LEAK DETECTION FROM MUNICIPAL MAINS WATER SYSTEMS IN THE GAUTENG (PWV) AREA USING ENVIRONMENTAL ISOTOPES

FINAL REPORT

to the

WATER RESEARCH COMMISSION

Investigators:

B. Th. Verhagen and M.J. Butler

Schonland Research Institute for Nuclear Sciences
University of the Witwatersrand
PO Wits, 2050

Report No 628/1/01
ISBN No 1 86845 719 2

CONTENTS

EXECUTIVE SUMMARY

The distinctive stable isotopic composition of imported water supplied by Rand Water in Gauteng is used in a feasibility study to detect leakage from mains supplies. The strategy used is to employ mainly privately owned boreholes as sampling points of ground water. The isotopic contrast between mains water and that of most naturally recharged ground water allows for the determination of the admixture of as little as 10% of mains water. The parameters measured are the concentrations of deuterium and oxygen-18 as fractional deviations from a standard. In addition, environmental tritium is measured in a selection of cases to establish the mobility of ground water. Electrical conductivity, total alkalinity, temperature and pH are measured in the field for supporting information.

In Pretoria, numerous boreholes were sampled in the township of Mountain View, situated on steeply sloping terrain. A fairly uniform increase in $\delta^{18}O$, E.C. and tritium concentration downslope is observed. This increase is ascribed to both natural and anthropogenic processes and provides a detailed insight into the geohydrology of the area. Several boreholes produce $\delta^{18}O$ values which do not conform to the values of surrounding boreholes. Additional deuterium measurements distinguish between isotopic shifts induced by local surface evaporation and mains water respectively. Once identified, the proportion of mains water is calculated. A few complete major ion analyses have clarified the chemical evolution of the ground water and confirmed the dominance of bicarbonate amongst the ions. Tritium concentrations increase downslope, taken as evidence of a change from fracture flow to intergranular flow of ground water.

In townships to the east of Mountain View with a more level topography, and more instances of suspected mains leaks, no coherent geographic isotopic or water quality pattern could be discerned. A few tritium measurements show that in general, ground water is being actively recharged. δD values are on average more positive than for Mountain View. A mean "natural" value of δD for the area was assessed and proportions of main water calculated for anomalously positive cases. These tend to form several clusters, strengthening the conclusion that leakage is occurring in several areas. A few samples from the township of Wonderboom South show a slope dependence similar to, but less pronounced than, at Mountain View.

Ground truthing of leakage sites identified by this method has to date not produced any physical evidence of mains leakage.

As few boreholes could be located in Johannesburg, a system of streams and open culverts in this city's eastern suburbs was sampled in an attempt to identify areas of mains water leakage. Considerable shifts in the isotopic values taken at the same points in August and November show the influence of the rain on stable isotopic values and the seasonal nature of the results. In some cases evaporative shifts in values were observed following rain, indicating the flushing of open water bodies. Much of the stable isotopic variation in the results can be ascribed to evaporation, rather than additions of mains water. It was therefore decided to curtail this aspect of the study.

Three samples taken from water flooding a Johannesburg basement in 1995, thought to be derived from mains water, could be shown unequivocally to be derived from ground water, the level of which had probably risen following heavy rains. This saved costly further investigations. An earlier exercise in identifying the source of increased flow of water into a basement sump, led to the identification of a major sub-surface mains leak which, as a result, could readily be pinpointed and repaired.

The unique isotopic composition of Rand Water mains has been known since the late 70's and confirmed by occasional measurements, which showed minor variations time. With the major rainfall since December 1995, the isotopic composition of mains water underwent a major negative excursion, to stabilize by early March 1997. Since then values are gradually rising. In the absence of further similar rainfalls, it is expected that isotopic values should eventually recover their former, long-term values. The major excursion in isotopic composition has been shown in a case study to act as an excellent tracer of the short-term fate of mains water, and can be useful in a variety of systems. It can also be employed to obtain valuable information on the hydrology of Vaal Dam.

This feasibility study has shown in a very practical way the unique value of environmental isotopes deuterium, oxygen-18 and tritium, in tracing mains water in the sub-surface and generally in understanding urban hydrology. It has further shown that, given the basic techniques, individual problems require unique approaches. Sampling is simple, the measurement technology is standard and the expected costs involved in most investigations modest.

ACKNOWLEDGEMENTS

The members of the steering committee for this project are thanked for their guidance and helpful suggestions:

Mr H. C. Chapman (Chairman), Water Research Commission
Mr P. Coetzee, Municipality of Johannesburg
Mr E. P. Marais, Water Research Commission
Mr F. P. Muldoon, South African Bureau of Standards
Prof R. E. Robinson, University of the Witwatersrand
Mr A. S. Talma, EMATEK, Council for Scientific and Industrial Research
Mr E. van Huyssteen, Municipality of Pretoria
Dr J. C. Vogel, EMATEK, Council for Scientific and Industrial Research

Various officials of the municipalities of Johannesburg and Pretoria are thanked for the information and support provided in the course of this study.

The numerous individual private borehole owners are thanked for their friendly cooperation in obtaining the many samples needed for this project.

The staff of the Environmental Isotope Laboratory of the Schonland Research Centre is thanked for the numerous isotopic measurements.

LIST OF FIGURES

LIST OF TABLES

1. AIMS

To study the feasibility of using environmental isotopes in ground water to locate leaks from Rand Water (RW) supply mains.

2. PRINCIPLES

2.1. Stable Isotopes

The stable isotope ratios of deuterium (^2H) and oxygen-18 (^{18}O) in the water molecule undergo small changes through fractionation processes such as evaporation and condensation [IAEA 1983; Verhagen et al. 1991]. The values for the individual ratios are expressed as δ values which are defined as:

$$\delta = ((R_{sample}/R_{ref}) - 1) \times 1000 ‰ \qquad ...1$$

where R_{sample} and R_{ref} are the isotope ratios ($^2H/^1H$ and $^{18}O/^{16}O$) for the sample and a reference standard, respectively. The universal reference is standard mean ocean water (SMOW). On a graph of δD (or δ^2H) against $\delta^{18}O$, with respect to SMOW, all precipitation (meteoric water) worldwide plots along a linear regression trend called the world meteoric water line (WMWL) (Fig. 1). Isotopic values of ground water derived by direct infiltration of rainwater will likewise fall on the WMWL. Their position on the line will be determined by geographic, climatological and physiographic factors. The isotopic ratios in ground water are conservative in the sense that they are not readily altered by processes in closed systems and the saturated zone. Even where subsequent changes in hydrochemistry might occur, the isotopic composition remains diagnostic of the origin of ground water.

When a surface water body is subjected to evaporation, the remaining water will become isotopically "heavier", but along a regression line of slope smaller than that of the WMWL, called an evaporation line (Fig.1). The slope of this line is determined by the local climate and air moisture conditions, the slope being lower for more arid areas. Water from such water bodies when infiltrating into the sub-surface, will produce ground water with this distinctive isotopic signal.

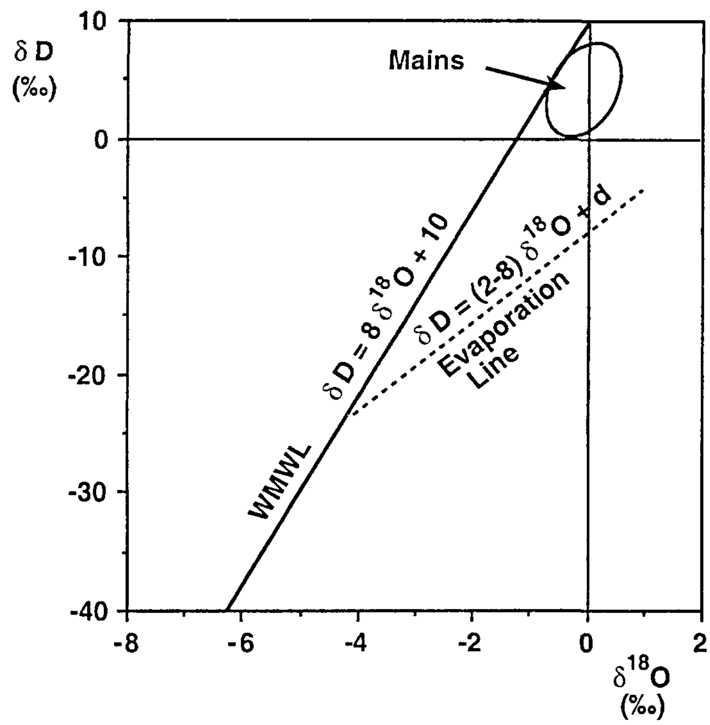

Figure 1 Generalised plot of δD vs. $\delta^{18}O$ showing world meteoric water line (WMWL), an evaporation line, and range of RW mains values (1979-1995)

2.2. Stable isotopes in Rand Water mains supply.

Water supplied by the RW supply system has a distinctive isotopic composition, which varies with time. For many years, the mean δD - $\delta^{18}O$ values were substantially more positive than the expected range of values of natural ground water but lying close to the WMWL (Fig 1). The WMWL thus also approximates a mixing line between the end members of ground water and the mean values for RW mains water. This difference amounted to some 30 x the standard deviation of measurement (±1.5 ‰ for δD; ±0.2 ‰ for $\delta^{18}O$), allowing the detection of down to 5-10% of RW mains water in most ground water. Furthermore, as its isotopic composition lies close to the WMWL, such RW mains water can be readily distinguished from ground water derived from surface water isotopically "heavier" through evaporation.

2.3. Radioactive isotopes

Where the stable isotopes provide information on the origin of ground water, the radioactive isotopes in ground water provide time dependent information [IAEA 1983; Verhagen et al. 1991].

Tritium (^3H) decays with a half-life of 12.32 years. Following the period of increased values due to thermonuclear fallout in the mid-sixties [IAEA 1992], the mid-nineties concentration in rain in Gauteng had returned to about the natural level of 5 TU (tritium units). The minimum detectable value is about 0.2 TU. The decay of tritium in ground water enables the estimation of turnover - or mean residence - times up to 100 years. Interpreted semi-quantitatively, ground water in the study areas with values greater than 1 TU has a turnover of less than 30 years.

3. FIELD STUDIES: INTRODUCTION

Discussions were initiated with municipal officials both in Johannesburg and Pretoria in order to home in on areas suitable for the feasibility study.

In Pretoria, the northern suburbs of Mountain View in the west, and Parktown Estate, Mayville, Roseville, Eloffsdaal and Les Marais on the eastern side of the Apies River, were chosen to conduct a sampling survey on the basis of rather extensive information on private borehole locations. Wonderboom South was added later. A decision in principle to sample basements of major buildings in downtown Pretoria was not followed up.

In Johannesburg, there is only a modest amount of information available on private boreholes. A different approach was decided upon, concentrating on the surface drainage systems in the area comprising Observatory, Dewetshof, Bezuidenhout Valley, Kensington and Bruma, mostly canalised in culverts. These feed Bruma Lake, the outflow of which is the source of the Jukskei River. Much of the water seeping into this drainage system constituting the baseflow was assumed to be derived from mains water. These drainages were to be sampled at various points in order to home in on the sources, which might constitute leakages.

4. SCOPE OF THE INVESTIGATION

A total of 248 samples has been taken during the project. In Pretoria, 111 samples were collected from private boreholes in the Mountain View area and 84 samples in the Parktown Estate, Mayville, Roseville, Eloffsdaal and Les Marais and Wonderboom South area. These numbers include tap and surface water samples.

In Johannesburg 26 samples were taken in the Observatory, Dewetshof, Bezuidenhout Valley, Kensington and Bruma area, mainly from surface streams and culverts, along with samples from a few boreholes, tap water and a basement.

Wellhead measurements were made of temperature, pH, E.C. and total alkalinity in all cases and as much verbal information as possible was gathered on individual borehole conditions and on any known mains leaks.

Isotope analyses generally were done on an ongoing basis, as samples were collected. Some 191 oxygen-18 and 245 deuterium measurements were performed on the samples taken. Deuterium, alternatively oxygen-18, was measured first during periods when the laboratory was set up for the measurement of one or the other of these isotopes respectively. In many cases, both deuterium and oxygen-18 were measured, giving two-parameter analyses.

Tritium analyses were performed on 13 samples. No samples were taken for radiocarbon analysis.

All the isotope data, along with the borehole location and the wellhead measurements of electrical conductivity, pH and total alkalinity are presented in Table 1.

Major ion chemical analysis was performed on 7 samples. The ionic concentrations are presented in Table 2.

Information on sampling point location and the geographic distribution of the isotope and electrical conductivity data are displayed on a series of maps on the three study areas. In addition, correlations between various perimeters and frequency distributions are presented in a series of graphical plots.

Information on borehole construction and depth could be obtained from only three individual householders in Mountain View. Clearly, interpretation of the data would have been significantly enhanced, had such information been more widely available. On the other hand, a substantial number of previously unrecorded boreholes was discovered in Pretoria, and their locations has been added to the database.

5. PRETORIA

5.1. Mountain View

5.1.1.Introduction

The township of Mountain View (Fig.2) on the southern slope of the Magaliesberg, has been in existence for some 60 years. Its mains reticulation system was reported to have been extensively renewed in the early 90's.

The Mountain View area was selected to initiate the survey, as it has a high density of known boreholes, and on account of the steeply sloping terrain (see Fig. 5) with an upper boundary to the built up area. These factors were seen as particularly advantageous for this study. It was assessed that, where there are no mains leakage points in the immediate vicinity, the boreholes situated highest up the slope should reflect natural stable isotope values for ground water. Any mains water leakage would tend to follow natural drainage and be reflected in boreholes downslope from the leakage points.

The sampling density finally achieved in Mountain View might be regarded as excessive for an operational survey. On the other hand, it provides an idea of the resolution attainable in an area with a similar population of boreholes.

5.1.2. Discussion of isotope and field data

The areal distribution of $\delta^{18}O$ values is shown in Figure 3. Immediately obvious is

- the rather gradual increase in $\delta^{18}O$ values downdip over the entire E-W extent of the township and
- the very negative $\delta^{18}O$ values found along the top of the slope.

In a number of cases the δD values were also measured. These pairs of values are plotted in the δD - $\delta^{18}O$ diagram in Fig.4. From this diagram it is clear that the range of observed $\delta^{18}O$ values is not influenced by evaporation, but generated by

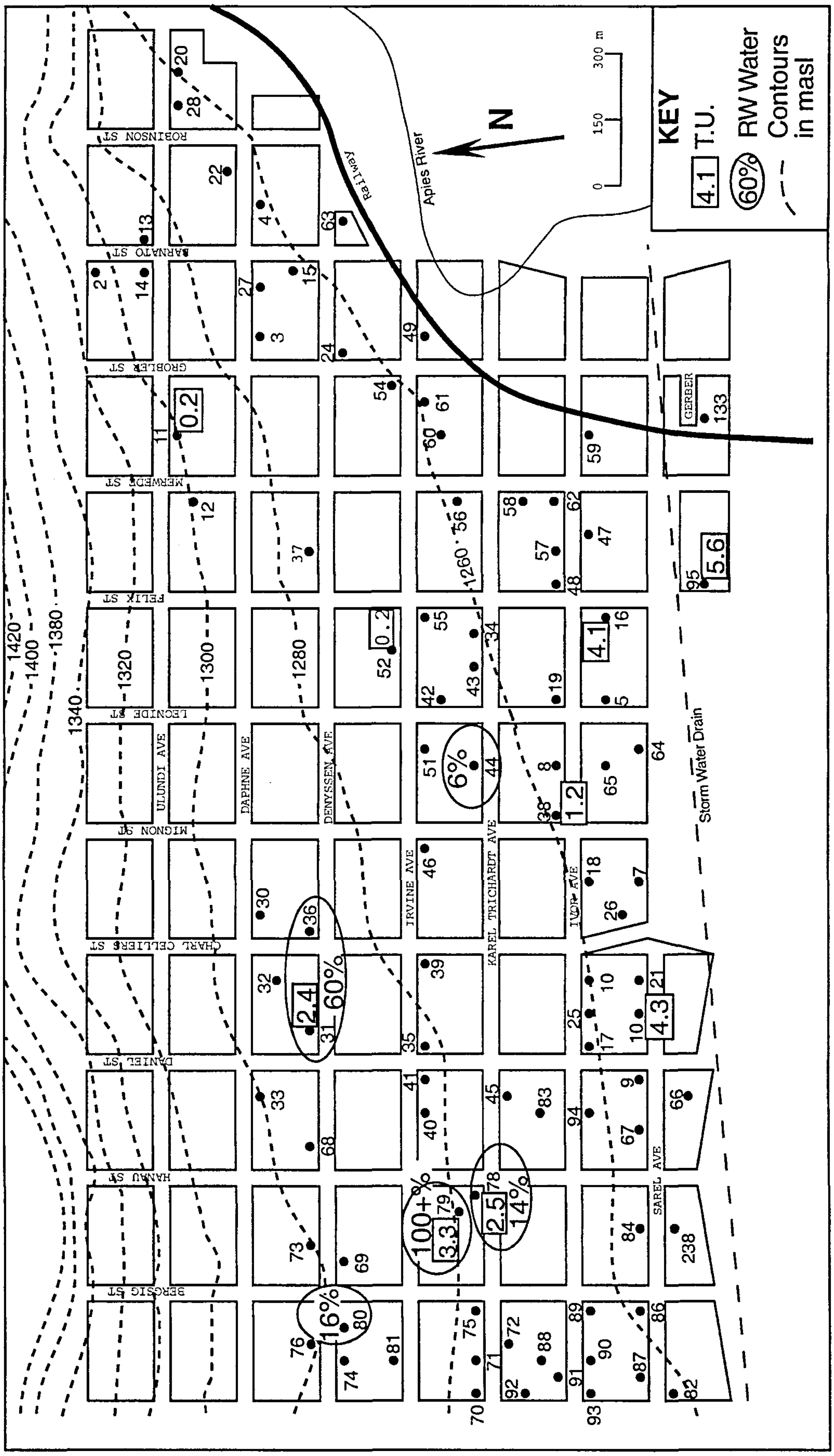

Figure 2 Map of Mountain View township, showing sample numbers (Table 1), tritium values and estimates of the percentage of mains water (see Section 5.1.5.)

