The Identification and Verification of Polluted Areas in the Dolomitic Aquifer of the PWV Area

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and J J van Blerk

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THE IDENTIFICATION AND VERIFICATION OF POLLUTED AREAS IN THE DOLOMITIC AQUIFER OF THE PWV AREA

Report prepared for

Water Research Commission

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ABSTRACT

The dolomitic formation of the Transvaal Sequence is one of the most important sources of groundwater within South Africa. Pollutants have already been identified at certain localities in recent studies, and this project was initiated because of the awareness of the need for the conservation of this resource. It was planned that boreholes identified as polluted were to be resampled to verify the existence of such pollution. This proved difficult as the boreholes had to be located on a coordinate basis alone, and very often the nearest borehole to the given coordinates was sampled. It could not be said with certainty that the original borehole was being resampled. A second phase of sampling was initiated in the Klip River/Natalspruit region which had previously been identified as a polluted area by Simonis in 1989. Field maps were available together with historic data, and this provided a much sounder basis around which the project could be developed.

As a consequence of this second phase two areas were chosen for more detailed investigation. The Elspark/Rondebult area had elevated nitrate values together with some instances of high sulphate values. The second area referred to as the Rietspruit/Ergo area showed elevated SO_4 values with isolated high NO_3 values. The aim of the detailed investigation was to establish the type and extent of the pollution, the potential source/s and any temporal variation thereof.

A field hydrocensus was carried out in both areas to provide background chemical values, waterlevel and geological data, together with landuse information. In addition to these conventional approaches, natural isotope studies were included. These proved invaluable for the determination of the vulnerability of the aquifer, the dynamic hydrogeology and the method by which pollution enters the groundwater system.

It was concluded that both study areas were being subjected to diffuse agricultural pollution producing elevated NO_3 levels. Point source pollution was identified in the Rietspruit/Ergo area in the vicinity of the new Ergo tailings dam, and the Ergo plant. This gave rise to elevated SO_4 levels in both ground and surface water together with elevated levels of trace elements such as nickel, copper and iron. As a consequence of the study it is recommended that the monitoring facilities associated with these point sources be revised and upgraded.

As part of the investigation, the potential for mapping pollution by using the ternary (three-component) imaging technique, was investigated. The initial images produced in this way showed that it could be an effective method for displaying in a single image ratio, information for three parameters. It was concluded that the method has useful application in pollution studies provided there is sufficient data coverage of the area studied (sufficient density). These maps are also useful as a geological tool for highlighting zones of uniform lithology and contacts between contrasting lithologies. It is recommended that the technique be further developed and the effect of concentration be added by the use of "saturation of colours".

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

1. BACKGROUND INFORMATION

During the mid-1980s the Department of Water Affairs and Forestry initiated a large-scale investigation of the dolomitic formations of the Transvaal sequence (commonly known as the *"dolomites"*) in order to determine their water-bearing properties and to ascertain whether they could be utilized for the provision of emergency water supplies to the PWV-region during periods of prolonged drought.

It was during this investigation that elevated levels of ions such as sulphate and nitrate were detected which led the Department to suspect pollution of the dolomitic aquifer in certain areas related to either mining, industrial or agricultural practices. Unfortunately, no long-term monitoring of the groundwater resource was initiated after the option of large-scale abstraction from the dolomitic aquifer was scrapped a few years later.

In 1991 the AEC submitted a proposal to resample the boreholes suspected by the Department as being polluted in order to ascertain whether there had been any change in the quality of the groundwater, and if possible, to relate the quality changes to landuse activities in the catchment areas of boreholes.

The main objectives of the project can be stated as follows:

- To locate boreholes in the field that have been identified as being polluted by previous studies of the Department of Water Affairs and have been entered into the National Groundwater Data Base.
- Resample these boreholes to verify that pollution does exist.
- Establish the type and extent of the pollution.
- Establish the source of the pollution and temporal variation thereof.
- Suggest remedial measures to reduce or stop further pollution.

During the course of the project, the AEC suggested using the ternary (three-component) imaging technique in order to examine variations from the ambient groundwater quality and to relate these to nearby landuse activities. This additional objective was added to the above list.

2. MAIN RESULTS

Initially, difficulty was experienced in locating in the field those boreholes identified as being *"polluted"* from Department of Water Affairs and Forestry records (due to rapid expansion of squatter settlements or poor recording of borehole coordinates). Consequently, it could not be said with any certainty that the original borehole was being resampled.

A second phase of sampling was consequently initiated in the Klip River/Natalspruit region where more detailed maps were available, which together with good historical data, provided a sounder basis around which the project could be developed. A field hydrocensus was carried out in two selected case study areas to provide background chemical values, waterlevel and geological data, together with landuse information. The areas selected for more detailed investigations revealed elevated sulphate and nitrate values.

In addition to the above routine hydrochemical and landuse data, natural isotope studies proved invaluable for determining the vulnerability of the aquifer, the dynamic hydrogeology, and the method by which pollution enters the groundwater system.

It was concluded that both case study areas are being subjected to diffuse agricultural pollution producing elevated nitrate levels.

Point source pollution from mining activities has given rise to elevated sulphate levels and elevated levels of trace metals such as nickel, copper and iron. The monitoring boreholes currently utilized to determine the impact of the tailings dams on groundwater quality were found to be inadequate for the purpose.

As part of the investigation, the potential for mapping pollution by using the ternary (three-component) imaging technique, was investigated. It was demonstrated that the method has useful application in pollution studies provided there are sufficient data points (data density) for the area under study.

3. CONCLUSIONS

Problems encountered during the initial phases of the project regarding the location of boreholes, highlighted the need for these to be properly documented in the form of accurate coordinates, together with a practical field map showing their location.

More detailed records should be kept concerning the method of sampling, together with information about the frequency of use of the borehole. Information of this sort is particularly important when attempting to compare water quality analyses for temporal variations in water quality.

Nitrate pollution of certain areas within the dolomites of Region H appears to be serious, with the level of nitrate frequently exceeding drinking water standards. The origin of the nitrate is believed to be related to the intensive irrigated agriculture and concomitant use of fertilizers, particularly related to market gardening.

Elevated sulphate values, particularly in the Rietspruit/Ergo area, appear to be a regional phenomena and may be a result of the geological history of doleritic intrusions found here. Obvious point source pollution from, for example, the new Ergo tailings dam is evident, superimposed on the regional sulphate background.

The ternary imaging technique proved extremely useful for differentiating between different lithologies based on hydrochemical data, and for analysing and interpreting the presence and character of pollutants present in the groundwater. The method, although in its infancy, can be enhanced considerably by adding *"total concentration"* to the graphical presentation of results.

4. RECOMMENDATIONS

It is recommended that when carrying out a pollution study of this kind, certain criteria must be adhered to, where possible:

- All available relevant data, past and present, must be incorporated into the study. This will give some understanding of the temporal development of suspected pollution.
- A detailed hydrocensus, including a detailed landuse survey, must be carried out to determine background levels and possible point sources of pollution.
- Detailed natural isotope studies should be included to gain a better understanding of the dynamic hydrogeology i.e. how polluted water is entering the groundwater system.

In relation to this particular study, it is recommended that a more comprehensive and functional monitoring system be installed at the new Ergo tailings dam. Pollution has been identified in the dolomitic formation to the west but the extent to which this pollution is taking place both aerially and vertically is unknown. The present monitoring system will not provide this information.

Ternary mapping reveals a good potential for mapping pollution provided a fair sampling density exists and the hydrochemical data are reliable. It is recommended that if further development of the technique be considered, then mapping of concentration should be added to enhance the ternary maps.

1 AIMS AND OBJECTIVES

The dolomitic formation of the Transvaal Sequence is one of the most important sources of groundwater within South Africa. It has been investigated and has been found to have the potential to be developed to provide emergency water supplies in times of drought. It is therefore imperative that this vulnerable resource be protected from pollution by mining and agricultural practices, and industrial and urban development.

Samples taken before 1987 by the Department of Water Affairs indicate that pollutants are present in groundwater at certain localities within the PWV area. The present status of these boreholes is unknown and no monitoring is either planned or is being carried out. The polluted areas have been highlighted in a previous report, Van der Merwe *et al.* (1991). The present study concentrated on the groundwater within the dolomites of the PWV region, also referred to as the H-region.

The objectives of this project were firstly, to locate boreholes in the field that have been identified as being polluted by previous studies carried out by the Department of Water Affairs and which have been entered on the National Groundwater Database, to then re-sample these boreholes in order to verify that pollution still exists. The critical aims of the project were then to establish the type and extent of the pollution, the source and any temporal variation thereof. The area was considered too large to be covered in relation to the finance available, and so two smaller areas were chosen to be investigated in greater detail. These areas were highlighted as a consequence of the initial phases of the investigation. The initial aims were applied to these areas together with consideration as to the method by which pollution is taking place. Suggestions have been given concerning remedial measures to reduce or stop further pollution from occurring.

The ability to image process hydrogeochemical data using a trilinear technique was thought to be promising with regard to this particular study and was therefore incorporated into the project, thereby broadening the scope of the investigations.

2 IDENTIFICATION AND VERIFICATION OF EXISTING POLLUTED BOREHOLES WITHIN THE PWV REGION - PHASE 1

2.1 Desk Study

Pollution had been detected in certain areas within the PWV region and indicated in a previous report by Van der Merwe *et al.* (1991). The National Groundwater Database was used in this investigation, as it had been in the above-mentioned report. The elements used to identify polluted boreholes included electrical conductivity, SO_4, Cl and NO_3. The coordinates given in the database were then used to plot these boreholes on the appropriate 1:50 000 topographic maps.

PWV AREA -[H-REGION] LOCALITY MAP OF POLLUTED AREAS AFTER VAN DER MERWE et al., 1991.

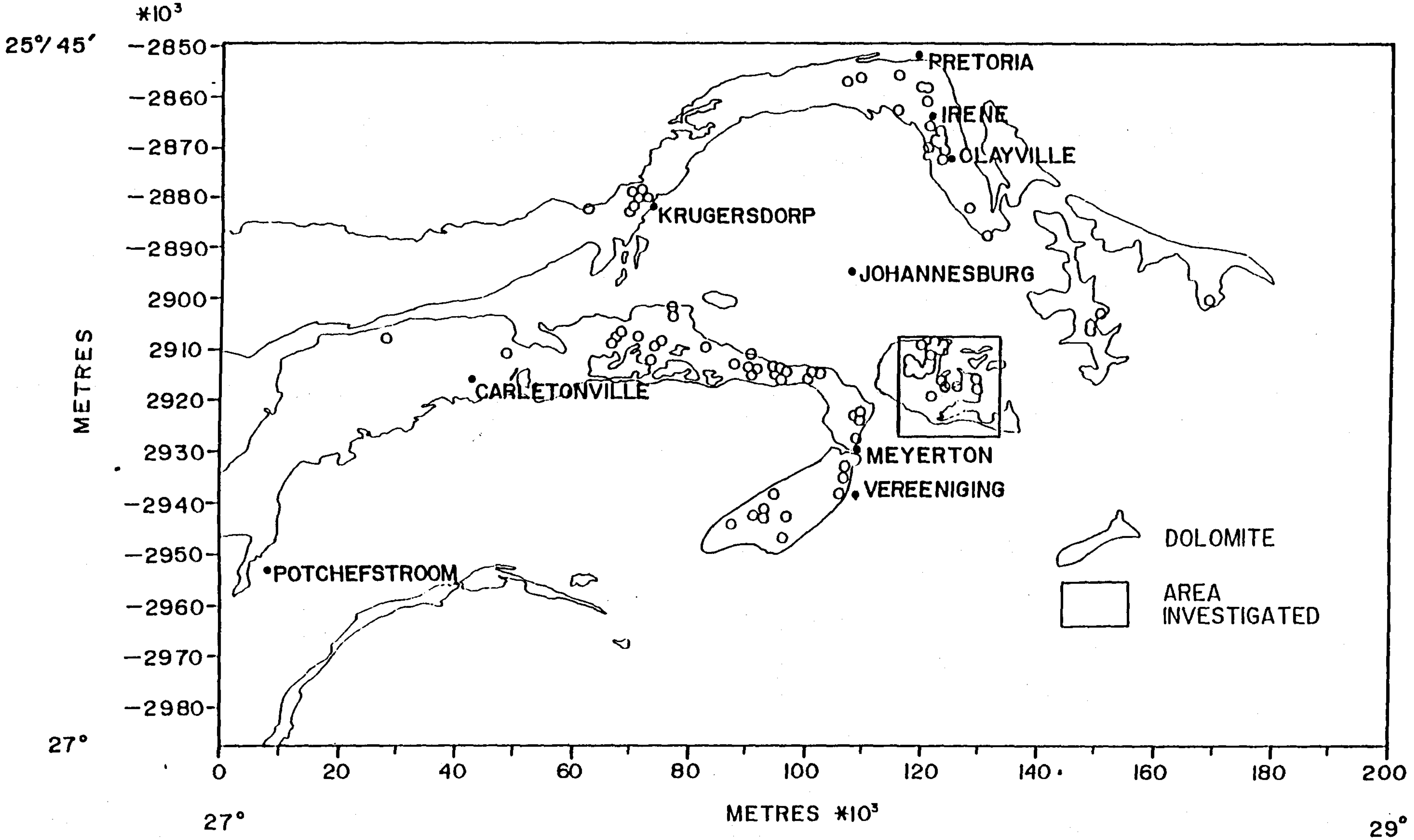

FIGURE I

2.2 Fieldwork

The actual boreholes, or those nearest to the exact coordinates were located in the field and wellhead chemistry providing EC, pH and HCO_3 values was carried out. A preliminary appraisal of landuse within the area of the borehole was done in order to determine the need for trace element analysis.

2.3 Discussion

It became apparent from the low EC values that very little pollution was taking place in the vicinity of these boreholes. Problems also arose in locating the boreholes on a coordinate basis alone. Very rarely was a borehole at the exact position indicated, and so the nearest boreholes were sampled. Correlation between historic and present day data could therefore not be guaranteed. Some boreholes could not be found because of encroachment of informal settlements, and other boreholes had collapsed or been infilled.

3 INVESTIGATION WITHIN THE KLIP RIVER/NATALSPRUIT AREA - PHASE 2

3.1 Desk Study

Due to the difficulties encountered in Phase 1 of the investigation, a second phase of sampling was done in the Klipriver area. Areas of pollution were identified from an investigation into the water quality in the Klip River area by Simonis (1989). Again, the elements SO_4, NO_3 and Cl together with EC were used as criteria to determine whether groundwater, and in some cases surface water, was polluted.

3.2 Fieldwork

Twenty one boreholes were investigated in the area shown in Figure 1. Of these only 15 water samples could be taken. The localities of most of the 21 boreholes are given in Figure 2. Four have been omitted, 2628CA 2/4 and DB 15/6 were considered insignificant because they showed very little pollution. BD 1A and BD 12, although they show elevated NO_3 levels are not indicated on the locality map because the NO_3 level was attributed to unsanitary conditions around the borehole. All four boreholes are outside the region covered by the map in Figure 5. Those showing elevated SO_4 and NO_3 levels are highlighted with a coloured circle.

Wellhead chemistry was carried out as in Phase 1 to accurately determine EC, pH and HCO_3 values, and cognisance was takenof the landuse around the borehole. Two water samples were taken, one of which was acidified as in Phase 1.

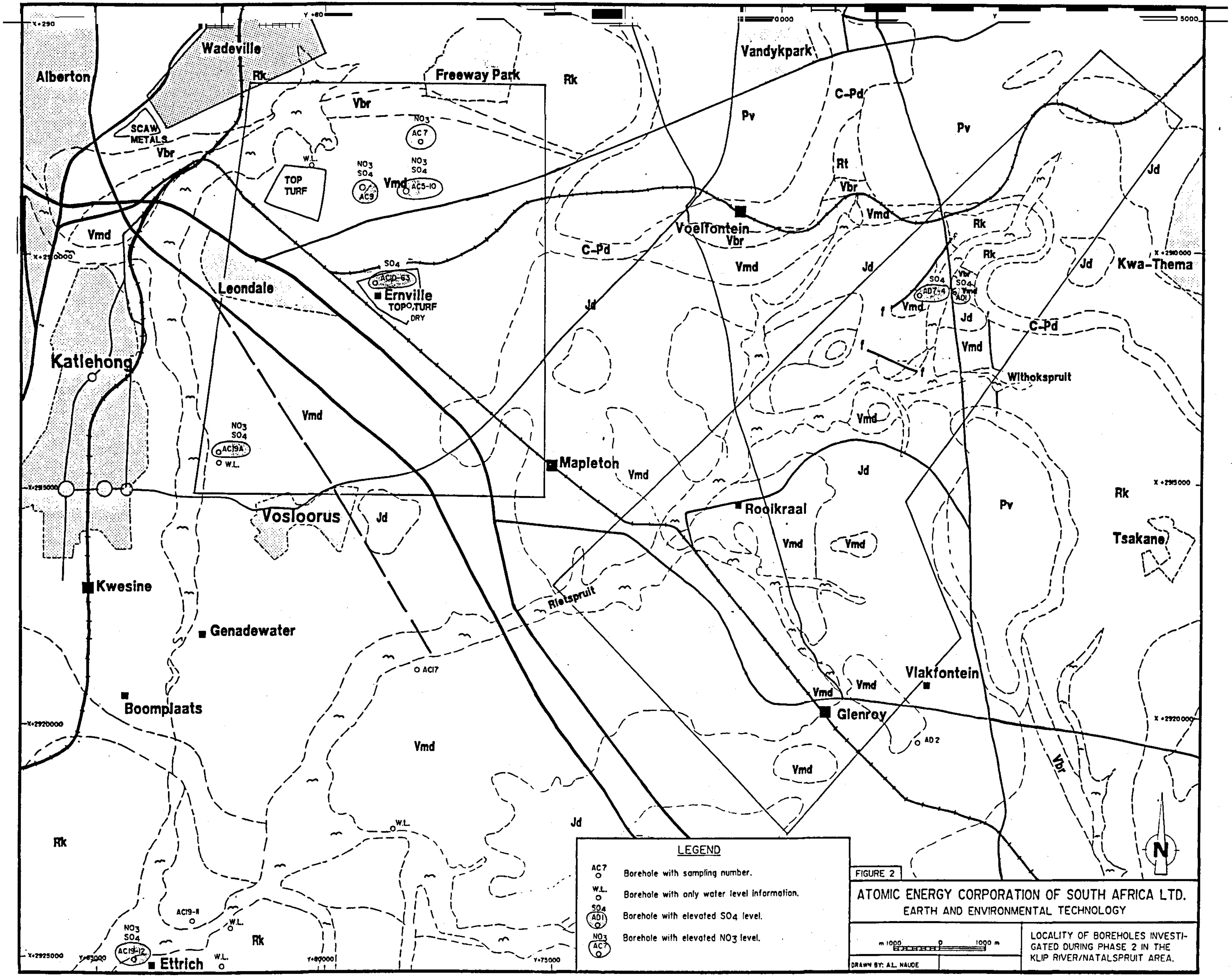

FIGURE 2

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LOCALITY OF BOREHOLES INVESTIGATED DURING PHASE 2 IN THE KLIP RIVER/NATALSPRUIT AREA.

Table 1. General chemistry of Boreholes sampled in Phase 2 - Klipriver/Natalspruit Area

Sample	pH	Cond mS/m	HCO_3 mg/ℓ	Cl mg/ℓ	SO_4 mg/ℓ	NO_3 mg/ℓ	PO_4 mg/ℓ	F mg/ℓ	Na mg/ℓ	K mg/ℓ	Ca mg/ℓ	Mg mg/ℓ	Fe mg/ℓ	Mn mg/ℓ	Zn mg/ℓ	Uranium mg/ℓ
2627 BD1A*	6.7	520	167	36	58	42	0.30	0.09	9	0.73	45	33	<0.10	<0.10	<0.10	<0.04
2627 BD12*	7.1	492	179	29	40	51	0.30	0.10	8	0.91	38	33	<0.10	0.14	0.10	<0.04
2627 BD 15/6*	6.9	766	511	22	35	1.7	0.30	0.10	10	1.94	79	60	<0.10	0.33	1.97	<0.04
2628 AC5/10	6.8	1 430	253	153	303	53	0.34	0.07	114	5.92	95	64	22.8	0.25	<0.10	<0.04
2628 AC7	7.1	1 204	227	130	135	183	0.27	0.06	25	2.28	121	72	<0.10	0.14	<0.10	<0.04
2628 AC9	7.4	1 880	166	185	288	208	0.30	0.05	33	2.61	206	113	<0.10	0.21	<0.10	<0.04
2628 AC10/63	7.6	1 590	376	130	390	30	0.34	0.07	135	12.2	129	67	<0.10	<0.10	<0.10	<0.04
2628 AC17	7.5	450	295	22	8	<0.1	0.30	0.20	18	1.92	23	35	6.00	<0.10	<0.10	<0.04
2628 AC19A	7.0	1 014	265	48	232	76	0.30	0.09	29	1.56	96	66	<0.10	0.16	<0.10	<0.04
2628 AC19/11	7.8	568	90	26	47	1.8	0.39	0.68	83	1.59	13	14	<0.10	0.14	<0.10	<0.04
2628 AC19/12	6.6	1 248	200	165	552	65	0.36	0.08	44	1.30	105	70	<0.10	0.18	8.86	<0.04
2628 AD1	6.8	804	132	54	230	28	0.38	0.08	17	1.85	71	58	<0.10	<0.10	<0.10	<0.04
2628 AD2	6.8	371	172	10	17	47	0.30	0.06	13	5.43	33	16	<0.10	<0.10	<0.10	<0.04
2628 AD7/4	7.4	1 560	169	170	460	30	0.30	0.09	102	7.28	145	66	<0.10	0.49	<0.10	<0.04
2628 CA2/4*	7.0	349	219	9	4	16.8	0.30	0.07	18	1.55	24	19	3.24	0.25	0.83	<0.04

*Not shown in Figure 2

3.3 Discussion

Figure 3 shows the groundwater characteristics with the aid of a Piper diagram for the 15 water samples taken in Phase 2. When the positions of the 15 water samples on the Piper diagram are compared with those given in Figure 4, showing a typical Piper diagram plot of boreholes within the PWV area, it can immediately be seen that the vast majority of the boreholes sampled in phase 2 lie outside this 'typical' area. These waters can therefore be considered to be undergoing ionic changes, i.e. a relatively higher proportion of SO_4, Cl and NO_3, which can most probably be associated with ongoing pollution. The areal distribution of polluted boreholes resulted in the delineation of two areas that merited further investigation (Figure 5). The first has predominantly nitrate pollution, this is referred to as the Elspark/Rondebult area. The second area is located further east around Sallies Mine and Ergo, and continuing along the Rietspruit down past the new Ergo tailings dam. This is referred to as the Rietspruit/Ergo area. Although only 1 borehole showed elevated SO_4 levels, surface water samples from the report by Simonis (1989) did indicate that pollution might be more widespread along the course of the Rietspruit. It was then decided to investigate both groundwater and surface water along the spruit, and boreholes located within the vicinity of the Ergo tailings dam. Both these areas are shown in Figure 5. The chemistry of the boreholes sampled in this phase is given in Table 1, and their locations are also given in Figure 5.

4 DETAILED INVESTIGATIONS - ELSPARK/RONDEBULT AREA

4.1 Geology and Physiography

The area lies on the dolomitic formation of the Malmani Subgroup of the Transvaal Sequence. To the north lies the basal Black Reef Formation consisting predominantly of quartzites with lenses of grit and conglomerate. Shales are found throughout the formation becoming more prevalent towards the top, close to the contact with the overlying Malmani Subgroup. The Black Reef Formation dips to the south at an angle of 5°. Formations of the area lie in a basin syncline structure with the younger dolomitic formation surrounded by older formations of the Klipriversberg Group. A syenite dyke striking north-west/south-east, cuts through the dolomitic formation, and is located to the east of the Natalspruit in the west and south-western portion of the area under investigation.

The main drainage in the area is the Natalspruit which drains in a southerly direction, and is located on the western margin of the study area. This drainage joins the Rietspruit which eventually flows into the Klip River occupying the adjacent drainage catchment to the west.

Figure 3. Piper diagram showing groundwater characteristics of water samples taken in phase 2 - Klip River/Natalspruit

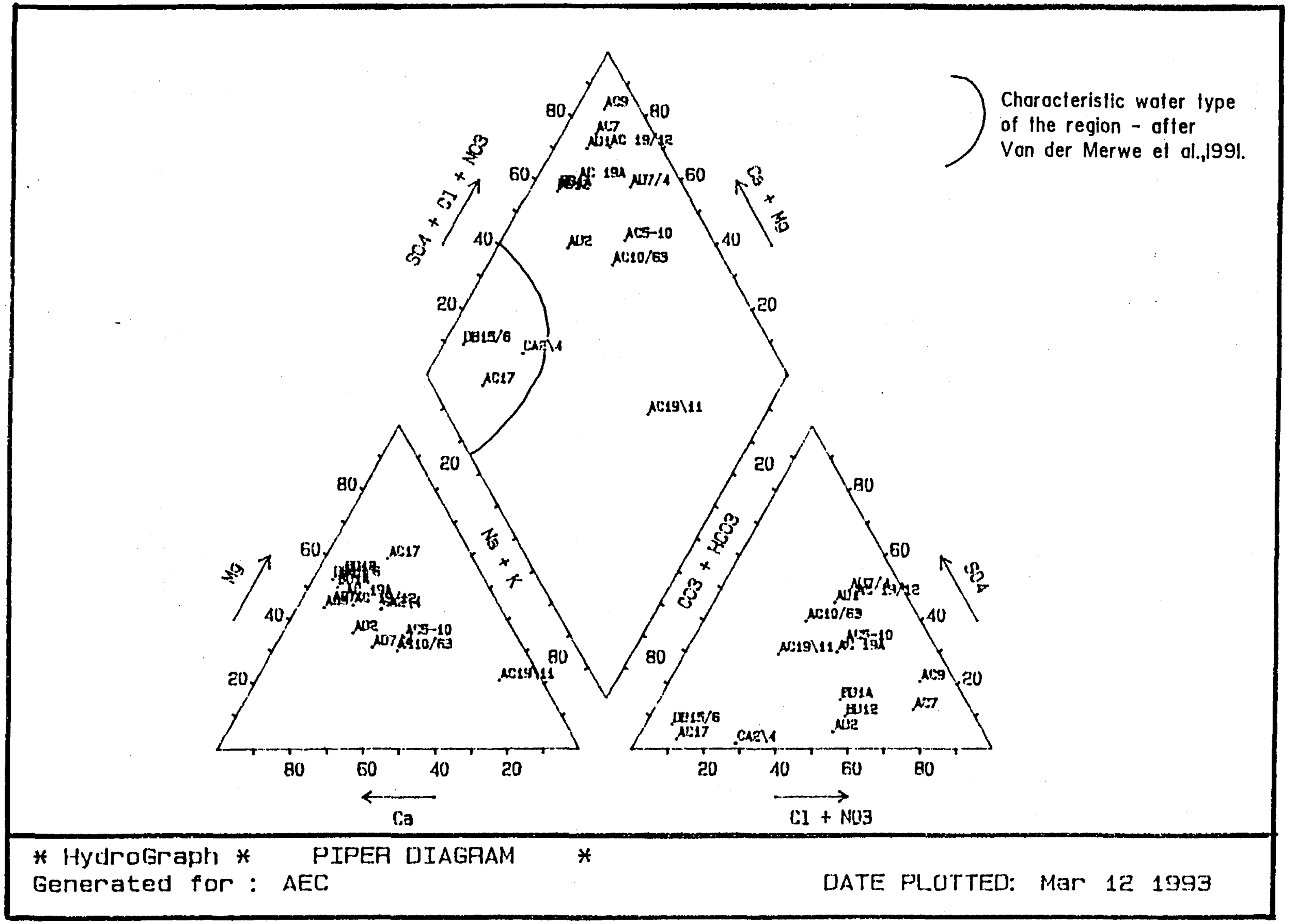
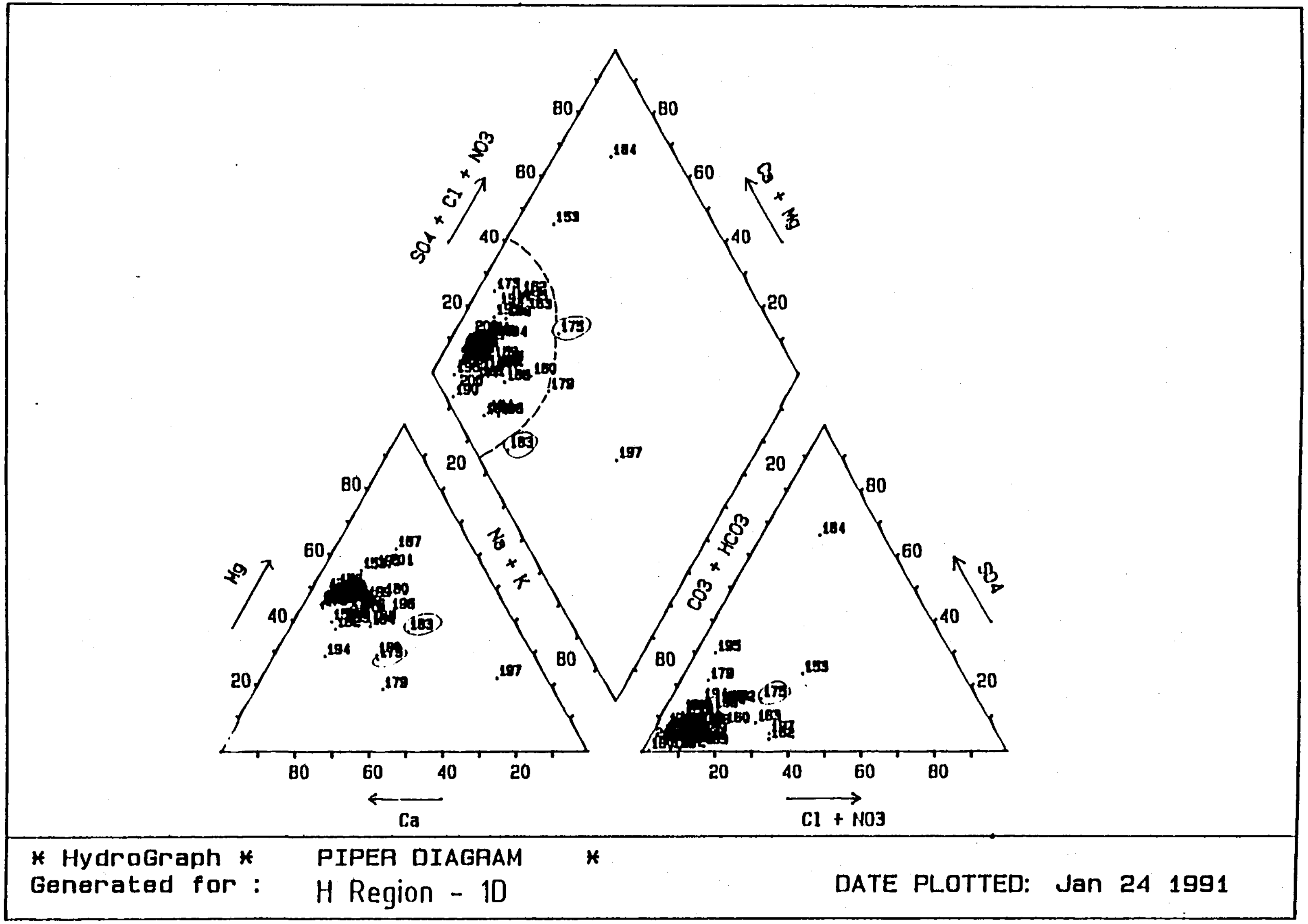


Figure 4. Piper diagram showing a typical plot of boreholes in the dolomite formation of the PWV region (after Van der Merwe *et al.*, 1991)



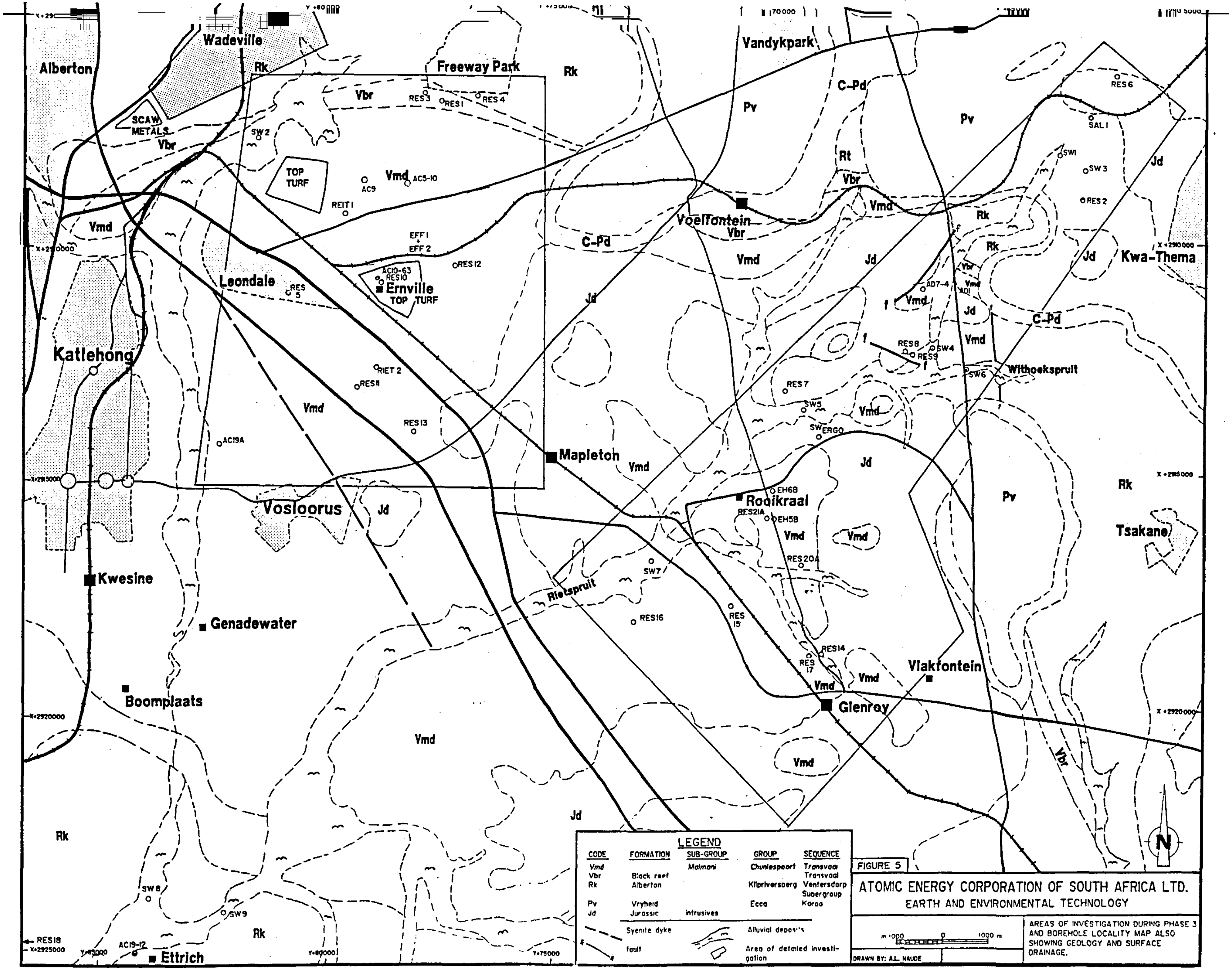


FIGURE 5

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AREAS OF INVESTIGATION DURING PHASE 3 AND BOREHOLE LOCALITY MAP ALSO SHOWING GEOLOGY AND SURFACE DRAINAGE.

4.2 Landuse

A substantial proportion of the area is covered by land used for agricultural purposes. In some localities intensive cultivation takes place producing vegetables and turf. Residential areas are present in the extreme northern sections, and isolated small residential developments are present within the mainly agricultural section. In the north-western area more commercial and industrial activities are present, mainly steelyards and workshops, timber yards and fuel depots. Just to the north-west of the area under investigation and north of the Elsburg Spruit lies Scaw Metals, a smelting and steel manufacturing industry. The suburb of Wadeville also has many steel storage depots and workshops. Although it is not considered probable that this industry affects the groundwater in this particular study area, it may have an influence on the quality and characteristics of the surface drainage water.

In the north-western section, south of the Elsburg Spruit is the company Top Turf. Intensive cultivation is carried out here under irrigation. The same company also utilize land for this purpose in the vicinity of Erville - Figure 6. Just to the south of the Van Dyk road lies a vlei area which has been converted into a bird sanctuary. Effluent from the sewage works is used to maintain this ecological environment.

4.3 Hydrogeology

The hydrogeological situation can only be deduced from the very scanty waterlevel information that could be collected. The water table lies approximately 13 m below ground surface, and groundwater flow is presumed to be in a westerly direction towards the surface drainage.

The dolomite is very heterogeneous, the evidence for this being provided by the estimated blowout yields of boreholes drilled by the Department of Water Affairs. Within the area investigated, estimated blowot yields range from 0,05 ℓ/sec to 100 ℓ/sec. This would suggest that groundwater flow would be along solution channels within the dolomite. Surface collapse has taken place in the vicinity of the sewage plant as described by the effluent inspector on site (personal communication), causing damage to the sewage tanks. This provides evidence for the belief that karstification is still taking place.

