RESEARCH ON THE CONTRIBUTION OF MINE DUMPS TO THE MINERAL POLLUTION LOAD IN THE VAAL BARRAGE

Steffen , Robertson & Kirsten (Pretoria) Ing

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TO THE MINERAL POLLUTION LOAD IN

THE VAAL BARRAGE

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The title of the project was

RESEARCH ON THE CONTRIBUTION OF MINE DUMPS TO THE MINERAL POLLUTION LOAD IN THE VAAL BARRAGE

The Steering Committee for this project consisted of the following persons:

Dr M J Pieterse	Water Research Commission (Chairman)
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EXECUTIVE SUMMARY

An investigation into the problems associated with pollution of the water supply from the Vaal Barrage was initiated by the Water Research Commission (WRC) in 1974. Studies by the Hydrological Research Unit at the University of the Witwatersrand and by the Consulting Engineers Stewart, Sviridov and Oliver indicated that non-point sources, including mine residues, accounted for about 50 % of the pollution load in the Vaal Barrage. The contribution from these non-point sources has previously been estimated by subtracting known point source loads from the total loads measured.

This project was initiated in order to establish the total load of salts contributed by mine deposits to the salt load in the Vaal Barrage and also to identify those deposits which require control methods to prevent pollution.

A tripartite contract was entered into between the WRC, the Department of Water Affairs (DWA) and Steffen, Robertson and Kirsten (Pretoria) Inc (SRK) in August 1983 in order to carry out the investigation. The WRC financed the project, whilst installation and maintenance of instrumentation was carried out by the DWA. SRK provided professional and technical expertise and carried out the investigation.

The method of investigation involved detailed monitoring of three selected mine deposits in the City Deep area. From this detailed study, the source of pollution and the salt load from the study area and from each selected deposit were established. This constituted Phases I and II of the investigation. In Phase III an inventory of mine deposits in the Vaal Barrage catchment was carried out. Each deposit was classified according to a number of physical parameters relating to its pollution potential into a low, medium or high apparent pollution potential category. The total load produced by all mine deposits was then estimated by extrapolating from the loads calculated for the selected deposits in the study area.

The three deposits selected in the City Deep area included a sand dump (3A17), a well-maintained slimes dam (3L44) and a poorly maintained slimes dam (4L4).

Monitoring was continued over three hydrological seasons and the following data were collected:

- continuous measurements of flow and conductivity at four gauging weirs
- water quality samples taken from 13 surface water sampling sites, 12 boreholes and 5 auger holes
- water quality samples taken during five individual storm events.

These data were then processed and analysed and the following parameters were obtained:

- daily and monthly means and annual values of flow and conductivity
- average chemical composition of the surface and ground water
- relationships between continuous conductivity and both total dissolved solids (TDS), and sulphate
- the variation in the chemistry of stream flow during storm events.

The major findings from Phases I and II of the investigation were as follows:

i) The streams in the study area are perennial and are partly fed by ground water since flow was continuous throughout the study period despite prolonged periods without rainfall.

ii) The chemical quality of water upstream from the monitored deposits is good but a marked deterioration in quality occurs in the vicinity of sand dump 3A17. This deterioration which persists into the eastern part of the study area where, however, no further deterioration was observed.

iii) Examination of the variation in water chemistry during storm events showed that direct runoff serves to reduce the salt concentration in the streamflow. Salt loads during storms, however, were greater than would have been the case if only baseflow had occurred. Direct runoff is not considered to be a major contributor of salts to the stream network.

iv) The investigation has shown that seepage from the deposits either directly into the streams, or indirectly via ground water which ultimately feeds the streams, is the probable source of the increased salt load in the baseflow of the stream as it passes the sand dump.

v) The total annual load of dissolved salts exported from the study area may be divided into two components: the contribution from sources upstream of the study sites and the contribution from the study sites alone. In 1985, 2 300 t of dissolved salts were derived from sand dump 3A17 while the slimes dams made negligible contributions to the salt load. Since 3 300 t of the total load were contributed from sources upstream of the study sites, the total annual load of dissolved salts exported from the study area was 5 600 t.

vi) The study had originally been designed on the assumption that runoff from the dumps would prove to be the major source of the salt loads contributed by the mine residue deposits. It has been shown, however, that this source is small and that in the study area the major contributor was seepage to a near surface ground water system which recharges the stream.

During Phase III of the investigation 273 deposits listed by the Chamber of Mines were visited. Excluding small deposits and those that had been reworked, 160 were classified of which 122 are slimes dams and 38 are sand dumps. The parameters used for classification included extent of vegetation, presence of toe dams, volume and surface area, and the pH, conductivity and permeability of the surface material. On the basis of

these parameters each deposit was inspected and sampled and then classified into a low, medium or high apparent pollution potential category. Those deposits with three or more of the following were classified as having a high potential; poor vegetation cover, no toe dam, large volume, low pH, high conductivity and high permeability. A total of 10 sand dumps and 15 slimes dams were classified into the high apparent pollution potential category. this classification allows a priority rating to be assigned to those deposits most urgently requiring remedial measures.

In the extrapolation of results from the detailed study to the whole Vaal Barrage catchment, several simplifying assumptions have been made, the most important being that only sand dumps are considered to contribute to the total load.

Estimations based on the information gathered during this study and on information supplied by the Chamber of Mines of South Africa indicate that approximately 50 000 t/a of salts seep from the sand dumps.

A presently unknown proportion of this emerges as recharge into streams and flows into the Vaal Barrage.

The major conclusions from this investigation were:

i) The mine deposits in the catchment of the Vaal Barrage discharged approximately 50 000 t of salts into the near surface environment in 1985; it is not known what proportion of this is eventually transported by surface streams or ground water to the Vaal Barrage. The 50 000 t of salt originating from these mine deposits can be compared with a total load of salts into the Barrage estimated from other studies of approximately 400 000 Ha.

ii) Direct runoff from the surfaces of the mine residues is not the major source of the high salt concentrations in the streamflow since these high levels exist in the baseflow.

iii) Seepage from the mine deposits into the streams is the probable source of high salt loads.

This investigation has evaluated the transportation of salt loads from mine deposits to streams in the study area and has identified those deposits with a high apparent pollution potential.

It has also highlighted the need for further investigation into, in particular the following:

- the movement of water through and out of mine residues;
- the direction and rate of movement of ground water affected by seepage from mine residue deposits;
- the changes in salt loads in the baseflow of surface streams in the vicinity of mine residue deposits;
- the mechanisms and rates of recovery in the quality of streamflow during its downstream passage towards the Vaal Barrage.

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RESEARCH ON THE CONTRIBUTION OF MINE DUMPS TO THE SALT LOAD IN THE VAAL BARRAGE

1 INTRODUCTION

1.1 Purpose of Investigation

An investigation into the problems associated with pollution of the water supply from the Vaal Barrage was initiated by the Water Research Commission (WRC) in 1974. Studies by the Hydrological Research Unit at the University of the Witwatersrand and by Stewart, Sviridov and Oliver, indicated that non-point sources, which include mine waste deposits, were responsible for about 50 % of the pollution load in the Vaal Barrage.

The purpose of this present study was to evaluate the degree to which runoff and drainage from mine waste deposits contributes to the total dissolved solids load in the Vaal

Barrage and to identify those types of deposits which were more likely to present a pollution threat. In this way rational decisions could be made regarding the judicial investment of public funds in pollution prevention and control methods.

To carry out this investigation a tripartite contract was entered into between the WRC, the Department of Water Affairs (DWA) and Steffen, Robertson and Kirsten (Pretoria) Ing (SRK) in August 1983. The WRC undertook to finance the research, whilst the DWA has been responsible for instrumentation and its maintenance. SRK have provided professional and technical expertise and have carried out the data collection, analysis and interpretation.

The investigation has involved monitoring run-off and surface and ground-water quality around three selected mine deposits as a basis for estimating the pollution potential from all mine deposits in the catchment of the Vaal Barrage.

1.2 Method of Investigation

The investigation has been carried out in three phases.

Phase I involved the selection of three mine deposits and the planning of a surface and ground-water monitoring network to establish the runoff and water quality. It also included the design and installation of the hydrological instrumentation for the measuring stations. This phase is described fully in Section 2.

Phase II has been ongoing throughout the duration of the project and has involved monitoring and data collection over three hydrological seasons. The data have subsequently been processed and analysed in order to evaluate the pollution

contribution from the three selected deposits. Detailed descriptions of the data collected and of their analysis and interpretation are given in Sections 3 and 4. Section 5 incorporates the conclusions drawn from phase II of the investigation.

Phase III has comprised the classification of all mine deposits within the catchment of the Vaal Barrage. These deposits have been inspected and an inventory made of pertinent parameters in order to assess the pollution potential of each deposit and hence of the overall contribution of mine deposits to the mineral load in the Vaal Barrage. This phase of the study is described and discussed in Section 6.

The major findings from the study, together with recommendations for further investigation, are given in Section 7.

1.3 Nature of the Problem

1.3.1 Salt pollution in the Vaal Barrage

The concentration of salts in the Vaal Barrage is of increasing concern due to its importance to the Pretoria-Witwatersrand-Vereeniging (PWV) area for water supply. An increasing salt concentration is of concern since it reduces the usefulness of water and can reduce the life of industrial and domestic equipment.

Both point sources and non-point sources contribute to this pollution.

Point sources include active mines, gold and uranium recovery operations, sewage works and industrial

effluents. These sources are readily identified and their contributions quantifiable.

Non-point sources are less easily identified and quantified. They include agricultural sources (fertilizers, fungicides, pesticides, herbicides and irrigation return flows), air pollution (dry and wet deposition), wash-off of pollutants from urban (impervious) areas and runoff and seepage from sand and slimes mine residues.

The contribution from non-point sources has previously been estimated by subtracting known point source loads from the total loads measured.

Earlier studies have indicated that approximately 50 % of the total dissolved solids load in the Vaal Barrage is attributable to non-point sources. Kempe (1983), found a figure of 47 % for loads generated in the Vaal Barrage catchment over the period September 1978 to October 1979; Herold et al, (1980), found a value of approximately 50 % for the dissolved solid load entering the Barrage from the southern PWV region. In a further study, Funke (1984) estimated that the contribution from mine residues alone to the load carried by the Klip River was less than 2 % of the total during the dry season 1982/83.

1.3.2 Mining residues

Mining operations at the turn of the century resulted in a waste material that was approximately 60 % sand and 40 % finer grained slimes. By about 1918, an all-sliming process was introduced, resulting in the elimination of further sand depositing. However, sand

treatment on established mines continued and was not completely phased out until the 1960's. These processes have resulted in there being many more slimes dams than sand dumps on the Witwatersrand.
Kempe (1983) asserts that the presence of pyrite in gold ores makes the Witwatersrand mining area the most serious source of water pollution in the country. Originally sand and slimes residues were deposited indiscriminately without regard to the environment, often adjacent to streams or on steep slopes. This resulted in pollutants from these residues entering the ground and surface water systems through both direct runoff and seepage.

Process of oxidation of pyrite

Acid mine water is the result of oxidation of iron pyrites which ultimately forms sulphuric acid causing high dissolved solids contents in water draining from mine residues. The oxidation of pyrite, which constitutes up to 3 % as sulphur (average 0,9 - 1,6%) of the mined product, can be described by three reactions (Thompson, 1980).

$$2FeS_2 + 7O_2 + 2H_2O = 2FeSO_4 + 2H_2SO_4 \quad \text{.....(i)}$$

$$4FeSO_4 + 2H_2SO_4 + O_2 = 2Fe_2(SO_4)_3 + 2H_2O \quad \text{.....(ii)}$$

$$3Fe_2(SO_4)_3 + 12H_2O = 2HFe_3(SO_4)_2(OH)_6 + 5H_2SO_4 \quad \text{....(iii)}$$

Reactions (i) and (ii) involve oxidation requiring aerobic conditions, whereas reaction (iii) is an hydrolysis reaction that can take place anaerobically. In addition, reactions (i) and (iii) are chemical reactions which may be accelerated by the presence of

bacteria, but reaction (ii) requires the presence of oxidizing bacteria for oxidation to occur.

Work on the bacterial oxidation of slime material (Mrost and Lloyd, 1970) has shown that the bacterium Thiobacillus ferrooxidans exercises a major role in accelerating pyrite oxidation and that the nutritional and environmental requirements of the bacterium (which include air and mildly acid conditions implying that some moisture should be present) are sufficiently met in slimes material within the depth of penetration of air.

Similarly for sand deposits, Whillier and Loos (1984) at the University of Stellenbosch, have shown that bacterial activity is found in regions of high moisture content and low pH. However, at greater depths within the deposit where conditions may be saturated, oxygen diffusion would seem to be depressed to a level unable to support the bacteria.

Rate and depth of oxidation

The rate of oxidation is related to the availablity of oxygen and the presence of bacteria. The depth of oxidation is therefore limited to the depth of oxygen penetration. This has been found to be between 2 m and 3 m in slimes and between 5 m and 10 m in the coarser grained sand deposits (Mrost, 1973; Kempe 1983; Marsden, 1985). The process of air penetration is believed to occur through expansion and contraction of pore-air due to diurnal and seasonal temperature changes. Complete oxidation of pyrite in the upper 0,1 m is achieved rapidly, within about 1 month, after which the rate decreases such that substantially

complete oxidation to a depth of 1,0 m is not usually achieved even within 2 - 3 years (Mrost, 1973). Mrost further states that the degree of acidity in residue surfaces is dependent on the rate at which soluble acid sulphates are leached and the rate at which surface material is lost by erosion.