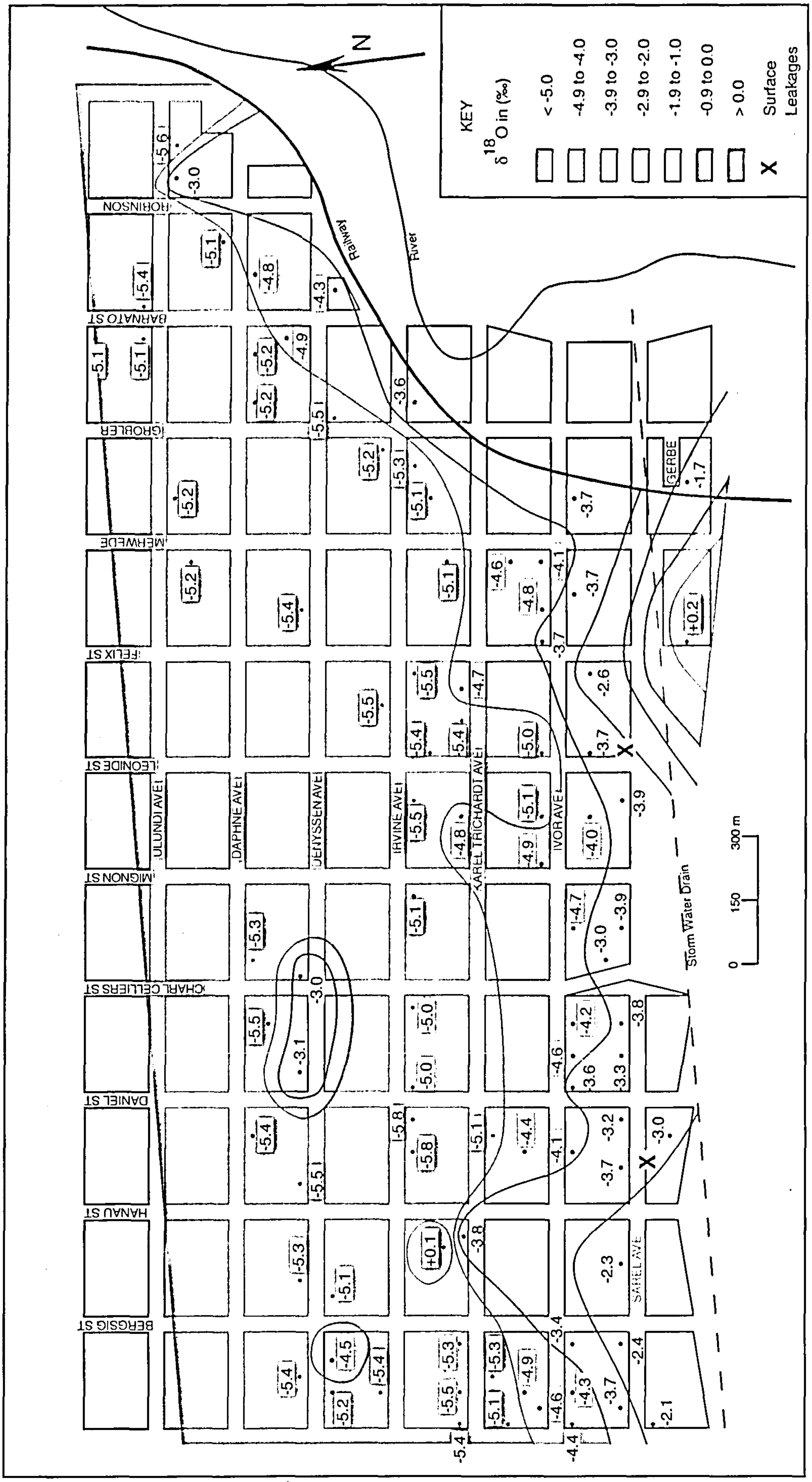

Figure 3 Map of Mountain View, showing δ18O values and zones of equal stable isotope composition. Two sites of surface expression of leaks are indicated.

- a natural gradient in rain recharge values, resulting from a rainfall selectivity/altitude effect/rain shadow effect, and/or
- a mixture of natural ground water with mains water.

Of the three possible natural effects, only the first (i.e. recharge selectivity) could produce a significant stable isotope shift away from the weighted mean precipitation, the long-term $\delta^{18}O$ value for Pretoria being some –3.7 ‰ [IAEA, 1992]. The selectivity will change with slope, and be at its most pronounced where the slope is greatest, i.e. at the highest point in the suburb. The altitude effect can account for at most some 0.2‰. The local micrometeorology is not known in any detail which could suggest a rain shadow effect. As most rainstorms originate in the south, this effect will be minimal. A similar, but less pronounced slope effect was observed for ground water in Wonderboom South (Section 5.2.2).

5.1.3. Proposed hydrological model

Very little information could be obtained on individual boreholes. The depths of three boreholes were reported and these are indicated on the profile in Figure 5. As no water levels could be established, a schematic ground water surface is portrayed by way of illustration. The considerably deeper boreholes higher up the slope are likely to have struck water in deeper fissures and joints of the unweathered quartzite well below the water table, i.e. the water could be locally confined. In the valley, boreholes would tap water in shallower weathered material and alluvium which would provide the main borehole yield. This model is given support by the tritium measurements shown in Figure 2. High up on the slope the values of 0.2 TU (limit of delectability) show mean residence times in excess of 100 years, whilst increasing tritium values downslope, to more than 4 TU, show turnover times of 30 years and less.

Ground water higher up the slope and deeper in the aquifer is therefore recharged under conditions different from those pertaining near the bottom. The depth of weathering is likely to increase downslope and recharge higher up the slope may drain downslope through interflow more rapidly than displacing the deeper ground water. The high $\delta^{18}O$ values at the bottom of the slope tending towards 0 ‰ suggest that the ground water there contains a substantial proportion of mains water.

The range of some 4 ‰ in $\delta^{18}O$ (or 32 ‰ in δD) observed for ground water in the area is therefore taken to be produced both by exceptional rainfall selection on the one hand and by mixing with mains water on the other.

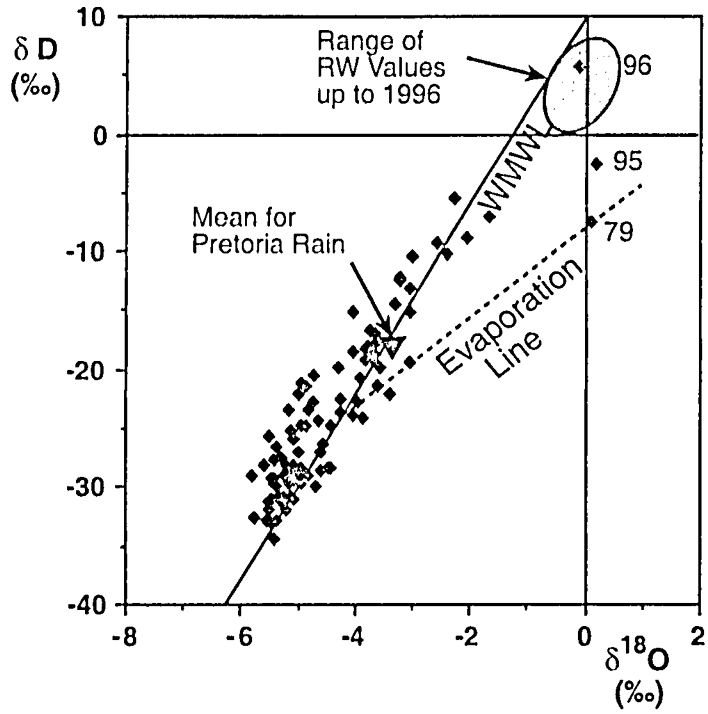

Figure 4 δD vs. $\delta^{18}O$ plot for Mountain View, showing the WMWL and a possible evaporation line.

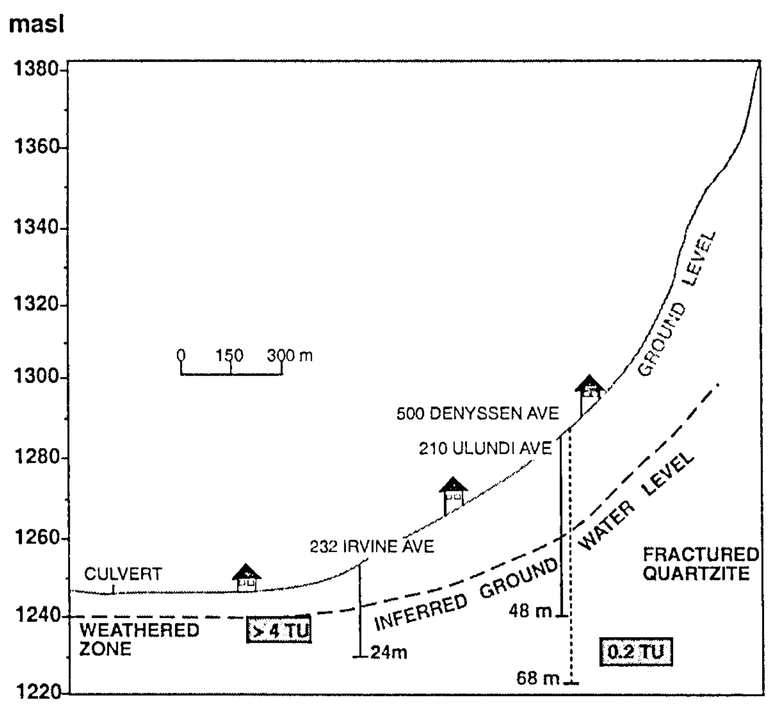

Figure 5 N-S Section of the surface topography of Mountain View, showing three boreholes for which depths could be ascertained. An inferred ground water level is shown by way of illustration.

5.1.4. Source apportionment

The areal distribution of total dissolved solid concentrations (as reflected by E.C.) in the ground water of Mountain View (Fig. 6) resembles that of the $\delta^{18}O$ values. This is confirmed by the correlation seen in the plot of E.C. vs. $\delta^{18}O$ for all available sampling points (Fig.7). A significant correlation can also be seen in the plot of alkalinity against E.C. (Fig.8), which suggests that an important component of the total dissolved solid load of the ground water in the area is made up of alkalinity. The low E.C., low alkalinity, low $\delta^{18}O$ group clusters closely in both correlations. Alkalinity for this group (E.C. < 25 mS/m) is plotted separately in Figure 9. This again shows a clear correlation, but with a slope greater than for the whole data set. This further underlines the somewhat different nature of ground water higher up on the slope. The higher $\delta^{18}O$ values near the bottom of the slope are ascribed in part to the admixture of RW mains. RW mains water however has a relatively low alkalinity. The underlying process is therefore interpreted as the infiltration of mains water applied at or near surface, e.g. through garden irrigation. In this way, the mains water changes its chemical characteristics, mainly through accumulating bicarbonate alkalinity in a manner similar to natural recharge, but retains its isotopic signature.

Several sampling points (#31, #36, #44, #78, #79 and #80) identified in Figs. 3 and 6 are regarded as anomalous w.r.t. the surrounding isotope values.

The value of $\delta^{18}O$ = + 0.12 ‰ for #79 some distance up the slope is somewhat more positive than expected for mains water. The value of –3.84 ‰ for #78, almost directly downslope, is at least 1 ‰ more positive than elsewhere in this zone. Values of –3.05 ‰ and –3.07 ‰ are found for #31 and #36 respectively, high in the township in an environment of ground water some 2 ‰ more negative.

The δD-$\delta^{18}O$ diagram (Fig.4) shows that most of the ground water results lie on or close to the WMWL / mains water mixing line. Any anomalously positive values can therefore be interpreted as due to mixing with mains water. The two exceptions (#79 and #95) lie off the WMWL and are clearly the result of surface evaporation. A possible evaporation line is shown in Figure 4 by way of illustration. Genetic association with RW mains is therefore difficult to determine in these two cases. In addition, they are both associated with high (>110 mS/m) E.C. values.

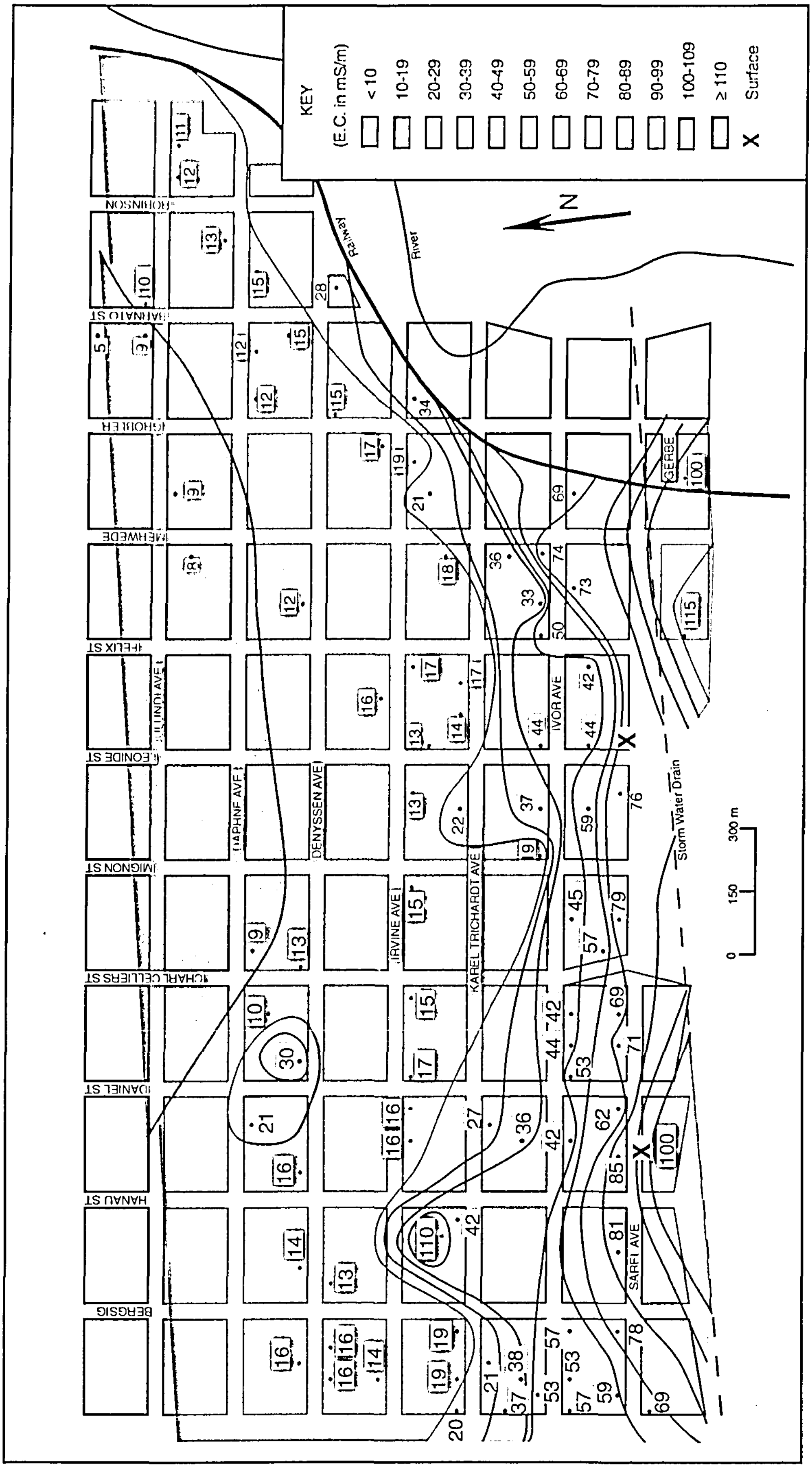

Figure 6 Map of Mountain View, showing E.C. values and zones of equal ground water mineralisation.

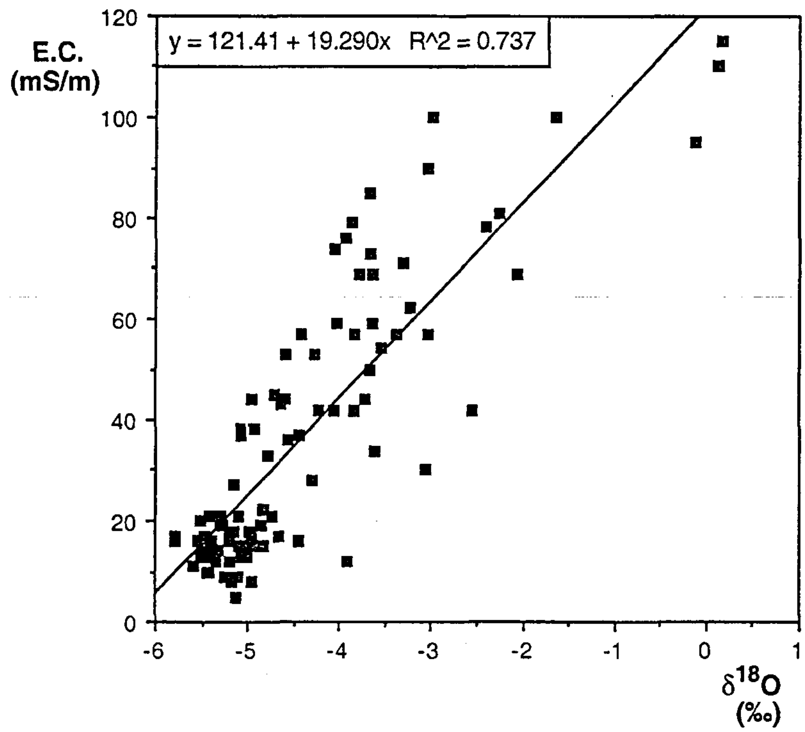

Figure 7 Plot of E.C. against $\delta^{18}O$ for Mountain View ground water. Note cluster in the low E.C., low $\delta^{18}O$ sector.

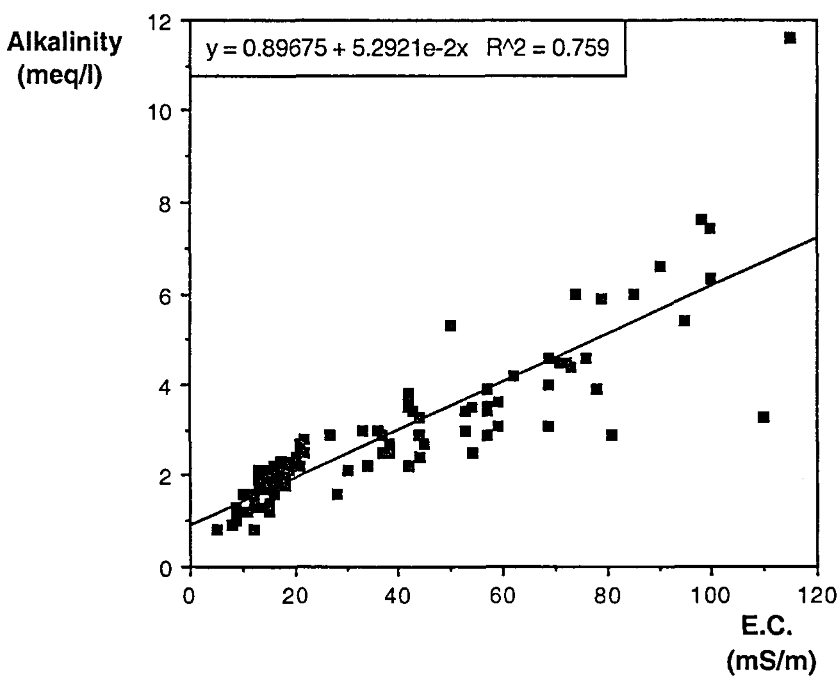

Figure 8 Plot of alkalinity against E.C. for Mountain View ground water. Note different trend for low E.C., low $\delta^{18}O$ cluster (cf. Figure 7).