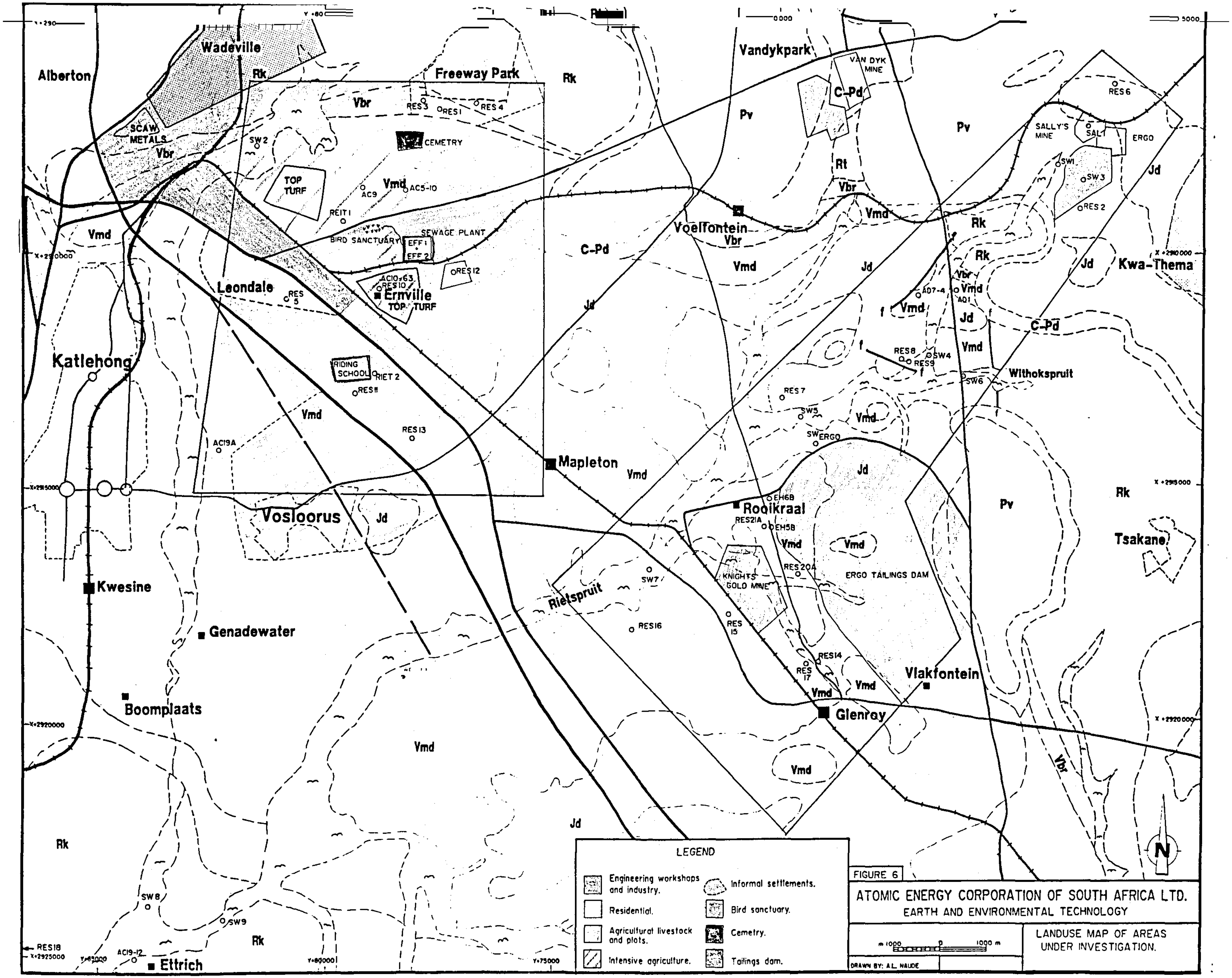

FIGURE 6

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LANDUSE MAP OF AREAS UNDER INVESTIGATION.

Figure 7. Piper diagram showing groundwater characteristics within the Elspark/Rondebult area - 1984-86 (after Simonis 1989)

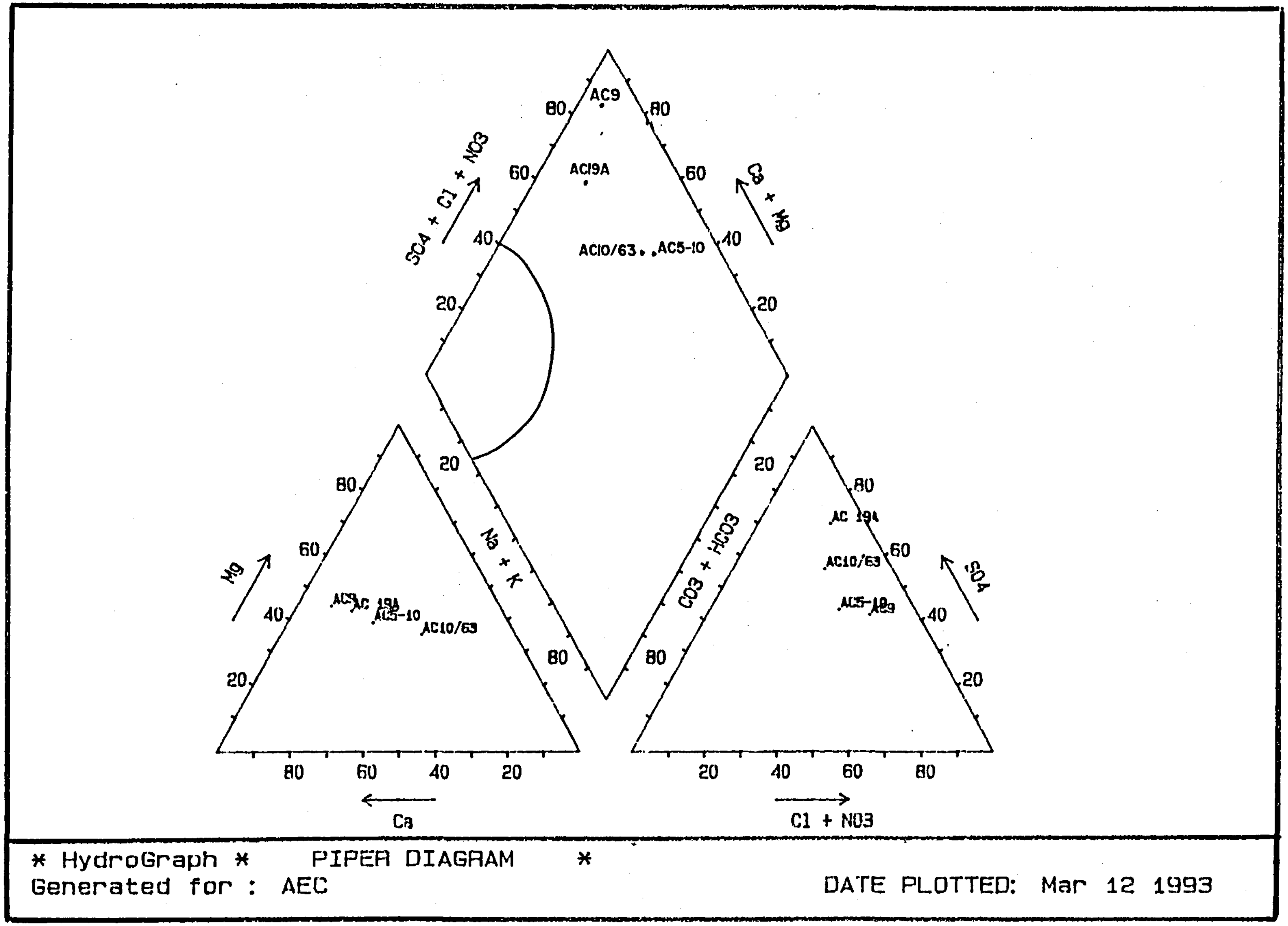
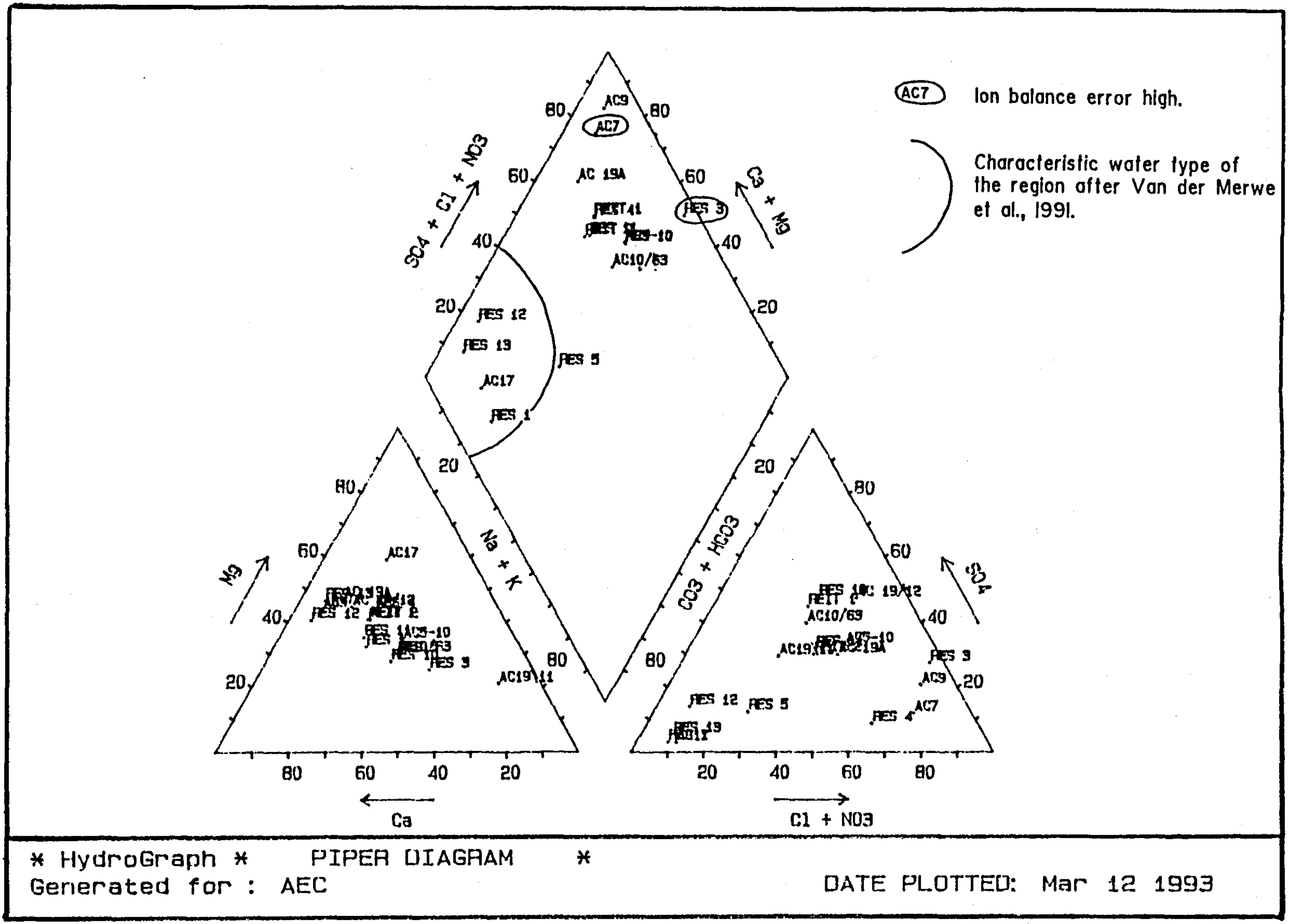


Figure 8. Piper diagram showing groundwater characteristics within the Elspark/Rondebult area - 1992



4.4 Hydrogeochemistry

4.4.1 Groundwater characteristics

Figures 7 and 8 are the Piper diagrams produced using data from 1984/86 and 1992 respectively. The boreholes sampled in 1984 were sampled again in 1992 and are included in Figure 8. The relative positions, and hence the temporal changes in chemical characteristics of these repeat samples, will be discussed in Section 4.1.4.4

Table 3 gives the groundwater chemistry of all the boreholes sampled in the hydrocensus carried out in June 1992 in the Elspark/Rondebult area. Table 2 gives the groundwater chemistry of boreholes sampled between 1984 and 1986 within the same area - after Simonis 1989.

Approximately 66% of the boreholes included in the hydrocensus fall outside the area typical of the regional groundwater as depicted by a Piper diagram. All these samples have elevated NO_3 and/or SO_4 levels (Table 3). In many cases the NO_3 levels are above that recommended for drinking purposes. The lack of data points prohibited the computation of hydrochemical contour maps for SO_4 and NO_3. The areal distribution of the levels of these elements are given in Figures 9 and 10 respectively.

Table 2. Groundwater Chemistry of Elspark/Rondebult Area - 1984 to 1986

Map Ref Number	Water Level (m)	pH	EC (mS/m)	HCO_3	Cl	SO_4	NO_3	F	Na	K	Ca	Mg
2628AC 9	10.35	7.3	68	128	165	313	34	0.7	31	2.7	145	84
2628AC 10-63	7.1	7.8	71	185	132	435	6	below detection	130	10.4	81	66
2628AC 5-10	13.80	7.8	74	210	154	340	21.1	below detection	90	3,2	131	82
2628AC 19A	1.1	7.5	126	183	193	1 013	8.4	0.1	94	7	230	143

*All elements in mg/ℓ unless otherwise stated

4.4.2 Surface water and effluent

A surface water sample (SW 2) was taken from the Natalspruit, its chemistry being given in Table 3. The high NO_3 content found in the groundwater does not seem to be present in the surface drainage water, although a relatively high SO_4 and fluoride content is noticeable. The elevated iron content may be associated with the runoff water from the storage depots and steelworks located in the suburb of Wadeville. High NO_3 levels are not found in the effluents released

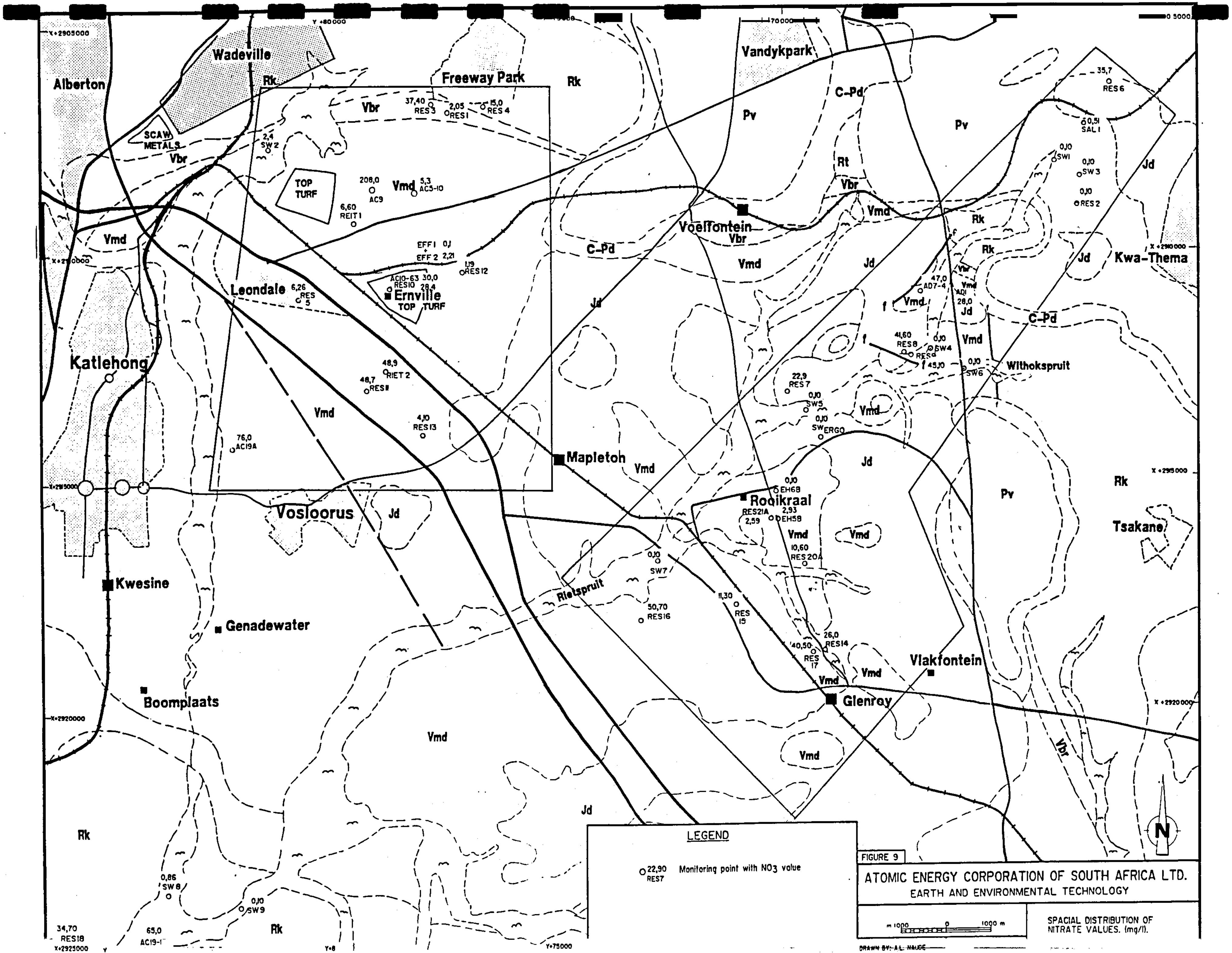


FIGURE 9

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SPACIAL DISTRIBUTION OF NITRATE VALUES. (mg/l).

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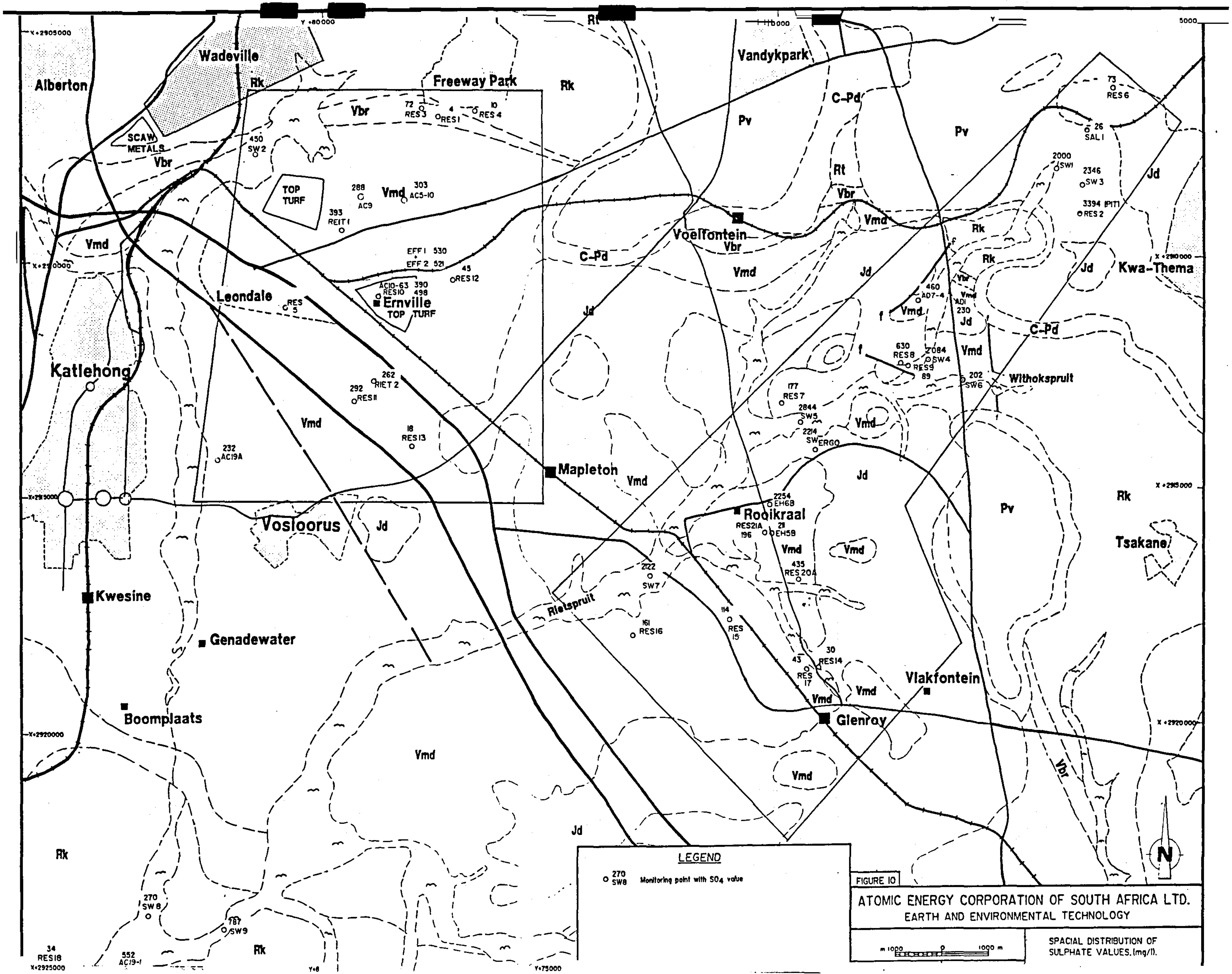

FIGURE 10

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SPACIAL DISTRIBUTION OF SULPHATE VALUES (mg/l).

from the sewage farm at the time of sampling. Spillages of untreated sewage however do occur from time to time during the daily operation of the farm. This would release water with a higher NO_3 content on an irregular basis. The effluent does, however, have relatively elevated levels of fluoride which cannot be traced in the groundwater of the area.

4.4.3 Groundwater quality and its relation to landuse

Most boreholes lie outside the area on the Piper diagram representing typical dolomitic groundwater (Figure 7). Those showing no signs of pollution include RES 1, 5, 12 and 13 and AC 17. The remaining samples all show distinct deviation from the regional groundwater characteristics.

Water sample RES 4 was taken from the Alberton Formation of the Klipriversberg Group and so deviation from the typical regional dolomitic groundwater is to be expected. Water sample RES 3 has an unacceptably high ion balance error and so the validity of this sample is in doubt, the same applies to sample AC 7.

The majority of sampled boreholes within the region show that ionic change has taken place. This is most probably representative of an ongoing pollution process. Most show elevated NO_3 levels with the exception of RES 10 which also shows elevated SO_4 levels and RIET 1 which shows elevated SO_4 levels only. The distribution of NO_3 values is given in Figure 9 and SO_4 values in Figure 10. The distribution of elevated NO_3 and SO_4 levels are similar in both historical sampling runs and at present. High NO_3 levels are found throughout the area mainly underlying the agricultural sections, but not in the vicinity of the residential areas. With the type of distribution seen in Figures 9 and 10, it is apparent that NO_3 and SO_4 occurrence takes the form of diffuse pollution. Point sources can also be identified and include the introduction of fertilizers within restricted areas, livestock and even close proximity to a cemetery.

4.4.4 Temporal variation

Figures 7 and 8 together with Tables 2 and 3 highlight the changes that have occurred between 1984 and 1992. Pollution has been ongoing for a considerable length of time. The samples taken during the period 1984 to 1986 already indicated elevated NO_3 and SO_4 levels. All boreholes show a significant increase in the NO_3 level whereas SO_4 levels are improving slightly. Fluoride levels have remained similar. Nitrates are therefore still being introduced to the system.

Table 3. Groundwater Chemistry of the Elspark/Rondebult Area - June 1992

Map Ref Number	pH	EC (mS/m)	HCO_3 mg/ℓ	Cl mg/ℓ	SO_4 mg/ℓ	NO_3 mg/ℓ	P mg/ℓ	F mg/ℓ	Si mg/ℓ	Na mg/ℓ	K mg/ℓ	Ca mg/ℓ	Mg mg/ℓ	Fe mg/ℓ	Cu mg/ℓ	Ni mg/ℓ	Pb mg/ℓ	Zn mg/ℓ
EFF 1	7.6	157	242	116	530	<0.1	0.26	7.50	7.88	165	17.5	127	47.0	<0.1	<0.1	0.38	0.007	<0.1
EFF 2	7.4	176	282	98.2	521	2.21	2.50	7.75	9.00	157	19.2	123	48.0	1.25	<0.1	0.22	0.010	<0.1
RES 1	7.0	28	145	2.64	3.77	2.05	0.26	0.18	8.82	8.46	1.19	12.9	6.34	21.4	<0.1	<0.1	0.003	<0.1
RES 3	5.5	27	13	39.4	71.5	37.4	0.21	0.11	7.40	22.7	1.41	13.0	6.69	0.22	<0.1	0.10	0.003	<0.1
RES 4	6.4	16	41	12.9	9.48	15.0	0.04	0.07	11.5	5.87	0.80	9.21	6.91	<0.1	<0.1	<0.1	0.0001	<0.1
RES 5	6.3	30	105	9.85	17.1	6.26	0.37	0.23	25.4	9.09	25.8	21.4	11.1	0.34	<0.1	<0.1	0.005	<0.1
RES 10	6.9	177	322	141	498	28.4	0.12	0.11	11.9	150	12	153	68.2	<0.1	<0.1	<0.1	0.004	<0.1
RES 11	7.0	148	383	113	292	48.7	0.12	0.10	13.5	84	4	137	71.4	<0.1	<0.1	<0.1	0.002	<0.1
RES 12	7.4	58	315	18.7	45.0	1.19	0.07	0.09	8.02	9	1.5	80.2	36.8	<0.1	<0.1	<0.1	0.001	<0.1
RES 13	7.3	61	364	11.5	17.7	4.10	0.11	0.11	12.7	8.85	1.32	61.2	37.2	<0.1	<0.1	<0.1	0.0001	<0.1
RIET 1	6.4	140	320	152	393	6.6	0.28	0.10	17.2	87.3	2.89	139	90.5	<0.1	<0.1	<0.1	0.001	<0.1
RIET 2	6.4	122	379	102	262	48.9	0.15	0.09	14.5	74.0	3.75	114	76.1	<0.1	<0.1	<0.1	0.003	<0.1
SW 2	6.8	173	328	144	450	2.40	2.05	3.57	7.55	195	16	133	40.2	1.05	<0.1	<0.1	0.004	<0.1

4.5 Isotope Studies

Isotope analyses were carried out on 3 water samples collected within the area. The objectives of the isotope study were to obtain an estimate of the vulnerability of the aquifer to pollution and to establish an isotopic signal of the water that infiltrates into the groundwater system. This would enable a better understanding of the method of the ongoing pollution process.

Analyses were carried out by the Schonland Research Centre for Nuclear Sciences.

The high tritium values (Table 4) found within the area indicate that the groundwater system is relatively young, at least in the upper section. The aquifer is therefore prone to pollution due to the active recharge taking place. Insufficient boreholes were sampled to comment on the recharge mechanism of the aquifer, but indications are the recharge takes place over the whole aquifer.

Figure 11 shows δD values plotted against $\delta^{18}O$ for all points in both areas under investigation. The points lie on two distinct lines, one of which is the meteoric water line, the other being the evaporation line for these particular areas. The slope of the evaporation line is peculiar to a specific area as it is dependent upon the climate, especially average humidity. Water samples that plot along this line have been subjected to evaporation and the water samples within the Elspark/Rondebult area lie along this line. Recharge, at least in these local areas, is therefore not only limited to direct rainfall. Other sources must include infiltration from surface water bodies such as rivers or lakes, together with leaking mains water pipes and water used for irrigation. The most probable main contributor to recharge other than direct rain infiltration is irrigation water. It is practiced extensively as part of the intensive market gardening carried out within the area. The heavy isotopic signal of the water samples may be caused by the addition of effluent from the sewage plant which itself has an extremely heavy signal. This effluent used for both irrigation and for supporting the vlei area of the bird sanctuary. Another possible cause of the heavy isotopic signal may be the recycling of groundwater during the irrigation process.

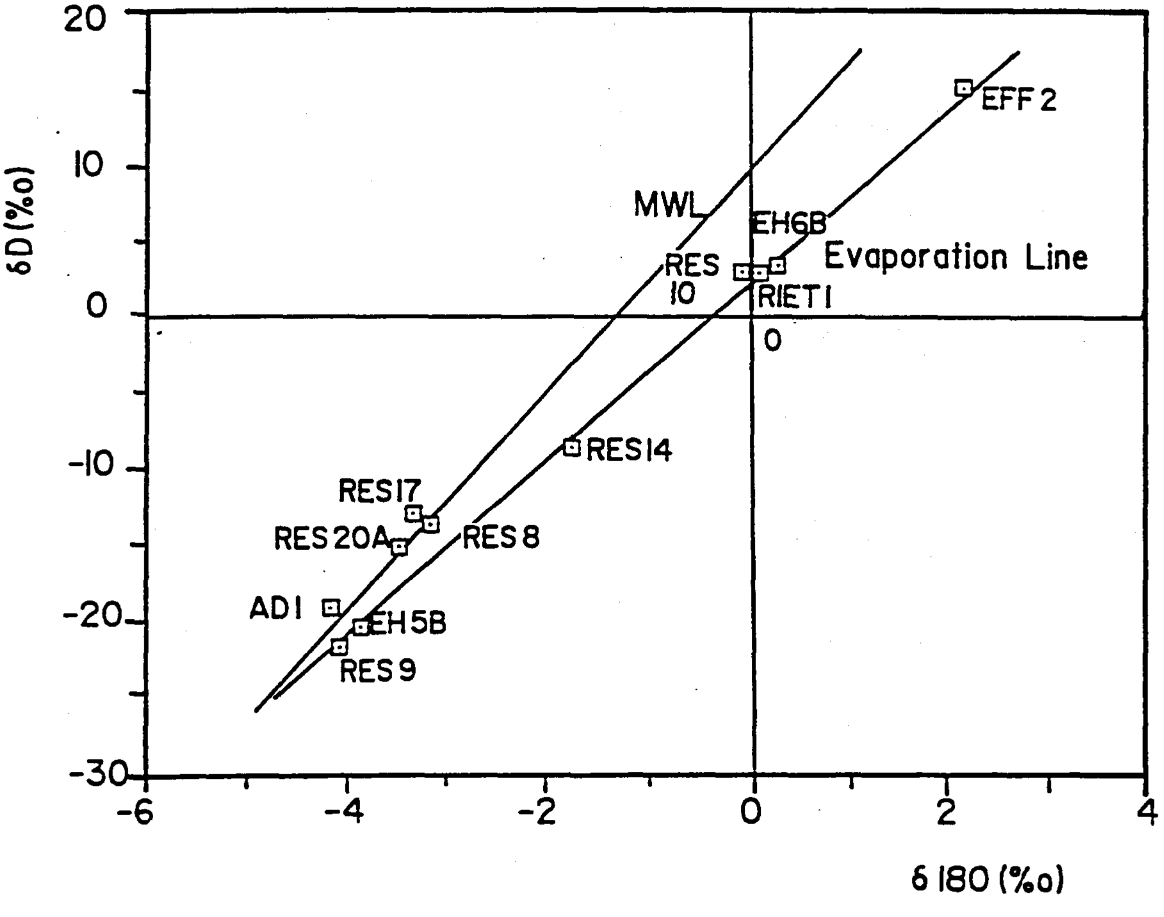
Table 4. Isotope data for Selected Boreholes in Both Study Areas

Sample No	3H (TU)	$\delta^{18}O$ (‰)	δD (‰)
RES 17		-3.31±0.15	-13.2±1,5
RES 8	3.9±0.3	-3.31	-13.9
RES 20A	1.8±0.2	-3.44	-15.5
RES 14	5.4±0.4	-1.74	- 8.7
RES 10	5.7±0.4	+0.11	+ 2.8
RES 9	1.1±0.2	-4.07	-22.8
EFF 2	6.2±0.4	+2.17	+15.1
AD 1	3.2±0.4	-4.17	-19.4
EH 58	0.8±0.3	-3.86	-20.6
RIET 1	4,4	-0.07	+ 2.8
EH 6B(2)		+0.29	+ 3.4

4.6 Discussion and Model of Ongoing Pollution

Most of the land as stated in Section 4.1.2 is used for agricultural practices. Intensive cultivation of vegetable crops being the most dominant. A turf producing company also uses a large proportion of the area for the growing of turf. The use of fertilizers and effluent from the sewage farm are the two most probable causes of the high nitrate content within the groundwater. Effluent is used by the turf company for irrigation, but is only applied to the land to the north of the sewage plant. The lands owned by Top Turf to the south-west use borehole water only. Effluent is also channelled to a vlei area designated as a bird sanctuary just to the north-west of the sewage farm, close to the Van Dyk road, (Figure 6), and is also used on the land immediately adjacent to the sewage farm for the cultivation of cattle fodder. However, the chemical analyses of the effluent gives a relatively low NO_3 content, suggesting that the nitrate is introduced via the application of fertilizers. Accidental spillages of sewage would not contribute significant amounts of NO_3 into the groundwater system. The high fluoride associated with the effluent is not noticeable within the groundwater, this again supports that NO_3 could be introduced via fertilizer application.

No mining activity or tailings dams are present within close proximity to the area and so it is highly unlikely that the elevated SO_4 levels are associated with the runoff and/or seepage from this type of industry.



δD (%o) US $\delta^{18}O$(%o) for selected water samples.

FIGURE 11

Taking both hydrogeochemical data and isotopic data into consideration, a tentative model regarding the process of pollution in this area can be outlined.

The nitrates have been introduced into the system relatively recently. The fact that the nitrate concentration is increasing indicates that the introduction of nitrates is an ongoing process, and will continue if farming practices remain the same. Higher sulphate and nitrate concentrations are found in the more rural regions of the area, and the fact that high sulphate is usually found in conjunction with high nitrate in samples within the agricultural region, may indicate that the method by which these elements enter the system are similar. There is only one exception, this being RIET 1 which has a high SO_4 and a low NO_3 content.

The residential areas have lower concentrations of both elements with the occasional high nitrate level. This indicates that pollution is a result of agricultural practices rather than general urban pollution. Point source pollution however is taking place within the residential areas, water sample RES 3 has an elevated nitrate level, the cause of which is not apparent. The areal variation in nitrate and sulphate levels throughout the area indicate diffuse pollution rather than a point source type.

The isotopic signal of the groundwater indicates that the groundwater system is relatively young and therefore is vulnerable to pollution. The heavy $\delta^{18}O$ signal suggests that a considerable proportion of the recharge to the system is via irrigation, at least to the upper layers within the aquifer, and that the irrigation process leads to recycling of the groundwater. This in turn is leading to a concentration of nitrate, especially as more fertilizer is added to the system annually and washed through the unsaturated zone with water already possessing a high nitrate level.

It does not appear that the effluent used for irrigation and environmental purposes is contributing to the high nitrate or SO_4 level. RIET 1 has a high sulphate level and is located in the area where sewage effluent is used for both irrigation and to maintain the vlei area for the bird sanctuary. From Table 3 it can be seen that the effluent does have a relatively high sulphate content, but other boreholes located in areas where effluent is not used also show high sulphate levels.

If the input mechanism for nitrates is as described above, then the pollution situation will definitely worsen unless control measures are taken on the use of fertilizers.

5 RIETSPRUIT/ERGO AREA

5.1 Geology and Physiography

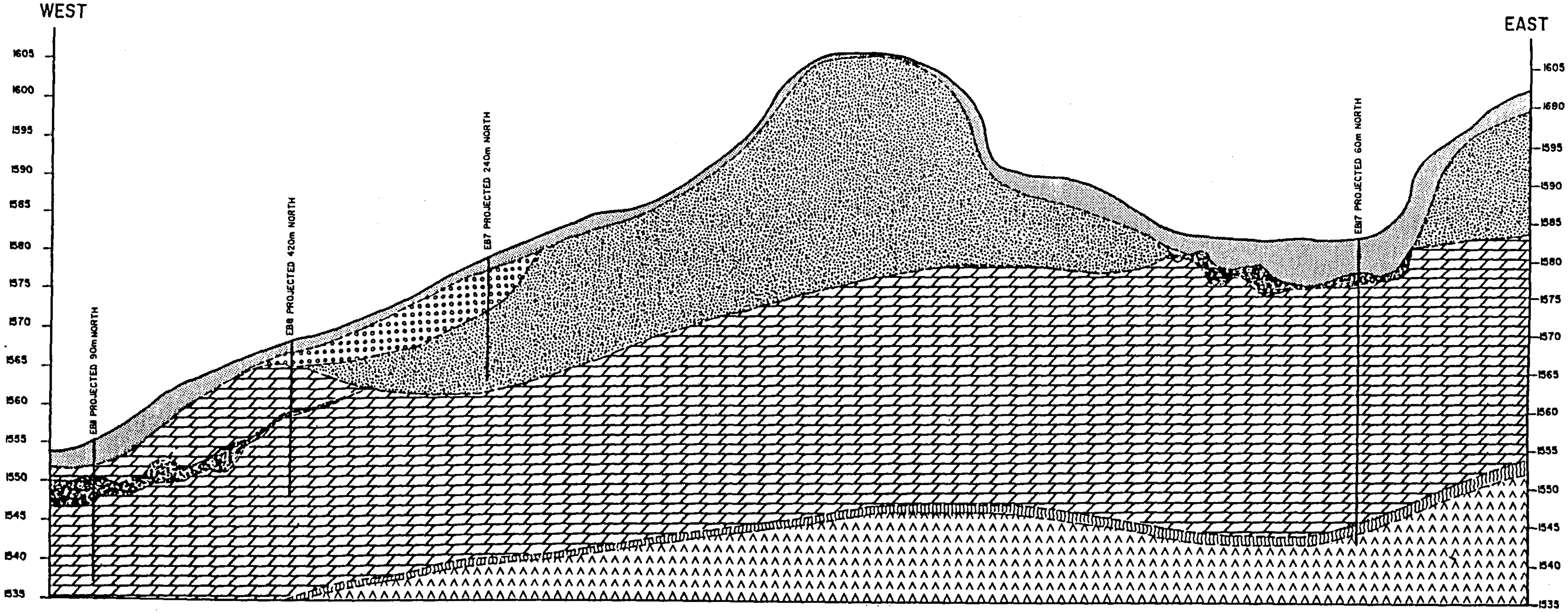
The area lies within the same synclinal structure as the Elspark/Rondebult area. Much of the region is overlain by post Karoo doleritic intrusions. There are no major structural geological features, only three faults are located in the upper reaches of the Withokspruit (Figure 6). Thin alluvial deposits overlay both dolomite and intrusives.

Detailed geological information in the Ergo tailings dam area was made available by the company WLPU. Figure 12 provides a geological cross-section across the dam from west to east, and shows that the tailings sit mainly on hard fine grained dolerite underlain by westerly dipping Monte Christo and Oaktree dolomite formations of the Malmani Subgroup. There are isolated areas where a thin layer of soil reaching a maximum of 6 m, sits directly on a thin layer of wad underlain by dolomite. Down-hole video recording into the dolomite revealed joint widths of between 5 and 20 mm, most of which had been infilled. Wad deposits were also present along with many minor cavities, the majority of which occurred between 12 and 19 m. Only one major cavity was identified, and sinkhole development was not encountered. Permeability values of the weathered dolomite were high, between 10^{-1} and 10^{-2}, and 10^{-4} m/s for fresh dolomite. Borehole EB 11 is shown on the western side of the cross section, and represents the same geological conditions as found in the sampled borehole EH 6B, located approximately 15 m towards the west.

5.2 Landuse

Figure 6 shows landuse within the area investigated. A large proportion of the land is covered by tailings dams of which some are at present being reworked. Sallies Mine is located in the northern section and which is in the process of closing down. The mine, because of its great depth, was chosen to dewater all the mines located to the north, by means of continuous pumping. In the early 1970's, 28 Mℓ/d was being pumped and the water table was locally lowered to 2 000 m, this depth being recorded in 1976. The water table is still recovering at a rate of 0,5 m/d following cessation of pumping. The water that was extracted from the mine was pumped to the adjacent Ergo plant, to be used in the reworking process to extract gold. Sludge was then transported by pipeline to the tailings dam.