Residual pollution threat

It is generally accepted that pollution from mine residues in their early life, when the rate of oxidation was rapid and run off from the dumps entered local water courses unchecked, was greater than it is today after the installation of runoff controls (toe paddocks and penstocks). Furthermore, Marsden (1985) has presented figures to show that sulphide concentrations in residue material have been reduced from 0,85 % to 1,6 % in the original ore to between 0,05 % and 0,25 % in the upper metre and little more in the underlying metre, implying that there is little remaining for further oxidation. Even where values are higher than these, Marsden (1985) argues that the rate of leaching is in any case very slow and therefore deduces that the remaining pollution release rate is low.

The results of Marsden (1985), however, also serve to show that a residual sulphide content does exist and is a potential threat to pollution if exposed to oxygen.

It is reasonable to suppose, therefore, that erosion of the dumps, or any other disturbance which would permit penetration by air, for example the reworking of old deposits, poses a potential pollution problem.

Surface runoff controls, the vegetation of dump surfaces and the construction of toe paddocks are all measures which are being implemented and which should aid in the reduction of direct pollution from mine dumps.

In summary, therefore, the potential pollution in the Vaal Barrage from mine dumps depends on several factors:

i) the mass of remaining sulphide in the residue
ii) the penetration of air into the residue which controls the rate of oxidation
iii) the movement of water through the deposit which controls the leaching rate
iv) the mechanism by which the leachate enters the catchment drainage network (ie whether directly into streams via surface runoff, or indirectly via seepage into near-surface or deep ground water and subsequently into the stream network)
v) the volume and rate of movement of the transporting medium be it ground water or surface water
vi) the presence and efficiency of pollution control measures.

2 PHASE I : SITE SELECTION AND DESCRIPTION, MONITORING NETWORK AND INSTRUMENTATION

2.1 Site Selection and Description

The site for the Phase I detailed investigation aspect of the research project was selected by the Chamber of Mines in conjunction with the Pollution Control Division of the DWA. Its location is shown in Fig 1. The site consists of a strip of land, approximately 5 km wide, which is elongated in an east-west direction and includes the New Municipal Market of Johannesburg. The area is highly industrialised.

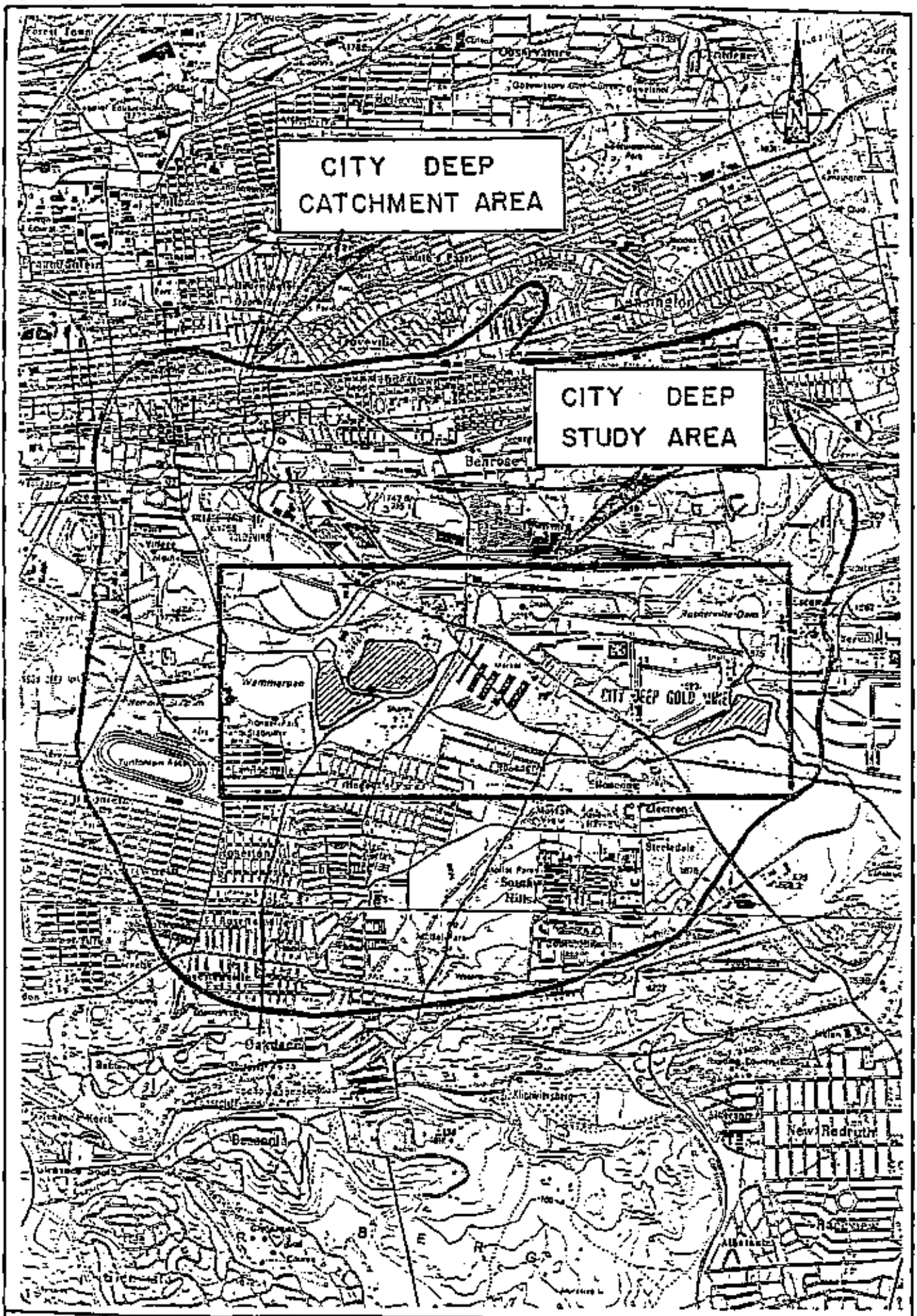
The area is drained by three perennial streams. One flows in a north-easterly and then easterly direction from the south-west corner of the site and joins another stream which flows south from Rosherville Dam. A third stream joins the easterly flowing stream from Moffat Park to the south of the study area. These streams eventually drain into the Natal Spruit.

Three mine deposits were selected both for their accessibility for monitoring purposes and to be representative of:-

- a well-maintained slimes dam - 3L44
- a poorly-maintained slimes dam - 4L4
- a typical sand dump - 3A17

These are shown in Fig 2.

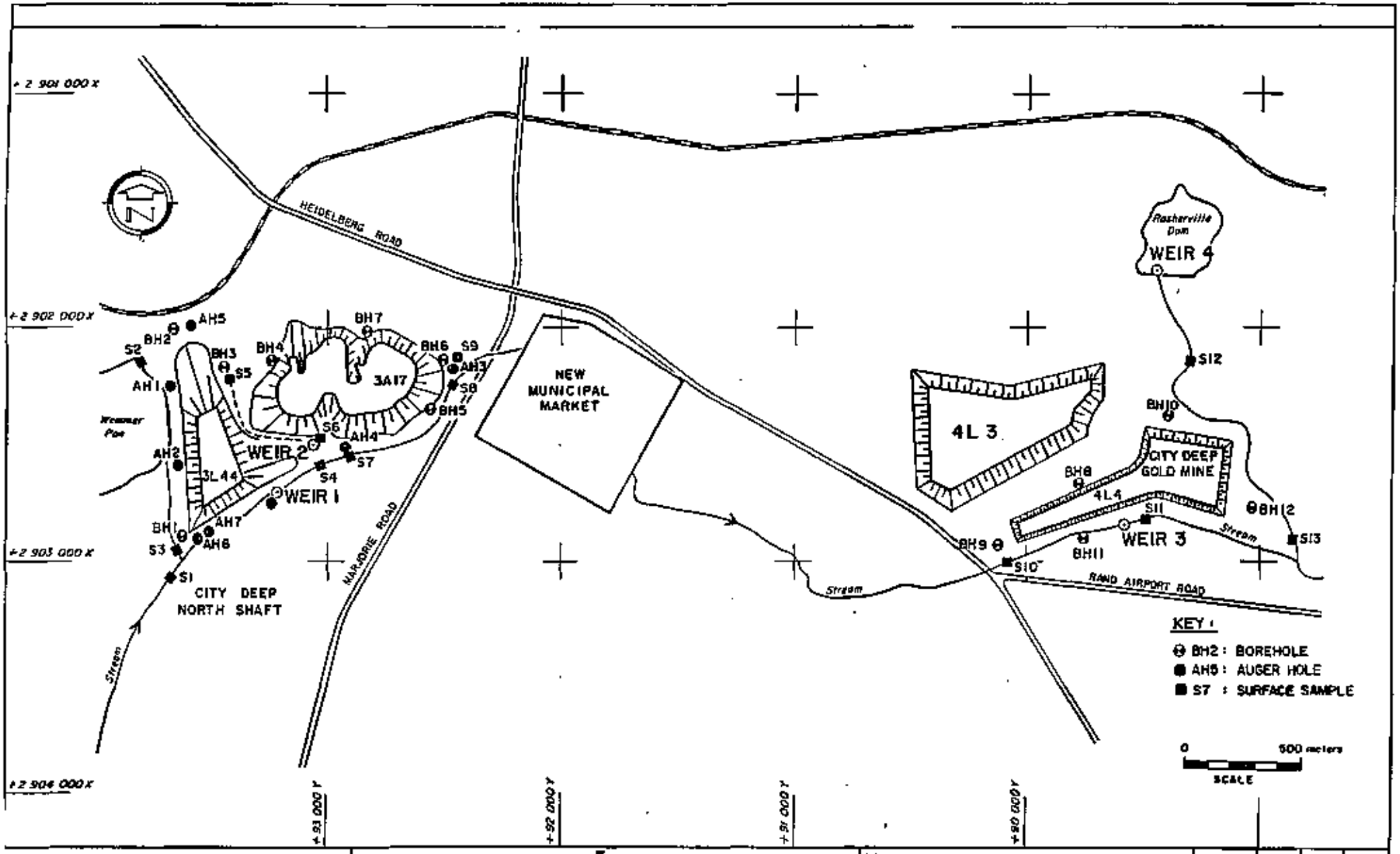
The numbers refer to the coding used by the Chamber of Mines in their classification of mine deposits.



	JOB Nº		FIG Nº
	PT 3632	WATER RESEARCH COMMISSION STUDY AREA LOCALITY PLAN	1

Drawing 61/5748

08-84



NOTES AND EXCHANGE

STEFFEN, ROBERTSON & KIRSTEN

CONSULTING ENGINEERS RAADGEWENDE INGENIEURS

INVESTIGATION OF CONTRIBUTION FROM MINE DUMPS

LOCATION OF SELECTED DEPOSITS, GAUGING WEIRS, SURFACE AND GROUND WATER SAMPLING SITES

CLIENT/KLIENT
WATER RESEARCH COMMISSION

	INITIALS	DATE	CHECKED
DESIGNED ONTWERP			
DRAWN GETEKEN			
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SCALE SKAAL			

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FIGURE 2

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The mine residues at the western end of the site comprise the sand dump, 3A17 and the slimes dam, 3L44. The sides of the sand dump are well vegetated with few signs of erosion, while the sides of the slimes dam are generally bare and covered with vertical erosion gullies. The tops of both deposits dip in the centre and have small ridges around the perimeters causing rainwater to pond in the centre. Between these two deposits the area is overgrown with reeds.

The slimes dam (4L4) is situated in the eastern part of the City Deep site. The sides of the dam are fairly well vegetated and are less eroded than those of the western slimes dam. There are no bodies of standing water in the vicinity.

2.2 Gauging Weirs

Four weirs were constructed by the DWA in the study area. The sites were selected on the basis of their suitability for construction and for recording as closely as possible to where discharge records were required. The position of the weirs are shown in Fig 2.

Crump weirs were constructed at points W1, W2 and W3. This type of weir was selected since it is relatively accurate at low flows, has an appropriate measuring capacity and is relatively easy to construct.

A sharp crested weir was installed at W4 in a breach in the Rosherville Dam. Peak flows at this site were not measured, but bypassed the weir in a second breach in the dam wall. It was found necessary to coat the weirs with an epoxy resin to prevent corrosion of the concrete due to the extreme acidity and high sulphate concentrations at some points in the stream.

Each weir was equipped with a lockable recording hut to house the measuring devices. Due to vandalism and theft of equipment, it was found necessary to install burglar alarms, security fencing and to emply watchmen. Following further vandalism, the huts were replaced with additionally re-inforced huts.

The measuring devices included a stage recorder and a continuous conductivity and temperature recording device installed by the Water Pollution Control Division. Stage recorder charts were replaced weekly and the magnetic memories from the conductivity recorders and the batteries replaced fortnightly. These memories were read at the computer facilities at the Water Pollution Control Division of the DWA. The stage recorder charts were digitized, processed and stored on disk for computer analysis at SRK.

Maintenance of the weirs and stage recorders was undertaken by the Hydrology Division of the DWA who had to de-silt the weirs on occasion. Maintenance of the conductivity and temperature recording devices was handled by Pollution Control who replaced the probes periodically due to the chemical characteristics of the water.

Additional equipment included the installation of automatic storm water samplers at Weirs 1 and 3 during the final hydrological season in order to obtain a series of water samples during storm events. These samplers were provided by Pollution Control.