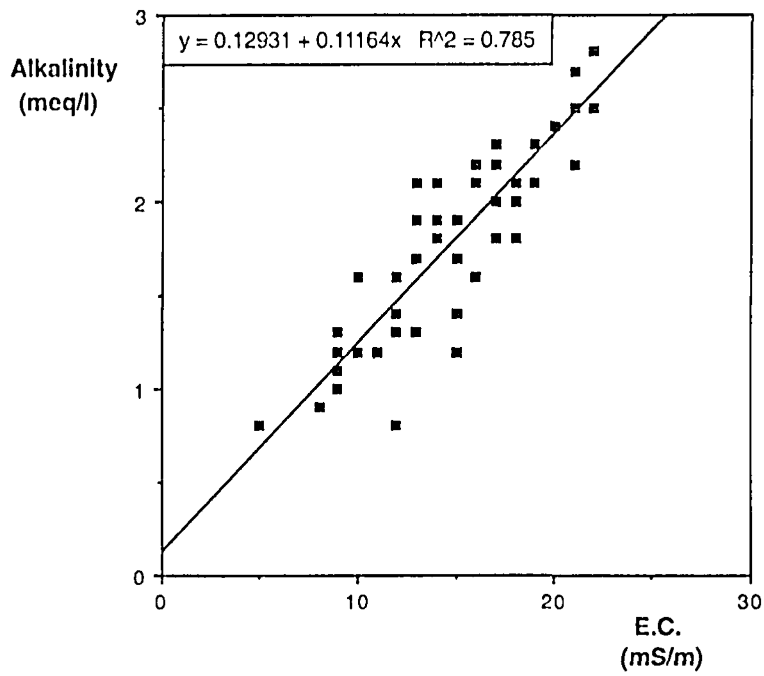

Figure 9 Plot of alkalinity vs. E.C., a detail of the cluster for E.C. values <25 mS/m (Fig. 8). Note greater slope.

5.1.5. Calculating mixing ratios

The percentage p_m of mains water for the various points on or near the WMWL / mixing line can be calculated from the equation:

$$p_m = \frac{\delta - \delta_g}{\delta_m - \delta_g} \times 100 \qquad .....2$$

where δ is the measured value in the sample, δ_g the estimated background value in the ground ıter of the area and δ_m the value in mains water. In calculating the percentages, δ_g was taken to be the mean value for the zone in which the point lies. δ_m (in this case $\delta^{18}O$) was taken to be –0.5 ‰.

The calculated percentages are shown for the various points in Figure 2. The result for #79 was obtained using the same criteria, giving a value of > 100 %. This value is very local. The outlier isotope values for #78, in close proximity downdip, are on the WMWL. The value for #95 again gives an evaporation signal. Although in close proximity to the storm water drain (#96), which at the time of sampling contained almost pure mains water, it must be derived from another source. As the mean δ_g value for the bottom of the valley is difficult to assess, no meaningful calculation of percentage could be made for e.g. #95.

It has not been possible to establish the nature of the sources of the anomalous results through ground truthing during the project period.

5.1.6. Chemical analyses

In order to assess and generalize some of the conclusions based on the field observations of E.C., total alkalinity and pH, a number of samples from the Mountain View area was taken for analysis of major ion concentrations. Sample sites were chosen to represent the main E.C. zones depicted in Figure 6, and include one for which a significant mains water component was identified. The analytical results are presented in Table 2.

Results are represented in a Schoeller diagram (Fig.10) and a Piper diagram (Fig.11). The following observations can be made:

1. The concentrations of all major cations and anions increase downslope accompanying the increase in E.C.
2. HCO_3 is the dominant anion in all cases, confirming field observations for the "background" samples.
3. The ionic ratio moves away from Ca, Mg-HCO_3 dominance as one moves downslope, due mainly to the increased proportions of chloride and sulphate.
4. The ionic composition of 542 Denyssen, interpreted on isotopic evidence as containing some 60% mains water, is similar to that of ground water in the lower part of the township.

A plot of alkalinity against conductivity for the 7 samples (Fig.12) shows the same relationships for the samples from the upper and lower parts of the township as were observed for the entire body of field data (Fig.8).

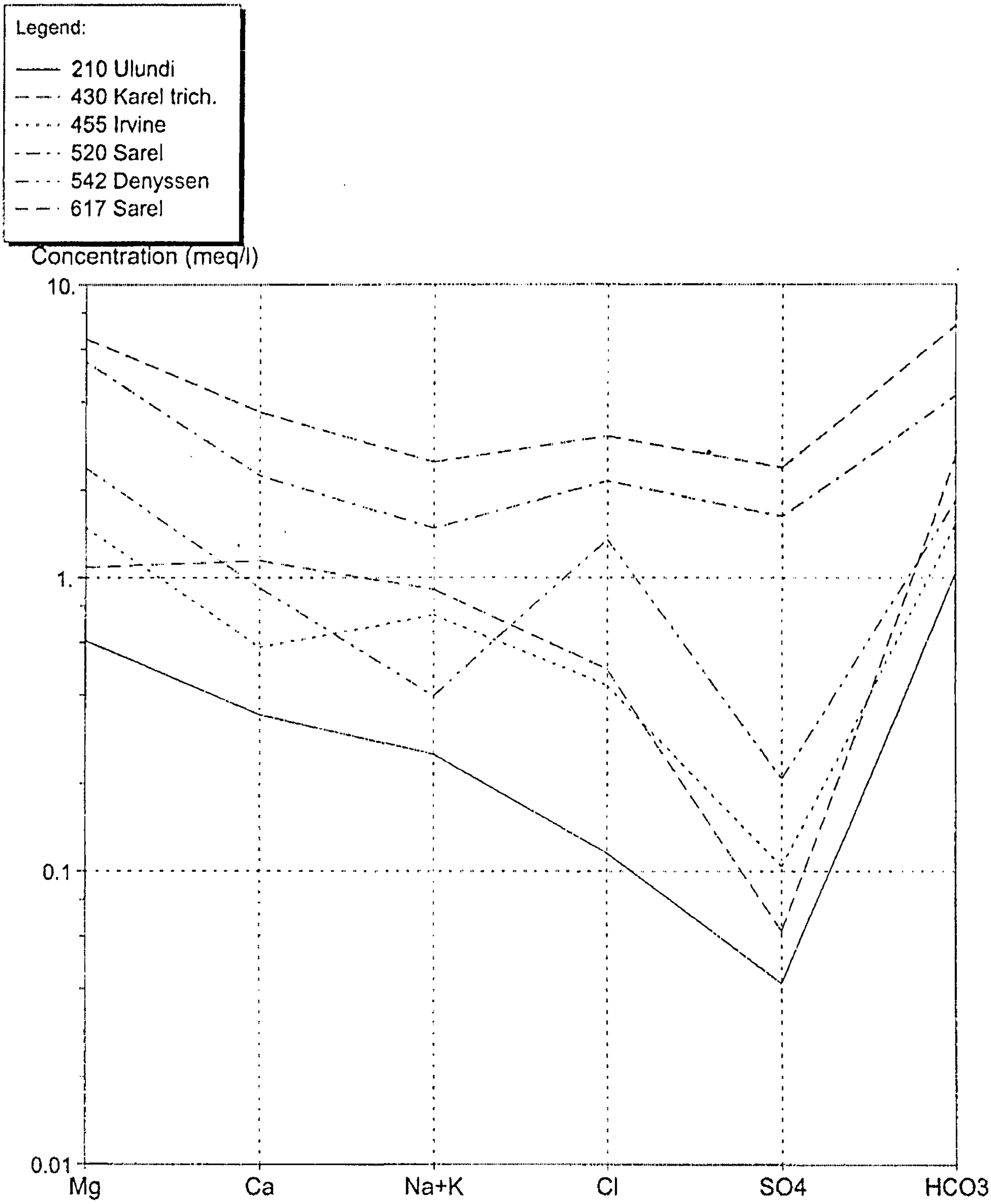

Figure 10 Schoeller diagram of major ion concentrations in selected samples from Mountain View.

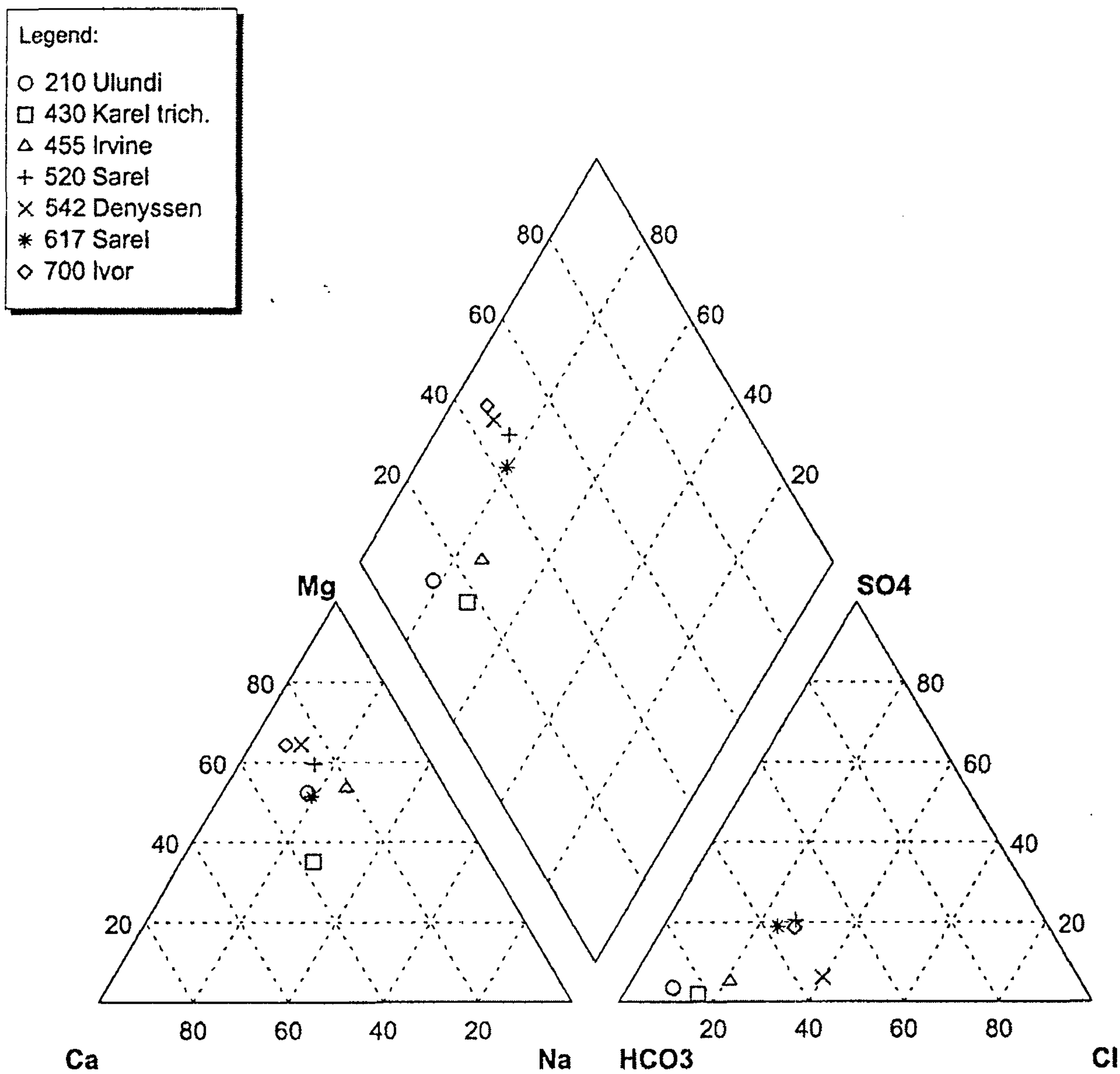

Figure 11 Piper diagram of major ion concentrations in selected samples from Mountain View.

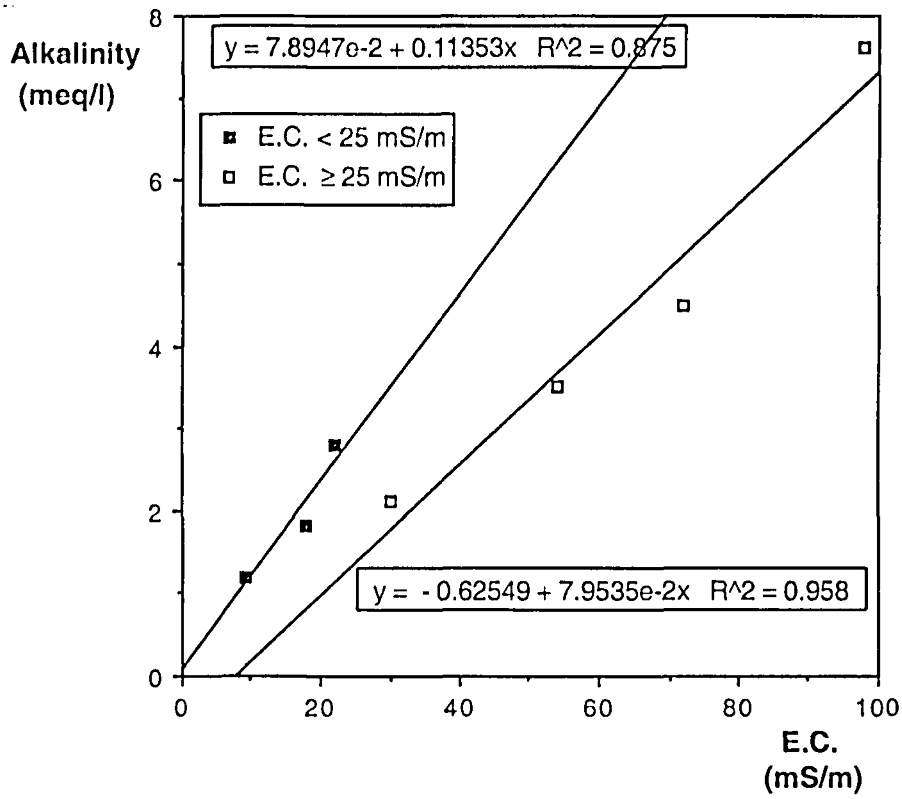

Figure 12 Plot of alkalinity vs. E.C. for selected samples from Mountain View, analysed for major ions. Note differences in slope for high and low E.C. groups (cf. Fig. 8).

5.1.7. Conclusions

The study in the township of Mountain View has elucidated some basic aspects of its geohydrology. Reports from the Municipality of Pretoria indicate that the reticulation system in the township of Mountain View had been substantially rehabilitated in the early 90's and leaks effectively eliminated. This seems to be confirmed by the isotopic pattern, which is surprisingly regular, and based on a rather dense sample coverage. Only a few exceptional point sources could be identified, of which two have been subject to evaporation before infiltration, i.e. from surface water bodies. The others are ascribed to mains water leakage. The very low $\delta^{18}O$ values at the top of the slope are ascribed to rainfall selectivity. The high $\delta^{18}O$ values at the bottom of the slope might be the result of downslope flushing of infiltrated mains water higher up in the township.

5.2. Townships to the east of the Apies River.

5.2.1. Introduction

The second study area in Pretoria lies to the east of the Apies River and comprises the townships of Parktown Estate, Mayville, Roseville, Eloffsdal and Les Marais (Fig.13). The area was reported as being subject to many unrehabilitated water mains leakages. The surface slope is very gentle and dipping northwards. The ground water level is assumed to have a similar slope in the same direction. These two factors were expected to present a geohydrological contrast with Mountain View.

In order to confirm the slope-dependent data obtained in Mountain View, a number of samples was taken in Wonderboom South, late in the project. This S-W facing sloping area is hydrologically separated from the adjacent townships by a streambed (Fig.13).

The cluster of townships, henceforth referred to as "eastern townships", represents an extensive area. To maximize the coverage for a minimum number of samples, three E-W lines of boreholes were sampled initially. Subsequently, the coverage was extended. Sampling points with numbers are shown in Figure 13. The wellhead observations and isotope data are shown in Table 1. As the laboratory was geared to the measurement of deuterium at the time of the first major sampling, this was the parameter measured on all samples. Some $\delta^{18}O$ analyses were subsequently performed.

5.2.2. Discussion of isotope and field data

As can be seen in Figure 14, the geographical dependence of stable isotopic values (δD) differs quite markedly from Mountain View. In the frequency histogram shown in Figure 15, strikingly different mean δD values, and only a limited overlap in range, is seen for the two areas. Except for the low values of δD in Wonderboom South and the rather higher values in the extreme west, no clear areal systematics can be discerned in the eastern townships. No major natural geographical trends in the isotopic composition of ground water were expected in this area with its rather flat topography, which implies slow ground water movement.

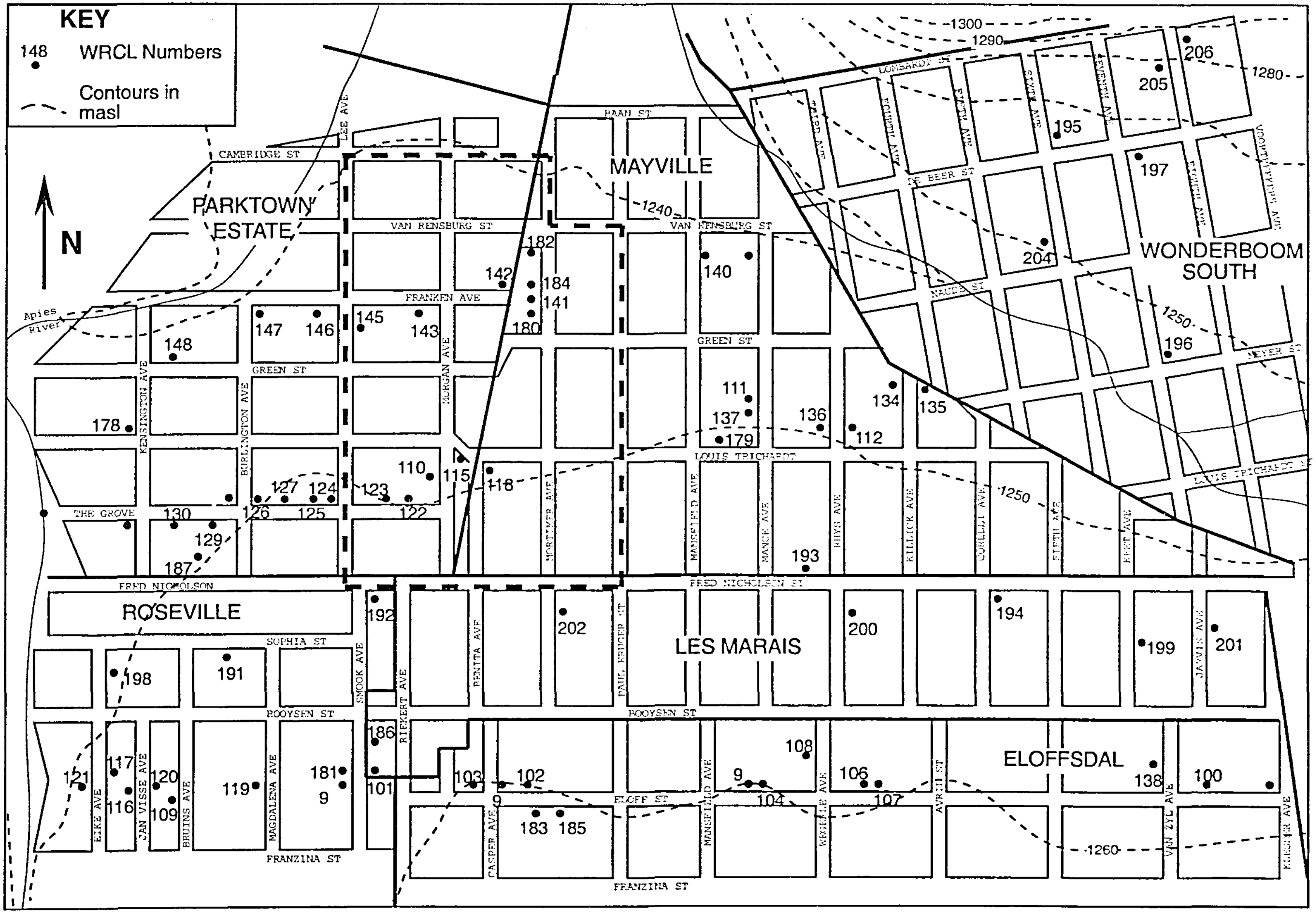

Figure 13 Map of "eastern townships", east of the Apies River, showing location of sampled boreholes and sample numbers (Table 1). For detail, outlined ------ see Figure 30.

