0	593.0	.8
A1E 32	7.50	84.1	86.4	334.7	28.5		9.4	695.0	238.2	12.0	1635.0	3.3
B1F 1	8.50	19.5	11.2	2357.1	31.4		24.0	2700.0	1404.0	20.0	5820.0	.4
B1F 2	8.80	30.0	17.0	2031.7	24.1		21.0	2360.0	1176.0	15.0	5342.0	.1
B1F 3	8.90	1.3	5.7	203.5	6.4		18.0	200.0	182.6	5.0	668.0	1.4
B1F 4	8.80	4.5	2.3	102.5	2.2		13.0	110.0	73.4	2.0	306.0	.5
B1F 5	8.70	5.2	2.8	107.3	2.2		15.0	120.0	71.0	4.0	293.0	.4
B1F 6	8.60	7.5	2.8	100.8	1.7		15.0	120.0	71.8	3.0	305.0	1.4
B1F 7	8.50	4.2	2.9	152.5	1.4		17.0	180.0	82.0	2.5	465.0	.1
B1F 8	8.30	2.7	3.4	68.5	1.1		9.0	89.0	39.9	2.0	188.0	1.4
B1F 9	8.20	2.6	4.0	51.5	.5		14.0	80.0	16.1	3.0	143.0	2.8
B1F 10	8.70	2.2	2.9	69.0	.6		12.0	87.0	34.2	2.5	185.0	.6
B1F 11	8.50	21.6	2.2	75.9	.8		11.0	100.0	62.9	3.0	213.0	2.5
B1F 12	8.30	56.3	84.0	151.5	11.8		1.5	340.0	287.7	5.0	929.0	2.9
B1F 13	8.00	40.0	60.0	127.6	12.8		1.4	21.5	661.8	2.0	770.0	3.5
B1F 14	7.70	6.1	8.4	136.4	5.1		5.4	103.2	196.2	6.0	496.0	.9
B1F 15	8.10	20.9	18.4	107.0	5.8		7.9	82.6	245.1	2.5	509.0	1.6
B1F 16	4.60	128.9	222.8	122.7	1.5		8.0	405.0	1037.5	5.0	2570.0	4.9
B1F 17	2.00	116.2	311.5	3.4	1.7		4.6	405.0	1100.0	4.0	3435.0	4.3
B1F 18	3.00	113.9	300.6	36.7	2.0		6.4	317.0	1109.5	4.0	2875.0	.2
B1F 19	2.30	182.9	218.6	110.4	1.6		7.0	411.0	939.0	4.0	2068.0	1.0
B1F 20	2.10	83.3	154.4	147.6	6.3		.8	277.0	709.3	3.0	1673.0	1.7
B1F 21	2.00	43.8	184.9	139.5	1.2		.3	281.5	700.9	3.6	1940.0	1.9
B1F 22	2.00	48.3	288.4	83.7	1.3		.4	391.0	892.1	2.0	2512.0	.3
B1F 23	3.60	40.1	74.1	188.5	13.5		.4	112.0	373.8	2.0	1018.0	.3
B1F 24	2.00	45.8	132.6	215.6	14.1		.4	305.0	632.8	3.0	1520.0	2.5
B1F 25	2.20	94.7	335.7	11.3	2.0		.4	467.0	947.5	2.0	2544.0	.1
B1F 26	2.20	88.9	451.6	4.3	1.7		.4	457.0	1359.8	2.6	3785.0	.7
B1F 27	2.20	45.8	503.5	3.4	1.6		.4	444.0	1534.1	1.6	4389.0	.7
B1F 28	2.20	127.1	487.0	6.9	1.9		.4	984.0	885.5	8.0	3340.0	.5
B1F 29	2.60	89.9	246.5	69.7	1.3		.5	854.0	223.8	9.0	1794.0	1.9
B1F 30	2.40	126.0	284.5	3.0	1.6		.7	711.0	417.0	6.0	2735.0	1.7
B1F 31	2.40	40.6	121.5	136.9	2.8		.5	500.0	151.4	5.0	1527.0	2.0
C2 1	8.80	20.3	7.7	264.5	1.1		9.8	390.0	91.1	12.0	849.0	.3
C2 2	8.70	3.9	2.8	207.5	1.6		5.6	250.0	88.9	10.0	648.0	1.8
C2 3	8.60	3.1	1.7	169.9	1.7		16.1	190.0	86.7	8.0	564.0	1.1
C2 4	8.80	6.2	5.2	313.6	3.1		12.4	400.0	154.3	10.0	972.0	1.4
C2 5	8.40	17.9	14.1	437.8	4.9		12.2	600.0	199.1	20.0	1387.0	.9
C2 6	8.50	7.3	5.1	258.9	3.2		11.0	380.0	93.3	15.0	817.0	3.8
C2 7	8.40	2.6	1.8	141.4	.7		12.1	200.0	41.2	16.0	480.0	3.8
C2 8	8.50	2.5	1.9	129.1	.9		11.9	170.0	46.2	10.0	408.0	1.6
C2 9	8.50	2.9	2.2	180.4	.9		12.0	240.0	65.8	8.0	551.0	1.6
C2 10	8.60	3.9	2.7	209.3	1.4		11.5	280.0	71.6	6.0	622.0	.6
C2 11	8.40	2.7	2.4	160.3	.7		10.3	196.0	65.8	2.6	532.0	1.5
C2 12	8.10	2.8	1.6	159.0	.6		14.8	208.0	60.5	3.0	467.0	1.5
C2 13	7.90	1.8	1.5	150.9	.6		3.8	204.0	68.0	6.0	454.0	3.8
C2 14	7.90	4.3	3.9	251.4	1.4		4.4	346.0	91.1	7.0	726.0	1.4
C2 15	7.90	3.7	3.8	215.7	1.3		3.8	306.0	70.6	8.0	648.0	1.9
C2 16	7.80	3.4	4.1	214.9	1.3		2.8	304.0	70.6	4.0	648.0	1.3
C2 17	7.70	5.9	7.1	268.2	1.4		2.3	390.0	93.3	3.0	804.0	1.8
C2 18	7.70	6.6	8.0	274.2	3.1		2.8	410.0	102.0	5.0	842.0	3.1
C2 19	8.00	23.5	22.3	288.9	10.1		7.8	486.0	93.3	6.0	940.0	.1
C2 20	7.90	24.6	30.3	364.6	12.4		3.8	636.0	126.4	12.0	1296.0	2.3
C2 21	8.00	11.0	21.9	245.4	8.7		3.6	404.0	88.9	8.0	842.0	.7
C2 22	3.50	86.8	115.0	207.1	24.3		.9	246.0	799.6	6.0	1426.0	.6
C2 23	6.70	4.7	24.1	106.5	8.5		.8	149.6	133.0	5.0	428.0	.1
C2 24	7.00	2.7	12.8	89.5	5.8		1.7	128.2	65.9	4.0	331.0	1.4
C2 25	7.10	3.3	3.8	101.4	7.8		1.8	138.0	60.7	4.0	343.0	1.6
C2 30	7.30	65.6	85.1	432.5	30.4		2.2	865.0	283.6	10.0	1854.0	1.1
C2 35	7.20	106.5	114.6	556.8	16.5		1.6	1000.0	538.3	12.0	2407.0	.3
C2 40	7.70	46.7	54.7	323.4	12.6		3.7	640.0	163.1	5.0	1360.0	.9
C2 45	7.70	57.5	60.1	438.1	17.0		3.4	880.0	184.2	6.0	1664.0	2.7
C2 50	7.80	54.5	68.2	433.7	15.3		3.2	860.0	171.7	6.0	1628.0	.7
C2 55	7.70	37.0	45.7	298.4	9.7		3.0	562.0	149.9	5.0	1161.0	.7
C2 60	7.60	47.3	65.9	291.4	13.3		2.1	544.0	272.1	4.0	1225.0	.7
C2 65	7.70	45.8	72.6	363.7	13.8		2.3	700.0	250.4	4.0	1487.0	1.3
C2 70	4.00	92.9	138.5	334.8	17.7		3.0	550.0	740.3	3.6	1947.0	.0
C2 75	7.80	46.4	68.1	317.3	12.4		5.1	696.0	136.4	3.0	1303.0	1.3

TABLE 6.5B (cont.) CHEMICAL ANALYSES OF LEACHATES DERIVED FROM PERCUSSION BOREHOLE CUTTINGS. (THE SECOND PART OF THE SAMPLE NUMBER INDICATES SAMPLE DEPTH IN METERS.)

Sample number	pH	Ca	Mg	Na	K		HCO3	Cl	SO4	NO3	T. D. S.	ERROR
		mg/l	mg/l	mg/l	mg/l		mg/l	mg/l	mg/l	mg/l	mg/l	%
D4 1	7.20	3.9	6.5	21.9	4.8		3.1	46.3	22.0	2.0	98.0	1.2
D4 2	7.40	5.5	5.9	13.9	4.4		2.8	41.0	15.0	2.5	64.0	2.6
D4 3	7.30	3.5	23.0	147.3	1.8		2.2	248.0	91.5	5.0	570.0	2.8
D4 4	7.40	1.7	13.7	198.2	2.3		1.6	304.0	80.1	6.0	651.0	2.3
D4 5	7.50	1.3	13.2	198.4	.5		1.9	274.0	91.5	6.0	583.0	.2
D4 6	7.80	1.8	3.1	178.5	.5		4.2	240.0	76.3	4.0	515.0	2.2
D4 7	7.60	2.0	8.6	181.3	.4		1.9	284.0	59.1	5.0	570.0	3.6
D4 8	7.50	1.6	9.8	157.4	.4		1.2	236.0	61.0	2.6	502.0	1.6
D4 9	7.50	1.8	12.7	154.5	.4		1.9	240.0	47.6	2.0	454.0	.3
D4 10	7.50	2.3	13.3	176.7	.4		1.8	276.0	43.7	4.0	508.0	.7
D4 11	7.50	4.5	17.6	220.1	.5		1.5	392.0	39.9	6.0	678.0	3.2
D4 12	7.50	4.4	17.9	227.0	.7		1.2	392.0	51.4	5.0	664.0	2.7
D4 15	7.50	5.1	19.0	267.4	1.4		2.6	398.0	110.6	4.0	766.0	.6
D4 21	7.20	24.2	63.4	332.0	11.1		.8	406.0	379.5	12.0	1342.0	1.6
D4 25	4.50	63.3	100.3	338.7	12.1		.6	468.0	566.1	10.0	1607.0	2.5
D4 30	6.90	11.7	48.5	155.5	4.6		2.0	298.0	89.6	9.0	630.0	4.6
D4 35	6.60	20.6	43.4	169.2	10.4		.5	236.0	286.7	4.0	800.0	1.9
EC 1	8.50	45.0	50.9	978.6	6.3		9.3	1536.0	310.9	15.0	3002.0	1.0
EC 2	7.70	17.7	35.6	664.1	10.1		1.3	1096.0	242.1	12.0	2174.0	4.7
EC 3	8.10	4.2	7.8	397.1	4.0		3.9	608.0	127.2	8.0	1317.0	4.6
EC 4	8.60	4.8	3.4	260.5	4.1		20.0	372.0	48.5	5.0	836.0	.2
EC 5	8.70	2.7	1.7	94.2	2.8		20.9	122.4	24.6	4.0	312.0	.8
EC 6	2.10	2.6	2.1	115.7	3.1		25.7	157.0	33.0	3.0	366.0	1.6
EC 7	8.80	1.2	1.4	99.1	2.3		18.5	117.5	43.8	4.0	312.0	.5
EC 8	8.60	3.9	8.5	88.4	3.1		26.0	92.0	60.0	2.6	271.0	5.5
EC 9	8.70	4.5	9.0	80.0	4.1		28.0	96.6	50.0	2.6	244.0	3.2
EC 10	8.50	4.0	8.0	75.0	5.1		24.0	97.4	56.0	2.0	244.0	1.0
EC 11	8.40	7.0	6.4	39.5	7.0		12.6	56.6	40.0	2.0	129.0	1.9
EC 12	8.00	6.0	6.0	45.0	8.6		17.3	63.5	46.0	3.0	217.0	1.8
EC 13	8.50	8.0	5.0	50.0	10.0		12.4	72.9	61.0	2.0	231.0	4.7
EC 14	8.30	7.0	8.0	28.6	3.8		8.5	37.4	60.0	2.0	132.0	2.8
EC 15	8.00	1.6	6.1	56.3	.7		4.8	60.5	66.6	2.5	170.0	2.6
EC 16	8.10	1.4	2.0	78.0	.8		2.6	107.0	22.6	3.0	258.0	.9
EC 17	7.80	4.7	18.9	120.7	.6		2.0	208.0	57.1	4.0	461.0	.7
EC 18	7.50	3.9	4.2	97.3	.7		1.8	137.0	45.7	3.0	380.0	1.1
EC 19	7.00	2.4	7.4	43.7	.9		3.6	60.8	34.0	2.5	153.0	2.5
EC 21	2.50	95.2	123.1	73.3	.7		1.7	19.5	871.0	4.0	1356.0	1.9
EC 26	3.00	87.0	108.9	88.9	15.6		.8	288.0	426.2	6.0	1133.0	1.3
EC 30	2.50	256.9	239.8	50.8	.7		1.2	296.0	1149.9	8.0	2177.0	3.5
EC 34	2.50	231.9	330.0	152.8	.6		1.7	125.6	2050.0	10.0	2983.0	1.1
F3B 1	6.80	.6	3.8	37.4	1.6		2.5	54.3	23.0	2.0	127.0	1.8
F3B 2	5.50	1.2	4.1	40.9	8.1		5.3	63.3	25.0	2.5	139.0	1.0
F3B 3	7.20	2.5	9.6	322.6	6.9		2.8	412.0	173.0	5.0	963.0	.7
F3B 4	7.20	3.8	11.2	312.3	7.0		1.4	444.0	114.3	6.0	899.0	.5
F3B 5	7.40	13.5	23.7	415.3	14.9		3.5	720.0	72.6	12.0	1345.0	3.7
F3B 6	8.00	11.8	8.8	267.8	11.9		8.0	448.0	46.9	8.0	878.0	2.2
F3B 7	8.10	10.6	10.4	259.2	13.2		8.5	438.0	43.0	6.0	857.0	1.9
F3B 8	8.20	9.4	6.6	230.1	12.9		8.1	359.6	67.0	6.0	736.0	1.8
F3B 9	8.20	10.3	6.4	256.7	10.1		8.9	402.0	68.3	5.0	835.0	2.1
F3B 10	8.20	7.4	4.0	248.1	6.5		9.7	354.0	90.3	5.0	765.0	1.9
F3B 11	8.30	5.4	3.4	217.2	5.7		11.1	312.0	63.9	3.0	651.0	1.1
F3B 12	8.30	2.8	2.2	175.1	4.4		9.8	230.0	57.7	2.6	524.0	1.0
F3B 13	8.20	3.8	3.5	195.5	3.8		10.1	280.0	67.7	3.0	623.0	2.4
F3B 14	8.20	7.4	4.6	200.8	6.4		8.8	306.0	73.0	4.0	651.0	3.6
F3B 15	8.30	5.6	4.7	197.9	2.8		11.8	280.0	67.0	4.0	609.0	1.1
F3B 16	8.40	2.6	4.8	132.4	1.8		11.7	186.0	36.5	3.0	424.0	.7
F3B 18	8.20	6.0	5.8	100.5	.9		9.9	141.8	51.3	2.6	343.0	1.0
F3B 22	8.10	7.2	6.3	58.4	1.7		6.6	80.0	44.5	2.0	212.0	2.0
F3B 24	8.00	9.3	7.8	58.4	3.1		5.3	106.0	39.8	2.0	244.0	2.8
F3B 27	7.80	13.6	10.4	87.1	1.5		5.0	171.0	34.8	2.0	382.0	2.7
F3B 30	7.80	7.4	8.1	78.4	2.1		2.5	109.0	79.7	3.0	319.0	3.5
F3B 35	7.80	19.0	10.9	60.8	1.6		3.7	84.7	112.5	4.0	342.0	3.5
F3B 40	8.00	6.5	2.5	53.5	3.6		6.1	87.6	16.0	3.0	219.0	.1
F3B 50	8.20	15.3	1.7	63.3	4.7		8.7	60.3	95.0	2.5	280.0	1.1
F3B 60	8.20	10.2	1.7	61.3	3.3		7.4	58.9	72.0	2.5	255.0	1.2
F3B 70	8.40	5.0	1.2	59.7	8.7		13.4	88.9	16.0	3.0	202.0	.9
F3B 80	8.20	60.0	15.9	86.3	6.7		8.3	31.0	371.0	5.0	605.0	3.5
F3B 90	8.50	9.5	1.9	46.4	7.8		12.5	26.3	85.0	2.5	202.0	1.6
F3B 100	8.40	11.3	2.3	50.5	7.0		9.6	42.8	89.2	2.0	228.0	2.0
R 18S	8.30	2.0	1.8	17.5	.6		2.3	21.5	16.9	8.0	86.0	4.7
R 18C	8.70	2.2	4.4	373.0	2.4		.5	382.0	303.8	12.0	1088.0	1.6

However, from 16 metres down to 31 metres very pyritic, micaceous black shale, chemically active during the storage period when oxidation and weathering occurred, gave very high leachate salinities ranging from 1018 mg/l (23m) to 4389 mg/l (27m).

In borehole C2, soil and alluvial sand and gravel extend down to 6 m, with values fluctuating from 564 mg/l at 3m to 1387 mg/l at 5 m depth. Below this, decomposed siltstone gave moderate values between 408 and 842 mg/l (the latter at 18m), and then stronger values in black shale between 19m and 60m (maximum of 2407 mg/l at 35m and a minimum of 331 mg/l in siltstone between 23 and 25m).

In borehole D4, drilled in alluvial deposits on the floodplain at a distance of 240 metres from the river, only moderate leachate salinities were encountered. (This area is well irrigated and used for lucern production).

Once again these low values are associated with decomposed siltstone with a yellow-green colour below a deposit of alluvial sand and gravel, and continue into fresh, dark grey siltstone below 12 metres. Below 16 metres black shale layers were encountered; these gave the higher salinities in the samples from 21 and 25 metres, whereas siltstone samples from 30 and 35 metres gave lower values again.

In borehole E1, the upper 4 metres of clay-rich soil carry a considerable amount of salt, with a maximumm of 3002 mg/l at 1 metre. This reduces with depth, and at the transition to brown decomposed shale and siltstone, becomes a moderate 312 mg/l. This reduces still further to a minimum of 132 mg/l in green, harder shale at 14 metres. The boundary between decomposed and unaltered bedrock lies at ± 19m. Below this level the black siltstone and shale contain much mica and pyrite which, through oxidation and alteration, produce high salinities such as the 2983 mg/l at a depth of 34 metres.

Borehole F3 was drilled to a depth of 100m into a mass of dense, black siltstone with interbedded shale layers in the upper part of the hole. The leachate salinities were low, only rising above 600 mg/l in the uppermost 15m, and giving a maximum of 1345 mg/l at a depth of 5m. The deeper lying siltstones do not contain the same amount of pyrite as samples from boreholes lower down the valley, and give low leachate salinities right down to 100m. There are few fractures and a very low yield of groundwater.

An assessment of all the boreholes tested in this way leads to the conclusion that a soluble salt concentration exists in the decomposed shale and siltstone and overlying soil materials in the upper 9 metres of the bedrock profile. As one proceeds downwards below 9 metres, the salinity is reduced, unless the bedrock contains an abundance of pyrite. In this case fractures which allow the downward passage of oxygen-rich meteoric water in the process of becoming groundwater facilitate the oxidation of the pyrite:

$$FeS_2 + {}^{7}/_{2}\, O_2 + H_2O = Fe^{++} + 2SO_4^{=} + 2H^{+} \quad (1)$$

(solid pyrite)

$$Fe^{++} + {}^{1}/_{4}\, O_2 + H^{+} = Fe^{+++} + {}^{1}/_{2}\, H_2O \quad (2)$$

$$Fe^{+++} + 3H_2O = \underset{\text{(solid)}}{Fe(OH)_3} + 3H^{+} \quad (3)$$

$$FeS_2 + 14\, Fe^{+++} + 8H_2O = 15\, Fe^{++} + 2SO_4^{=} + 16H^{+} \quad (4)$$

For every mole of pyrite, five protons are released, one of which is used to oxidize the ferrous iron to ferric iron.

Stumm and Morgan (1970) further point out that upon initiation of pyrite oxidation, the ferric iron can be reduced by the pyrite itself as shown in equation (4). Therefore pyrite continues to oxidize as long as there is regeneration of the ferric iron.

The oxidation of ferrous to ferric iron need not be a slow reaction nor does it always control the rate of pyrite oxidation. At low pH values in the range of 2 to 3 Thiobacillus ferro-oxidans may rapidly oxidize ferrous to ferric iron, especially during the exponential phase of the bacterial population growth. Also, sulphur-oxidizing bacteria such as Thiobacillus thio-oxidans and Thiobacillus ferro-oxidans can eliminate the need for ferric iron, especially in the presence of oxygen and carbon dioxide. The sulphuric acid so formed is chemically active and causes leaching of ions from clay minerals and sericite mica.

This chemically active zone then slowly progresses downwards with the denudation of the bedrock in the valley, alternatively producing saline seepages

after heavy rainfall, or the precipitation of calcite in fractures and calcrete in the soil.

The results from the earlier piezometer sample analyses showed that in most cases the groundwater increased in salinity with depth, notwithstanding the fact that the unaltered, deeper lying bedrock contains less adsorbed salt. It is thought that this is caused by two processes:

(i) sinking of salts to lower levels within the groundwater contained in joints and fractures along which flow is restricted.

(ii) more rapid lateral flow of water near the upper surface of the groundwater table with mixing of infiltrated rainwater having a lower TDS.

7. IN SITU LEACHING OF SOILS

7.1 Leaching by irrigation water

In response to recommendations by the Project Steering Committee after a workshop held in September 1984 at which Prof. Geoff Wagenet of the U.S.A. acted as a consultant, a program of monthly sampling and analysis of irrigation water and irrigation return flow was commenced on 1st October 1984. The results served to give an understanding of the amount of salt leached from the soil, and its chemical nature.

Ten areas were selected for this survey; five were on the left bank (north side) of the river, and five on the right bank (south side). Samples of irrigation water were taken in dams and canals just prior to their application and the positions marked as I1 to I10; the return flow seepage samples were taken in drainage trenches at the lower ends of the irrigated fields and orchards, and marked IR1 to IR10 (App. Fig. 2.1t). The average width of the fields from their top ends to the drainage ditches at their lower ends was 500 metres.

Both the irrigation water samples and the return flow samples were analyzed for their principal chemical components. The results are shown in TABLE 7.1 (The period of sampling extended from October 1985 to December 1985.).

At the outset, it is clear that some very strong mineralization of water occurred in its passage through the soil, particularly at IR4 and IR5. Some extremely high salinities were encountered at the latter, for example 17 354 mg/l in March 1985; these have to be discarded because the samples were taken from evaporating pools and alongside saline encrustations. However, flowing water was sampled in the drainage lines during other months and gave more accurate indications of the type and amount of salt taken up from the soil.

TABLE 7.1 CHEMICAL ANALYSES OF IRRIGATION WATER (I1 to I10) and IRRIGATION RETURN FLOW (IR1 toIR10).