2.3 Surface Water Sampling Sites

Fourteen surface water sampling points were selected on the basis of obtaining an upstream and downstream comparison of stream chemical quality in relation to the stream's course

past the selected mine residues. These are designated S1 to S14. The position of these points are shown on Fig 2. No samples were collected from S5 since no surface water was present for most of the study period. S14 was added late in the study. It is located in the toe paddock at the base of sand dump 3A17 and was added for comparison with S9 which is in close proximity to the toe paddock. All water samples were submitted to the Hydrological Research Institute of the DWA for analysis.

2.4 Siting of Boreholes and Piezometer Installation

Information on the movement and quality of the ground water at City Deep was obtained by sampling from twelve percussion boreholes drilled for this purpose. Eight auger holes were also drilled at sites that were inaccessible to the drilling rig. These are designated BH1 to BH12 and AH1 to AH8 respectively.

The twelve boreholes were drilled towards the end of 1983 at the positions shown on Fig 2.

The borehole positions were selected to provide five boreholes around the perimeter of each mine deposit, with at least one borehole sited higher on the hydraulic gradient than the deposit in order to assess the baseline water quality.

Because of the difficulties experienced in transporting the drilling rig, many of the selected borehole positions in the western part of the site were found to be inaccessible. Shallow auger holes were then used so that the near surface ground-water quality could be monitored. These auger holes were put down immediately prior to piezometer installation, but three of the holes collapsed before monitoring could commence.

In order that the ground-water levels could be monitored and samples taken for chemical analysis, each borehole, with the exception of BH1 and BH2, was furnished with two independent Casagrande piezometers. These were grouted in place at two different depths so that water samples could be taken on a multi-level basis. The deeper piezometers were installed approximately 5 m above the bases of the boreholes, and the upper piezometers about 3 m below the levels where the ground-water was first struck. Single piezometers were installed in the auger holes.

In BH1 no piezometers were installed because the hole was difficult to access, and in BH2 only one was used because the end of the borehole and the point at which water was first encountered were close.

The diagram in Appendix A illustrates the construction of the borehole piezometers. The depths of the boreholes, water strikes, casings and piezometers are given in Table 1.

TABLE 1 – DEPTH CRITERIA FOR THE CITY DEEP BOREHOLES

Bore hole No	Hole Depth (m)	Casing Depth (m)	Depth of water strike (m)	Piezometer depth A (m)	Piezometer depth B (m)
1	55	18,3	22	-	-
2	40	18,3	28	29,1	-
3	24	2,0	9	22,05	10,0
4	27	5,1	14 & 20	23,55	14,9
W 5	90	4,2	Damp at 27 water at 80	84,7	27,8
6	100	2,0	65	64,1	5,0
7	60	6,8	50	51,9	10,8
8	36	7,1	28	30,0	10,0
9	36	4,5	30	31,85	10,35
10	52	2,0	50	45,4	9,85
E 11	60	1,5	50	52,7	4,75
12	40	2,0	73	35,05	7,15

W = Western part of study area E = Eastern part of study area

3 PHASE II : SURFACE WATER HYDROLOGY

3.1 Data Collection and Processing

3.1.1 Flow measurement

Monitoring of water level (stage) at the four weirs was carried out from January 1984 to April 1986. Breaks in the record exist for the periods when one or more gauging stations were out of commission due either to maintenance or vandalism.

Digitization and processing of the stage records into discharge values (break point, daily and monthly mean values and flow duration curves) were carried out. Discharge rating curves for the four weirs had been prepared by the Division of Hydrology of the DWA.

3.1.2 Surface water sampling

Surface water samples were collected initially at fortnightly intervals and subsequently at monthly intervals after the average chemical composition at each site had been established.

Fifty four sets of surface water samples were collected. At each sampling site a 250 ml sample was taken for a macro-analysis and a 25 ml sample preserved with 1 ml of nitric acid was taken for a trace metal analysis. The macro samples were analysed for pH, conductivity, calcium, magnesium, sodium, potassium, ammonium, total alkalinity (TAL), sulphate, chloride, nitrate, phosphate and silicon; TDS was determined by summation.

The micro samples were analysed for iron, manganese, nickel, aluminium, boron, zinc, cobalt, chromium, copper and strontium.

The results of all the analyses were stored on magnetic tape and are available as computer printouts. A summary of the results is presented in Section 3.2.3.

3.1.3 Continuous conductivity records

Conductivity and temperature were recorded continuously at the four gauging stations. Records for the period August 1984 to April 1986 were processed by the Pollution Control Division of the DWA to give conductivity at 25°C. Results were transferred on disk to the computing facilities at SRK. Breaks in the records again occurred for periods when the gauging stations were out of commission.

Whereas conductivity was monitored continuously, TDS and sulphate were only determined periodically (Section 3.1.2). By defining relationships between conductivity and both TDS and sulphate, continuous records of the latter two constituents were generated. These were then combined with flow records to obtain TDS and sulphate loads during the study period.

3.1.4 Rainfall during study period

The daily rainfall record for the Weather Bureau rainfall station 476/044 at Turffontein, which lies within the study catchment, is given in Table 2. The figures in brackets are for a rainfall station approximately 3 km away, maintained by the Vegetation

TABLE 2 : Daily rainfall in mm

DAY	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1			0,5	4,5	0,5			1,8						0,1		66,0		2,2 (5,0)		3,3 (9,0)	0,9
2			0,2		8,0			3,2										1,0	7,5 (24,0)	22,5 (24,0)	
3			0,5			2,6											0,9	9,5			
4					2,8	10.2								12,5				(10,0)	5,0 (5,0)		
5				24,5		2,0			0,5												
6						3,0		0,8	2,6			0,1								16,5 (16,0)	
7			1,6			0,3	6,0	6,7					0,1			4,0				3,5 (10,0)	0,1
8			0,8			2,6	11,7	30,7							3,7	2,5	27,2			0,5	
9			7,5		1,5													4,0 (4,0)	1,0 (10,0)	6,5 (10,0)	1,1
10				13,5		4,8	0,7												0,1 (1,0)	5,6 (2,0)	4,0
11			12,2	0,2	6,4			4,7		1,6		5,4					0,4	1,0			6,6
12		1,6						0,2		7,0								8,6 (11,0)			26,8
13		1,0		5,8	0,3			2,4							1,9		4,0	3,0 (10,0)		4,5 (12,0)	
14			1,3	2,0				5,0							12,1		7,7	0,3		21,7 (5,5)	6,8
15		9,0		7,5	15,0	1,6	4,5												9,6 (8,0)		8,0
16		0,5	4,7		16,3	70,3												15,4 (14,0)		43,4 (5,5)	
17					2,7	15,5		4,5									1,2			11,7 (5,5)	
18					5,9	27,5		10,4							0,9			18,8		10,8 (14,0)	
19			3,6	0,2													6,0	12,9 (26,0)			
20			8,0	7,2	3,7		0,5									1,0	7,0	4,8			
21							21,5									1,7	8,8	1,0			
22							2,0										7,5	3,0 (4,0)			
23			10,0														0,7		0,9		
24			11,5			5,5									0,9					3,0 (3,0)	
25				10,5			23,2	23,2									2,0	5,5 (10,5)			
26							11,7	9,0						1,2		9,7	18,9				1,7
27		0,1		0,8			0,6							15,0							0,1
28		0,1	0,5	7,7		7,0	2,8								0,3	6,4	2,5	2,2 (3,0)			
29			0,1	38,0												11,3	6,8	7,4			
30	1,7			22,0		1,3								0,3	55,3	0,1	0,4	48,9 (85,0)			
31					3,7								6,7		31,5						
Total	1,7	12,3	63,0	14,4	66,8	154,2	85,2	92,6	3,1	9,9	0,0	5,5	6,8	29,1	117,9	98,2	102,6	142,1(182,5)	52,4 (95,0)	126,2(108,0)	55,1

Annual Total	(1984)	487,7	(1985)	705,1

Unit of the Chamber of Mines and which is in close proximity to Weir 1. The differences in magnitude and timing of falls over such a short distance illustrate the localized nature of storms in this region.

3.1.5 Discharge - conductivity data base

The data bases described in Sections 3.1.1 and 3.1.3 were combined to give comparable records at each weir of mean daily flow and mean daily conductivity. Days when any of the gauging stations were out of commission were removed from the record at all stations. This resulted in a record of 324 (non-consecutive) days out of a possible 608 days (August 1st 1984 to March 31st 1986) of which 222 fell in 1985. These 324 days received 772 mm of the total of 1313 mm precipitation during this period.

It is considered that total flows and loads calculated from this data base are adequate annual estimates for the year 1985, if the following adjustments are made:

i) multiply the totals by 365/324 to allow for the reduced number of days;

ii) reduce the totals by the ratio of the total rainfall for 1985 (705 mm) and the total rainfall which fell on the 324 non consecutive days (722 mm) to allow for the bias towards wet days ie 705/772.

Combining the two adjustments gives a factor of approximately 1, i.e.

$$\frac{365}{324} \times \frac{705.1}{771.8} = 1,03$$

3.2 Analysis and Interpretation of Data

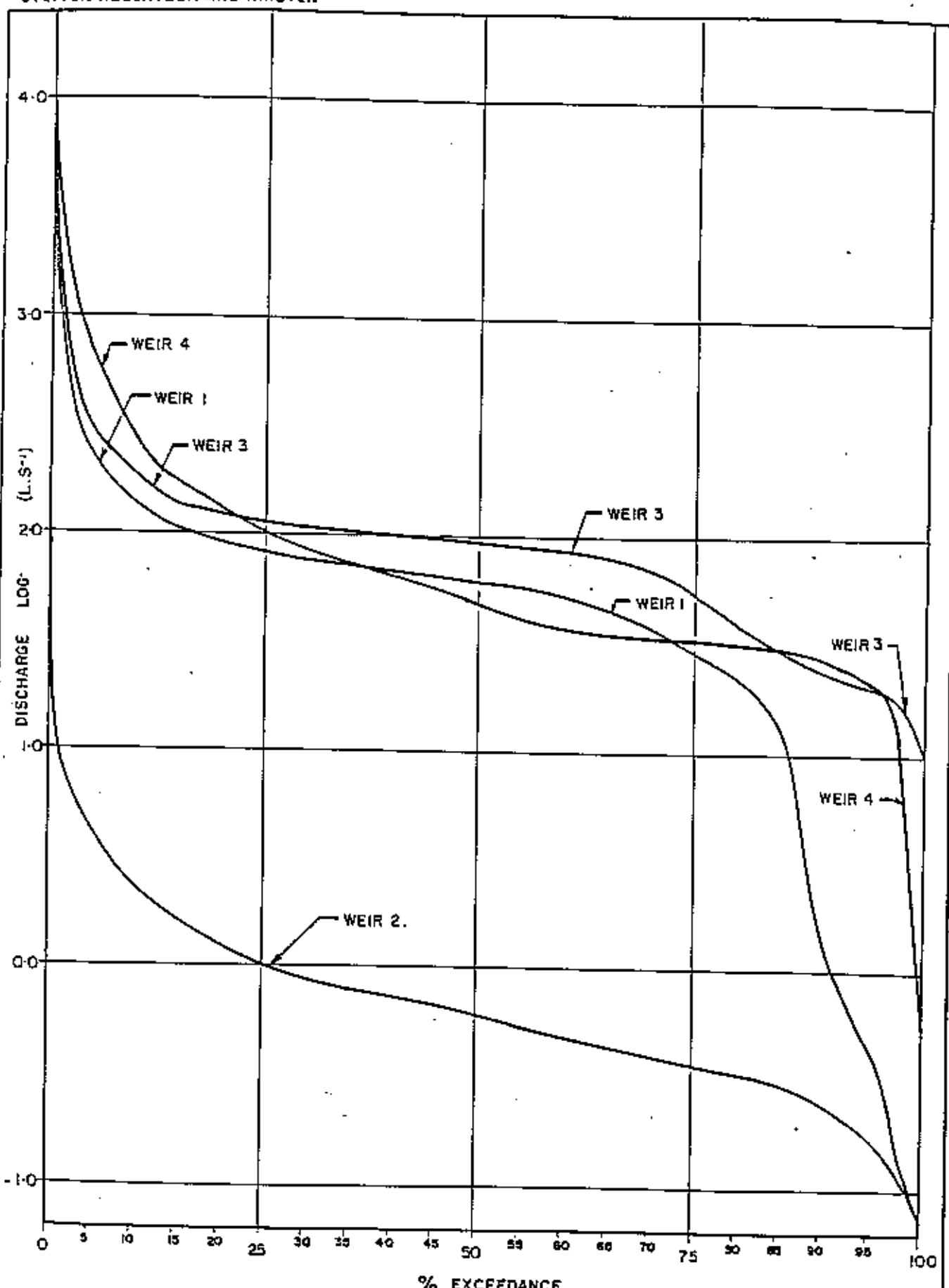
3.2.1 Flow records

Flow duration curves for each gauging station are illustrated in Fig 3 and estimates of baseflow are given in Table 3. Table 4 gives the mean monthly flows during the period August 1984 to March 1986 and Table 5 gives the estimated annual flows at each weir.

During the study period an unexplained shift in the relationship between Weirs 1 and 3 occurred. After October 1984 the flow at Weir 1 represented a greater proportion of the flow at Weir 3 than prior to this date. It is important to note that the tributary draining the urban area to the south is ungauged and enters the monitored stream between the two weirs. This could influence the relationship between flows in the study area.