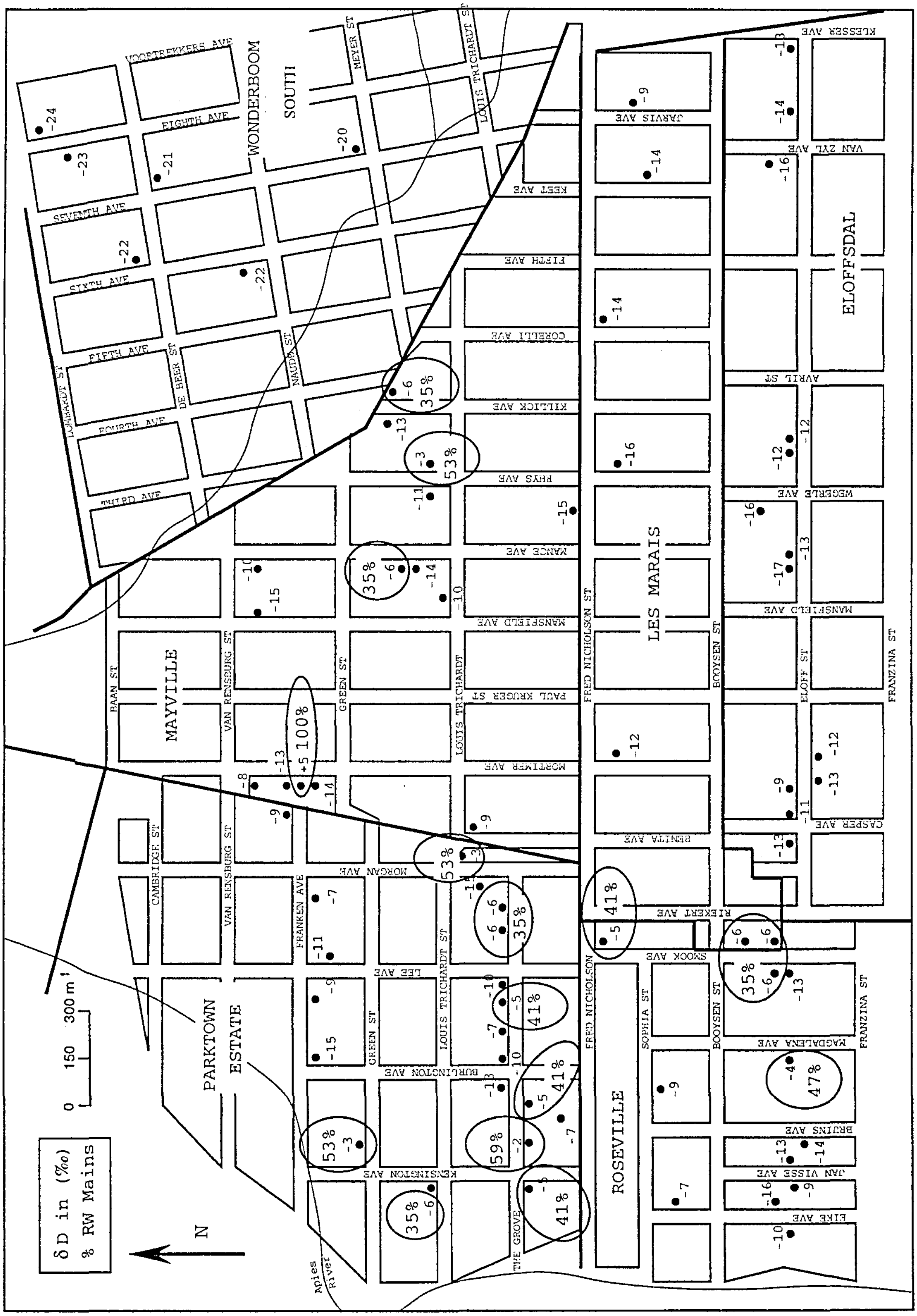

Figure 14 Map of "eastern townships", showing δD values in ground water and estimated percentages of mains water.

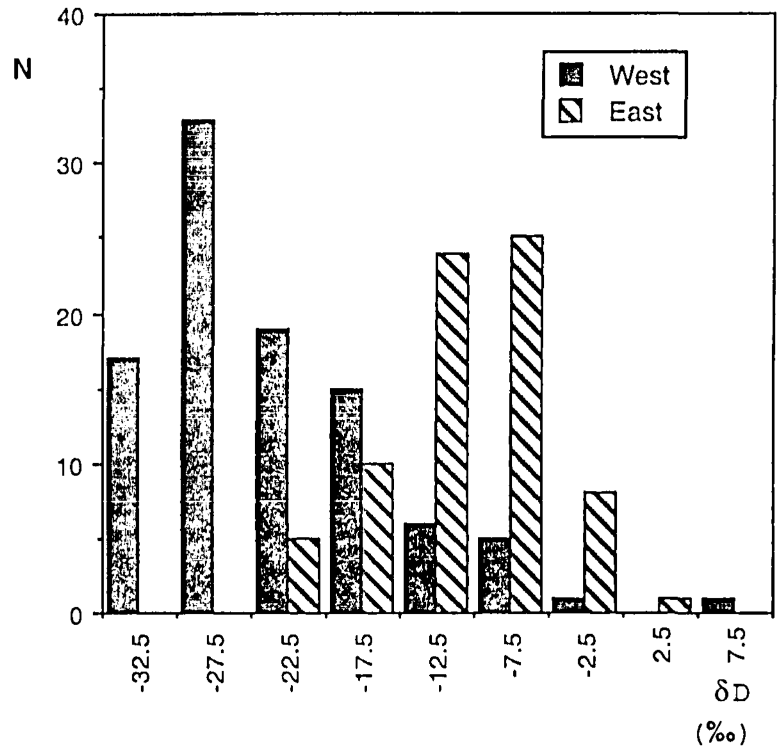

Figure 15 Frequency histograms of δD values for the "eastern townships" and Mountain View. Note the difference in distribution.

Ground water E.C. values for the eastern townships are shown on a map in Figure 16. For the greater part of the area a discernible pattern, as in Mountain View, could not be observed. Values are somewhat lower in the higher-lying terrain of Eloffsdal, and more markedly so on the SW hill slope in Wonderboom South.

As in Mountain View there is a clear correlation between alkalinity and E.C. (Fig.17), showing that in general the ground water undergoes normal hydrochemical development in the soil zone with HCO_3 dominance. In contrast, Figure 18 shows that there is practically no correlation of E.C. with isotopic composition, confirming the absence of trends expected due to the low slope of the area. A further influence might be the expected existence of numerous mains leaks. This is suggested in the peak of the δD frequency distribution for the eastern townships (Fig.15) falling on the higher end of the range for nearby Mountain View. It is further emphasized by the comparative distributions of $\delta^{18}O$ for the eastern townships and for the values [Simpson 1990] obtained for a wider spread of samples from Pretoria townships (Fig.19).

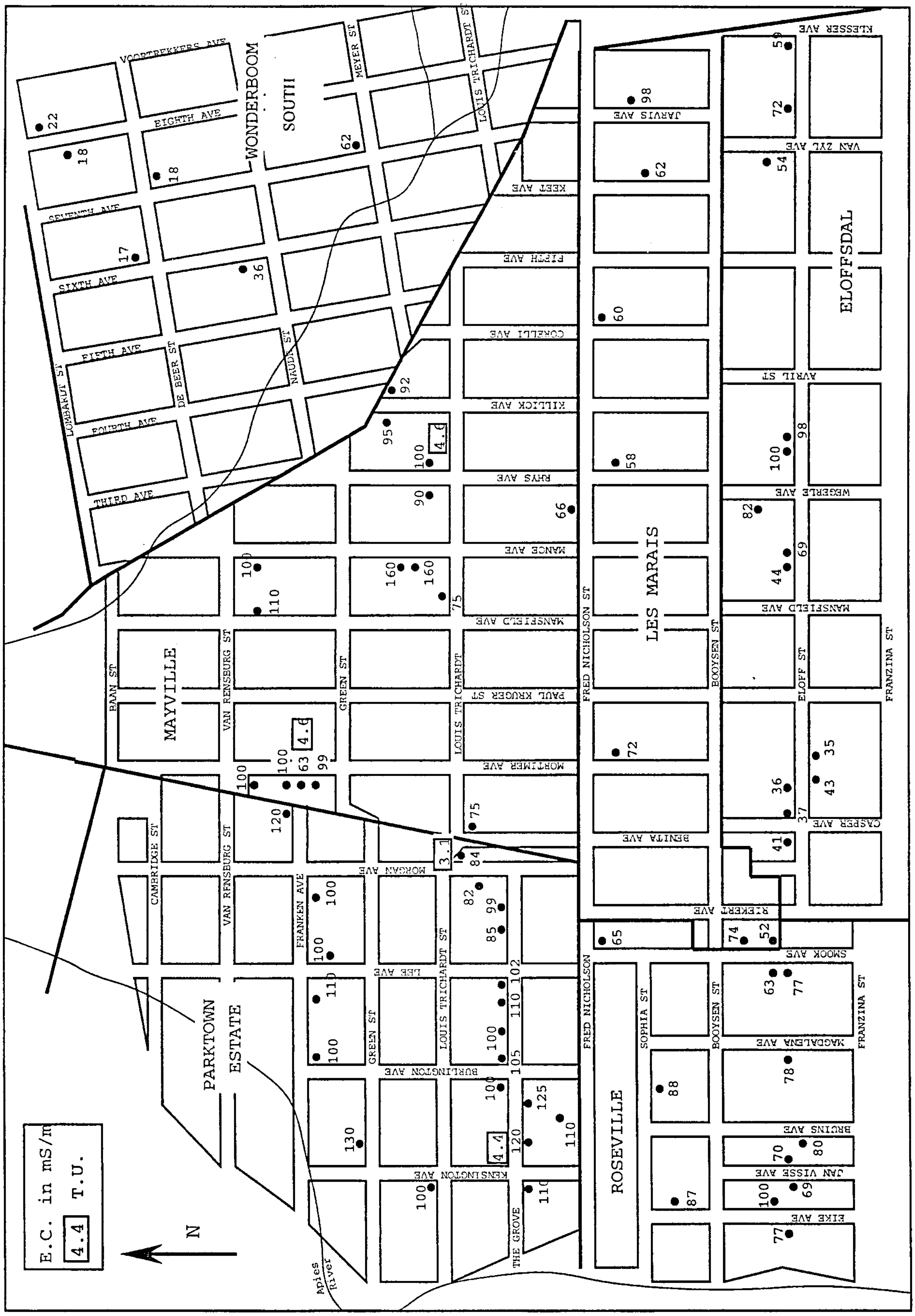

Figure 16 Map of the “eastern townships”, showing ground water E.C. and tritium values. Note lower E.C. values in the higher terrain to the south and north-east.

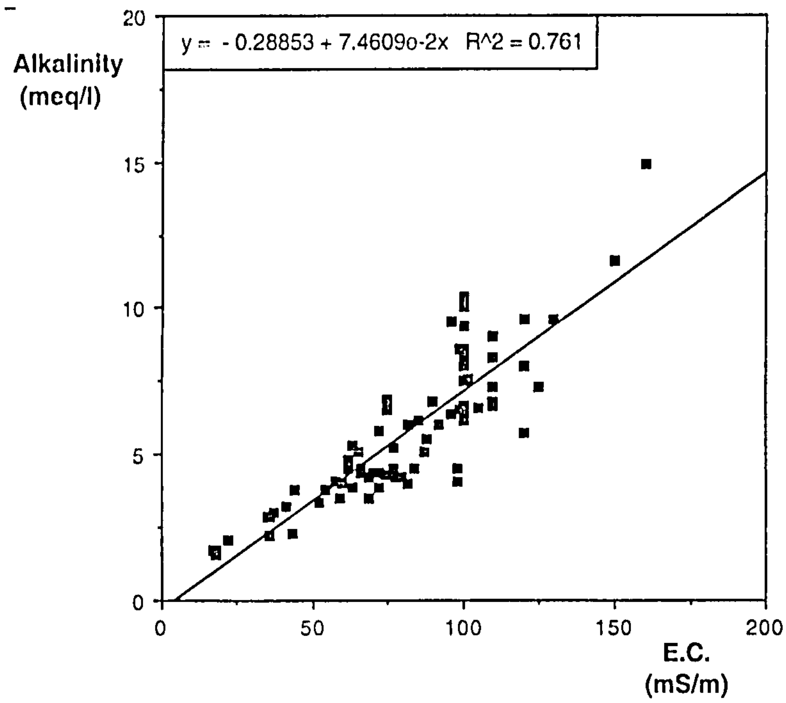

Figure 17 Plot of alkalinity vs. E.C. for ground water in the "eastern townships".

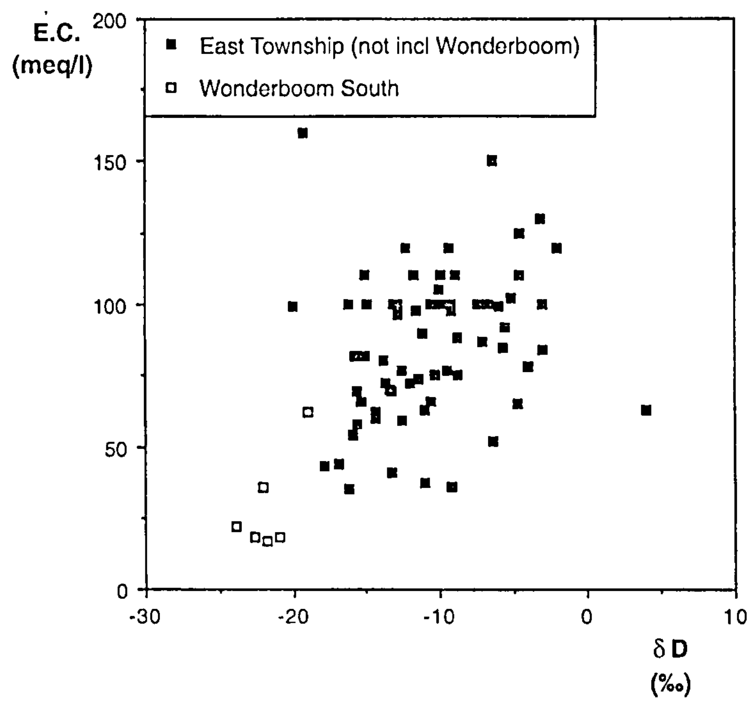

Figure 18 Plot of E.C. vs. δD for ground water in the "eastern townships". Note: tighter cluster for Wonderboom South.

The pairs of δD-$\delta^{18}O$ values available are displayed on the diagram in Figure 20. There is a degree of scatter, but the data points can be taken to fall on the WMWL / mains water mixing line. There is a fair number of points which have $\delta D > -7$ ‰. These are taken to be cases with clear mains water influence (see also histograms, Figs. 15 and 19). When the mean background value is calculated for the set of eastern suburbs data, from which these positive cases, as well as the values for Wonderboom South, were removed, a value of δD=-12 ‰ is obtained. Although this value may have a bias on account of the selection of sampling points, and might be somewhat too positive, it is arrived at on the basis of firm criteria and is taken as the natural ground water end member for the terrain. The percentage mains water p_m in the postulated mixtures is then calculated using Eqn 2.

The assessed mains water percentages for the eastern suburbs, based on deuterium values, were calculated using δ_g = -12 ‰ and δ_m = +5 ‰, and are shown on the map in Figure 14. The most negative value considered was δ = -6 ‰, which gives a corresponding value of p_m = 35 %. Lower percentages were regarded as too imprecise. In the light of the probably too positive estimate of δ_g, these percentages are therefore conservative.

In only one case (#141) was essentially pure mains water encountered. All the other cases lie at <60 %. They do, however, constitute a fair proportion of the samples taken. This confirms the suspicion that the area is prone to extensive mains leaks. There is a suggestion of clustering of these points, although this may be partially influenced by the sampling coverage.

A few tritium measurements were performed to give an overall idea of the residence time for the eastern townships. These values ranging from 3.1 to 4.6 TU are presented in Table 1 and shown in Figure 16. Although the coverage is sparse, it does suggest that ground water mean residence times in these townships are generally less than 30 years. An average borehole penetration of the saturated zone of 20 m, and an aquifer porosity of 0.1 are assumed. Using the well-mixed model [Verhagen et al. 1991], this represents a minimum equivalent rain recharge rate of ~65 mm a^{-1}. Ground water is therefore responding actively to surface and near-surface water inputs.

The δD results for Wonderboom South (Fig.14) are more negative than the spread of values found in the adjacent townships, and there is a degree of slope dependence. This confirms and generalizes the results obtained for Mountain View, the gentler slope in Wonderboom

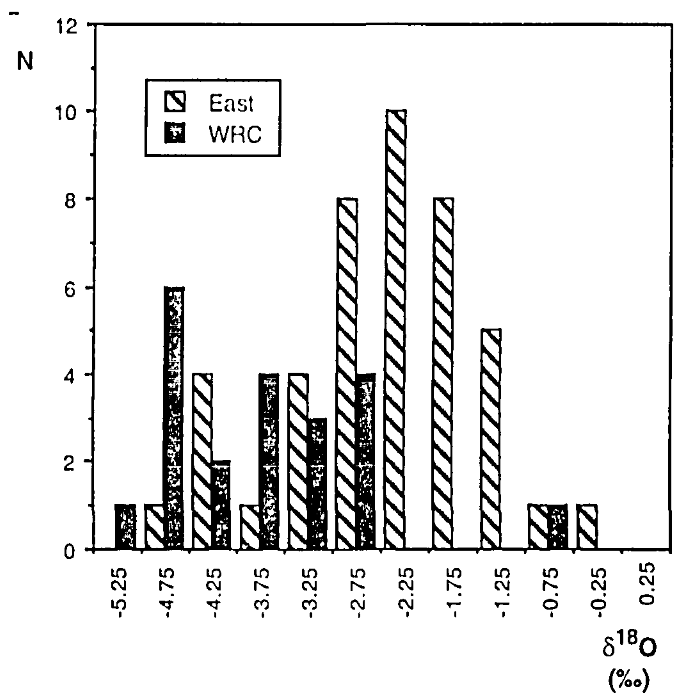

Figure 19 Frequency histograms of $\delta^{18}O$ values in ground water for the "eastern townships" and other Pretoria townships [Simpson, 1990].