Sample number	pH	Ca	Mg	Na	K		HCO3	Cl	SO4	NO3	T. D. S.	ERROR
		mg/l	mg/l	mg/l	mg/l		mg/l	mg/l	mg/l	mg/l	mg/l	%
I1 OCT 84	9.70	15.8	18.2	96.5	3.7		70.0	190.0	10.0	8.0	478.6	2.0
I2	6.40	5.8	8.9	44.4	2.1		40.0	72.0	16.0	7.0	234.4	4.1
I3	8.60	56.0	108.0	617.5	11.8		102.0	1120.0	288.0	15.0	2507.8	.8
I4	8.70	74.3	105.0	612.5	11.5		200.0	1134.0	264.0	7.0	2544.6	2.0
I5	8.00	8.9	5.4	17.8	2.2		40.0	20.0	17.0	12.0	124.3	1.4
I6	7.30	5.4	7.1	31.6	2.9		50.0	47.0	6.0	12.0	180.4	3.4
I7	7.20	7.8	8.5	26.1	2.1		50.0	40.0	2.0	17.0	177.4	.3
I8	6.60	14.9	12.5	30.5	17.3		51.0	60.0	31.0	20.0	263.9	.6
I9	6.70	10.1	11.5	29.4	10.3		50.0	52.0	33.0	13.0	223.4	3.1
I10	8.90	8.9	9.8	35.5	1.6		45.0	60.0	4.0	13.0	222.9	2.0
IR1	8.60	57.0	125.0	472.5	20.0		293.0	766.0	298.0	40.0	2349.8	1.4
IR2	7.30	13.6	22.5	217.1	2.9		195.0	265.0	34.0	30.0	852.1	.4
IR3	7.60	56.6	64.1	211.5	7.7		210.0	304.0	259.0	33.0	1176.7	.1
IR4	7.80	196.5	376.3	2514.0	46.6		280.0	3908.0	1344.0	86.0	9305.2	2.4
IR5	9.10	210.6	457.9	2514.0	99.9		275.0	5508.0	120.0	77.0	9799.7	1.1
IR6	6.90	26.6	47.0	58.3	12.3		122.0	146.0	140.0	34.0	639.8	3.6
IR7	6.70	34.9	60.2	206.5	2.5		303.0	309.0	144.0	33.0	1257.9	4.5
IR8	7.90	82.0	173.0	885.5	23.0		800.0	1185.0	528.0	76.0	3918.4	1.1
IR9	9.70	15.7	42.3	596.1	3.7		208.0	609.0	452.0	64.0	1971.5	1.2
IR10	8.40	53.3	123.0	642.5	40.5		365.0	853.0	684.0	97.0	2759.4	4.7
I1 NOV 84	9.50	33.3	34.5	174.0	6.5		120.0	266.0	106.0	22.0	885.0	.8
I2	7.40	3.7	7.1	33.3	.8		35.0	44.0	2.1	20.0	195.8	1.3
I3	8.50	58.0	108.0	605.0	10.0		372.0	1004.0	264.0	43.0	2673.0	2.9
I4	8.60	54.2	108.0	613.0	10.0		385.0	1008.5	192.0	44.0	2666.6	1.2
I5	7.50	6.3	8.1	18.9	1.5		30.0	34.0	14.0	2.0	124.0	3.5
I6	7.40	5.6	7.7	32.7	4.2		38.0	50.0	21.0	1.0	195.5	.9
I7	6.60	6.8	7.1	23.3	2.4		46.0	30.0	6.0	20.0	158.4	1.2
I8	6.40	6.8	7.1	24.4	2.0		36.0	32.0	1.0	22.0	158.3	4.3
I9	7.00	7.9	9.5	27.2	3.8		38.0	40.0	7.0	28.0	175.3	2.2
I10	7.10	7.2	7.1	23.9	2.7		30.0	32.0	8.0	21.0	155.2	3.9
IR1	7.80	43.5	51.8	217.5	8.8		249.0	321.0	158.0	31.0	1237.5	2.4
IR2	7.50	103.0	149.0	805.0	8.0		509.0	1267.0	368.0	63.0	3503.6	.1
IR3	9.10	35.0	64.0	293.8	13.0		340.0	419.0	144.0	35.0	1526.7	2.0
IR4	8.00	180.6	318.0	2181.4	39.9		484.0	4024.8	596.0	75.0	8357.9	1.5
IR5	8.50	210.6	507.8	2356.0	69.9		424.0	5041.4	552.0	83.0	9450.4	1.7
IR6	6.90	27.8	29.0	53.3	11.1		86.0	109.0	88.0	28.0	444.7	3.0
IR7	6.90	55.0	62.5	201.3	4.5		276.0	365.0	108.0	31.0	1226.2	2.4
IR8	7.60	28.5	48.8	227.5	7.0		140.0	375.0	98.0	32.0	1007.1	.7
IR9	9.30	20.8	55.0	647.5	3.0		255.0	855.0	316.0	72.0	2396.1	3.2
IR10	7.90	83.0	111.5	630.0	26.0		336.0	912.0	472.0	71.0	2610.7	1.0
I1 DEC 84	9.20	31.5	52.3	265.0	9.5		274.0	403.0	115.0	8.0	1264.2	2.0
I2	7.50	5.3	8.5	53.3	1.5		80.0	68.0	10.0	5.0	250.6	2.9
I3	9.00	20.6	15.2	33.3	15.3		75.0	75.0	37.0	4.5	321.8	.9
I4	9.10	20.6	15.5	44.9	15.3		90.0	77.0	38.0	5.0	314.7	1.3
I5	8.00	14.9	7.8	49.3	2.9		41.0	51.0	62.0	4.0	170.8	1.9
I6	7.70	5.7	8.2	39.9	3.1		37.0	61.0	24.0	4.0	203.8	2.2
I7	7.00	7.4	6.2	38.8	2.5		39.0	65.0	10.0	3.0	174.8	1.8
I8	6.90	9.0	5.8	40.0	1.5		44.0	53.0	13.0	4.0	152.4	2.9
I9	6.80	8.9	8.5	33.3	2.5		55.0	52.0	16.0	4.0	203.9	2.0
I10	6.90	8.5	7.8	53.8	2.4		65.0	68.0	15.0	4.0	197.0	1.6
IR1	7.90	44.9	86.3	359.6	21.6		182.0	612.0	226.0	12.0	1761.5	.8
IR2	7.90	13.8	52.3	432.9	10.9		287.0	529.0	265.0	13.0	1665.8	2.5
IR3	9.20	32.3	52.3	347.9	15.7		224.0	554.0	125.0	12.0	1510.5	1.5
IR4	8.10	118.2	308.0	2222.8	33.3		286.0	4083.0	384.0	86.0	7882.3	.2
IR5	8.80	258.8	672.5	3500.0	85.0		338.0	7242.0	370.0	123.0	12778.7	.7
IR6	7.20	31.0	44.4	71.5	15.8		94.0	151.0	94.0	6.0	582.8	5.2
IR7	7.10	55.0	61.3	235.0	5.3		147.0	376.0	184.0	6.0	1242.7	3.4
IR8	7.60	20.8	39.1	146.5	21.8		121.0	239.0	126.0	9.8	830.5	1.4
IR9	8.80	17.0	16.0	1640.0	17.0		612.0	1753.0	396.0	126.0	4772.9	2.9
IR10	7.90	28.5	122.0	1010.0	41.0		600.0	1285.0	492.0	8.0	3765.8	.0
TEST	7.50	195.5	144.0	765.0	400.0		465.0	1607.0	276.0	180.0	4117.2	2.8
I1 JAN 85	8.80	36.6	60.5	314.0	10.8		164.0	551.0	110.0	4.0	1447.3	.4
I2	7.50	4.8	10.2	58.9	1.8		19.0	110.0	14.0	1.0	303.7	.5
I3	9.50	12.5	12.0	56.3	3.4		70.0	88.0	18.0	3.0	278.6	2.8
I4	9.60	12.7	16.5	56.3	3.8		77.0	90.0	34.0	3.0	283.1	.2
I5	8.60	7.2	2.2	14.6	2.1		23.0	23.0	11.0	2.0	78.7	2.3
I6	8.10	6.4	9.5	55.5	4.4		33.0	94.0	22.0	.5	228.8	.4
I7	9.20	8.9	9.2	44.1	2.9		36.0	74.0	18.0	2.0	197.3	1.7
I8	7.50	8.9	9.2	41.0	1.8		31.0	78.0	16.0	1.0	200.7	.4
I9	6.70	9.1	7.9	39.4	1.9		30.0	71.0	15.0	2.0	183.2	.7
I10	6.80	7.2	7.1	39.3	2.3		22.0	65.0	12.0	1.5	157.2	4.7
IR1	8.00	66.6	97.9	421.2	18.3		310.0	687.0	301.0	6.0	2021.5	1.1
IR2	8.30	32.8	51.6	444.6	17.9		329.0	527.0	234.0	10.0	1708.1	.8
IR3	9.30	32.8	50.6	403.0	17.9		246.0	605.0	163.0	7.0	1595.0	1.7
IR4	8.20	150.0	293.0	2280.0	34.9		455.0	3574.0	946.0	117.0	7728.1	.7
IR5	9.30	110.0	195.0	1045.0	35.0		214.0	2041.0	400.0	36.0	4283.7	1.5
IR6	7.60	48.7	44.2	116.5	11.9		156.0	289.0	10.0	10.0	861.2	1.7
IR7	7.20	41.1	48.0	225.0	10.0		218.0	303.0	222.0	4.0	1110.7	2.3
IR8	7.50	89.2	31.9	134.8	5.7		199.0	205.0	168.0	3.0	748.1	1.9
IR9	8.30	32.0	125.0	850.0	9.0		600.0	1275.0	218.0	16.0	3409.8	1.5
IR10	7.90	39.6	44.0	270.0	18.8		206.0	378.0	206.0	3.0	1313.4	3.7

TABLE 7.1 CHEMICAL ANALYSES OF IRRIGATION WATER (I1 to I10) and IRRIGATION RETURN FLOW (IR1 toIR10). (cont.)

Sample number	pH	Ca	Mg	Na	K		HCO3	Cl	SO4	NO3	T. D. S.	ERROR
		mg/l	mg/l	mg/l	mg/l		mg/l	mg/l	mg/l	mg/l	mg/l	%
I1 FEB 85	8.40	38.6	62.6	378.0	10.0		107.0	592.0	198.0	4.0	1466.4	2.4
I2	8.70	6.9	10.5	78.3	1.3		22.0	122.0	34.0	3.0	281.2	1.0
I3	7.30	5.0	2.5	14.0	1.1		22.0	20.4	8.0	2.0	76.9	2.2
I4	7.40	5.0	2.2	14.5	.9		22.0	23.0	6.0	1.0	74.2	3.0
I5	7.20	20.5	9.5	27.8	11.4		56.0	53.0	34.0	7.0	258.4	1.1
I6	8.30	6.6	9.2	34.3	4.2		40.0	60.0	20.0	2.0	255.3	2.0
I7	7.60	9.8	9.5	30.0	3.2		40.0	55.0	22.0	3.0	228.3	1.0
I8	7.50	4.4	3.0	22.0	1.1		15.0	36.0	5.0	2.0	96.6	1.9
I9	7.70	16.8	5.8	34.9	3.2		21.0	54.0	46.0	6.0	189.7	.1
I10	7.40	5.8	5.1	30.0	2.4		30.0	47.0	6.0	3.0	138.2	2.1
IR1	8.20	37.5	64.9	319.0	10.3		178.0	553.0	108.0	11.0	1567.4	1.0
IR3	9.20	27.9	43.6	373.0	17.6		148.0	502.0	211.0	16.0	1436.2	1.0
IR4	7.70	75.0	225.0	2150.0	42.8		675.0	3583.0	384.0	55.0	7498.9	1.7
IR5	8.70	221.3	435.0	2287.0	50.0		484.0	4691.0	215.0	56.0	8591.9	.7
IR6	7.10	41.6	47.3	121.5	26.1		175.0	217.0	152.0	8.0	928.4	1.5
IR7	6.90	34.9	43.1	219.8	1.2		206.0	319.0	121.0	5.0	1016.6	.3
IR8	7.40	14.6	27.9	124.3	4.2		83.0	208.0	81.0	4.0	620.2	2.5
IR9	8.90	42.8	112.5	687.5	14.0		370.0	1097.0	252.0	20.0	2698.0	1.1
IR10	7.80	92.5	98.5	462.5	25.0		300.0	544.0	648.0	22.0	2232.4	.9
I1 MAR 85	9.00	25.3	63.5	311.3	10.3		102.0	589.0	94.0	21.0	1451.8	.7
I2	7.40	4.1	8.2	47.6	.8		19.0	89.0	2.1	8.0	201.7	.4
I3	7.20	3.9	12.8	35.5	4.5		93.0	36.0	4.0	10.0	350.2	2.2
I4	8.00	3.9	12.8	67.2	4.5		101.0	30.0	77.0	11.0	365.3	.0
I5	7.40	4.0	2.5	20.0	1.3		24.0	20.0	6.1	14.0	67.2	.1
I6	9.10	7.0	10.2	60.5	4.7		44.0	104.0	6.0	8.0	308.4	.4
I7	7.60	11.0	12.8	47.2	4.1		49.0	71.0	37.0	12.0	287.9	.1
I8	8.90	6.1	5.7	28.3	1.5		28.0	48.0	3.1	11.0	146.2	.3
I9	7.80	9.4	3.6	14.4	1.6		23.0	23.0	12.0	10.0	115.7	.2
I10	7.50	5.0	4.6	18.3	5.3		20.0	36.0	5.2	10.0	109.2	1.7
IR1	8.20	93.0	167.0	685.0	22.0		323.0	1291.5	317.0	31.0	3896.1	.1
IR3	8.60	35.0	49.0	436.0	22.0		376.0	546.0	122.0	19.0	1655.0	1.8
IR4	7.40	133.0	283.0	2556.0	44.0		536.0	4558.0	522.0	69.0	8981.3	4.4
IR5	8.50	359.0	963.0	4628.0	103.0		615.0	9773.8	426.0	127.0	17354.4	.7
IR6	6.80	36.0	50.0	116.0	21.0		201.0	206.0	133.0	19.0	854.1	2.9
IR7	6.80	37.0	38.0	148.3	12.4		207.0	201.0	144.0	11.0	960.2	2.1
IR9	8.20	64.0	98.0	545.0	5.5		339.0	898.0	246.0	28.0	2440.2	1.9
I1 APR 85	8.70	50.0	65.0	300.0	28.0		122.0	641.0	49.0	60.0	1367.0	1.1
I2	7.60	3.9	7.7	57.7	1.3		19.0	106.0	4.0	2.0	218.7	.7
I3	7.50	18.8	15.4	81.6	2.3		70.0	128.0	46.0	17.0	477.6	1.6
I4	7.60	16.0	12.9	80.4	2.6		68.0	115.0	35.0	17.0	394.5	.6
I5	7.30	4.6	1.7	10.0	1.1		14.0	20.0	3.0	.7	62.1	2.1
I6	8.50	7.4	9.2	84.8	5.1		40.0	145.0	8.0	2.3	353.6	.0
I7	7.60	10.4	11.9	65.5	4.8		63.0	91.0	37.0	12.0	291.0	1.0
I8	7.50	4.3	2.7	11.7	1.4		13.0	20.0	11.0	.4	86.6	1.6
I9	6.80	9.4	5.3	34.0	2.5		32.0	57.0	15.0	7.0	187.3	2.2
I10	6.50	4.3	7.8	13.3	1.7		20.0	32.0	12.0	1.5	94.2	.9
IR1	8.40	89.0	175.0	715.0	23.0		475.0	1413.0	216.0	100.0	3448.3	3.1
IR3	7.80	33.6	59.3	457.9	25.0		203.0	756.0	156.0	18.5	1971.1	2.0
IR5	8.65	40.0	190.0	983.5	10.0		371.0	1758.0	240.0	111.0	4122.5	1.5
IR6	7.56	50.0	56.8	170.0	21.3		209.0	308.0	120.0	71.0	1241.2	2.1
IR7	7.40	33.3	35.9	168.9	1.3		282.0	186.0	144.0	18.0	938.3	4.6
IR9	8.70	61.5	109.0	1030.0	16.0		478.0	1800.0	48.0	2.0	3991.8	2.0
I1 MAY 85	9.00	25.3	37.5	241.2	6.8		104.0	477.0	10.0	2.0	1049.8	1.3
I2	6.60	3.6	6.9	50.0	.9		28.0	95.0	2.1	.3	212.2	3.9
I3	6.70	15.5	16.0	61.6	5.4		42.0	124.0	23.2	8.0	410.3	1.1
I4	6.90	15.9	16.0	60.5	5.4		43.0	124.0	23.1	10.0	404.8	.4
I5	7.50	12.9	3.7	17.8	2.0		28.0	30.7	28.0	.8	154.2	4.0
I6	9.40	8.0	10.0	91.0	4.7		38.0	164.0	8.0	1.0	395.3	1.2
I7	6.70	16.4	19.4	91.0	4.8		61.0	183.0	23.0	4.0	453.0	1.6
I8	8.00	32.5	6.1	30.5	1.2		65.0	61.0	20.0	.6	203.0	4.0
I9	6.20	5.2	5.1	24.4	1.4		36.0	30.0	12.0	.5	112.3	1.6
I10	6.40	5.2	3.7	29.7	1.6		41.0	33.0	11.0	.6	123.8	1.5
IR1	8.30	24.8	38.5	283.8	8.5		150.0	484.0	42.0	3.0	1066.2	.2
IR3	8.00	44.5	47.9	286.4	14.6		216.0	450.0	187.0	4.0	1455.7	3.1
IR5	8.00	135.1	275.6	4680.0	8.0		282.0	8250.0	144.0	71.0	14069.3	1.7
IR6	6.20	33.3	58.9	148.2	1.2		147.0	275.0	154.0	2.0	963.5	1.6
IR7	6.50	31.9	33.3	184.0	1.3		209.0	240.0	140.0	3.0	872.2	3.1
IR9	6.70	25.0	55.5	970.0	8.0		585.0	1134.0	417.0	10.0	3491.2	2.2
IR10	8.40	45.3	54.9	291.4	26.3		281.0	460.0	104.4	30.0	1525.7	.3

TABLE 7.1 CHEMICAL ANALYSES OF IRRIGATION WATER (I1 to I10) and IRRIGATION RETURN FLOW (IR1 toIR10). (cont.)

Sample number	pH	Ca	Mg	Na	K		HCO3	Cl	SO4	NO3	T. D. S.	ERROR
		mg/l	mg/l	mg/l	mg/l		mg/l	mg/l	mg/l	mg/l	mg/l	%
I1 JUNE 85	9.70	21.9	30.6	182.3	5.8		105.0	314.0	48.0	12.0	808.3	.4
I2	7.40	3.5	6.4	49.4	.3		16.0	92.0	5.0	1.0	186.1	2.1
I3	7.40	14.2	12.8	60.5	3.9		60.0	109.0	18.0	11.0	331.5	1.3
I4	7.20	14.3	12.2	61.6	3.9		62.0	110.0	12.0	12.0	336.5	.7
I5	7.00	18.5	1.9	10.0	.8		40.0	30.0	2.0	1.0	93.7	.8
I6	6.90	9.3	9.4	62.0	2.8		53.0	102.0	17.0	4.0	301.9	1.9
I7	8.70	9.7	7.3	36.0	.9		38.0	63.0	15.0	1.0	206.3	1.0
I8	8.00	10.3	8.2	37.8	1.3		40.0	60.0	20.0	2.0	218.3	1.2
I9	7.20	7.5	5.7	28.8	2.2		33.0	51.0	14.0	2.0	178.8	3.8
I10	6.90	5.4	3.7	16.7	1.1		24.0	30.0	9.0	1.0	110.7	4.1
IR1	6.30	114.0	165.0	745.0	15.0		194.0	1350.0	528.0	55.0	3208.6	1.0
IR3	7.50	55.0	51.0	270.0	9.8		218.0	434.0	132.0	7.0	1305.7	.7
IR5	6.90	391.0	829.0	4113.0	80.0		521.0	8540.0	336.0	130.0	13894.7	1.9
IR6	5.90	17.3	26.8	104.9	8.4		105.0	137.0	120.0	6.0	604.7	3.6
IR7	6.10	26.6	34.8	168.7	.4		127.0	253.0	110.0	4.0	821.3	1.8
IR9	8.40	39.0	49.0	1245.0	4.0		460.0	1431.0	502.0	146.0	3658.7	.4
IR10	7.70	53.9	64.6	502.8	23.9		442.0	709.0	237.0	35.0	1972.5	3.6
I1 JULY 85	9.00	25.4	32.3	179.0	5.0		89.0	322.0	69.0	10.0	771.2	1.3
I2	7.90	5.2	7.7	50.5	1.2		38.0	86.0	15.0	1.0	196.3	4.0
I3	8.10	14.8	9.5	67.7	3.5		64.0	90.0	46.0	9.0	329.5	1.5
I4	8.00	15.2	12.5	64.9	3.6		46.0	105.0	41.0	7.0	320.4	.2
I5	9.00	11.5	1.7	28.5	.9		38.0	36.0	10.0	3.0	114.3	2.1
I6	6.90	5.9	4.9	26.6	.6		41.0	36.0	.1	.5	157.8	4.8
I7	8.00	8.2	6.7	36.1	.8		38.0	60.0	14.0	.7	203.3	1.3
I8	6.40	5.5	5.2	25.5	1.4		33.0	45.0	5.0	2.0	148.8	2.6
I9	6.20	8.3	6.7	35.0	3.8		36.0	60.0	14.0	2.0	197.3	.4
I10	6.30	6.1	4.9	26.6	1.1		21.0	45.0	16.0	1.0	148.7	1.8
IR1	6.50	124.5	184.0	840.0	21.0		332.0	1582.0	403.0	49.0	3404.7	.7
IR3	7.30	45.6	44.5	306.3	8.8		280.0	446.0	117.0	2.0	1356.2	.4
IR5	6.40	230.0	252.0	1065.0	32.0		517.0	2200.0	418.0	29.0	4678.6	.2
IR6	5.90	15.1	34.5	154.0	26.9		240.0	235.0	21.0	8.0	846.9	.7
IR7	5.60	36.6	36.6	129.0	18.5		205.0	200.0	111.0	4.0	856.1	2.0
IR9	7.30	29.0	43.5	787.5	5.5		880.0	829.0	58.0	80.0	2752.0	1.1
IR10	7.40	59.1	78.5	632.7	25.9		645.0	751.0	314.0	49.0	2335.7	1.9
I1 AUG 85	8.40	18.1	18.3	92.0	4.1		106.0	153.0	28.0	3.0	496.8	1.3
I2	6.50	3.3	9.4	61.6	.8		61.0	95.0	2.1	1.0	270.0	1.4
I3	7.30	24.6	35.0	206.5	5.5		186.0	321.0	89.0	13.0	1016.5	3.4
I4	7.00	23.9	37.5	204.8	6.1		167.0	334.0	100.0	14.0	992.8	4.0
I5	7.60	9.4	3.3	14.9	2.9		27.0	31.0	7.0	1.0	117.7	.5
I6	6.20	3.1	3.3	20.0	2.7		23.0	38.0	4.0	1.0	117.7	6.3
I7	6.10	6.8	6.2	31.1	3.3		30.0	60.0	20.0	1.0	178.6	6.7
I8	6.00	4.6	5.9	23.0	5.8		30.0	44.0	13.0	2.0	143.7	4.4
I9	6.00	5.3	4.4	25.5	2.3		28.0	45.0	8.0	3.0	149.9	4.0
I10	5.80	4.0	3.8	32.0	1.6		26.0	50.0	9.0	1.0	154.8	3.9
IR1	6.10	22.6	31.5	166.5	8.8		166.0	316.0	29.0	.1	824.8	4.5
IR3	8.10	42.1	39.0	300.0	7.5		285.0	407.0	170.0	25.0	1422.8	4.0
IR5	7.90	285.0	517.5	2712.5	57.5		308.0	5287.0	262.0	61.0	9812.5	4.6
IR6	6.60	38.3	52.6	119.0	32.8		248.0	205.0	98.0	26.0	874.0	.2
IR7	6.20	39.0	37.5	180.7	1.7		225.0	235.0	149.0	4.0	898.3	2.1
IR8	7.10	27.6	18.5	109.0	12.9		150.0	188.0	19.0	9.0	773.2	2.0
IR9	7.50	39.3	63.0	900.0	4.5		632.0	1142.0	214.0	8.0	3123.1	.8
IR10	7.40	53.9	71.3	546.0	21.9		526.0	708.0	310.0	6.0	2242.2	3.4
I1 SEP 85	8.90	22.2	13.7	62.7	3.1		93.0	136.0	26.0	1.4	393.2	.8
I2	6.50	4.7	7.9	54.5	2.2		28.0	104.0	5.0	.5	254.2	2.8
I3	8.20	32.9	50.3	311.0	6.0		208.0	501.0	125.0	8.0	1386.7	2.0
I4	8.20	32.5	51.0	312.5	6.0		228.0	508.0	117.0	8.0	1396.8	2.7
I5	8.60	9.5	3.9	15.6	2.0		36.0	27.0	12.0	2.0	140.3	3.5
I6	5.60	6.3	3.9	19.4	2.3		21.0	39.0	8.0	.3	119.7	2.5
I7	7.20	5.4	7.4	30.6	2.1		25.0	60.0	16.0	1.7	182.2	4.2
I8	5.20	5.4	5.6	25.6	4.2		26.0	50.0	11.0	1.2	153.2	3.3
I9	7.40	7.8	4.4	18.9	2.1		21.0	40.0	10.0	3.0	135.7	3.0
I10	7.20	5.8	4.7	22.3	2.6		26.0	40.0	14.0	.6	143.2	4.0
IR1	7.60	41.6	51.9	220.6	10.5		292.0	309.0	166.0	2.4	1115.3	2.4
IR3	8.90	38.8	46.5	350.0	12.3		200.0	501.0	188.0	2.2	1484.6	.1
IR5	8.80	218.9	469.5	2264.0	59.1		317.0	4476.0	427.0	36.0	8636.0	3.0
IR6	7.70	39.9	49.9	138.3	32.8		194.0	294.0	17.0	101.0	1040.6	1.9
IR7	7.40	43.3	45.1	183.0	2.0		282.0	302.0	46.0	10.0	984.3	1.3
IR8	7.90	19.5	36.3	164.0	5.2		202.0	278.0	22.0	5.2	882.6	2.0
IR9	9.20	41.0	82.5	730.0	2.5		711.0	826.0	344.0	30.0	2795.2	2.3
IR10	8.90	62.8	65.9	486.0	21.9		639.0	500.0	300.0	27.0	2073.6	1.6

TABLE 7.1 CHEMICAL ANALYSES OF IRRIGATION WATER (I1 to I10) and IRRIGATION RETURN FLOW (IR1 toIR10). (cont.)

Sample number	pH	Ca	Mg	Na	K		HCO3	Cl	SO4	NO3	T. D. S.	ERROR
		mg/l	mg/l	mg/l	mg/l		mg/l	mg/l	mg/l	mg/l	mg/l	%
I1 OCT 85	8.40	25.0	27.0	249.5	6.4		109.0	349.0	137.5	5.0	982.4	.3
I2	6.80	5.2	11.0	70.8	1.7		20.0	120.0	27.9	1.2	279.2	.3
I3	6.90	7.5	6.0	13.3	1.6		29.0	30.0	11.5	.5	123.7	2.7
I4	6.90	7.0	5.8	12.8	1.6		30.0	30.0	11.5	.0	124.2	5.1
I5	7.00	8.9	6.2	14.9	1.8		36.0	28.0	15.0	1.4	139.3	2.0
I6	7.10	8.7	6.7	22.2	3.4		38.0	40.0	18.7	1.2	156.3	2.9
I7	7.20	10.6	10.0	40.1	2.0		45.0	68.0	21.9	.8	240.9	.4
I8	7.30	12.3	8.5	27.7	4.6		48.0	58.0	13.0	.6	200.4	1.3
I9	7.20	4.3	9.2	35.0	2.3		44.0	53.0	19.2	.6	230.4	.8
I10	7.30	3.5	8.1	33.7	2.6		29.0	50.0	23.4	.5	192.7	.2
IR1	8.00	50.0	51.0	246.3	10.6		225.0	402.0	140.0	5.0	1276.3	1.0
IR3	8.90	48.6	55.0	357.9	14.9		208.0	641.0	156.0	10.0	1712.7	4.2
IR5	8.60	180.0	280.0	1300.0	40.0		309.0	2768.0	628.0	20.0	5861.0	3.7
IR6	8.00	54.3	75.0	104.4	38.4		208.0	204.0	274.0	7.0	1007.7	2.0
IR7	7.20	38.7	49.8	171.9	2.1		250.0	271.0	117.0	1.3	1079.0	2.4
IR8	7.60	20.2	38.8	150.3	5.2		158.0	207.0	170.0	.6	877.3	4.8
IR9	8.90	28.5	44.0	292.5	13.4		282.0	377.0	158.5	8.0	1466.3	1.6
IR10	8.20	60.9	63.4	399.6	19.3		586.0	482.0	117.0	30.0	2009.7	.0
I1 NOV 85	8.40	69.3	70.6	341.3	20.3		235.0	558.0	165.0	5.0	1533.4	3.2
I2	7.60	3.3	6.7	35.5	1.4		20.0	60.0	16.0	.8	161.2	1.5
I3	7.40	6.6	9.7	60.0	2.4		33.0	109.0	26.2	1.7	255.8	4.9
I4	7.40	6.4	9.8	60.0	2.3		33.0	102.0	26.2	1.2	255.8	2.4
I5	7.30	11.7	5.6	19.4	2.7		41.0	40.0	12.5	.8	138.8	2.9
I6	7.00	3.0	4.3	17.8	1.1		14.0	32.0	8.0	.8	88.1	.2
I7	7.10	9.1	8.8	44.4	2.5		37.0	78.0	24.0	1.0	215.8	2.3
I8	7.00	6.2	6.0	27.2	2.3		28.0	50.0	17.0	.9	147.2	4.5
I9	6.90	6.9	5.8	21.1	2.4		26.0	43.0	14.0	.7	131.2	3.8
I10	7.10	7.3	6.9	30.6	2.5		24.0	57.0	22.0	.9	160.2	3.1
IR1	8.40	70.0	100.0	680.0	24.0		740.0	919.0	200.0	4.5	3122.9	.4
IR2	8.70	46.6	46.6	436.2	16.3		407.0	524.0	147.5	11.0	1586.8	1.7
IR3	9.40	51.9	50.6	420.0	17.6		350.0	587.0	166.5	5.5	1710.8	.7
IR5	8.20	195.0	301.7	1834.0	55.0		390.0	3376.0	712.0	16.0	6698.1	.4
IR6	7.20	51.0	56.0	203.0	45.8		206.0	383.0	185.0	5.0	1160.6	2.7
IR7	6.80	47.5	46.8	233.0	1.9		305.0	372.0	114.5	2.0	1121.9	4.4
IR8	7.40	30.0	48.3	285.0	9.0		331.0	332.0	192.0	3.0	1275.1	2.0
IR9	8.80	38.5	94.0	795.0	5.0		637.0	926.0	460.0	27.0	2860.6	2.4
IR10	7.90	66.6	69.9	493.0	19.3		768.0	600.0	130.0	25.0	2120.1	2.5
I1 DEC 85	8.40	18.7	23.8	134.0	5.7		89.0	202.0	91.5	5.0	627.2	1.5
I2	6.70	2.6	5.6	36.0	1.2		40.0	47.0	11.0	2.4	165.3	1.4
I3	6.70	4.6	8.1	62.0	1.7		44.0	91.0	19.4	1.0	242.4	1.0
I4	6.70	4.6	8.2	62.0	1.7		41.0	91.0	19.6	.8	240.8	.6
I5	8.40	13.9	3.6	16.0	1.9		40.0	31.0	9.8	2.7	144.3	1.2
I6	7.30	15.2	6.0	29.0	3.4		53.0	55.0	13.5	1.0	174.9	2.2
I7	7.10	20.0	13.2	35.5	1.8		77.0	67.0	20.3	.8	219.1	1.2
I8	6.80	16.8	5.3	25.5	2.1		38.0	50.0	19.4	1.3	152.3	.4
I9	6.90	6.2	6.4	40.0	2.7		40.0	50.0	28.8	1.4	179.3	.8
I10	6.60	26.0	5.2	24.0	2.2		56.0	54.0	21.0	.9	161.4	1.2
IR1	8.30	142.0	117.0	660.0	96.0		985.0	958.0	243.0	49.0	3320.4	1.2
IR2	7.70	26.9	52.9	446.0	13.0		609.0	456.0	152.0	31.0	1917.4	2.1
IR3	8.20	31.3	34.3	293.0	11.4		375.0	346.0	110.0	10.0	1294.5	2.6
IR4	7.20	17.3	36.3	383.0	3.6		434.0	382.0	166.0	1.6	1576.5	1.8
IR5	8.40	216.0	596.0	3397.0	77.0		990.0	5145.0	1325.0	48.0	12202.9	5.0
IR6	6.30	19.8	29.5	185.0	21.5		215.0	253.0	90.0	.7	1024.5	2.3
IR7	6.80	29.0	43.5	219.0	1.5		204.0	256.0	112.0	13.0	1045.6	5.4
IR8	7.30	20.6	33.5	190.0	5.9		253.0	212.0	142.0	5.2	890.5	3.8
IR9	8.90	20.0	78.5	745.0	5.5		891.0	659.0	358.0	36.0	2706.6	1.5
IR10	7.10	32.3	62.6	303.0	17.9		535.0	360.0	96.0	25.0	1711.8	2.2