TABLE 3 - ESTIMATES OF BASEFLOW, $l.s^{-1}$

Weir	Flow exceeded 70% of time	Most commonly occurring flow
1	35,0	70,0
2	0,4	1,0
3	70,0	100,0
4	36,0	35,0



FLOW DURATION CURVES FOR CITY DEEP WEIRS

	JOB Nº		FIG Nº
	PT 3632	WATER RESEARCH COMMISSION	3

TABLE 4 - MEAN MONTHLY DISCHARGES AT THE FOUR GAUGING STATIONS $l.s^{-1}$

Year	Month	Weir 1	Weir 2	Weir 3	Weir 4
1984	Aug	27,4	0,6	104,4	157,0
	Sep	30,7	0,4	76,7	41,0
	Oct	28,4	2,2	89,6	195,6
	Nov	143,3	0,7	189,2	263,0
	Dec	117,5	1,0	171,2	247,5
1985	Jan	393,1	4,4	722,8	339,3
	Feb	163,0	2,5	211,7	150,1
	Mar	146,2	2,3	235,1	172,6
	Apr	75,9	1,2	111,3	41,1
	May	73,3	1,0	117,6	57,0
	Jun	68,0	0,8	105,8	36,8
	Jul	65,7	0,9	108,0	47,5
	Aug	59,5	1,0	97,9	36,6
	Sep	75,9	0,7	-	59,5
	Oct	148,0	1,5	252,4	228,7
	Nov	251,0	3,8	257,3	307,3
	Dec	172,7	0,7	222,2	290,0
1986	Jan	161,0	2,5	140,1*	340,7
	Feb	92,8	1,3	49,4*	220,4
	Mar	132,1	1,5	266,8	264,6

(-) gauging station out of commission during this period

* incomplete months

TABLE 5 - ESTIMATED ANNUAL FLOWS (1985) AT THE FOUR GAUGING STATIONS

Weir	Flow m^3x10^6	Baseflow m^3x10^6	Surface runoff m^3x10^6
1	3,533	2,208	
2	0,444	,032	
3	5,729	3,154	
4	4,762	1,104	
3+4[1]	10,491	4,258	6,233

1: The sum of flows at Weirs 3 and 4 gives the total flow from the study area. The surface runoff is the difference between the total flow and the baseflow.

3.2.2 Continuous conductivity records

Table 6 gives the mean monthly conductivities at the four gauging weirs. Conductivity gives a useful measure of the TDS concentration of the water. The relationship between the two is dicussed more fully in Section 3.2.4. In general, the mean monthly conductivities indicate a good quality water at Weir 1 with a poorer quality at Weirs 3 and 4. Only at Weir 2 where flow is very small do they on the whole exceed the General Effluent standard maximum conductivity of 250 $mS.m^{-1}$. However a mean monthly figure conceals the variation that can occur on a shorter time scale. This is discussed in Section 3.2.6.

* TABLE 6 - MEAN MONTHLY CONDUCTIVITIES AT 25°C AT THE FOUR GAUGING STATIONS, $mS.m^{-1}$

Year	Month	Weir 1	Weir 2	Weir 3	Weir 4
1984	Aug	28	362	104	111
	Sep	24	337	95	108
	Oct	23	519	64	80
	Nov	28	374	68	66
	Dec	33	261	63	52
1985	Jan	30	246	82	66
	Feb	35	303	61	85
	Mar	39	382	55	71
	Apr	38	311	69	104
	May	35	314	73	98
	Jun	34	309	84	102
	Jul	31	435	127	105
	Aug	25	483	-	110
	Sep	19	285	-	85
	Oct	21	628	81	83
	Nov	32	627	73	107
	Dec	23	670	56	59
1986	Jan	26	796	58	62
	Feb	26	839	185	90
	Mar	30	724	158	103
	Apr	30	691	161	170

(-) gauging station out of commission during this period

3.2.3 Routine surface water sampling

Analysis of water samples

All samples were analysed by the Hydrological Research Institute of the DWA. Because of the low pH and high TDS concentrations in many of the samples collected

during this investigation, difficulties were sometimes experienced in their analysis. Despite being first filtered, the samples sometimes caused the auto-analysers to clog. Cation/anion balances were often found to be unsatisfactory particularly at low pH when the sum of anions often far exceeded the sum of cations. However, at these low pH values an over-estimate of the negative ions can occur, for example by assuming the sulphate to be present as SO_4^{2-} whereas it is likely to be present also as bisulphate, i.e. HSO_4^-.

In addition, some of the sulphate values obtained seemed very high. It is often assumed, for these type of samples, that the sulphate solubility is limited to about 2000 mgl^{-1} by the solubility product of calcium sulphate and that calcium is the major cation present. However, as shown in the following tables, several other cations in addition to calcium are present. Checks were carried out on some of these anomalous results; in particular for some of the samples from sites S9 and S14 where sulphate values were exceptionally high. These high values were confirmed and it was also reported that the samples were clear, indicating that no precipitation had taken place.

Spurious results, for example where the sulphate value exceeded the calculated TDS value, clearly the result of analytical error, have been discarded from the statistical analysis.

Variation in surface water quality within the study area

Table 7 gives the mean values for pH, conductivity, TDS and sulphate for the surface sampling points. The mean percentage composition of the total dissolved solids (TDS) at 7 representative sites was calculated from the complete analyses carried out and is illustrated in Fig 4. The mean values of these main constituents are shown in Table 8. For the calculation of mean pH the anti-logarithm of each pH value was taken before summing. Also indicated in these tables are the sites at which the General Effluent standards and the crisis drinking water limits proposed by Kempster and Smith (1984) are exceeded. The values in Table 7 compare reasonably with the values quoted by Kempe (1983) as the limits of pollution from seepage from sand dumps which are also given in the table. In addition, the concentrations for sites S11 and S12 are similar to the values quoted by the Rand Water Board (1983) at their nearby sampling sites N3 and N2 as shown in Table 8.

It is apparent from these tables that the quality of water at sites S1 to S4 and at site S7 is of moderate quality although even at these sites the levels of some trace metals, notably iron, aluminium and manganese are high. Site 6 is upstream of Weir 2 where flow is low and water often ponds causing high concentrations at this point. Site 7, downstream of site 6 but on the faster flowing mainstream, is of similar quality to sites S1 and S4. As the stream flows along the southern flank of sand dump 3A17 the water becomes more acidic with an increasing sulphate load as indicated by the chemistry at S8. S9 is

situated in a small stream in a marshy area and is in close proximity to a toe paddock at the base of the dump. The poor quality of the water at S9 is believed to be due to seepage from this toe dam. For this reason samples were taken from the toe dam (S14) and compared with the quality at S9. In Figure 4 the mean percentage composition of the TDS for the two sites can be seen to be almost identical, particularly in the percentage contribution of the four main constituents; sulphate, iron, aluminium and magnesium, which would seem to confirm that the water at both sites has the same source. However, a comparison of the mean concentrations, albeit based on only 4 samples for S14, indicates that the quality at S9 is in fact worse than that in the toe paddock, a point which is discussed more fully in Section 5.1.1. The quality at sites S10 and S11, approximately 3 km downstream, whilst still acidic and high in TDS, has improved through dilution and no deterioration is apparent during the stream's passage along the southern side of slimes dam 4L4. The water flowing down the Rosherville stream is of better quality than that at sites S10 and S11 but nevertheless is acidic and high in TDS and sulphate. Again no apparent quality deterioration is evident between sites S12 and S13.

It is interesting to note the increase in the trace metal concentrations in particular of iron, aluminium, zinc and manganese at those sites in close proximity to, and downstream from, the eastern end of sand dump 3A17. A possible source of trace metals in these waters was the metal plating industries to the north of the study area. However, examination of the water analyses taken from sampling sites on the northern

TABLE 7 - MEAN WATER QUALITY AT SURFACE SAMPLING SITES

Site (See Fig 2)		pH	n	Conductivity mS/m	n	TDS $mg.l^{-1}$	n	SO_4 $mg.l^{-1}$	n
	1	6.5	54	39	54	259	36	55	51
		6.7	52	46	52	255	34	94	50
	3	6.8	46	41	46	277	29	96	44
	4	6.8	54	39	54	266	36	69	52
W	6	2.8*	54	376*	54	3050*	36	2089	52
	7	6.6	54	42	54	267	36	83	52
	8	2.7*	54	154	54	820	35	845	51
	9	2.3*	45	2436*	45	59890*	29	37004	43
	14	2.3*	4	1097*	4	28223*	4	17804	4
	10	2.5*	54	173	54	954*	35	1006	52
	11	2.5*	54	175	54	973*	35	878	52
	12	3.8*	51	117	51	767*	33	509	48
E	13	3.8*	51	120	51	792*	33	502	48
LOWER		3.1				6200		3400	
UPPER		2.4				51000		26000	

Notes :

Mean pH calculated from anti-logged values

n is the number of samples on which mean value is based

Lower/Upper limits of pollution from seepage from sand dumps after Kempe(1983)

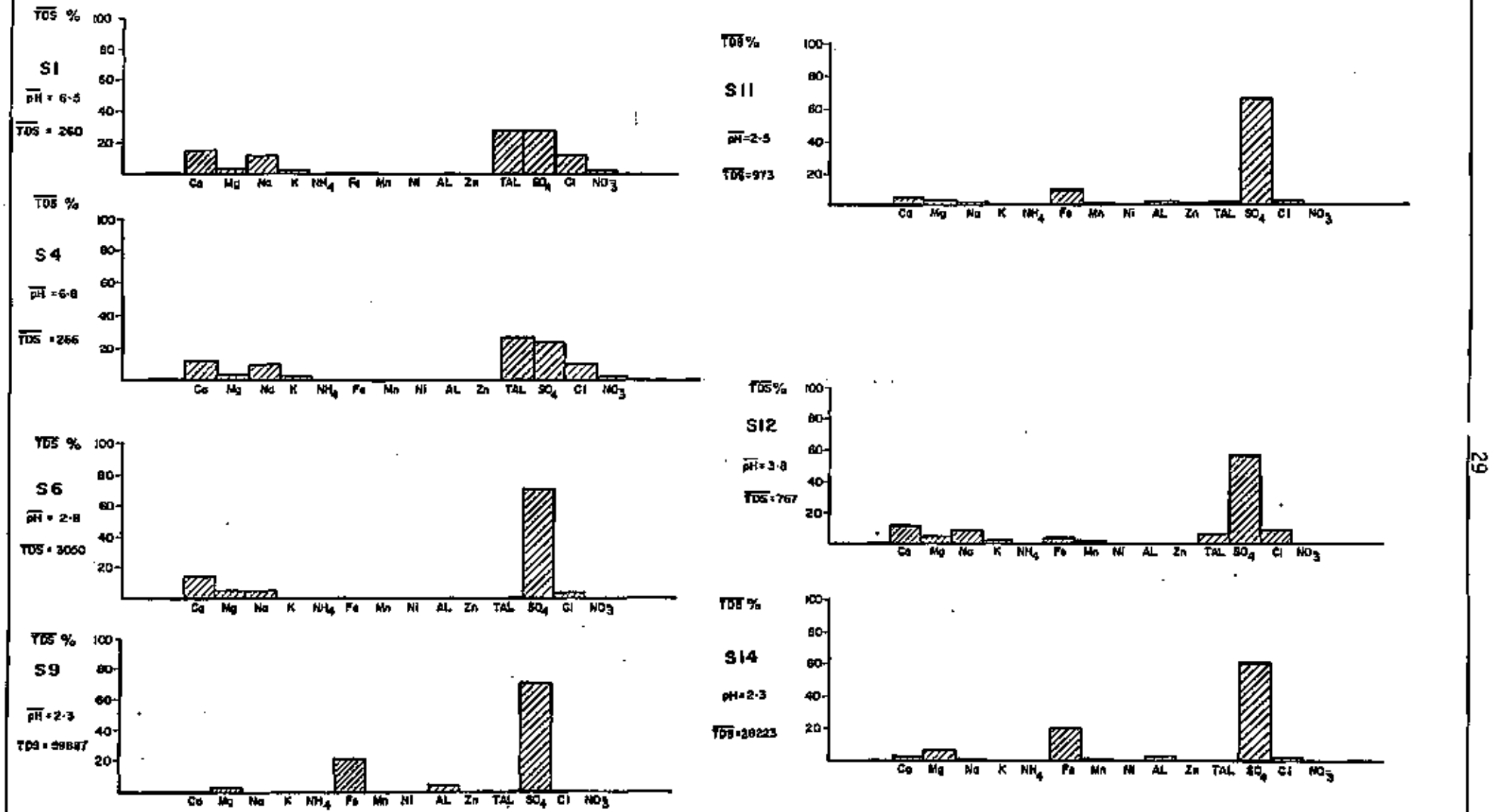
* Exceeds General Effluent standard

W : Western part of study area

E : Eastern part of study area

TDS : Total Dissolved Solids

SO_4 : Sulphate



STEFFEN, ROBERTSON & KIRSTEN

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AVERAGE TDS COMPOSITION AT 7 REPRESENTATIVE SITES

WATER RESEARCH COMMISSION

FIGURE 4

TABLE 8 - MEAN CHEMICAL COMPOSITION OF WATER AT SELECTED SITES, $mg.l^{-1}$

CONSTITUENT	SAMPLING SITES								
	S1	S4	S6	S9	S14	S11	S12	N3[1]	N2[1]
Ca	32,3	34,5	405,0*	474,0	649,0*	55,8	83,8	68,0	87,0
Mg	7,3	9,7	132,1	1639,0*	2023,0*	35,4	33,5	58,0	39,0
Na	26,6	25,8	150,0*	112,0	133,0	31,4	62,7	36,0	62,0
K	5,0	5,0	41,3	14,3	4,6	6,6	9,6		
NH_4	0,07	0,17	3,84	7,36	0,66	0,53	3,96		
Fe	0,12	0,16	24,20*	12438,0*	5999,0*	112,51*	15,10*		
Mn	0,01	0,08	27,40°*	133,3°*	42,3°*	3,62°*	6,91°*		
Ni	0,02	0,12	1,22*	104,2*	54,7*	1,47*	0,82		
Al	0,28	0,24	20,55*	1795,0	911,3*	22,90*	0,56		
Zn	0,11	0,13	0,95	122,0°*	59,6°*	11,41°*	0,87		
Total Alk	61,0	70,94	7,6	1,64	6,0	8,64	42,3		
SO_4	62,4	63,6	2019,0*	41809,0*	17804,0*	676,8*	417,0	1060,0	415,0
Cl	26,0	23,3	66,3	100,6	493,0	34,9	63,6	41,0	71,0
NO_3	3,9	2,2	0,2		0,5	1,3	0,03		
TDS	259,0	266,0	3050,0	59887,0	28223,0	973,0	767,0		
pH	6,5	6,8	2,8°*	2,3°*	3,8°*	2,5°*	2,3°*		

1 N3 and N2 are Rand Water Board sampling sites which can be compared with S11 and S12 respectively

* exceeds crisis drinking water limit (after Kempster and Smith, 1984)

° exceeds General Effluent Standard

side of the study area did not reveal any evidence of this and it is therefore concluded that the high trace metal concentrations are almost certainly derived from the pyrite-containing mine residues.