Natural vlei areas are present along the course of the Withokspruit and Rietspruit, and dams have been constructed by farmers to provide water for various farming practices. Most of the land used for agriculture is left natural for livestock grazing, however there is an area shown on Figure 6 where intensive dairy farming is carried out. The farm uses borehole water (RES 16), but supplements its supply with river water for irrigation of maize crops. Surface water sample SW 7 would be representative of the water used for irrigation at this particular locality.



WEST-EAST GEOLOGICAL SECTION

FIGURE 12

HORIZONTAL SCALE 1:10 000

LEGEND

▨	SOIL			
▨	DOLERITE . . . . POST KAROO DOLERITE INTRUSIVES			
⁘	CHERT RESIDIUM	ROOIHOOGTE		TRANSVAAL SEQUENCE
▱	DOLOMITE	MONTE CHRISTO AND OAKTREE FORMATIONS	MALMANI SUBGROUP	
■	WAD			
▥	BLACK REEF QUARTZITE			
^	VENTERSDORP LAVA . . . . . .VENTERSDORP SUPERGROUP			

5.3 Hydrogeology

The hydrogeology of the region can only be discussed in general terms due to the limited availability of boreholes within the study area.

The dolomites in the area of the Ergo tailings dam dip towards the west, and the topography also generally slopes in this direction towards the Rietspruit. This, together with limited waterlevel data indicates groundwater flow to be in a westerly direction. Surface runoff is likely to occur and drain both in a westerly direction towards the Rietspruit, and a northerly direction towards the Withokspruit. There is evidence to suggest that there are two groundwater systems, a more confined deeper aquifer overlain by a more dynamic system. Boreholes RES 21(A) and EH 5B are artesian, the latter having a flow rate of approximately 0.27 ℓ/s. Isotopic measurements also indicate the existence of 2 separate groundwater systems. This will be discussed further in Section 4.2.5.

Water level data also provides evidence for the existence of two separate groundwater systems. Two boreholes are located in the vicinity of RES 21(A) (Figure 6), one of which is artesian, the other has a water level 16 m below surface. The distance between the boreholes is approximately 200 m and the difference in water levels cannot be attributed to topographic variations.

The degree of mixing of groundwater of both systems is not known. More extensive studies would have to be done to comment on this aspect of the hydrogeology.

5.4 Hydrogeochemistry

5.4.1 Groundwater characteristics

The determination of the regional groundwater characteristics is described in Section 4.4.1. Figure 13 shows the groundwater characteristics of the Rietspruit/Ergo area. All boreholes are located in the dolomite formation, one or two may have penetrated dolerite in their upper sections and may therefore show contamination from this formation producing a slightly different water type. These boreholes include RES 7, RES 8 and AD 1. SAL 1 is water typical of the younger Karoo deposits within the north-eastern part of the study area. With RES 14 being the only exception, all the groundwater samples fall outside the area on the Piper diagram representative of the regional groundwater chemistry. Most water samples show an elevated SO_4 level and in some cases NO_3 level, but the latter can be attributed to farming practices within the immediate vicinity of the borehole. This is discussed in more detail in Section 4.4.3. All groundwater chemistry for the area is given in Table 5.

Figure 13. Piper diagram showing groundwater characteristics within the Rietspruit/Ergo area - 1992

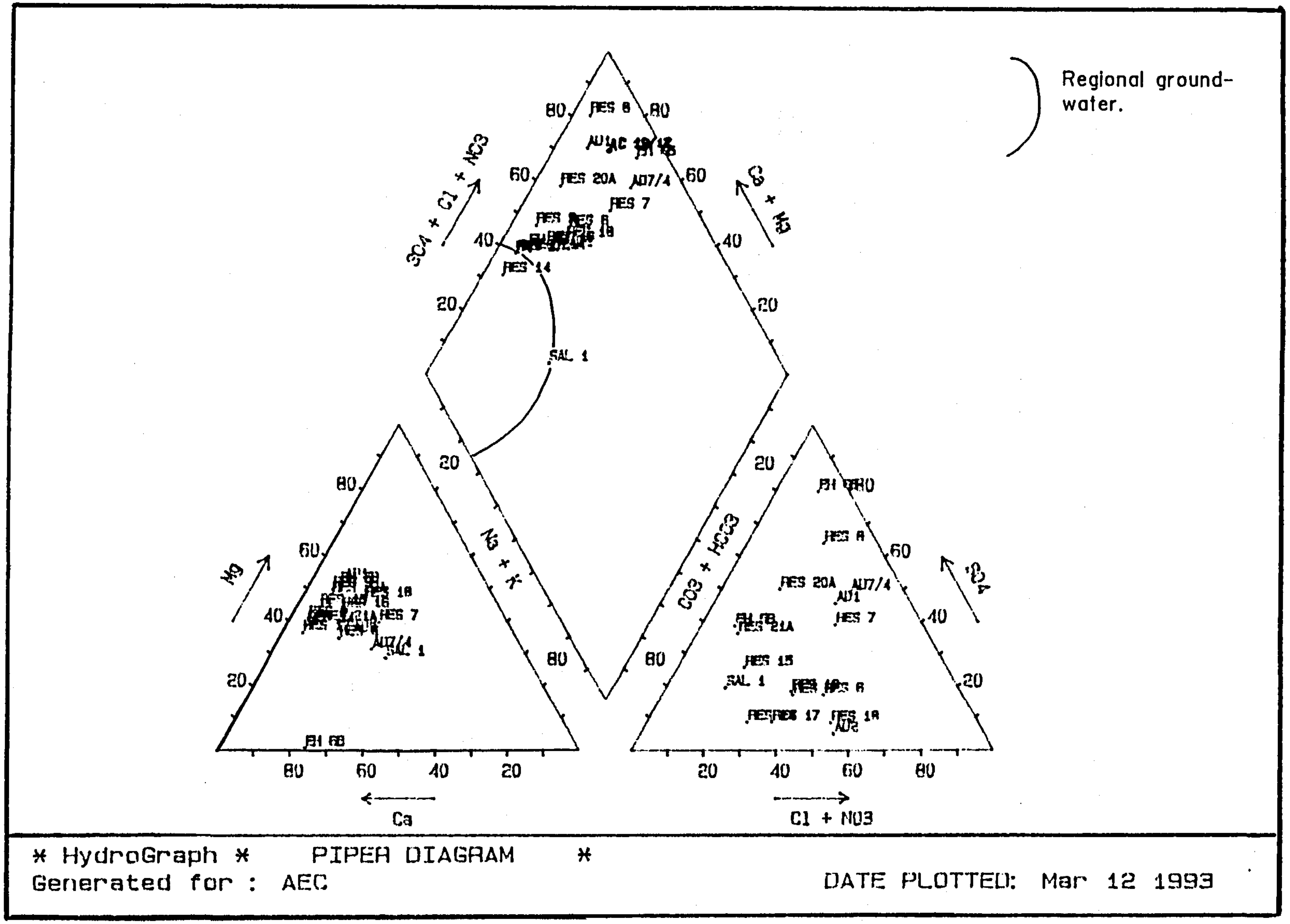


Table 5. Groundwater Chemistry of the Rietspruit/Ergo Area - 1992

Sample No	pH	EC mS/m	HCO_3 mg/ℓ	Cl mg/ℓ	SO_4 mg/ℓ	NO_3 mg/ℓ	P mg/ℓ	F mg/ℓ	Si mg/ℓ	Na mg/ℓ	K mg/ℓ	Ca mg/ℓ	Mg mg/ℓ	Fe mg/ℓ	Cu mg/ℓ	Ni mg/ℓ	Pb mg/ℓ	Zn mg/ℓ
RES 2	7.2	509	115	501	3 394	<0.1	0.04	0.31	9.18	401	29.9	495	515	1.03	<0.1	<0.1	0.025	<0.1
RES 6	6.3	61	202	48	73	35.7	0.18	0.13	29.6	17	11	63	27	0.68	0.13	<0.1	0.008	2.51
RES 7	9.6	109	138	65	177	22.9	0.18	0.71	26.7	169	17.5	227	153	8.37	<0.1	0.48	0.011	0.18
RES 8	7.0	144	184	48	630	41.6	0.11	0.09	30.6	17.6	3.69	215	98	0.21	<0.1	<0.1	0.007	0.11
RES 9	7.4	79	307	24	89	45.1	0.14	0.23	29.3	11	3.2	73	51	0.14	<0.1	<0.1	0.005	0.10
RES 14	7.4	53	283	7	30	26.0	0.18	0.10	17.5	6.8	0.9	71	30	0.19	<0.1	<0.1	0.001	<0.1
RES 15	7.2	78	314	32	114	11.3	0.09	0.12	15.5	11.3	2.53	72	50	<0.1	<0.1	<0.1	0.0	<0.1
RES 16	7.0	152	517	99	161	50.7	0.09	0.10	17.7	44.0	7.31	150	90	<0.1	<0.1	<0.1	0.001	<0.1
RES 17	7.2	70	362	26	43	40.5	0.09	0.09	15.3	8.47	2.94	102	39	0.22	<0.1	<0.1	0.002	0.15
RES 18	7.4	55	207	63	34	34.7	0.09	0.09	24.0	22.7	2.89	46	36	<0.1	<0.1	0.14	0.001	<0.1
RES 20A	7.5	108	376	77	435	10.6	0.28	0.13	16.5	27	2.4	152	100	0.13	<0.1	<0.1	0.005	0.46
RES 21A	7.6	97	360	39	196	2.59	0.13	0.12	11.8	15	2.4	82	38	<0.1	<0.1	<0.1	0.015	<0.1
EH 5B	7.6	111	361	31	211	2.93	0.13	0.16	12.9	21.1	2.92	102	78	0.98	<0.1	<0.1	0.0002	0.11
EH 6B1	7.2	413	340	252	2 337	<0.1	0.38	0.08	24.4	183	10.6	533	329	7.68	<0.1	<0.1	0.022	<0.1
EH 6B2	7.1	420	307	242	2 254	<0.1	0.22	0.08	17.3	183	9.80	524	3	1.40	<0.1	0.20	0.022	<0.1
SAL 1	7.8	30	109	15	26	0.51	0.07	0.18	1.08	14	4.58	18	8	0.15	<0.1	<0.1	0.005	0.12
SW 1	7.6	358	110	187	2 000	<0.1	0.86	0.60	3.26	192	47.3	668	62	0.81	3.39	8.80	0.019	<0.1
SW 3	4.6	406	1	224	2 346	<0.1	1.13	0.07	13.3	283	44	585	115	35.5	0.39	<0.1	0.020	0.90
SW 4	5.4	395	7	297	2 084	<0.1	0.16	0.16	20.0	267	45	519	139	0.26	0.19	21.4	0.021	14.5

Sample No	pH	EC mS/m	HCO_3 mg/ℓ	Cl mg/ℓ	SO_4 mg/ℓ	NO_3 mg/ℓ	P mg/ℓ	F mg/ℓ	Si mg/ℓ	Na mg/ℓ	K mg/ℓ	Ca mg/ℓ	Mg mg/ℓ	Fe mg/ℓ	Cu mg/ℓ	Ni mg/ℓ	Pb mg/ℓ	Zn mg/ℓ
SW 5	8.1	426	112	327	2 844	<0.1	0.40	0.26	8.10	278	38	599	333	1.12	<0.1	0.50	0.020	<0.1
SW 6	7.7	94	296	18	202	<0.1	0.02	0.36	11.8	45	8.6	95	37	1.76	<0.1	<0.1	0.003	<0.1
SW 7	7.0	389	193	286	2 122	<0.1	0.20	0.33	4.68	182	20.6	506	288	<0.1	<0.1	1.04	0.020	0.27
SW 8	7.6	119	154	117	270	0.86	3.67	0.41	6.87	100	15.5	81	30	0.30	<0.1	<0.1	0.004	<0.1
SW 9	7.8	160	243	124	787	<0.1	0.12	0.23	3.19	59	20	208	130	0.49	<0.1	0.25	0.008	<0.1
SW 10	7.5	125	148	114	300	1.58	2.79	0.44	6.87	97	13.5	111	67	0.51	<0.1	<0.1	0.003	<0.1
SW ERGO	6.2	365	268	242	2 214	<0.1	0.42	0.23	17.0	200	25	460	198	11.9	<0.1	0.26	0.014	<0.1
AD 1	6.7	80	134	54	230	28	0.38	0.08	-	17	1.85	71	58	<0.01	-	-	-	<0.1

The position on the Piper diagram (Figure 13) of the group of water samples obtained in 1992 falls just outside that typical of a dolomitic environment is most probably a reflection of the age of the groundwater. Migration to this position suggests that the groundwater is slightly older and the groundwater regime less dynamic.

5.4.2 Surface water and effluent

Surface water samples were taken at various localities in the Withokspruit and the Rietspruit (Figure 6) into which runoff water from the tailings dam at the Ergo plant and the new tailings dam flow. All effluents have an extremely high SO_4 content, as have the surface water samples, especially those in the upper reaches of the Rietspruit. Further downstream SO_4 levels are generally lower. Elevated trace elements are also detected, those effluents originating from Sallies Mine and Ergo plant contain high nickel, copper and iron, while that originating from the new tailings dam has only an elevated iron content. Low pH values are associated with both the effluent samples (SW 3 and SW ERGO - Table 5), explaining the presence of iron still in solution.

5.5 Isotope Studies

The same objectives for the isotope studies apply to this area as described in Section 4.1.5.

Tritium levels in the majority of the samples are lower than in the Elspark/Rondebult area indicating that the groundwater regime is slightly older and less dynamic. Water sample RES 14 is an exception to the rule, the high tritium content can be attributed to the fact that the borehole is situated next to a dam on a small ephemeral surface drainage. Recharge to this shallow hole is therefore partly from runoff, and partly from infiltration of the dam water. The heavier $\delta^{18}O$ value supports this. The variation in tritium levels is small ranging from 0.8 TU for the artesian hole EH 5B, to 3,2 TU for borehole AD 1. These values do not include anomalous boreholes such as RES 14, RES 8 and EH 6B. The reason for the anomaly of RES 14 has been given previously and the mechanism of recharge of RES 8 is not known. From field measurements, the borehole from which water sample EH 6B2 was taken is only 4.70 m deep, with a waterlevel of 1.80 m below surface. The heavy isotopic signal associated with this water sample may be a result of overland flow seeping into the borehole. Alternatively, water may have infiltrated from open water bodies on the tailings dam, and flowed as part of an very shallow groundwater system, in a westerly direction, following a layer of decomposed dolomite (Figure 12). The borehole was pumped for 45 minutes at 0.2 ℓ/s, and so the standing water in the borehole was removed. The water sample could then be considered as a true reflection of the water quality of the supposed "perched" water table or upper section of the aquifer within the dolomitic formation. The evidence provided by the isotope data, such as higher tritium levels and a greater concentration of ^{18}O, favour this model.

The tritium values when correlated with sulphate levels do suggest that both the shallow groundwater system in the near vicinity of the tailings dam (EH 6B2) and the deeper, slightly older system (RES 20A) are contaminated. The borehole log of RES 20A is not available and it is possible that the wad layer found in EB 11 (situated next to EH 6B), may extend to RES 20A. Contamination from the upper section of the dolomite may thus be possible. However, the tritium level and the position on the δD‰ vs $\delta^{18}O$‰ plot (Figure 11) does not indicate an appreciable amount of mixing with younger water, or the water with a heavier $\delta^{18}O$ signal typical of borehole EH 6B.

5.6 Discussion and Model of Ongoing Pollution

It is probable that the high sulphate level in the effluents or runoff from the tailings dams are causing elevated sulphate levels in the surface water within the drainage system. Sulphates may also be associated with the dolerite intrusions within the area over which the surface drainage runs. However, in some cases the high SO_4 occurs with elevated nickel and/or iron, which suggests that the SO_4 is associated with the runoff coming from the Ergo plant and tailings dam (Table 4). The runoff from Sallies/Ergo area does not comply with the guidelines laid by the Department of Water Affairs in respect to the elements iron and copper. Iron is also above the recommended limit in the runoff from the new Ergo tailings dam.

High NO_3 levels found in certain ground water samples is not thought to be associated with any pollution entering from the surface drainage system. No elevated NO_3 levels were measured in any of the surface water samples. It can therefore be assumed that higher NO_3 values are a result of diffuse pollution related to specific agricultural practices.

Water sample RES 8 is taken from a deep borehole, approximately 130 m in depth with the main water strike at 120 m; this also being the pump installation depth. It has a very high NO_3 and SO_4 level. With the available data, this anomaly cannot be explained. Tritium levels suggest this water to be of fairly recent age and the $\delta^{18}O$ (‰) value indicates that recharge is mainly from rainfall (Section 4.5, Figure 11). It is possible that the recharge to this borehole is to some extent facilitated by the fault situated just to be south-west of the borehole. The fault cuts the surface drainage channel which may allow surface water to infiltrate into the fault zone. Water sample SW 4 taken from the river at a nearby locality also has a very high SO_4 together with a high zinc and nickel value. The trace elements however were not detected in the borehole and the $\delta^{18}O$ value would have been more positive for such a situation. This causes an element of doubt into this mode of recharge. It would therefore seem more probable the high NO_3 and SO_4 levels are associated with surface water contamination within the immediate vicinity of the borehole, or seepage water from varying geological formations intercepted within the borehole.

Boreholes within the immediate vicinity of the new Ergo tailings dam on the western border (RES 20A, EH 5B) are showing signs of pollution, with elevated levels of sulphate, iron, zinc and in one case nickel (Table 5). Shallow borehole EH 6B indicates pollution is definitely taking place in the upper portion of the aquifer and deeper borehole, RES 20A, suggests that pollution is more widespread both spatially and vertically.

There is no strong evidence to support the theory that widespread pollution is taking place within this area. Sulphate levels are generally elevated and so identification of pollution above the background levels is extremely difficult. There are however very high sulphate levels within the area which do indicate point source pollution. The same applies to nitrate levels which also are generally elevated throughout the area. There are higher nitrate values but these are randomly distributed and can be attributed to agricultural practices within the immediate vicinity of the borehole. Six of the groundwater samples have levels above the minimum value recommended for drinking water, two of which are above the medium value. Again, extremely low nitrate levels are found in the surface water samples, therefore nitrate pollution via infiltration of river water is not feasible.

This theory also applies in the case of sulphate pollution. The runoff coming from the Sallies/Ergo area in the north-east of the region is extremely high in sulphate, copper, iron and nickel. That coming from the new Ergo tailings dam had only a high iron and sulphate content. The concentration of all these elements such as iron, nickel and sulphate in the river water generally decreases downstream, indicating that these two areas may be a point source of pollution as far as surface water is concerned. If contamination was taking place from the surface drainages, the elements found in the runoff and within the river water would be detected in the groundwater samples, especially in those close to the rivers. However, very few elevated levels of trace elements were detected except in boreholes near the new Ergo tailings dam. Evidence therefore again suggests that pollution of the groundwater is via point sources, in particular the new Ergo tailings dam. A knowledge of the spatial and vertical extent of which cannot be ascertained due to the lack of data points.

Natural isotope data does not clearly define the two groundwater systems. This is due to the lack of data points. Indications are, that the two systems do not differ greatly in age, and that their existence is therefore most probably due to geological circumstance, i.e. semi-confinement between dolerite sills or between dolerite sill and Ventersdorp Lava. Artesian conditions may therefore be a very local phenomena. Only more data points would clarify this assumption.

Isotope studies have identified the aquifer as being vulnerable to pollution, but the method by which this pollution is taking place is not apparent due to the lack of information.

6 TERNARY MAPPING

Background

Hydrogeochemical data have traditionally been presented as kriged or interpolated contour maps or just as point values for a specific element or parameter. The ratio between two elements or their values normalized to concentration could also be presented in this way.

After studying the ternary (three-component) radioelement mapping method described by Broome *et al.* (1987) it was decided to apply the method to hydrogeochemical data. The initial image produced in this way for a dolomitic area, using the HCO_3, SO_4 and Cl values showed that it could be an effective method for displaying in a single image ratio, information for the three parameters. The potential for mapping pollution of SO_4 and Cl in a HCO_3-dominated environment such as a dolomite area, was realized and a research proposal to study the usefulness of this technique was presented to the Water Research Commission (WRC). This aspect was conveniently incorporated into the project investigating pollution of the dolomitic aquifers.

6.1 Map Generation Procedure

The ternary hydrogeochemical map (Fig 14) is produced on an ink-jet plotter by using different ink colours to represent the HCO_3, SO_4 and Cl concentrations. In this example cyan is used for HCO_3, yellow for SO_4 and magenta for Cl. At any location the relative concentrations of the three parameters are represented by the colour hue produced by mixing appropriate amounts of the three ink colours. For example, equal proportions of the three parameters would produce an orange colour on the image.

Since a distinct colour hue is used to represent each ternary ratio on the map, zones with similar ratios will be represented by a unique colour. This distinct relationship between colour hue and ternary ratio allows the map to represent the parameter concentration distribution better than any contour map of one parameter only or the ratio between two parameters.

The parameter concentrations are first normalized to ensure they fall in the same numerical range. In order to do this the highest value for each parameter is taken as one and all the other values are scaled accordingly. The relative concentrations for each element are then quantified as a percentage of the sum of the three concentrations.

It is clear that the density of data points may present problems with coverage of values over an area. In order to overcome this problem, interpolated maps of the three parameters are produced from the dot maps (Figs 15, 16 and 17) as shown in Figs 18, 19 and 20. Continuous data coverage now exists for each parameter over the whole area. The reliability of the data still depends, however, upon the density of initial data points.

The final image consists of pixels (small squares) for which values were calculated. The size of the pixel can vary to represent smaller or larger areas on the map. The more data points and the more reliable the data, the smaller can be the selection of the pixel size representing an area on the map.

6.2 Ternary Map Interpretation

To allow the plotted colours to be related to absolute ratio values, the relative calculated levels are used to produce the ternary diagram shown in Fig 14. Since the relative concentration of each parameter varies from 0 to 100 percent on the legend, approximate ratios can be determined by matching the hue of mapped colours with those on the legend.

6.3 Ternary Maps from the Project Area

In addition to the interpolated maps for HCO_3, SO_4 and Cl shown in Figs 18 to 20, interpolated maps were also produced for NO_3, Ca, Mg, and SiO_2. With the interpolated maps available, ternary maps with any combination of these chemical parameters can now be produced. The ternary maps produced have to be interpreted taking into consideration the geology and the pollution sources in the area, as discussed previously.

6.3.1 Anion combinations

Bicarbonate is the dominant anion in unpolluted dolomitic groundwater and the first ternary maps produced were those with HCO_3 as one of the parameters. Two combinations show the pollution distribution best, namely:

$HCO_3 : Cl : SO_4$ and
$HCO_3 : Cl : NO_3$

(a) $HCO_3 : Cl : SO_4$

This image was one of the initial ones which showed the potential for the technique, as SO_4 and Cl anomalies stood out in the HCO_3 dominated background as illustrated in Figure 14. The general geology of the area is depicted in Figure 21 and a transparency thereof is superimposed on Figure 14 to facilitate interpretation.

SO_4 pollution is apparent at the Ergo tailings dams, Knights and Sallies mines and in the western part of the Kathlahong-Vosloorus area where it could also be due to urban pollution such as ash or sanitary waste disposal. South of Vosloorus but off the dolomites is another area showing SO_4 pollution associated also with higher Cl levels. This in the vicinity of the confluence of three drainage tributaries. As previously reported (4.4.2) the surface water does show higher SO_4 levels. The Cl dominated area east of Vlakfontein is based on the analyses from two boreholes and the source is considered to be mainly agricultural and suspected to be due to poor conditions around stock watering points.

(b) *HCO_3 : Cl : NO_3*

This image is depicted in Figure 22 and it is interesting to note that the sulphate pollution from the mines does not show associated Cl or NO_3. East of Wadeville and east of Vlakfontein the Cl anomalies of Figure 14 have become mixed with NO_3, indicating a sewage or manure source of pollution. The yellowish-greenish tint of areas within the dolomites with no associated Cl may be defuse pollution from agricultural practices using fertilizers.

(c) *NO_3 : Cl: SO_4*

This ternary map (Figure 23) illustrates the complexity of the chemical matrix of different groundwater sources. The anionic composition of the groundwater varies considerably over short distances. The dominance of SO_4 in the Knights and Ergo area is again highlighted. Except for one borehole, Cl does not dominate the water on its own but rather combines with the other two ions.

6.3.2 Cation combinations

Cation combinations performed involved mainly Ca and Mg, and the following combinations serve to illustrate their usefulness:

SiO_2 : Ca : Mg
HCO_3 : Ca : Mg

(a) *SiO_2 : Ca : Mg*

The Ca/Mg character of the dolomite is illustrated in Figure 24 by this combination while the more siliceous character of the surrounding terrain of shales, lavas and quartzites is evident. Critical to outlining lithostratigraphic units is sufficient borehole density and the presence of unpolluted groundwater.

(b) *HCO_3 : Ca : Mg*

The image illustrated in Figure 25 shows the colour hue of the three colours combined. One would expect equal percentages of the three parameters (normalized values) in the groundwater such as shown in Figure 25. The surrounding rock types show deviation from this ratio and the pattern that emerges is similar to that in Figure 24.

FIGURE 14

TERNARY MAPPING – PWV POLLUTION STUDY

HC03:Cl:S04

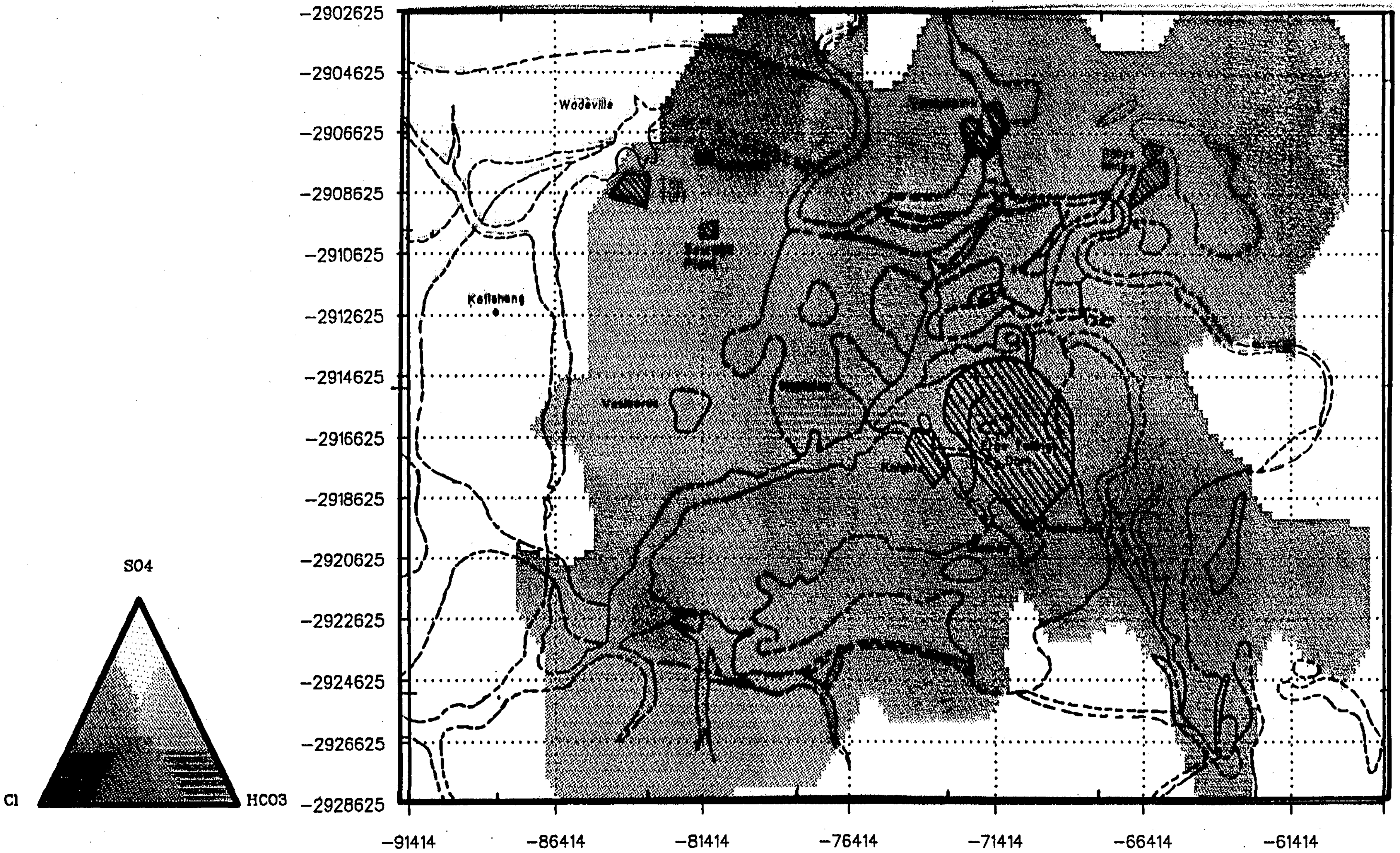
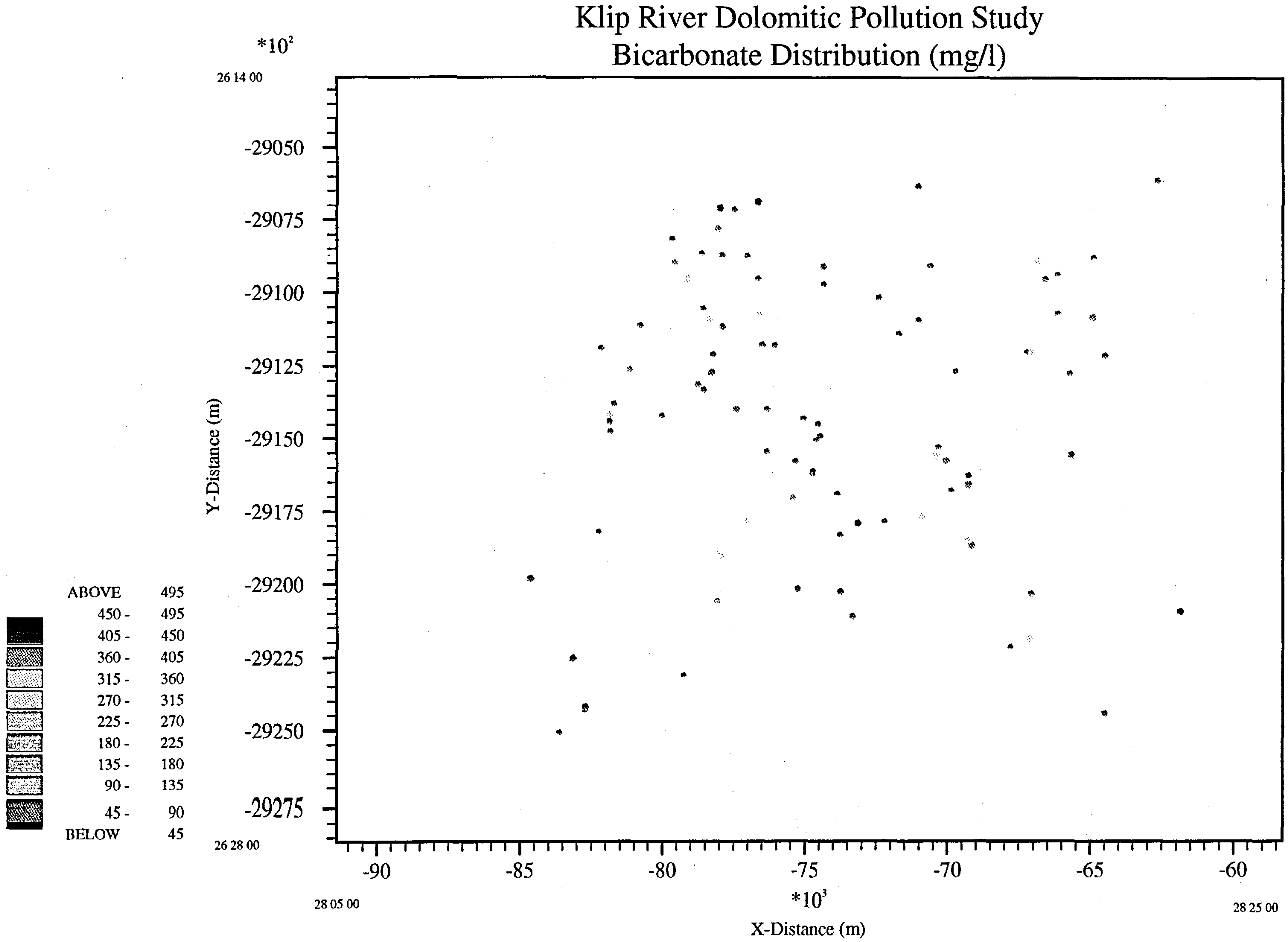


FIGURE 15



Klip River Dolomitic Pollution Study
Bicarbonate Distribution (mg/l)

FIGURE 16

Klip River Dolomitic Pollution Study
Sulphate Distribution (mg/l)

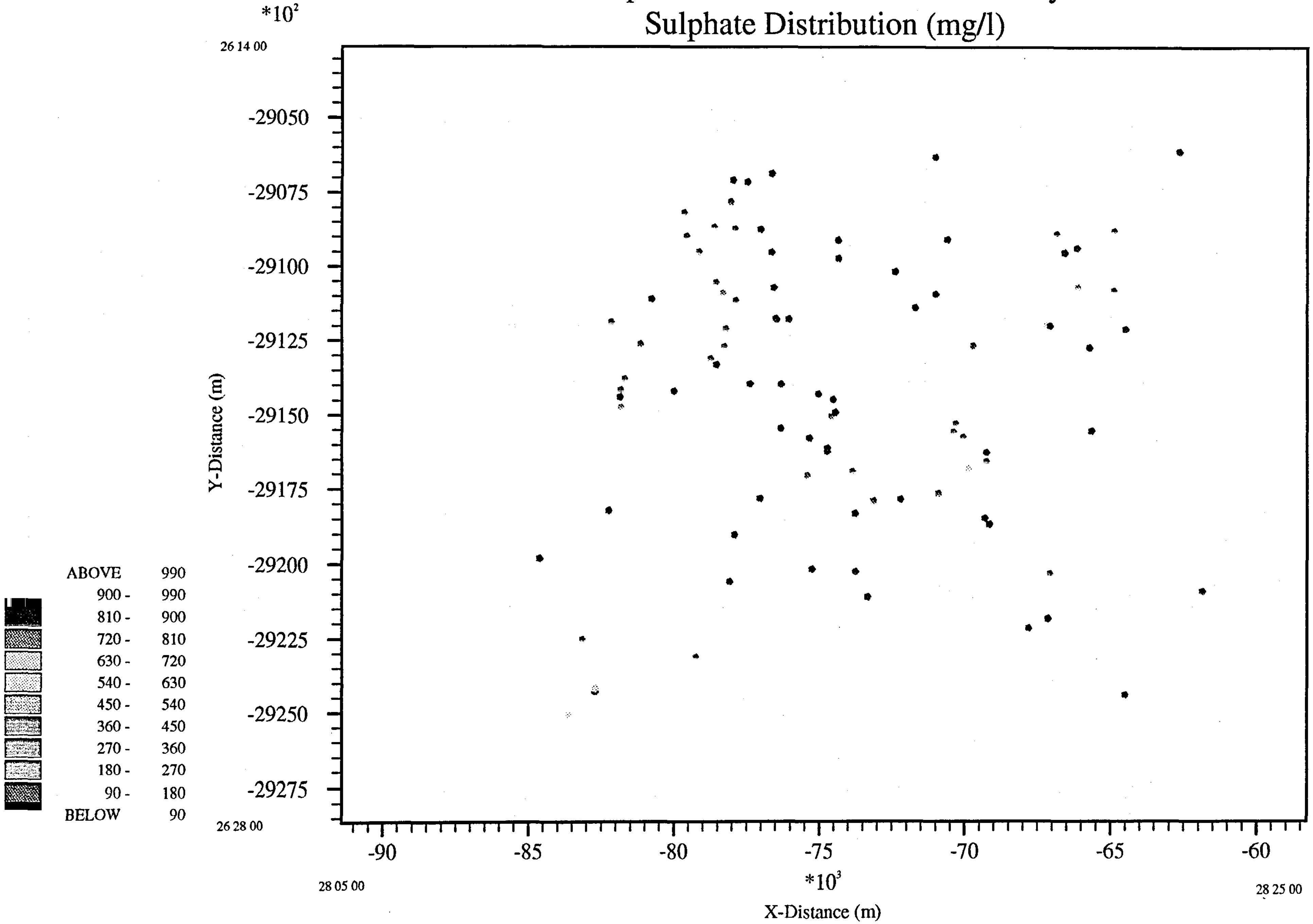


FIGURE 17

Klip River Dolomitic Pollution Study
Chloride Distribution (mg/l)

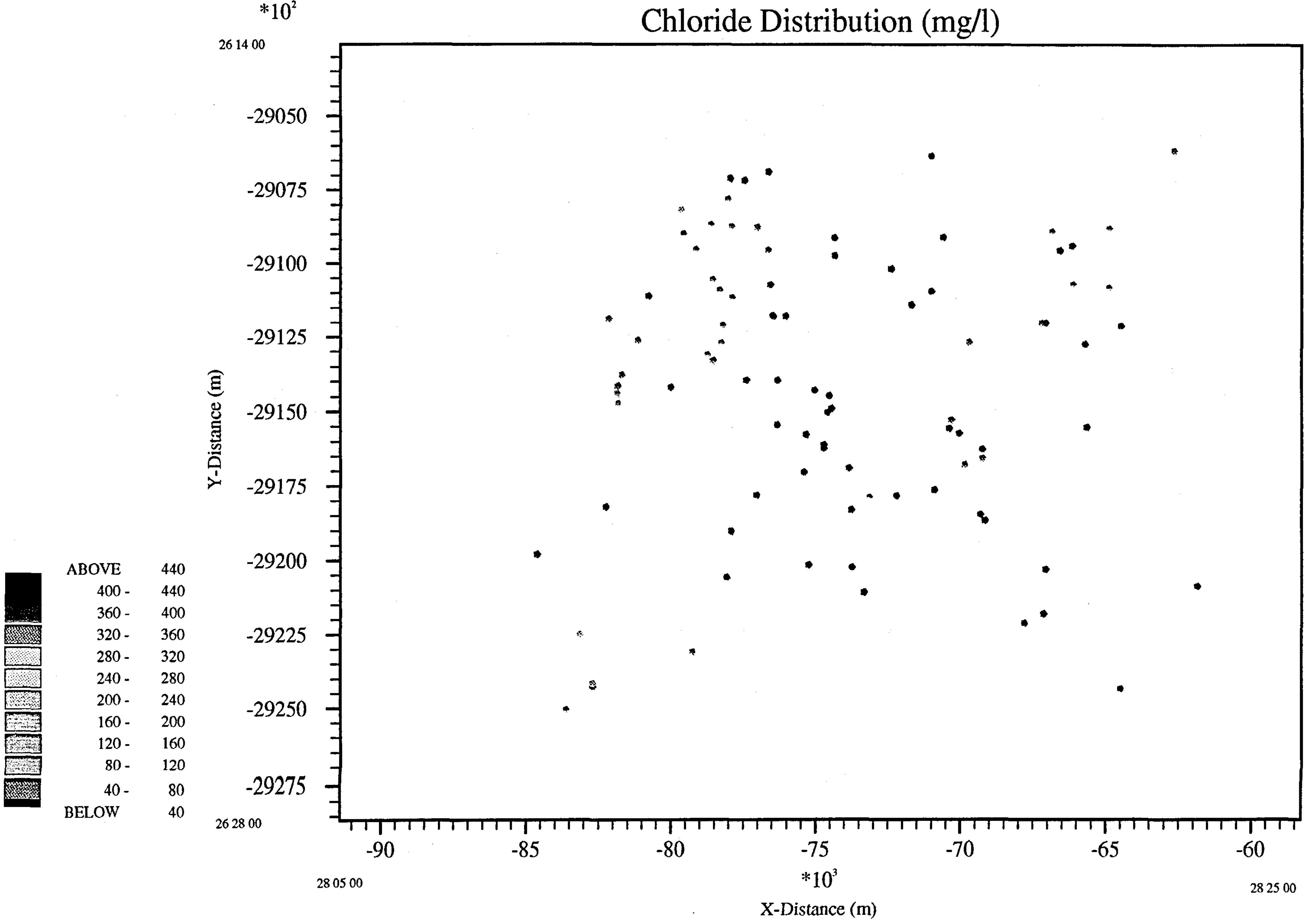


FIGURE 18

Klip River Dolomitic Pollution Study
Bicarbonate Distribution (mg/l)