The analytical results were used to make comparisons of the ratios between the major cations in irrigation water and those in the return flow, and between the anions on the same basis. For example, if figures for the cations for sample I1 (October 1984) are used, we see the following:

I1	ANALYSES (OCT. 1984)		RATIOS	
Ca	15.8	mg/l	15.8/134.2	= 0.1178
Mg	18.2	mg/l	18.2/134.2	= 0.1356
Na	96.5	mg/l	96.5/134.2	= 0.7191
K	3.7	mg/l	3.7/134.2	= 0.0275
TOTAL	134.2	mg/l		1.0000

And if we then examine the cations for sample IR1 (October 1984) we see:

IR 1	ANALYSES (OCT. 1984)		RATIOS	
Ca	57.0	mg/l	57/674.5	= 0.0845
Mg	125.0	mg/l	125/674.5	= 0.1853
Na	472.5	mg/l	472.5/674.5	= 0.7005
K	20.0	mg/l	20/674.5	= 0.0297
TOTAL	674.5	mg/l		1.0000

Comparison of ratios:

	I1 IONIC RATIOS	IR 1 IONIC RATIOS	RELATIVE INCREASE (%)	CATION/S WITH INCREASE >10%
Ca	0.1178	0.0845	-28.27	
Mg	0.1356	0.1853	+36.65	* Mg
Na	0.7191	0.7005	-2.58	
K	0.0275	0.0297	+8.00	

Comparison of ionic ratios for the cations in the rest of the irrigation water and return flow samples during October 1984 are as follows:

CATIONS	IONIC RATIOS		RELATIVE INCREASE (%)	CATION/S WITH INCREASE > 10%
	I2	IR2		
Ca	0.0948	0.0531	- 43.98	
Mg	0.1454	0.0879	- 39.55	
Ng	0.7254	0.8477	+ 16.85	* Na
K	0.0344	0.0113	- 67.15	
	I3	IR3		
Ca	0.0706	0.1665	+ 135.84	* Ca
Mg	0.1362	0.1185	- 12.99	
Na	0.7783	0.6222	- 20.06	
K	0.0149	0.0227	+ 52.35	* K
	I4	IR4		
Ca	0.0925	0.0627	- 32.22	
Mg	0.1307	0.0120	- 90.81	
Na	0.7025	0.8023	+ 14.21	* Na
K	0.0143	0.0149	+ 4.19	
	I5	IR5		
Ca	0.2009	0.0642	- 68.04	
Mg	0.1219	0.1395	+ 14.43	* Mg
Na	0.4018	0.7659	+ 90.61	* Na
K	0.0496	0.0304	- 38.71	
	I6	IR6		
Ca	0.1149	0.1845	+ 60.57	* Ca
Mg	0.1511	0.3259	+ 115.68	* Mg
Na	0.6723	0.4043	- 39.86	
K	0.0617	0.0853	+ 38.24	* K
	I7	IR7		
Ca	0.1752	0.1148	- 34.47	
Mg	0.1910	0.1979	+ 3.61	
Na	0.5865	0.6791	+ 15.79	* Na
K	0.0472	0.0082	- 82.63	

CATIONS	IONIC RATIOS		RELATIVE INCREASE (%)	CATION/S WITH INCREASE > 10%
	I8	IR8		
Ca	0.2052	0.0704	- 65.69	
Mg	0.1721	0.1487	- 13.60	
Na	0.4200	0.7606	+ 81.09	* Na
K	0.2383	0.0198	- 91.69	
	I9	IR9		
Ca	0.1661	0.0239	- 14.22	
Mg	0.1891	0.0643	- 65.99	
Na	0.4836	0.9062	+ 87.39	* Na
K	0.1694	0.0056	- 96.69	
	I10	IR10		
Ca	0.1595	0.0620	- 61.12	
Mg	0.1756	0.1431	- 18.51	
Na	0.6362	0.7477	+ 17.52	* Na
K	0.0287	0.0471	+ 64.11	* K

Similar calculations to compare the anion ratios in the same samples (October 1984) gave the following results:

ANIONS	IONIC RATIOS		RELATIVE INCREASE (%)	ANION/S WITH INCREASE > 10%
	I1	IR1		
HCO_3	0.2518	0.2097	- 16.71	
Cl	0.6835	0.5483	- 19.78	
SO_4	0.0359	0.2133	+ 493.95	* SO_4
NO_3	0.0288	0.0286	- 0.69	
	I2	IR2		
HCO_3	0.3357	0.3721	+ 10.84	* HCO_3
Cl	0.5035	0.5057	+ 0.44	
SO_4	0.1119	0.0649	- 42.00	
NO_3	0.0489	0.0573	+ 17.08	* NO_3

CATIONS	IONIC RATIOS		RELATIVE INCREASE (%)	CATION/S WITH INCREASE > 10%
	I3	IR3		
HCO_3	0.0669	0.2605	+ 289.39	* HCO_3
Cl	0.7344	0.3772	- 48.63	
SO_4	0.1888	0.3213	+ 70.18	* SO_4
NO_3	0.0098	0.0409	+ 317.35	* NO_3
	I4	IR4		
HCO_3	0.1246	0.0498	- 60.03	
Cl	0.7065	0.6956	- 1.52	
SO_4	0.1645	0.2392	+ 45.41	* SO_4
NO_3	0.0044	0.0153	+ 247.72	* NO_3
	I5	IR5		
HCO_3	0.4494	0.0459	- 89.78	
Cl	0.2247	0.9210	+ 309.87	* Cl
SO_4	0.1910	0.0200	- 89.52	
NO_3	0.1349	0.0129	- 90.43	
	I6	IR6		
HCO_3	0.4347	0.2760	- 36.51	
Cl	0.4086	0.3303	- 19.16	
SO_4	0.0522	0.3167	+ 506.70	* SO_4
HNO_3	0.1043	0.0769	- 26.27	
	I7	IR7		
HCO_3	0.4587	0.3840	- 16.28	
Cl	0.3669	0.3916	+ 6.73	
SO_4	0.0183	0.1825	+ 897.26	* SO_4
NO_3	0.1559	0.0418	- 73.18	
	I8	IR8		
HCO_3	0.3148	0.3087	- 1.87	
Cl	0.3703	0.4577	+ 23.60	* Cl
SO_4	0.1913	0.2039	+ 6.58	
NO_3	0.1234	0.0294	- 76.18	
	I9	IR9		
HCO_3	0.3378	0.1560	- 53.81	
Cl	0.3514	0.4569	+ 30.02	* Cl
SO_4	0.2229	0.3391	+ 52.13	* SO_4
NO_3	0.0878	0.0480	- 45.33	

CATIONS	IONIC RATIOS		RELATIVE INCREASE (%)	CATION/S WITH INCREASE > 10%
	I10	IR10		
HCO_3	0.3688	0.1826	- 50.48	
Cl	0.4918	0.4267	- 13.23	
SO_4	0.0328	0.3422	+ 943.29	* SO_4
NO_3	0.1066	0.0485	- 54.50	

All the analyses concerned with irrigation were handled in this way, and the cation/s or anion/s showing relative increases greater than 10% marked with asterisks on a table of results (TABLE 7.2). Also shown on this table are:

(a) the T.D.S. values of the return flow seepage sampled in drainage lines below the irrigated fields, e.g. 2349 mg/l in October 1984, and

(b) Tr/Ti, a factor showing the relative mineralization or increase in salinity of irrigation water as it passes through the soil into drainage lines. (return flow TDS divided by irrigation water TDS). During October 1984 this amounted to 2349/478.6, ie 4.91.

Averages calculated from the lists in TABLE 7.2 are shown in TABLE 7.3. If the extremely high, evaporated value for return flow at IR5 during March 1985 is discarded, the mean T.D.S. for the return flow at this spot reduces to 8920, and the Tr/Ti to 70.3; this is a very heavy mineralization factor for water which, after being used for irrigation, passes down drainage lines to the Poesjesnels River and eventually the Breë River. Other areas of high mineralization are: I2 (9.2), I4 (27.3), I9 (18.2) and I10 (13.9). The lowest increase in salinity is found at I1 (2.5).

The average T.D.S. values for all ten areas were found to be:

a. applied irrigation water = 312.2 mg/l
b. return flow seepage = 2965.6 mg/l

If all the analyses are taken into account, the average mineralization increase factor for all ten areas works out at 16.77.

TABLE 7.2

CHANGES IN PRINCIPAL COMPONENT RATIOS DURING APPLICATION AND MOVEMENT OF IRRIGATION WATER THROUGH SOIL INTO DRAINAGE LINES.

DATE	SAMPLE	* = MAJOR CATIONS AND ANIONS WITH THE LARGEST RELATIVE INCREASES							
		CATIONS			ANIONS				
		Ca^{++}	Mg^{++}	Na^{+}	Cl^{-}	$SO_4^{=}$	HCO_3^{-}	TDSmg/l	$Tr/Ti^{\#}$
OCT 84	IR1		*			*		2349	4.91
	IR2			*			*	852	3.64
	IR3	*				*	*	1176	0.47
	IR4			*		*		9305	3.65
	IR5		*	*	*			9799	78.8
	IR6	*	*			*		639	3.55
	IR7			*		*		1258	7.09
	IR8			*	*			3918	14.85
	IR9			*	*	*		1971	8.83
	IR10			*		*		2759	12.37
NOV 84	IR1		*				*	1238	1.39
	IR2			*	*			3504	17.88
	IR3		*				*	1527	0.57
	IR4			*	*			8358	3.13
	IR5			*	*			9450	76.21
	IR6		*			*		445	2.28
	IR7		*		*			1226	7.74
	IR8			*	*			1007	6.36
	IR9			*	*			2376	13.67
	IR10			*	*			2611	16.82

$^{\#}$ Tr/Ti = TDS of return flow/TDS of irrigation water.

		Ca^{++}	Mg^{++}	Na^{+}	Cl^{-}	$SO_4^{=}$	HCO_3^{-}	TDSmg/l	$Tr/_{Ti}$#
DEC 84	IR1		*		*	*		1762	1.39
	IR2			*		*		1666	6.65
	IR3			*	*			1511	4.70
	IR4			*	*			7882	25.05
	IR5		*	*	*			12779	74.82
	IR6		*			*		583	2.86
	IR7		*			*		1243	7.11
	IR8		*			*		831	5.45
	IR9			*	*			4773	23.41
	IR10			*	*			3766	19.12
JAN 85	IR1		*			*		2022	1.39
	IR2			*		*	*	1708	5.62
	IR3		*	*	*			1595	5.73
	IR4		*	*	*			7728	27.30
	IR5		*	*	*			4284	54.43
	IR6	*	*				*	861	3.76
	IR7					*		1111	5.63
	IR8	*				*	*	748	3.73
	IR9			*	*			3410	18.61
	IR10			*		*	*	1313	8.35
FEB 85	IR1		*				*	1567	1.07
	IR3			*	*	*		1436	18.67
	IR4			*	*			7499	101.06
	IR5			*	*			8592	33.25
	IR6	*	*			*	*	928	3.64
	IR7			*	*			1017	4.45
	IR8		*	*		*		620	6.42
	IR9		*	*	*			2698	14.22
	IR10		*			*		2232	16.15

		Ca^{++}	Mg^{++}	Na^{+}	Cl^{-}	$SO_4^{=}$	HCO_3^{-}	TDSmg/l	$Tr/Ti^{\#}$
MAR 85	IR1		*			*	*	3896	2.68
	IR3			*	*			1655	4.72
	IR4			*	*			8981	24.59
	IR5		*		*			17354	258.25
	IR6		*			*	*	854	2.77
	IR7						*	960	9.24
	IR9			*	*			2440	21.09
APR 85	IR1		*			*	*	3448	2.52
	IR3			*	*			1971	4.13
	IR5		*	*	*			4123	66.38
	IR6	*	*			*		1241	3.51
	IR7		*	*		*	*	938	3.38
	IR9			*	*			3992	21.31
MAY 85	IR1			*		*	*	1066	1.01
	IR3			*		*		1456	3.55
	IR5			*	*			14069	91.24
	IR6		*			*	*	964	2.44
	IR7	*				*		872	1.93
	IR9			*	*			3491	31.09
	IR10			*	*			1526	12.32
JUN 85	IR1		*			*		3209	3.97
	IR3			*		*	*	1306	3.94
	IR5			*	*			13895	148.29
	IR6		*			*		605	2.00
	IR7		*	*		*	*	821	3.98
	IR9			*	*	*		3659	20.46
	IR10			*	*			1973	17.82

		Ca^{++}	Mg^{++}	Na^{+}	Cl^{-}	$SO_4^{=}$	HCO_3^{-}	TDSmg/l	$Tr/_{Ti}$#
JUL 85	IR1		*			*		3405	4.42
	IR3			*	*			1356	4.12
	IR5		*		*			4679	40.93
	IR6		*			*		847	5.37
	IR7		*				*	856	4.21
	IR9			*		*		2752	13.95
	IR10			*		*	*	2336	15.71
AUG 85	IR1		*	*	*			825	1.66
	IR3	*			*	*		1423	1.40
	IR5		*	*	*			9813	83.37
	IR6		*			*	*	874	7.43
	IR7		*			*	*	898	7.63
	IR8	*		*			*	773	5.38
	IR9			*	*			3123	20.83
	IR10			*		*		2242	14.48
SEP 85	IR1		*			*		1115	2.84
	IR3			*		*		1485	1.07
	IR5		*	*	*			8636	61.55
	IR6		*			*	*	1041	8.69
	IR7	*					*	984	5.40
	IR8		*	*			*	883	5.76
	IR9			*		*	*	2795	20.59
	IR10			*		*	*	2074	14.48
OCT 85	IR1		*				*	1276	1.30
	IR3			*	*			1713	13.85
	IR5			*	*			5861	42.07
	IR6		*			*		1008	6.45
	IR7		*			*	*	1079	4.47
	IR8		*	*		*		877	4.38
	IR9			*		*		1466	6.36
	IR10			*			*	2009	10.42

		Ca^{++}	Mg^{++}	Na^{+}	Cl^{-}	$SO_4^{=}$	HCO_3^{-}	TDSmg/l	$Tr/Ti^{\#}$
NOV 85	IR1			*			*	3123	2.04
	IR2			*			*	1587	9.84
	IR3			*			*	1711	6.69
	IR5			*	*			6698	48.26
	IR6	*				*		1161	13.17
	IR7		*				*	1122	5.20
	IR8			*		*	*	1275	8.66
	IR9			*		*		2861	21.80
	IR10			*			*	2120	13.23
DEC 85	IR1	*					*	3320	5.29
	IR2			*			*	1917	11.60
	IR3			*			*	1295	5.34
	IR4			*		*	*	1577	6.55
	IR5		*	*	*			12203	84.57
	IR6		*	*			*	1025	5.86
	IR7			*		*		1046	4.77
	IR8		*	*		*		891	5.85
	IR9			*			*	2787	15.54
	IR10		*	*			*	1712	10.61

$^{\#}$ Tr/Ti = TDS of return flow/TDS of irrigation water.

In any normal irrigation situation the return flow or drainage water will always have a greater salinity than the applied water. This is due to evaporation, transpiration and the take-up of salts from the soil and underlying materials. Different soil types will naturally contribute their own combination of ionic species for such a dissolution process.

The relative increase of certain ions when compared with others will therefore give an indication of the chemical characteristics of that soil, or groups of soils in a particular part of the catchment.

The ions showing the largest relative increases, indicated by asterisks on Table 7.2, also manifest a significant movement towards the corner of a trilinear diagram on which the results are plotted, reflecting the chemical nature of the soil being irrigated. Such diagrams (after Piper and Durov) have been constructed and are presented in Section 8.8.

A combination of all the results in each sampling area over the 15 month period, shown in TABLE 7.4, gives an overall impression of the relative ionic increases in irrigation return flow in the upper, middle and lower parts of the valley.

TABLE 7.3

AVERAGE T.D.S. VALUES FOR MONTHLY SAMPLES OF IRRIGATION WATER AND IRRIGATION RETURN FLOW OVER 15 MONTHS PERIOD FROM OCTOBER 1984 TO DECEMBER 1985

Irrigation Sample:	Mean TDS of applied irrigation water (mg/l)	Mean TDS of return flow (mg/l)	Mean ratio Tr/Ti #	Number of analyses
I 1	1001.5	2241.4	2.525	15
2	227.4	1872.3	9.205	6
3	424.5	1507.7	5.26	13
4	423.4	7332.8	27.33	7
5	119.2	9482.3*	82.83**	15
6	209.2	871.6	4.53	15
7	227.6	1028.6	5.48	15
8	164.8	1182.3	6.68	10
9	172.9	2974.3	18.24	15
10	151.3	1724.8	13.99	13

* = 8920 if March 1985 is dicarded.

** = 70.3 if March 1985 is discarded.

Tr/Ti = TDS of return flow/TDS of irrigation water

TABLE 7.4 : SUMMARY OF RELATIVE IONIC INCREASES IN RETURN FLOW

VALLEY AREA	SAMPLE SITE	NUMBER OF MOST PROMINENT RELATIVE IONIC INCREASES					
		CATIONS			ANIONS		
		Ca^{++}	Mg^{++}	Na^{+}	Cl^{-}	$SO_4^{=}$	HCO_3^{-}
UPPER	IR 1	1	12	3	2	9	8
	IR 2	-	-	6	1	2	4
MID	IR 3	2	2	12	8	6	5
LOWER	IR 4	-	1	7	5	2	1
	IR 5	-	9	13	15	-	-
UPPER	IR 6	6	14	1	0	13	7
	IR 7	2	8	5	2	9	8
MID	IR 8	2	5	8	2	6	4
LOWER	IR 9	-	1	15	10	5	2
	IR 10	-	2	12	4	6	6
	TOTALS	13 CA^{++}	54 Mg^{++}	82 Na^{+}	49 Cl^{-}	58 $SO_4^{=}$	45 HCO_3^{-}

According to these results, the contribution of salt by irrigated fields to applied water is follows:

CATIONS:

IR1, IR6, IR7 (upper valley): $Mg^{++} > Na^{+} > Ca^{++}$
IR2, IR3, IR8 (mid-valley): $Na^{+} > Mg^{++}, Ca^{++}$
IR4, IR5, IR9, R10 (lower valley): $Na^{+} >> Mg^{++} > Ca^{++}$

ANIONS:
IR1, IR6, IR7 (upper valley) $SO_4^{=} > HCO_3^{-} > Cl^{-}$
IR3, IR4, IR5, IR9: (middle valley) $Cl^{-} > SO^{=}_4 \geq HCO_3^{-}$

There seems to be a tendency for Ca^{++}, Mg^{++}, $SO_4^{=}$ and HCO_3^{-} ions to be produced in the upper and middle part of the valley, and Na^{+} and Cl^{-} ions to be produced in the lower part of the valley.

This variation in principal component chemistry as one moves from the upper to the lower part of the valley is clearly demonstrated on the graphs shown in FIG 7.1, which are based on the results in TABLE 7.4.

The grouping together of ions into salts gives a clear indication that NaCl increases downstream, while both $MgSO_4$ and $CaHCO_3$ show a relative decrease in return flow waters.

The strong increase in the ratio of NaCl in the soil and decomposed shale at the lower end of the Poesjesnels River valley is probably due to the progressive rainfall leaching in a downstream direction of the Bokkeveld marine shale in the upper and central part of the valley, where these shales are either exposed or only thinly covered with soil on steeper gradients. Lower downstream the gradients are more moderate so that thicker soil profiles and clay layers have developed on top of deeper zones of decomposed Bokkeveld shale; these materials have acted as ionic collectors, retaining the NaCl by adsorption on clay mineral surfaces, until released by deep ploughing and irrigation.

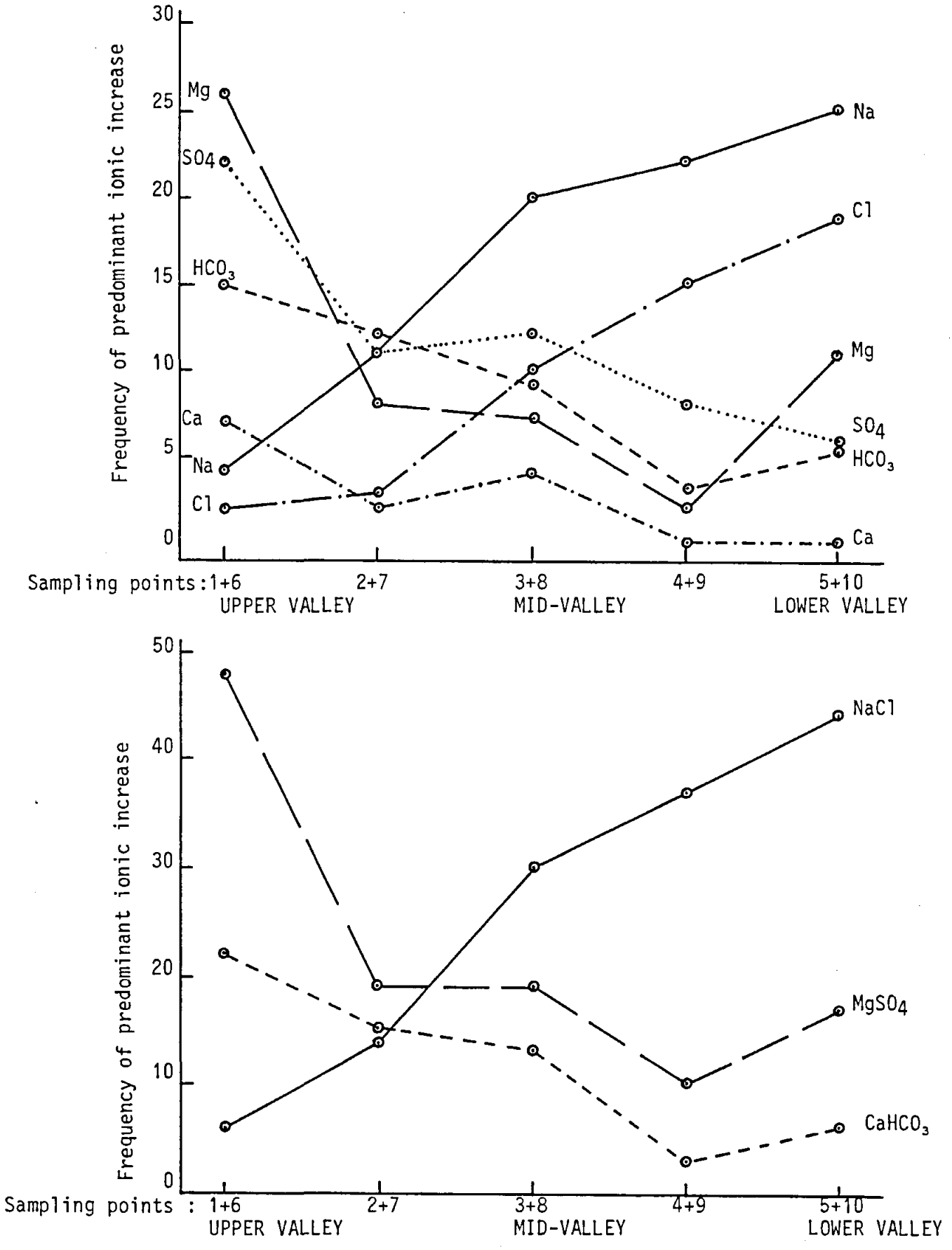


FIG. 7.1 : CHEMICAL CHANGES IN THE RETURN FLOW WATER ALONG THE POEJESNELS VALLEY

7.2 Leaching by rainwater

At the start of project, the farmers in the valley were questioned as to their plans regarding development of new fields for the planting of vines or orchards. As a result of information from Mr. Wouter de Wet of the farm De Wilgen to the effect that he intended developing new areas on the south bank of the Mosiesleegte River, boreholes were drilled into the bedrock (transect A1 and A2), and samples of water were taken below the bank of the Mosiesleegte whenever rainfall had caused some seepage to occur. It was hoped that the ripping and development would take place before the period of sampling for the project data came to an end; unfortunately this did not eventuate. During 1987 and 1988 Mr. De Wet however did commence the development, and 25 hectares of new vineyards and orchards were laid out after deep ripping with a D9 bulldozer (single tooth) to a minimum depth of 1 metre.