Statistical comparison of the sampling sites

The sampling points were chosen to given an estimate of the water quality upstream and downstream of the three monitored deposits. To assess the influence of the deposits on the water quality a series of statistical comparisons was carried out between pairs or groups of sampling sites. Of the four parameters compared, pH, conductivity, TDS and suphate, the value of sulphate was found to be the most discerning discriminator between sites. Since the sulphate value is a product of pyrite oxidation differences in its value between various sampling sites were considered to be good indicators of the influence of the mine deposits. Departures from normality in the distribution of the above parameters were identified using the Kolmogorov-Smirnov one-sample test. Comparisons of the distributions of the sulphate values between sampling sites were made using the Kolmogorov-Smirnov two-sample test. The null hypothesis for these tests was that there is no significant difference between the two sets of sample values for each site or group of sites. This was rejected when there was only a 1 % or less chance of being wrong. The distribution of the sulphate values measured at the following sites, or groups of sites, as shown below in the left hand column, have been shown to be significantly different from any other site or group in that column:

Site	Remark
S1,S4,S7	Characterizes quality of "background" water
S2,S3	Characterizes quality of water in Wemmer Pan
S6	Indicates influence from deposits 3L17 and/or 3L44
S8	Influenced by sand dump 3A17
S9	Influenced by seepage from toe paddock
S10,S11	Indicates no deterioration in quality along south side of deposit 4L4
S12,S13	Indicates no deterioration in quality along east side of deposit 3L44

This grouping can be interpreted in the following way. Water qualities at sites S6, S8 and S9 are not similar to those at any other sampling sites, whereas there are no significant differences in the quality of water at sites S1, S4 and S7; at sites S2 and S3; at sites S10 and S11 and at sites S12 and S13.

3.2.4 Relationships between conductivity, TDS and sulphate

Nature of the relationships

Conductivity is used as a practical indicator of TDS as it is easily measured. However, natural waters are not simple solutions and the factors affecting conductivity can be complex. A linear relationship, therefore, between conductivity and TDS may not be the most appropriate, or may only be valid in certain environments, or between certain limits of, for example, pH. However, for the purposes of this investigation linear relationships were considered to

be adequate and were defined by means of simple regression. Justification for this is that the relationships obtained at the sites were all significant at the 1 % level (i.e. there is only a 1 % chance of being wrong in rejecting the null hypothesis that the regression slope equals zero and there is no linear relationship). In addition, residual analysis showed the errors (ie the observed TDS values minus the values predicted by the regressions) to be approximately normally distributed. Separate relationships were derived for each site, since most sites have been shown to have a unique chemistry (Section 3.2.3).

Although conductivity is a useful estimator of TDS, because sulphate is only one component of TDS and of variable significance, conductivity is not such a clear indicator of sulphate. For this project the relatively large data base allows sulphate to be represented as a percentage of the TDS at each site. This percentage was determined by taking the mean of the percentages calculated for every sample taken at each site. The coefficient of variation for these means varied between 14 and 48 %. Thus on this basis it was considered that a sufficiently reliable relationship between conductivity and sulphate had been established for this project.

Relationship between laboratory determined conductivity and continuous conductivity

The relationships described above (Section 3.2.4) were derived from the TDS and conductivity values determined in the laboratory. To obtain continuous records of TDS and hence sulphate, these measures of

laboratory conductivity were related to the continuous records of conductivity. Differences in the values of conductivity recorded in the field and in the laboratory are to be expected due to changes which can occur during storage related to temperature and pH changes.

For the four sampling sites adjacent to the gauging stations (S4 (Weir 1), S6 (Weir 2), S11 (Weir 3) and S12 (Weir 4)) and which were used in the calculation of loads at each weir, this was done by comparing the laboratory conductivity values to the continuously recorded conductivity values at the nearest gauging station at the time the sample was taken. A highly significant linear relationship was established.

For the calculation of loads from individual deposits (described more fully in Section 3.2.5), additional relationships were required between laboratory conductivity at sampling sites not adjacent to weirs and the continuous records. It was found that significant relationships could be derived using mean daily conductivity measured at the weirs as the independent variable.

3.2.5 Calculation of salt loads in the study area

Annual export of TDS and sulphate from study area

The annual load of TDS and sulphate at each weir in the study area was calculated using the 324 day record of discharge and conductivity discussed in Section 3.1.5.

The daily conductivity was used to estimate a corresponding TDS and sulphate value via the relationships discussed above. These were then multiplied by the flow rate and summed over the 324 days. The loads established are given in Table 9.

TABLE 9 - ANNUAL LOADS OF TDS AND SULPHATE AT THE FOUR GAUGING STATIONS, (t)

Weir	TDS	Sulphate
1	1123	264
2	104	70
3	3353	2114
4	2271	1256
3+4*	5624	3370

* The sum of loads at Weirs 3 and 4 gives the total load exported from the study area (= load from study sites + load originating upstream of study sites).

Apportionment of load to specific mine residues

One of the objectives of this project was to ascertain the sources of the pollution generated within the study area and it was to this end that the monitoring network was designed. By reference to Fig 2 the possible load emanating from each of the monitored deposits can be expressed by the following series of mass balance equations:-

Load from slimes dam 3L44:-

$$S3.QS3 - S2.QS2 + S4.QW1 - (S1.QS1 + S3.QS3) + (S6.QW2 - S5.QS5).F1$$

Load from the sand dump 3A17:-

$$(S6.QW2 - S5.QS5).F2 + S8(QW2 + QW1) - S7(QW2 + QW1) + S9.QS9 - S1.QS9$$

Load from slimes dam 4L4:-

$$(S11 - S10).QW3 + (S13 - S12).QW4$$

Where:

QW1 to QW4 are discharges at Weirs 1 to 4
QS1 to QS9 are discharges at sampling points S1 to S9
S1 to S13 are concentrations of TDS or sulphate at the surface sampling sites
S1 is taken to represent the background quality of the water
F1 and F2 are coefficients representing the relative contributions of dam 3L44 and dump 3A17 and F1+F2=1.0

The above equations can be simplified by making the following assumptions:-

QS7=QS8=QW1+QW2
QS5=0, QS9=0
QS1+QS3=QW1
QS2=QS3
QS1=QW1-QS2
QS2=QW1-QS1

These are all reasonable assumptions except for QS9=0. The latter can be justified on the basis that although for much of the study period flow has been negligible, some flow is known to have occurred, and in the absence of any measurements a value of zero has been used. This will result in a more conservative estimate for the load from sand dump 3A17. If, in addition, QS3 is considered to be a negligible contribution to the main stream, which is certainly so in the winter months, (eg.. from 30/4/85 to 31/10/85 there was no flow at S3) then QS1 may be approximated by QW1 and consequently

$$QS2 = 0 \text{ i.e. } QS1 = QW1,\ QS2 = 0$$

Introducing these simplifications the equations become:-

Load from 3L44: $(S4 - S1).QW1 + S6.QW2.F1$
Load from 3A17: $S6.QW2.F2 + (S8 - S7)(QW2 + QW1)$
Load from 4L4 : $(S11 - S10).QW3 + (S13 - S12).QW4$

A further simplification can be made for the last of these equations. In Section 3.2.3 it was shown that there is no significant difference in the quality of water between sites S10 and S11 or between S12 and S13. Consequently (S11-S10) and (S13-S12) become zero, i.e. there is no contribution to the load from slimes dam 4L4.

The only remaining unknowns in the above equations are the coefficients F1 and F2 which describe the relative contributions to load from deposits 3L44 and 3A17 into the stream between the dumps which is measured by W2. Only subjective values can be ascribed and three different combinations have been applied:-

i) F1 = F2 = 0,5 i.e. each deposit contributes equally.

ii) F1 = 0,0, F2 = 1,0 i.e. the whole load is contributed by sand dump 3A17. This is based on the knowledge that slimes dam 4L4, which is less well maintained than dam 3L44, contributes a negligible load so it is reasonable to assume the same of the better maintained dam.

iii) F1 = 0,167, F2 = 0,833 This combination is derived in the following way. The western flank of slimes dam 3L44 is not considered to contribute any load since the quality at S3 is similar to that at S2. Similarly the southern flank does not appear to affect the quality at S4, although the sulphate value is higher than at S1. However, S6 is polluted, suggesting that the eastern (i.e. lower on the hydraulic gradient) flank of the dam may contribute to the load. The value of 0,167 is obtained by considering that only one in three flanks is contributing to the load at S6 and at least half of the load at S6 is likely to be derived from the sand dump, i.e. 1/3 x 1/2 = 1/6 = 0,167. Although selected fairly arbitrarily, this combination does serve to provide values which are intermediate between the other two pairs. Table 10 shows that the loads calculated are in fact fairly insensitive to these coefficients.

Applying these equations to the 324 day data base and using the relationships between conductivity, TDS and sulphate, described in Section 3.2.4, annual loads attributable to deposits 3L44 and 3A17 have been calculated and are shown in Table 10.

TABLE 10 LOADS (T/A) ATTRIBUTABLE TO MINE DEPOSITS 3L44 AND 3A17 IN THE STUDY AREA

Coefficients		TDS load	SO4 load	TDS load	SO4 load
F1	F2	from 3L44	from 3L44	from 3A17	from 3A17
0,5	0,5	96	72	2274	1586
0,167	0,833	38	33	2312	1625
0,0	1,0	9	13	2342	1645

Thus, the combined load from these two deposits is 2350 t/a of TDS of which 1658 t/a are sulphate. The proportion of these loads which are due to the sand dump varies according to the values selected for coefficients F1 and F2 from 95,9 to 99,6 % for TDS and from 95,7 to 99,2 % for sulphate.

A similar result is obtained if the combined load from deposits 3L44 and 3A17 is estimated by subtracting from the load calculated at Weir 3 the background load at S1. This background load has been calculated in the same way and by approximating the flow at S1 by that at S4 (Weir 1) and was found to be 869 tonnes of TDS of which 194 tonnes are sulphate:-

TDS load at Weir 3 - TDS load at S1 = 3353-869
= 2484 t/a

Sulphate load at Weir 3 - sulphate load at S1
= 2114-194 = 1920 t/a.

These figures compare favourably with those obtained from application of the full mass balance equations.

3.2.6 The effect of storm events on the chemistry and salt load in streamflow

Purpose and method of analysis

The analysis of storm events was carried out to investigate the effect of stormwater on the quality of water and the salt load in streams.

If the quality of water improves during a storm event the implication is that the surface runoff is of a better quality than the baseflow in the stream and serves to dilute this component. Alternatively, if the quality were to deteriorate this would imply that the surface runoff was introducing a poorer quality of water to the stream. One possible source of contaminants was accumulated salts on the surface of the mine residues, or in the upper horizons, which were flushed into the streams by quickflow. However, other sources in the catchment may also contribute to the stormflow eg wash-off from impervious surfaces in urban and industrial areas.

In order to examine the effect of storm events on the chemistry of streamwater quality, two automatic samplers were installed, one at Weir 1 and the other at Weir 3. However, due to the unreliability of the automatic samplers, all storms monitored were sampled manually. Laboratory analysis of the samples taken enabled the variation in concentration of several elements during the storms to be analysed. Samples were collected during a relatively short period

covering the peak and recession of a single event (usually a matter of hours). Salt loads were calculated using the continuous record of conductivity covering the period of time from the initial rise in discharge, to the point where discharge had returned to its initial base value, a period of up to several days.