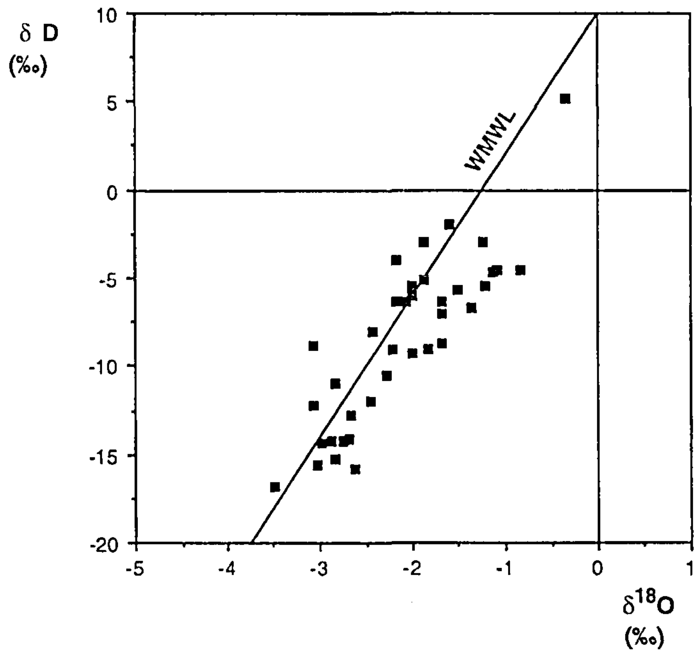

Figure 20 Plot of δD vs. $\delta^{18}O$ for ground water in the "eastern townships". Note one almost pure RW mains case.

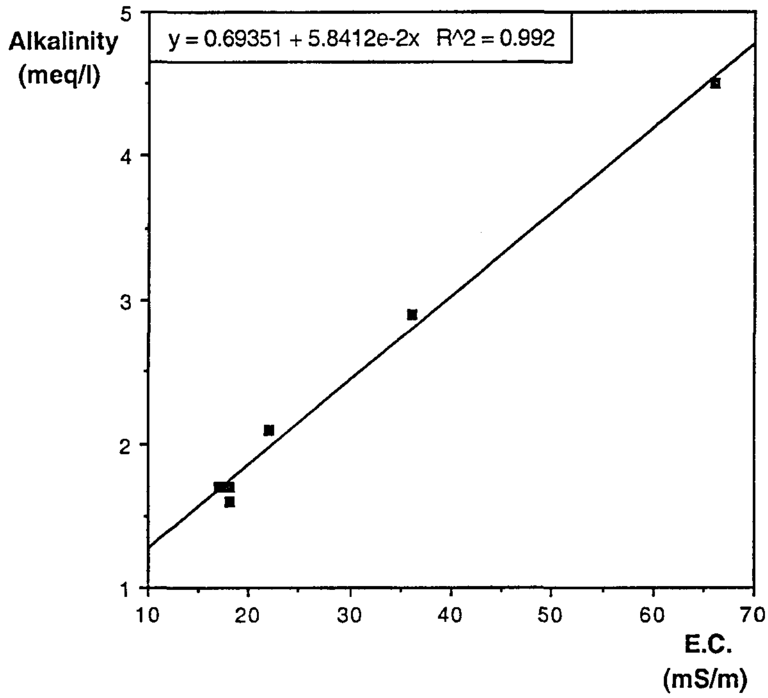

Figure 21 Plot of alkalinity vs. E.C. for Wonderboom South samples.

South being reflected in a less pronounced isotope contrast. The slope of the alkalinity vs. E.C. plot (Fig.21) is similar to that of the topographically higher group in Mountain View.

5.2.3. Conclusions

As expected from the different physiography, isotopic and dissolved solid distributions are quite different for the eastern townships as compared to Mountain View. A substantial number of cases was identified where the isotopic value at sampling points suggests the admixture of significant amounts of mains water. The initial impression of clustering at these points was confirmed by increased sampling density, but still influenced by the initial strategy of sampling. Ground truthing by municipal officials has not produced any clear association of these results with traceable mains leaks.

6.JOHANNESBURG

6.1.Introduction

The approach to the study in Johannesburg differs from that in Pretoria, in that surface water was sampled as a reflection of seepages of shallow ground water. An initial survey was conducted in the suburbs of Observatory, Cyrildene, Bruma, Kensington, Dewetshof and Bezuidenhout Valley (Fig.22). A total of 27 water samples has been taken. These were from streams and open culverts during two sampling periods: the first in August 1994 and the second in November 1994 on the day following a major rainstorm in the area. In addition, the only two boreholes which could be located in the area (#154 and #175), and some seepages on the southern slope of Linksfield Ridge, were sampled. The location of sampling points is shown in Figure 22. Details of the samples are given in Table 1, along with field measurements and isotope data.

6.2. Discussion of isotope and field data

Deuterium was measured on all samples, as the laboratory was set up for the measurement of this isotope during the collection of the basic sample set. The geographic spread of the δD values for the two sets of samples (August 1994 and November 1994) is given in Figure 23. The shift in δD values between the sample sets is illustrated in Figure 24. Some large shifts are observed, especially in the north-west channel, which in November was still flowing more strongly than the usual baseflow, and in the main channel.

$\delta^{18}O$ values were determined for most of the samples. The δD-$\delta^{18}O$ diagram for the entire sample set is shown in Figure 25. This suggests that although a number of the results follow the WMWL, several show considerable kinetic evaporation. The most extreme case (#165 / #173), the culvert flowing into the lake from the south, was diluted somewhat by the rain. The culvert below Rhodes Park dam (#164 / #175) showed an unexpected shift away from the WMWL to a distinctly evaporative signal following the rain event. This probably represents a transient flushing of evaporated water by the increased flow rate induced by the rain. The two ground water samples (#154, #175) lie very close to the long-term weighted mean for precipitation in Pretoria [IAEA, 1992]. The seepages??at the golf club (#152, #153, #155, #167) indicate minimal influence of mains water.

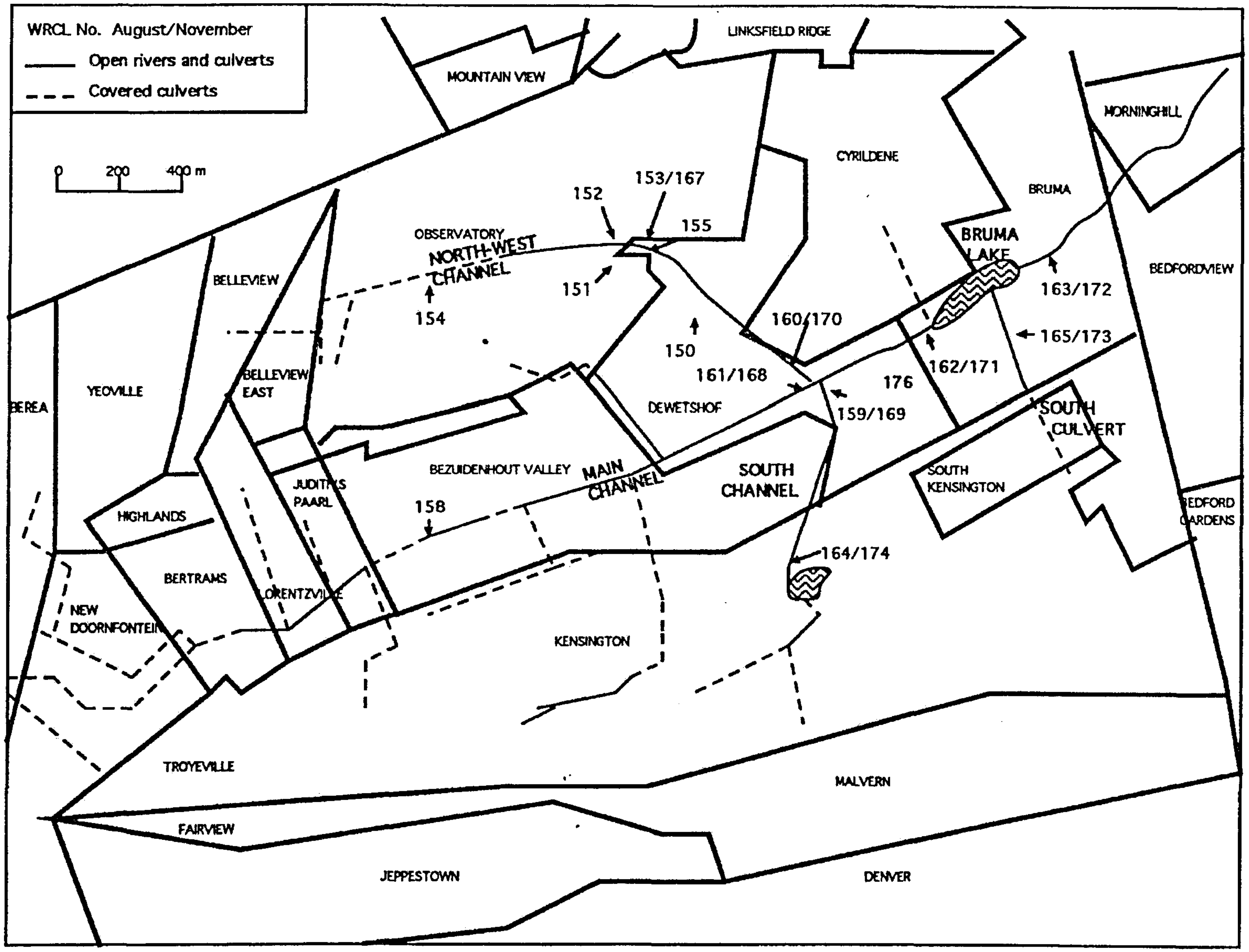

Figure 22 Map of townships in the Johannesburg study area, showing surface drainages and locations of sample numbers (Table 1).

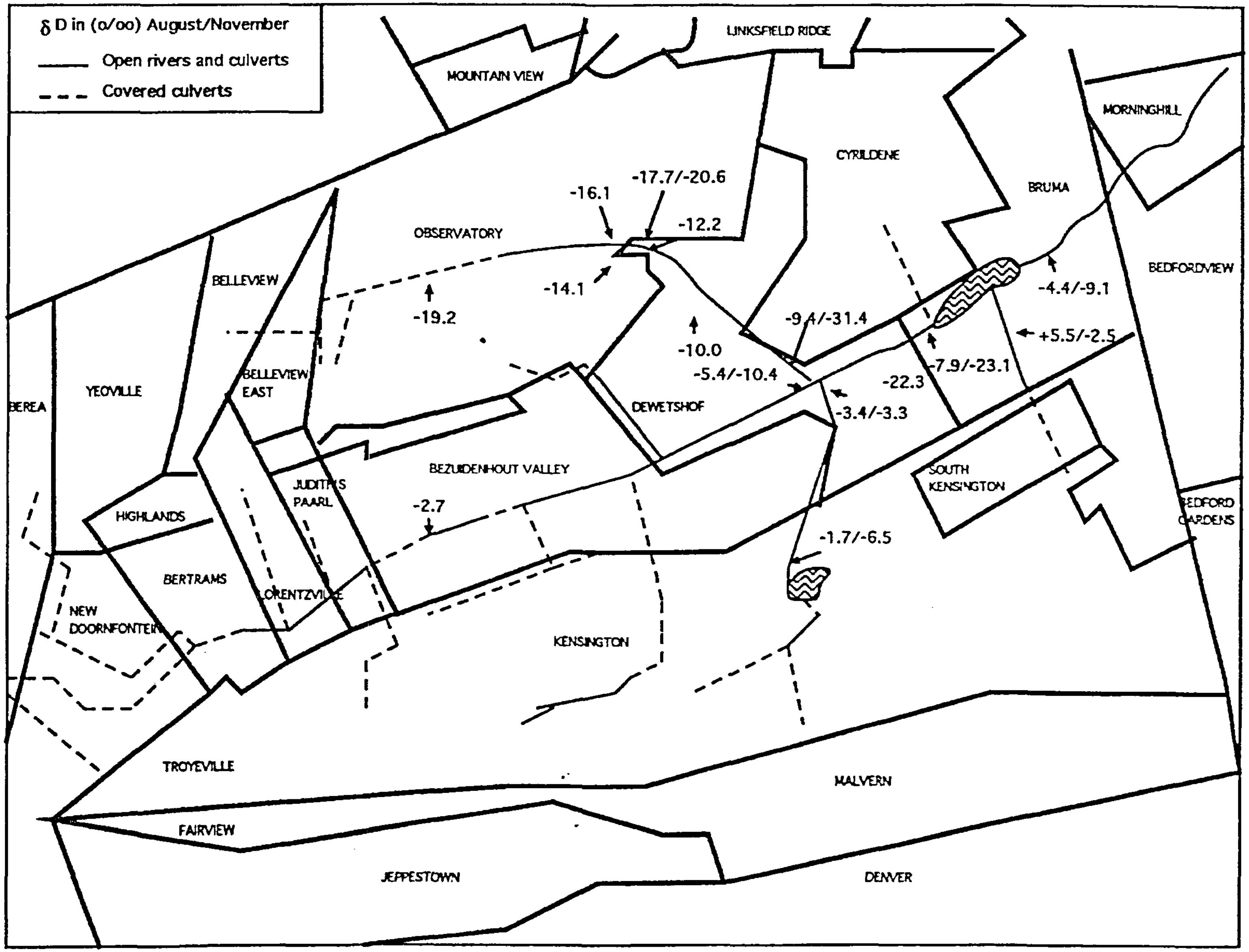

Figure 23 Map of townships in the Johannesburg study area, showing δD values for the two sampling periods.

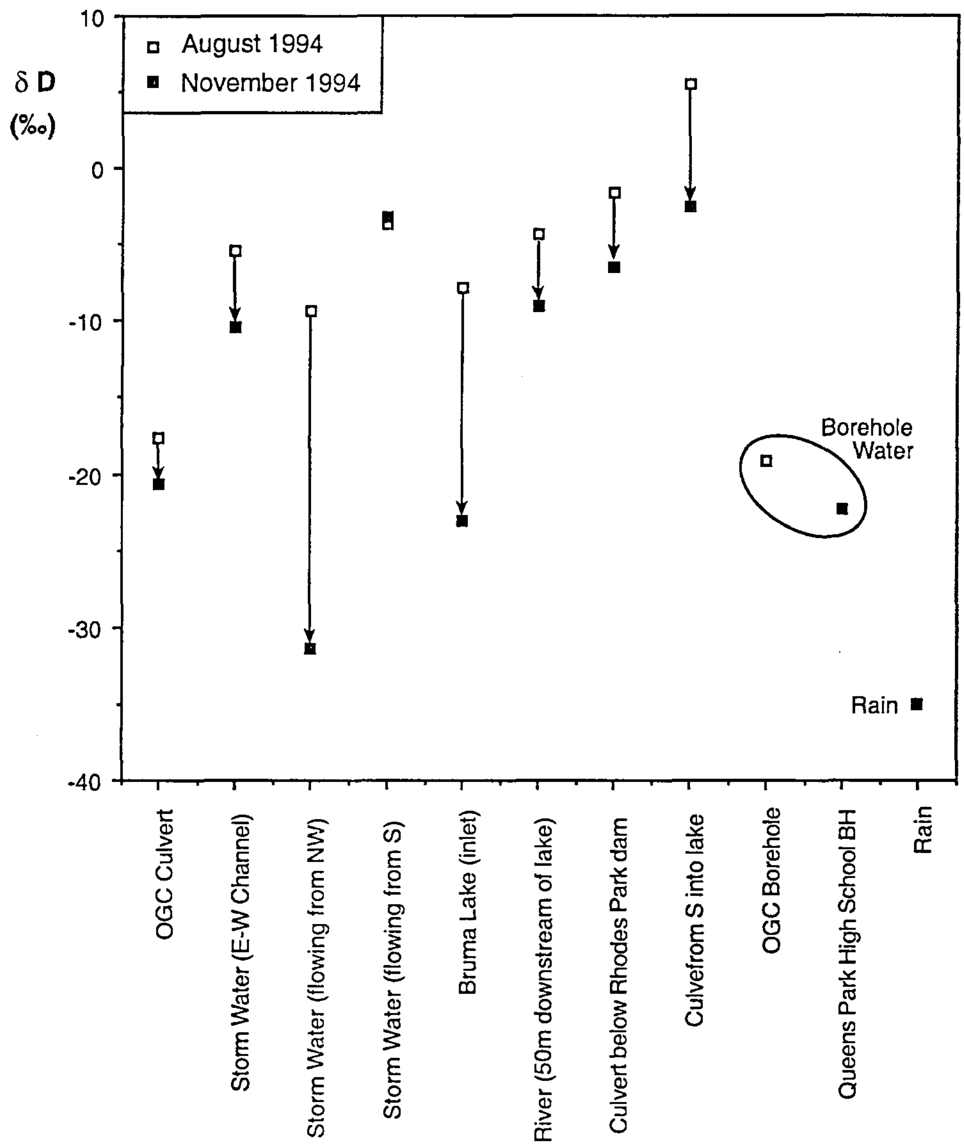

Figure 24 δD values for sites sampled in August 1994 and repeated in November 1994, showing negative shifts.

Results δD > -5 ‰; $\delta^{18}O$ > -2 ‰, lying close to the WMWL, may be compatible with a limited degree of RW mains admixture, the regression line running close to the WMWL. The alkalinity for all these samples is plotted against electrical conductivity as a measure of the dissolved solid load of the water (Fig. 26). The good correlation suggests that the mineralisation of the water is mainly associated with soil processes, the slope of the correlation line being comparable to those observed for the two study areas in Pretoria.

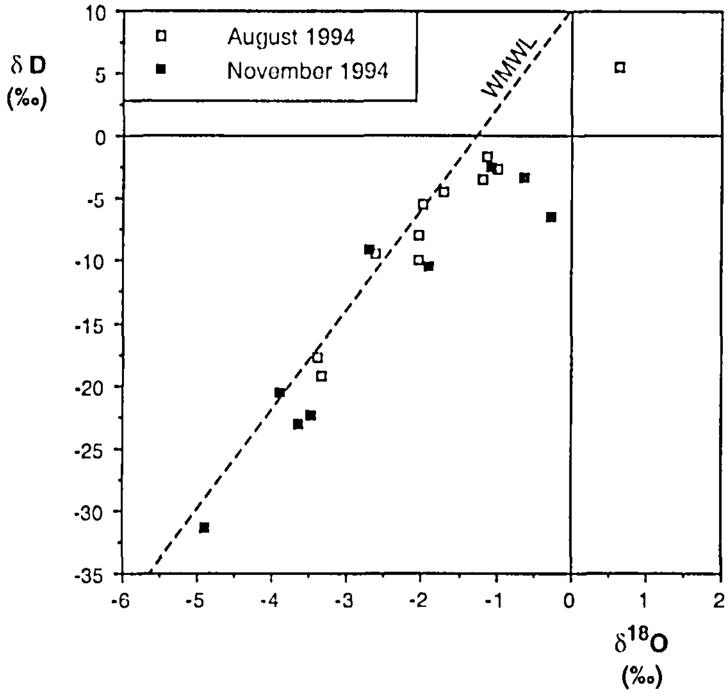

Figure 25 δD vs. $\delta^{18}O$ plot for surface water samples from the Johannesburg study area. Note cases of evaporation.