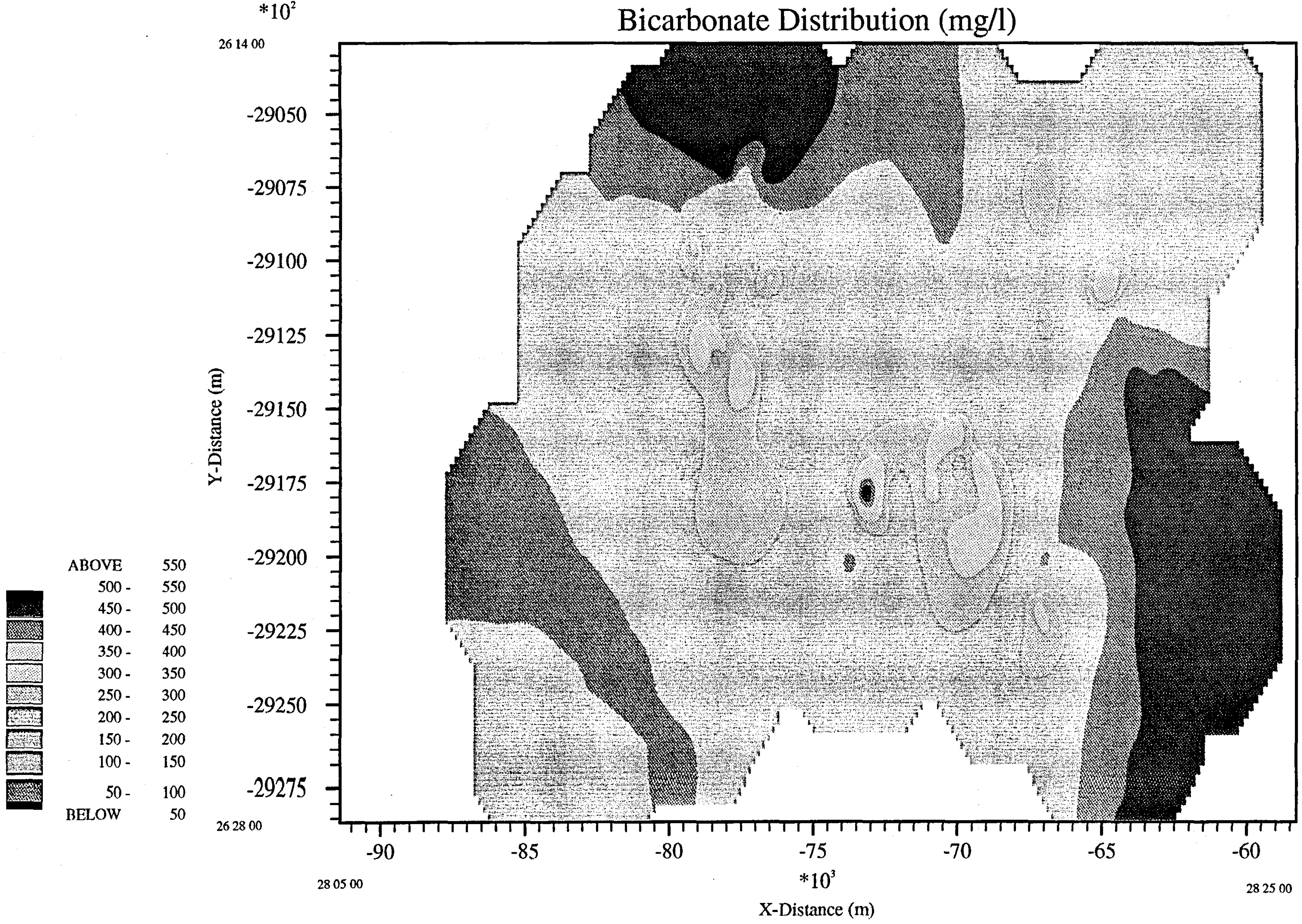


FIGURE 19

Klip River Dolomitic Pollution Study
Sulphate Distribution (mg/l)

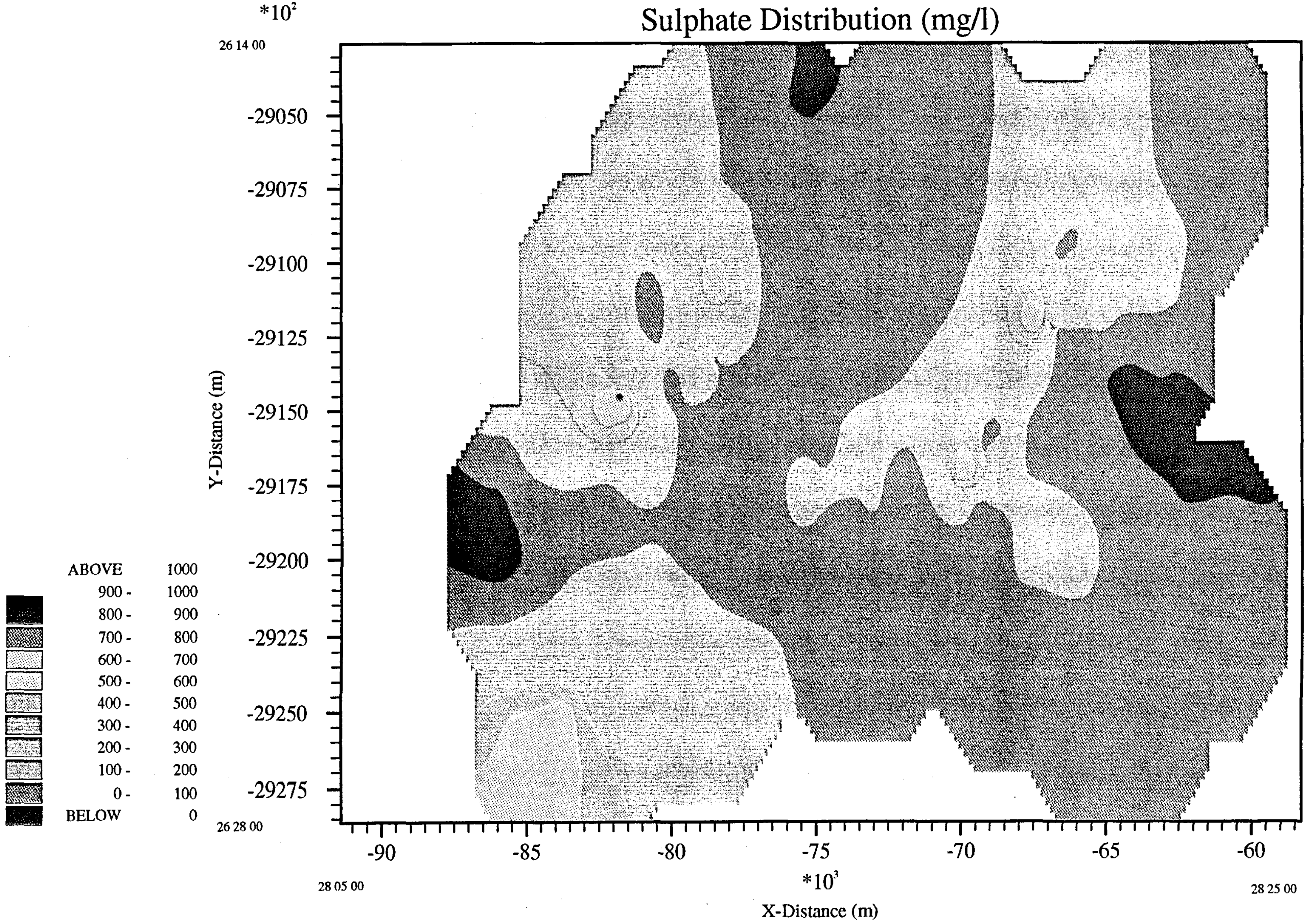
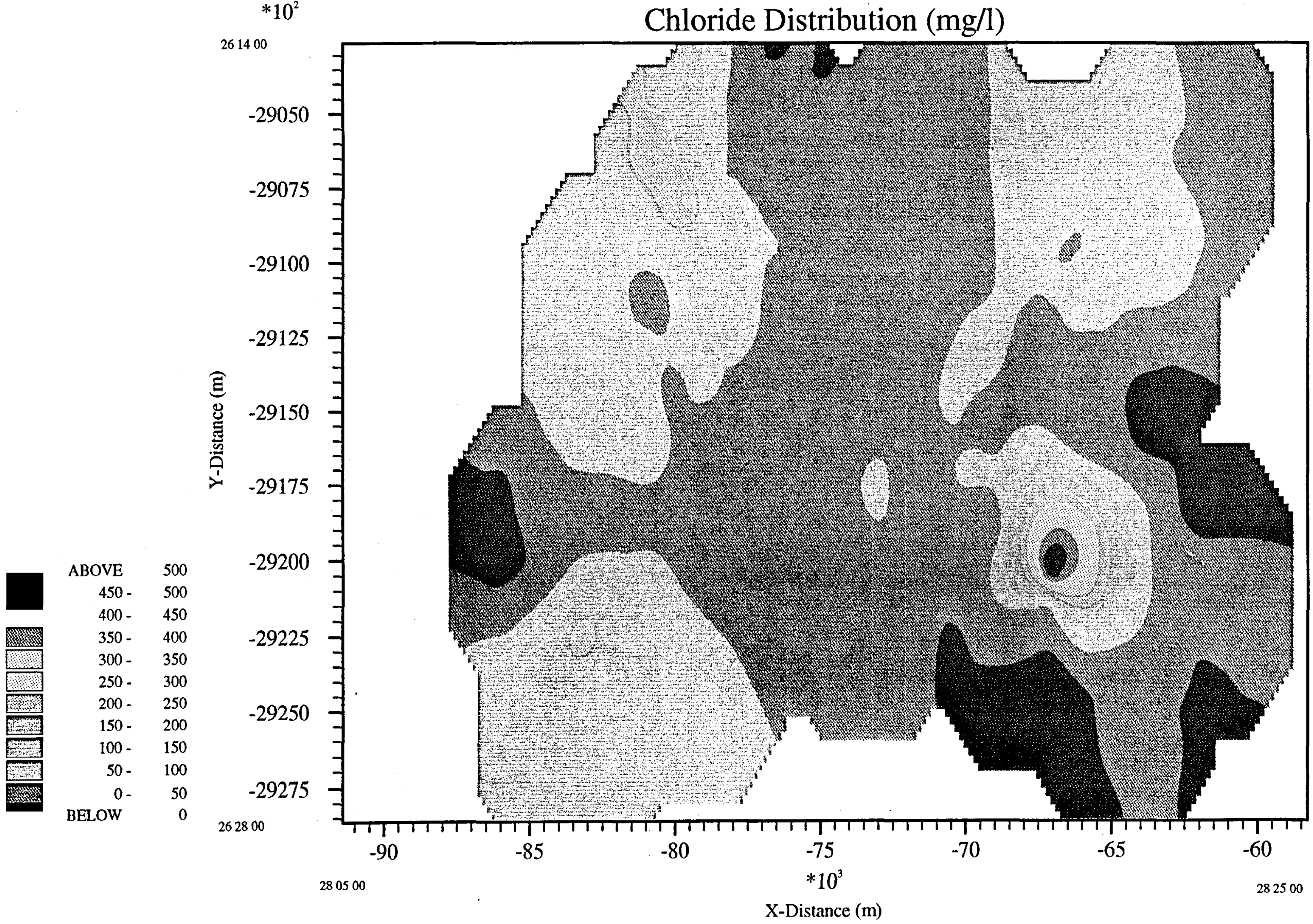


FIGURE 20

Klip River Dolomitic Pollution Study
Chloride Distribution (mg/l)



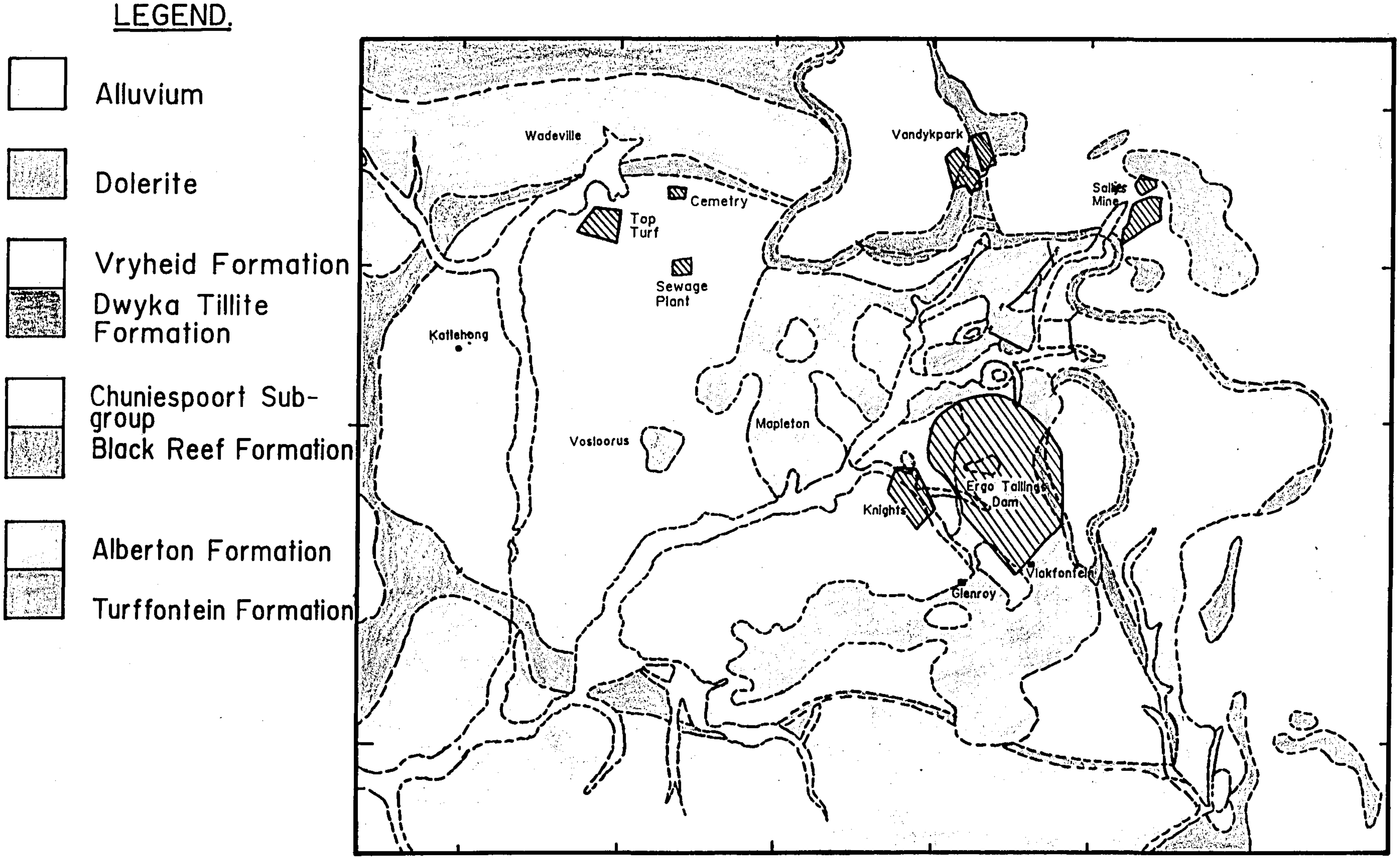


FIGURE 21

GEOLOGICAL MAP OF THE AREA IMAGED.

FIGURE 22

TERNARY MAPPING - PWV POLLUTION STUDY

HCO3:Cl:NO3

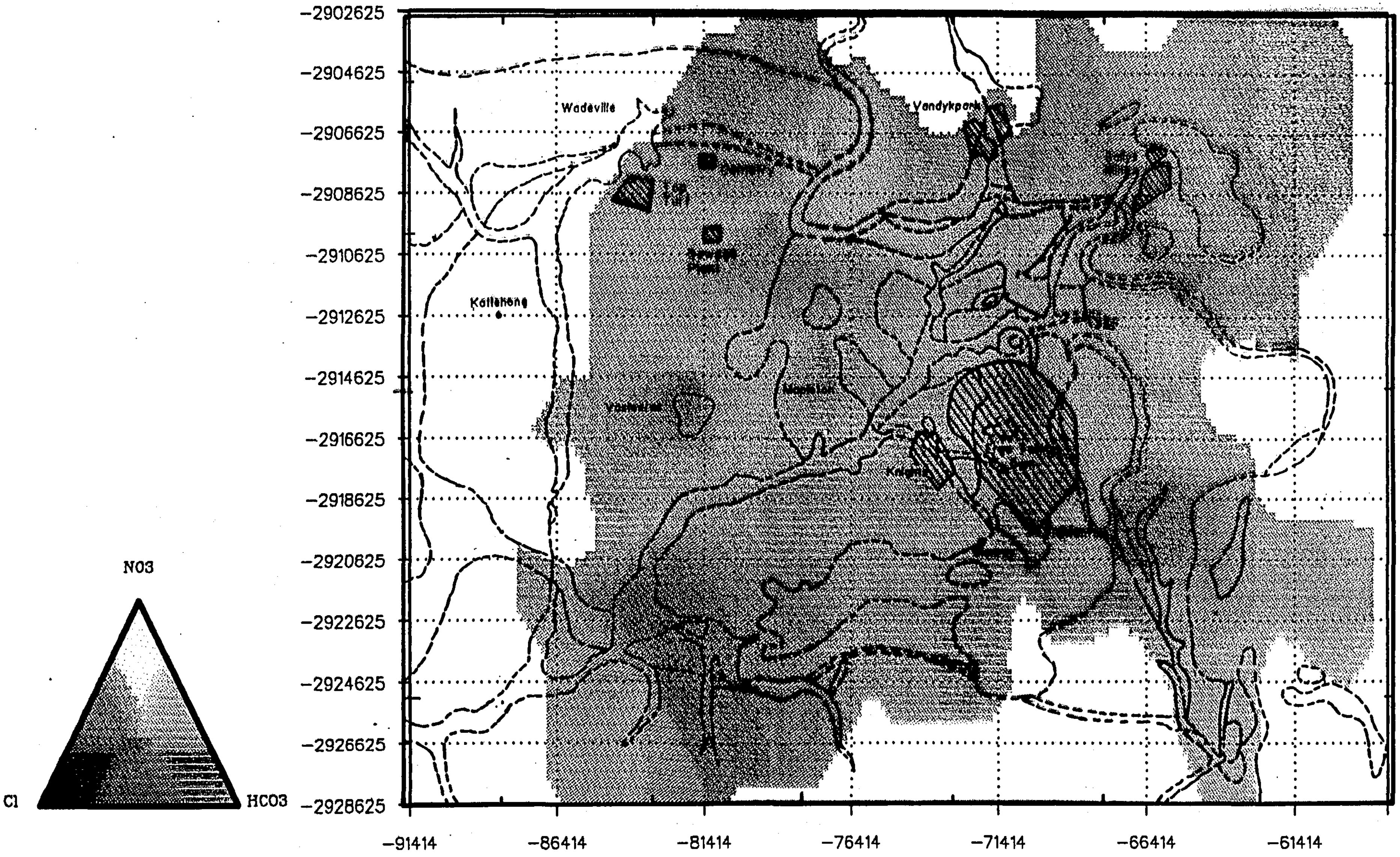


FIGURE 23

TERNARY MAPPING – PWV POLLUTION STUDY

NO3:Cl:SO4

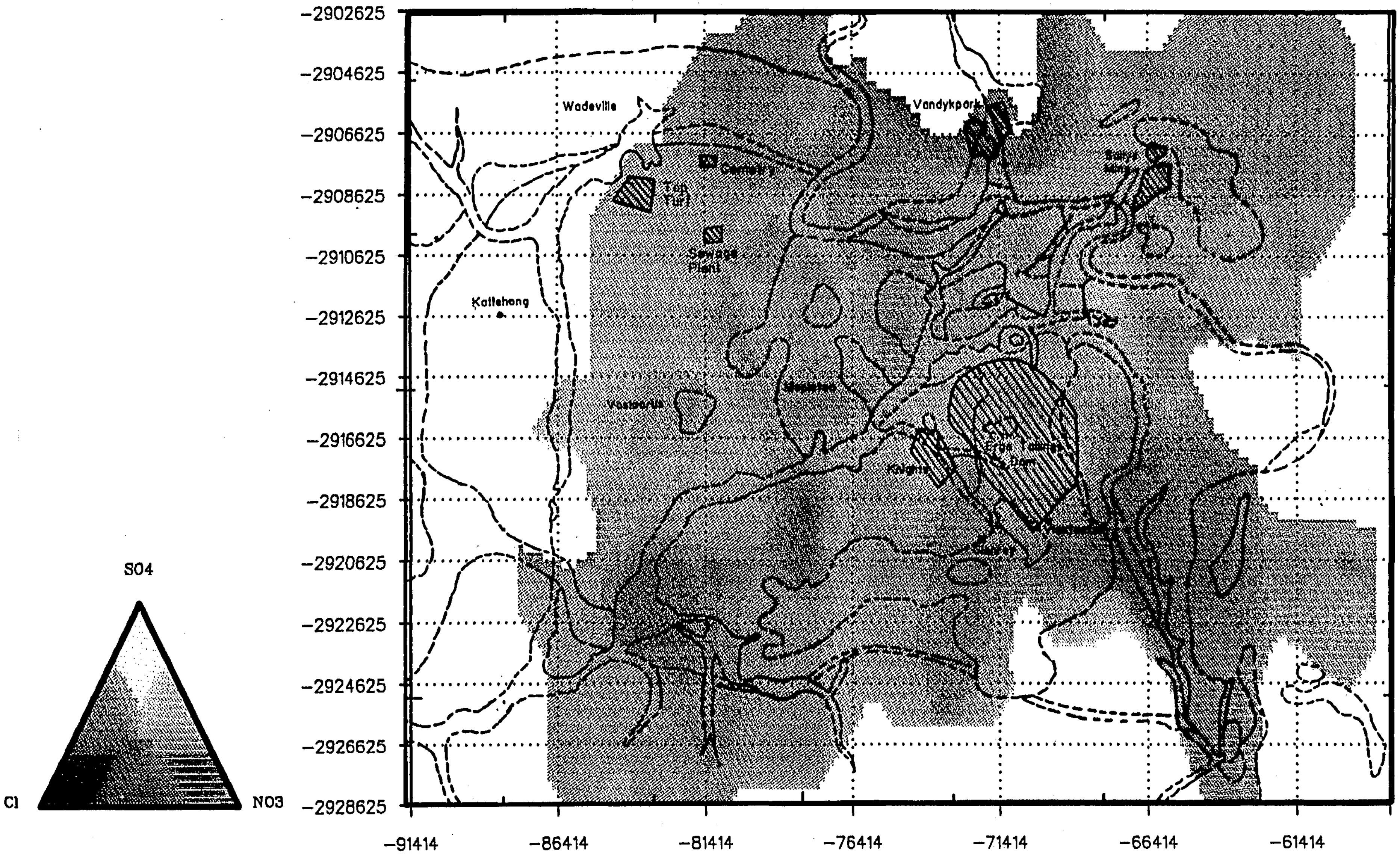


FIGURE 24

TERNARY MAPPING – PWV POLLUTION STUDY

Si02:Ca:Mg

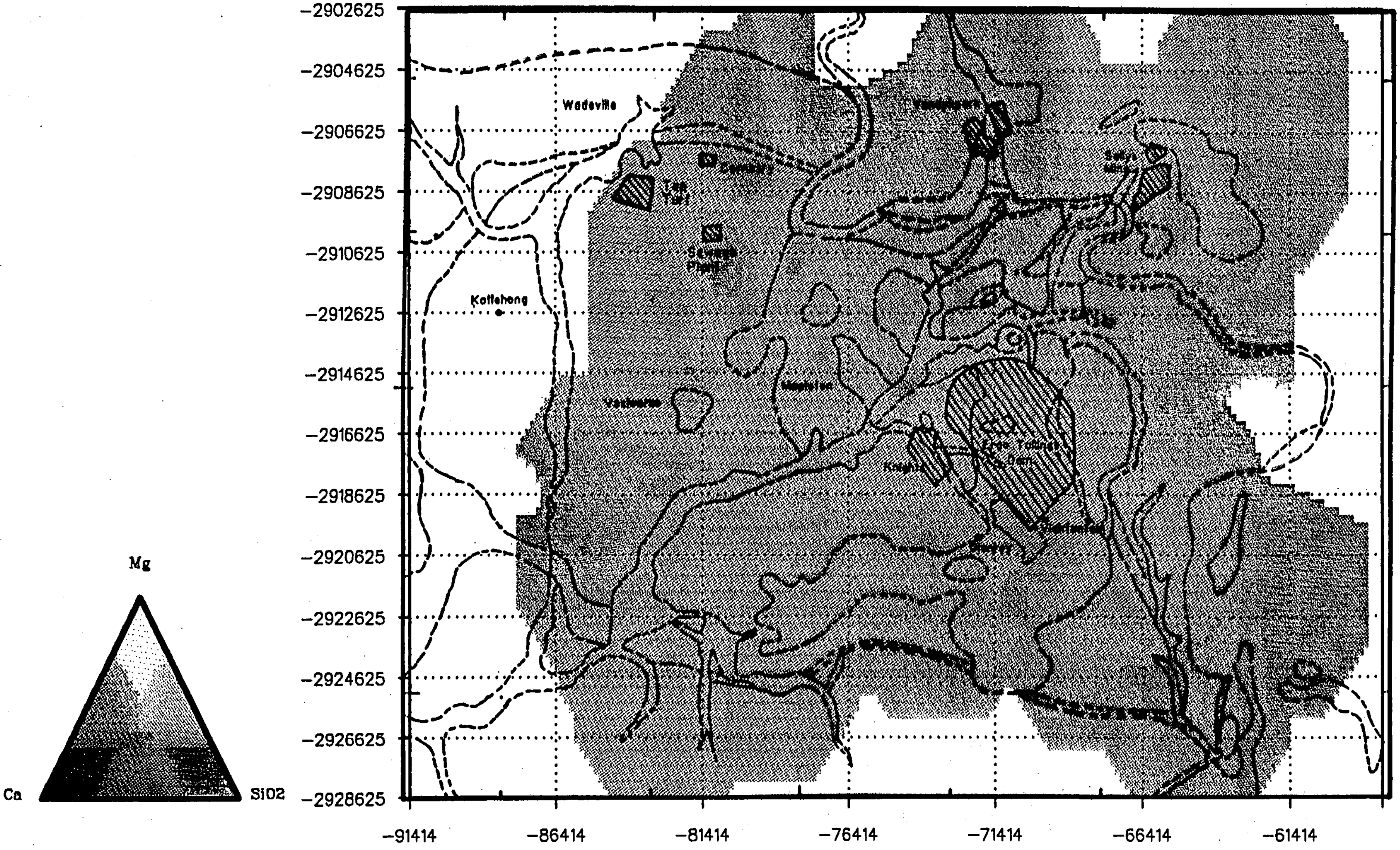
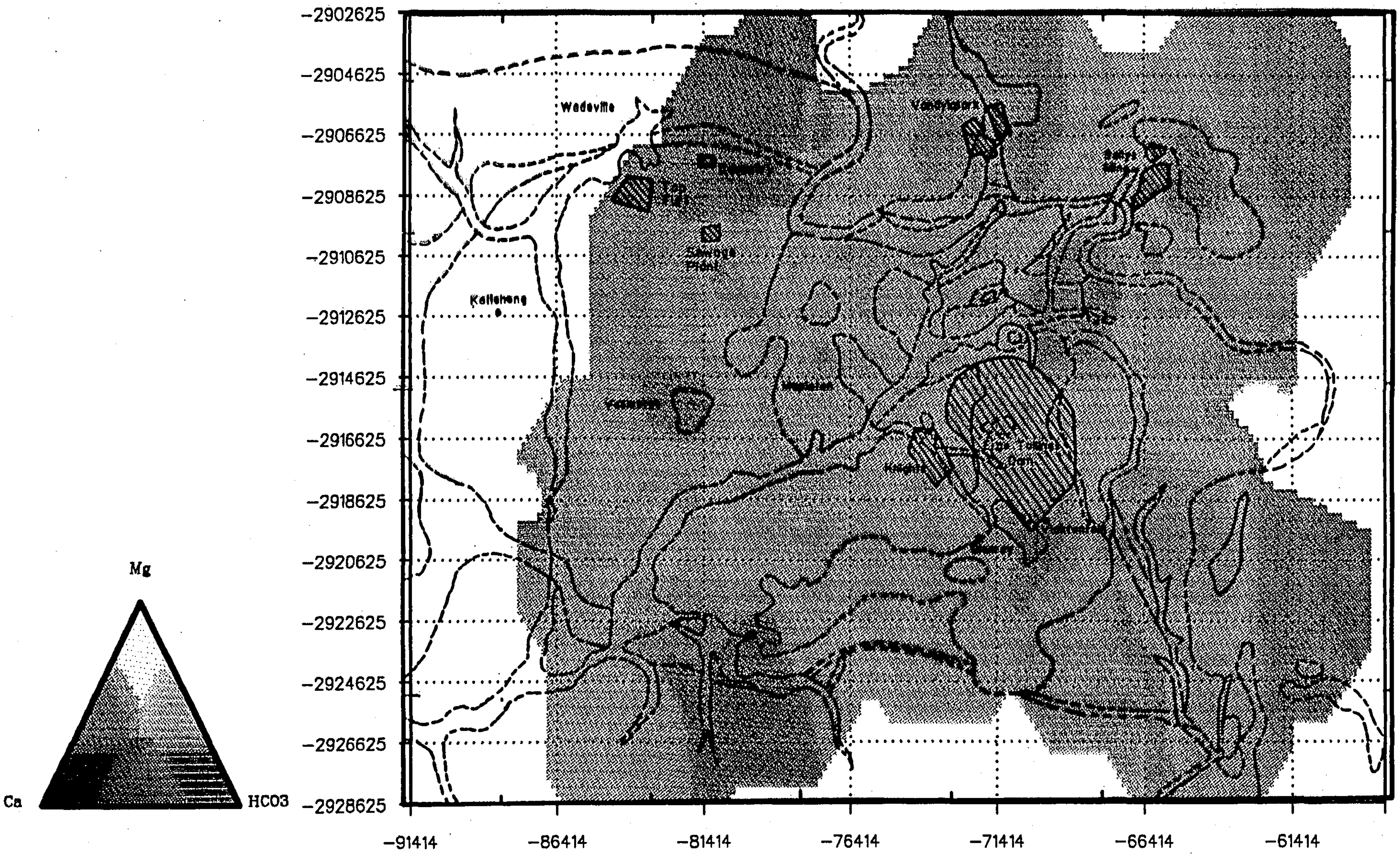


FIGURE 25

TERNARY MAPPING – PWV POLLUTION STUDY

HCO3:Ca:Mg



7 CONCLUSIONS

7.1 General

Problems encountered in the initial phases of the project highlight the need for boreholes to be properly documented in the form of accurate coordinates, together with a practical field map showing their location. Field identification could also be enhanced by using borehole marking techniques.

More detailed information should be supplied concerning the method of sampling i.e. pumped or bailed, together with information about the frequency of use of the borehole. Information of this sort is particularly important when attempting to compare water analyses for temporal variations in water quality.

The techniques employed during the investigation did determine the vulnerability of the aquifer, and highlight potential pollution areas together with potential sources of pollution. The seriousness of the pollution was gauged, and a reasonable model describing the method of pollution could be applied.

The need for a complete hydrocensus was highlighted during the investigation because of the elevated background levels of certain elements that are considered potential indicators of pollution.

7.2 Elspark/Rondebult Area

Nitrate pollution in this area can be considered a serious problem. In some cases the level of nitrate in the groundwater samples exceeded that recommended for drinking water. The pollution can still be considered as localized at present, but concentrations are increasing. The irrigation process widely used in this area may be containing the pollution, by producing an artificial closed groundwater regime where the water is essentially being recycled.

Isotope techniques proved extremely useful in determining the vulnerability of the aquifer to pollution and in the identification of the method of pollution. It is highly recommended that this methodology be incorporated into subsequent pollution studies.

7.3 Rietspruit/Ergo Area

Groundwater pollution does not appear to be significant. The elevated sulphate level appears to be a regional phenomenon and may be a result of the post Karoo dolerite intrusives and the basal Ventersdorp Lavas. Due to the higher regional concentrations of sulphate, difficulties were encountered in the identification of potentially polluted areas. Relatively elevated sulphate levels were however identified in boreholes located on the western side and within close proximity to the new Ergo tailings dam. The borehole RES 20A has a sulphate level approaching the maximum value allowed in drinking water (i.e. 500 mg/ℓ - Kempster *et al.*, 1980).

The vast majority of surface water samples have a sulphate value greater than that recommended for river or dam water.

Generally nitrate levels appear elevated when compared to values expected for dolomitic aquifers. Some samples such as RES 16 and RES 9 are above the medium allowed for drinking water. These high levels can be attributed to point source pollution, and are related to local conditions around the borehole.

There is insufficient evidence to suggest that pollution is originating from the surface drainages. The only positive indications of pollution is that associated with the new Ergo tailings dam.

Isotope studies assisted in the determination of hydrogeological conditions, but budgetry constraints did not allow for the sampling to be as comprehensive as was needed for this particular situation. However, for future reference, natural isotope studies did prove promising. Had more funds been available, and hence more boreholes and surface water points been sampled, a better understanding of the local artesian conditions would have been gained. A more detailed model of pollution could also then have been given.

The monitoring holes around the new Ergo tailings dam are inadequate. In many cases the diameter of the piezometer tube within the borehole does not allow a meaningful pumped sampled to be taken. In addition to this, the two boreholes that were sampled were totally inadequate as monitoring holes. EG 6B is an extremely shallow hole (± 5 m), whether this was intended, or is a result of borehole collapse is unclear. EH 5B is an open artesian hole and is therefore susceptible to surface pollution. As a result of the investigation it is known that the upper portion of the dolomitic aquifer is heavily polluted; how far this extends vertically into the dolomite is impossible to say. Careful monitoring on the western side of the tailings dam within the dolomite should be carried out, with properly constructed monitoring holes being incorporated into a revised monitoring programme.

7.4 Ternary Mapping

Provided the chemical data are reliable and the data comprise a fair density of sampling points, the following conclusions can be drawn regarding ternary mapping of hydrogeochemical data:

1. Since particular rock types such as the dolomites often have characteristic ratios of three chemical parameters, a map of these ratios is a useful geological tool for highlighting zones of uniform lithology and contacts between contrasting lithologies.

2. More important, however, is the potential to use one or more of the ternary maps of an area to analyse and interpret the presence and character of pollutants in the groundwater.

This technique is still in its infancy and has the potential to be developed further. The potential of using this technique in hydrogeochemical exploration of base metals should also be investigated and researched.

One weakness in the method as compared to the geophysical application, is to incorporate total concentration. This is possible by adding this information to the image by varying the "saturation" of the colours with the concentration. This means the colour hue, which contains the ratio information, remains constant but its "saturation" or scaled intensity (less or more intense) are used to produce a map showing whether anomalies are due to higher concentration or not.

8 RECOMMENDATIONS

It is recommended that when carrying out a pollution study of this kind, certain criteria must be adhered to where possible.

- All available relevant data, past and present, must be incorporated into the study. This will give some understanding of the temporal development of suspected pollution.
- A detailed hydrocensus, including a detailed landuse survey, must be carried out to determine background levels and possible point sources of pollution.
- Detailed natural isotope studies should be included to gain a better understanding of the dynamic hydrogeology i.e. methods of recharge and hence vulnerability of the aquifer. These techniques proved useful in this particular study in identifying possible modes of pollution i.e. how polluted water was entering the groundwater system.

In relation to this particular study, it is recommended that a more comprehensive and functional monitoring system be installed at the new Ergo tailings dam. Pollution has been identified in the dolomitic formation to the west but the extent to which this pollution is taking place both areally and vertically is unknown. The present monitoring system will not provide this information.

Ternary mapping reveals a good potential for mapping pollution provided a fair sampling density exists and the hydrochemical data are reliable. It is recommended that if further development of the technique be considered, then mapping of concentration should be added to enhance the ternary maps.