Rainfall during the first half of the year was restricted to a few drops which hardly moistened the surface. This situation extended through July into August, and as fears of a drought began to rise, farmers in the Caledon region just south of the Riviersonderend Mountains began to let their sheep graze the stunted growth of wheat what on their fields. Then on the weekend of 27/28th August rain at last began to fall, and by the time the weather cleared on Monday morning the 29th, 40mm had been registered at Le Chasseur. On Monday afternoon, runoff had ceased and seepage sampling was carried out in the Mosiesleegte stream below the bank where the new vineyard had been laid out, as well as upstream of the developed areas, lower down towards the main road and at the H4M18 measuring weir. Results of the analyses of these samples are as follows (TABLE 7.5; ions and TDS in milligrams per litre):

TABLE 7.5: Chemical analyses of seepage after rainfall on 27/28 August 1988

Sample N° and description: (date sampled: 29.8.88)		pH	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	$SO_4^{=}$	NO_3^{-}	TDS
1	Natural seepage upstream of new vineyard	7.8	11.3	11.2	124	8.5	129	134	56	0.2	474
2	Seepage at top end of new vineyard	8.1	15.7	12.3	96	10.4	141	111	32	1.3	420
3	Seepage at mid-point below new vineyard (sampling station MLA)	7.7	435.6	378.5	1789	31.5	231	4053	732	2.4	7653
4	Base flow in Mosiesleegte at sampling station MLA	8.1	241.6	236.6	1058	25.9	180	2293	436	1.7	4473
5	Seepage at lower end of new vineyard (A tributary stream joins the Mosiesleegte at this point)	7.9	103	91.3	584	18.7	189	1067	231	1.5	2286
6	Seepage downstream of the new vineyard	7.9	98.6	127.5	936	17.8	255	1558	370	0.6	3364
7	Base flow in Mosiesleegte midway between vineyards and main road	8.4	111.2	231.3	1582	43.5	411	2519	797	0.1	5695
8	Base flow in Mosiesleegte at road bridge (sampling station MLB)	7.7	182.4	206	1249	38	313	2088	659	18.8	4754
9	Flow in Poesjesnels River at measuring weir H4 M18	8.2	153.2	220.5	1398	24.5	503	2317	678	1.4	5296

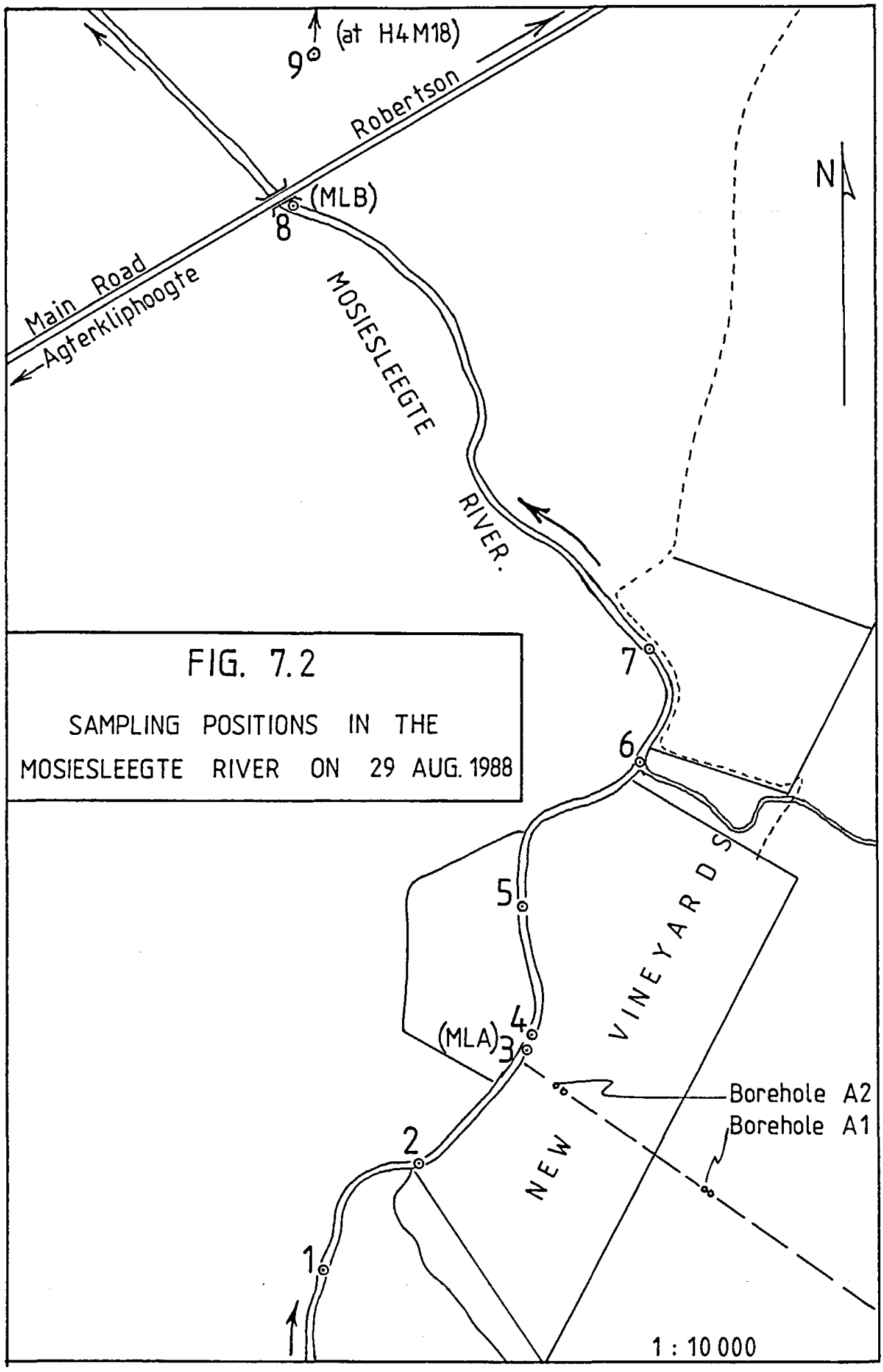


FIG. 7.2

SAMPLING POSITIONS IN THE MOSIESLEEGTE RIVER ON 29 AUG. 1988

Fig. 7.1 shows the layout of the new vineyards in relation to the Mosiesleegte River and the points where samples were taken on 29 August 1988.

Results show that untouched veld produces natural seepage and base flow with moderate salinity, even if the bedrock underlying the soil consists of Bokkeveld shale and siltstone. Sample N° 1 contains only 474 mg/l; a second sample taken near point 1 contained 336 mg/l. An equilibruim has clearly been established due to leaching of salts by rainfall over the centuries, so that only low amounts of salt are presently being mobilized by rainfall. At the top end of the newly developed vineyards, a similar salinity value of 420 mg/l was measured in base flow in the Mosiesleegte River.

Then, moving about 300 metres downstream to a point midway along the new vineyard, the seepage coming out below the riverbank was measured at a hefty 7653 mg/l (sample 3) and the base flow in the Mosiesleegte at this point (MLA) at 4473 mg/l (sample 4). Prior to the development of the new vineyard, samples of water were taken at MLA after rainfall during September 1984 and December 1985, and salinity levels of 2325 and 1170 mg/l measured (App. Fig. 4.5).

A severe increase in base flow salinity due to saline seepage from the riverbank below the new vineyard has therefore occurred. The farmer has added gypsum to the soil as part of his preparation, and some of the Ca^{++} and $SO_4^{=}$ in the seepage must be acribed to this source. However, the large amout of Na^{+} (1789 mg/l) and Cl^{-} (4053 mg/l) on 29th August 1988 must have been caused by the ripping of the deeper soil layers and upper decomposed shale materials during development; this clearly disturbed the equilibrium and led to greatly increased leaching of subsurface salts into the Mosiesleegte River.

Sample 5 was taken further downstream, at the lower end of the new development area, and opposite a point where the Mosiesleegte River is joined by a stream which drains the sandstone mountain to the south. The stream had already drained away, but its baseflow seepage caused some dilution of the Mosiesleegte base flow, as the level of salinity here was measured at only 2286 mg/l.

Further downstream the salinity again rose to 3364 and 5695 mg/l (samples 6 and 7) and then at the main road bridge MLB) it measured 4754 mg/l. This value is lower than some MLB measurements made during dry summer months at the

peak of irrigation (see App. Fig. 4.5), but is higher than values determined during August, September and October 1984 (2056.7, 4471.5 and 4171.2 mg/l), the latter two being sampled after a very similar rainfall event in early September.

The final sample, N°9, was taken at the H4M18 weir. Throughout the period that measurements of river salinity have been recorded at this position, values have fluctuated between a low of 433 mg/l (June 1983) and a high of 4503 mg/l (June 1984). During the afternoon of 29th August 1988 it exceeded all previous measurements, reaching 5026 mg/l.* (The flow was judged to be ± 100 litres per second). Over 5 grams of salt per litre of water flowing down the Poesjesnels to the Breë River is cause for serious concern; the development of the 25 hectares of new vineyards on De Wilgen has contributed to this increased salinity, as very little development of new irrigation acreage occurred higher up in the valley over the same period.

The chemical analyses of the principal components in all the water samples have now been presented in various tables.

Evaluation of the balances between these components, and comparison of the ionic character of the various water bodies is facilitated by means of Piper trilinear and Durov rectangular diagrams, which will be discussed in the next section.

* *HRI records show that on the morning of 29 August 1988 the TDS in the river at H4M18 registered 5 405 mg/l while the flow gauge registered 82 l/s (0.082 cumecs).*

8. Chemical differentiation of the various water bodies

The various types or bodies of water that were sampled and analyzed for principal components during the project include:

a. Monthly river water samples (22 selected from the full 40 samples in the Poesjesnels River, one from the Rietvlei River, one from the Poespasvlei River, two from the Mosiesleegte River) - Table 4.5.

b. Artesian water flowing from borehole B2 and B4. - Table 4.5.

c. Borehole piezometer samples - Table 5.4.

d. Leachates derived from percussion borehole cuttings - Table 6.5B.

e. Leachates derived from auger samples - Table 6.3.

f. Leachates derived from crushed diamond drill cores - Table 6.4B.

g. Irrigation water and irrigation return flow at ten selected areas - Table 7.1.

h. Bank seepage and base flow below newly developed vineyards following good rainfall - Table 7.5.

8.1 Piper and Durov hydrochemical diagrams

These are graphic representations of the ionic composition of water samples for visual inspection and assessment of large numbers of analyses.

The Piper diagrams are based on the percentages of ionic concentrations, and consist of two trilinear parts (one for cations and the other for anions) which are then extrapolated to a quadrilinear area where intersection results in a single point for all the principal components. This diagram was first designed by Hill (1940) and further developed by Piper (1944).

Some of the shortcomings of the trilinear graphs of the type developed by Hill and Piper are removed in the diagram introduced by S.A. Durov, which uses

percentage plotting of cations and anions in separate triangles similar to the Piper diagram. The intersection of lines extended from the two sample points on the triangles to a central rectangle gives a point that represents the major-ion composition on a percentage basis.

Both these diagrams are useful for visually describing differences in major-ion chemistry in groundwater flow systems. Hydrochemical facies or groundwater types can be designated according to domains on segments of the diagram in the following Figure:

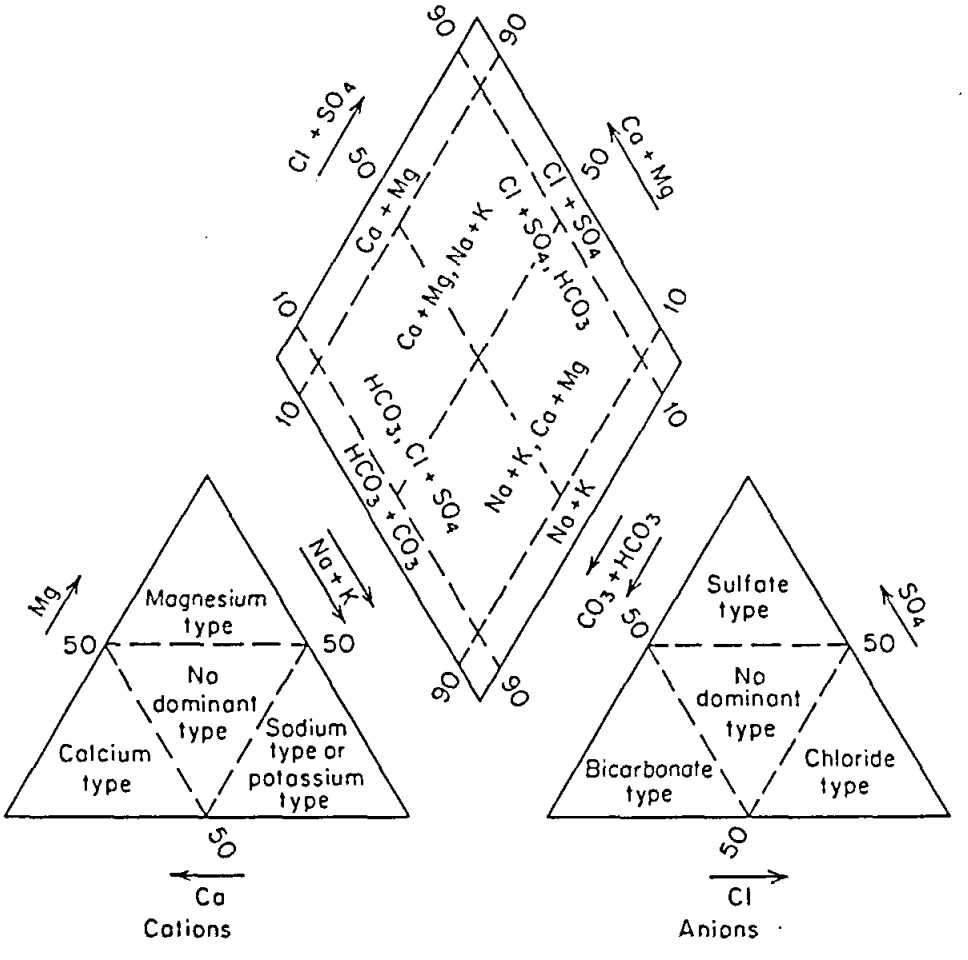


Fig. 8.0 Classification diagram for hydrochemical cation and anion facies (after Morgan and Winner, 1962; and Back, 1966)

The analytical data were entered into the Data General computer of Steffen Robertson and Kirsten in Johannesburg, and processed with a Chemanal program created by Jos Stern, Senior Systems Analyst of the company. A maximum of 15 analyses were plotted on each diagram after calculation of ionic milliequivalents per litre and cation or anion percentages. The results are presented in App. Figs. 8.2-8.9

8.2 Hydrochemical plots of river water samples and artesian borehole flows in the P.R. valley

Full chemical analyses were carried out on 22 of the 40 monthly samples taken from the Poesjesnels River in the period February 1983 to November 1984, at positions extending from N° 1 on Mountain View in the headwater area, to N° 40 at the confluence with the Breë River. Samples were also taken from the Rietvlei, Poespasvlei and Mosiesleegte rivers and artesian water flows from B2 and B4. (Sampling of the latter two only commenced after drilling, in October 1983).

To improve point visibility on the hydrochemical plots, the monthly analyses had to be divided into two groups with ±12 points on each diagram, resulting in a large mass of diagram pages. To save space, only diagrams for the analyses done from October 1983 to October 1984 are presented in this report - App. Figs. 8.2A to Z.

Amongst this group is a diagram (App. Fig. 8.2L) showing analyses of an extra sampling run carried out on the 13th March 1984 immediately following 40mm of rainfall in the catchment which ended a 4 - month summer drought. This was done to investigate any significant changes in the ionic balances in the river by accelerated natural leaching of riverbank soils in the valley. Most of the water showed greatly reduced salinities, but the balance of ions did not vary greatly. The water in the two tributary streams, the Rietvlei and Poespasvlei Rivers (RV and PPV) however showed increased salinities.

8.2.1 Chemical differentiation trends

The increase in salinity as the Poesjesnels River flows down the length of the valley has already been demonstrated. Examination of the Piper and Durov plots of the upper and lower sections of the valley did not reveal a clear trend of

changing ionic ratios. The points tended to plot close together in the lower right sections of the cation and anion triangles, particularly during the winter months when the river was flowing strongly. Randomness precluded the discernment of any established chemical trend or change in ionic ratios. The analyses for the summer months tended to show more widely spaced plots.

In a further attempt to find a trend along the river, analyses from more widely spaced sampling points along the full length of the river were plotted. On the anion triangle these showed that the Cl^- ratios increased from the upper to the lower middle part of the river (S.St. 1 to 28) and then decreased again from 28 down to 40. The ratios for Na^+, although not as clearly defined, showed a similar trend on the cation triangle (FIG 8.1A, March 1983). The Durov diagram for the same month is shown in FIG 8.1B.

These results indicate that a tendency existed during the dry summer months for some water, strongly charged with NaCl, to enter the river from the riverbanks or the riverbed along the central part of the valley. (During the winter months the effect of this water on the larger volume of water in the river could not be detected.)

The water which entered the river was probably derived from two sources:

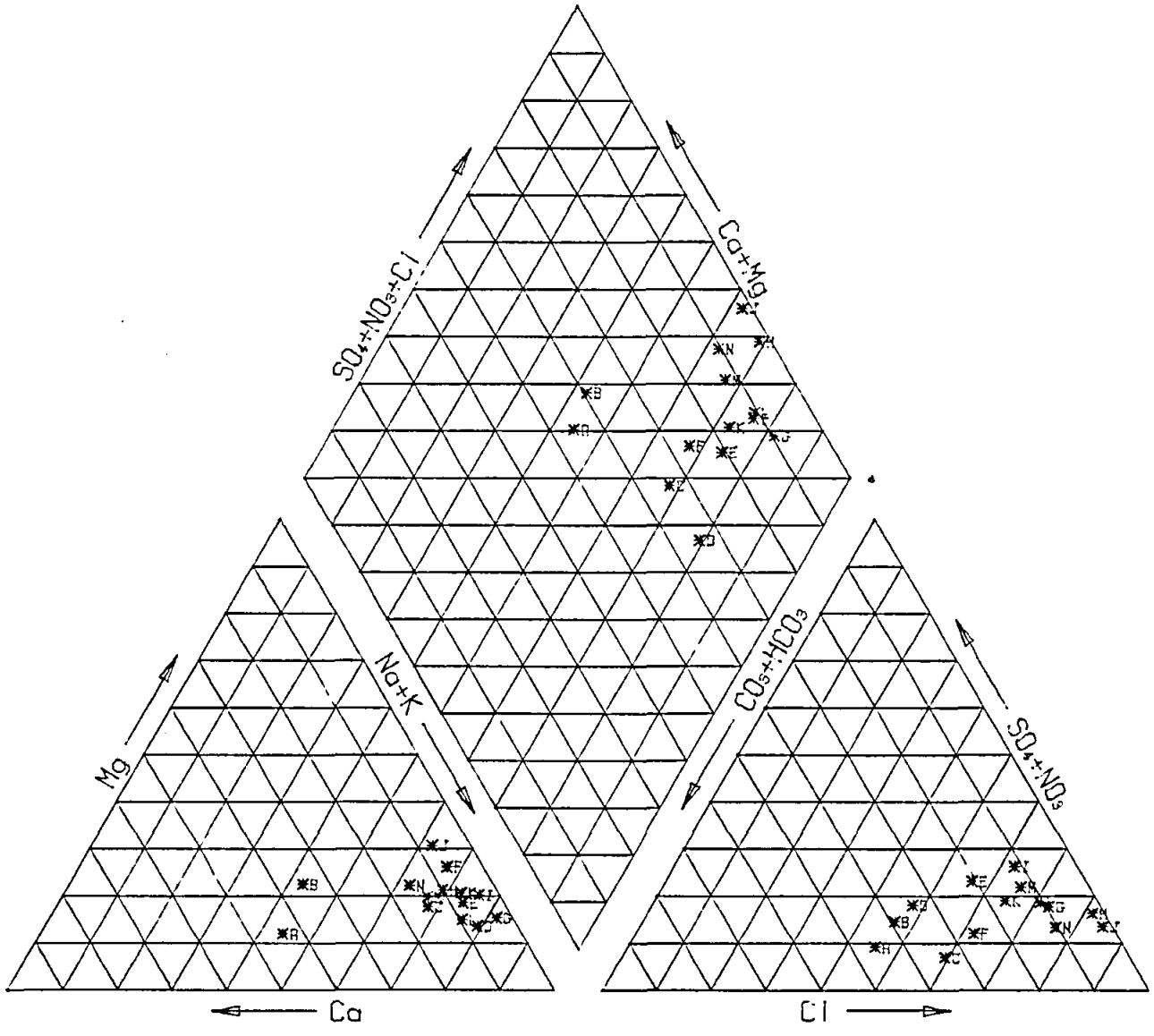
1. irrigation return flow from Bokkeveld soils

2. groundwater seeping into the river from fractures in the Bokkeveld bedrock under pressure from the head of groundwater in the elevated valley sides and mountain catchments (i.e. "effluent" conditions existing).

Both these water sources had very strong NaCl components (Section 7.1, 8.3 and 8.8) As the river flowed past sampling station 28, a steadily increasing amount of irrigation return flow from the well developed and ever widening, relatively flat area of alluvial soils was less saline, with lower Na and Cl ratios, causing the movement of the plots away from this corner of the chemical diagram:

S.St.		TDS	
A	1	80.1	mg/l
B	5	122.7	
C	10	291.1	
D	12	1407.6	
E	14	1431.9	
F	18	2084.1	
G	20	7196.4	
H	22	15785.9	
I	24	5322.8	
J	26	23016.9	
K	28	4036.1	
L	30	2672.5	
M	35	2182.5	
N	40	2016.5	

PIPER TRILINEAR DIAGRAM



PERCENT OF TOTAL MILLIEQUIVALENTS PER LITRE

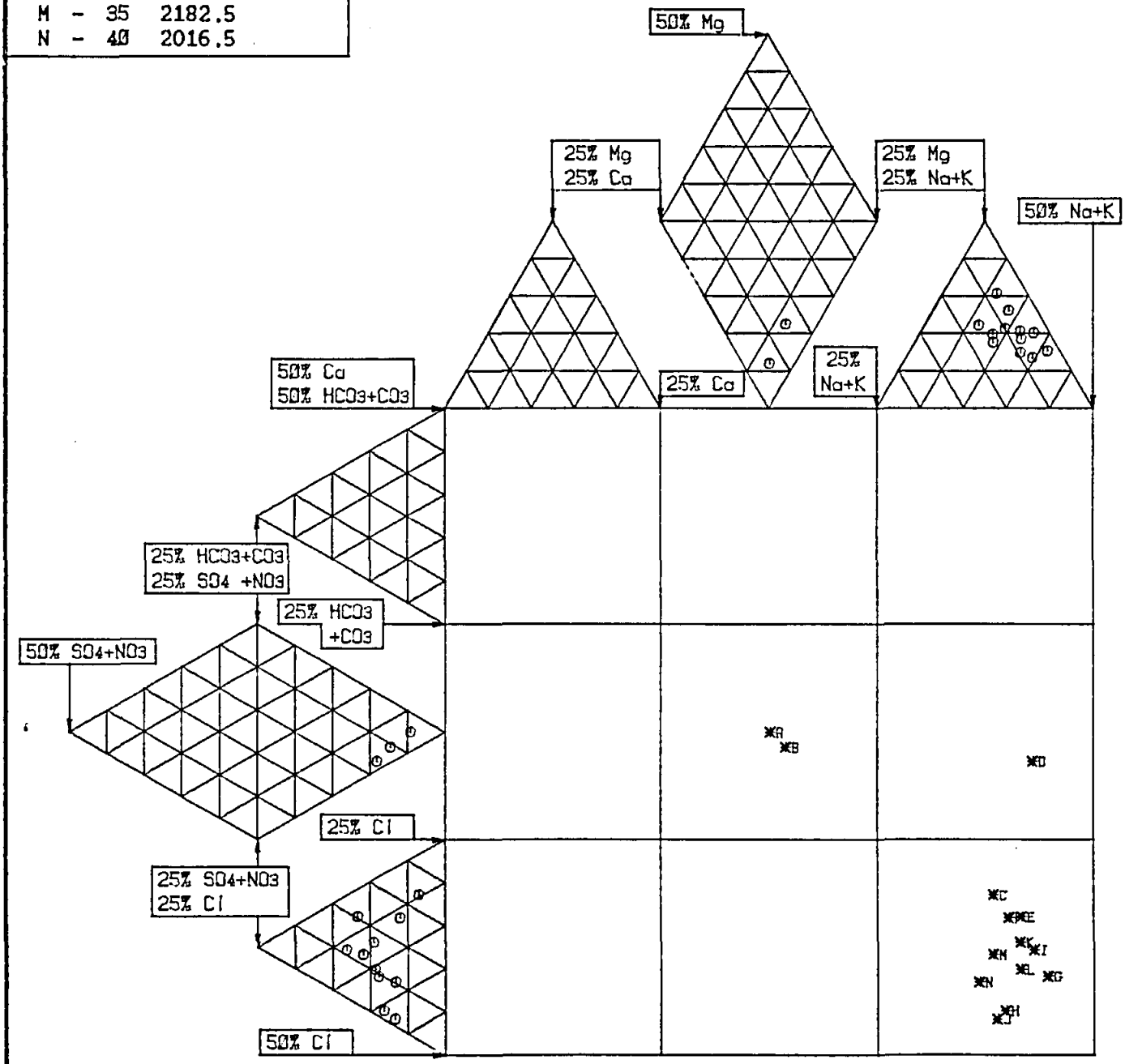
HYDROCHEMICAL PLOTS

JOB No.		FIG No.
PR0383	POESJESNELS RIVER WATER (FULL LENGTH)	8.1A

S.St. TDS

A	-	1	80.1 mg/l
B	-	5	122.7
C	-	10	291.1
D	-	12	1407.6
E	-	14	1431.9
F	-	18	2084.1
G	-	20	7196.4
H	-	22	15785.9
I	-	24	5322.8
J	-	26	23016.9
K	-	28	4036.1
L	-	30	2672.5
M	-	35	2182.5
N	-	40	2016.5

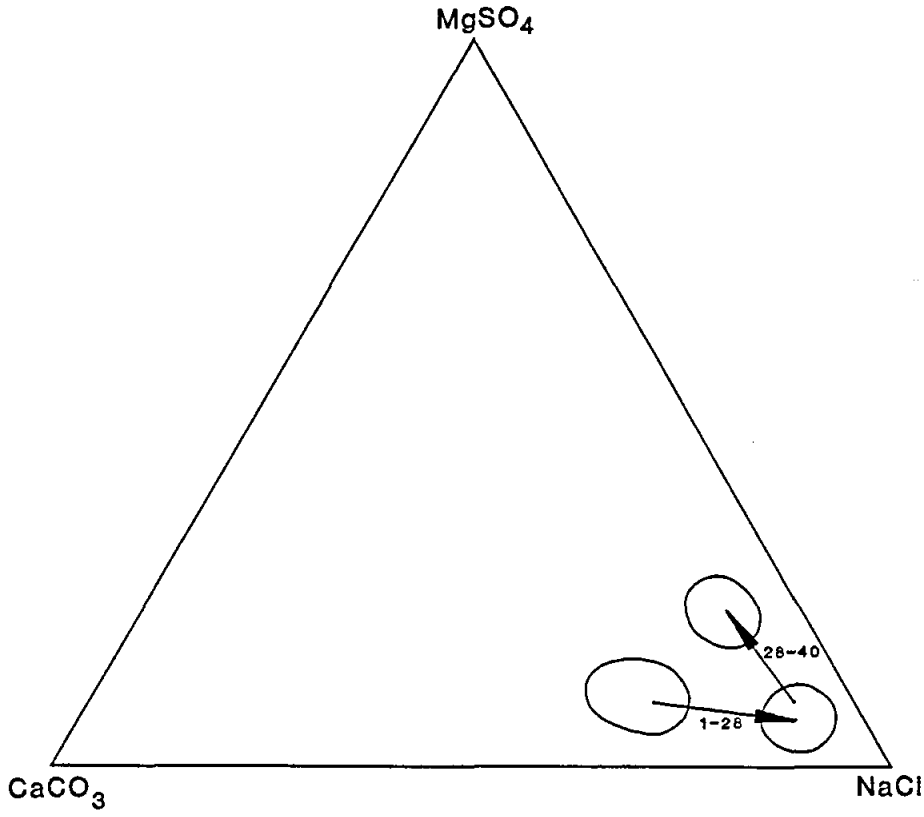
MODIFIED DUROV DIAGRAM



PERCENT OF TOTAL MILLIEQUIVALENTS PER LITRE

HYDROCHEMICAL PLOTS

	JOB No.		FIG No.
	PR0383	POESJESNELS RIVER WATER (FULL LENGTH)	8.1 B



The outflow of rain and irrigation leachates from newly developed orchards on Bokkeveld soils in the Mosiesleegte subcatchments during 1987 and 1988 caused more saline water with a high NaCl content to enter the Poesjesnels River below S.St.33; the effect of this was not measured during the summer months, but a sample from S.St.36 at the H4M18 weir taken during August 1988 clearly reflected an increase in TDS and the NaCl ratio (TABLE 7.5 and App. FIG. 8.9)

The many sources of water which together constitute the flow in the Poesjesnels River produce a complicated mixture which cannot easily be differentiated or fingerprinted. Study of the chemical diagrams only confirm that contributions are made by specific components such as irrigation return flow and groundwater.