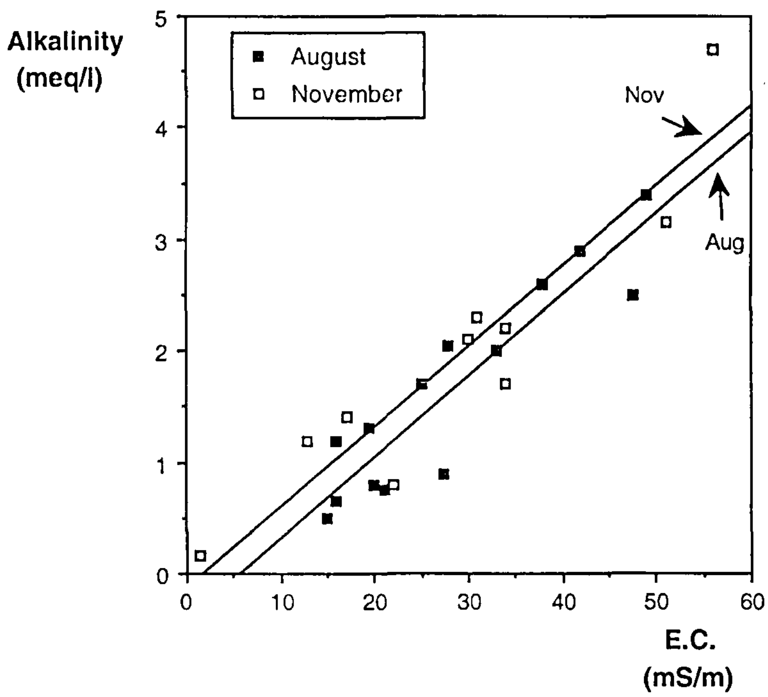

Figure 26 Alkalinity vs. E.C. plots for surface and seepage water in the Johannesburg study area. The correlation suggests that most of the water is derived from ground water seepage.

The more positive δD-$\delta^{18}O$ values and their variations observed during this survey appear to have been generated more by kinetic evaporation than by admixture of RW mains. It is possible that evaporation so modifies the seepage water that the original isotopic signal can no longer clearly be established.

6.3. Conclusions

It is concluded that, although the observations in south-east Johannesburg revealed considerable spatial and temporal differences in the isotopic composition of the surface water surveyed, it did not lead to the identification of any clear influence of mains water in any of the samples analysed. The more positive isotopic values observed can readily be ascribed to evaporative modification before infiltration. This survey has fallen far short of identifying isotopic values which could lead to the location of mains water leakages. The isotopic changes observed in samples taken before and after the major downpour in November 1994 show the potential of using these changes for hydrograph separation.

7. OPERATIONAL APPLICATIONS

A number of operational applications of the RW mains isotopic signal have been successfully completed. Two examples are described briefly below.

7.1. Basement at 120 End Street, Johannesburg

The basement of the Nedcor building at 120 End Street in Doornfontein, Johannesburg, used for parking, goes down 4 levels. On the lowest level, a substantial amount of water was infiltrating through cracks around the bases of the supporting pillars. The Johannesburg Municipality was advised of this and subsequently took samples of water from the floor. Due to the high chloride content of the water, it was suspected that the flooding was the result of mains leakage.

During May 1995, three more samples (WRCL 188-190) were taken from the basement for stable isotope analyses. A sample was taken from the leakage through a hole in the floor, a second from water lying on the basement floor, and a third sample from a tap in the basement. The samples were analysed for both deuterium and oxygen-18, and the results plotted in Figure 27.

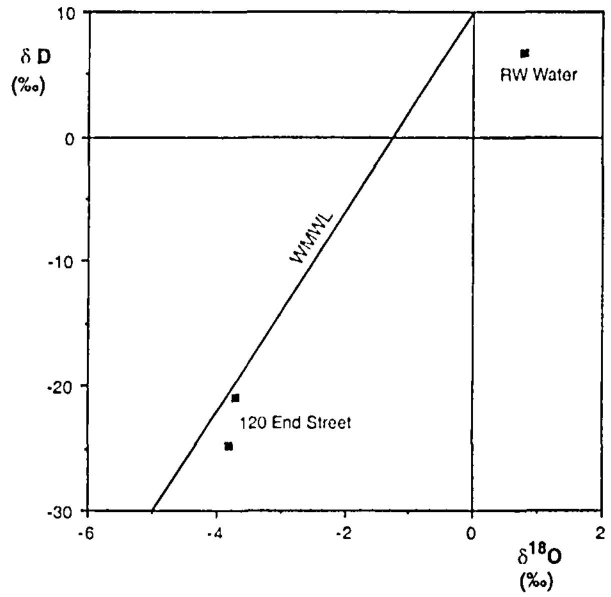

Figure 27 Diagram showing WMWL and δD-$\delta^{18}O$ values for basement samples and contemporaneous mains sample (April 1995).

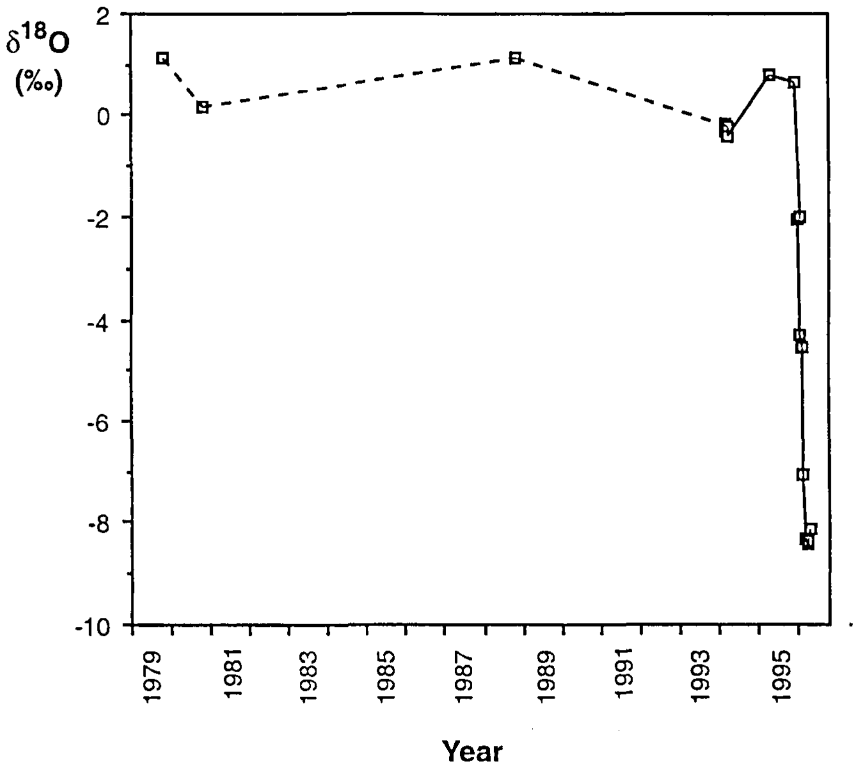

Figure 28 Values of $\delta^{18}O$ for RW mains water since 1979. The major decline in $\delta^{18}O$ (and δD) commenced in December 1995.

A large difference is evident in the stable isotopic composition of the tap (RW) water and the two samples from the garage basement. This clearly identifies the seepage into the basement as not derived from mains water. The source is more probably the result of a rising water table due to the large amount of rain at this time. Clear differences between the seeping water and RW mains water are also seen in both electrical conductivity and alkalinity measurements (see Table 1).

7.2. Basement of Schonland Research Institute, University of the Witwatersrand

Some years previously, the flow of water into a basement sump at the Schonland Research Institute (then Centre), University of the Witwatersrand increased instead of an expected decline during the dry winter months. Samples taken from the sump and from a nearby borehole used for irrigating the playing fields showed that water in the sump was isotopically much heavier than borehole water, and resembled RW mains water. This information led to an investigation of buried mains conduits in the vicinity of the sump. A major leak was pinpointed and repaired.

8.THE HISTORY OF RW MAINS ISOTOPIC VALUES

8.1. Rand Water mains isotopic values since 1979

The distinctive isotopic composition observed in RW mains, used in this study to assess the proportion of such water in ground water, has been observed, with some minor fluctuations, since the late 1970's (Fig.28). The cause of this distinctive composition, much more positive than most water in the environment – in particular ground water – but not far off the WMWL, can possibly be related to evaporation under particular air moisture conditions over the Vaal Dam, the principal source of RW mains water.

This signal has been employed to pinpoint mains leakages in the present study, and in certain operational applications (see i.a. above). It was crucial in establishing the principle of "incipient pollution" in the study of dolomite ground water in Midrand and in demonstrating the extreme heterogeneity of Karoo clays in their ability to seal off land fill seepage [Verhagen et al. 1996].

8.2. Rand Water mains isotopic values since December 1995

Exceptionally heavy rainfall late in 1995, lasting well into 1996, caused the δD values of RW mains to decline, from about +8 ‰ in early December 1995 to values around –55 ‰ in mid-March 1996 (Fig.28 and in detail in Fig.29). A commensurate drop was observed in $\delta^{18}O$, which shows that the change occurred along the WMWL (Fig.30). Isotopic values for rainfall over this period were exceptionally low, values of $\delta^{18}O$ = -11.3 ‰ and δD = -71 ‰ being measured in individual rainstorms. Historical monthly values for Pretoria (Fig.31 [IAEA 1992]) are shown for comparison.

The stable isotope record of Johannesburg mains water, plotted as a function of time in Figure 28, shows that highly enriched values persisted with only relatively small variations since the late 70's up to late 1995. As values were only occasionally measured, short-term fluctuations of greater amplitude might have gone unnoticed during that period. Following the major decline, values stabilized and show an upward trend. There is every indication that former long-term enriched values will in time be re-established.

8.3. Case study using the changed isotopic signal in RW mains

Following the dramatic drop in δD and $\delta^{18}O$ values in RW mains between December 1995 and March 1996, the question arose whether this signal could be detected in ground water. The most pronounced case of mains leakage found in this study (#141, at δD = +5 ‰; see detail in Fig.14) and other boreholes in the vicinity, were re-sampled in May/June 1996. The results are displayed in Figure 32, along with the original values, measured on samples taken in 1994 and 1995.

The borehole with the 100 % mains contribution (#141, 883 Mortimer Street) showed a major drop of δD = 15 ‰ since the last sampling. In spite of the exceptional 1995/1996 rainy season, with very negative δ values, the surrounding boreholes, which earlier had produced isotopic values within the range regarded as "normal" for ground water in the area, have shown no significant shift in isotopic values.

These results are interpreted as follows.

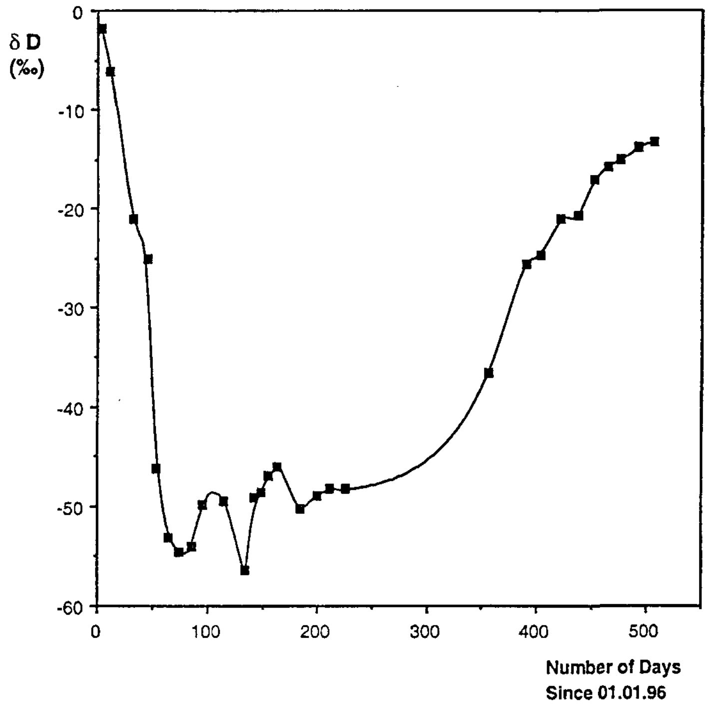

Figure 29 Detail of decline in δD values with time since 01.01.1996. Note recovery trend since May 1996.

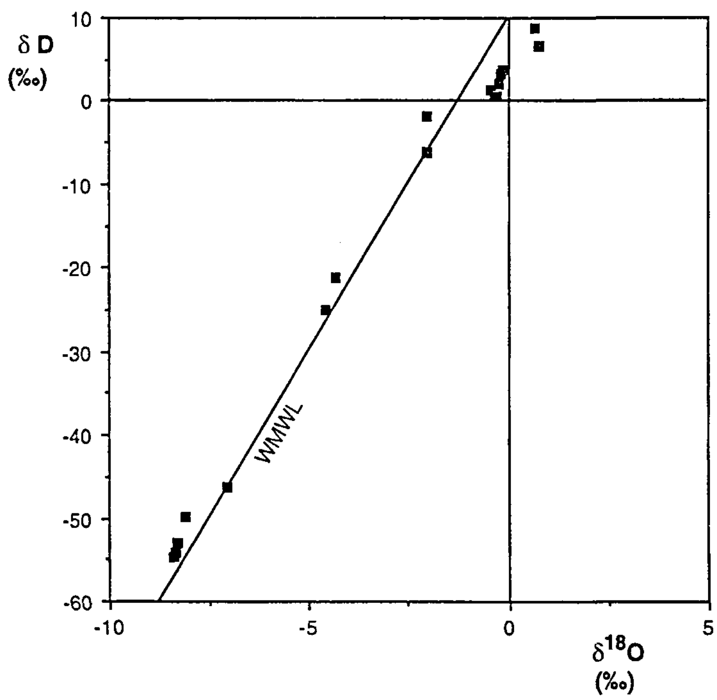

Figure 30 δD-δ^{18}O plot for RW mains isotopic values during the period December 1995 to April 1996. Note the closeness of fit to the WMWL.

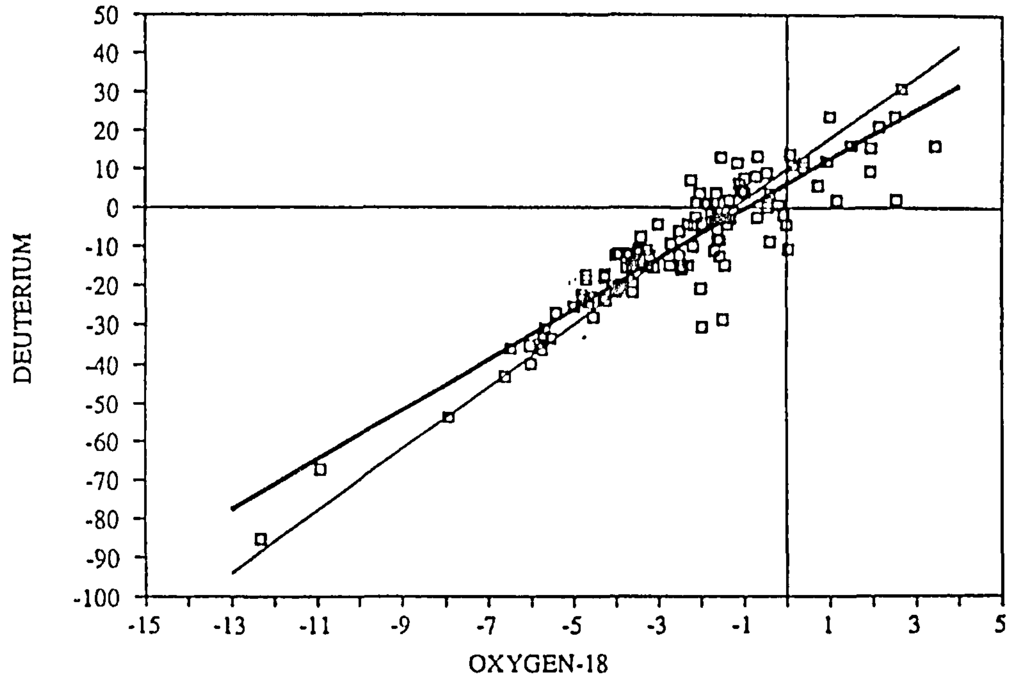

Figure 31 Monthly δD-δ¹⁸O values for Pretoria rainfall 1961 – 1975 [IAEA 1992].

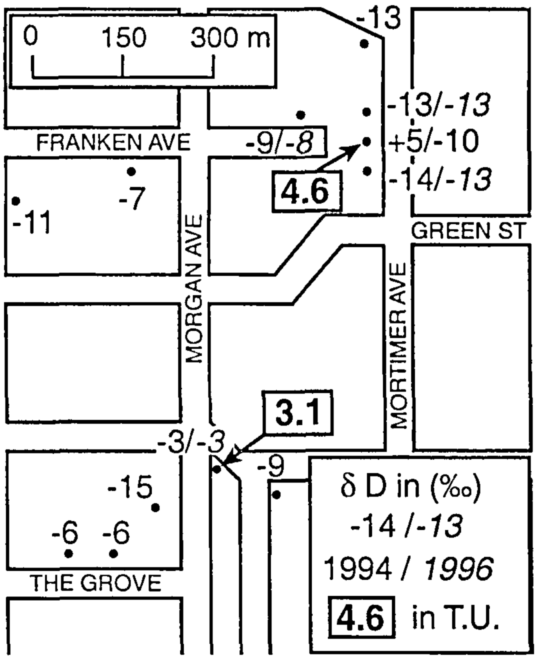

Figure 32 Detail map (------, Figure 13) showing re-sampled points in eastern suburbs, with δD values for 1994/95 and June 1996.

The drop in δD values observed at 883 Mortimer Street confirms the earlier interpretation that this borehole pumps practically pure mains water. The sharp drop in delta values during December 1995-March 1996 was already visible in the water produced from the borehole, and the values were likely to continue dropping as the more recent input of mains water displaced the earlier leakage water. As the high tritium value of 4.6 TU suggests, turnover of ground water there is rapid.

The absence of any response of the surrounding boreholes, at 879 and 895 Mortimer Street and 140 Franken Avenue, although within tens of metres of 883 Mortimer Street, shows that the effect of the leakage was very localised and therefore not of very long duration – probably only a few years. #115/224, to the south, which showed an estimated 53 % mains contribution, also remained unchanged. It may be speculated that the lower tritium concentration (3.1 TU) is evidence of this lower proportion as well as a somewhat slower response.

The lack of response of the boreholes in the vicinity of 883 Mortimer Street also shows that the recent exceptional rainfall had not, at the time, had any measurable effect on the isotopic value of the ground water in the area. Using the assumptions applied above, the effective water column tapped by these boreholes is of the order of 20 m x 0.1 = 2 m. Assuming the recent rain to have had a mean value of δD = -50 ‰, the ground water –15 ‰ and the resolution of measurement of the order of δD = 1 ‰, the maximum recharge would be of the order of 3 % of storage, or 60 mm. Conversely, it is firmly established that the isotopic shift at 883 Mortimer Street was leakage, and not rainfall, related.