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GEA-1045

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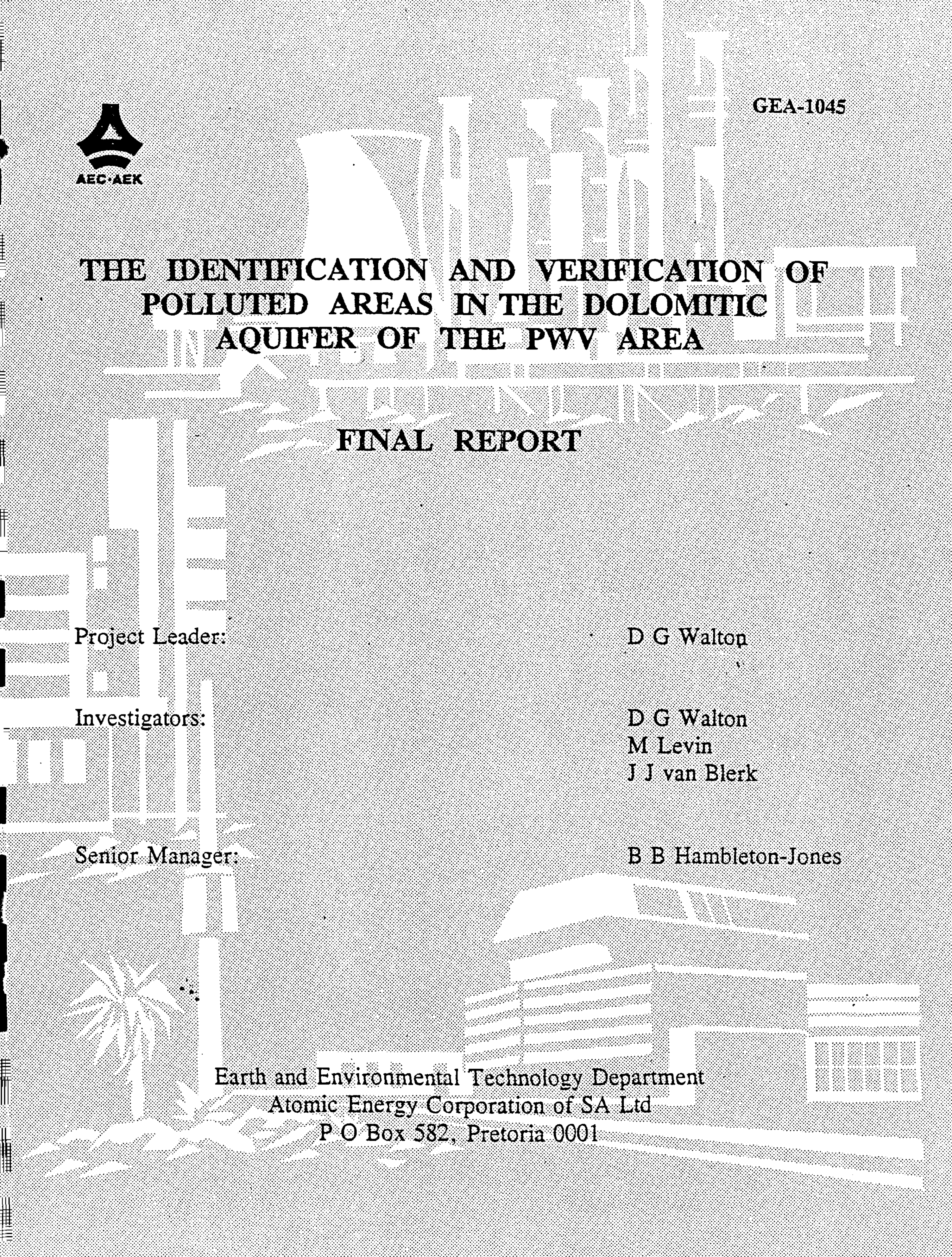

THE IDENTIFICATION AND VERIFICATION OF POLLUTED AREAS IN THE DOLOMITIC AQUIFER OF THE PWV AREA

FINAL REPORT

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Investigators: D G Walton
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J J van Blerk

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NOVEMBER 1993

AEC·AEK

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Water Research Commission

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ABSTRACT

The dolomitic formation of the Transvaal Sequence is one of the most important sources of groundwater within South Africa. Pollutants have already been identified at certain localities in recent studies, and this project was initiated because of the awareness of the need for the conservation of this resource. It was planned that boreholes identified as polluted were to be resampled to verify the existence of such pollution. This proved difficult as the boreholes had to be located on a coordinate basis alone, and very often the nearest borehole to the given coordinates was sampled. It could not be said with certainty that the original borehole was being resampled. A second phase of sampling was initiated in the Klip River/Natalspruit region which had previously been identified as a polluted area by Simonis in 1989. Field maps were available together with historic data, and this provided a much sounder basis around which the project could be developed.

As a consequence of this second phase two areas were chosen for more detailed investigation. The Elspark/Rondebult area had elevated nitrate values together with some instances of high sulphate values. The second area referred to as the Rietspruit/Ergo area showed elevated SO_4 values with isolated high NO_3 values. The aim of the detailed investigation was to establish the type and extent of the pollution, the potential source/s and any temporal variation thereof.

A field hydrocensus was carried out in both areas to provide background chemical values, waterlevel and geological data, together with landuse information. In addition to these conventional approaches, natural isotope studies were included. These proved invaluable for the determination of the vulnerability of the aquifer, the dynamic hydrogeology and the method by which pollution enters the groundwater system.

It was concluded that both study areas were being subjected to diffuse agricultural pollution producing elevated NO_3 levels. Point source pollution was identified in the Rietspruit/Ergo area in the vicinity of the new Ergo tailings dam, and the Ergo plant. This gave rise to elevated SO_4 levels in both ground and surface water together with elevated levels of trace elements such as nickel, copper and iron. As a consequence of the study it is recommended that the monitoring facilities associated with these point sources be revised and upgraded.

As part of the investigation, the potential for mapping pollution by using the ternary (three-component) imaging technique, was investigated. The initial images produced in this way showed that it could be an effective method for displaying in a single image ratio, information for three parameters. It was concluded that the method has useful application in pollution studies provided there is sufficient data coverage of the area studied (sufficient density). These maps are also useful as a geological tool for highlighting zones of uniform lithology and contacts between contrasting lithologies. It is recommended that the technique be further developed and the effect of concentration be added by the use of "saturation of colours".

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

1. BACKGROUND INFORMATION

During the mid-1980s the Department of Water Affairs and Forestry initiated a large-scale investigation of the dolomitic formations of the Transvaal sequence (commonly known as the *"dolomites"*) in order to determine their water-bearing properties and to ascertain whether they could be utilized for the provision of emergency water supplies to the PWV-region during periods of prolonged drought.

It was during this investigation that elevated levels of ions such as sulphate and nitrate were detected which led the Department to suspect pollution of the dolomitic aquifer in certain areas related to either mining, industrial or agricultural practices. Unfortunately, no long-term monitoring of the groundwater resource was initiated after the option of large-scale abstraction from the dolomitic aquifer was scrapped a few years later.

In 1991 the AEC submitted a proposal to resample the boreholes suspected by the Department as being polluted in order to ascertain whether there had been any change in the quality of the groundwater, and if possible, to relate the quality changes to landuse activities in the catchment areas of boreholes.

The main objectives of the project can be stated as follows:

- To locate boreholes in the field that have been identified as being polluted by previous studies of the Department of Water Affairs and have been entered into the National Groundwater Data Base.
- Resample these boreholes to verify that pollution does exist.
- Establish the type and extent of the pollution.
- Establish the source of the pollution and temporal variation thereof.
- Suggest remedial measures to reduce or stop further pollution.

During the course of the project, the AEC suggested using the ternary (three-component) imaging technique in order to examine variations from the ambient groundwater quality and to relate these to nearby landuse activities. This additional objective was added to the above list.

2. MAIN RESULTS

Initially, difficulty was experienced in locating in the field those boreholes identified as being *"polluted"* from Department of Water Affairs and Forestry records (due to rapid expansion of squatter settlements or poor recording of borehole coordinates). Consequently, it could not be said with any certainty that the original borehole was being resampled.

A second phase of sampling was consequently initiated in the Klip River/Natalspruit region where more detailed maps were available, which together with good historical data, provided a sounder basis around which the project could be developed. A field hydrocensus was carried out in two selected case study areas to provide background chemical values, waterlevel and geological data, together with landuse information. The areas selected for more detailed investigations revealed elevated sulphate and nitrate values.

In addition to the above routine hydrochemical and landuse data, natural isotope studies proved invaluable for determining the vulnerability of the aquifer, the dynamic hydrogeology, and the method by which pollution enters the groundwater system.

It was concluded that both case study areas are being subjected to diffuse agricultural pollution producing elevated nitrate levels.

Point source pollution from mining activities has given rise to elevated sulphate levels and elevated levels of trace metals such as nickel, copper and iron. The monitoring boreholes currently utilized to determine the impact of the tailings dams on groundwater quality were found to be inadequate for the purpose.

As part of the investigation, the potential for mapping pollution by using the ternary (three-component) imaging technique, was investigated. It was demonstrated that the method has useful application in pollution studies provided there are sufficient data points (data density) for the area under study.

3. CONCLUSIONS

Problems encountered during the initial phases of the project regarding the location of boreholes, highlighted the need for these to be properly documented in the form of accurate coordinates, together with a practical field map showing their location.

More detailed records should be kept concerning the method of sampling, together with information about the frequency of use of the borehole. Information of this sort is particularly important when attempting to compare water quality analyses for temporal variations in water quality.

Nitrate pollution of certain areas within the dolomites of Region H appears to be serious, with the level of nitrate frequently exceeding drinking water standards. The origin of the nitrate is believed to be related to the intensive irrigated agriculture and concomitant use of fertilizers, particularly related to market gardening.

Elevated sulphate values, particularly in the Rietspruit/Ergo area, appear to be a regional phenomena and may be a result of the geological history of doleritic intrusions found here. Obvious point source pollution from, for example, the new Ergo tailings dam is evident, superimposed on the regional sulphate background.

The ternary imaging technique proved extremely useful for differentiating between different lithologies based on hydrochemical data, and for analysing and interpreting the presence and character of pollutants present in the groundwater. The method, although in its infancy, can be enhanced considerably by adding *"total concentration"* to the graphical presentation of results.

4. RECOMMENDATIONS

It is recommended that when carrying out a pollution study of this kind, certain criteria must be adhered to, where possible:

- All available relevant data, past and present, must be incorporated into the study. This will give some understanding of the temporal development of suspected pollution.
- A detailed hydrocensus, including a detailed landuse survey, must be carried out to determine background levels and possible point sources of pollution.
- Detailed natural isotope studies should be included to gain a better understanding of the dynamic hydrogeology i.e. how polluted water is entering the groundwater system.

In relation to this particular study, it is recommended that a more comprehensive and functional monitoring system be installed at the new Ergo tailings dam. Pollution has been identified in the dolomitic formation to the west but the extent to which this pollution is taking place both aerially and vertically is unknown. The present monitoring system will not provide this information.

Ternary mapping reveals a good potential for mapping pollution provided a fair sampling density exists and the hydrochemical data are reliable. It is recommended that if further development of the technique be considered, then mapping of concentration should be added to enhance the ternary maps.

1 AIMS AND OBJECTIVES

The dolomitic formation of the Transvaal Sequence is one of the most important sources of groundwater within South Africa. It has been investigated and has been found to have the potential to be developed to provide emergency water supplies in times of drought. It is therefore imperative that this vulnerable resource be protected from pollution by mining and agricultural practices, and industrial and urban development.

Samples taken before 1987 by the Department of Water Affairs indicate that pollutants are present in groundwater at certain localities within the PWV area. The present status of these boreholes is unknown and no monitoring is either planned or is being carried out. The polluted areas have been highlighted in a previous report, Van der Merwe *et al.* (1991). The present study concentrated on the groundwater within the dolomites of the PWV region, also referred to as the H-region.

The objectives of this project were firstly, to locate boreholes in the field that have been identified as being polluted by previous studies carried out by the Department of Water Affairs and which have been entered on the National Groundwater Database, to then re-sample these boreholes in order to verify that pollution still exists. The critical aims of the project were then to establish the type and extent of the pollution, the source and any temporal variation thereof. The area was considered too large to be covered in relation to the finance available, and so two smaller areas were chosen to be investigated in greater detail. These areas were highlighted as a consequence of the initial phases of the investigation. The initial aims were applied to these areas together with consideration as to the method by which pollution is taking place. Suggestions have been given concerning remedial measures to reduce or stop further pollution from occurring.

The ability to image process hydrogeochemical data using a trilinear technique was thought to be promising with regard to this particular study and was therefore incorporated into the project, thereby broadening the scope of the investigations.

2 IDENTIFICATION AND VERIFICATION OF EXISTING POLLUTED BOREHOLES WITHIN THE PWV REGION - PHASE 1

2.1 Desk Study

Pollution had been detected in certain areas within the PWV region and indicated in a previous report by Van der Merwe *et al.* (1991). The National Groundwater Database was used in this investigation, as it had been in the above-mentioned report. The elements used to identify polluted boreholes included electrical conductivity, SO_4, Cl and NO_3. The coordinates given in the database were then used to plot these boreholes on the appropriate 1:50 000 topographic maps.

PWV AREA -[H-REGION] LOCALITY MAP OF POLLUTED AREAS
AFTER VAN DER MERWE et al., 1991.

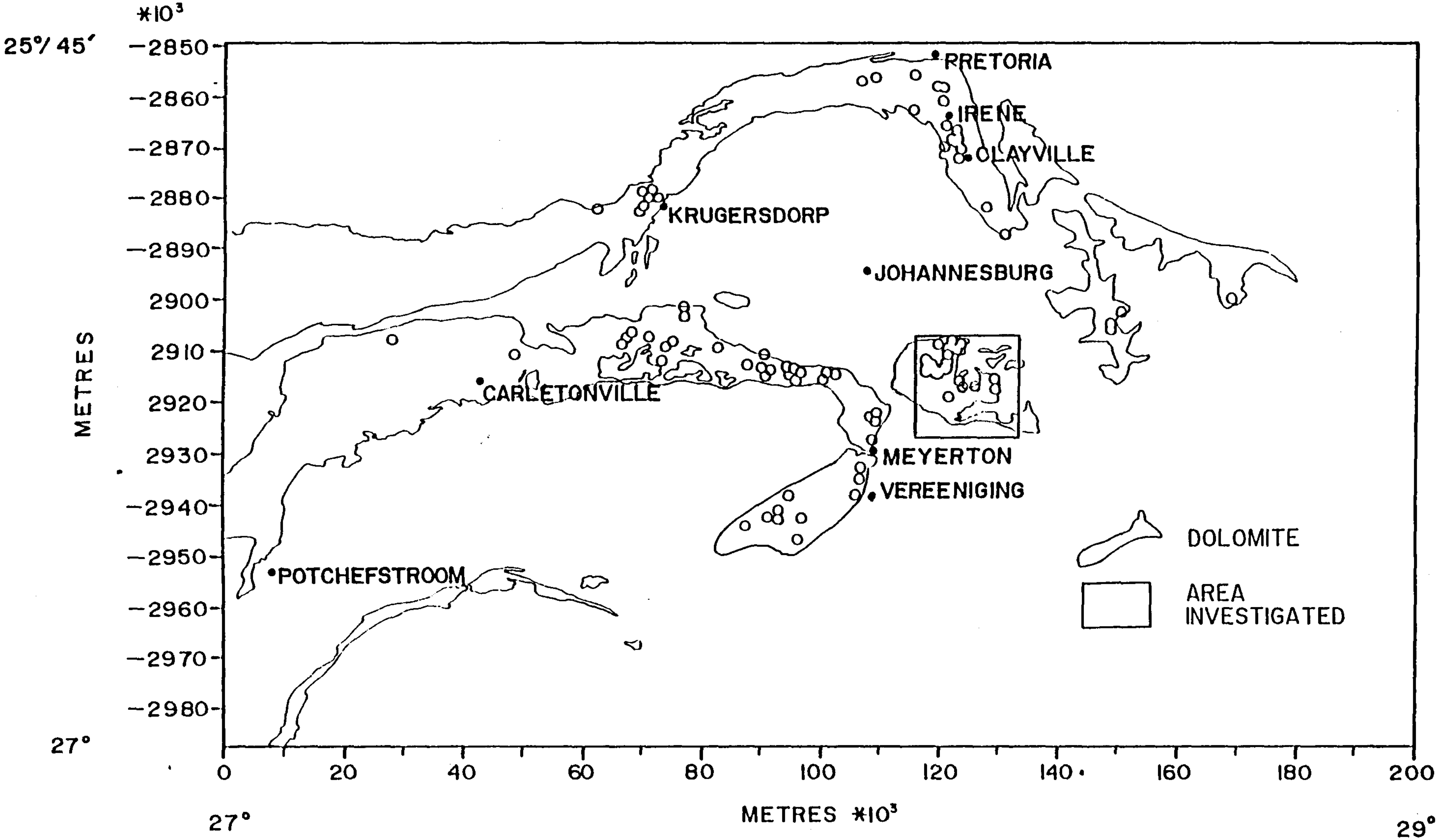


FIGURE I

2.2 Fieldwork

The actual boreholes, or those nearest to the exact coordinates were located in the field and wellhead chemistry providing EC, pH and HCO_3 values was carried out. A preliminary appraisal of landuse within the area of the borehole was done in order to determine the need for trace element analysis.

2.3 Discussion

It became apparent from the low EC values that very little pollution was taking place in the vicinity of these boreholes. Problems also arose in locating the boreholes on a coordinate basis alone. Very rarely was a borehole at the exact position indicated, and so the nearest boreholes were sampled. Correlation between historic and present day data could therefore not be guaranteed. Some boreholes could not be found because of encroachment of informal settlements, and other boreholes had collapsed or been infilled.

3 INVESTIGATION WITHIN THE KLIP RIVER/NATALSPRUIT AREA - PHASE 2

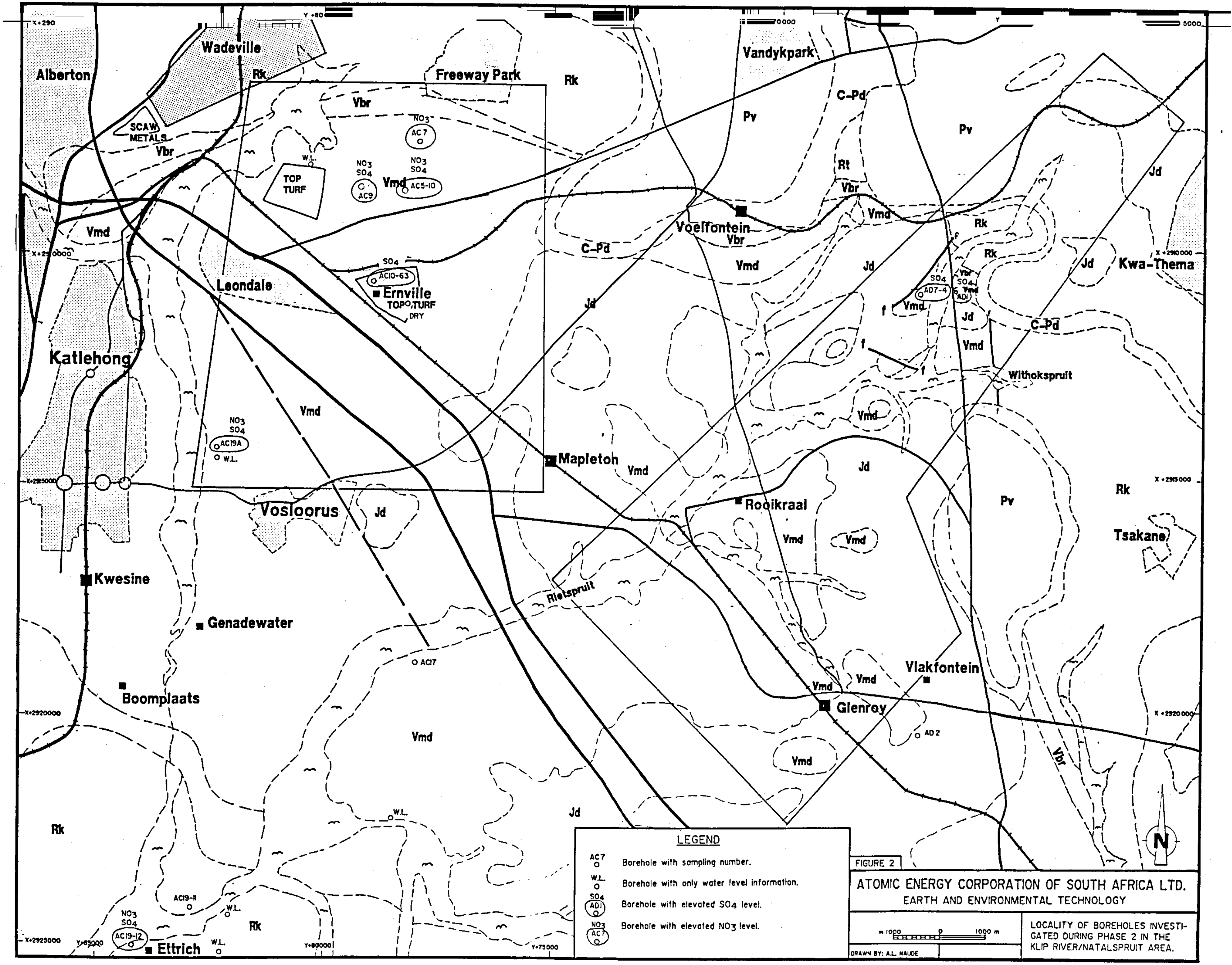
3.1 Desk Study

Due to the difficulties encountered in Phase 1 of the investigation, a second phase of sampling was done in the Klipriver area. Areas of pollution were identified from an investigation into the water quality in the Klip River area by Simonis (1989). Again, the elements SO_4, NO_3 and Cl together with EC were used as criteria to determine whether groundwater, and in some cases surface water, was polluted.

3.2 Fieldwork

Twenty one boreholes were investigated in the area shown in Figure 1. Of these only 15 water samples could be taken. The localities of most of the 21 boreholes are given in Figure 2. Four have been omitted, 2628CA 2/4 and DB 15/6 were considered insignificant because they showed very little pollution. BD 1A and BD 12, although they show elevated NO_3 levels are not indicated on the locality map because the NO_3 level was attributed to unsanitary conditions around the borehole. All four boreholes are outside the region covered by the map in Figure 5. Those showing elevated SO_4 and NO_3 levels are highlighted with a coloured circle.

Wellhead chemistry was carried out as in Phase 1 to accurately determine EC, pH and HCO_3 values, and cognisance was taken of the landuse around the borehole. Two water samples were taken, one of which was acidified as in Phase 1.



LEGEND

AC7 ○	Borehole with sampling number.
W.L. ○	Borehole with only water level information.
SO4 (AD1)	Borehole with elevated SO4 level.
NO3 (AC7)	Borehole with elevated NO3 level.

FIGURE 2

ATOMIC ENERGY CORPORATION OF SOUTH AFRICA LTD.
EARTH AND ENVIRONMENTAL TECHNOLOGY

m 1000 0 1000 m

LOCALITY OF BOREHOLES INVESTIGATED DURING PHASE 2 IN THE KLIP RIVER/NATALSPRUIT AREA.

DRAWN BY: A.L. NAUDE

Table 1. General chemistry of Boreholes sampled in Phase 2 - Klipriver/Natalspruit Area

Sample	pH	Cond mS/m	HCO_3 mg/ℓ	Cl mg/ℓ	SO_4 mg/ℓ	NO_3 mg/ℓ	PO_4 mg/ℓ	F mg/ℓ	Na mg/ℓ	K mg/ℓ	Ca mg/ℓ	Mg mg/ℓ	Fe mg/ℓ	Mn mg/ℓ	Zn mg/ℓ	Uranium mg/ℓ
2627 BD1A*	6.7	520	167	36	58	42	0.30	0.09	9	0.73	45	33	<0.10	<0.10	<0.10	<0.04
2627 BD12*	7.1	492	179	29	40	51	0.30	0.10	8	0.91	38	33	<0.10	0.14	0.10	<0.04
2627 BD 15/6*	6.9	766	511	22	35	1.7	0.30	0.10	10	1.94	79	60	<0.10	0.33	1.97	<0.04
2628 AC5/10	6.8	1 430	253	153	303	53	0.34	0.07	114	5.92	95	64	22.8	0.25	<0.10	<0.04
2628 AC7	7.1	1 204	227	130	135	183	0.27	0.06	25	2.28	121	72	<0.10	0.14	<0.10	<0.04
2628 AC9	7.4	1 880	166	185	288	208	0.30	0.05	33	2.61	206	113	<0.10	0.21	<0.10	<0.04
2628 AC10/63	7.6	1 590	376	130	390	30	0.34	0.07	135	12.2	129	67	<0.10	<0.10	<0.10	<0.04
2628 AC17	7.5	450	295	22	8	<0.1	0.30	0.20	18	1.92	23	35	6.00	<0.10	<0.10	<0.04
2628 AC19A	7.0	1 014	265	48	232	76	0.30	0.09	29	1.56	96	66	<0.10	0.16	<0.10	<0.04
2628 AC19/11	7.8	568	90	26	47	1.8	0.39	0.68	83	1.59	13	14	<0.10	0.14	<0.10	<0.04
2628 AC19/12	6.6	1 248	200	165	552	65	0.36	0.08	44	1.30	105	70	<0.10	0.18	8.86	<0.04
2628 AD1	6.8	804	132	54	230	28	0.38	0.08	17	1.85	71	58	<0.10	<0.10	<0.10	<0.04
2628 AD2	6.8	371	172	10	17	47	0.30	0.06	13	5.43	33	16	<0.10	<0.10	<0.10	<0.04
2628 AD7/4	7.4	1 560	169	170	460	30	0.30	0.09	102	7.28	145	66	<0.10	0.49	<0.10	<0.04
2628 CA2/4*	7.0	349	219	9	4	16.8	0.30	0.07	18	1.55	24	19	3.24	0.25	0.83	<0.04

*Not shown in Figure 2

3.3 Discussion

Figure 3 shows the groundwater characteristics with the aid of a Piper diagram for the 15 water samples taken in Phase 2. When the positions of the 15 water samples on the Piper diagram are compared with those given in Figure 4, showing a typical Piper diagram plot of boreholes within the PWV area, it can immediately be seen that the vast majority of the boreholes sampled in phase 2 lie outside this 'typical' area. These waters can therefore be considered to be undergoing ionic changes, i.e. a relatively higher proportion of SO_4, Cl and NO_3, which can most probably be associated with ongoing pollution. The areal distribution of polluted boreholes resulted in the delineation of two areas that merited further investigation (Figure 5). The first has predominantly nitrate pollution, this is referred to as the Elspark/Rondebult area. The second area is located further east around Sallies Mine and Ergo, and continuing along the Rietspruit down past the new Ergo tailings dam. This is referred to as the Rietspruit/Ergo area. Although only 1 borehole showed elevated SO_4 levels, surface water samples from the report by Simonis (1989) did indicate that pollution might be more widespread along the course of the Rietspruit. It was then decided to investigate both groundwater and surface water along the spruit, and boreholes located within the vicinity of the Ergo tailings dam. Both these areas are shown in Figure 5. The chemistry of the boreholes sampled in this phase is given in Table 1, and their locations are also given in Figure 5.

4 DETAILED INVESTIGATIONS - ELSPARK/RONDEBULT AREA

4.1 Geology and Physiography

The area lies on the dolomitic formation of the Malmani Subgroup of the Transvaal Sequence. To the north lies the basal Black Reef Formation consisting predominantly of quartzites with lenses of grit and conglomerate. Shales are found throughout the formation becoming more prevalent towards the top, close to the contact with the overlying Malmani Subgroup. The Black Reef Formation dips to the south at an angle of 5°. Formations of the area lie in a basin syncline structure with the younger dolomitic formation surrounded by older formations of the Klipriversberg Group. A syenite dyke striking north-west/south-east, cuts through the dolomitic formation, and is located to the east of the Natalspruit in the west and south-western portion of the area under investigation.

The main drainage in the area is the Natalspruit which drains in a southerly direction, and is located on the western margin of the study area. This drainage joins the Rietspruit which eventually flows into the Klip River occupying the adjacent drainage catchment to the west.

Figure 3. Piper diagram showing groundwater characteristics of water samples taken in phase 2 - Klip River/Natalspruit

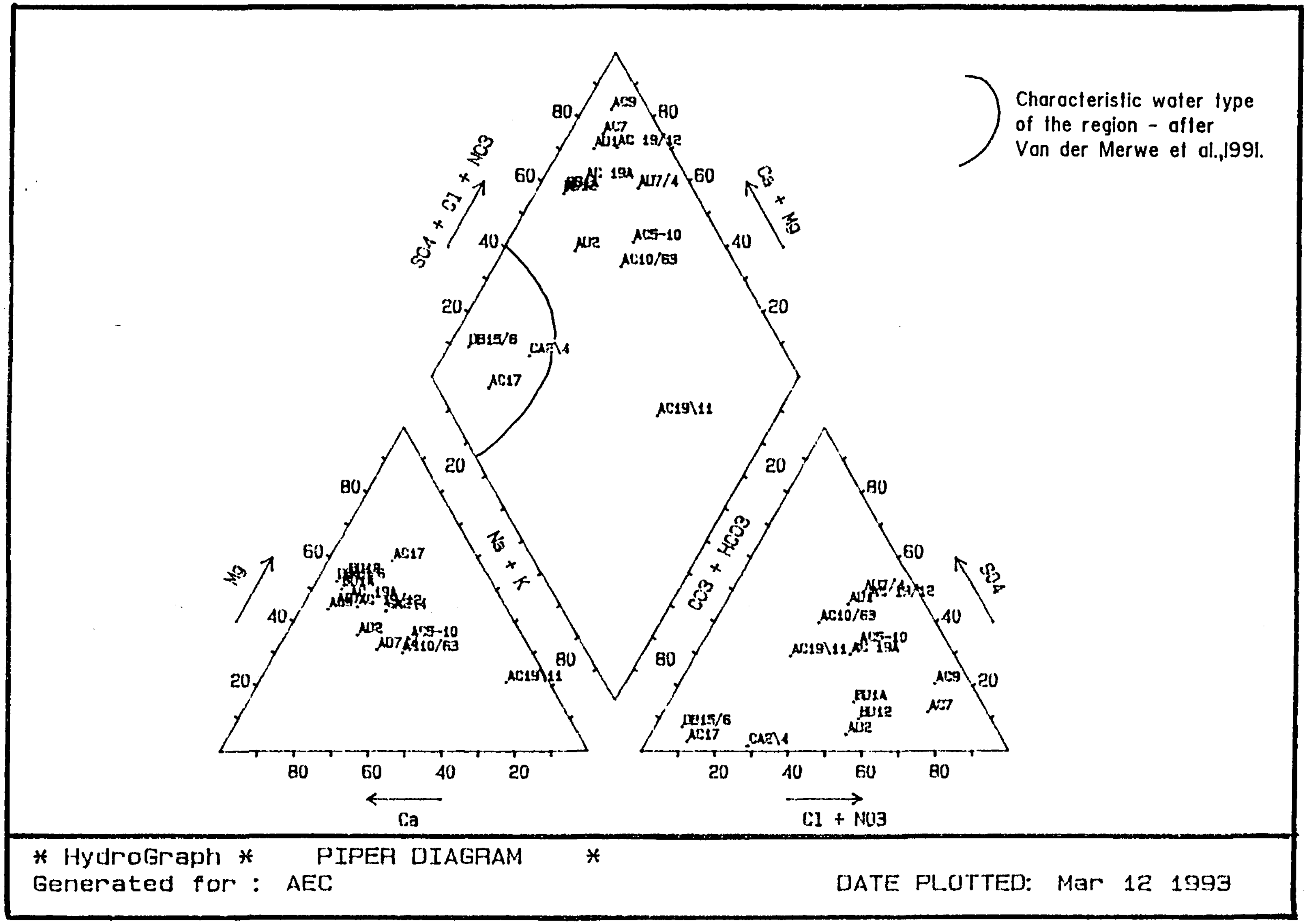
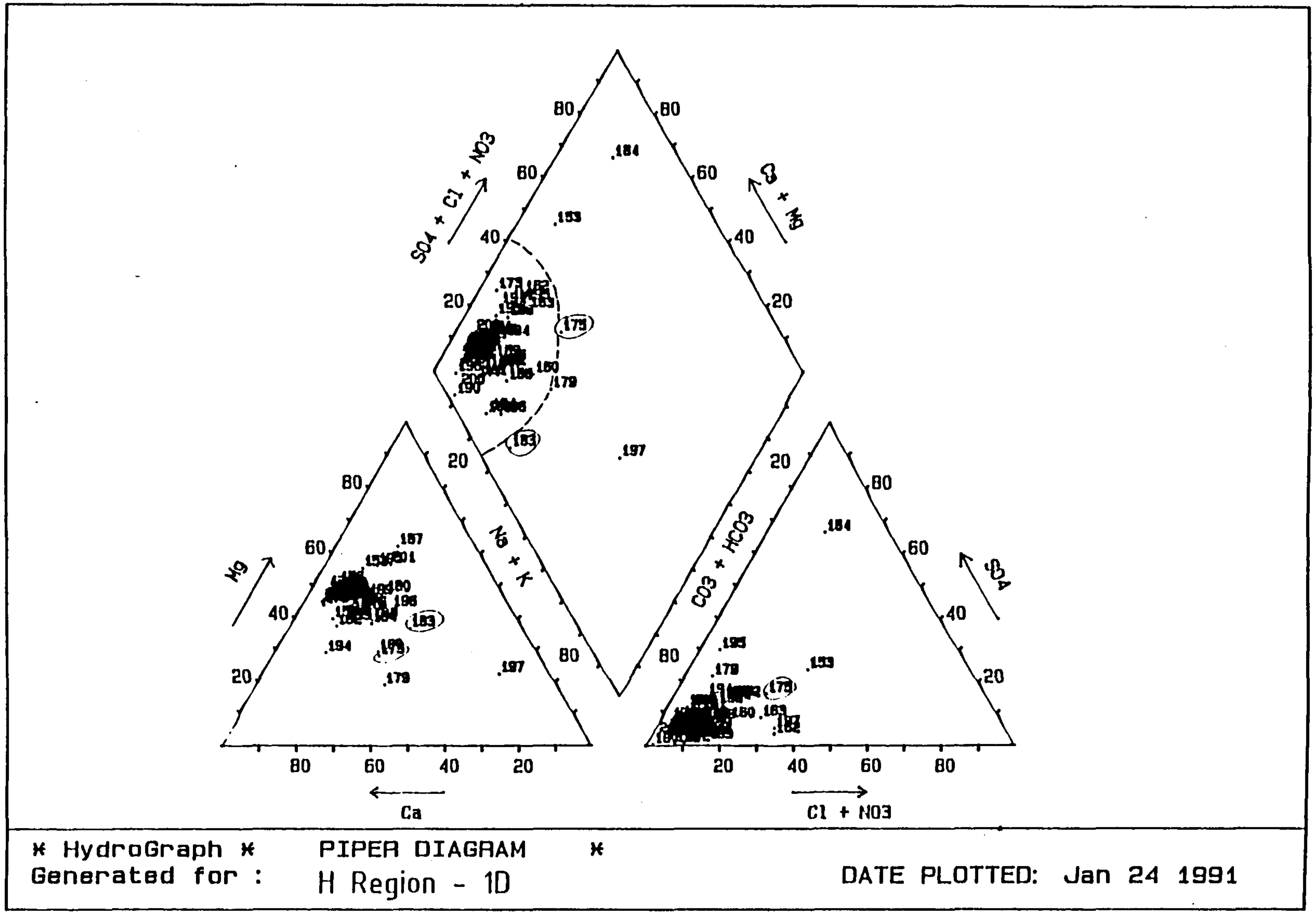
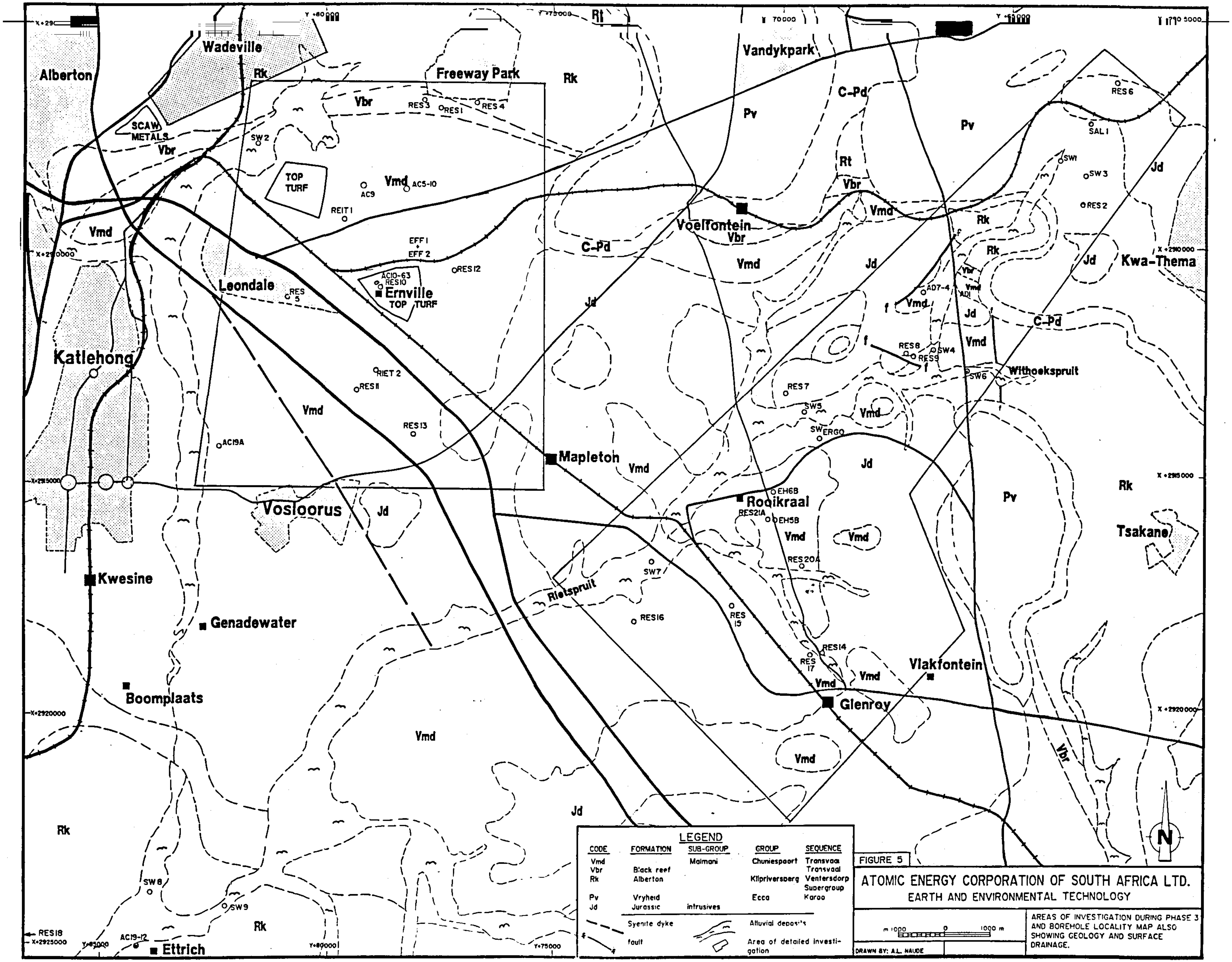


Figure 4. Piper diagram showing a typical plot of boreholes in the dolomite formation of the PWV region (after Van der Merwe *et al.*, 1991)





LEGEND

CODE	FORMATION	SUB-GROUP	GROUP	SEQUENCE
Vmd		Malmani	Chuniespoort	Transvaal
Vbr	Black reef			Transvaal
Rk	Alberton		Klipriversberg	Ventersdorp Supergroup
Pv	Vryheid		Ecca	Karoo
Jd	Jurassic	intrusives		

Syenite dyke

fault

Alluvial deposits

Area of detailed investigation

FIGURE 5

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m 1000 0 1000 m

DRAWN BY: A.L. NAUDE

AREAS OF INVESTIGATION DURING PHASE 3 AND BOREHOLE LOCALITY MAP ALSO SHOWING GEOLOGY AND SURFACE DRAINAGE.