Before looking at the plots for water samples from borehole piezometers in the next section, some attention must be focused on the artesian water which was encountered in boreholes B2 and B4. The chemical plots for analyses of this water also appear on the diagrams for the river water samples. In most cases, the anions in these samples plot closer to the chloride corner of the diagram than the river samples (e.g. App. FIG. 8.2F for December 1983). On the cation triangles the artesian water is indistinguishable from the river water, even though it has a higher TDS, and plots together with the river water in the sodium corner of the

diagrams.

The steady increase of salinity in the river as it moves downstream, and the similarity in ionic ratio to that of the artesian water in the bedrock suggests that an equilibrium exists between the water in the Poesjesnels River and the groundwater in the bedrock into which it has cut its channel on its way down to the Breë River. Changes in the ionic ratio in the river water are therefore caused by additions of water from other sources such as return flow from newly irrigated soils.

8.3 Plots of borehole piezometer samples

Borehole piezometers were sampled at three month intervals, i.e. during June and September 1984 and January, May, August and December 1985.

The samples from boreholes A2, B1 and C2 were plotted one diagram and boreholes D1 and E1 on another; these diagrams are presented in volume II as App. Fig. 8.3 A to L.

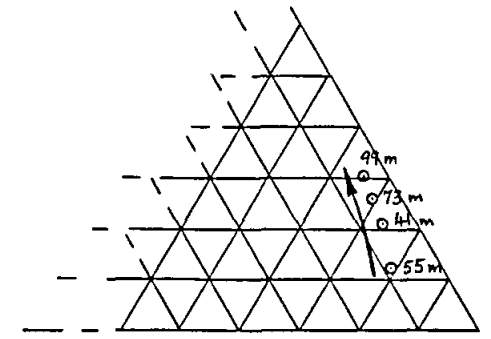
8.3.1 Chemical differentiation

In section 5.2.5 the salinity of water drawn from the piezometers in five percussion boreholes was discussed; the vertical distribution of salinity and comparative TDS values for the boreholes were identified.

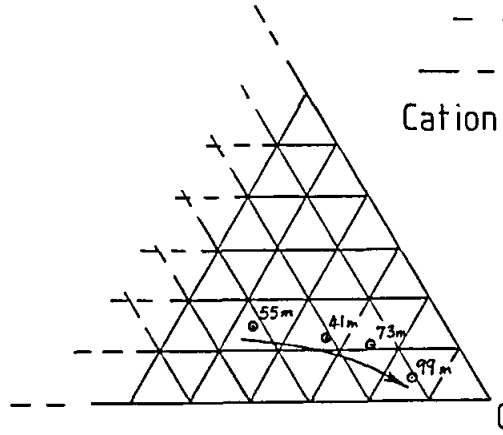
In this section attention is focused on variations in the ionic ratios or chemical character of water drawn from piezometers at different levels in the five boreholes.

The chemical plots in App. FIGS. 8.3A to L, representing analyses over a period of 18 months, were combined into one diagram in FIG 8.3. All the plots for each borehole fall within domains outlined on the cation and anion triangles and the upper intersection diamond, where the domains are more clearly differentiated.

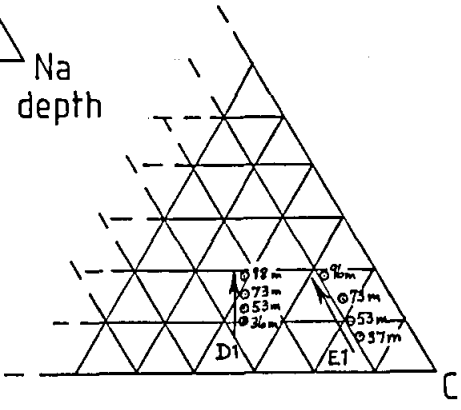
Although all the water samples plot in the Na and Cl corners of the triangles and there is some overlapping of domain boundaries, clear differences are evident in the average ionic ratios or the domain centres for the five boreholes fitted with piezometers.



Cation trend in B1 with depth in May 1985



Anion trend in B1 with depth in May 1985.



Anion trends with depth: D1 in June 1984, E1 in May 1985.

The Chemical Plots for each Borehole fall within the areas outlined on the diagrams.

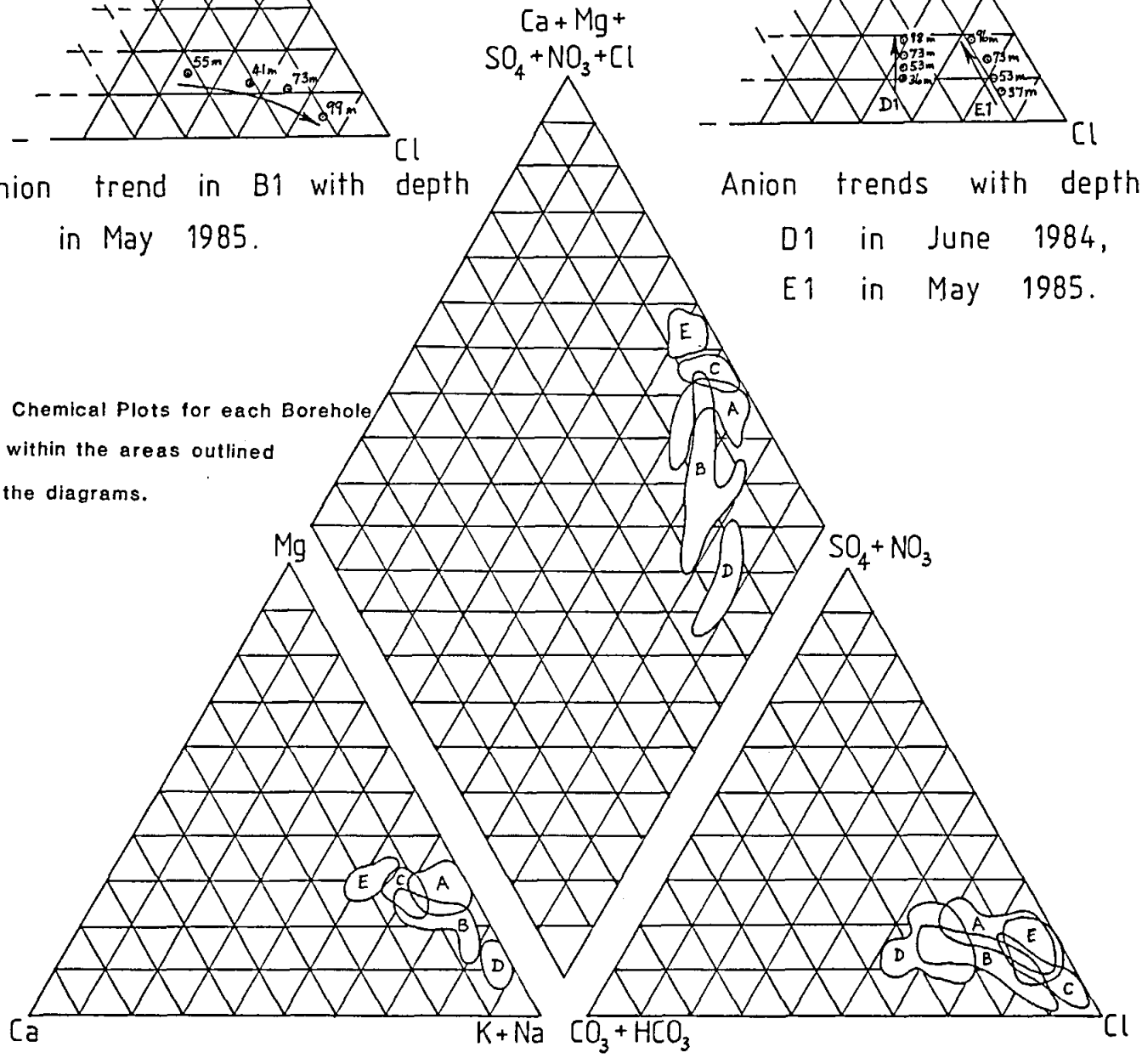


FIG. 8.3 CHEMICAL CHARACTERIZATION OF WATER DRAWN FROM BOREHOLES A2, B1, C2, D1 and E1 BY PIEZOMETERS DURING THE PERIOD JUNE 1984 TO DECEMBER 1985.

Ionic ratios of domain centres on the cation triangle:

	Na %	Mg %	Ca %
Borehole A2:	67	28	5
Borehole B1:	70	22	8
Borehole C2:	60	28	12
Borehole D1:	85	11	4
Borehole E1:	51	30	19

Ionic ratios of domain centres on the anion triangle:

	Cl %	SO_4 %	HCO_3 %
Borehole A2:	71	19	10
Borehole B1:	71	12	17
Borehole C2:	85	8	7
Borehole D1:	60	15	25
Borehole E1:	80	14	6

From FIG. 8.3 and the table above it can be seen that boreholes D1 and E1 lie at opposite ends of the domain group, particularly on the cation triangle and the intersection diamonds, and show the largest chemical variance, particularly with regard to Na^+ and HCO_3^-; water from D1 contains much more Na^+ while E1 has a higher Mg^{++} content. A2, B1 and C2 fall between these extremes. On the anion triangle more overlapping occurs, but it is still clear that D1 clearly contains more HCO_3^- than the other boreholes which tend to have very high Cl^- ratios.

Within the domains themselves, some clear trends of chemical change with increasing depth may be discerned: in borehole B1 there is an increase in Cl^- with depth, seen particularly well in the May 1985 samples. (App. FIG. 8.3 G) In the D1 samples (June 1984) and E1 samples (May 1985) there is an increase of $SO_4^=$ and a decrease of Cl^- with depth (upper diagrams in FIG 8.3). Plots on the cation trilinear diagrams are more closely spaced, but an increase of Mg^{++} and a decrease in Na^+ is evident in samples from B1.

8.4 Plots of leachate chemistry derived from a sample of shale from the riverbed at S.St 18

The ionic relationships produced by the leaching of this sample (discussed in section 6.1) are plotted on the single diagram, App. Fig. 8.4.

Combination of all the leachates derived from the surface of the sample produced a TDS of 86 mg/l, while that from the crushed sample produced 1088 mg/l. Although both plotted in the Na^+ corner of the cation trilinear, the crushed material gave an extreme Na^+ ratio of 98% relative to Mg^{++} and Ca^{++}.

On the anion diagram the surface and the crushed sample leachates showed very low HCO_3^- content. This is probably caused by acidity related to the pyrite content of the black shale sample in the process of oxidation to sulphate, driving off any $CO_3^=$ as CO_2.

Both leachate plots A and B indicated ratios that have higher $SO_4^=$ content than the water in the river, groundwater, or irrigation return flows. (43% $SO_4^=$ in the surface leach and 38% in the crushed sample leach.) Similar ionic ratios were encountered in leachates derived from bedrock cuttings provided by the percussion drilling program (Section 8.6).

8.5 Plots of leachate chemistry derived from auger samples

These leachates show the ionic composition of the deep soil layers and decomposed upper part of the underlying bedrock. All the auger sample leachate plots are labelled as FIG. No. 8.5 in the Appendix, followed by the appropriate auger hole number, e.g. H1, etc.

The following chemical trends are seen in these hydrochemical plots:

8.5.1. Auger line H (upper part of valley, App. Fig. 6.2)

Hole H1 : (± 400 metres from the river)
On the Piper diagram, a clear trend of increasing Na^+ and Cl^- with depth is evident on the lower cation and anion triangles, as well as on the Durov rectangle.

It is also evident that very little Ca^{++} and HCO_3^- are present. The T.D.S. is high, rising to 3381 mg/l at a depth of 2.0 meters but dropping from there down to 1490 mg/l at 3.8 metres.

Hole H2 :
Although the HCO_3^- content is still very low, there seems to be an increase in the Ca^{++}. The trend with depth have seems to be an increase in Mg^{++} and $SO_4^=$; the T.D.S. is much lower than in H1.

Hole H3 : (on riverbank)
Still very low in HCO_3^-; no clear trend is evident, and Na^+ reaches a maximum of only 70% on the cation diagram.

Hole H4 : (on riverbank)
Same as above, but with depth there is a clear trend of $SO_4^=$ increase, coinciding with a decline in the TDS.

Hole H5 :
Same chemical ratios as in H4.

8.5.2 Auger Line P. (Lowest part of valley, App. Fig. 6.3)

Hole P1:
Low TDS, but a clear increase in the $SO_4^=$ content at the expense of Cl^-, and in the Na^+ at the expense of Mg^{++}. The Ca^{++} levels are much greater than at line H.

Hole P2:
An even balance between the cations with Ca^{++} greater than 50% at a depth of 1.4m. The anions show an increase of Cl^- with depth from 0.2 to 2.0 metres in the sandy alluvium, but as the cobble gravel and clay was encountered below 2.5m, a large change to $SO_4^=$ was registered.

Hole P3:
The high Ca^{++} values at the shallow levels (A and B) suggest that Gypsum has been applied to the soil.

Deeper down the trend is towards an increase in Na^+ and Cl^-.

Hole P4:
An even balance between cations, with an increase in Cl^- with depth in the anion triangle. A high $SO_4^=$ reading at 0.2m (A) seen also on the Durov diagram, may be surface contamination with gypsum.

Hole P5:

A very typical profile through irrigated vineyards and into decomposed shale.
A very strong trend from high $SO_4^=$ to high Cl^-percentages is evident on the anion trianigle (HCO_3^- is less than 10% throughout). The cations remain closely grouped, with an increase in Na^+ between 1.4 and 3.4 m (C - F).

Hole P6:

No clear trend seen. Cations are well balanced with Na^+ reducing with depth. HCO_3^- remains lower than 20% on the anion triangle.

8.5.3 Auger line B. (central part of valley, App. Figs. 6.4 and 6.5)

Hole B6:
Very high Na^+ and Cl^- percentages evident. There is a suggestion of increase of $SO_4^=$ with depth. Extremely high TDS (A) is due to surface salt contamination from borehole B1.

Holes B7, B8 and B9:
High Na^+ percentages seem to reach a maximum at depths between 0,8 to 1.4m, while anions remain very high in Cl^- and very low in HCO_3^-

Hole B10:
Ionic balance very constant, with high Na^+ and Cl^-.

Hole B11:
Same as B10, with a reduction in Na^+ below 2.0 metres in favour of Mg^{++}.

Holes B12 and B13:
Variation in the already high Na^+ and Cl^- values does not follow a clear trend.

8.5.4 Auger line C. (central valley, App. Fig. 6.6)

Hole C3: (Shallow soil overlying decomposed shale).
Very high Na^+ and Cl^- percentages, with an increasing trend in Na^+ and $SO_4^=$ with depth.

Hole C4:
No clear trend. Na^+ and Cl^- remain predominant.

Hole C5:
Increase of Na^+ with depth; Cl^- dominates the anion group.

Hole C6: (On edge of alluvial terrace)
Better balance between cations, with 45% Ca^{++} at 0.8 m. Cl^- still dominates the anion group.

8.5.5 Auger line D (central valley, App. Fig. 6.7)

Hole D5:
High Ca^{++} at the surface, changes to high Na^+ percentage with depth; the anion triangle shows an initial increase of $SO_4^=$ at the cost of Cl^- in the first 1.4m (A to C), which then reverses, with Cl^- increasing again below this level. All materials are alluvial.

Hole D6:
A very clear trend of Na^+ increase against Ca^{++} and Mg^{++} with depth. The anions do not vary much, with Cl^- predominating.

Hole D7:
Similar to D6, but a reduction of HCO_3^- with depth is evident.

Hole D8:
Trends of increase with depth for both Na^+ and Cl^-.

8.5.6 Auger line F (upper valley, App. Fig. 6.8)

Hole F5:
An indication of increase of Na^+ and Cl^- against Mg^{++} and $SO_4^=$, but no clear depth trend seen. Low T.D.S. registered.

Hole F6:
High Na^+, high Cl^-, very low HCO_3^- in the alluvial sand, clay and gravel alongside the river.

Hole F7: (Deep alluvial sand overlying decomposed siltstone)
Cation balance dominated by Na^+, with a small increase with depth. The anion triangle however shows a clear trend of increasing $SO_4^=$ against Cl^- while HCO_3^- is extremely low.

Hole F8: (Hillwash soil overlying decomposed siltstone ±200 m from the river)
A much more balanced cation chemistry is evident, starting at more than 50% Ca^{++}. As the auger went down, the Ca^{++} reduced, while Na^+ increased from 23% to 60%, and Mg^{++} increased from 26% to more than 30%. The anion triangle showed a slight increase in the already high Cl^- from surface to 2.6 metres, but then an increase in $SO_4^=$ against Cl is present from 2.6 to 3.6 metres, in the bedrock.

Hole F9:
Higher Mg^{++} percentage (45% at 0.8m) is seen among cations, and the trend with depth is $SO_4^=$ increasing against Cl^-.

Hole G1:
No trend evident; 40 - 50% $SO_4^=$ in leachates.

A summary of all these trends is listed in Table 8(a).

8.6 Plots of leachate chemistry derived from percussion borehole cuttings

As described in section 6.5, these samples had undergone some oxidation before being leached and the leachates analyzed (Table 6.5A).

The plots of these analyses are numbered as follows:

APP. Fig. N°	Borehole	Samples
8.6/1	A1e	1 - 32m
8.6/2	B1f	1 - 11m
8.6/3	B1f	12 - 22m
8.6/4	B1f	23 - 31m
8.6/5	C2	1 - 12m
8.6/6	C2	13 - 24m
8.6/7	C2	25 - 75m
8.6/8	D4	1 - 9m
8.6/9	D4	10 - 35m
8.6/10	E1c	1 - 12m
8.6/11	E1c	13 - 34m
8.6/12	F3b	1 - 10m
8.6/13	F3b	11 - 27m
8.6/14	F3b	30 - 100m

All these analyses showed extremely low HCO_3^- values, which only rose to any appreciable value (± 10%) in borehole E1c, and in the upper samples from borehole B1f (±8%).

8.6.1 Borehole A1e (App. Fig. 8.6/1)

The upper and lowermost samples (A at 1 metere and L at 32 metres) show ±20% Ca^{++} and Mg^{++}, but the rest are very closely concentrated in the Na^{+} corner.

The anion triangle shows the strong Cl^{-} concentration of 70 to 85% against $SO_4^{=}$.

8.6.2 Borehole B1f (App. Fig. 8.6/2, 3 and 4)

Down to 10 metres, a very strong Na^{+} percentage dominates the cation triangle, but sample K (11 metres) shows movement away from the Na^{+} corner. From 12 metres downwards, a massive swing away from Na^{+} takes place towards Mg^{++}, with Ca^{++} generally below 20% and never exceeding 30%. The samples from depths of 25 to 50 metres are particularly strong in Mg^{++}, very depleted in Na^{+} and have up to 20% Ca^{++}. The Fe^{++} content (not analysed) from pyrite oxidation must be appreciable.

On the anion side, a Cl^{-}: $SO_4^{=}$ ratio of around 60:40 in the first 12 metres changes with depth into a very strong $SO_4^{=}$ concentration of 60 to 70% between 14 and 27 metres (A to E on Fig. 8.6/4), with a high of 95% at 13 metres; below 28 metres the $SO_4^{=}$ again reduces as the Cl^{-} rises to 83%.

These very strong changes in leachate chemistry below 12 metres coincide with the change from decomposed to fresh siltstone bedrock which consists mainly of sericitic siltstone containing much graphite and pyrite. (App. FIG. 5.4)

8.6.3 Borehole C2 (App. Figs. 8.6/5,6 and 7)

Cations: A very strong concentration of Na^{+} exists in the upper part of the borehole (1 -18m), and below that, there is some movement towards the Mg^{++} corner. This is never as strong as in the previous borehole, reaching a maximum of only 40% Mg^{++}, with 19% Ca^{++} and 41% Na^{+} (point J, at 22 metres). A close grouping around 10% Ca^{++}, 25% Mg^{++} and 65% Na^{+} exists from 30 metres down to 65metres, and at 75 metres.

The sharp change in particularly the Na^+ and Mg^{++} content again coincides with the change from decomposed to fresh bedrock at ± 19 m depth. (App. FIG. 5.9)

Anions: There is not much variation here from a Cl^- percentage between 70 and 90 in relation to $SO_4^=$ (HCO_3^- is very low). At 22 and 23 metres (J and K) the $SO_4^=$ rises to 70% and 40% respectively against Cl^-, but drops back again below this depth. The borehole log indicates much pyrite.

8.6.4 Borehole D4 (App. Figs. 8.6/8 and 9)

A cation trend towards Na^+ from 2 metres down to about 15 metres in the decomposed material, then changes towards Mg^{++} below this depth. In the anion triangle, the Cl^- again predominates over $SO_4^=$ (although the ratio was about 50-50 at 1 metre due to the application of gypsum to the soil).

8.6.5 Borehole E1c (App. Figs. 8.6/10 and 11)

A strong Na^+ percentage dominates down to a depth of 7 metres; then from 8 metres and moving downwards, a trend towards Mg^{++} starts up (H - L). This swings back towards Na^+ again from 15 metres down to 18 metres, and then very sharply moves across the diagram to values of Mg^{++} between 50 and 60% (Na^+ between 6 and 24% and Ca^{++} at ± 30%) below a depth of 20 metres.

The anion triangle shows few values of HCO_3^- in excess of 10%, and again has a predominance of Cl^-, especially in the upper 7 metres. Below this, more $SO_4^=$ is seen down to 15 metres, after which it swings back to Cl^- between 16 and 18 metres, and then swings very strongly towards $SO_4^=$ below 20 metres. (The parallel between Mg^{++} and $SO_4^=$ increases is clearly evident here and again coincides with the change from decomposed to fresh bedrock at ± 19 metres.)

8.6.6 Borehole F3b (App. Figs. 8.6/12, 13 and 14)

The cation ratios are tightly bunched in the Na^+-rich corner at an average of 90% for most samples from this borehole. There is some movement away from these high values only from 17 to 35 metres, and again at 80 metres. The anions in similar fashion remain in a tight range between 73-92% from 1 metre down to 18

metres; below this the $SO_4^=$ levels begin to increase against Cl^-, reaching a high of 88% at a depth of 80 metres. (Samples from 40 metres (C) and 70 metres (F) however show high Cl^- values in the midst of the high $SO_4^=$ values, indicating absence of pyrite in those zones).

A summary of all these trends is listed in TABEL 8(b). (page 167)

8.7 Plots of leachate chemistry derived from crushed diamond core samples

Chemical analyses of these leachates are to be found in Table 6.4B (page 108). Hydrochemical plots of the analytical data are numbered App. Fig. 8.7/1 for the first leach, and App. Fig 8.7/2 for the second leach.

Shallow group:
- A (A1 at 9 m)
- D (B1 at 6 m)
- J (C2 at 9 m)
- L (D1 at 6 m)

Deep group:
- B (A1 at 18 m)
- C (A1 at 51 m)
- E (B1 at 10 m)
- F (B1 at 14 m)
- G (B1 at 22 m)
- H (B1 at 42 m)
- I (B1 at 49 m)
- K (C2 at 42 m)
- M (D1 at 45 m)

8.7.1 The first leach of crushed core

Two distinct groups of cations are evident. The first group with very high Na^+ values in excess of 85%, include samples A, B, J and L which are all from the decomposed, yellow or greenish brown bedrock. The same samples also plot at over 83% in the Cl^- - rich corner of the anion triangle, giving clear evidence that the upper, oxidized and even slightly decomposed bedrock tends to be a collecter for Sodium Chloride. (Sample D from the upper part of borehole B1 although rich in Cl^-, has a lower Na^+ content than the other decomposed samples). The second group of cations, ie. C, D, E, F, G, H, I, K and M plot at ±60% Na^+ and ±40% Mg^{++}, and the anions from these leachates form two groups, ie. D, E, K and M with 50 to 60% Cl^- and C, F, G, H and I with a very low Cl^- ratio of 5 to 10% and extremely high $SO_4^=$ of between 90 and 95%.

This second cation group are with the exception of sample D from borehole B1, all derived from fresh, deepseated diamond cores and show a distinct $MgSO_4$ character.

8.7.2 The second leach of crushed core

Examination of the trilinear diagrams shows that the upper decomposed Na Cl group and the lower fresh bedrock Mg SO_4 group are not as distinct from each other as on the diagram for the first leach.

Nevertheless, the Na^+ - rich corner of the cation triangle is occupied by A, J and L again. (B lies further towards Mg^{++}, and samples I and K seem to be richer in Na^+).

On the anion triangle A, B, J and L are present in the Cl^- - rich corner, confirming the result of the first leach. This time sample D (borehole B1 at 6m) is present with high Cl^- content.

Sample E and K have 60 to 70% Cl^-, similar to the anionic ratios they carried in the first leach. The rest of the anions in leachates derived from deep bedrock cores, ie. C, F, G, H and I show very high $SO_4^=$ of more than 90%.

This result is also clearly evident on the Durov rectangular plot of the analytical data from the second leach.

The tendency for the deep bedrock to contain soluble $MgSO_4$ in contrast to the NaCl salinity of the shallower decomposed materials is confirmed by both the first and second leachings of crushed diamond core samples.

8.8 Plots of irrigation water and irrigation return flow seepage to show the leachate chemistry of the soil

The hydrochemical plots for these analyses (described in section 7) are also included in the Appendix (Volume II) and are each given Figure number 8.8, followed by a letter which indicates the sequence of months during which this survey was done, for example A = October 1984; B = November 1984; C =

December 1984; etc. The last part of the Figure number is either "I" for an irrigation water sample, or "R" for a return flow seepage sample.

Data presented in section 7.1 show the substantial increase in T.D.S. as irrigation water is applied to the soil and a surplus reaches the drainage ditches as return flow. The hydrochemical plots show that large changes also take place in the ionic ratios during this process, indicating that leaching of various ions in the soils and subsoil layers produces a large degree of specific mineralization in addition to the normal salinity increase due to evapotranspiration.