8.4. Conclusions

1. Although the original “heavy” isotope signal in RW mains water has been temporarily and drastically altered, the basic concept remains: the isotopic contrast between imported and local water can be a useful signal with which to trace the fate of such imported water.

2. The very rapid drop in isotope values of RW mains was a very distinct time-marker for systems in which there is a continuous input of mains water.

3. There was a window of opportunity for using the isotopically negative signal in the RW mains to identify point sources in the presence of diffuse input.

4. The near-complete resetting of the isotopic value of the Vaal Dam and its recovery, as witnessed by measurements done on mains water, allows for a variety of studies of the hydrology of this water body, such as evaporation, the causes of mineralisation and eutrophication, internal mixing processes, etc.

9. OVERALL CONCLUSIONS

1. The overriding conclusion drawn from the study is that the potential of environmental isotope measurements to assess the origins of ground water, in particular w.r.t. the tracing of RW mains in the saturated zone, has been proven.

2. In Mountain View, the importance of establishing a terrain background has been clearly identified. In this sloping terrain, major assumed differences in depth to ground water and rainfall selectivity produce a significant and fairly uniform gradient in stable isotope values, probably enhanced by the presence of significant proportions of mains water near the bottom. This needs to be known in order to assess, and calculate percentages of mains water for, individual point observations.

3. In the eastern townships, with a much gentler slope, the local terrain background values could not be as well established, on account of the much larger area to be covered and absence of areal systematics. The area also reportedly had a high incidence of mains leakages. Here the approach was to estimate a mean terrain background value for the entire area by eliminating cases of assumed major mains water influence. A number of apparent leakage points was thus identified.

4. The approach of employing surface water as an indicator of mains water leakages in Johannesburg has met with limited success. The paucity of boreholes in the area was a distinct impediment. The overlay of numerous sources and the significant degree of surface evaporation between source and sampling point has to date frustrated the clear identification of any mains leakages. The potential of employing environmental isotopes in surface water to effect hydrograph separation in such areas was however identified and could be further investigated.

5. Various practical applications of the technique have shown its considerable power in simply and rapidly identifying the presence or absence of mains water in e.g. sources of flooding into building basements, of which two examples have been given.

6. The drop in δ values in RW mains at the beginning of 1996 can find numerous applications, i.a. acting as a time-marker in systems continuously fed by mains water. Its practical application has already been demonstrated in one case study.

10. RECOMMENDATIONS

This investigation was originally conceived as a feasibility study for using environmental isotope tracers of leakages of Rand Water mains in the sub-surface. In view of the very positive results obtained in this study as well as in an earlier investigation in Midrand (Verhagen et al. 1996), it is recommended that:

1) regular monitoring of the RW mains system be continued;

2) sites where strong indications of mains leakages were obtained should be re-sampled, preferably before the 1996/7 rainy season. Any abrupt negative changes in δ values would produce important time-dependent information on leakages;

3) the Vaal Dam, having been isotopically "reset", be studied from the point of view of evaporation losses and mixing processes;

4) the use of stable (deuterium and oxygen-18) and radioactive (e.g. tritium) isotopes as environmental tracers in the solution of hydrological problems in the urban and industrial environments be actively propagated through literature and seminars.

11. REFERENCES

IAEA (1983) Guidebook on nuclear techniques in hydrology. Tech. Rep. Series No. 91. Vienna (IAEA).

IAEA (1992) Statistical treatment of data on environmental isotopes in precipitation. Tech. Rep. Series No. 331. Vienna (IAEA).

Simpson, G.C. (1990) Vol. 1. Research into ground water abstraction in residential areas. Vol. 2. Data from research into ground water abstraction in residential areas. WRC Report No. 211/1 and 2/90.

Verhagen, B. Th.; Geyh, M. A.; Froehlich, K.; Wirth, K. (1991) Isotope hydrological methods for the quantitative evaluation of ground water resources in arid and semi-arid areas. Research reports of the Federal Ministry for Economic Cooperation of the Federal Republic of Germany, Bonn. pp. 164.

Verhagen, B. Th.; Levin, M.; Walton, D. G. and Butler, M. (1996) Geohydrological, hydrochemical, and isotope study of ground water pollution due to waste disposal. Final Report K5/311, Water Research Commission.

TABLE 1

WRCL NO.	LOCATION	$\delta^{18}O$ (‰)	δD (‰)	E.C. (mS/m)	pH	ALK (meq/l)	^3H (TU)	SAMPLE DATE
1	RW WATER (166 DAPHNE)	-0.15	+3.7					8/3/94
2	1419 BARNATO	-5.13	-25.2	5	6.1	0.8		8/3/94
3	211 DAPHNE	-5.21	-28.2	12	6.6	1.3		8/3/94
4	179 DAPHNE	-4.84	-24.8	15	6.2	1.2		8/3/94
5	381 IVOR	-3.72	-16.7	44	6.8	3.3		8/3/94
6	525 IVOR	-4.23	-23.7	42	6.6	3.5		8/3/94
7	470 SAREL	-3.87	-24.1	79	6.8	5.9		8/3/94
8	428 IVOR	-5.07	-25.9	37	7.1	2.9		8/3/94
9	1105 DANIEL	-3.22	-12.1	62	6.9	4.2		8/3/94
10	520 SAREL	-3.29	-14.4	71	6.8	4.5	4.3±0.4	8/3/94
11	263 ULUNDI	-5.20	-29.2	9	6.6	1.0	0.2±0.3	8/3/94
12	1385 MERWEDE	-5.18	-29.2	8	6.8	0.9		10/3/94
13	200 ULUNDI	-5.42	-29.6	10	6.4	1.2		10/3/94
14	210 ULUNDI	-5.11	-30.8	9	7.1	1.1		10/3/94
15	1333 BARNATO	-4.93	-29.1	15	7.0	1.4		10/3/94
16	359 IVOR	-2.55	-9.2	42	7.1	3.8	4.1±0.4	10/3/94
17	549 IVOR	-3.55	-19.8	54	6.6	2.5		10/3/94
18	471 IVOR	-4.72	-22.8	45	6.8	2.7		10/3/94
19	378 IVOR	-4.96	-24.8	44	6.7	2.9		10/3/94
20	133 ULUNDI	-5.58	-28.2	11	7.4	1.2		10/3/94
21	516 SAREL	-3.79	-18.1	69	6.7	4.0		10/3/94
22	166 DAPHNE	-5.07	-28.1	13	6.5	1.3		10/3/94
23	RW WATER (144 ULUNDI)	-0.28	+0.5	20	7.8	1.9		10/3/94
24	245 DENYSSEN	-5.50	-31.9	15	7.0	1.7		15/3/94
25	531 IVOR	-4.59	-28.5	44	6.7	2.4		15/3/94
26	492 SAREL	-3.03	-15.1	57	6.9	3.9		15/3/94
27	205 DAPHNE	-5.19	-28.2	12	7.0	1.4		15/3/94
28	149 ULUNDI	-3.92	-20.8	12	6.3	0.8		15/3/94
29	RW WATER (383 IVOR)	-0.32	+0.7					15/3/94
30	499 DAPHNE	-5.25	-29.1	9	7.0	1.3		15/3/94
31	542 DENYSSEN	-3.05	-19.4	30	6.6	2.1	2.4±0.3	15/3/94

TABLE 1

WRCL NO.	LOCATION	$\delta^{18}O$ (‰)	δD (‰)	E.C. (mS/m)	pH	ALK (meq/l)	^3H (TU)	SAMPLE DATE
32	1329 CHARL CELLIERS	-5.45	-31.0	10	6.5	1.6		15/3/94
33	557 DAPHNE	-5.41	-27.7	21	7.1	2.5		15/3/94
34	374 KAREL TRICHARDT	-6.28	-30.0	17	7.1	2.2		15/3/94
35	545 IRVINE	-6.66	-21.2	17	7.0	2.3		15/3/94
36	500 DENYSSEN	-6.80	-26.9	13	6.6	1.7		17/3/94
37	328 DENYSSEN	-5.35	-29.9	12	6.7	1.6		17/3/94
38	444 IVOR	-4.86	-21.3	19	8.1	2.1	1.2±0.4	17/3/94
39	505 IRVINE	-4.98	-29.2	15	6.7	1.9		17/3/94
40	565 IRVINE	-5.79	-29.1	16	6.9	2.2		17/3/94
41	563 IRVINE	-5.77	-32.5	17	6.9	2.2		17/3/94
42	1246 LEONIDE	-5.44	-33.1	13	6.8	1.9		17/3/94
43	378 KAREL TRICHARDT	-5.37	-26.5	14	7.0	1.8		17/3/94
44	430 KAREL TRICHARDT	-4.83	-29.0	22	7.6	2.5		17/3/94
45	567 KAREL TRICHARDT	-5.14	-29.6	27	6.9	2.9		17/3/94
46	455 IRVINE	-5.09	-28.4	15	6.6	1.7		17/3/94
47	317 IVOR	-3.67	-19.2	73	7.0	4.4		17/3/94
48	332 IVOR	-3.66	-19.4	50	7.8	5.3		17/3/94
49	232 IRVINE	-3.62	-21.5	34	6.5	2.2		30/3/94
50	RW WATER (591 DAPHNE)	-0.43	+1.3					30/3/94
51	425 IRVINE	-5.51	-32.9	13	6.9	2.1		30/3/94
52	382 IRVINE	-5.49	-25.6	16	7.0	2.2	0.2±0.2	30/3/94
53	RW WATER (1225 FELIX)	-0.20	+3.2	19	8.0	2.1		30/3/94
54	268 IRVINE	-5.21	-31.0	17	7.1	1.8		30/3/94
55	355 IRVINE	-5.46	-29.3	17	7.2	2.0		30/3/94
56	1219 MERWEDE	-5.14	-23.3	18	7.2	2.0		30/3/94
57	328 IVOR	-4.79	-23.5	33	6.8	3.0		30/3/94
58	316 IVOR	-4.56	-26.4	36	6.8	3.0		30/3/94
59	283 IVOR	-3.65	-16.8	69	7.1	4.6		30/3/94
60	279 IRVINE	-5.10	-29.1	21	7.3	2.2		30/3/94
61	271 IRVINE	-5.30	-27.4	19	7.4	2.3		30/3/94
62	312 IVOR	-4.05	-15.1	74	6.8	6.0		30/3/94

TABLE 1

WRCL NO.	LOCATION	$\delta^{18}O$ (‰)	δD (‰)	E.C. (mS/m)	pH	ALK (meq/l)	^{3}H (TU)	SAMPLE DATE
63	183 DENYSSEN	-4.30	-19.8	28	6.6	1.6		30/3/94
64	414 SAREL	-3.94	-22.7	76	6.8	4.6		30/3/94
65	418 SAREL	-4.02	-18.4	59	6.8	3.6		5/4/94
66	567 SAREL	-2.99	-10.3	100	7.2	7.4		5/4/94
67	562 SAREL	-3.66	-17.9	85	6.7	6.0		5/4/94
68	586 DENYSSEN	-5.53	-32.9	16	7.1	2.1		5/4/94
69	645 DENYSSEN	-5.08	-31.0	14	6.5	1.8		5/4/94
70	696 KAREL TRICHARDT	-5.38	-32.9	21	6.7	2.5		5/4/94
71	686 KAREL TRICHARDT	-5.52	-31.3	20	6.7	2.4		5/4/94
72	679 KAREL TRICHARDT	-5.30	-31.3	21	6.9	2.7		5/4/94
73	638 DENYSSEN	-5.32	-30.8	14	6.7	2.1		5/4/94
74	659 DENYSSEN	-5.21	-31.9	16	6.7	2.1		5/4/94
75	662 KAREL TRICHARDT	-5.26	-30.7	19	7.0	2.3		5/4/94
76	664 DENYSSEN	-5.40	-29.2	16	6.5	1.6		5/4/94
77	RW WATER (667 DENYSSEN)	-0.23	+2.0	20	7.9	2.2		5/4/94
78	608 KAREL TRICHARDT	-3.84	-19.2	42	6.8	3.7	2.5±0.3	5/4/94
79	612 KAREL TRICHARDT	0.12	-7.4	110	7.1	3.3	3.3±0.3	11/4/94
80	657 DENYSSEN	-4.45	-28.3	16	6.3	1.6		11/4/94
81	690 IRVINE	-5.43	-34.3	14	7.3	1.9		11/4/94
82	699 SAREL	-2.06	-8.8	69	6.4	3.1		11/4/94
83	578 IVOR	-4.44	-28.4	37	6.7	2.5		11/4/94
84	616 SAREL	-2.26	-5.4	81	6.3	2.9		11/4/94
85	MAINS WATER LEAK	-0.39	+2.1					11/4/94
86	662 SAREL	-2.40	-10.2	78	6.6	3.9		11/4/94
87	682 SAREL	-3.65	-18.8	59	6.4	3.1		11/4/94
88	686 IVOR	-4.58	-27.0	53	6.5	3.0		11/4/94
89	669 IVOR	-3.37	-22.0	57	6.6	2.9		11/4/94
90	681 IVOR	-4.27	-22.6	53	7.2	3.4		11/4/94
91	688 IVOR	-4.93	-29.7	38	6.5	2.7		11/4/94
92	692 IVOR	-5.07	-29.5	38	6.5	2.5		11/4/94
93	699 IVOR	-4.43	-24.8	57	6.6	3.4		11/4/94

WRCL NO.	LOCATION	$\delta^{18}O$ (‰)	δD (‰)	E.C. (mS/m)	pH	ALK (meq/l)	^3H (TU)	SAMPLE DATE
94	575 IVOR	-4.05	-23.9	42	6.9	2.2		30/6/94
95	1054 FELIX	0.18	-2.5	115	7.2	11.6	5.6±0.4	30/6/94
96	STORM WATER DRAIN (BELOW FELIX)	-0.13	+5.8	95	8.6	5.4		30/6/94
97	244 ELOFF	-3.49	-16.8	44	7.0	3.8		30/6/94
98	621 SMOOK		-12.5	77	7.2	4.5		30/6/94
99	162 ELOFF	-2.83	-11.0	37	7.0	3.0		30/6/94
100	398 ELOFF		-13.7	72	6.9	3.9		30/6/94
101	630 SMOOK	-2.17	-6.4	52	6.8	3.4		30/6/94
102	166 ELOFF	-2.21	-9.1	36	6.9	2.2		30/6/94
103	158 ELOFF		-13.2	41	6.9	3.2		30/6/94
104	250 ELOFF		-13.2	69	7.1	3.5		30/6/94
105	635 KLESSER		-12.5	59	7.4	3.5		30/6/94
106	292 ELOFF		-12.3	120	6.8	5.7		30/6/94
107	298 ELOFF		-11.5	98	6.8	4.5		5/7/94
108	633 WEGERLE	-2.61	-15.8	82	7.0	4.0		5/7/94
109	623 BRUINS		-13.8	80	7.0	4.2		5/7/94
110	767 MORGAN		-15.1	82	7.2	6.0		5/7/94
111	815 MANCE	-2.07	-6.4	150	7.0	11.6		5/7/94
112	810 RHYS	-1.87	-3.0	100	6.8	6.7	4.6±0.4	5/7/94
113	RW WATER (627 BRUINS)		+7.9	26	7.9	2.4		5/7/94
114	RW WATER (809 MANCE)		+7.3	23	7.8	2.3		5/7/94
115	776 MORGAN	-1.23	-3.0	84	6.6	4.5	3.1±0.3	5/7/94
116	623 JAN VISSE		-15.6	69	7.6	4.2		5/7/94
117	626 EIKE		-9.2	100	7.1	6.3		5/7/94
118	MAYVILLE LAERSKOOL		-8.8	75	7.3	6.5		5/7/94
119	617 MAGDALENA	-2.17	-4.0	78	6.7	4.2		5/7/94
120	622 JAN VISSE		-13.4	70	7.4	4.4		5/7/94
121	623 EIKE		-9.5	77	7.3	5.2		14/7/94
122	120 THE GROVE		-6.0	99	6.9	6.5		14/7/94
123	110 THE GROVE	-1.52	-5.7	85	7.5	6.2		14/7/94
124	98 THE GROVE		-9.8	110	7.1	7.3		14/7/94

TABLE 1

WRCL NO.	LOCATION	$\delta^{18}O$ (‰)	δD (‰)	E.C. (mS/m)	pH	ALK (meq/l)	^3H (TU)	SAMPLE DATE
125	92 THE GROVE	-1.87	-5.1	102	7.2	7.6		14/7/94
126	78 THE GROVE		-10.0	105	7.3	6.6		14/7/94
127	82 THE GROVE		-7.3	100	7.1	7.5		14/7/94
128	68 THE GROVE		-12.8	100	7.1	6.2		14/7/94
129	65 THE GROVE	-1.09	-4.5	125	7.1	7.3		14/7/94
130	59 THE GROVE	-1.59	-2.0	120	7.0	8.0	4.4±0.4	14/7/94
131	749 KENSINGTON	-0.82	-4.5	110	6.8	6.8		14/7/94
132	RIVER WATER (WEST OF GROVE)	-0.48	-1.6	52	8.6	3.7		14/7/94
133	267 GERBER	-1.65	-7.0	100	7.1	6.3		14/7/94
134	826 KILLICK	-2.01	-5.5	92	6.9	6.0		14/7/94
135	825 KILLICK		-12.8	96	6.9	6.4		14/7/94
136	811 RHYS		-11.1	90	7.2	6.8		21/7/94
137	236 LOUIS TRICHARDT		-10.3	75	7.2	6.9		21/7/94
138	637 VAN ZYL		-15.9	54	6.8	3.8		21/7/94
139	899 MANCE		-9.8	100	7.0	8.3		21/7/94
140	886 MANSFIELD		-15.0	110	7.5	9.0		21/7/94
141	883 MORTIMER	-0.34	+5.2	63	7.3	5.3	4.6±0.5	21/7/94
142	140 FRANKEN	-2.01	-9.3	120	7.3	9.6		21/7/94
143	117 FRANKEN		-6.7	100	7.4	8.3		21/7/94
144	RW WATER (878 LEE)		+6.8	26	7.9	2.4		21/7/94
145	870 LEE		-10.6	100	7.4	8.0		21/7/94
146	95 FRANKEN		-8.9	110	7.3	8.3		21/7/94
147	894 BURLINGTON		-14.9	100	7.3	10.0		21/7/94
148	54 GREEN	-1.28	-3.1	130	7.0	9.6		21/7/94
149	RW WATER (MAYVILLE LAERSKOOL)		+6.1	23	7.9	4.7		21/7/94
150	BEZUIDENHOUT PARK BELOW OBS. RD.	-2.05	-10.0	16	7.4	1.2		4/8/94
151	OBSERVATORY GOLF CLUB IRRIGATION		-14.1	21	6.6	0.8		4/8/94
152	O.G.C. SEEPAGE (POND AT HOLE NO. 7)		-16.1	15	6.9	0.5		4/8/94
153	O.G.C. CULVERT(NEXT TO HOLE NO. 7)	-3.4	-17.7	20	6.9	0.8		4/8/94
154	O.G.C. BOREHOLE	-3.35	-19.2	28	6.5	0.9		4/8/94
155	O.G.C. SEEPAGE (EAST OF POND)		-12.2	16	6.3	0.7		4/8/94