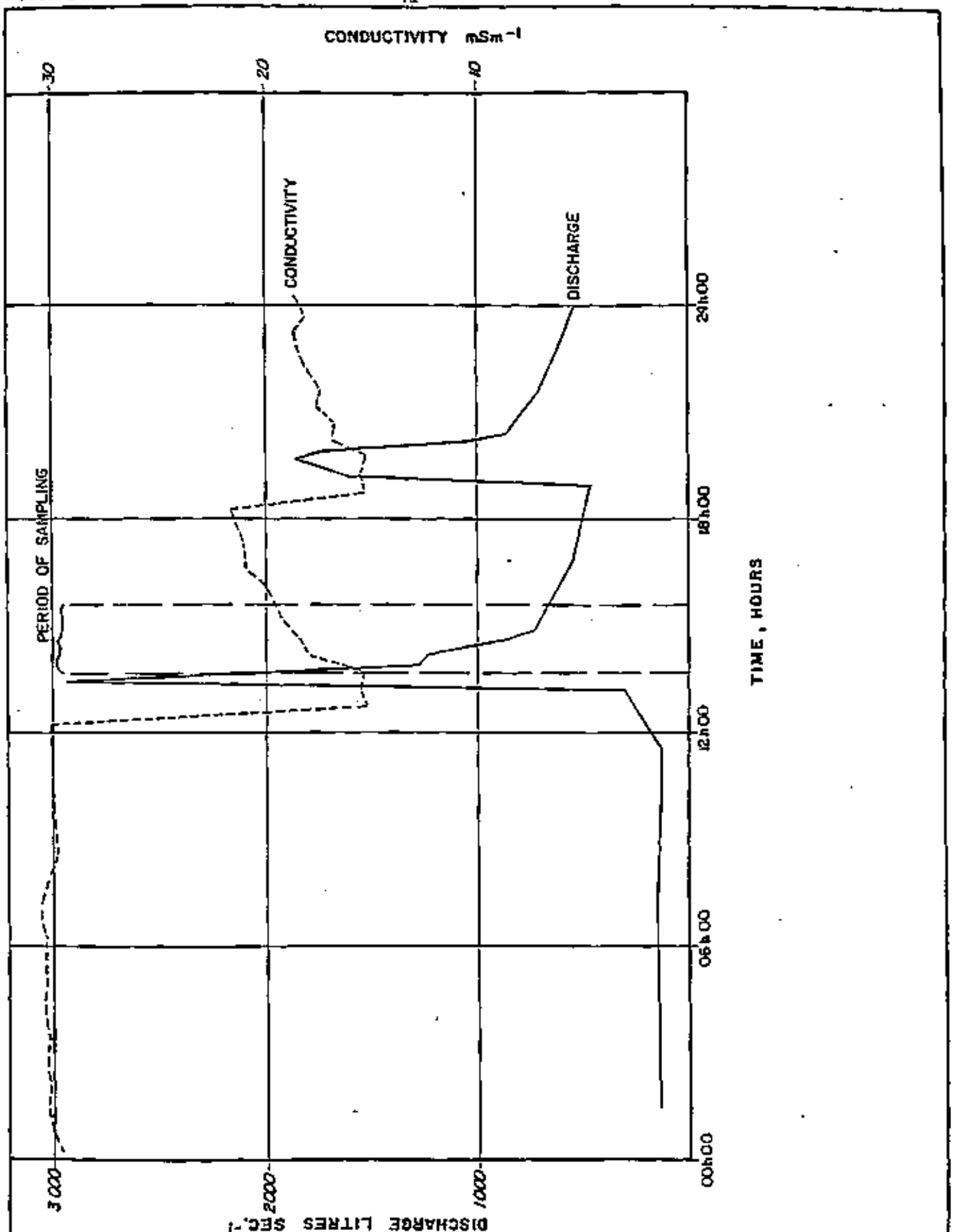
Analysis and interpretation of storm sampling

Five storms were sampled, three at Weir 1 and two at Weir 3. In general the results were similar for each storm, consequently only one storm at each weir is discussed.

The storm event occurring on the 26 December 1985 was monitored at both weirs and the analyses carried out on these events serve as a basis for discussion.

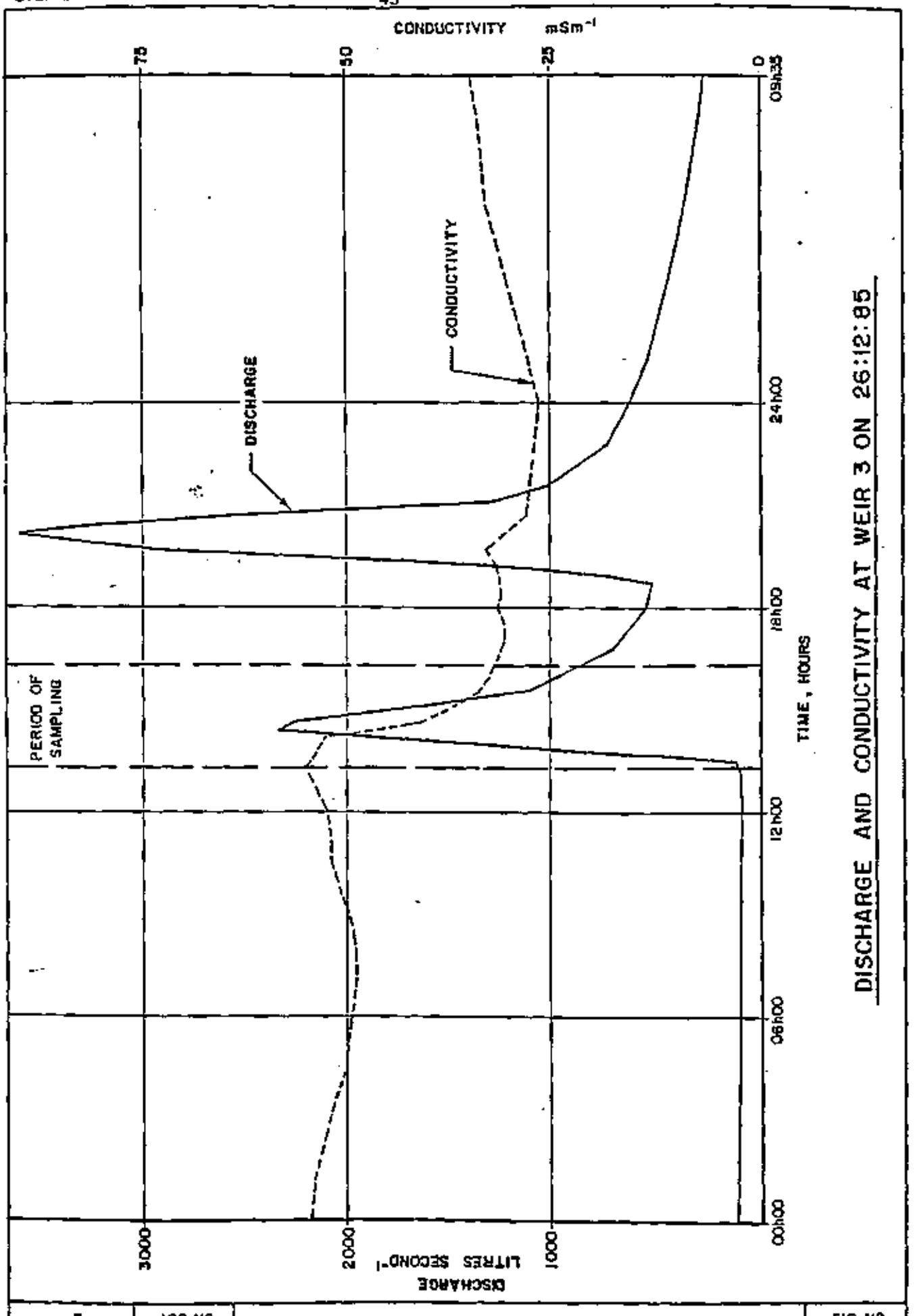
Figs 5 and 6 illustrate the variation in conductivity at the two weirs for the whole day in which the event occurred. Also shown in these figures is the period during which sampling was carried out. At Weir 1 the dilution effect is clearly seen; the conductivity fell rapidly with the arrival of storm runoff and recovered steadily during the hydrograph recession. This recovery was interrupted by the arrival of a second, smaller event which caused another drop in conductivity and subsequent recovery.

The situation at Weir 3 differed slightly in that the drop in conductivity following the arrival of the storm water occured later than at Weir 1 and continued to fall whilst the hydrograph receded. Just as the



DISCHARGE AND CONDUCTIVITY AT WEIR I ON 26:12:85

	JOB Nº		FIG Nº
	PT3632	WATER RESEARCH COMMISSION	5



DISCHARGE AND CONDUCTIVITY AT WEIR 3 ON 26:12:85

	JOB Nº		FIG Nº
	PT 3632	WATER RESEARCH COMMISSION	6

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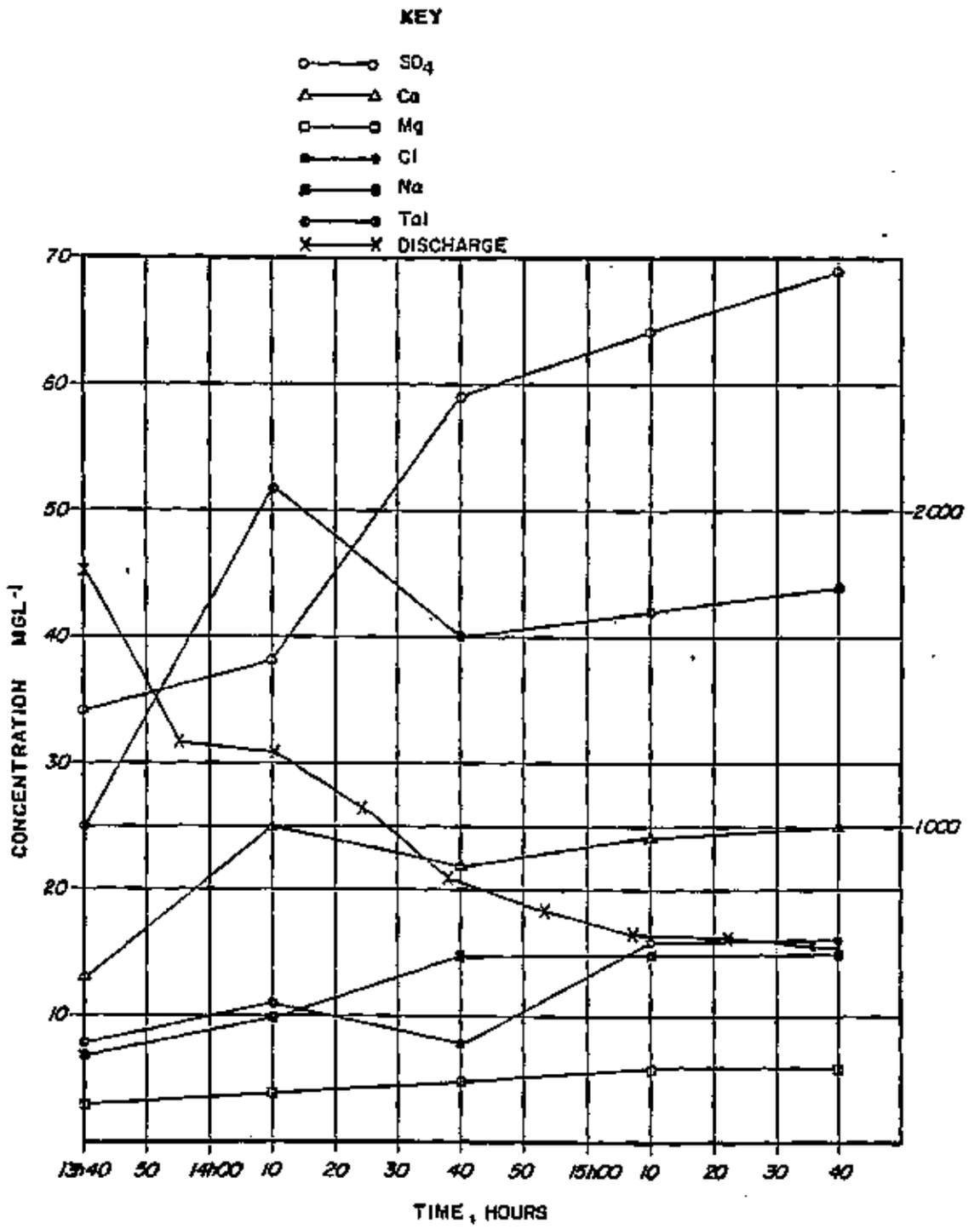
conductivity recovered, a second, much larger event occured causing the conductivity to drop again ,but only slightly compared to the volume of storm water. The conductivity gradually picked up as the second event receded and flow returned to baseflow. The surprisingly small drop in conductivity during the second event is believed to be due to the fact that the water has already been diluted to a quality similar to that in the storm runoff by the first event such that any further decrease is unlikely. In addition, there was less recovery in the value of conductivity before the arrival of the second event than was the case between events at Weir 1.