Samples I1 to I5 extend in a downstream direction on the south side of the valley, and I6 to I10 downstream on the north side of the valley (App. FIG 2.4t and FIG. 2.3 B to F).

These tests were carried out for the first time in October 1984. Comparison of the Hydrochemical Plots for the irrigation water samples (I) and the return flow samples (IR) on the Piper Trilinear and the Durov Rectangular Diagrams clearly showed the changes in ionic ratios for these analyses, giving visual confirmation of the results tabulated on pages 129 -133 in Section 7.1. (The letters in parentheses indicate the plotted positions of the samples on the trilinear diagrams):

Cations:		Anions:	
Increase in Na^+:	IR 2 (B)	Increase in Cl^-:	IR 2 (B)
	IR 4 (D)		IR 5 (E)
	IR 5 (E)		IR 8 (H)
	IR 7 (G)		IR 9 (I)
	IR 9 (I)		
	IR10 (J)		

Increase in Mg^{++}:	IR 1 (A)	Increase in $SO_4^{=}$:	IR 1 (A)
	IR 6 (F)		IR 3 (C)
	IR 8 (H)		IR 4 (D)
			IR 6 (F)
			IR 7 (G)
			IR10 (J)
Increase in Ca^{++}:	IR 3 (C)	Increase in HCO_3^{-}:	IR 2 (B)
	IR 6 (F)		IR 3 (C)

<u>November 1984</u>

<u>Cations</u>:		<u>Anions</u>:	
Increase in Na^{+}:	IR 2 (B)	Increase in Cl^{-}:	IR 2 (A)
	IR 4 (D)		IR 4 (C)
	IR 5 (E)		IR 5 (F)
	IR 8 (H)		IR 7 (G)
	IR 9 (I)		IR 8 (H)
	IR10 (J)		IR 9 (I)
			IR10 (J)
Increase in Mg^{++}:	IR1 (A)	Increase in $SO_4^{=}$:	IR 6 (F)
	IR3 (C)		
	IR6 (F)	Increase in HCO_3^{-}:	IR 1 (A)
	IR7 (G)		IR 3 (C)

December 1984

Cations:		**Anions:**	
Increase in Na^+:	IR 2 (A)	Increase in Cl^-:	IR 1 (A)
	IR 3 (C)		IR 3 (C)
	IR 4 (D)		IR 4 (D)
	IR 5 (E)		IR 5 (E)
	IR 9 (I)		IR 9 (I)
	IR10 (J)		IR10 (J)
Increase in Mg^{++}:	IR 1 (A)	Increase in $SO_4^=$:	IR 1 (A)
	IR 5 (E)		IR 2 (B)
	IR6 (F)		IR 6 (F)
	IR 7 (G)		IR 7 (G)
	IR 8 (H)		IR 8 (H)

January 1985

Cations:		**Anions:**	
Increase in Na^+:	IR 2 (B)	Increase in Cl^-:	IR 3 (C)
	IR 3 (C)		IR 4 (D)
	IR 4 (D)		IR 5 (E)
	IR 5 (E)		IR 9 (I)
	IR 9 (I)		
	IR10 (J)		
Increase in Mg^{++}:	IR 1 (A)	Increase in $SO_4^=$:	IR 1 (A)
	IR 3 (C)		IR 2 (B)
	IR 4 (D)		IR 7 (G)
	IR 5 (E)		IR 8 (H)
	IR 6 (F)		IR10 (J)

Increase in Ca^{++}:	IR 6 (F)	Increase in HCO_3^-:	IR 2 (B)
	IR 8 (H)		IR 6 (F)
			IR 8 (H)
			IR 10 (J)
No change:	IR 7 (G)		

In this way, ionic changes can be traced on all the diagrams confirming the results in Section 7 which have been tabulated, and are shown for all the months in TABLE 7.2 (page 136), with a consolidated summary in TABLE 7.4 (page 143).

Naturally all the principal components are released during irrigation leaching, but it appears from these results that there is a tendency for Mg SO_4 to predominate in the upper valley areas, Ca $(HCO_3)_2$ in the centre and Na Cl in the lower part of the valley.

9. The Groundwater Table

Upon completion of the drilling program the standing water levels were measured in each borehole. These were again measured during the pump testing program, and also during the routine sampling runs. These are included on the borehole logs, App. Fig. 5.2 - 5.12). Attempts were also made to monitor the water levels in selected boreholes by means by automatic recording devices, but these instruments performed very poorly and this approach had to be abandoned.

During 1986 a program of weekly and monthly water level measurements were carried out by the field assistant. Both percussion and auger holes were measured; the latter gave very poor results due to influx of loose sand and shallowness of the holes. (Only F7 could be used).

The borehole transects are widely spaced within the catchment, and although this precludes the construction of an accurate groundwater table contour map for the valley, an attempt was nevertheless made to draw a sketch map with the levels present on 23rd September 1986, based on the sparse GWT information available and the topographical contour map of the valley. This map is shown in App. Fig. 9.

Although the contours are based on widely separated borehole positions, an indication of the probable directions of groundwater movement below the GWT in various parts of the valley may be deduced by drawing flow lines at right angles to the contours which are used as equipotential lines. The changes in groundwater table gradients and the variations in transmissivity in different parts of the valley naturally preclude an accurate determination of the groundwater flow. These changes are brought about by the considerable variation in bedrock geology (especially where formations are steeply dipping) and the structure within the valley, which have produced variations in permeability and porosity in the saturated zone.

Groundwater table gradients have been determined where accurate measurements of distance between boreholes and depth to water table were made on the borehole transects set out at right angles to the river. These are used to calculate the outflow of groundwater into the river:

Transect A: Distance A1 - A2 = 300 m
Difference in GWT elevations = 2.02 m
GWT gradient = $\frac{2.02}{300}$ = 0.0067

Transect B: Distance B1 - B2 = 220 m
Difference in GWT elevations = 0.86 m
GWT gradient = $\frac{0.86}{220}$ = 0.0039

Transect C: Distance C1 - C2 = 320 m
Difference in GWT elevations = 9.85 m
GWT gradient = $\frac{9.85}{320}$ = 0.0308

Transect D: Distance D1 - D2 = 320 m
Difference in GWT elevations = 0.85 m
GWT gradient = $\frac{0.85}{320}$ = 0.0027

Transect E: Widely spaced boreholes not available.

Transect H (Auger holes):
Distance H2 - H3 = 190 m
Difference in GWT elevations = 1.43 m
GWT gradient = $\frac{1.43}{190}$ = 0.0075

Transect P (Auger holes):
Distance P4 - P5 = 255 m
Difference in GWT elevations = 4.65 m
GWT gradient = $\frac{4.65}{255}$ = 0.018

The average gradient for the six transects works out at 0.0116.

9.1 Calculation of groundwater flow into the river

The volume of groundwater entering the river may be calculated by multiplying the average effective transmissivity by the length of the river which has cut its channel into the upper part of the aquifer on both banks, and this in turn by the average G.W.T. gradient.

Extrapolation of the groundwater table from the riverbanks into the river channel, shows that the riverbed generally lies at elevations between 1 and 2 metres lower than the extended GWT producing an effluent relationship, and the transmissivity of 62 m^2/day for the whole of the fractured aquifer is therefore reduced to an effective transmissivity of 1.5 m^2/day as only the upper strip of the aquifer acts as a groundwater conduit for horizontally moving effluent water carrying heavy loads of salt leached from the soil and decomposed bedrock materials.

Thus, the average annual inflow of groundwater into the river over a channel length of 16 km between Mountain View and the H4M18 measuring station is given by:

E_a = Transmissivity (m^2/day) x length (m) x GWT gradient x 365 days
= 1.5 x 32 000 x 0.0116 x 365 m^3
$\therefore E_a$ = 203 232 m^3 of groundwater per annum.

This figure correlates well with the 203 000 m^3 needed to complete the salt balance model in Section 4.3 (page 53).

The average TDS of the groundwater in this part of the model was assessed at 3 000 mg/l, but it was shown in Section 7 that some riverbank areas such as the Mosiesleegte produce seepage running at an average of over 5 000 mg/l. This suggests that groundwater of lower TDS must also be entering the Poesjesnels River to balance up the salt load. Such low TDS water would be encountered in faults and fracture zones in the underlying Table Mountain sandstone formations, and we thus have an indication of upward movement of this water along these faults under the head of elevated groundwater in the encircling mountains.

9.2 Seasonal GWT movement in borehole transects

App. Table 9.1 shows the seasonal fluctuations in the boreholes on all the transects during 1986, and Figs. 9.1 A and B show graphic plots of these changes together with a histogram reflecting rainfall events. The levels in the groups of monitor boreholes around each deep borehole could not be separated on the graph and one line is therefore used to indicate changes in the group as a whole, e.g. E1a, E1b, E1c, E1d and E1e. One piezometer in each of the deep boreholes was also measured (p), and these levels sometimes varied from those in the monitor holes.

The largest water level difference was seen at borehole transect B1, where the level in the monitor holes was 1.01 metre higher than in the 41m piezometer standpipe. (The 99m piezometer was artesian).

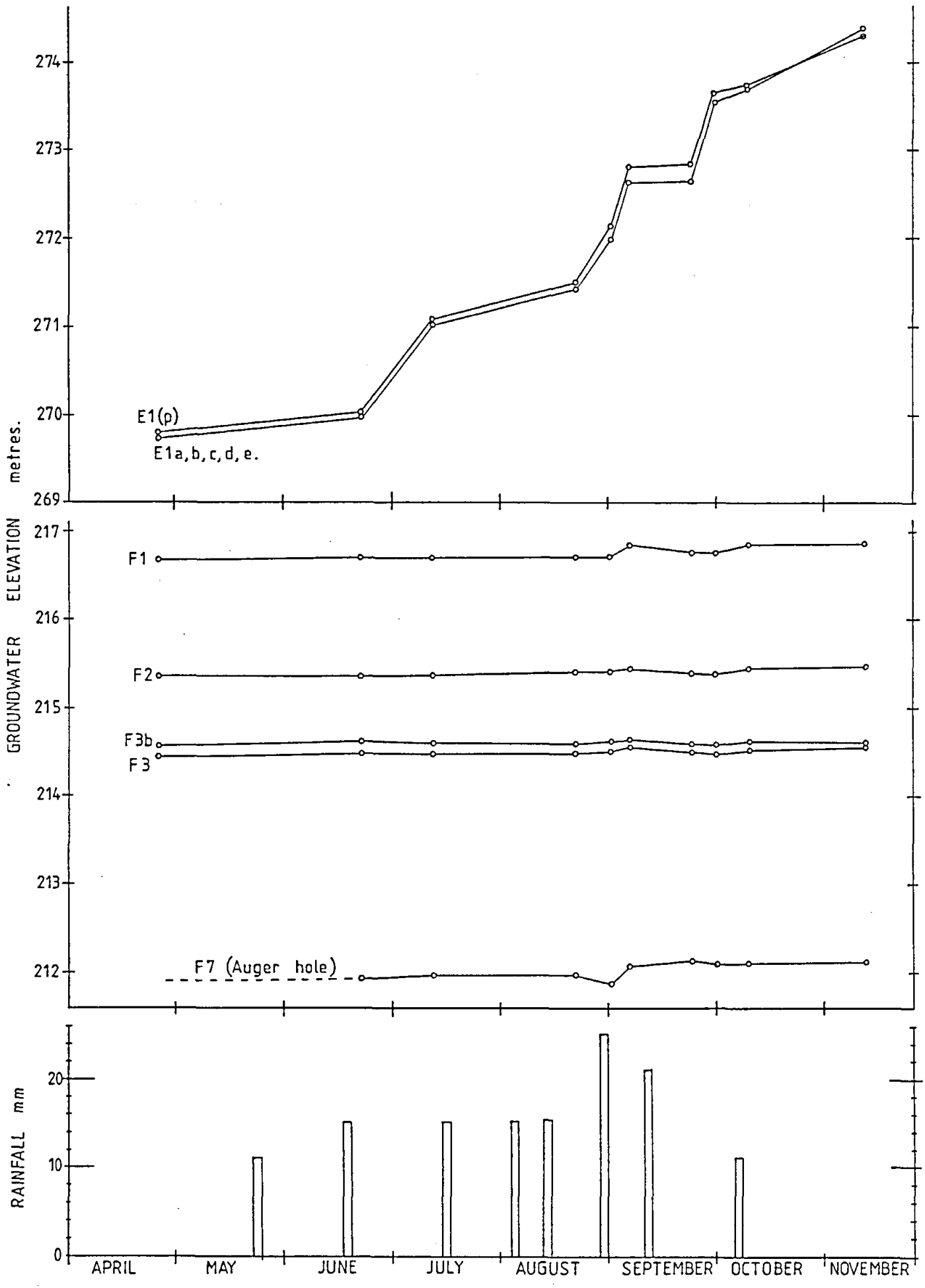


FIG. 9.1A SEASONAL WATER LEVEL CHANGES IN BOREHOLE TRANSECTS – 1986.

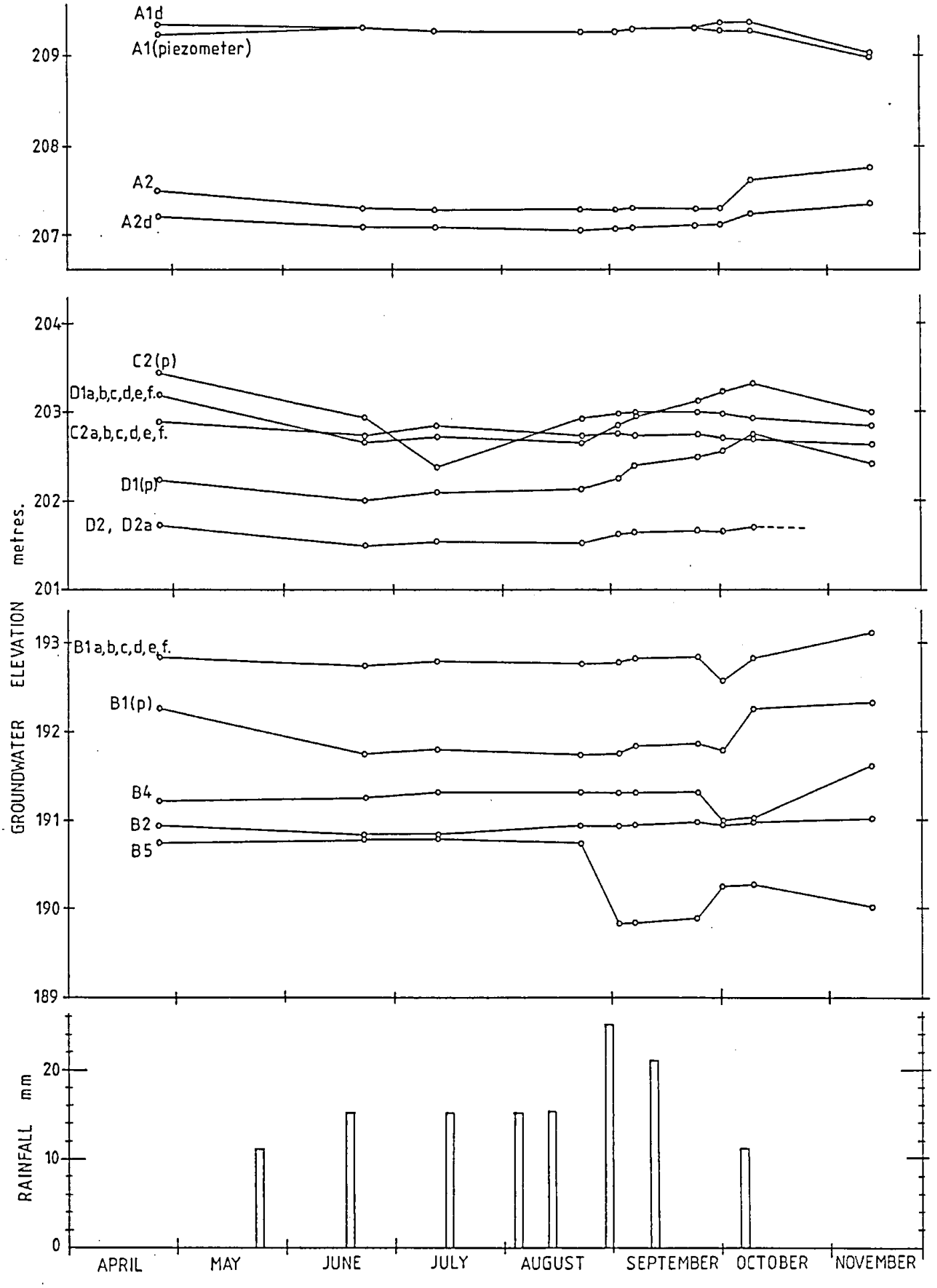


FIG. 9.1B SEASONAL WATER LEVEL CHANGES IN BOREHOLE TRANSECTS – 1986.

The difference between the piezometer levels and the monitor holes at transect A1 was less than 2 cm.

At transects A1, B1, D1 and F3, the water levels in the deep boreholes were lower than the shallow monitor holes, while at A2, C2 and E1 they were higher.

The graphs show a variety of water level changes. In Fig. 9.1A at transect E1 the low levels in April at the end of summer, rose by more than 4 metres during the winter months, reaching an elevation of 274.4m in November. In sharp contrast, the water levels in F1, F2, and F3 remained almost static over the same period even though good rains fell in August. The proximity of the mountains appears to have had a profound effect on the groundwater table in the E1 borehole group. By contrast the very low permeability of the F borehole group is shown in the static GW levels.

In Fig. 9.1B, at lower elevations in the valley, water levels were found to drop over the period April to September, and the winter rains had a delayed affect, causing the water table to rise until November. The sharp decline in GW level in borehole B5 during August and September was probably caused by pumpage from a nearby borehole by the farmer. (This producing borehole, situated about 100 metres south of B5, is periodically used for irrigation of vegetable fields.) Boreholes B1 and B4 on the other side of the river are situated at distances of 450 and 350 metres respectively from this borehole. The extraction of groundwater seems to have had an effect on these holes as well, although the water level graphs show a smaller decline after a four week delay. The results clearly indicate that groundwater flow is taking place within this transect, probably along the fractures in the Boplaas Sandstone Formation (C_2Q_3) below the Waboomberg Shale (C_2S_4) -App. FIG. 2.6.

Holes A1 and A2 present an enigma: although separated by a distance of only 300 metres, the water level during October and November rises in A2 while it falls in A1 higher up the slope. The infiltration of rainfall runoff into siltstone beds could explain the rise in A2, because this borehole encountered many open quartz veins and fractures and is situated near the Mosiesleegte River. The lower permeability of the bedrock at A1 is probably the reason why the response to winter rainfall has not yet affected the GWT at this point.

Boreholes C2 and D1 also show a decline in the water levels during the dry period from November to May, following a rise in response to the July August and September rainfall events.

(N.B. A swarm of bees in the D2 borehole denied the field assistant any access to the water levels in this hole or in D2a alongside - a painful experience!)

9.3 Seasonal water level changes in boreholes on Vredenhof (App. FIG. 2.3C)

The water levels in a number of boreholes on the farm Vredenhof were monitored monthly over a period of 2½ years, from April 1986 to September 1988 by the owner, Mr Deon Jordaan, who had become very interested in the project.

App. Fig. 9.2 shows the results; rainfall events at Vredenhof are included on the graph.

It must be remembered that Vredenhof lies at the foot of a massive sandstone mountain (Riviersonderend Range) which has a higher rainfall than the valley. The farm actually straddles the contact between the sandstone of the Table Mountain Group and the shale of the Bokkeveld Group. Recharge of the groundwater regime takes place a lot more quickly in sandstone formations than in shales; a rising groundwater table in such sandstone would therefore affect the shale formations in close contact with it, forcing water through all available fractures and causing a GWT rise in the shale as well.

This seems to have been the case at Vredenhof, where boreholes DH, ZH, VH and RH, situated in Bokkeveld shale within 400 metres of the sandstone contact, showed large water level fluctuations between summer and winter. The holes further away (RH and E1) had smaller fluctuations. The rundown is as follows:

TABLE 9.2 Ground water levels on Vredenhof

Borehole	Distance from TMS contact (metres)	Maximum & Minimum GWT elevations. (metres)		Decline in levels during Summer (m)
		Winter 1986	Summer 1987	
DJB	0.0 (artesian)	Above ground	As above	-
DH	0.0 (at contact)	268.5	248	20.5
ZH	150	267	243	24
VH	300	269.2	233.8	35.4
RH	320	264.5	228.5	36
KH	750	275	265	10
E1*	600	272.8	268	4.8

* on the farm alongside Vredenhof

The decline in water levels in some holes such as RH and VH during summer must be related to the pumpage of large volumes of groundwater from boreholes on the farms Kasra and Werk en Rus, which adjoin Vredenhof and lie close to these boreholes. Recharge in response to the heavy July-August rainfall reaches a peak at the beginning of October. The time lag seems to be 1½ months between heavy rain and water level maxima. The very heavy rain early in March 1988 interrupted the normal decline of the water levels, causing recharge and upward trends in the graphs of holes VH and RH to take place earlier than in the previous year.

10. MOVEMENT OF GROUNDWATER THROUGH THE BEDROCK

As shown in section 5.3.1, the bedrock materials in the valley are impermeable. The fact that some very strong groundwater yields were produced by a number of boreholes indicates that secondary fracturing has a significant influence on groundwater movement. Some of these fractures were actually seen in diamond core samples; others were evidenced by pieces of vein quartz or calcite in the cuttings from the percussion boreholes.

10.1 Joint orientations in the valley

The attitudes of a few joints or fractures were measured by down the hole techniques during the diamond drilling program (Table 5.6, Section 5.3).

A large number of joints were also measured in the field on exposures of bedrock. Most of these were vertical or near vertical joint planes (App. Fig. 2.5C) and gave the following preferred strike directions in areas near the borehole profile lines:

TABLE 10.1 STRIKE OF JOINTS IN THE P.R. VALLEY.

AREA	BOREHOLE LINE	MOST PROMINENT	SECOND SET	THIRD SET
1	A	130°	137°	155°
2	B & D	130°	150°	140°
3	C	12°	174°	120°
4	E	172°	137°	155°
5	F	122°	141°	148°

A rose diagram of the 396 joints which were measured shows a preferred jointing direction of 120° to 140° in the valley, ie. NW-SE. only two measurements in the diamond core boreholes correlated with abovementioned azimuths, ie. 122°and 150.°

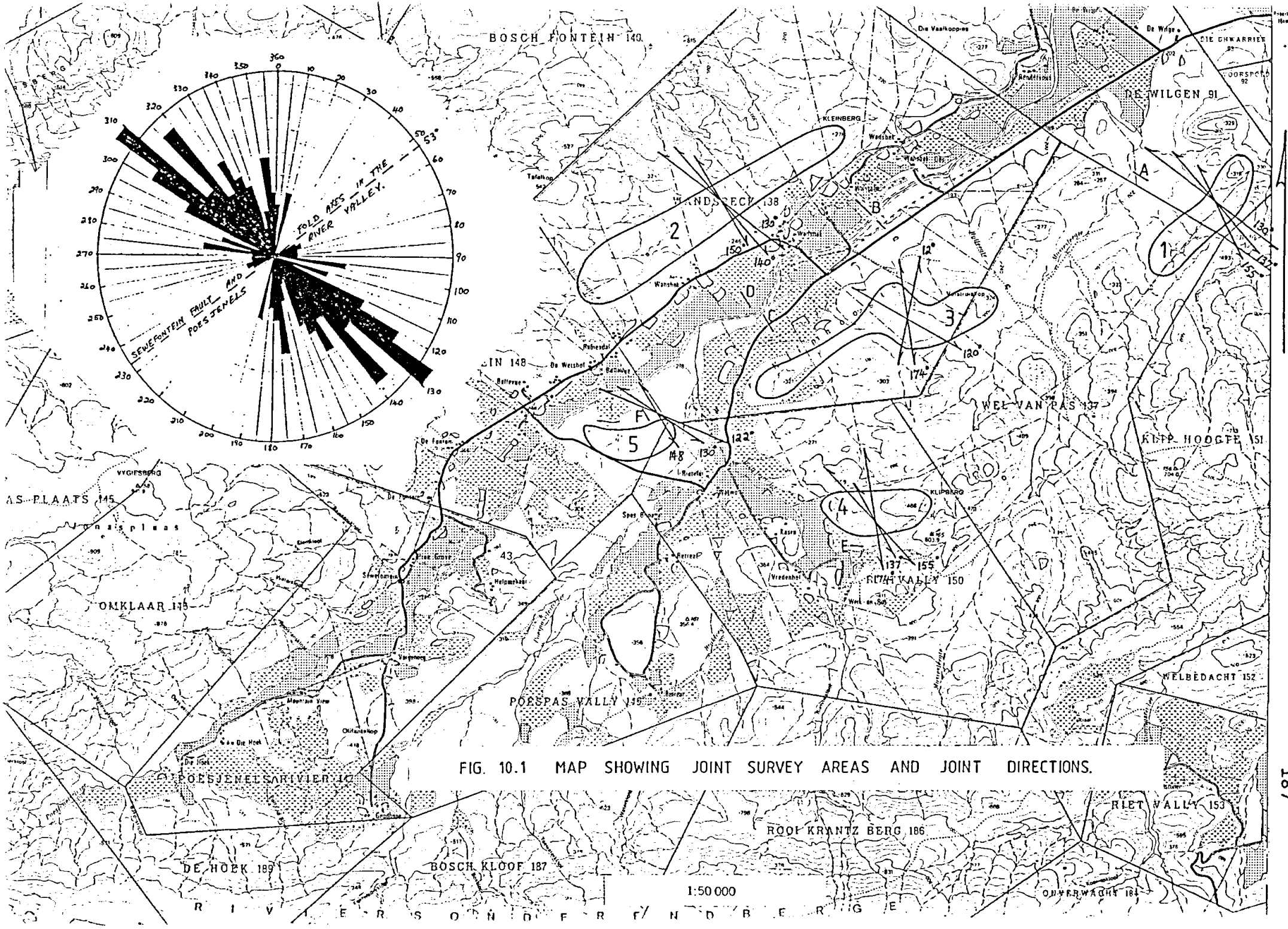


FIG. 10.1 MAP SHOWING JOINT SURVEY AREAS AND JOINT DIRECTIONS.

Fig. 10.1 shows the surveyed areas and the joint directions on a map of the valley. The Sewefontein of Fault runs through the valley in a NE - SW direction, which is also the direction of the fold axes and the strike of the shale and sandstone beds.

The main joint direction therefore crosses the catchment almost at right angles to the fold axes of the formations and the most important fault lines. They provide migration paths for groundwater within the Table Mountain sandstone aquifer; this water therefore migrates into the Bokkeveld shale and quartzite under piezometric pressure from the hydraulic head in the mountains, utilizing every fracture.

10.2 Tracer tests

Although radio-active isotopes had initially been planned, and bromide had been tried but found to be unsuccessful, it was finally decided to use Na-Fluorescein. this highly pervasive fluorescent colouring agent was added to the uppermost borehole of each array, as a tracer (T) and the other holes checked at 6 hours, 12 hours, 24 hours and then twice a day after that, for a period of one month. Results are shown in TABLE 10.2A. Unfortunately, the tracer was introduced to the boreholes as a mixture in ±2 litres of water; this immediately produced an unnatural head of water which in turn led to accelerated groundwater migration - a situation further aggravated by the airlifting of water samples from piezometers in the deep boreholes on five of the transects, which reduced the water levels at those centres, increasing the gradient of the GWT still further. An average migration rate of 0.0529 metres per hour was determined in this first tracer experiment during 1985.