TABLE 1

WRCL NO.	LOCATION	δ¹⁸O (‰)	δD (‰)	E.C. (mS/m)	pH	ALK (meq/l)	³H (TU)	SAMPLE DATE
156	YEOVILLE RESERVOIR		+5.1	20	7.8	2.2		4/8/94
157	BEREA RESERVOIR			21	8.0	2.2		4/8/94
158	STORM WATER DRAIN (2ND ST)	-0.99	-2.7	42	7.8	2.9		9/8/94
159	STORM WATER (FLOWING FROM SOUTH)	-1.18	-3.4	25	8.7	1.7		9/8/94
160	STORM WATER (FLOWING FROM N.W.)	-2.63	-9.4	20	8.0	1.3		9/8/94
161	STORM WATER (E-W CHANNEL)	-1.99	-5.4	48	8.0	2.5		9/8/94
162	BRUMA LAKE WATER (AT INLET)	-2.04	-7.9	33	8.9	2.0		9/8/94
163	RIVER (50m DOWNSTREAM OF LAKE)	-1.7	-4.4	38	9.6	2.6		9/8/94
164	CULVERT BELOW RHODES PARK DAM	-1.12	-1.7	28	8.6	2.1		9/8/94
165	CULVERT FLOWING FROM S. INTO LAKE	0.63	+5.5	49	8.5	3.4		9/8/94
166	RW WATER (ELLIS PARK POOL)		+3.5	20	8.1	2.3		9/8/94
167	O.G.C. CULVERT(NEXT TO HOLE NO. 7)	-3.89	-20.6	22	7.1	0.8		3/11/94
168	STORM WATER (E-W CHANNEL)	-1.90	-10.4	51	8.4	3.2		3/11/94
169	STORM WATER (FLOWING FROM SOUTH)	-0.63	-3.3	31	8.7	2.3		3/11/94
170	STORM WATER (FLOWING FROM N.W.)	-4.88	-31.4	13	7.6	1.2		3/11/94
171	BRUMA LAKE WATER (AT INLET)	-3.66	-23.1	34	7.6	1.7		3/11/94
172	RIVER (50m DOWNSTREAM OF LAKE)	-2.71	-9.1	17	7.4	1.4		3/11/94
173	CULVERT FLOWING FROM S. INTO LAKE	-1.07	-2.5	56	9.1	4.7		3/11/94
174	CULVERT BELOW RHODES PARK DAM	-0.26	-6.5	30	8.1	2.1		3/11/94
175	QUEENS PARK HIGH SCHOOL-BOREHOLE	-3.47	-22.3	34	7.1	2.2		3/11/94
176	RAIN WATER (04/11/94)	-6.08	-35.0	20	4.9	0.2		4/11/94
178	805 KENSINGTON	-1.22	-5.5	100	7.4	9.4		25/11/94
179	809 MANCE	-2.74	-14.2	160	7.4	14.9		25/11/94
180	879 MORTIMER	-2.69	-14.1	99	7.5	8.6		25/11/94
181	625 SMOOK	-2.00	-6.0	63	6.8	3.9		25/11/94
182	919 MORTIMER	-2.43	-8.1	100	7.4	10.4		25/11/94
183	169 ELOFF	-2.67	-12.8	43	7.2	2.3		25/11/94
184	895 MORTIMER	-3.06	-12.8	100	7.5	8.6		25/11/94
185	175 ELOFF	-3.07	-12.2	35	7.1	2.9		25/11/94
186	642 SMOOK	-1.69	-6.4	74	6.7	4.3		25/11/94

WRCL NO.	LOCATION	$\delta^{18}O$ (‰)	δD (‰)	E.C. (mS/m)	pH	ALK (meq/l)	^{3}H (TU)	SAMPLE DATE
187	64 FRED NICHOLSON	-1.36	-6.7	110	7.5	6.7		25/11/94
188	FLOODED BASEMENT-120 END ST	-3.69	-20.9	31		0.8		25/4/95
189	FLOODED BASEMENT-120 END ST	-3.80	-24.8	29		0.8		25/4/95
190	RW WATER (120 END)	+0.78	+6.7	20		1.7		25/4/95
191	81 SOPHIA	-1.69	-8.7	88		5.5		21/1/95
192	109 FRED NICHOLSON	-1.12	-4.7	65		5.1		21/1/95
193	268 FRED NICHOLSON	-2.83	-15.3	66		4.4		21/1/95
194	331 FRED NICHOLSON	-2.87	-14.3	60		4.0		21/1/95
195	404 DE BEER	-4.07	-21.8	17		1.7		21/1/95
196	434 MEYER	-4.04	-19.0	62		4.8		21/1/95
197	435 DE BEER	-3.77	-20.9	18		1.6		21/1/95
198	670 EIKE	-1.68	-7.0	87		5.1		21/1/95
199	680 KEET	-2.98	-14.4	62		4.5		27/1/95
200	680 RHYS	-3.02	-15.6	58		4.1		27/1/95
201	682A JARVIS	-1.84	-9.1	98		4.1		27/1/95
202	688 MORTIMER (42m)	-2.45	-12.0	72		5.8		27/1/95
203	756 FIFTH	-2.27	-10.5	66		4.5		27/1/95
204	915 SIXTH	-4.25	-22.0	36		2.9		27/1/95
205	977 EIGHTH	-4.28	-22.6	18		1.7		27/1/95
206	988 EIGHTH	-4.56	-23.9	22		2.1		27/1/95
207	VAAL RIVER BARRAGE	-1.17	+2.5	56		2.1		1/12/95
208	KLIP RIVER	-0.45	+3.1	74		2.8		1/12/95
209	SUIKERBOSRAND RIVER	-1.72	-7.9	100		3.5		1/12/95
210	WILGE RIVER	-4.73	-23.0	11		1.1		1/12/95
211	VAAL RIVER BELOW DAM WALL	+0.18	+5.8	6		1.0		1/12/95
212	VAAL-WILGE CONFLUENCE	-0.67	-0.4	15		1.3		1/12/95
213	VAAL RIVER	-1.22	-4.6	22		1.8		1/12/95
214	RW WATER (01/12/95)	+0.66	+8.9	15		1.6		1/12/95
215	1385 MERWEDE	-4.96	-28.3	8		0.9		19/12/95
216	428 IVOR	-4.65	-24.3	43		3.4		19/12/95

TABLE 1

WRCL NO.	LOCATION	$\delta^{18}O$ (‰)	δD (‰)	E.C. (mS/m)	pH	ALK (meq/l)	^3H (TU)	SAMPLE DATE
217	430 KAREL TRICHARDT	-4.74	-20.6	21		2.5		19/12/95
218	562 SAREL	-3.03	-13.1	90		6.6		19/12/95
219	681 IVOR	-3.83	-18.2	57		3.5		19/12/95
221	455 IRVINE	-4.98	-22.1	18		2.1		19/12/95
222	RW WATER (03/01/96)	-2.03	-1.9					3/1/96
223	RW WATER (12/01/96)	-2.01	-6.2					12/1/96
224	RW WATER (01/02/96)	-4.33	-21.1					1/2/96
225	RW WATER (15/02/96)	-4.57	-25.0					15/2/96
226	GUTTER IN BASEMENT (15/02/96)	-3.99	-19.9					15/2/96
227	RAIN (15/02/96)	-11.27	-70.9					15/2/96
228	RW WATER (22/02/96)	-7.05	-46.2					22/2/96
229	RW WATER (05/03/96)	-8.29	-53.1					5/3/96
230	RW WATER (15/03/96)	-8.40	-54.6					15/3/96
231	RW WATER (25/03/96)	-8.34	-54.1					25/3/96
232	RW WATER (04/04/96)	-8.12	-49.8					4/4/96
233	RW WATER (24/04/96)	-7.94	-49.5					24/4/96
234	RW WATER (13/05/96)	-7.67	-56.3					13/5/96
235	210 ULUNDI	-4.93	-20.8	9	6.7	1.2		23/5/96
236	455 IRVINE	-4.23	-20.1	18	6.4	1.8		23/5/96
237	520 SAREL	-3.25	-13.0	72	6.7	4.5		23/5/96
238	617 SAREL	-2.05	-13.8	98	6.8	7.6		23/5/96
239	430 KAREL TRICHARDT	-4.84	-24.4	22	7.1	2.8		23/5/96
240	700 IVOR	-4.38	-22.3	54	6.5	3.5		23/5/96
241	542 DENYSSEN	-3.48	-16.2	30	6.5	2.1		23/5/96
242	RW WATER (700 IVOR)	-7.82	-48.4					23/5/96
243	883 MORTIMER	-2.05	-8.4	96	7.3	9.5		23/5/96
244	776 MORGAN	-1.32	-3.3	72	6.9	4.4		23/5/96
245	RW WATER (22/05/96)	-7.88	-49.2					22/5/96
246	RW WATER (27/05/96)	-7.77	-48.5					27/5/96
247	RW WATER (04/06/96)	-7.66	-46.9					4/6/96

WRCL NO.	LOCATION	$\delta^{18}O$ (‰)	δD (‰)	E.C. (mS/m)	pH	ALK (meq/l)	^3H (TU)	SAMPLE DATE
248	RW WATER (11/06/96)	-7.71	-46.1					11/6/96
249	879 MORTIMER	-2.93	-13.3					13/6/96
250	883 MORTIMER	-2.41	-10.2					13/6/96
251	895 MORTIMER	-2.70	-12.6					13/6/96
252	140 FRANKEN	-1.94	-7.6					13/6/96
253	RW WATER (03/07/96)	-7.39	-50.2					3/7/96
254	RW WATER (19/07/96)	-7.69	-48.9					19/7/96
255	STERKFONTEIN DAM	-0.22	-2.2					28/7/96
256	RW WATER (30/07/96)	-7.35	-48.3			old 18O		30/7/96
257	815 MANCE	-3.03	-17.4			-2.07		8/8/96
258	617 MAGDALENA	-2.76	-15.1			-2.17		8/8/96
259	664 DENYSSEN	-4.99	-27.7			-5.40		8/8/96
260	54 GREEN	-2.41	-13.0			-1.28		8/8/96
261	542 DENYSSEN	-3.47	-18.2			-3.05		8/8/96
262	430 KAREL TRICHARDT	-5.19	-28.8			-4.83		8/8/96
263	657 DENYSSEN	-4.69	-25.1			-4.45		8/8/96
264	59 THE GROVE	-1.98	-10.3			-1.59		8/8/96
265	612 KAREL TRICHARDT	-4.91	-25.6			0.12		8/8/96
266	92 THE GROVE	-1.82	-11.7			-1.87		8/8/96
267	642 SMOOK	-2.90	-13.6			-1.69		8/8/96
268	776 MORGAN	-1.92	-8.6			-1.23		8/8/96
269	825 KILLICK	-2.56	-14.7					8/8/96
270	RW WATER (14/08/96)	-7.37	-48.3					14/8/96
271	1 - 0.1m - Wall	-7.26	-45.2					20/8/96
272	1 - 0.3m		-46.0					20/8/96
273	1 - 0.5m		-46.3					20/8/96
274	1 - 1.0m	-7.29	-45.9					20/8/96
275	1 - 1.5m		-45.6					20/8/96
276	1 - 2.0m		-46.9					20/8/96

TABLE 1

WRCL NO.	LOCATION	δ¹⁸O (‰)	δD (‰)	E.C. (mS/m)	pH	ALK (meq/l)	³H (TU)	SAMPLE DATE
277	1 - 5.0m	-6.06	-43.5					20/8/96
278	1 - 10.0m	-7.24	-46.8					20/8/96
279	1 - Bottom		-45.6					20/8/96
280	1x2 - 0.1m - Between Wall and Confl.	-7.33	-45.3					20/8/96
281	1x2 - 0.3m							20/8/96
282	1x2 - 0.5m							20/8/96
283	1x2 - 1.0m		-45.7					20/8/96
284	1x2 - 1.5m							20/8/96
285	1x2 - 2.0m		-46.5					20/8/96
286	1x2 - 5.0m	-7.27	-46.0					20/8/96
287	1x2 - 10.0m	-7.46	-46.5					20/8/96
288	1x2 - Bottom							20/8/96
289	2 - 0.1m - Confluence	-7.06	-46.0					20/8/96
290	2 - 0.3m							20/8/96
291	2 - 0.5m							20/8/96
292	2 - 1.0m	-7.01	-46.2					20/8/96
293	2 - 1.5m							20/8/96
294	2 - 2.0m		-44.3					20/8/96
295	2 - 5.0m	-7.39	-43.9					20/8/96
296	2 - 10.0m	-7.16	-43.2					20/8/96
297	2 - Bottom							20/8/96
298	3 - 0.1m - Wilge River	-7.61	-44.4					20/8/96
299	3 - 0.3m							20/8/96
300	3 - 0.5m							20/8/96
301	3 - 1.0m	-6.99	-43.8					20/8/96
302	3 - 1.5m							20/8/96
303	3 - 2.0m		-42.2					20/8/96
304	3 - 5.0m	-7.48	-43.2					20/8/96
305	3 - 10.0m	-7.22	-42.8					20/8/96
306	3 - Bottom							20/8/96
307	4 - 0.1m - Vaal River	-5.04	-30.7					20/8/96

WRCL NO.	LOCATION	$\delta^{18}O$ (‰)	δD (‰)	E.C. (mS/m)	pH	ALK (meq/l)	^3H (TU)	SAMPLE DATE
308	4 - 0.3m							20/8/96
309	4 - 0.5m							20/8/96
310	4 - 1.0m		-30.5					20/8/96
311	4 - 1.5m							20/8/96
312	4 - 2.0m		-31.1					20/8/96
313	4 - 5.0m	-5.08	-32.3					20/8/96
314	4 - 10.0m	-5.31	-31.8					20/8/96
315	4 - Bottom							20/8/96
316	RW WATER (28/08/96)		-46.2					28/8/96
317	RW WATER (17/09/96)	-7.16						17/9/96
318	1 - 0.1m - Wall	-7.13						17/9/96
319	1 - 1.0m	-7.03						17/9/96
320	1 - 2.0m	-6.92						17/9/96
321	1 - 5.0m	-6.91						17/9/96
322	1 - 10.0m	-7.19						17/9/96
323	1 - Bottom	-6.87						17/9/96
324	2 - 0.1m - Confluence	-6.91						17/9/96
325	2 - 1.0m	-6.73						17/9/96
326	2 - 2.0m	-7.05						17/9/96
327	2 - 5.0m	-7.06						17/9/96
328	2 - 10.0m	-6.62						17/9/96
329	3 - 0.1m - Wilge River	-6.84						17/9/96
330	3 - 1.0m	-6.71						17/9/96
331	3 - 2.0m	-6.90						17/9/96
332	3 - 5.0m	-6.89						17/9/96
333	3 - 10.0m	-6.74						17/9/96
334	4 - 0.1m - Vaal River	-6.62						17/9/96
335	4 - 2.0m	-6.78						17/9/96
336	4 - 5.0m	-6.75						17/9/96
337	5 - 0.1m - South Bay	-7.15						17/9/96

WRCL NO.	LOCATION	$\delta^{18}O$ (‰)	δD (‰)	E.C. (mS/m)	pH	ALK (meq/l)	^{3}H (TU)	SAMPLE DATE
338	5 - 4.0m	-7.14						17/9/96
339	5 - 8.0m	-7.25						17/9/96
340	RW WATER (02/10/96)	-7.01						2/10/96
341	RW WATER (10/10/96)	-7.02						10/10/96
342	RW WATER (22/10/96)							22/10/96
343	VAALBANK RESORT							23/10/96
344	VISCHGAT ZOEKFONTEIN							23/10/96
345	VERGENOEG							23/10/96
346	1 - 0.1 m		-41.2					19/11/96
347	1 - 2.0 m		-38.8					19/11/96
348	1 - 5.0 m		-41.0					19/11/96
349	1 - 10 m		-36.6					19/11/96
350	1 - Bottom		-37.9					19/11/96
351	2 - 0.1 m		-33.2					19/11/96
352	2 - 2.0 m		-33.4					19/11/96
353	2 - 5.0 m		-33.2					19/11/96
354	2 - 10 m		-33.1					19/11/96
355	2 - Bottom		-32.6					19/11/96
356	3 - 0.1 m		-33.8					19/11/96
357	3 - 2.0 m		-34.9					19/11/96
358	3 - 5.0 m		-34.0					19/11/96
359	3 - 10 m		-33.1					19/11/96
360	3 - Bottom		-32.0					19/11/96
361	4 - 0.1 m		-8.7					19/11/96
362	4 - 2.0 m		-10.2					19/11/96
363	4 - 5.0 m		-12.9					19/11/96
364	4 - 10 m		-10.3					19/11/96
365	4 - Bottom		-5.2					19/11/96
366	RW WATER (12/12/96)		-37.6					12/12/96
367	RW WATER (20/12/96)		-36.6					20/12/96

TABLE 1

WRCL NO.	LOCATION	δ¹⁸O (‰)	δD (‰)	E.C. (mS/m)	pH	ALK (meq/l)	^{3}H (TU)	SAMPLE DATE
368	RW WATER (24/01/97)		-25.5					24/1/97
369	RAIN (25 & 26 JANUARY 1996)	-14.81	-103.2					26/1/96
370	RAIN (21 FEBRUARY 1996)		-21.5					21/2/96
371	RW WATER (06/02/97)		-24.6					6/2/97
372	RW WATER (24/02/97)		-21.1					24/2/97
373	542 DENYSSEN		-22.4					25/2/97
374	617 SAREL		-9.6					25/2/97
375	700 IVOR		-25.0					25/2/97
376	882 MORTIMER		-10.4					25/2/97
377	RW WATER (12/03/97)		-20.7					12/3/97
378	RW WATER (27/03/97)		-17.1					27/3/97
379	RW WATER (09/04/97)		-15.7					9/4/97
380	RW WATER (22/04/97)		-15.1					22/4/97
381	RW WATER (07/05/97)		-13.8					7/5/97
382	RW WATER (22/05/97)		-13.3					22/5/97
383	RW WATER (10/06/97)		-14.1					10/6/97
384	RW WATER (26/06/97)		-14.8					26/6/97

TABLE 2

SAMPLE MARKS	210 ULUNDI	455 IRVINE	520 SAREL	617 SAREL	430 KAREL TRICH.	700 IVOR	542 DENYSSEN
Hardness as $CaCO_3$	48	103	384	510	112	302	166
Alkalinity as $CaCO_3$	52	76	208	360	128	156	92
Calcium, Ca	6.9	11.6	45	74	23	37	18.5
Magnesium, Mg	7.4	18.1	66	79	13.2	51	29
Sodium, Na	4.8	16.3	33	56	19.8	11	9
Potassium, K	1.7	1.4	2	2.2	1.9	0.5	0.2
Bicarbonate, HCO_3	63	93	254	439	156	190	112
Carbonate, CO_3	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Chloride, Cl	4.1	15.3	76	108	17.3	57	48
Sulphate, SO_4	2	5	78	114	3	52	10
Nitrate, NO_3	0.6	42	66	18	0.4	41	8.5
Fluoride, F	0.2	0.1	0.2	0.2	0.4	0.2	0.1
Dissolved Iron, Fe	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Values expressed in mg/l							
Analyses by INSPECTORATE M & L (PTY) LTD							