4.2 Landuse

A substantial proportion of the area is covered by land used for agricultural purposes. In some localities intensive cultivation takes place producing vegetables and turf. Residential areas are present in the extreme northern sections, and isolated small residential developments are present within the mainly agricultural section. In the north-western area more commercial and industrial activities are present, mainly steelyards and workshops, timber yards and fuel depots. Just to the north-west of the area under investigation and north of the Elsburg Spruit lies Scaw Metals, a smelting and steel manufacturing industry. The suburb of Wadeville also has many steel storage depots and workshops. Although it is not considered probable that this industry affects the groundwater in this particular study area, it may have an influence on the quality and characteristics of the surface drainage water.

In the north-western section, south of the Elsburg Spruit is the company Top Turf. Intensive cultivation is carried out here under irrigation. The same company also utilize land for this purpose in the vicinity of Erville - Figure 6. Just to the south of the Van Dyk road lies a vlei area which has been converted into a bird sanctuary. Effluent from the sewage works is used to maintain this ecological environment.

4.3 Hydrogeology

The hydrogeological situation can only be deduced from the very scanty waterlevel information that could be collected. The water table lies approximately 13 m below ground surface, and groundwater flow is presumed to be in a westerly direction towards the surface drainage.

The dolomite is very heterogeneous, the evidence for this being provided by the estimated blowout yields of boreholes drilled by the Department of Water Affairs. Within the area investigated, estimated blowot yields range from 0,05 ℓ/sec to 100 ℓ/sec. This would suggest that groundwater flow would be along solution channels within the dolomite. Surface collapse has taken place in the vicinity of the sewage plant as described by the effluent inspector on site (personal communication), causing damage to the sewage tanks. This provides evidence for the belief that karstification is still taking place.

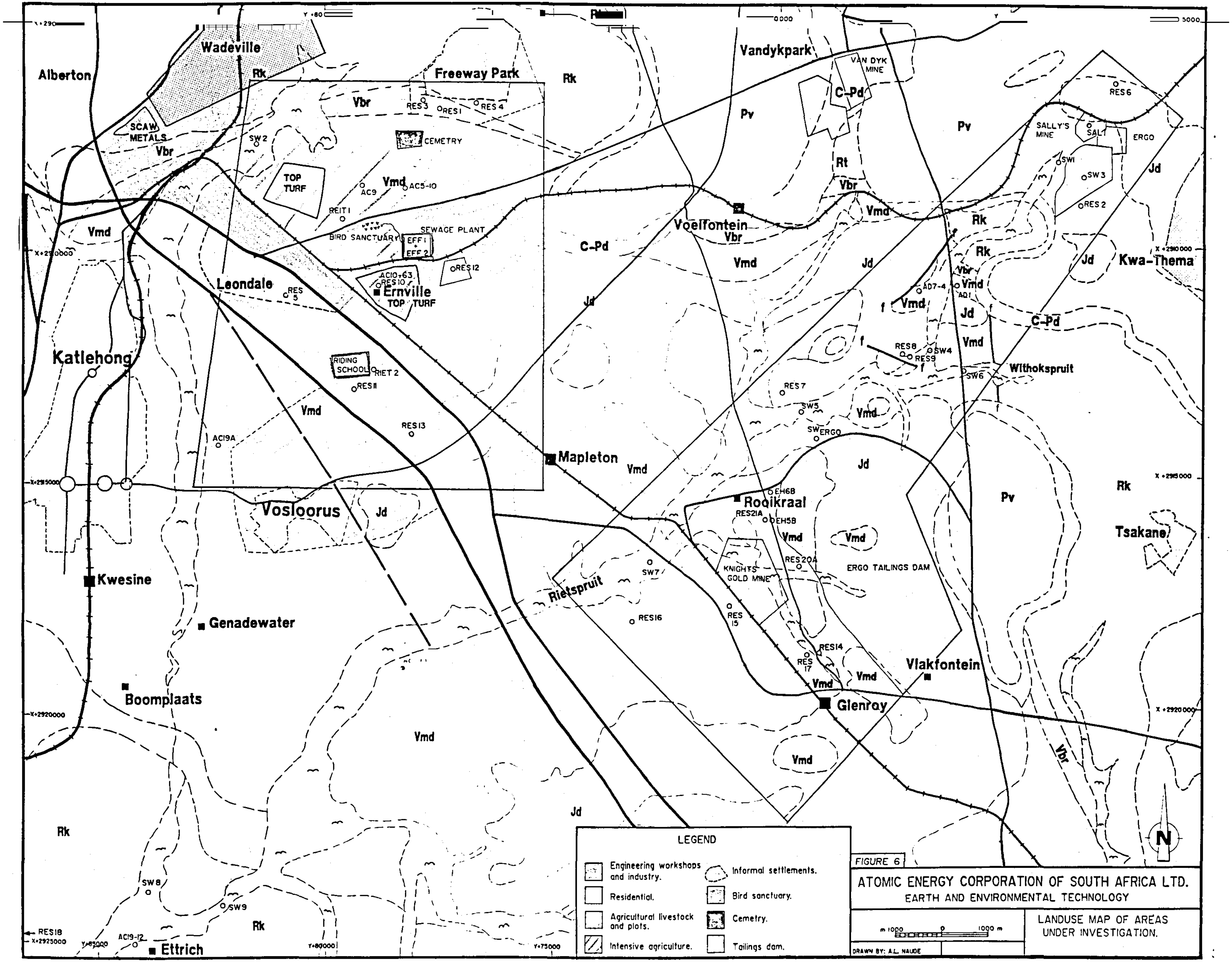


FIGURE 6

ATOMIC ENERGY CORPORATION OF SOUTH AFRICA LTD.
EARTH AND ENVIRONMENTAL TECHNOLOGY

LANDUSE MAP OF AREAS UNDER INVESTIGATION.

DRAWN BY: A.L. NAUDE

Figure 7. Piper diagram showing groundwater characteristics within the Elspark/Rondebult area - 1984-86 (after Simonis 1989)

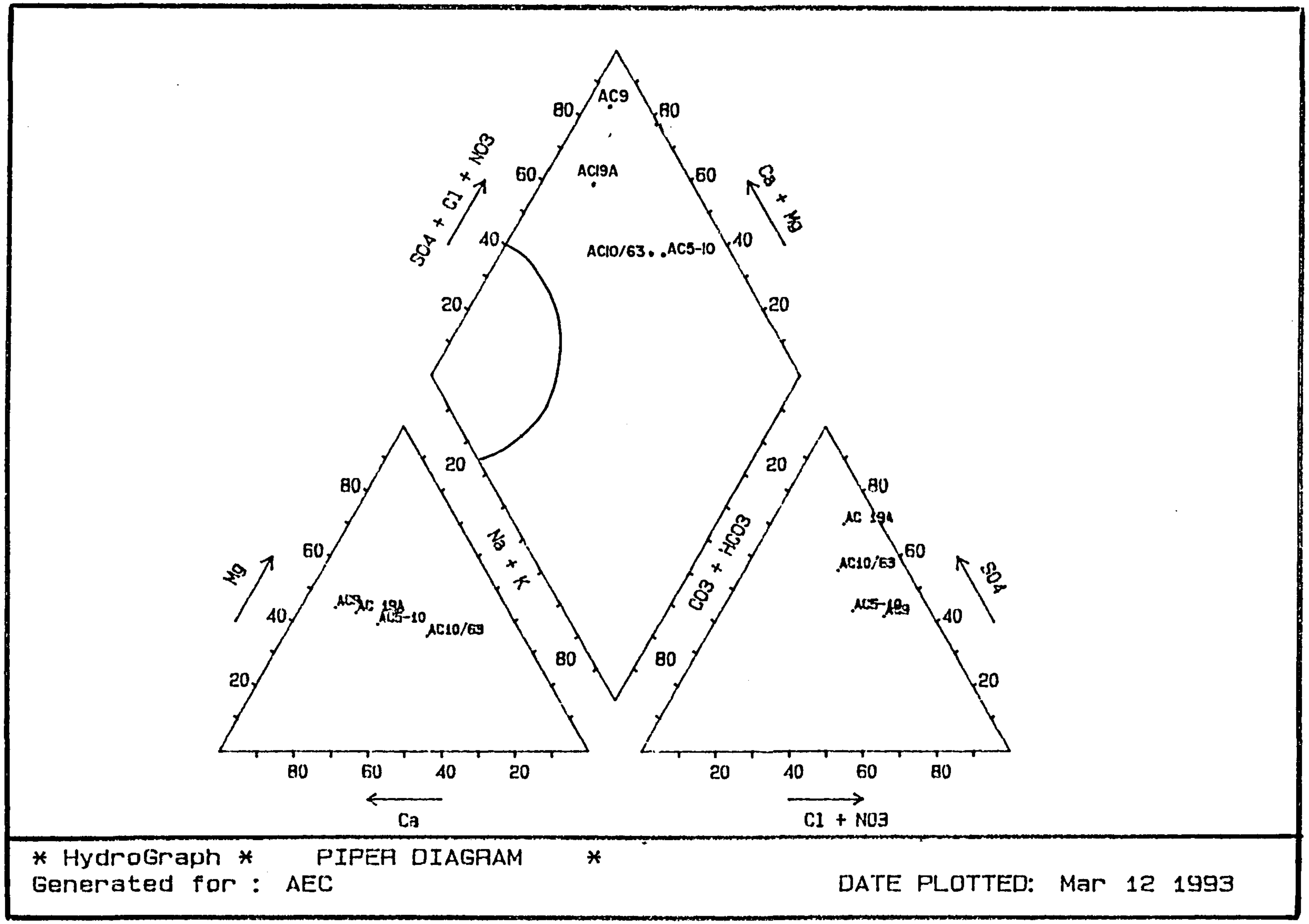
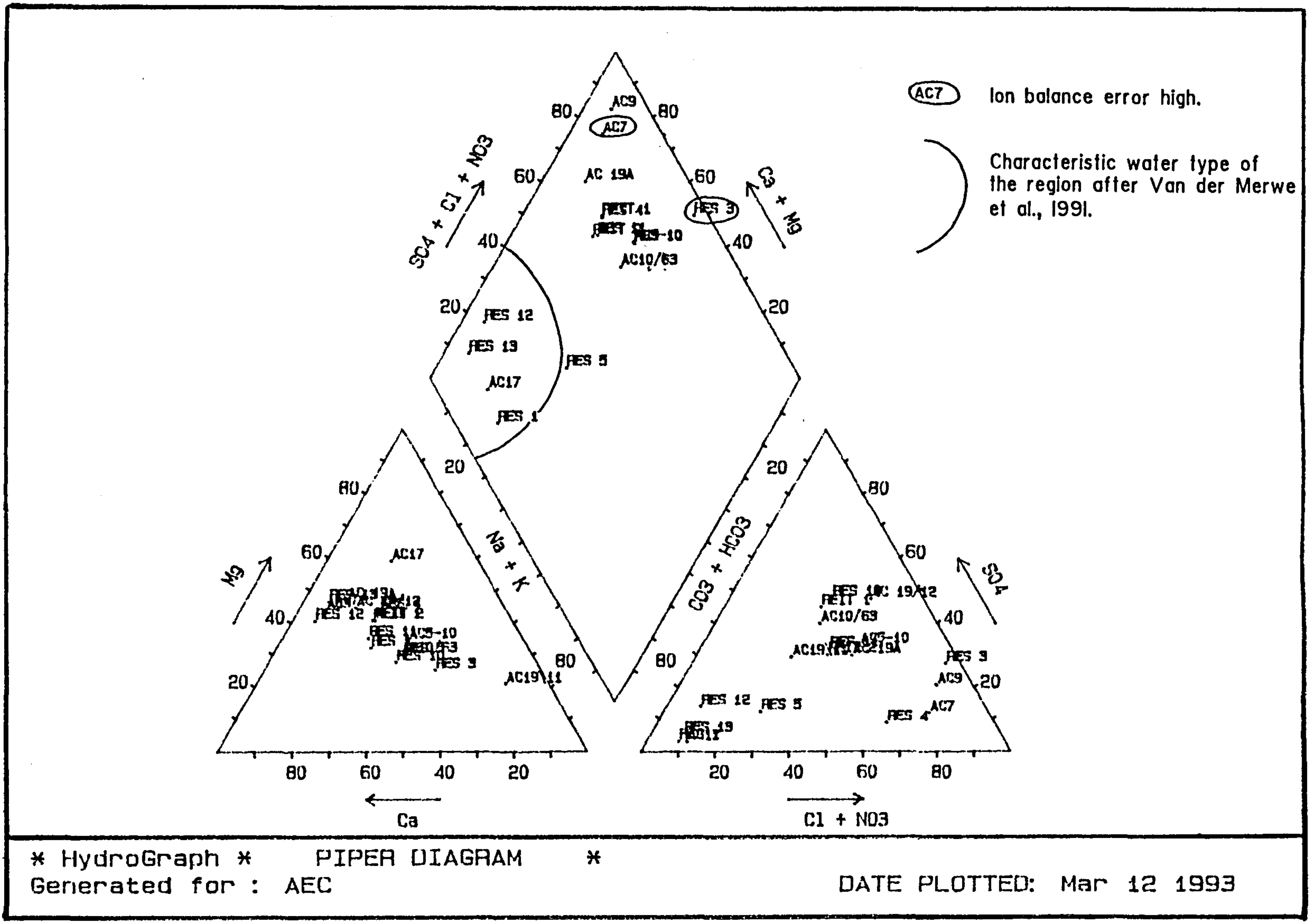


Figure 8. Piper diagram showing groundwater characteristics within the Elspark/Rondebult area - 1992



AC7 Ion balance error high.

Characteristic water type of the region after Van der Merwe et al., 1991.

* HydroGraph * PIPER DIAGRAM *
Generated for : AEC
DATE PLOTTED: Mar 12 1993

4.4 Hydrogeochemistry

4.4.1 Groundwater characteristics

Figures 7 and 8 are the Piper diagrams produced using data from 1984/86 and 1992 respectively. The boreholes sampled in 1984 were sampled again in 1992 and are included in Figure 8. The relative positions, and hence the temporal changes in chemical characteristics of these repeat samples, will be discussed in Section 4.1.4.4

Table 3 gives the groundwater chemistry of all the boreholes sampled in the hydrocensus carried out in June 1992 in the Elspark/Rondebult area. Table 2 gives the groundwater chemistry of boreholes sampled between 1984 and 1986 within the same area - after Simonis 1989.

Approximately 66% of the boreholes included in the hydrocensus fall outside the area typical of the regional groundwater as depicted by a Piper diagram. All these samples have elevated NO_3 and/or SO_4 levels (Table 3). In many cases the NO_3 levels are above that recommended for drinking purposes. The lack of data points prohibited the computation of hydrochemical contour maps for SO_4 and NO_3. The areal distribution of the levels of these elements are given in Figures 9 and 10 respectively.

Table 2. Groundwater Chemistry of Elspark/Rondebult Area - 1984 to 1986

Map Ref Number	Water Level (m)	pH	EC (mS/m)	HCO_3	Cl	SO_4	NO_3	F	Na	K	Ca	Mg
2628AC 9	10.35	7.3	68	128	165	313	34	0.7	31	2.7	145	84
2628AC 10-63	7.1	7.8	71	185	132	435	6	below detection	130	10.4	81	66
2628AC 5-10	13.80	7.8	74	210	154	340	21.1	below detection	90	3,2	131	82
2628AC 19A	1.1	7.5	126	183	193	1 013	8.4	0.1	94	7	230	143

*All elements in mg/ℓ unless otherwise stated

4.4.2 Surface water and effluent

A surface water sample (SW 2) was taken from the Natalspruit, its chemistry being given in Table 3. The high NO_3 content found in the groundwater does not seem to be present in the surface drainage water, although a relatively high SO_4 and fluoride content is noticeable. The elevated iron content may be associated with the runoff water from the storage depots and steelworks located in the suburb of Wadeville. High NO_3 levels are not found in the effluents released

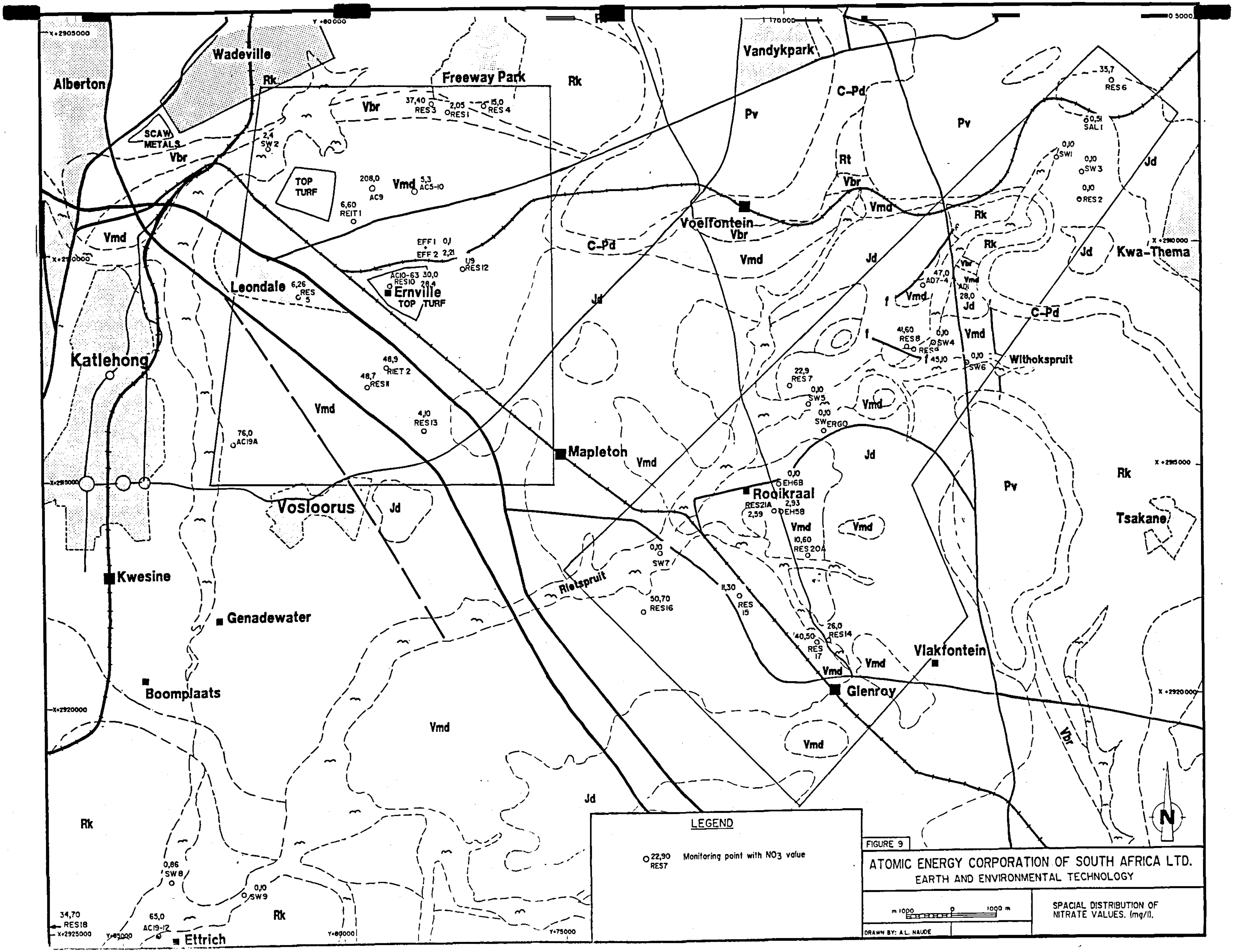


FIGURE 9

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SPACIAL DISTRIBUTION OF NITRATE VALUES. (mg/l).

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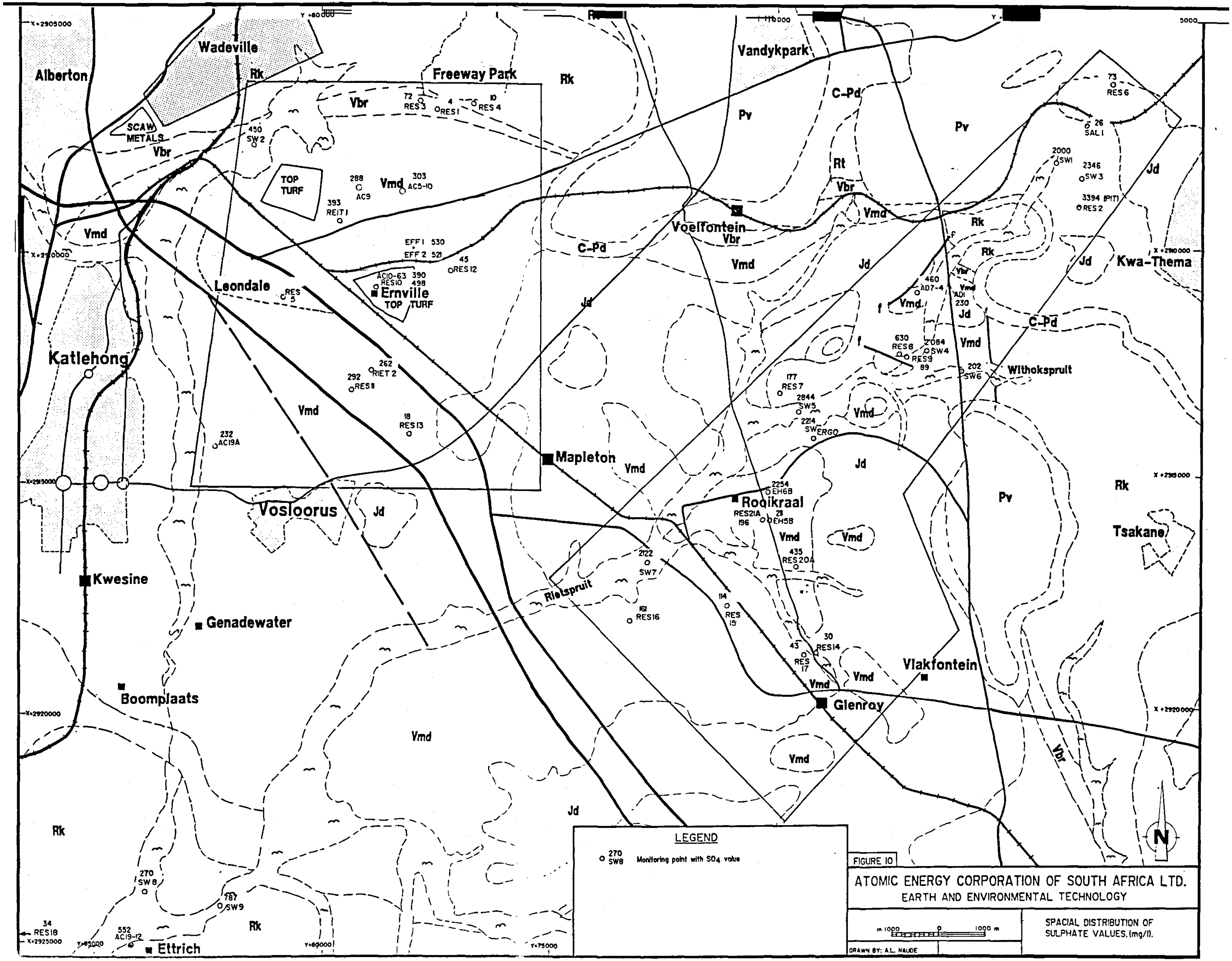


FIGURE 10

ATOMIC ENERGY CORPORATION OF SOUTH AFRICA LTD.
EARTH AND ENVIRONMENTAL TECHNOLOGY

SPACIAL DISTRIBUTION OF SULPHATE VALUES.(mg/l).

DRAWN BY: A.L. NAUDE

from the sewage farm at the time of sampling. Spillages of untreated sewage however do occur from time to time during the daily operation of the farm. This would release water with a higher NO_3 content on an irregular basis. The effluent does, however, have relatively elevated levels of fluoride which cannot be traced in the groundwater of the area.

4.4.3 Groundwater quality and its relation to landuse

Most boreholes lie outside the area on the Piper diagram representing typical dolomitic groundwater (Figure 7). Those showing no signs of pollution include RES 1, 5, 12 and 13 and AC 17. The remaining samples all show distinct deviation from the regional groundwater characteristics.

Water sample RES 4 was taken from the Alberton Formation of the Klipriversberg Group and so deviation from the typical regional dolomitic groundwater is to be expected. Water sample RES 3 has an unacceptably high ion balance error and so the validity of this sample is in doubt, the same applies to sample AC 7.

The majority of sampled boreholes within the region show that ionic change has taken place. This is most probably representative of an ongoing pollution process. Most show elevated NO_3 levels with the exception of RES 10 which also shows elevated SO_4 levels and RIET 1 which shows elevated SO_4 levels only. The distribution of NO_3 values is given in Figure 9 and SO_4 values in Figure 10. The distribution of elevated NO_3 and SO_4 levels are similar in both historical sampling runs and at present. High NO_3 levels are found throughout the area mainly underlying the agricultural sections, but not in the vicinity of the residential areas. With the type of distribution seen in Figures 9 and 10, it is apparent that NO_3 and SO_4 occurrence takes the form of diffuse pollution. Point sources can also be identified and include the introduction of fertilizers within restricted areas, livestock and even close proximity to a cemetery.

4.4.4 Temporal variation

Figures 7 and 8 together with Tables 2 and 3 highlight the changes that have occurred between 1984 and 1992. Pollution has been ongoing for a considerable length of time. The samples taken during the period 1984 to 1986 already indicated elevated NO_3 and SO_4 levels. All boreholes show a significant increase in the NO_3 level whereas SO_4 levels are improving slightly. Fluoride levels have remained similar. Nitrates are therefore still being introduced to the system.

Table 3. Groundwater Chemistry of the Elspark/Rondebult Area - June 1992

Map Ref Number	pH	EC (mS/m)	HCO_3 mg/ℓ	Cl mg/ℓ	SO_4 mg/ℓ	NO_3 mg/ℓ	P mg/ℓ	F mg/ℓ	Si mg/ℓ	Na mg/ℓ	K mg/ℓ	Ca mg/ℓ	Mg mg/ℓ	Fe mg/ℓ	Cu mg/ℓ	Ni mg/ℓ	Pb mg/ℓ	Zn mg/ℓ
EFF 1	7.6	157	242	116	530	<0.1	0.26	7.50	7.88	165	17.5	127	47.0	<0.1	<0.1	0.38	0.007	<0.1
EFF 2	7.4	176	282	98.2	521	2.21	2.50	7.75	9.00	157	19.2	123	48.0	1.25	<0.1	0.22	0.010	<0.1
RES 1	7.0	28	145	2.64	3.77	2.05	0.26	0.18	8.82	8.46	1.19	12.9	6.34	21.4	<0.1	<0.1	0.003	<0.1
RES 3	5.5	27	13	39.4	71.5	37.4	0.21	0.11	7.40	22.7	1.41	13.0	6.69	0.22	<0.1	0.10	0.003	<0.1
RES 4	6.4	16	41	12.9	9.48	15.0	0.04	0.07	11.5	5.87	0.80	9.21	6.91	<0.1	<0.1	<0.1	0.0001	<0.1
RES 5	6.3	30	105	9.85	17.1	6.26	0.37	0.23	25.4	9.09	25.8	21.4	11.1	0.34	<0.1	<0.1	0.005	<0.1
RES 10	6.9	177	322	141	498	28.4	0.12	0.11	11.9	150	12	153	68.2	<0.1	<0.1	<0.1	0.004	<0.1
RES 11	7.0	148	383	113	292	48.7	0.12	0.10	13.5	84	4	137	71.4	<0.1	<0.1	<0.1	0.002	<0.1
RES 12	7.4	58	315	18.7	45.0	1.19	0.07	0.09	8.02	9	1.5	80.2	36.8	<0.1	<0.1	<0.1	0.001	<0.1
RES 13	7.3	61	364	11.5	17.7	4.10	0.11	0.11	12.7	8.85	1.32	61.2	37.2	<0.1	<0.1	<0.1	0.0001	<0.1
RIET 1	6.4	140	320	152	393	6.6	0.28	0.10	17.2	87.3	2.89	139	90.5	<0.1	<0.1	<0.1	0.001	<0.1
RIET 2	6.4	122	379	102	262	48.9	0.15	0.09	14.5	74.0	3.75	114	76.1	<0.1	<0.1	<0.1	0.003	<0.1
SW 2	6.8	173	328	144	450	2.40	2.05	3.57	7.55	195	16	133	40.2	1.05	<0.1	<0.1	0.004	<0.1

4.5 Isotope Studies

Isotope analyses were carried out on 3 water samples collected within the area. The objectives of the isotope study were to obtain an estimate of the vulnerability of the aquifer to pollution and to establish an isotopic signal of the water that infiltrates into the groundwater system. This would enable a better understanding of the method of the ongoing pollution process.

Analyses were carried out by the Schonland Research Centre for Nuclear Sciences.

The high tritium values (Table 4) found within the area indicate that the groundwater system is relatively young, at least in the upper section. The aquifer is therefore prone to pollution due to the active recharge taking place. Insufficient boreholes were sampled to comment on the recharge mechanism of the aquifer, but indications are the recharge takes place over the whole aquifer.

Figure 11 shows δD values plotted against $\delta^{18}O$ for all points in both areas under investigation. The points lie on two distinct lines, one of which is the meteoric water line, the other being the evaporation line for these particular areas. The slope of the evaporation line is peculiar to a specific area as it is dependent upon the climate, especially average humidity. Water samples that plot along this line have been subjected to evaporation and the water samples within the Elspark/Rondebult area lie along this line. Recharge, at least in these local areas, is therefore not only limited to direct rainfall. Other sources must include infiltration from surface water bodies such as rivers or lakes, together with leaking mains water pipes and water used for irrigation. The most probable main contributor to recharge other than direct rain infiltration is irrigation water. It is practiced extensively as part of the intensive market gardening carried out within the area. The heavy isotopic signal of the water samples may be caused by the addition of effluent from the sewage plant which itself has an extremely heavy signal. This effluent used for both irrigation and for supporting the vlei area of the bird sanctuary. Another possible cause of the heavy isotopic signal may be the recycling of groundwater during the irrigation process.

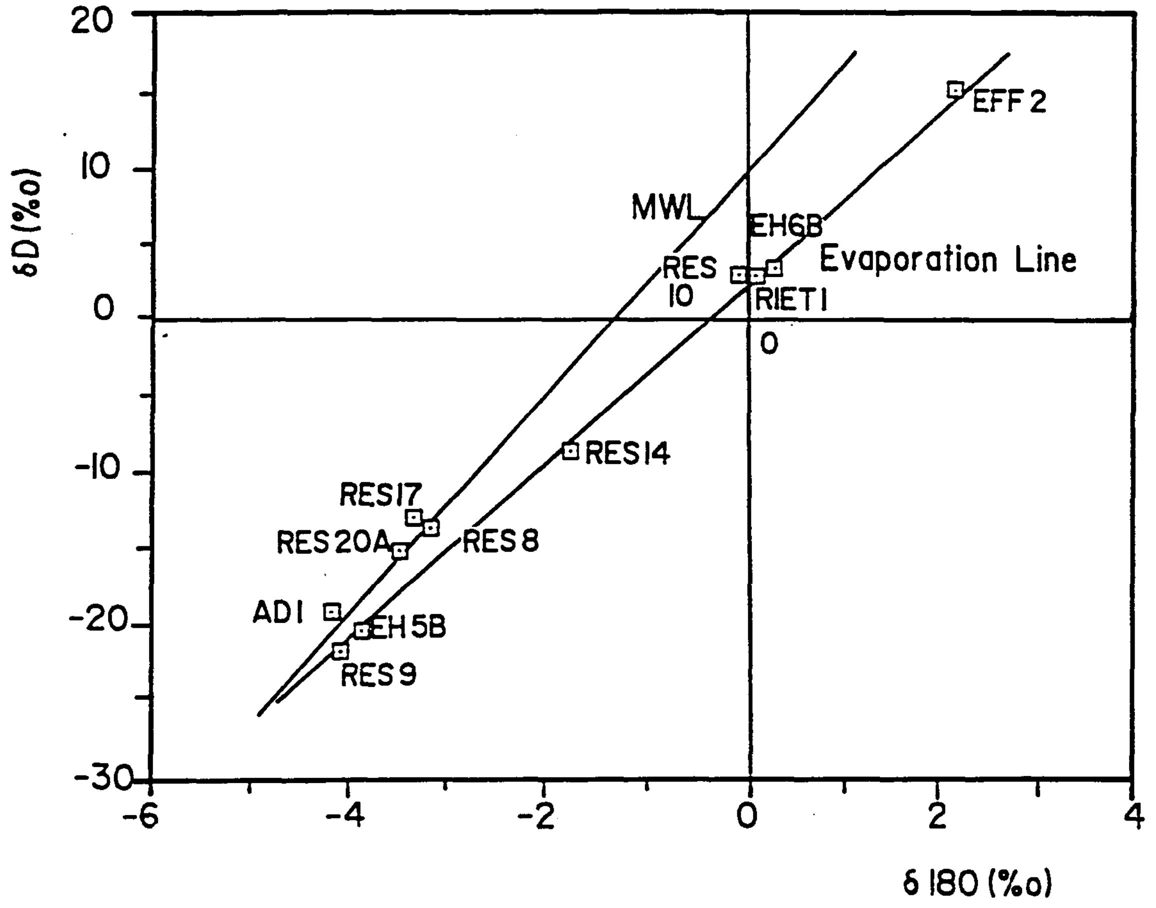
Table 4. **Isotope data for Selected Boreholes in Both Study Areas**

Sample No	3H (TU)	$\delta^{18}O$ (‰)	δD (‰)
RES 17		-3.31±0.15	-13.2±1,5
RES 8	3.9±0.3	-3.31	-13.9
RES 20A	1.8±0.2	-3.44	-15.5
RES 14	5.4±0.4	-1.74	- 8.7
RES 10	5.7±0.4	+0.11	+ 2.8
RES 9	1.1±0.2	-4.07	-22.8
EFF 2	6.2±0.4	+2.17	+15.1
AD 1	3.2±0.4	-4.17	-19.4
EH 58	0.8±0.3	-3.86	-20.6
RIET 1	4,4	-0.07	+ 2.8
EH 6B(2)		+0.29	+ 3.4

4.6 Discussion and Model of Ongoing Pollution

Most of the land as stated in Section 4.1.2 is used for agricultural practices. Intensive cultivation of vegetable crops being the most dominant. A turf producing company also uses a large proportion of the area for the growing of turf. The use of fertilizers and effluent from the sewage farm are the two most probable causes of the high nitrate content within the groundwater. Effluent is used by the turf company for irrigation, but is only applied to the land to the north of the sewage plant. The lands owned by Top Turf to the south-west use borehole water only. Effluent is also channelled to a vlei area designated as a bird sanctuary just to the north-west of the sewage farm, close to the Van Dyk road, (Figure 6), and is also used on the land immediately adjacent to the sewage farm for the cultivation of cattle fodder. However, the chemical analyses of the effluent gives a relatively low NO_3 content, suggesting that the nitrate is introduced via the application of fertilizers. Accidental spillages of sewage would not contribute significant amounts of NO_3 into the groundwater system. The high fluoride associated with the effluent is not noticeable within the groundwater, this again supports that NO_3 could be introduced via fertilizer application.

No mining activity or tailings dams are present within close proximity to the area and so it is highly unlikely that the elevated SO_4 levels are associated with the runoff and/or seepage from this type of industry.



δD (%o) US $\delta^{18}O$(%o) for selected water samples.

FIGURE 11

Taking both hydrogeochemical data and isotopic data into consideration, a tentative model regarding the process of pollution in this area can be outlined.

The nitrates have been introduced into the system relatively recently. The fact that the nitrate concentration is increasing indicates that the introduction of nitrates is an ongoing process, and will continue if farming practices remain the same. Higher sulphate and nitrate concentrations are found in the more rural regions of the area, and the fact that high sulphate is usually found in conjunction with high nitrate in samples within the agricultural region, may indicate that the method by which these elements enter the system are similar. There is only one exception, this being RIET 1 which has a high SO_4 and a low NO_3 content.

The residential areas have lower concentrations of both elements with the occasional high nitrate level. This indicates that pollution is a result of agricultural practices rather than general urban pollution. Point source pollution however is taking place within the residential areas, water sample RES 3 has an elevated nitrate level, the cause of which is not apparent. The areal variation in nitrate and sulphate levels throughout the area indicate diffuse pollution rather than a point source type.

The isotopic signal of the groundwater indicates that the groundwater system is relatively young and therefore is vulnerable to pollution. The heavy $\delta^{18}O$ signal suggests that a considerable proportion of the recharge to the system is via irrigation, at least to the upper layers within the aquifer, and that the irrigation process leads to recycling of the groundwater. This in turn is leading to a concentration of nitrate, especially as more fertilizer is added to the system annually and washed through the unsaturated zone with water already possessing a high nitrate level.

It does not appear that the effluent used for irrigation and environmental purposes is contributing to the high nitrate or SO_4 level. RIET 1 has a high sulphate level and is located in the area where sewage effluent is used for both irrigation and to maintain the vlei area for the bird sanctuary. From Table 3 it can be seen that the effluent does have a relatively high sulphate content, but other boreholes located in areas where effluent is not used also show high sulphate levels.

If the input mechanism for nitrates is as described above, then the pollution situation will definitely worsen unless control measures are taken on the use of fertilizers.