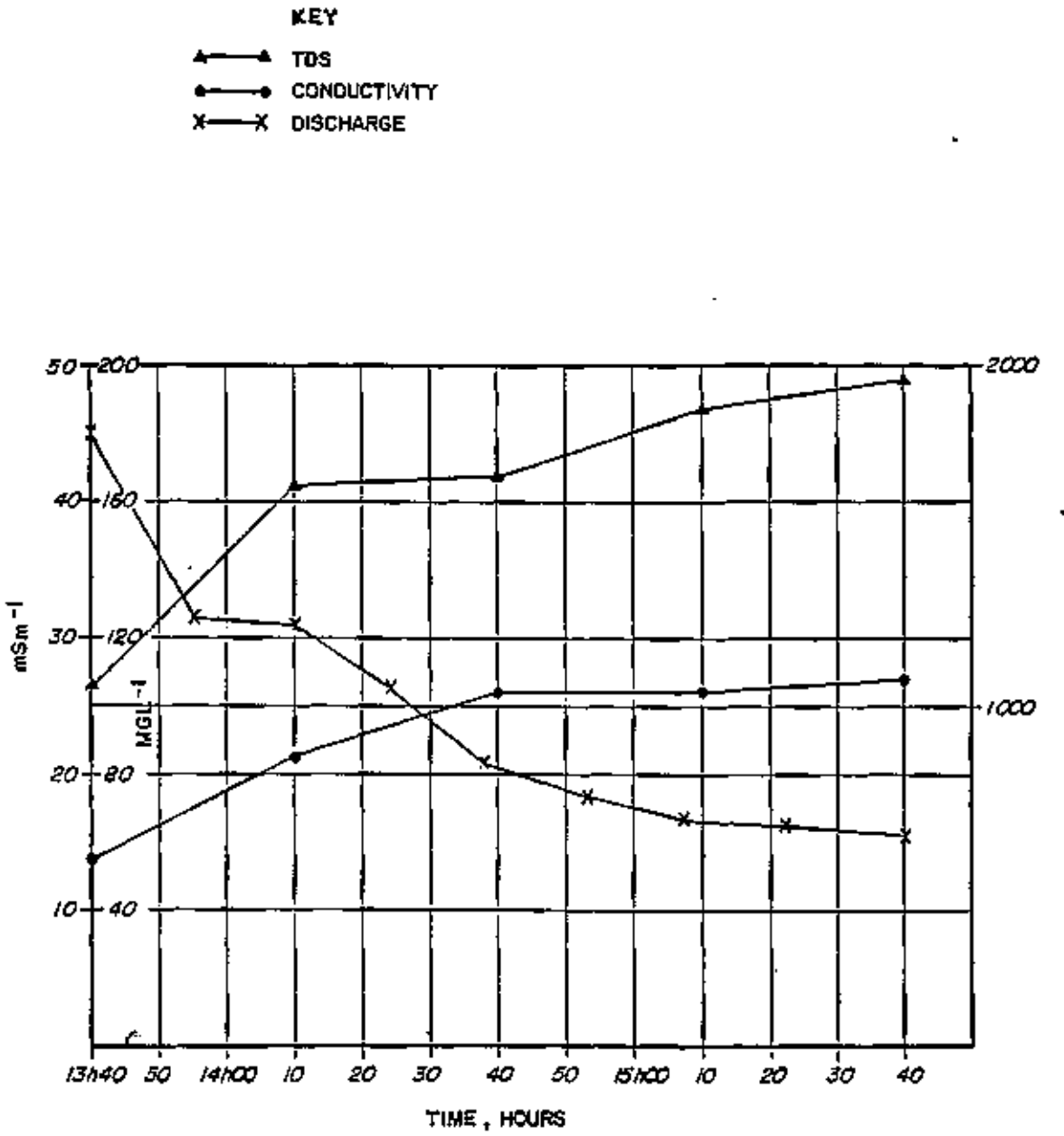
The variation in the concentration of the main constituents comprising TDS during the storm event at Weir 1 is shown in Fig 7 and the variation in TDS and conductivity is shown in Fig 8. As expected, conductivity closely follows the TDS curve as do sulphate and sodium. Total alkalinity, calcium and chloride show an increase in concentration corresponding to a deviation in the hydrograph recession (at time 14h10) which could be due to the removal of these salts from surface horizons by slower moving interflow.

Similar plots are shown for the variation in water chemistry at Weir 3 in Figs 9 and 10. Again conductivity and sulphate (which is a major component of TDS at this site) closely reflect the TDS curve, whilst the other major constituents show only a gradual decrease. An unexplained increase in magnesium occurs (at 14h20) whilst the hydrograph is still rising. In another sampled storm event an increase in both magnesium and iron was seen during the recession and a



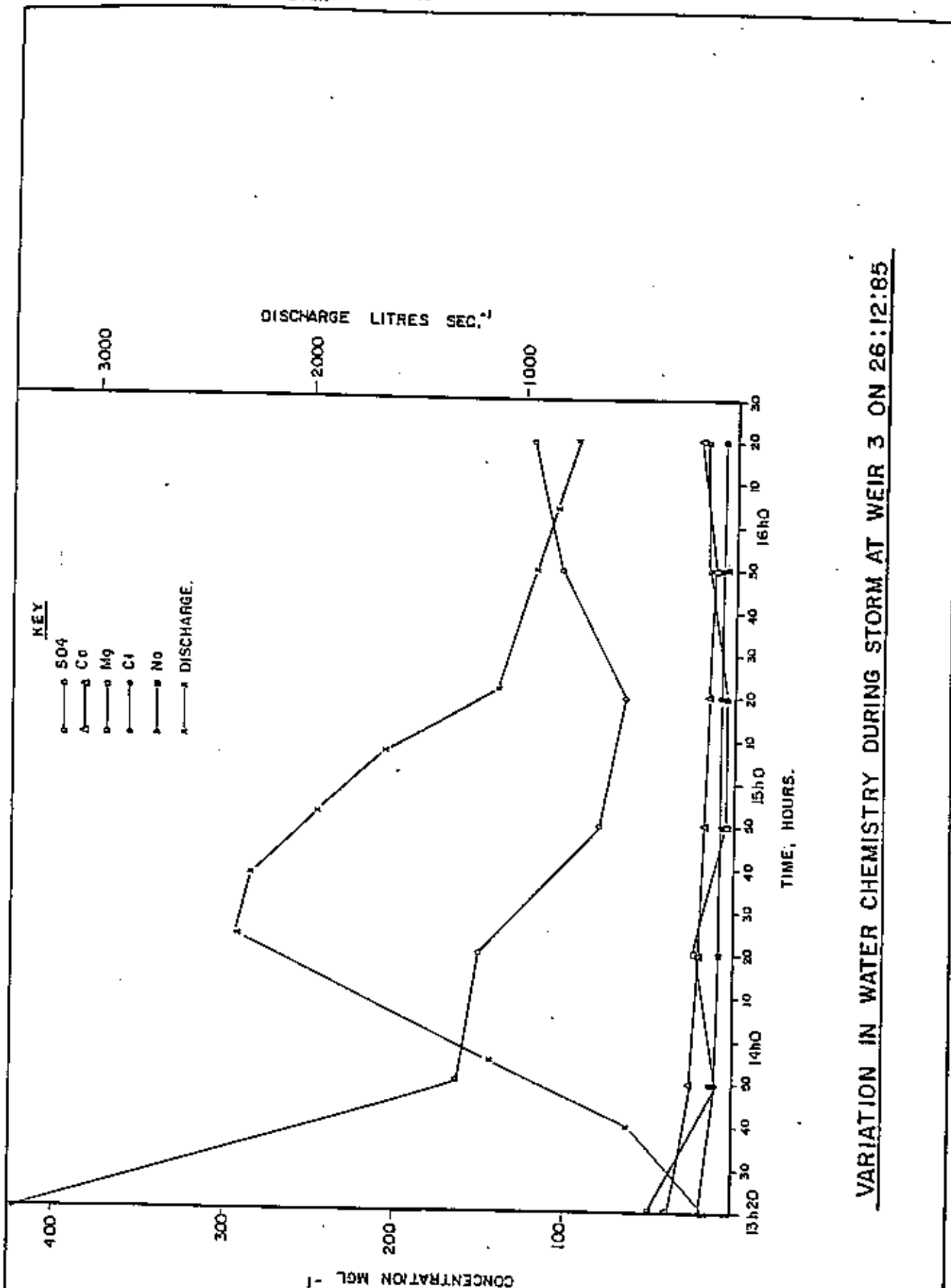
VARIATION IN WATER CHEMISTRY DURING STORM AT WEIR 1 ON 26:12:85

	JOB Nº		FIG Nº
	PT 3632	WATER RESEARCH COMMISSION	7

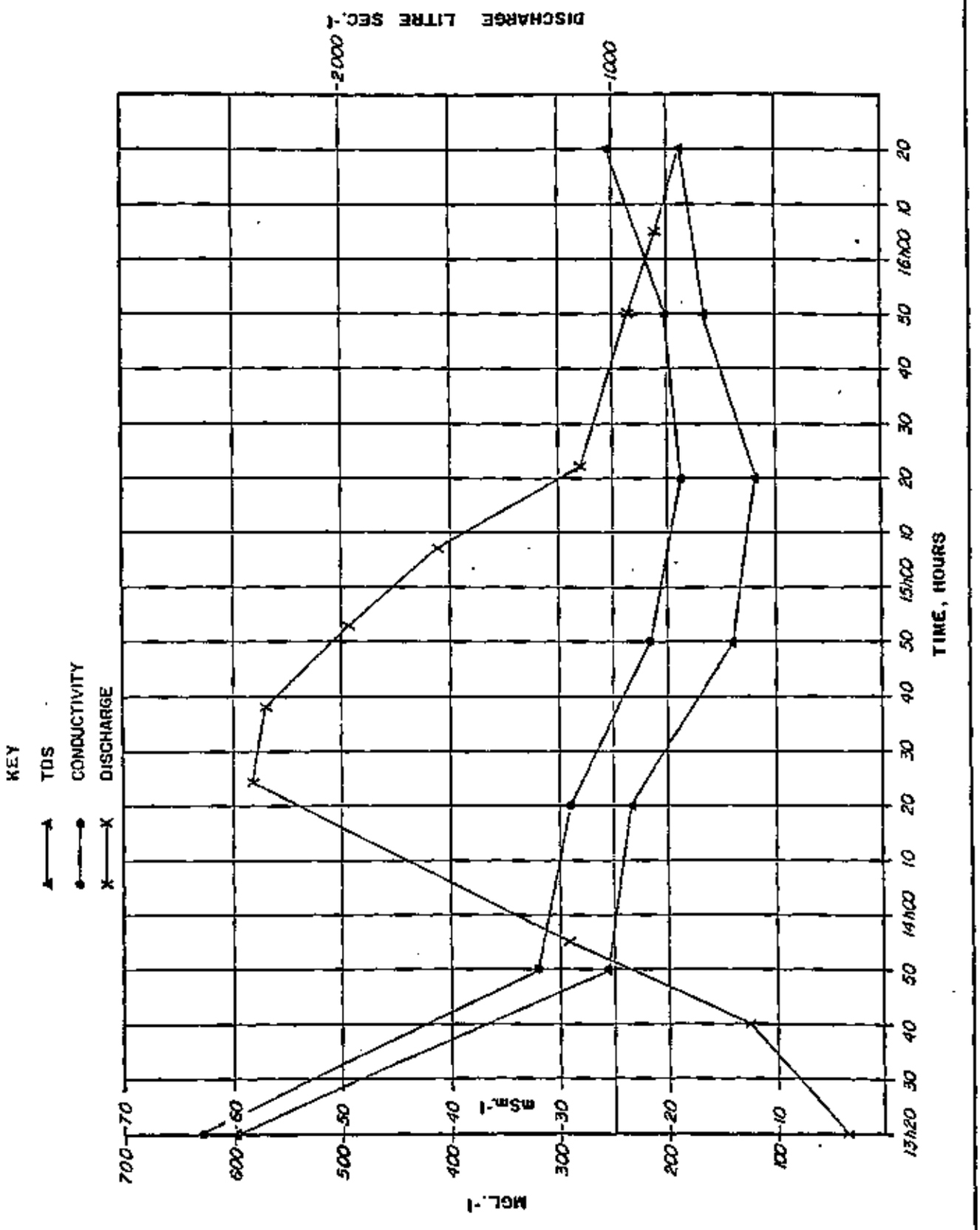


VARIATION IN WATER CHEMISTRY DURING STORM AT WEIR 1 ON 26:12:85

	JOB Nº		FIG Nº
	PT 3632	WATER RESEARCH COMMISSION	8



	JOB N9		FIG N9
	PT 3632	WATER RESEARCH COMMISSION	9



VARIATION IN WATER CHEMISTRY DURING STORM AT WEIR 3 ON 26:12:85

	JOB Nº		FIG Nº
	PT3632	WATER RESEARCH COMMISSION	10

similar mechanism to that proposed for total alkalinity, calcium and chloride at Weir 1 is believed to be responsible.

It is interesting to note that a negligible iron concentration existed during the event on December 26 at Weir 3 where, on average, iron represents 11 percent of the TDS. This event followed a period of ten days in which rain had fallen on eight days and flow was consistently above baseflow. Routine sampling three days prior to the event gave a pH value of 3,2, compared to the average for this site of 2,4. During the storm event, pH ranged between 4,0 and 4,7 and it was noted at the time of sampling that iron was being precipitated. It would seem that the large volume of storm runoff caused the pH to increase above 4,0 resulting in the formation of iron hydroxides which then precipitated out as a characteristic yellowish brown deposit known locally as "yellow-boy" and resulting in the low concentrations of iron in solution. In contrast, a smaller storm sampled on April 10th 1986 occurred following a period of sixteen days with no rain and when flow was less than half the average baseflow. In the routine sampling nine days prior to the event a pH of 2,1 was recorded and during the event the pH ranged from 2,0 to 2,7. The concentration of iron in solution varied from 415 $mg.l^{-1}$ to 37 $mg.l^{-1}$ compared to the average for the site of 113 $mg.l^{-1}$.

Comparison of average conductivity above and during baseflow

From the analyses of the storm events, it has been shown that stormwater runoff is, in general, of better

quality than streamflow. As a test of this contention a Student 't' test was carried out between the mean daily conductivities on days when only baseflow occurred and the mean daily conductivities when flow was above baseflow.

These tests showed that at Weirs 3 and 4 the conductivity was greater during baseflow confirming the hypothesis. At Weir 2 no significant difference was found between the mean conductivities above and during baseflow. This is not unexpected considering the ponding that occurs at this weir.

However, at Weir 1, the opposite result was found in that conductivity was greater above baseflow, although the difference in conductivities was small.

A possible explanation for the apparent anomaly at Weir 1 is that the quality of baseflow at the weir was good (the average conductivity during baseflow is 28mS.m^{-1}) and that the stormwater quality was similar (the average conductivity above baseflow is 30 mS.m^{-1}). At Weirs 3 and 4, the average conductivities of the baseflow were respectively 96 and 103 mS.m^{-1} so that the stormwater, which may be of similar quality to that running off in the vicinity of Weir 1, served to improve the quality of baseflow at Weirs 3 and 4. The average conductivity above baseflow at these weirs is 75 and 85 mS.m^{-1}, which was more than twice the value of conductivity during baseflow at Weir 1.