On recommendations of the Steering Committee, further testing was carried out in 1986, making sure than no water was added to the borehole during introduction of the tracer, that no water was withdrawn from piezometers and that once water had been checked for tracer, the sample was returned to the monitor hole.

(The Na-Fluorescein powder was introduced by means of a weighted, slotted plastic container which was allowed to pass down into the water in the borehole, flushed up and down and then withdrawn without its powder charge.)

This test was carried out during the post winter period (August-September 1986) when rising GWT would provide maximum groundwater migration velocities.

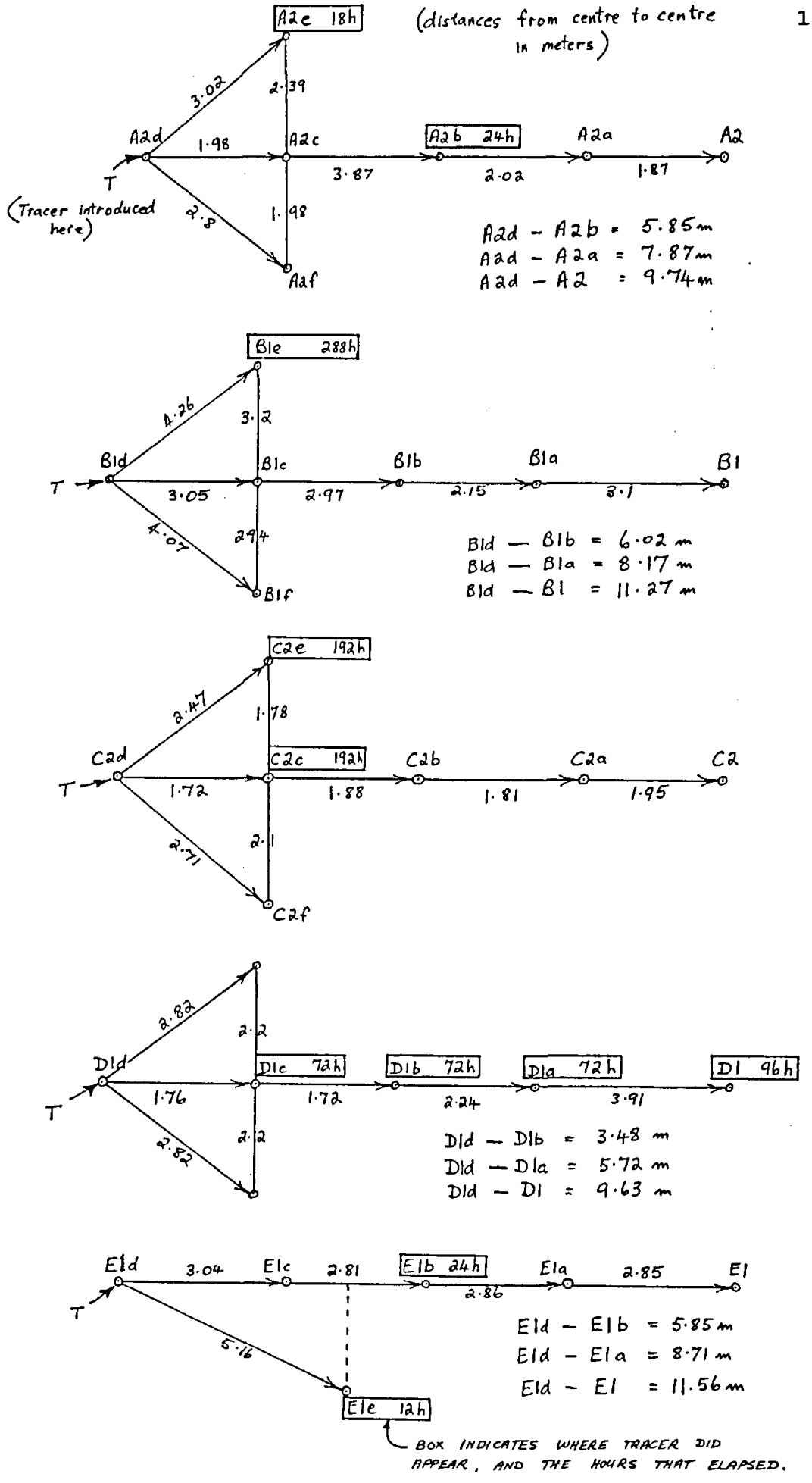


FIG. 10.2 BOREHOLE ARRAYS AT THE 5 PROFILES USED FOR TRACER TESTS. (T = Na-Fluorescein)

TABLE 10.2a

RESULTS OF TRACER TESTS — 1985.

LINE	Tracer Positive	Tracer Negative	Distance (m)	Time (h)	Rate (m/h)
A2		A2	9.74	>480	< .0203
		A2a	7.87	>480	< .0164
	A2b		5.85	24	0.2438
		A2c	1.98	>480	< .0042
	A2e		3.02	18	0.1678
		A2f	2.8	>480	< .0058
B1		B1	11.27	>480	< .0235
		B1a	8.17	>480	< .0170
		B1b	6.02	>480	< .0125
		B1c	3.05	>480	< .0064
	B1e		4.26	288	0.0148
		B1f	4.07	>480	< .0085
C2		C2	7.36	>480	< .0153
		C2a	5.41	>480	< .0113
		C2b	3.6	>480	< .0075
	C2c		1.72	192	0.0089
	C2e		2.47	192	0.0129
		C2f	2.71	>480	< .0056
D1	D1		9.63	96	0.1003
	D1a		5.72	72	0.0794
	D1b		3.48	72	0.0483
	D1c		1.76	72	0.0244
		D1e	2.82	>480	< .0059
		D1f	2.82	>480	< .0059
E1		E1	11.56	>480	< .0241
		E1a	8.71	>480	< .0182
	E1b		5.85	24	0.2438
		E1c	3.04	>480	< .0063
	E1e		5.16	12	0.4300
D4	D4		2.0	72	0.0278

By means of this second technique, tracer was only detected in four of the monitored holes over a period of three months.

TABLE 10.2b Results of tracer tests, 1986

Tracer introduced to borehole:	Monitored in borehole:	Distance (m)	Time elapsed	Rate m/h
A2e	A2b	2.7	240h	0.0113
B1f	-	-	-	<0.0001
C2f	-	-	-	<0.0001
D1f	D1d	2.82	30h	0.094
E1e	E1c	2.56	288h	0.0089
F7 (auger)	F7s	5.0	71h	0.07
Average Rate of the four positive results: 0.04605 m/h				

The average rate of movement for the groundwater under natural conditions is therefore much lower, and although difficult to calculate with so few results, appears to be in the order of 0.0018 metres per hour or 1.3 metres per month if the average rate from TABLE 10.2B is divided by the 26 negative results on the 5 profiles which were evaluated.

Undoubtedly this rate is far exceeded along fault zones and open fractures since high yields are obtained from boreholes which intersect these zones. As the bed of the river is covered by alluvium along most of its length, one cannot see where faults are traversed by the river; these places are expected to be channels of outflow for saline seepage coming through the Bokkeveld bedrock under pressure from the high GWT in the mountains. Attention is given to this aspect in the next section.

11. The Natural Isotope Survey

11.1 Tritium in groundwater

During the 1970's as part of a preliminary examination of water from all the boreholes in the P.R. catchment as well as areas outside the catchment, the Tritium content was analyzed by Dr. Balt Verhagen of the Nuclear Research Institute at the University of the Witwatersrand. The results indicated that groundwater from the Bokkeveld shale and siltstone formations in the central part of the valley contained a much higher tritium content than water from artesian boreholes and fountains in the Table Mountain sandstone. The water in the shale was therefore seen to be young in comparison with some old, deep-seated water in the TMS. (The details were submitted to the WRC in 1979.)

Rain water which had infiltrated the upper areas of sandstone mountains had been moving downwards over many years through joints and fracture zones, and appears to have met with some resistance at the Bokkeveld shale contact. This slow movement along deep flow paths allowed the radio-active Tritium to decay, and caused ageing of the water. Water in the upper parts of the Bokkeveld shale in the central part of the valley appeared to have been introduced by more recent rainfall.

Water in the Poesjesnels River showed high Tritium values, ie. mainly rainfall runoff and Le Chasseur canal water reaching the river as return flow.

11.2 Oxygen Isotope studies

After consultation with Prof. Arieh Issar at the Jacov Blaustein Desert Research Centre at Sede Boker in Israel during 1985, his suggestion that ^{18}O isotopes be used to "fingerprint" different water bodies in order to understand their distribution and movement was followed up in the Poesjesnels River catchment during 1986.

Of special interest to hydrologists are the ratios of the main isotopes that comprise the water molecule, $^{18}O/^{16}O$ and also $^{2}H/^{1}H$. The isotope ratios are expressed in delta units (δ) as per mille (parts per thousand or ‰) differences relative to an arbitrary standard known as Standard Mean Ocean Water (SMOW)

$$‰ = [(R - R_{standard})/ R_{standard}] \times 1000$$

where R and $R_{standard}$ are the isotope ratios $^{2}H/^{1}H$ or $^{18}O/^{16}O$ of the sample and the standard respectively. The accuracy of measurement on a mass spectrometer is usually better than ± 0.2‰ for ^{18}O and ± 2‰ for ^{2}H.

The different isotopic forms of water have slightly different vapour pressures and freezing points. These two properties give rise to differences in the ^{18}O and ^{2}H concentrations in various parts of the hydrologic cycle, and the changes in isotope content as a result of changes in isotope content as a result of evaporation, condensation, freezing, melting, chemical reactions or biological processes is known as isotopic fractionation. (Freeze and Cherry, 1979)

When water evaporates from the oceans, the water vapour produced is depleted in ^{18}O relative to ocean water by about 12 - 15‰. When water vapour condenses, the rain or snow that forms has higher ^{18}O concentration than the remaining water vapour. As the water vapour moves further inland as part of regional or continental atmospheric circulations systems, and as the process of condensation and precipitation is repeated many times, rain or snow becomes characterized by low concentrations of the heavy isotope ^{18}O. The ^{18}O content of precipitation at a given locality at a particular time depends in a general way on the location within the continental land mass, and more specifically on the condensation-precipitation history of the atmospheric water vapour. (Issar et.al., 1984).

In shallower groundwater systems with normal temperatures the concentrations of the ^{18}O isotope are little, if at all, affected by chemical processes. In these flow regimes, ^{18}O is a nonreactive, naturally occuring tracer that has a concentration determined by the isotopic composition of the precipitation that falls on the ground surface, and on the amount of evaporation that occurs before the water penetrates below the upper part of the soil zone. Once the water moves below the upper part of the soil zone, the ^{18}O concentration becomes a characteristic property of the subsurface water mass, which in many hydrogeologic settings enables the source areas and mixing patterns to be determined by sampling and analysis for this isotope. (Freeze & Cherry, 1979)

The Riviersonderend and Suurberg Mountains lie at a distance of about 150km from the western seaboard where northwesterly winds enter the subcontinent and bring precipitation in the winter months. Some rain is brought from the southeast coast in early summer as well, over a similar distance.

Cloud formation against successive mountain ranges and precipitation from the clouds, further depletes the already ^{18}O depleted water vapour from the oceanic evaporation, and when the rain finally falls on the P.R. catchment mountains, its ^{18}O content is very low. As runoff passes down streams and rivers, or is restrained in dams, it naturally begins to evaporate again, and the ^{18}O concentration again begins to rise. Rainfall trapped in an aquifer retains its ^{18}O status because it is protected from evaporation.

If such groundwater moves through bedrock which contains cognate or infiltrated salts particularly on the surface of mica and clay minerals or adsorbed along microfractures, leaching will take place, and the water will be characterized by low ^{18}O levels and high TDS values.

Headwater streams which flow for some distance over well-leached sandy alluvium would increase in ^{18}O content while retaining their low TDS value. Water samples for isotope analyses were taken from the valley during summer base-flow periods, to gain as much information about the isotopic character of sources of water along the length of the P.R. High flow conditions during winter would blanket any such changes.

TABLE 11 shows the ^{18}O concentrations relative to SMOW in water sampled in February 1986, as well as in December 1986. These analyses were kindly done for the project by Mr. S. Talma of the NPRL at the CSIR. Some further ^{3}H analyses were carried out by Dr. Balt Verhagen of the Schönland Research Centre in Johannesburg, and are included on the table. (One Tritium Unit or T.U. = one ^{3}H atom per 10^{18} Hydrogen atoms)

TABLE 11

ISOTOPE ANALYSES FROM THE POESJESNELS RIVER VALLEY

BOREHOLE or SAMPLE N°	FEBRUARY 1986		DECEMBER 1986		
	^{18}O(‰ SMOW)	TDS mg/l	^{18}O(‰ SMOW)	TDS mg/l	^{3}H (T.U.)
A1			-6.2	4740	
A1a			-6.3	4740	
A1b			-6.25	4740	
A1c			-6.15	4740	
A1e			-6.1	4740	
A1f			-6.1	4710	
A2 (20m pz.)*	-4.9	5900	-5.2	2880	
A2 (54m pz.)	-5.7	7100			
A2 (76m pz.)	-5.9	6700			
A2 (91m pz.)	-5.8	6050			
A2a			-5.2	3980	
A2c			-5.6	5670	
A2f			-6.1	6072	
B1 (41m pz.)	-3.0	2150			
B1 (55m pz.)	-2.4	1500			
B1 (73m pz.)	-4.2	2600	-4.4	2592	
B1 (99m pz.)	-4.1	3100			
B1a			-2.8	1692	
B1b			-2.8	1638	
B1c			-2.8	1620	
B1e			-2.7	1518	

BOREHOLE or SAMPLE N°	FEBRUARY 1986		DECEMBER 1986		
	^{18}O(‰ SMOW)	TDS mg/l	^{18}O(‰ SMOW)	TDS mg/l	^{3}H (T.U.)
B2 (artesian)			-4.8	5850	1.5 ±0.3
B2a			-4.4	4536	
B2b			-4.3	5040	
B2d			-4.5	5220	
B4 (artesian)	-3.9	2580	-4.2	2352	1.4 ±0.4
B4a			-3.9	2274	
B5			-4.8	3540	
C2 (40m pz.)	-4.6	8200			
C2 (59m pz.)	-4.8	8200			
C2 (80m pz.)	-5.0	7740	-4.6	5034	
C2 (98m pz.)	-4.6	8600			
C2b			-4.3	6300	
C2c			-4.7	6580	
C2e			-4.4	8000	
D1 (36m pz.)	-2.5	1950	-3.0	1368	
D1 (53m pz.)	-2.1	2180			
D1 (73m pz.)	-2.3	2720			
D1 (98 pz.)	-2.4	1900			
D1a			-2.4	1812	
D1b			-2.4	1824	
D1c			-2.2	1614	
D1d			-2.1	1536	
D1e			-1.0	990	
DF (artesian)			-6.6	112	0.3 ±0.2
DJB (artesian)	-6.2	390	-6.1	336	
DK (artesian)				-6.1	84

BOREHOLE or SAMPLE N°	FEBRUARY 1986		DECEMBER 1986		
	^{18}O(‰ SMOW)	TDS mg/l	^{18}O(‰ SMOW)	TDS mg/l	^{3}H (T.U.)
E1 (37m pz.)	-5.4	3700	-5.4	3480	
E1 (53m pz.)	-5.4	4100			
E1 (73m pz.)	-5.4	4300			
E1 (96m pz.)	-5.5	4360			
E1a			-5.8	3700	
E1b			-6.0	3552	
E1e			-5.9	3594	
F1			-6.1	2082	
F2			-5.7	2484	
F3			-5.5	3180	
F3a			-5.4	7050	
IR5	-2.2	9300			
IR9	-2.0	2160			
IR10	-2.3	2240			
LC			-1.2	52.8	3.3 ±0.4
PR1	-4.8	50			
PR8			-5.6	129	
PR10	-4.4	260			
PR16			-1.7	2568	
PR25			-1.7	4446	
PR30	-2.1	7200			
PR36			-2.1	3570	3.2 ±0.5
PR40	-2.0	1900	-2.1	2904	
Rainwater					5.0 ±0.5
VC			-5.5	93	

*All samples are from boreholes or borehole piezometers (pz.) on profile lines with the exception of the following:

DF = Borehole on the farm De Fontein
DJB = Borehole on the farm Vredenhof
DK = Borehole on the farm De Knop, just to the east of the catchment
IR = Irrigation return flow seepage (at sites no. 5, 9 and 10)
LC = Le Chasseur Canal
PR = Poesjesnels River (at eight selected sites)
VC = Vredenhof Canal

The most depleted sample, taken from artesian borehole DF on the farm De Fontein, contained - 6.6‰ ^{18}O. Other artesian water samples DJB (on Vredenhof) and DK (on De Knop, a farm just to the east of the catchment) also had low values of - 6.1‰ ^{18}O. These three water samples are also characterized by very low TDS values; their movement through the Table Mountain sandstone formations has therefore taken place without any increase in salinity -- a clear testimony to the very fresh, clean nature of these sedimentary rocks.

In order to differentiate between the various types of water, the $\delta\ ^{18}O$ values were plotted against T.D.S. (App. FIG. 11.1; FIG. 11.2). On this graph a leaching trend and an evaporation trend can be illustrated. The former shows the change in TDS of migrating groundwater which undergoes no evaporation; the latter shows the increase in both TDS and ^{18}O as river water undergoes evaporation as it moves downstream, or is stored in dams.

The analyses of groundwater encountered in the various borehole transects is of particular significance. Not only are there large differences in TDS, but the ^{18}O content varies appreciably. Based on ^{18}O content, three groups of water may be differentiated:

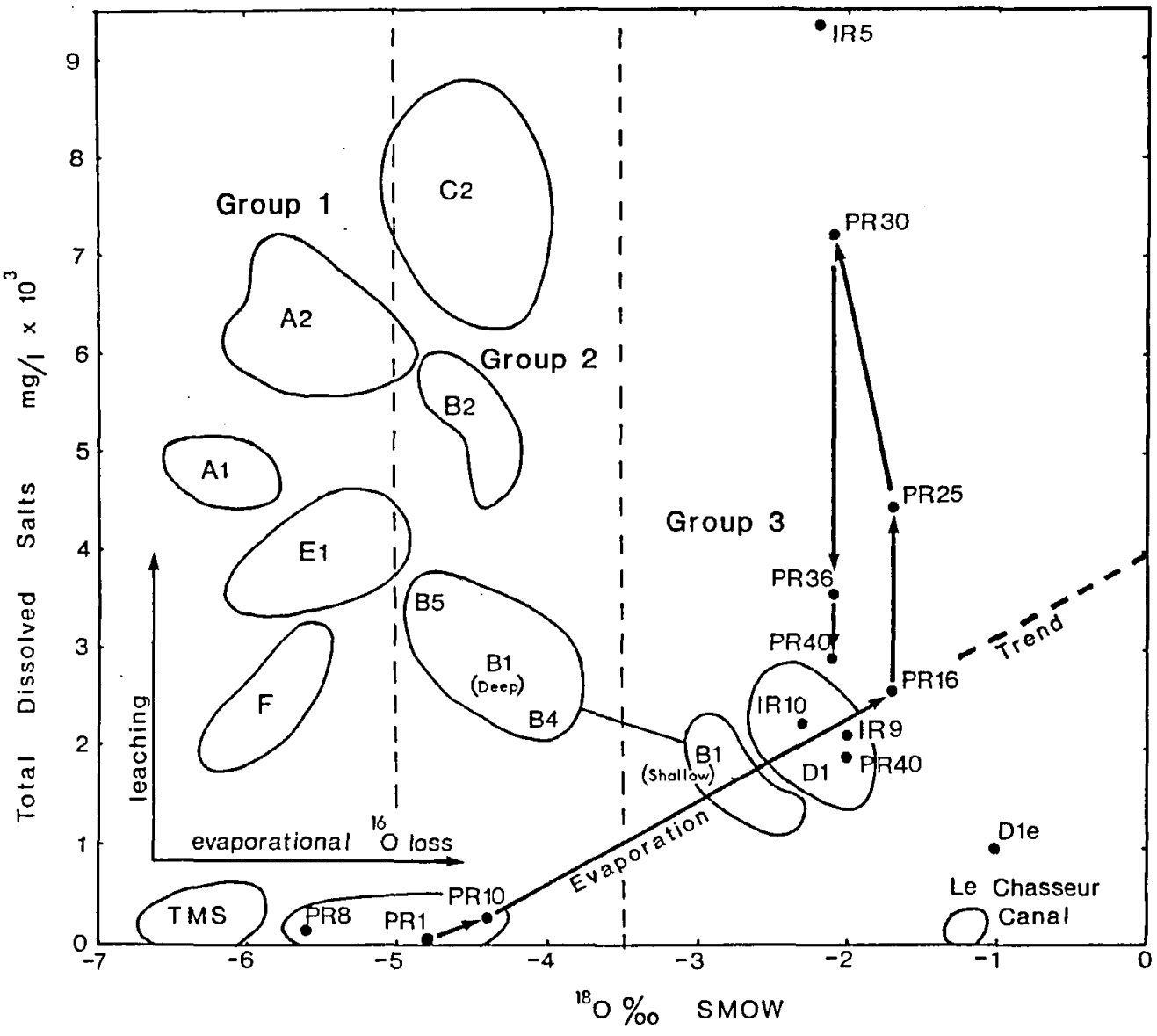


Fig. 11.2

SALINITY / ^{18}O DIFFERENTIATIATION of GROUPS OF BOREHOLES, RIVER WATER SAMPLES and IRRIGATION RETURN FLOWS in the POESJESNELS RIVER CATCHMENT. (DEEP LEACHING of BOKKEVELD FORMATIONS VS. CHANGES PRODUCED BY SURFACE FLOW EVAPORATION.)

GROUP 1 (Very depleted water)

Plots of analyses from transects F, E1, A1, and A2 are positioned above the TMS artesian borehole group and lie in order of increasing salinity, along the Leaching Trend line. Their ^{18}O concentrations are between -5 and -6.3‰ SMOW, very similar to TMS water, and on maps of the catchment it can be seen that boreholes A1 and A2 and E lie near the Bokkeveld - TMS contact.

These results show a direct salinity increase due to leaching along Bokkeveld bedrock fractures as water has migrated from the Nardouw sandstone into the bedrock below borehole transects A1, A2 and E1. Boreholes of the F group plot even closer to the TMS artesian corner even though they lie further from the contact; it is believed that the Sewefontein fault which passes close to the F boreholes, brings depleted ^{18}O water from the Suurberg/De Fontein area into the Bokkeveld shales and siltstones from below. The very impervious nature of the bedrock below transect F has resisted the infiltration of evaporated rainwater from puddles and the soil overburden, preserving the low ^{18}O values of this groundwater.

GROUP 2 (Mildly depleted water)

Plots of borehole transects B2, B4, C2 and borehole B5 lie to the right of GROUP 1. Their ^{18}O values vary from -3.9 to -5, and are similar to those in the river at PR 10.

Interaction between the river water and the underlying Bokkeveld bedrock through joints and fractures, particularly in siltstone formations, could explain this similarity in ^{18}O content. The very much higher TDS content of the groundwater would result from leaching as the water moves through the bedrock.

It should be noted that these boreholes are further from the TMS contact than the GROUP 1 boreholes, and that more mixing of Bokkeveld water with deeper lying TMS water would take place as this water moves upwards by means of faults and fractures. The high salinities in the C2 borehole group would be caused by the longer migration paths, fitting such a model; it must be remembered that the Sewefontein Fault crosses borehole profile line C and passes south of borehole B5, providing a permeable conduit for deep groundwater.

A further explanation for the position of the C2 boreholes on the graph lies in the nature of the irrigation water which is applied to some large areas above C2. This water is obtained from the Vredenhof Canal (VC) which carries water from the Riviersonderend Mountain, and has a depleted ^{18}O value of -5.5. Some evaporation and accelerated leaching of subsurface salts due to deep ripping and ploughing would then produce the particular isotopic and chemical nature of the water sampled at the C2 transect and also at borehole B5 on the same side of the river. Vredenhof Canal water eventually reaches a big dam on De Wilgen, where it is used for irrigation. The highly saline return flow from this (IR5), plots on the graph in the upper right corner; if an evaporation trend line is extended from boreholes C2b and C2c, it would pass very close to the plotted position of IR5.

The B2 and B4 artesian water outflows also plot in this Group. They differ from the TMS artesian water flows by having higher ^{18}O values, and considerably higher salinities. Furthermore, the Tritium content of the TMS artesian water at De Fontein (DF) was measured at 0.3 ± 0.2 T.U.,* (old water) while the B2 and B4 artesian water gave 1.5 ± 0.3 and 1.4 ± 0.4 respectively. (i.e. middle aged or "mixed" water.)

Tritium values for rain water, Le Chasseur canal water and Poesjesnels River water were 5.0, 3.3 and 3.2 ± 0.5 T.U. respectively; these are the values for young water.

Based on these results, the artesian water from B2 and B4 cannot be directly related to the underlying Table Mountain Sandstone or to recent infiltration of rain or river water. The source for this water must be found in the outcrop areas of Bokkeveld siltstone beds, particularly the Hex River Sandstone (C_2Q_2) above Bellevue and Rabiesdal which dips in an easterly direction below the Tra Tra Shale (C_2S_3), the Boplaas Sandstone (C_2Q_3) and the Waboomberg Shale (C_2S_4) into which the boreholes were sunk (App. Fig. 2.2b photo 3; App. Fig. 2.2c photo 1 and 3; App. Fig. 2.9A).

* *1 T.U. (Tritium Unit) = One ^3H atom per 10^{18} atoms ^1H; the half-life of ^3H is 12.3 years.*

Rain water which infiltrates the Bokkeveld siltstone formations in their outcrop areas undergoes ageing as it moves slowly through the bedrock in a downstream direction under the influence of the piezometric groundwater pressure head in the elevated areas. If the Tritium levels in the artesian water had been much lower, one could have postulated stagnation; they are however measurably higher than those in the TMS, and indicate that a measure of infiltration and migration is taking place.

GROUP 3 (Evaporated water)

Water from the boreholes on transects B1 and D1 show a much higher, evaporated ^{18}O content and lie on or about the natural evaporation trend for river water samples. (The deeper piezometers in B1 are more depleted than the upper ones, indicating a change in water character with depth; the same is seen in A2 piezometers.)

The infiltration of irrigation water into the soil and bedrock at these transects is probably responsible for the more evaporated ^{18}O character of water from these boreholes, particularly in the shallower parts of the groundwater regime.

It can also be seen that the irrigation return flow samples IR9 and IR10 plot in the same zone; IR5 had the same ^{18}O content, but extremely high salinity (return flow from shallow soils.)

The ^{18}O value for the Le Chasseur canal water (LC) is high at -1.2‰ SMOW, and it may be classified as "highly evaporated water." It has a very low salinity, showing that its source (ie. the Brandvlei Dam) contains extremely good quality low - TDS water. Possibly the rain that falls on the Du Toit Kloof mountains to the west of Worcester is not as depleted in ^{18}O as that which falls on the mountains near Robertson, and the runoff into the Brandvlei Dam has a higher ^{18}O value to start with.