5 RIETSPRUIT/ERGO AREA

5.1 Geology and Physiography

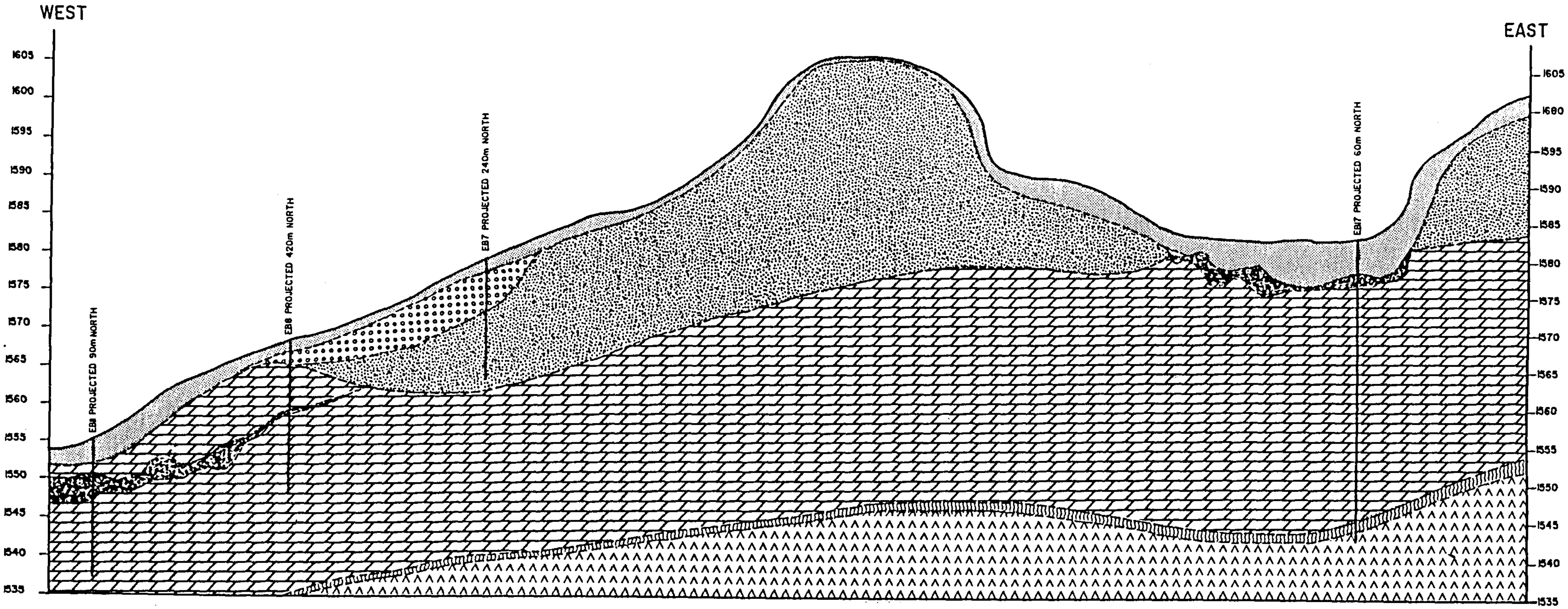
The area lies within the same synclinal structure as the Elspark/Rondebult area. Much of the region is overlain by post Karoo doleritic intrusions. There are no major structural geological features, only three faults are located in the upper reaches of the Withokspruit (Figure 6). Thin alluvial deposits overlay both dolomite and intrusives.

Detailed geological information in the Ergo tailings dam area was made available by the company WLPU. Figure 12 provides a geological cross-section across the dam from west to east, and shows that the tailings sit mainly on hard fine grained dolerite underlain by westerly dipping Monte Christo and Oaktree dolomite formations of the Malmani Subgroup. There are isolated areas where a thin layer of soil reaching a maximum of 6 m, sits directly on a thin layer of wad underlain by dolomite. Down-hole video recording into the dolomite revealed joint widths of between 5 and 20 mm, most of which had been infilled. Wad deposits were also present along with many minor cavities, the majority of which occurred between 12 and 19 m. Only one major cavity was identified, and sinkhole development was not encountered. Permeability values of the weathered dolomite were high, between 10^{-1} and 10^{-2}, and 10^{-4} m/s for fresh dolomite. Borehole EB 11 is shown on the western side of the cross section, and represents the same geological conditions as found in the sampled borehole EH 6B, located approximately 15 m towards the west.

5.2 Landuse

Figure 6 shows landuse within the area investigated. A large proportion of the land is covered by tailings dams of which some are at present being reworked. Sallies Mine is located in the northern section and which is in the process of closing down. The mine, because of its great depth, was chosen to dewater all the mines located to the north, by means of continuous pumping. In the early 1970's, 28 Mℓ/d was being pumped and the water table was locally lowered to 2 000 m, this depth being recorded in 1976. The water table is still recovering at a rate of 0,5 m/d following cessation of pumping. The water that was extracted from the mine was pumped to the adjacent Ergo plant, to be used in the reworking process to extract gold. Sludge was then transported by pipeline to the tailings dam.

Natural vlei areas are present along the course of the Withokspruit and Rietspruit, and dams have been constructed by farmers to provide water for various farming practices. Most of the land used for agriculture is left natural for livestock grazing, however there is an area shown on Figure 6 where intensive dairy farming is carried out. The farm uses borehole water (RES 16), but supplements its supply with river water for irrigation of maize crops. Surface water sample SW 7 would be representative of the water used for irrigation at this particular locality.



WEST-EAST GEOLOGICAL SECTION

HORIZONTAL SCALE 1:10 000

FIGURE 12

LEGEND

▒ SOIL

▒ DOLERITE . . . . POST KAROO DOLERITE INTRUSIVES

⁘ CHERT RESIDIUM ROOIHOOGTE

▤ DOLOMITE } MONTE CHRISTO AND OAKTREE FORMATIONS } MALMANI SUBGROUP } TRANSVAAL SEQUENCE

▓ WAD

▥ BLACK REEF QUARTZITE

⋀⋀ VENTERSDORP LAVA . . . . . VENTERSDORP SUPERGROUP

5.3 Hydrogeology

The hydrogeology of the region can only be discussed in general terms due to the limited availability of boreholes within the study area.

The dolomites in the area of the Ergo tailings dam dip towards the west, and the topography also generally slopes in this direction towards the Rietspruit. This, together with limited waterlevel data indicates groundwater flow to be in a westerly direction. Surface runoff is likely to occur and drain both in a westerly direction towards the Rietspruit, and a northerly direction towards the Withokspruit. There is evidence to suggest that there are two groundwater systems, a more confined deeper aquifer overlain by a more dynamic system. Boreholes RES 21(A) and EH 5B are artesian, the latter having a flow rate of approximately 0.27 ℓ/s. Isotopic measurements also indicate the existence of 2 separate groundwater systems. This will be discussed further in Section 4.2.5.

Water level data also provides evidence for the existence of two separate groundwater systems. Two boreholes are located in the vicinity of RES 21(A) (Figure 6), one of which is artesian, the other has a water level 16 m below surface. The distance between the boreholes is approximately 200 m and the difference in water levels cannot be attributed to topographic variations.

The degree of mixing of groundwater of both systems is not known. More extensive studies would have to be done to comment on this aspect of the hydrogeology.

5.4 Hydrogeochemistry

5.4.1 Groundwater characteristics

The determination of the regional groundwater characteristics is described in Section 4.4.1. Figure 13 shows the groundwater characteristics of the Rietspruit/Ergo area. All boreholes are located in the dolomite formation, one or two may have penetrated dolerite in their upper sections and may therefore show contamination from this formation producing a slightly different water type. These boreholes include RES 7, RES 8 and AD 1. SAL 1 is water typical of the younger Karoo deposits within the north-eastern part of the study area. With RES 14 being the only exception, all the groundwater samples fall outside the area on the Piper diagram representative of the regional groundwater chemistry. Most water samples show an elevated SO_4 level and in some cases NO_3 level, but the latter can be attributed to farming practices within the immediate vicinity of the borehole. This is discussed in more detail in Section 4.4.3. All groundwater chemistry for the area is given in Table 5.

Figure 13. Piper diagram showing groundwater characteristics within the Rietspruit/Ergo area - 1992

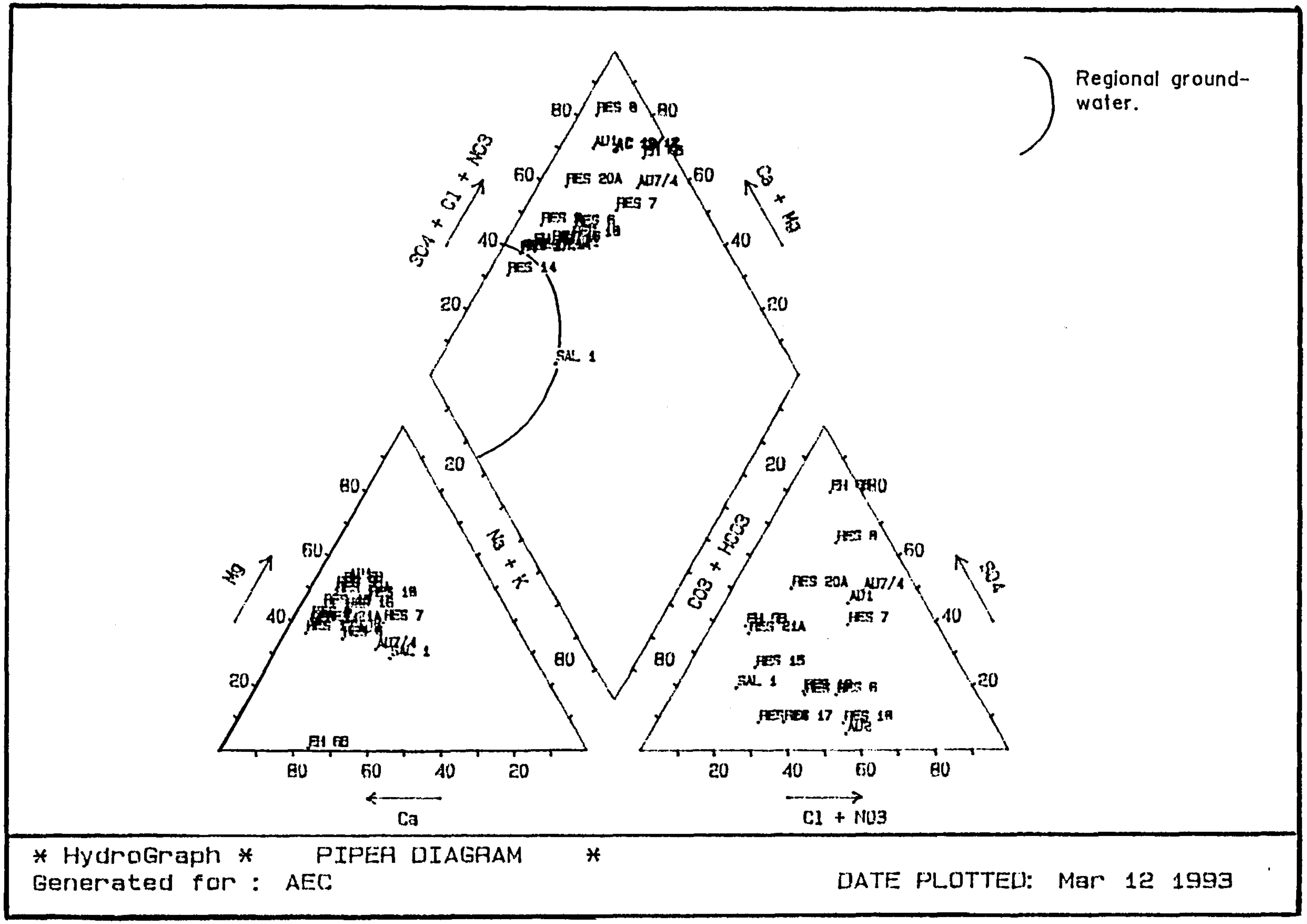


Table 5. Groundwater Chemistry of the Rietspruit/Ergo Area - 1992

Sample No	pH	EC mS/m	HCO_3 mg/ℓ	Cl mg/ℓ	SO_4 mg/ℓ	NO_3 mg/ℓ	P mg/ℓ	F mg/ℓ	Si mg/ℓ	Na mg/ℓ	K mg/ℓ	Ca mg/ℓ	Mg mg/ℓ	Fe mg/ℓ	Cu mg/ℓ	Ni mg/ℓ	Pb mg/ℓ	Zn mg/ℓ
RES 2	7.2	509	115	501	3 394	<0.1	0.04	0.31	9.18	401	29.9	495	515	1.03	<0.1	<0.1	0.025	<0.1
RES 6	6.3	61	202	48	73	35.7	0.18	0.13	29.6	17	11	63	27	0.68	0.13	<0.1	0.008	2.51
RES 7	9.6	109	138	65	177	22.9	0.18	0.71	26.7	169	17.5	227	153	8.37	<0.1	0.48	0.011	0.18
RES 8	7.0	144	184	48	630	41.6	0.11	0.09	30.6	17.6	3.69	215	98	0.21	<0.1	<0.1	0.007	0.11
RES 9	7.4	79	307	24	89	45.1	0.14	0.23	29.3	11	3.2	73	51	0.14	<0.1	<0.1	0.005	0.10
RES 14	7.4	53	283	7	30	26.0	0.18	0.10	17.5	6.8	0.9	71	30	0.19	<0.1	<0.1	0.001	<0.1
RES 15	7.2	78	314	32	114	11.3	0.09	0.12	15.5	11.3	2.53	72	50	<0.1	<0.1	<0.1	0.0	<0.1
RES 16	7.0	152	517	99	161	50.7	0.09	0.10	17.7	44.0	7.31	150	90	<0.1	<0.1	<0.1	0.001	<0.1
RES 17	7.2	70	362	26	43	40.5	0.09	0.09	15.3	8.47	2.94	102	39	0.22	<0.1	<0.1	0.002	0.15
RES 18	7.4	55	207	63	34	34.7	0.09	0.09	24.0	22.7	2.89	46	36	<0.1	<0.1	0.14	0.001	<0.1
RES 20A	7.5	108	376	77	435	10.6	0.28	0.13	16.5	27	2.4	152	100	0.13	<0.1	<0.1	0.005	0.46
RES 21A	7.6	97	360	39	196	2.59	0.13	0.12	11.8	15	2.4	82	38	<0.1	<0.1	<0.1	0.015	<0.1
EH 5B	7.6	111	361	31	211	2.93	0.13	0.16	12.9	21.1	2.92	102	78	0.98	<0.1	<0.1	0.0002	0.11
EH 6B1	7.2	413	340	252	2 337	<0.1	0.38	0.08	24.4	183	10.6	533	329	7.68	<0.1	<0.1	0.022	<0.1
EH 6B2	7.1	420	307	242	2 254	<0.1	0.22	0.08	17.3	183	9.80	524	3	1.40	<0.1	0.20	0.022	<0.1
SAL 1	7.8	30	109	15	26	0.51	0.07	0.18	1.08	14	4.58	18	8	0.15	<0.1	<0.1	0.005	0.12
SW 1	7.6	358	110	187	2 000	<0.1	0.86	0.60	3.26	192	47.3	668	62	0.81	3.39	8.80	0.019	<0.1
SW 3	4.6	406	1	224	2 346	<0.1	1.13	0.07	13.3	283	44	585	115	35.5	0.39	<0.1	0.020	0.90
SW 4	5.4	395	7	297	2 084	<0.1	0.16	0.16	20.0	267	45	519	139	0.26	0.19	21.4	0.021	14.5

Sample No	pH	EC mS/m	HCO_3 mg/ℓ	Cl mg/ℓ	SO_4 mg/ℓ	NO_3 mg/ℓ	P mg/ℓ	F mg/ℓ	Si mg/ℓ	Na mg/ℓ	K mg/ℓ	Ca mg/ℓ	Mg mg/ℓ	Fe mg/ℓ	Cu mg/ℓ	Ni mg/ℓ	Pb mg/ℓ	Zn mg/ℓ
SW 5	8.1	426	112	327	2 844	<0.1	0.40	0.26	8.10	278	38	599	333	1.12	<0.1	0.50	0.020	<0.1
SW 6	7.7	94	296	18	202	<0.1	0.02	0.36	11.8	45	8.6	95	37	1.76	<0.1	<0.1	0.003	<0.1
SW 7	7.0	389	193	286	2 122	<0.1	0.20	0.33	4.68	182	20.6	506	288	<0.1	<0.1	1.04	0.020	0.27
SW 8	7.6	119	154	117	270	0.86	3.67	0.41	6.87	100	15.5	81	30	0.30	<0.1	<0.1	0.004	<0.1
SW 9	7.8	160	243	124	787	<0.1	0.12	0.23	3.19	59	20	208	130	0.49	<0.1	0.25	0.008	<0.1
SW 10	7.5	125	148	114	300	1.58	2.79	0.44	6.87	97	13.5	111	67	0.51	<0.1	<0.1	0.003	<0.1
SW ERGO	6.2	365	268	242	2 214	<0.1	0.42	0.23	17.0	200	25	460	198	11.9	<0.1	0.26	0.014	<0.1
AD 1	6.7	80	134	54	230	28	0.38	0.08	-	17	1.85	71	58	<0.01	-	-	-	<0.1

The position on the Piper diagram (Figure 13) of the group of water samples obtained in 1992 falls just outside that typical of a dolomitic environment is most probably a reflection of the age of the groundwater. Migration to this position suggests that the groundwater is slightly older and the groundwater regime less dynamic.

5.4.2 Surface water and effluent

Surface water samples were taken at various localities in the Withokspruit and the Rietspruit (Figure 6) into which runoff water from the tailings dam at the Ergo plant and the new tailings dam flow. All effluents have an extremely high SO_4 content, as have the surface water samples, especially those in the upper reaches of the Rietspruit. Further downstream SO_4 levels are generally lower. Elevated trace elements are also detected, those effluents originating from Sallies Mine and Ergo plant contain high nickel, copper and iron, while that originating from the new tailings dam has only an elevated iron content. Low pH values are associated with both the effluent samples (SW 3 and SW ERGO - Table 5), explaining the presence of iron still in solution.

5.5 Isotope Studies

The same objectives for the isotope studies apply to this area as described in Section 4.1.5.

Tritium levels in the majority of the samples are lower than in the Elspark/Rondebult area indicating that the groundwater regime is slightly older and less dynamic. Water sample RES 14 is an exception to the rule, the high tritium content can be attributed to the fact that the borehole is situated next to a dam on a small ephemeral surface drainage. Recharge to this shallow hole is therefore partly from runoff, and partly from infiltration of the dam water. The heavier $\delta^{18}O$ value supports this. The variation in tritium levels is small ranging from 0.8 TU for the artesian hole EH 5B, to 3,2 TU for borehole AD 1. These values do not include anomalous boreholes such as RES 14, RES 8 and EH 6B. The reason for the anomaly of RES 14 has been given previously and the mechanism of recharge of RES 8 is not known. From field measurements, the borehole from which water sample EH 6B2 was taken is only 4.70 m deep, with a waterlevel of 1.80 m below surface. The heavy isotopic signal associated with this water sample may be a result of overland flow seeping into the borehole. Alternatively, water may have infiltrated from open water bodies on the tailings dam, and flowed as part of an very shallow groundwater system, in a westerly direction, following a layer of decomposed dolomite (Figure 12). The borehole was pumped for 45 minutes at 0.2 ℓ/s, and so the standing water in the borehole was removed. The water sample could then be considered as a true reflection of the water quality of the supposed "perched" water table or upper section of the aquifer within the dolomitic formation. The evidence provided by the isotope data, such as higher tritium levels and a greater concentration of ^{18}O, favour this model.

The tritium values when correlated with sulphate levels do suggest that both the shallow groundwater system in the near vicinity of the tailings dam (EH 6B2) and the deeper, slightly older system (RES 20A) are contaminated. The borehole log of RES 20A is not available and it is possible that the wad layer found in EB 11 (situated next to EH 6B), may extend to RES 20A. Contamination from the upper section of the dolomite may thus be possible. However, the tritium level and the position on the $\delta D‰$ vs $\delta^{18}O‰$ plot (Figure 11) does not indicate an appreciable amount of mixing with younger water, or the water with a heavier $\delta^{18}O$ signal typical of borehole EH 6B.

5.6 Discussion and Model of Ongoing Pollution

It is probable that the high sulphate level in the effluents or runoff from the tailings dams are causing elevated sulphate levels in the surface water within the drainage system. Sulphates may also be associated with the dolerite intrusions within the area over which the surface drainage runs. However, in some cases the high SO_4 occurs with elevated nickel and/or iron, which suggests that the SO_4 is associated with the runoff coming from the Ergo plant and tailings dam (Table 4). The runoff from Sallies/Ergo area does not comply with the guidelines laid by the Department of Water Affairs in respect to the elements iron and copper. Iron is also above the recommended limit in the runoff from the new Ergo tailings dam.

High NO_3 levels found in certain ground water samples is not thought to be associated with any pollution entering from the surface drainage system. No elevated NO_3 levels were measured in any of the surface water samples. It can therefore be assumed that higher NO_3 values are a result of diffuse pollution related to specific agricultural practices.

Water sample RES 8 is taken from a deep borehole, approximately 130 m in depth with the main water strike at 120 m; this also being the pump installation depth. It has a very high NO_3 and SO_4 level. With the available data, this anomaly cannot be explained. Tritium levels suggest this water to be of fairly recent age and the $\delta^{18}O$ (‰) value indicates that recharge is mainly from rainfall (Section 4.5, Figure 11). It is possible that the recharge to this borehole is to some extent facilitated by the fault situated just to be south-west of the borehole. The fault cuts the surface drainage channel which may allow surface water to infiltrate into the fault zone. Water sample SW 4 taken from the river at a nearby locality also has a very high SO_4 together with a high zinc and nickel value. The trace elements however were not detected in the borehole and the $\delta^{18}O$ value would have been more positive for such a situation. This causes an element of doubt into this mode of recharge. It would therefore seem more probable the high NO_3 and SO_4 levels are associated with surface water contamination within the immediate vicinity of the borehole, or seepage water from varying geological formations intercepted within the borehole.

Boreholes within the immediate vicinity of the new Ergo tailings dam on the western border (RES 20A, EH 5B) are showing signs of pollution, with elevated levels of sulphate, iron, zinc and in one case nickel (Table 5). Shallow borehole EH 6B indicates pollution is definitely taking place in the upper portion of the aquifer and deeper borehole, RES 20A, suggests that pollution is more widespread both spatially and vertically.

There is no strong evidence to support the theory that widespread pollution is taking place within this area. Sulphate levels are generally elevated and so identification of pollution above the background levels is extremely difficult. There are however very high sulphate levels within the area which do indicate point source pollution. The same applies to nitrate levels which also are generally elevated throughout the area. There are higher nitrate values but these are randomly distributed and can be attributed to agricultural practices within the immediate vicinity of the borehole. Six of the groundwater samples have levels above the minimum value recommended for drinking water, two of which are above the medium value. Again, extremely low nitrate levels are found in the surface water samples, therefore nitrate pollution via infiltration of river water is not feasible.

This theory also applies in the case of sulphate pollution. The runoff coming from the Sallies/Ergo area in the north-east of the region is extremely high in sulphate, copper, iron and nickel. That coming from the new Ergo tailings dam had only a high iron and sulphate content. The concentration of all these elements such as iron, nickel and sulphate in the river water generally decreases downstream, indicating that these two areas may be a point source of pollution as far as surface water is concerned. If contamination was taking place from the surface drainages, the elements found in the runoff and within the river water would be detected in the groundwater samples, especially in those close to the rivers. However, very few elevated levels of trace elements were detected except in boreholes near the new Ergo tailings dam. Evidence therefore again suggests that pollution of the groundwater is via point sources, in particular the new Ergo tailings dam. A knowledge of the spatial and vertical extent of which cannot be ascertained due to the lack of data points.

Natural isotope data does not clearly define the two groundwater systems. This is due to the lack of data points. Indications are, that the two systems do not differ greatly in age, and that their existence is therefore most probably due to geological circumstance, i.e. semi-confinement between dolerite sills or between dolerite sill and Ventersdorp Lava. Artesian conditions may therefore be a very local phenomena. Only more data points would clarify this assumption.

Isotope studies have identified the aquifer as being vulnerable to pollution, but the method by which this pollution is taking place is not apparent due to the lack of information.

6 TERNARY MAPPING

Background

Hydrogeochemical data have traditionally been presented as kriged or interpolated contour maps or just as point values for a specific element or parameter. The ratio between two elements or their values normalized to concentration could also be presented in this way.

After studying the ternary (three-component) radioelement mapping method described by Broome *et al.* (1987) it was decided to apply the method to hydrogeochemical data. The initial image produced in this way for a dolomitic area, using the HCO_3, SO_4 and Cl values showed that it could be an effective method for displaying in a single image ratio, information for the three parameters. The potential for mapping pollution of SO_4 and Cl in a HCO_3-dominated environment such as a dolomite area, was realized and a research proposal to study the usefulness of this technique was presented to the Water Research Commission (WRC). This aspect was conveniently incorporated into the project investigating pollution of the dolomitic aquifers.

6.1 Map Generation Procedure

The ternary hydrogeochemical map (Fig 14) is produced on an ink-jet plotter by using different ink colours to represent the HCO_3, SO_4 and Cl concentrations. In this example cyan is used for HCO_3, yellow for SO_4 and magenta for Cl. At any location the relative concentrations of the three parameters are represented by the colour hue produced by mixing appropriate amounts of the three ink colours. For example, equal proportions of the three parameters would produce an orange colour on the image.

Since a distinct colour hue is used to represent each ternary ratio on the map, zones with similar ratios will be represented by a unique colour. This distinct relationship between colour hue and ternary ratio allows the map to represent the parameter concentration distribution better than any contour map of one parameter only or the ratio between two parameters.

The parameter concentrations are first normalized to ensure they fall in the same numerical range. In order to do this the highest value for each parameter is taken as one and all the other values are scaled accordingly. The relative concentrations for each element are then quantified as a percentage of the sum of the three concentrations.

It is clear that the density of data points may present problems with coverage of values over an area. In order to overcome this problem, interpolated maps of the three parameters are produced from the dot maps (Figs 15, 16 and 17) as shown in Figs 18, 19 and 20. Continuous data coverage now exists for each parameter over the whole area. The reliability of the data still depends, however, upon the density of initial data points.

The final image consists of pixels (small squares) for which values were calculated. The size of the pixel can vary to represent smaller or larger areas on the map. The more data points and the more reliable the data, the smaller can be the selection of the pixel size representing an area on the map.

6.2 Ternary Map Interpretation

To allow the plotted colours to be related to absolute ratio values, the relative calculated levels are used to produce the ternary diagram shown in Fig 14. Since the relative concentration of each parameter varies from 0 to 100 percent on the legend, approximate ratios can be determined by matching the hue of mapped colours with those on the legend.

6.3 Ternary Maps from the Project Area

In addition to the interpolated maps for HCO_3, SO_4 and Cl shown in Figs 18 to 20, interpolated maps were also produced for NO_3, Ca, Mg, and SiO_2. With the interpolated maps available, ternary maps with any combination of these chemical parameters can now be produced. The ternary maps produced have to be interpreted taking into consideration the geology and the pollution sources in the area, as discussed previously.

6.3.1 Anion combinations

Bicarbonate is the dominant anion in unpolluted dolomitic groundwater and the first ternary maps produced were those with HCO_3 as one of the parameters. Two combinations show the pollution distribution best, namely:

$HCO_3 : Cl : SO_4$ and
$HCO_3 : Cl : NO_3$

(a) $HCO_3 : Cl : SO_4$

This image was one of the initial ones which showed the potential for the technique, as SO_4 and Cl anomalies stood out in the HCO_3 dominated background as illustrated in Figure 14. The general geology of the area is depicted in Figure 21 and a transparency thereof is superimposed on Figure 14 to facilitate interpretation.

SO_4 pollution is apparent at the Ergo tailings dams, Knights and Sallies mines and in the western part of the Kathlahong-Vosloorus area where it could also be due to urban pollution such as ash or sanitary waste disposal. South of Vosloorus but off the dolomites is another area showing SO_4 pollution associated also with higher Cl levels. This in the vicinity of the confluence of three drainage tributaries. As previously reported (4.4.2) the surface water does show higher SO_4 levels. The Cl dominated area east of Vlakfontein is based on the analyses from two boreholes and the source is considered to be mainly agricultural and suspected to be due to poor conditions around stock watering points.

(b) $HCO_3 : Cl : NO_3$

This image is depicted in Figure 22 and it is interesting to note that the sulphate pollution from the mines does not show associated Cl or NO_3. East of Wadeville and east of Vlakfontein the Cl anomalies of Figure 14 have become mixed with NO_3, indicating a sewage or manure source of pollution. The yellowish-greenish tint of areas within the dolomites with no associated Cl may be defuse pollution from agricultural practices using fertilizers.

(c) $NO_3 : Cl : SO_4$

This ternary map (Figure 23) illustrates the complexity of the chemical matrix of different groundwater sources. The anionic composition of the groundwater varies considerably over short distances. The dominance of SO_4 in the Knights and Ergo area is again highlighted. Except for one borehole, Cl does not dominate the water on its own but rather combines with the other two ions.

6.3.2 Cation combinations

Cation combinations performed involved mainly Ca and Mg, and the following combinations serve to illustrate their usefulness:

$SiO_2 : Ca : Mg$
$HCO_3 : Ca : Mg$

(a) $SiO_2 : Ca : Mg$

The Ca/Mg character of the dolomite is illustrated in Figure 24 by this combination while the more siliceous character of the surrounding terrain of shales, lavas and quartzites is evident. Critical to outlining lithostratigraphic units is sufficient borehole density and the presence of unpolluted groundwater.

(b) $HCO_3 : Ca : Mg$

The image illustrated in Figure 25 shows the colour hue of the three colours combined. One would expect equal percentages of the three parameters (normalized values) in the groundwater such as shown in Figure 25. The surrounding rock types show deviation from this ratio and the pattern that emerges is similar to that in Figure 24.

FIGURE 14

TERNARY MAPPING – PWV POLLUTION STUDY

HCO3:Cl:SO4

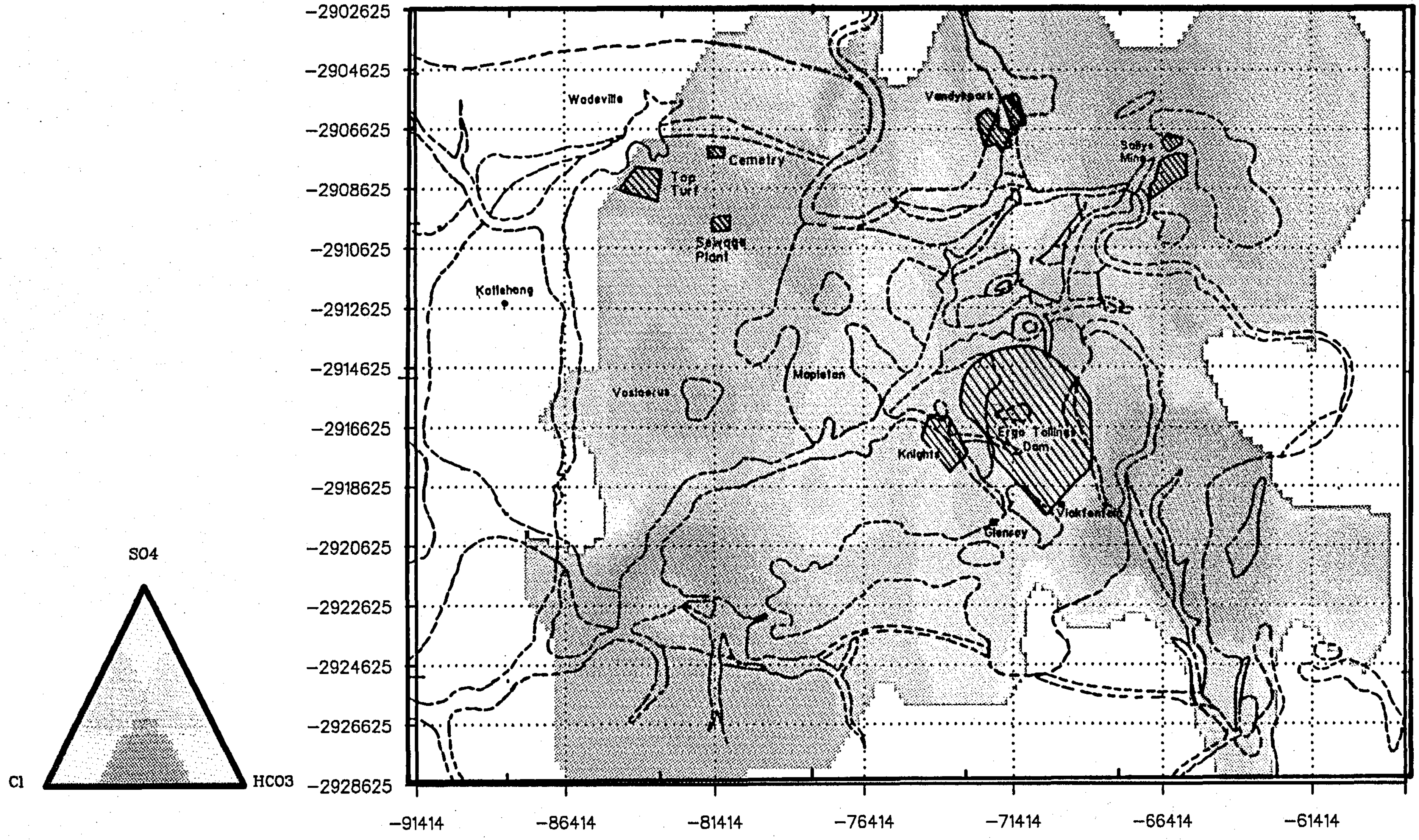


FIGURE 15

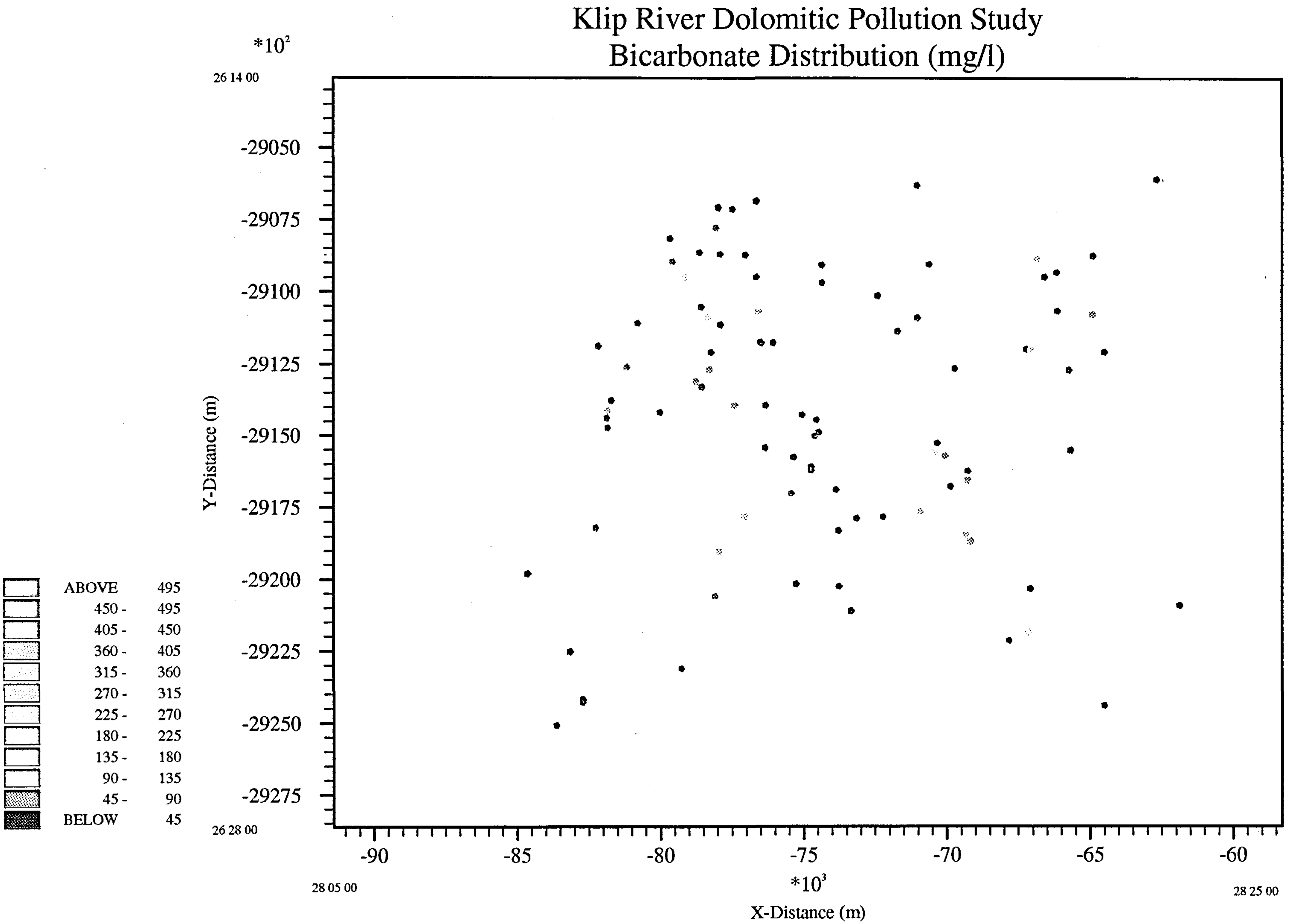

Klip River Dolomitic Pollution Study
Bicarbonate Distribution (mg/l)
*10²
26 14 00
-29050
-29075
-29100
-29125
-29150
-29175
-29200
-29225
-29250
-29275
26 28 00
Y-Distance (m)
-90
-85
-80
-75
-70
-65
-60
*10³
X-Distance (m)
28 05 00
28 25 00
ABOVE 495
450 - 495
405 - 450
360 - 405
315 - 360
270 - 315
225 - 270
180 - 225
135 - 180
90 - 135
45 - 90
BELOW 45

FIGURE 16

Klip River Dolomitic Pollution Study
Sulphate Distribution (mg/l)