As much of the irrigation water in the lower part of the P.R.V. comes from the Le Chasseur canal, the tendency should be for the irrigation return flow to draw the river water downwards off the evaporation trend towards the lower right corner of the graph as the river proceeds downstream towards the Breë River. In the case of the Poesjesnels River this natural trend is severely disturbed above H4M18.

The higher ^{18}O value for PR40 near the confluence with the Breë River sampled in February 1986 does in fact lie below the evaporation trend joining PR10 and PR16 indicating that the sheer volume of irrigation return flow entering the river in the Le Chasseur area below H4M18 begins to dominate the ^{18}O character of the water, effectively masking the seepage of a smaller volume of ^{18}O - depleted saline groundwater into the river.

11.3 Interpretation of the isotope and salinity results

Of all the samples taken from the river, those from the upper part of the valley (PR1, PR8 and PR10) have the most depleted ^{18}O concentrations,because the flow is produced by rainfall runoff, artesian flows or fountains in the sandstone. These waters have very low salinities. From PR 10 however, as the river flows more slowly through alluvial gravels and reeds, the water changes in character along the evaporation trend line to PR16. (Both the ^{18}O and the TDS increase.)

The graphs in App. FIG. 11.1 and FIG. 11.2 show that the chemical nature of the river water deviates sharply as it passes from PR16 to PR25: the salinity increases while the ^{18}O content remains constant, causing the samples to plot away from the evaporation line.

The rapid increase in salinity is caused by the leaching of salt from the shale in the riverbed and by the influx of saline irrigation return flow from riverbank areas, but this does not explain the ^{18}O figures. From PR25 to PR30 the trend of river water away from the evaporation line is even stronger, because the TDS continues to rise and the ^{18}O content is actually lowered. Clearly, some water is being added to the river and causing a TDS increase together with a decrease of ^{18}O, contrary to the natural evaporation trend.

Irrigation water from the Le Chasseur canal has a very high ^{18}O content compared with the other waters in the valley. After irrigation with this water, the return flow should be further ^{18}O enriched as a result of evaporation. the fact that the ^{18}O content remains constant at -1.2 is therefore an indication that water with a very low ^{18}O content is being added to the river from some source. The graph shows that such water exists within the Bokkeveld bedrock (encountered in borehole transects A, B, C, E and F) and in the Table Mountain sandstone formations. The isotopic trend on the graph is therefore interpreted as a clear indication that ^{18}O - depleted

groundwater is moving along permeable zones in the bedrock such as the Bellevue, De Fontein and Sewefontein Faults as well as many joints and fractures and is entering the river from below under piezometric pressure from the hydraulic head in the elevated sides of the catchment. The artesian conditions encountered in boreholes B1, B2 and B4 are probably due to the absence of a fault zone in the vicinity of these boreholes, causing the groundwater to be trapped in the Boplaas sandstone below the Waboomberg shale aquiclude; these formations which dip gently towards the east, were both penetrated by the B-line boreholes. (Fig 5.1A)

This mixing of groundwater with the river water would explain the "back somersault" in the trend of the ^{18}O/TDS plots away from the evaporation trend between samples PR16, 25, 30, 36 and 40. (FIG. 11.2) Calculation of actual volumes of groundwater involved in this process by means of the abovementioned isotope data is not possible because the actual flow in the river is too low to be measured between stations PR 16 and PR 30 during the dry summer months.

The ^{18}O depletion seen in the river water during the summer months is not expected to be noticeable during periods of stronger flow in autumn, winter and early spring months. The total volume of effluent groundwater entering the river during summer is probably of the same order as the total irrigation return flow volume produced along the length of the valley above H4M18. Much of this flow actually takes place below surface, within the gravels which constitute the riverbed.

12. SUMMARY

Section 1: The research emphasis is placed on:

1. determining the salinity potential of the soil and bedrock in the catchment.

2. gaining an understanding of the movement of groundwater.

3. presentation of data for a mathematical model of the catchment.

The water in the Breë River has been deteriorating over the past twenty years, and measurements have shown that tributaries such as the Poesjesnels River contribute increasingly heavy salt loads to this important Western Cape river as more areas are developed for irrigation in these catchments. This project was initiated to investigate the origin and movement of the salt, and to provide data for a model which is needed to control the whole Breë River irrigation system. Soil analyses by Dr. J.H. Moolman indicated a load of salt at 1 metre depth over much of the Poesjesnels River valley(1979), and water analyses by Dr. J.M. Fourie indicated high salt loads in the Poesjesnels River during summer months, causing damage to crops irrigated with Breë River canal water at Bonnievale. Previous borehole surveys indicated that the Bokkeveld shale formations contained a large amount of salt and produced mineralized groundwater.

The modelling concept is explained, with a view to the implementation of a hydrological working model for the Breë River valley and its tributaries so that future irrigation needs and return flow volumes may be effectively managed.

Section 2:

The geology, physiography and rainfall of the catchment are presented, so that the annual precipitation on the two major rock types i.e. shale and sandstone may be distinguished.

The annual rainfall volume averages are:

sandstone mountains - 50.87 million cubic metres
shale valley areas - 32.89 million cubic metres.

Evaporation figures for the valley are high, reaching 10 mm per day during summer.

Whole rock chemical analyses indicated that higher K_2O and Al_2O_3 content occurs in the black (carboniferous) micaceous shale, but no chloride values could be determined by the XRF technique. The marine origin of the sediments is proved by the minor or trace element content, and a correlation between sulphur and pyrite was established.

Section 3:

The total area under irrigation in the valley amounted to 1794.29 hectares; this has recently grown to 1820 hectares due to new development on the western side of the farm DE WILGEN and the adjacent eastern side of the farm WEL VAN PAS by the owner, Mr Wouter De Wet. (Section 7.2, p 146)

The average irrigation volume applied to the whole catchment amounts to ± 13 million cubic metres per annum, generally concentrated over an 8 month period (September to April.)

The total amount of water introduced by the Le Chasseur canal from the Brandvlei Dam amounts to 6.78 million cubic metres per annum according to figures supplied by the farmers.

The total input of water to the catchment from all sources amounts to 90.45 million cubic metres; only one tenth of this water i.e. 9.4 million cubic metres has been estimated to flow out of the catchment (Hasenjager, 1980) lending support to the high evapotranspiration figures.

Section 4:

The river sampling and analysis indicated a strong increase in salt load as the river flowed into the central part of the valley between sampling stations 15 and 34. The pH also rises from acidic to alkaline conditions and calcrete is precipitated in central valley soils. The southern tributaries (Rietvlei and Mosiesleegte rivers) brought in

heavy salt loads, mainly in the form of irrigation return flow seepage with salinities as high as 3 000 and 7 000 mg/l respectively.

Seasonally, an inverse relationship between flow and salinity was established, with salinity rising as flow diminishes after the winter months.

During the summer months (December - January) extensive irrigation on well established vineyards on alluvial soils at Le Chasseur produces a good quality return flow which restrains the trend of rising salinity to some degree.

The flow measuring device at H4M18 (Le Chasseur bridge) indicated an annual average of ± 8 million cubic metres, 1.4 million lower than the figure calculated by Hasenjager. According to the work by Flügel (1989), some water may be lost from the catchment through faults and fractures. He calculated the flow of groundwater through fractures into the Breë River to be 9.91 m^3/s along a 58 km stretch of the river. This amounts to 99.5% of the groundwater inflow while the other 0.5% flows in laterally through sandy alluvium (Flügel, 1989). A unit inflow of 0.085 m^3/s per kilometre of single riverbank was determined.

Based on daily average flow and conductivity, the average annual salt load passing the H4M18 measuring station at the lower end of the Poesjesnels River was calculated at 7674 tons.

A salt load model based on all possible increments contributing to this tonnage leads to an understanding of the salt contributed to the Poesjesnels River annually by inflow of groundwater, i.e. 609 tons and 203 000 m^3 respectively.

Based on the values used in the model, the annual rainfall together with the water applied to irrigated Bokkeveld shale soils releases 344.25 grams of salt per cubic metre, while irrigated alluvial soils produce only 77.16 grams per cubic metre. Leaching tests in Section 6 confirm that much heavier loads of salt are actually available in these materials, but the natural leaching process takes place more gradually over many years.

Principal component chemistry of the river water varies as follows: $NaCl > MgSO_4 > CaHCO_3$. There is also a seasonal change in the ionic character of the water, with

the ratio of NaCl : Mg/Ca + SO_4/HCO_3 increasing during winter and decreasing during summer.

Section 5:

Six areas were selected for the drilling of groups of boreholes to examine the lithology and groundwater of the valley. Geophysical logging and pumping tests were carried out. Groundwater salinity in most cases tended to increase with depth, especially where low permeability was encountered in black shales.

Transmissivity calculated on less than ideal borehole spacings amounted to 62 m^2/day. (An aquifer thickness of 62 metres is assumed because fractures and open joints occur to at least such a depth below the GWT in the bedrock). A storativity of 1.3×10^{-3} was also determined.

Section 6:

Leaching experiments on fresh and decomposed bedrock materials are described. Salinity as high as 5658 mg/l was encountered in leachates from some shallow auger borehole samples at the transition from soil to decomposed shale or clay.

Leaching of crushed diamond drill cores indicated that sericitic black shale contained more adsorbed salt than sandstone layers.

Oxidation of pyrite from percussion borehole cuttings produced some high salinities, indicating the very active chemical nature of the sediments, e.g. 4389 mg/l at a depth of 27 metres in borehole B1f in pyritic micaceous black shale; sandstone on the other hand gave values as low as 143 mg/l at a depth of 9 metres.

Section 7:

Natural leaching of soil materials by irrigation water and rainfall releases considerable loads of salt into drainage lines and the Poesjesnels River.

The average salinity of applied irrigation water is 312.2 mg/l, and that of the return flow seepage is 2965,6 mg/l (i.e. ± 3 000 mg/l.)

Change in the ratios of principal chemical components indicates that more $MgSO_4$ and $CaHCO_3$ are released from the soils of the upper part of the catchment with NaCl predominating in the soils of the lower part of the catchment.

New, deep ploughing development on 25ha of thinner soils overlying Bokkeveld shales allowed for the release of heavy salt loads when subjected to heavy rainfall and irrigation. Increase in salinity in the Mosiesleegte stream as a result of such development followed by 40 mm of rainfall on 27/28 August 1988 on the farm De Wilgen amounted to 7233 mg/l, the TDS of the stream increasing from 420 to 7653 mg/l due to seepage from the developed area. Most of the salt consisted of NaCl. Simultaneously the salinity at the Le Chasseur bridge in the Poesjesnels River rose to its highest level yet measured by project staff, namely 5026 mg/l (The flow was judged to be ± 100 l/s). HRI records show that the TDS on 29 August 1988 was measured at 5 405 mg/l, while the flow gauge registered 82 l/s.

Section 8:

Piper trilinear and Durov rectangular diagrams showed the changing trends of chemical constituents in the various water bodies sampled during the project.

The plots confirmed an increase of NaCl ratio in the river as it flowed through the central and lower reaches of the catchment. Below sampling station 28 the return flow from irrigation on alluvial soils opposed this trend and produced lower NaCl ratios.

Water from artesian boreholes in Bokkeveld bedrock reflected the same chemical characteristics as that flowing in the Poesjesnels River, suggesting that in interchange is taking place between the groundwater in the bedrock and the water in the river.

Plots of the chemical analyses of samples from borehole-piezometers show that the five main borehole groups can be differentiated by their cation and anion ratios, but they all show very high NaCl contents in relation to the other chemical constituents.

Only a few chemical trends with depth could be detected and these were not constant. An increase in Cl^- with depth was found in borehole B1, but a decrease in Na^+. By contrast, Cl^- decreases with depth in boreholes D1 and E1.

Plots of the auger hole leachate analyses show some $CaCO_3$ at surface but a very strong NaCl component in the decomposed layers below the soil. At line H in the upper part of the valley, $MgSO_4$ was found to increase with depth in auger holes near the river. However, hole H1 situated 400 metres from the river gave the same trend of NaCl increase with depth as found in auger holes elsewhere in the valley.

Trilinear plots of leachates from the percussion borehole cuttings and crushed diamond drill core samples all confirm a stronger NaCl concentration in the shallow, decomposed parts of the profile with Ca/Mg SO_4 increasing in the deeper, unaltered bedrock.

Changes in ionic ratios are also visible on trilinear plots of irrigation return flow seepage water, which comes from the leaching out of salts at shallow levels in the soil. $MgSO_4$ predominates in the upper valley soils, $Ca(HCO_3)_2$ in the central part and NaCl in the lower part of the valley, probably due to a long period of leaching out of the latter in the upper valley areas and its adsorption onto clay materials in the downstream areas.

Section 9:

Groundwater table gradients were determined at various borehole transects in the valley; the average gradient for the riverbank areas of the valley works out at 0.0116.

The flow of groundwater reaching the river through the uppermost intersected part of the groundwater table was calculated to be 203 232 m^3 per annum and consists mainly of saline lateral seepage. Additional amounts of low TDS water upwelling along fault zones, will not seriously affect the salt balance model.

Seasonal movements of the GWT in the various boreholes are sluggish in the central part of the valley but clearly visible in boreholes near the foot of the mountains (close to the Bokkeveld/TMS contact), such as at the E1 group and the boreholes on Vredenhof.

Section 10:

Fractures play an important role in the passage of groundwater through the impervious bedrock of Bokkeveld shale in the valley.

Measurements indicated that the main joint direction crosses the valley at right angles to the fold axes and the most important fault lines. They are well situated to allow groundwater migration under pressure from the elevated GWT in the Table Mountain aquifer, eventually welling up into the river from below.

Tracer tests provided evidence of some lateral movement of groundwater through same of the borehole arrays, i.e. 0.046 metres per hour in four boreholes where positive results were found. (If the sites where no movement was detected are brought into reckoning, the average flow rate reduces to 0.0018 metres per hour.)

Along fault zones the rate of groundwater flow will be much greater, but no such zone was intersected by two boreholes which could have been used for a tracer experiment.

Section 11:

Tritium analyses showed old water in the Table Mountain sandstone and younger water in the Bokkeveld shale. (Greeff, 1979)

Oxygen isotope studies revealed that ^{18}O-depleted groundwater exists in the Table Mountain sandstone layers which underlie the Bokkeveld formations in the valley, and that thus type of water is finding its way into the Poesjesnels River, probably by moving upwards along fault zones in the vicinity of the river, under pressure from the hydraulic head of elevated groundwater in the mountainous parts of the catchment.

The volume or flow rate of this water could not be measured or calculated, and its chemistry is unknown.

Although the effect of this ^{18}O depleted water may not be detected during the winter high flow period, its presence in summer is clearly indicated.

13. CONCLUSIONS

Bearing in mind the aims of the research project (page 3), the following conclusions may be drawn from all the analytical and geological data:

13.1 Salinity potential of the bedrock formations:

This was the most important requirement of the whole project, given the fact that salinity levels in the Breë River during the summer months when irrigation water is required from the river had risen to very disturbing proportions, and information about a typical tributary draining Bokkeveld shale was required to assist future planning.

Early on, the chemical analyses of water sampled along the full length of the Poesjesnels River gave a clear signal that some heavy mineralization was taking place in the valley. Hydrographs of the flow and salinity clearly indicated that heavy salt loads were being introduced to the water along the middle reaches of the river particularly at the onset of the first rains during autumn. During periods of strong flow after periods of heavy rainfall in winter and spring, the salinities naturally were reduced.

The percussion, diamond-core and auger boreholes which were drilled in the riverbank areas adjacent to the stretches of river with the highest salinity, revealed the distribution of salts in the vertical profile.

Leaching tests on samples of soil obtained from the auger boreholes showed that the uppermost layers were relatively free of salt, but that the materials from depths between 1 on 4 metres contained strong salt accumulations (App. FIGS 6.2 - 6.8.) The alluvial sandy soils tended to have less salt, particularly in the areas where irrigation had been practiced for more than forty years near the Le Chasseur bridge. Clays and decomposed shales encountered below a thin covering of soil a little further from the river contained much greater quantities of salt, for example more than 2 800 mg/l in 1:1 leachates in auger holes B13, C4, D6, more than 3 000 mg/l in auger hole H1 and a value in excess of 4 000 mg/l at a depth of 4 metres in auger hole B11. (1:1 leachate = 1 kg. sample taken up in 1 litre H_2O)

Unfortunately the trend of rising salinity with depth could not be followed effectively because the auger penetration was limited to 4 metres.

Samples from these deeper levels were supplied by diamond core boreholes and percussion boreholes, and leaching tests carried out on them indicated that the fresh, deeper lying bedrock could also release significant amounts of salt; the maximum salinity achieved by 1:1 leaching of crushed diamond core was 799 mg/l from a decomposed shale at a depth of 6.3 metres in borehole D1. Other high values were 741 mg/l from fresh black graphitic shale carrying sericite mica at 22.2 metres in borehole B1 and 734 mg/l from fresh black graphitic silty shale at 51 metres in borehole A1. (p 112)

The leaching of cuttings from percussion boreholes produced higher salinity values, even though material similar to that obtained from diamond core holes was tested. The high values have resulted from the oxidation of pyrite within the shales and the chemical activity which followed (TABLE 6.5A) as well as a high sericite mica content. High values in borehole A1e for example are seen in samples from depths between 2 and 7 metres, in C2 between 4 and 6 metres and in F3 at 5 metres, all within the lower part of the zone of decomposition.

The high values at depths of 20 metres in borehole C2 and at 21 metres in D4 and E1 are clearly related to a prominent black micaceous shale layer.

Taking all the leach tests into account, it appears that most of the chemical activity is concentrated near the surface of the soil, between depths of 1 and 7 metres, in the zone of decomposition, particularly if pyritic micaceous black shale layers are present. However, under natural conditions an equilibrium has been established between rainfall, runoff, infiltration, leaching of salts at the contact between soil and decomposed shale, seepage into natural drainage lines and the precipitation of substances such as calcrete and ferricrete in the soil profile. The salt content of natural seepage entering drainage lines is probably similar to that measured in the Mosiesleegte stream after rainfall in the subcatchment described in Section 7, i.e. 474 mg/l. Further downstream in the main river, prior to irrigation development, salinity was probably higher, possibly reaching 1 000 mg/l during low flow periods, but never as high as values being recorded in the Poesjesnels River at present (5 000 mg/l).

Analytical comparison of applied irrigation water and the return flow appearing in drainage lines gives a very good impression of the difference in salt leaching or mobilization as a result of the development activities by farmers, particularly recent development such as on De Wilgen, where deep ripping of 25 hectares to a depth of 1 metre produced drainage water containing more than 7 grams per litre in a stream which had been carrying less than 1/2 gram per litre only 300 metres further upstream.

The groundwater below this area on De Wilgen, encountered by boreholes A1 and A2 contained ± 4 300 and 5 500 mg/l respectively during the drilling process. Piezometer samples drawn from borehole A2 gave even higher TDS values in excess of 6 000 mg/l. It is therefore not surprising that the accumulation of salt in the decomposed bedrock materials at the top of the profile has produced such highly saline water after its first big rainfall event.

Other irrigation areas do not produce return flows with quite such high salinities; TABLE 7.3 shows that eight of the ten areas tested produce return flow with TDS between 871.6 and 2974 mg/l; the average TDS of return flow for all ten areas tested works out at 2965.6 mg/l.

13.2 Groundwater table and groundwater movement

Too few boreholes were available in the valley for the construction of a good groundwater contour map, but the borehole traverse lines running at right angles to the river made it possible to determine a groundwater table gradient of 0.0116. Together with a transmissivity figure of 62 m^2/day this value was used to calculate a flow of 203 232 m^3 of groundwater at an average TDS of 3 000 mg/l into a 16 km length of the river.

This figure of 3 000 mg/l for groundwater is a reasonable estimate, not only because of the TDS of irrigation return flow, but also if the salinity of water drawn from borehole piezometers is taken into account:

Borehole	Lowest TDS mg/l	Highest TDS mg/l	Pumpage yield l/s
A1	3 502	7 776	13
B1	1 535	3 288	14
C2	7 209	9 325	12.5
D1	1 951	2 970	7.2
E1	3 709	4 748	12

Boreholes not fitted with piezometers, but sampled during drilling:

Borehole	Lowest TDS mg/l	Highest TDS mg/l	Pumpage yield l/s
A1	4 247	4 515	4
B2	3 478	5 740	23.5
B4	2 196	2 844	4.4
B5	-	3 540	17.5
C1	6 174	7 660	4.4
D2	1 083	2 145	3.5
D4	4 389	4 779	-

The artesian water encountered at B2 and B4 confirms the fact that groundwater is under pressure in the central part of the valley; the TDS of this artesian water is very high, namely ± 5 800 mg/l (B2) and ± 2 700 mg/l (B4), indicating long migration paths through Bokkeveld shales and siltstones, during which extended leaching occurred.

Tracer tests produced results which indicated a very low average flow rate for groundwater through the Bokkeveld shale, i.e. 0.0018 metres per hour. At the four positive test sites where the tracers were identified in monitor holes by virtue of some joints or fractures linking them to the injection borehole, an average groundwater migration rate of 0.046 metres per hour was determined; even this is a very slow rate of movement, but it does give a figure to work with.

The average yield of the boreholes which were used in the tracer tests is 12 l/s or 43.2 m^3/h.

If the total area of the open joints through which fracture flow takes place across a given cross section of bedrock can be determined, another approach can be made to finding the volume of groundwater entering the river laterally and from below.

Many of the siltstone outcrop areas showed a pattern of joints cutting across the valley, with an average of 2 open vertical joints per metre (App. FIG 2.5c). Given that each joint is 0.25 mm wide, this gives a total area of openings of 2 metres x 0.25 mm = 500 mm^2 or 0.0005 m^2 for every vertical square metre of bedrock.

Using a GW migration rate half way between 0.0018 m/h and 0.046 m/h, ie 0.0239 m/h, a volume of flow through each square metre of rock can be calculted by multiplying the area of the openings by this migration rate,

i.e. 0.0005 x 0.0239 = .0000 1195 m^3/h.

Across a valley length of 16 km, and assuming that only 100 metres of aquifer depth is involved, we find the following volume of flow:

= 16 000 m x 100 m x .0000 1195 m^3/h
= 19.12 m^3/h
= 458.88 m^3/day
= 167 491.2 m^3 per annum

The less elevated northern watershed which consists mainly of Bokkeveld formations is not able to transmit the same volume of groundwater to the central valley bedrock. If the abovementioned flow is cut by half, i.e. 83 745.6 m^3 per annum, both valley sides would together produce 251 236.8 m^3 of groundwater flow according to this model. (Any excess figure determined in Section 9 (page 179) would constitute deep

percolation of low TDS water from the underlying TMS along faults.) A depth of 100 m for an aquifer of this nature is also very conservative, as open fractures were encountered at that depth in some of the boreholes. One should probably calculate down to 300 metres, but the flow will diminish with increasing depth.

The ^{18}O isotope studies gave clear evidence that movement of groundwater is taking place at deeper levels in the valley, and that groundwater from the Table Mountain sandstone layers eventually finds it's way into the Poesjesnels River, probably by way of the main fault zones. The ^{3}H content of the artesian boreholes B2 and B4 indicate water which is older than that usually encountered in the Bokkeveld bedrock, and is suggestive of some input from the underlying TMS. However, the ^{18}O content of this artesian water is not particularly depleted and it cannot therefore be directly linked to the underlying strongly depleted TMS groundwater, unless a mixing process can be proved. (The TDS content of B2 and B4 is very high.)

13.3 Alluvial salt concentrations

Although the main emphasis was placed on an examination of the bedrock formations, a number of shallow auger boreholes were sunk into alluvial sand and/or gravel during the course of the project, and some areas of high salinity were found (i.e. > 1 000 mg/l) These are the following:

Borehole	Leachate TDS mg/l	Depth m.
B9	1 844	2.4
B10	3 087	0.4
B11	5 658	1.0
B11	5 557	2.8
D6	2 974	1.0
F6	2 690	2.0
H1	3 557	1.8
H3	1 984	0.6
H4	1 145	0.2

Most of these areas lie below irrigated fields and therefore receive some irrigation return flow seepage. F6 is an exception, and has probably received its salinity from natural runoff draining a terrace slope cut into decomposed shale and topped by thin Bokkeveld soil in the vicinity of position F4. (App. FIG 6.8) Evapotranspiration in low lying areas without effective drainage naturally increases the salt buildup in these soils, but their effects are rather localized and do not pose the same threat as the decomposed shale salt reservoirs.

The leachates from the alluvial samples taken near the Le Chasseur bridge (P1 - P6) showed very little salinity, and bear testimony to the effective drainage and application of low TDS irrigation water in this well developed area.

13.4 Soil characteristics at levels deeper than 1.5 metres have indeed been studied and analyzed by means of auger, percussion and diamond core-drill boreholes and leaching tests, and are presented in many figures and sections.

13.5 The data from this project are hereby submitted for integration into mathematical models for the Breë River catchments and for calibration and testing of such models by modellers of the Department of Agriculture and Fisheries, the HRI the WRC and the CSIR.

We trust that they will be of much use for future planning.

14. RECOMMENDATIONS

14.1 A deep borehole (± 500 m) should be drilled down into one of the fault zones and sampled at its maximum depth by means of a sealed off packer, to test the possible upwelling of TMS water.

14.2 A time series of water sampling of seepage in a drainage stream below untouched veld should be carried out on an hourly basis during a heavy rainfall event in the catchment, and continued until all water has disappeared from the stream. Ripping should then be carried out to different depths over accurately measured areas alongside the drainage stream, and a second set of hourly sampling of seepage carried out following subsequent rainfall events. Analyses of the flow in the stream and the chemistry of the samples will give clearer indication of the release of salts per hectare following agricultural development.

14.3 The volume of high quality water stored in the Sandstone mountain watershed and its exploitation by means of horizontal boreholes should be assessed, as such water could be added to irrigation canals in the catchment. The untapped potential of very high quality water within the Table Mountain sandstone must be explored. Some vertical boreholes have been sunk into sandstone in the area, and yields in excess of $10m^3$ per hour realized. Having seen what Prof. Issar has achieved with horizontal adits into sandstone in Israel, and remembering the enormous flows of water encountered in the tunnels put through the Cape mountains for the Theewaterskloof scheme and the Huguenot Road Tunnel, we should consider at least an attempt to drive horizontal boreholes into the sandstone with a view to intersecting vertical or subvertical brecciated fault zones (such as the one exploited at DJB) at depths not greater than 200 metres. The high quality water so produced, could be used for low-TDS irrigation as well as dilution of return flow runoff and beneficiation of the Breë River water quality.

Ten boreholes in a valley such as the Poesjesnels, intersecting a number of fault zones along their length, could then flow under their own piezometric pressure at 20 to 25 m^3 per hour, giving a total of ± 150 000 m^3 per month. This could be allowed to flow in summer and sealed off during winter for recharge.

14.4 Uncontrolled development of new irrigation areas which entail the deep ripping of thin Bokkeveld soils must be restricted if the salinity levels in the catchment drainage are to be kept within present limits, which are already putting pressure on the Brandvlei - Kwaggaskloof water supply system.

14.5 A high level canal would open up large new areas for irrigation and agricultural production, and the Breë River would have to become the drainage for all the irrigation return flow.

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