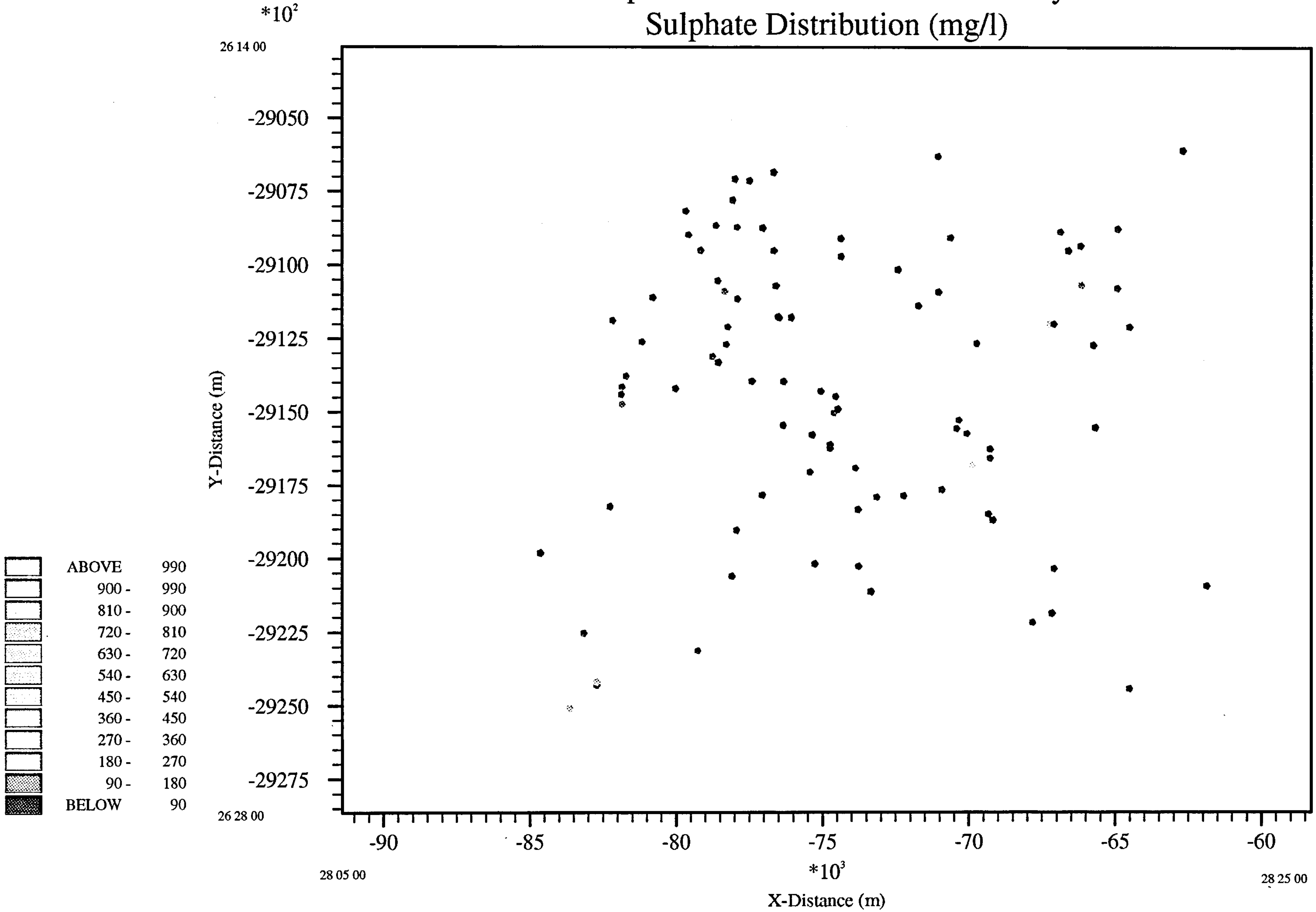


FIGURE 17

Klip River Dolomitic Pollution Study
Chloride Distribution (mg/l)

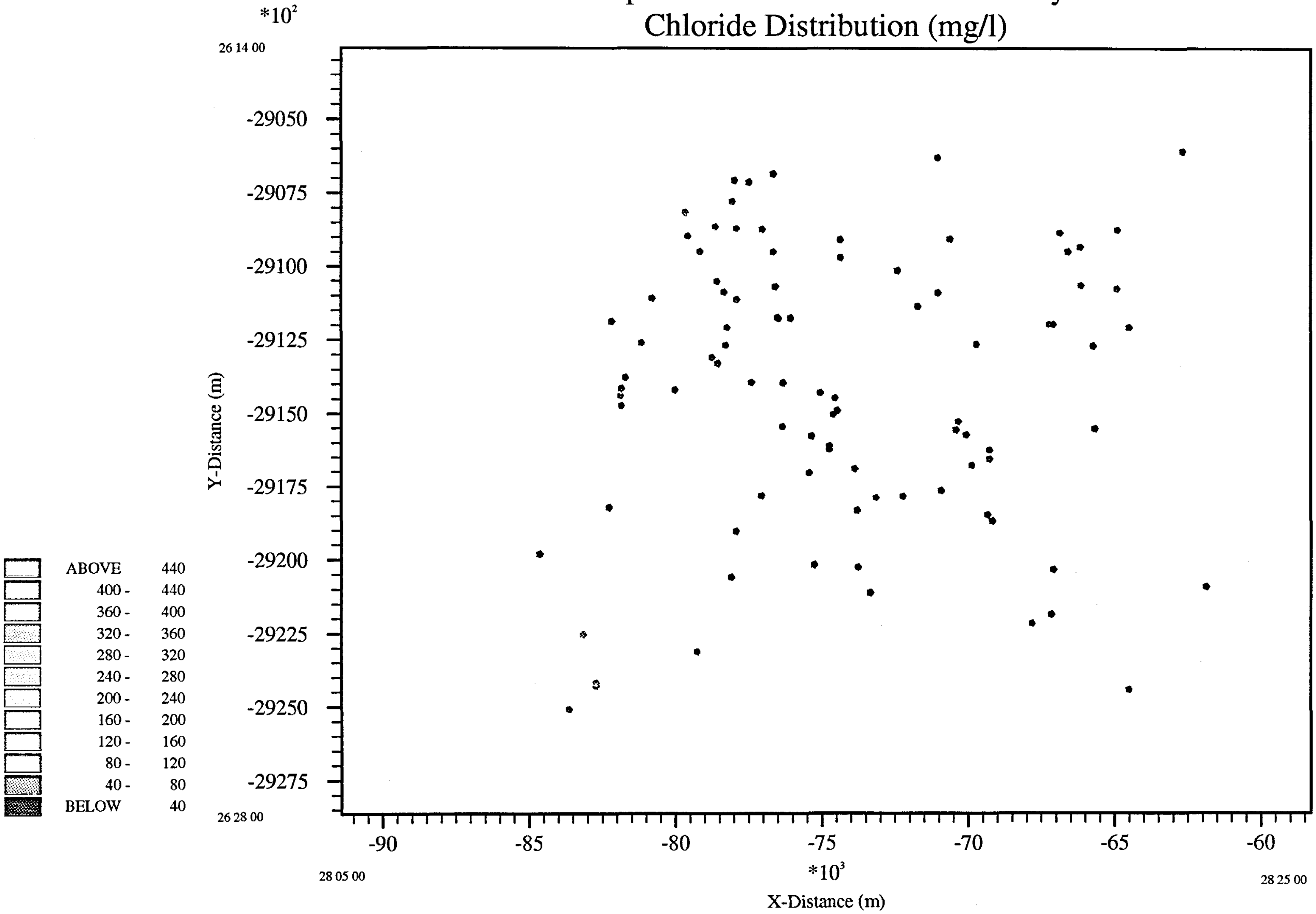
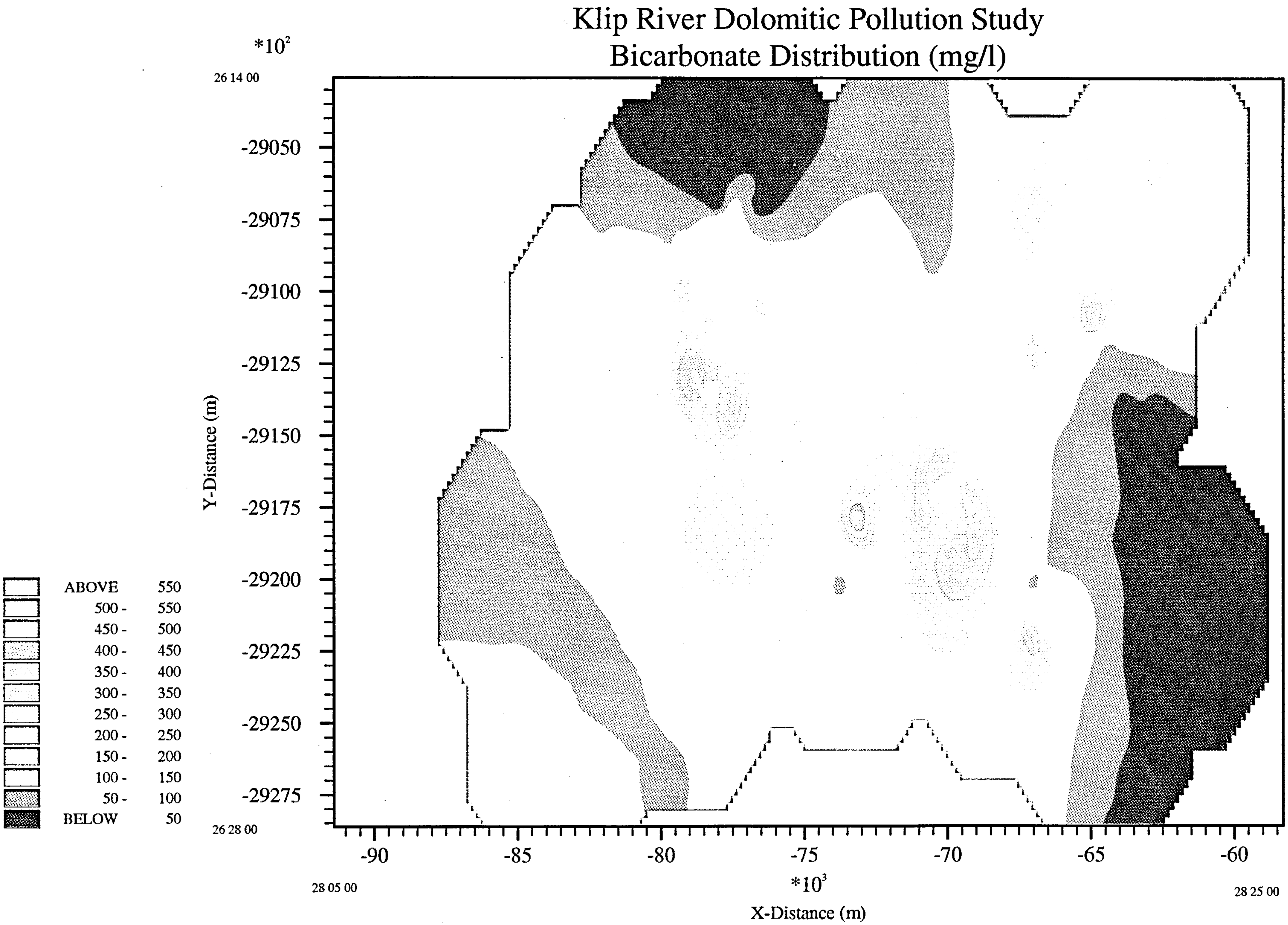


FIGURE 18



Klip River Dolomitic Pollution Study
Bicarbonate Distribution (mg/l)

FIGURE 19

Klip River Dolomitic Pollution Study
Sulphate Distribution (mg/l)

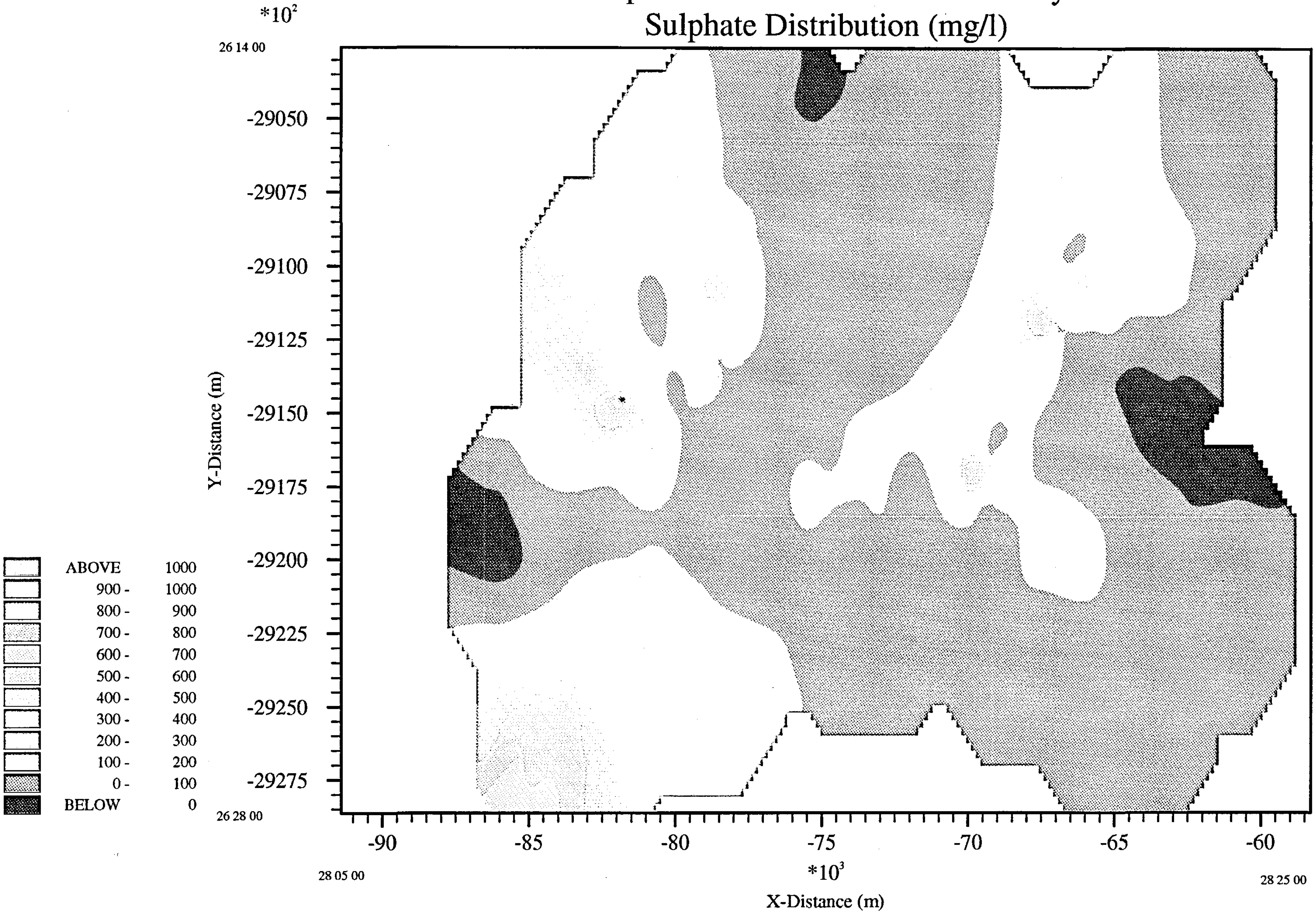
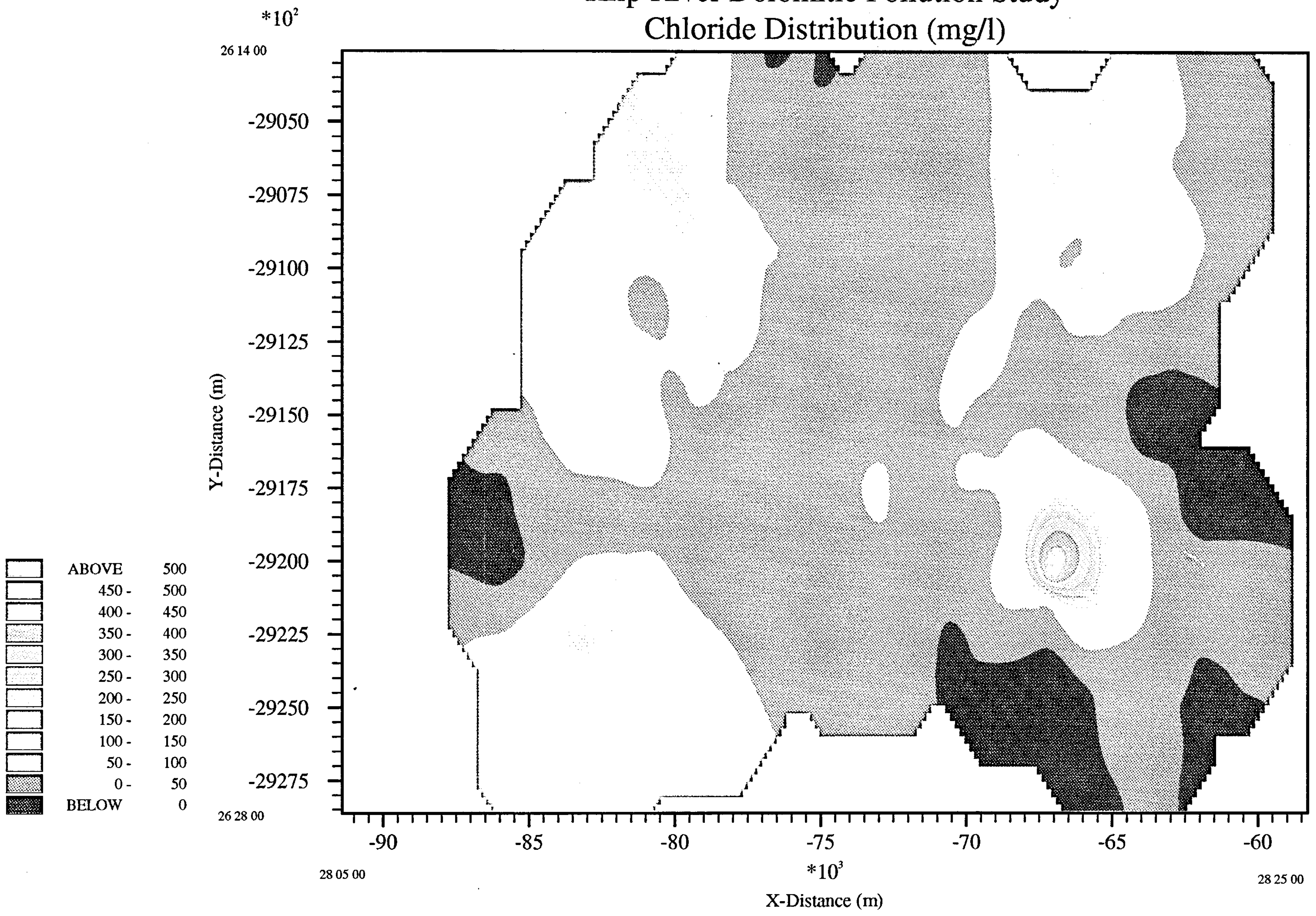


FIGURE 20

Klip River Dolomitic Pollution Study
Chloride Distribution (mg/l)



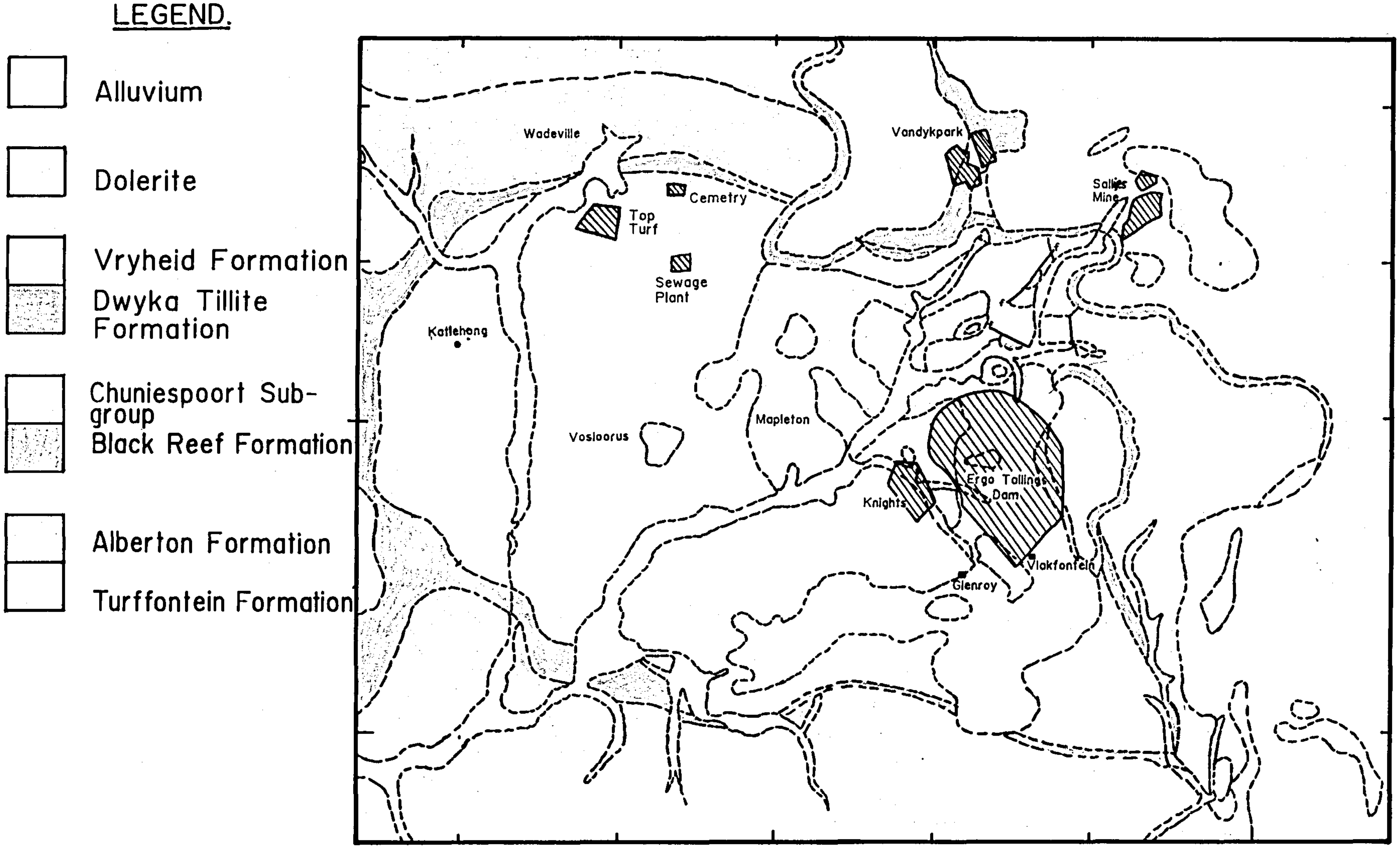


FIGURE 21

GEOLOGICAL MAP OF THE AREA IMAGED.

FIGURE 22

TERNARY MAPPING – PWV POLLUTION STUDY

HC03:Cl:N03

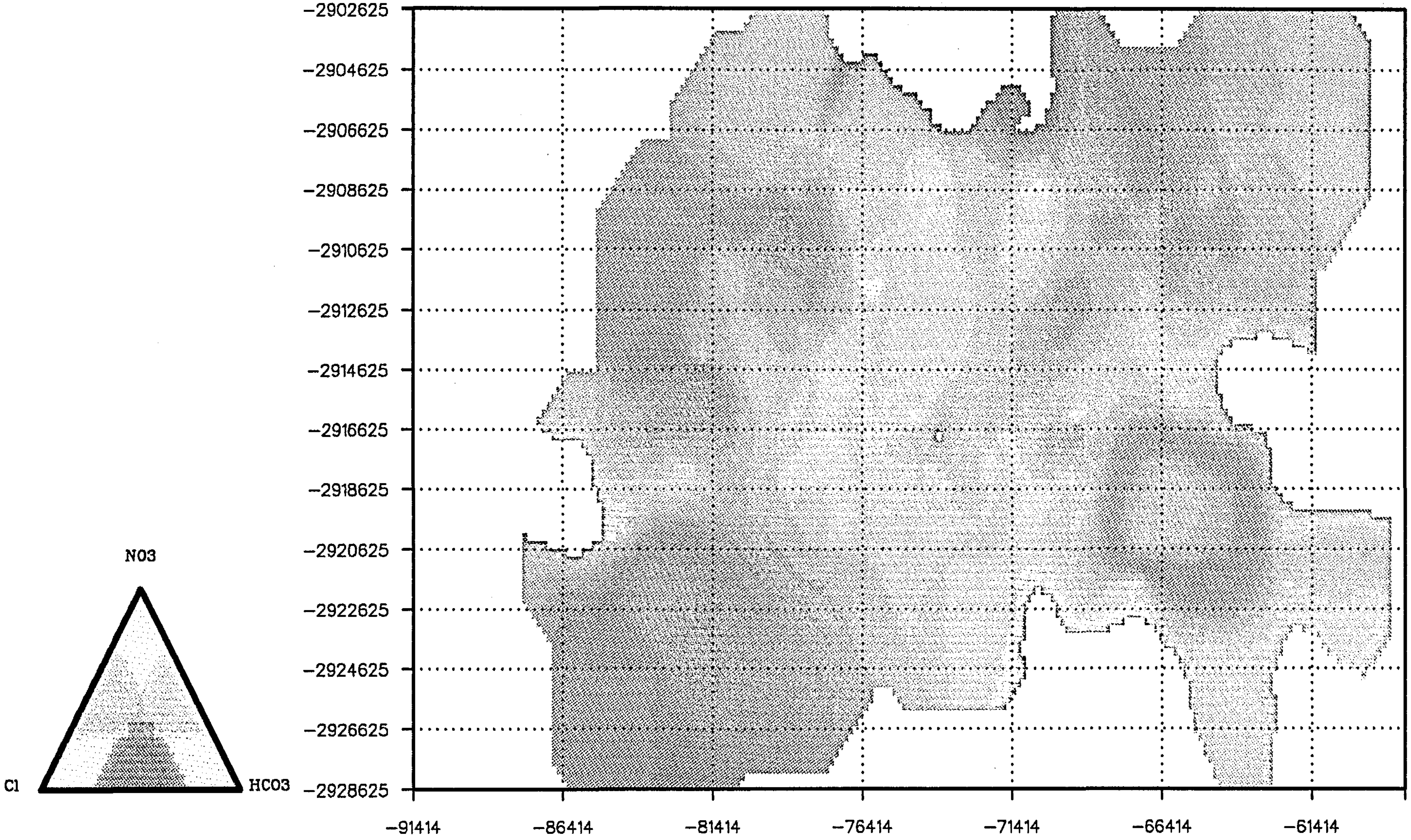


FIGURE 23

TERNARY MAPPING – PWV POLLUTION STUDY

N03:Cl:S04

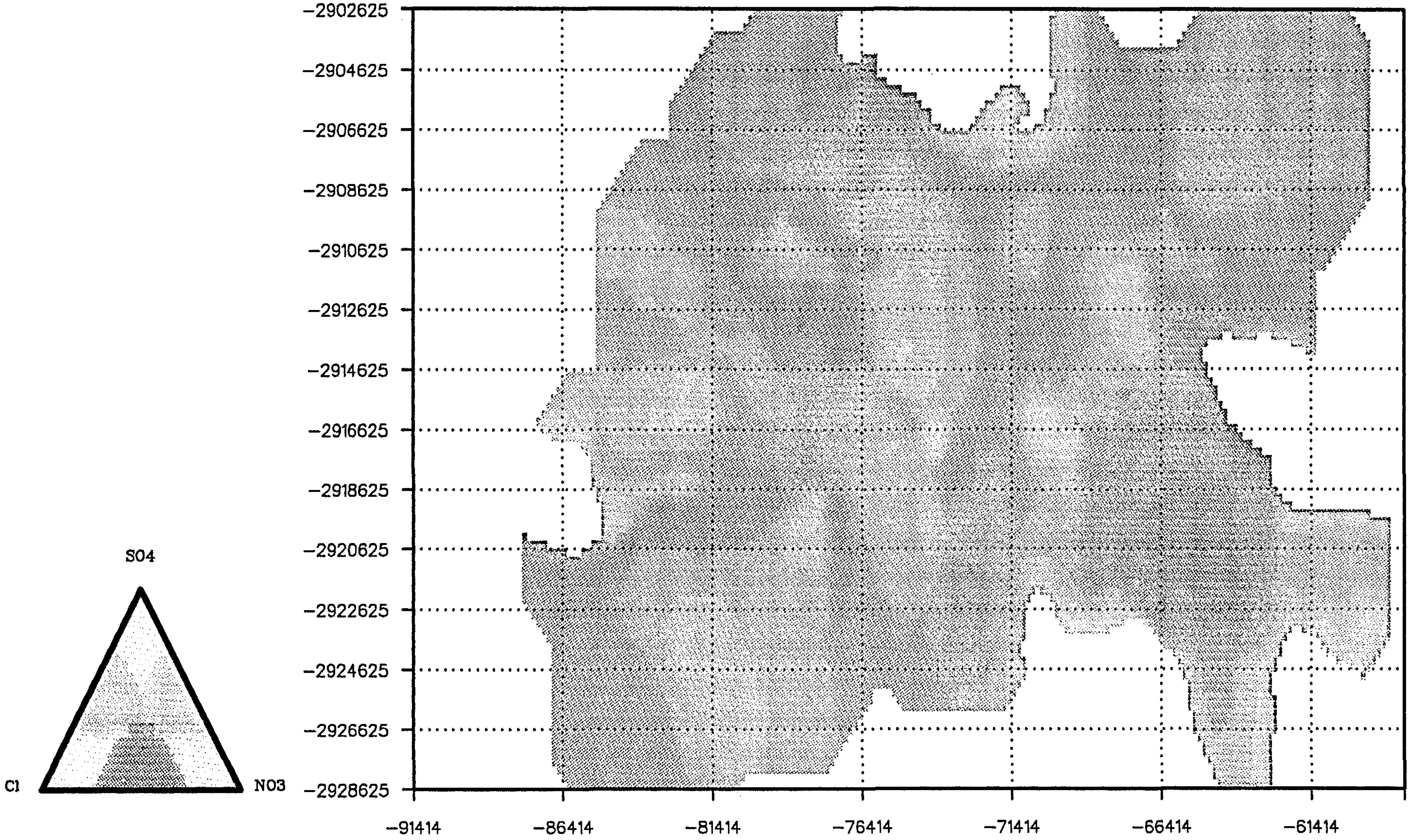
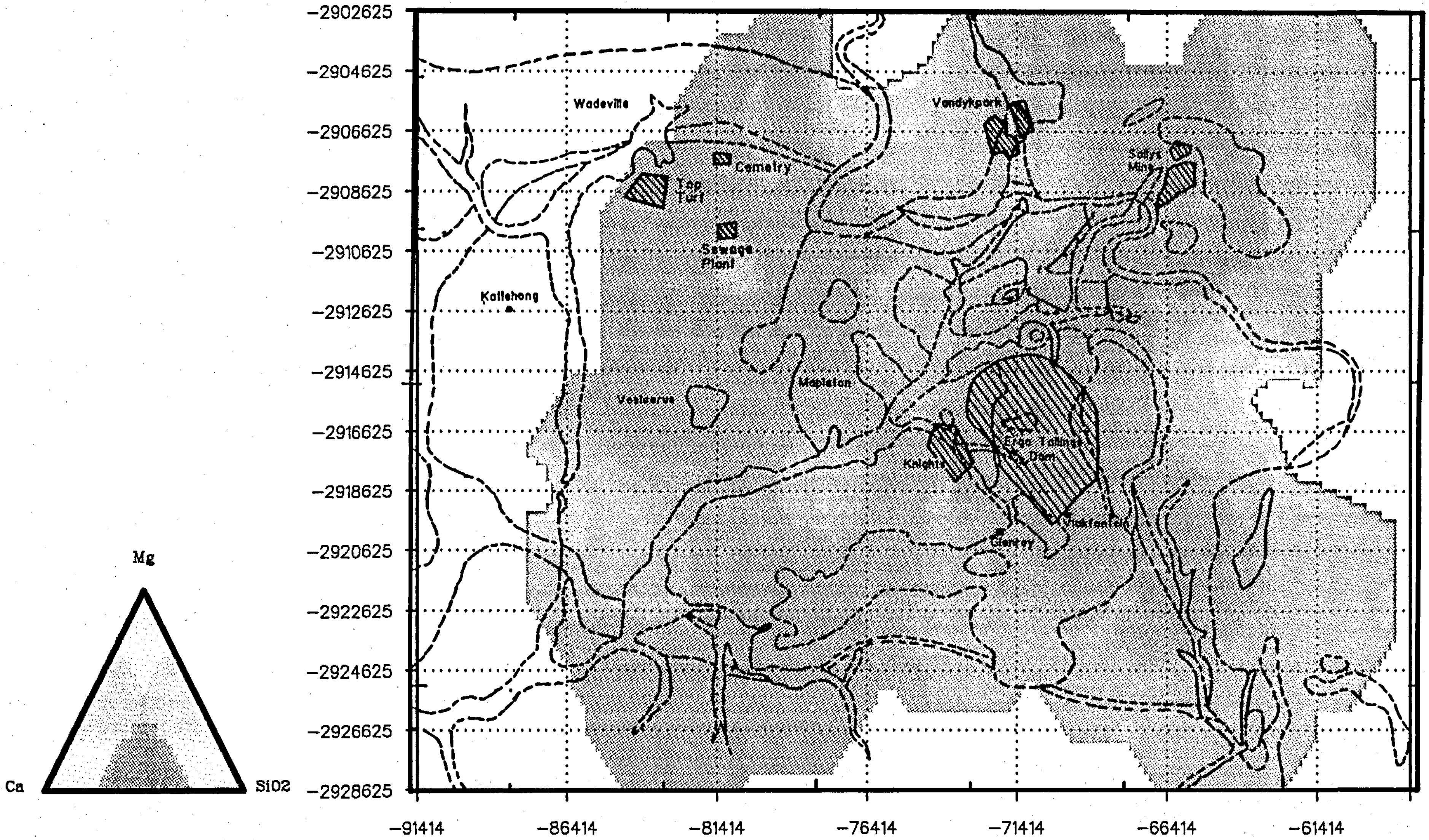


FIGURE 24

TERNARY MAPPING - PWV POLLUTION STUDY

SiO2:Ca:Mg



7 CONCLUSIONS

7.1 General

Problems encountered in the initial phases of the project highlight the need for boreholes to be properly documented in the form of accurate coordinates, together with a practical field map showing their location. Field identification could also be enhanced by using borehole marking techniques.

More detailed information should be supplied concerning the method of sampling i.e. pumped or bailed, together with information about the frequency of use of the borehole. Information of this sort is particularly important when attempting to compare water analyses for temporal variations in water quality.

The techniques employed during the investigation did determine the vulnerability of the aquifer, and highlight potential pollution areas together with potential sources of pollution. The seriousness of the pollution was gauged, and a reasonable model describing the method of pollution could be applied.

The need for a complete hydrocensus was highlighted during the investigation because of the elevated background levels of certain elements that are considered potential indicators of pollution.

7.2 Elspark/Rondebult Area

Nitrate pollution in this area can be considered a serious problem. In some cases the level of nitrate in the groundwater samples exceeded that recommended for drinking water. The pollution can still be considered as localized at present, but concentrations are increasing. The irrigation process widely used in this area may be containing the pollution, by producing an artificial closed groundwater regime where the water is essentially being recycled.

Isotope techniques proved extremely useful in determining the vulnerability of the aquifer to pollution and in the identification of the method of pollution. It is highly recommended that this methodology be incorporated into subsequent pollution studies.

7.3 Rietspruit/Ergo Area

Groundwater pollution does not appear to be significant. The elevated sulphate level appears to be a regional phenomenon and may be a result of the post Karoo dolerite intrusives and the basal Ventersdorp Lavas. Due to the higher regional concentrations of sulphate, difficulties were encountered in the identification of potentially polluted areas. Relatively elevated sulphate levels were however identified in boreholes located on the western side and within close proximity to the new Ergo tailings dam. The borehole RES 20A has a sulphate level approaching the maximum value allowed in drinking water (i.e. 500 mg/ℓ - Kempster *et al.*, 1980).

The vast majority of surface water samples have a sulphate value greater than that recommended for river or dam water.

Generally nitrate levels appear elevated when compared to values expected for dolomitic aquifers. Some samples such as RES 16 and RES 9 are above the medium allowed for drinking water. These high levels can be attributed to point source pollution, and are related to local conditions around the borehole.

There is insufficient evidence to suggest that pollution is originating from the surface drainages. The only positive indications of pollution is that associated with the new Ergo tailings dam.

Isotope studies assisted in the determination of hydrogeological conditions, but budgetry constraints did not allow for the sampling to be as comprehensive as was needed for this particular situation. However, for future reference, natural isotope studies did prove promising. Had more funds been available, and hence more boreholes and surface water points been sampled, a better understanding of the local artesian conditions would have been gained. A more detailed model of pollution could also then have been given.

The monitoring holes around the new Ergo tailings dam are inadequate. In many cases the diameter of the piezometer tube within the borehole does not allow a meaningful pumped sampled to be taken. In addition to this, the two boreholes that were sampled were totally inadequate as monitoring holes. EG 6B is an extremely shallow hole (± 5 m), whether this was intended, or is a result of borehole collapse is unclear. EH 5B is an open artesian hole and is therefore susceptible to surface pollution. As a result of the investigation it is known that the upper portion of the dolomitic aquifer is heavily polluted; how far this extends vertically into the dolomite is impossible to say. Careful monitoring on the western side of the tailings dam within the dolomite should be carried out, with properly constructed monitoring holes being incorporated into a revised monitoring programme.

7.4 Ternary Mapping

Provided the chemical data are reliable and the data comprise a fair density of sampling points, the following conclusions can be drawn regarding ternary mapping of hydrogeochemical data:

1. Since particular rock types such as the dolomites often have characteristic ratios of three chemical parameters, a map of these ratios is a useful geological tool for highlighting zones of uniform lithology and contacts between contrasting lithologies.

2. More important, however, is the potential to use one or more of the ternary maps of an area to analyse and interpret the presence and character of pollutants in the groundwater.

This technique is still in its infancy and has the potential to be developed further. The potential of using this technique in hydrogeochemical exploration of base metals should also be investigated and researched.

One weakness in the method as compared to the geophysical application, is to incorporate total concentration. This is possible by adding this information to the image by varying the "saturation" of the colours with the concentration. This means the colour hue, which contains the ratio information, remains constant but its "saturation" or scaled intensity (less or more intense) are used to produce a map showing whether anomalies are due to higher concentration or not.

8 RECOMMENDATIONS

It is recommended that when carrying out a pollution study of this kind, certain criteria must be adhered to where possible.

- All available relevant data, past and present, must be incorporated into the study. This will give some understanding of the temporal development of suspected pollution.
- A detailed hydrocensus, including a detailed landuse survey, must be carried out to determine background levels and possible point sources of pollution.
- Detailed natural isotope studies should be included to gain a better understanding of the dynamic hydrogeology i.e. methods of recharge and hence vulnerability of the aquifer. These techniques proved useful in this particular study in identifying possible modes of pollution i.e. how polluted water was entering the groundwater system.

In relation to this particular study, it is recommended that a more comprehensive and functional monitoring system be installed at the new Ergo tailings dam. Pollution has been identified in the dolomitic formation to the west but the extent to which this pollution is taking place both areally and vertically is unknown. The present monitoring system will not provide this information.

Ternary mapping reveals a good potential for mapping pollution provided a fair sampling density exists and the hydrochemical data are reliable. It is recommended that if further development of the technique be considered, then mapping of concentration should be added to enhance the ternary maps.

9 REFERENCES

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