The results of these 't' tests were based on the mean daily values of conductivity and flow and not on individual storm events such as discussed in the previous section. A mean daily figure does not

reflect the short term variation that can occur on an event basis, so that the results obtained from these 't' tests are not strictly comparable to those obtained above in the storm event analysis. In fact, the analyses illustrate the influence of the antecedent conditions prevailing before the storm events. For example, the difference in the iron concentrations between the two events monitored at Weir 3 was due to the contrasting antecedent conditions. For the storm events discussed above, both flow and conductivity prior to the event at Weir 1 were higher than the average for that weir (139 compared to 70 $l.s^{-1}$ and 30 compared to 28 $mS.m^{-1}$) figures which were in agreement with the comparison of the mean daily figures. At Weir 3, flow preceding the storm was also slightly greater than average baseflow (110 compared to 100 $l.s^{-1}$) and conductivity was lower than that for baseflow (approximately 50 as opposed to 96 $mS.m^{-1}$). The conditions prior to the event then were in agreement with the results from the 't' tests.

Salt loads during storm events

Whilst it has been established above that the stream-water concentrations were generally diluted during a storm event it is still necessary to determine actual loads transported during these events. These were calculated for each of the five storm events sampled. The loads were calculated for the whole period during which flow was greater than the baseflow immediately prior to the event. These loads were then compared with the loads that would have been transported if no event had taken place. The latter were calculated by assuming that the baseflow and conductivity prevailing immediately prior to the events would have been

maintained throughout the period during which the events occurred. The results are shown in Table 11. This table shows that, although the effect of stormwater was to reduce the concentration of salts, the additional volume of flow resulted in a greater transport of salts during the storm event than would have been the case if no event had occurred. The final row in Table 11 shows the ratio of the storm load to the baseflow load. For these five events the storm load exceeded the baseflow load by between 18 % and 190 %.

The significance of stormwater runoff on the chemistry and salt levels in streamflow

From the preceding analyses it is apparent that the stormwater runoff did not detrimentally affect the quality of water in the streams. The effect was dependent both on the relative quality of the stormwater and the stream baseflow and also, on an event basis, on the antecedent conditions. On an event basis the effect of a storm was usually one of dilution as illustrated by the events occurring on 26th December 1985.

These analyses have shown that the quality of surface runoff was similar to that of the baseflow at Weir 1 resulting in little difference between the quality of water above and during baseflow. However, at Weir 3 where the quality of the baseflow was poor, the surface runoff diluted the flow resulting in lower concentrations in flows greater than baseflow.

It would seem that the poor quality of water in some areas of the City Deep study area is not exacerbated

TABLE 11 - COMPARISON OF ACTUAL STORM EVENT SALT LOADS WITH ESTIMATED BASEFLOW SALT LOADS

Date of storm	26/12/85	9/1/86	20/1/86	26/12/85	10/4/86
Weir	1	1	1	3	3
Time of start	10h35 26th	05h00 9th	22h35 19th	12h00 26th	09h00 10th
Conductivity mSm^{-1}	30	33	19	53	45
Discharge $l.s^{-1}$	137,0	82,6	187,3	114,1	48,9
Time of end	22h35 30th	12h45 10th	12h00 21st	07h10 28th	08h00 11th
Conductivity mSm^{-1}	34	34	18	52	132
Discharge $l.s^{-1}$	132,0	82,6	187,3	160,5	48,9
Estimated conductivity mSm^{-1}	32	34	19	53	245
Estimated baseflow $l.s^{-1}$	134,0	82,6	187,3	114,1	48,9
Load during storms, tonnes	29,33	4,02	13,28	21,4	13,70
Estimated load, no storm, tonnes	18,12	3,41	6,03	7,17	6,46
Storm load as % base load	162	118	220	290	212

by the flushing of salts from the residue surfaces or from other, impervious surfaces by surface runoff as evidenced by the dilution effect. It is possible that this type of flushing of salts occurs, but the effect is masked by the large volume of stormwater generated in the catchment. Although concentration levels are reduced by the addition of storm flow, the additional volumes of flow result in greater loads being transported from the study area than would have occurred in the absence of these events.

4 PHASE II - GROUND WATER HYDROLOGY

4.1 Introduction

Whilst this investigation was primarily a surface water study, it was recognized that leaching of salts from the mine dumps could cause contamination of the local ground water and that these contaminants, carried in the ground water, may find their way to surface streams and so contribute to the pollution of the water in the Vaal Barrage. It was therefore necessary to attempt to characterize the local, and possibly the regional, ground water regime in order to assess its role as a potential source of pollution.

This section describes the ground water investigation of the study area.

The approach to the investigation involved determining the general flow directions of the ground water and the variations in quality across the study area using available geological information and the auger hole and borehole data collected during the study period.

4.2 Sources of Information

No detailed geological maps of the City Deep site existed, so a map was compiled from the following sources:

- the 1:250 000 scale Geological Survey Sheet No 2628 of the East Rand;

- the 1:60 000 scale 'Geological Map of the Witwatersrand Goldfields' by E T Mellor (1917);

- a map, available at the offices of the City Engineer in Johannesburg, entitled 'Geological Map of Johannesburg' by Findlay and Van Nierop (1976);

- a plan of the City Deep underground workings, on a scale of 1:15 000, kindly supplied by Rand Mines Ltd.

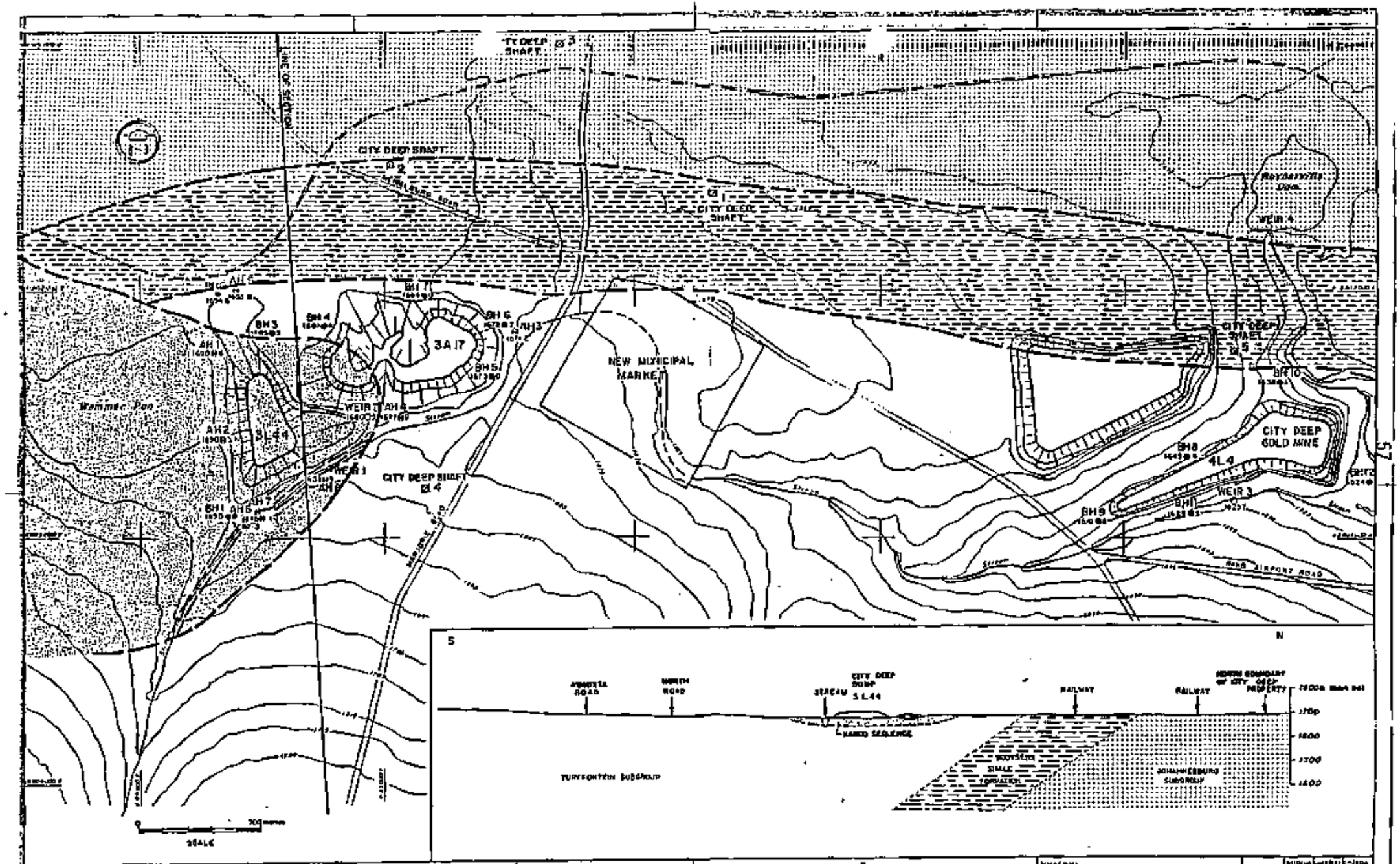
Unfortunately, each of the three surface geology maps show the boundaries of the various rock groups in slightly differing positions. This makes the precise locations of the geological boundaries on the composite map (Fig 11) uncertain. However, the accuracy of the composite map is sufficient for the current purpose.

4.3 Geology of the City Deep Study Area

The composite geological map (Fig 11), together with the accompanying cross section, shows that the geology at City Deep consists of rocks of the Witwatersrand Supergroup, which are overlain in the west by a thin outlier of Karoo Sequence sediments.

The names, lithologies and approximate thicknesses of the various geological units are given in Table 12.

The composite geological map shows no diabase dykes or sills, although many intrusions were recorded on the City Deep underground mine plan (Appendix B). From the topography of the area, the large intrusions would be expected to account for the valleys in the quartzite to the south and east of the mine dumps. However, thorough field checking of the stream beds revealed no signs of intrusions or faults. The exception to this is a length of stream in the western area of the site between Weir 1 and auger hole (AH) 7 where the bedrock is not exposed. The central, low-lying, area containing the main City Deep deposits also has a noticeable absence of



APPROXIMATE GEOLOGICAL BOUNDARY

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COMPOSITE GEOLOGICAL MAP OF CITY DEEP

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FIGURE NO. 11

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TABLE 12 - THE LITHOLOGIES OF ROCK UNITS UNDERLYING THE CITY DEEP AREA (BRINK, 1979)

Name		Lithology	Thickness (m)
Karoo Sequence	Ecca Group	Shale, sandstone, clay, conglomerate	? 0-20
	Dwyka Formation	Tillite, shale	
	Turffontein Subgroup (formerly Kimberley Elsberg Series)	Coarse grained, polymitic conglomerate	500
		Gritty subgreywacke - quartzite	900
Witwatersrand Supergroup		Well sorted and rounded conglomerate with argillaceous quartzite and shale bands	300
	Booysens Shale Formation (formerly Kimberley Shale)	Shale, siltstone	150
	Johannesburg Subgroup (formerly Main-Bird Series)	Quartzite with conglomerate bands and amygdaloidal lava horizon	200
		Quartzite with glassy zones and pebbly conglomerate bands	750

rock, with the streams deeply incised into soil. This strip of land runs parallel to the strike of the Witwatersrand rocks and may be underlain by a shale horizon, possibly Booysens Shale, or a sill. However, there is no further evidence available to support this.

Drill cuttings were logged from the percussion drilling of the boreholes drilled for water sampling (Section 2.5), and the borehole logs are included in Appendix C. They confirm the basic geology shown on the geological map (Fig 11) - except that BH1 encountered residual and weathered

Witwatersrand quartzite as opposed to Karoo sediments - and reveal the nature of the materials underlying the site in more detail.

The western part of the site, adjacent to Wemmer Pan, has a variable depth of weathering, with weathered quartzite being recorded to at least 55 m depth in BH1 and 40 m in BH2. The depth of weathering appears to decrease east of BH4 and unweathered quartzite was found at 12 m below surface in BH7. Unweathered quartzite was also found at 19 m depth in BH5 and BH6.

BH2 may have intersected an acid rock intrusion between 14 m and 15 m depth, but this could not be confirmed. BH7 passed through mine sand in the top 6 m.

The eastern side of the study area has a more uniform geology. Transported and residual soils are approximately 1 m to 2 m thick, and unweathered quartzite occurs between 6 m and 34 m below ground level.

Typical soil-rock profiles from the two parts of the site are:

WEST		EAST	
0 - 1 m	Reddish brown colluvium	0 - 1 m	Reddish brown colluvium
1 - 3 m	Light yellow and brown residual quartzite	1 - 15 m	Pinkish-grey, weathered and slightly weathered quartzite

3 - 20 m	Light yellowish grey, weathered and slightly weathered quartzite	below 15 m	Yellowish-grey and greenish-grey unweathered quartzite
below 20 m	Greenish-yellowish grey, unweathered quartzite		

Ground water was encountered in all the boreholes, but at greatly varying depths (Table 1 p 15). These indicate that the water is held in widely spaced fractures and only enters the borehole when a fracture is intersected. It is probable that free-flowing ground water is also present in the soils covering the site. A permeability contrast is likely to exist between the soils and the rock resulting in increased flow along the soil-rock boundary.

4.4 Analysis and Interpretation of Data

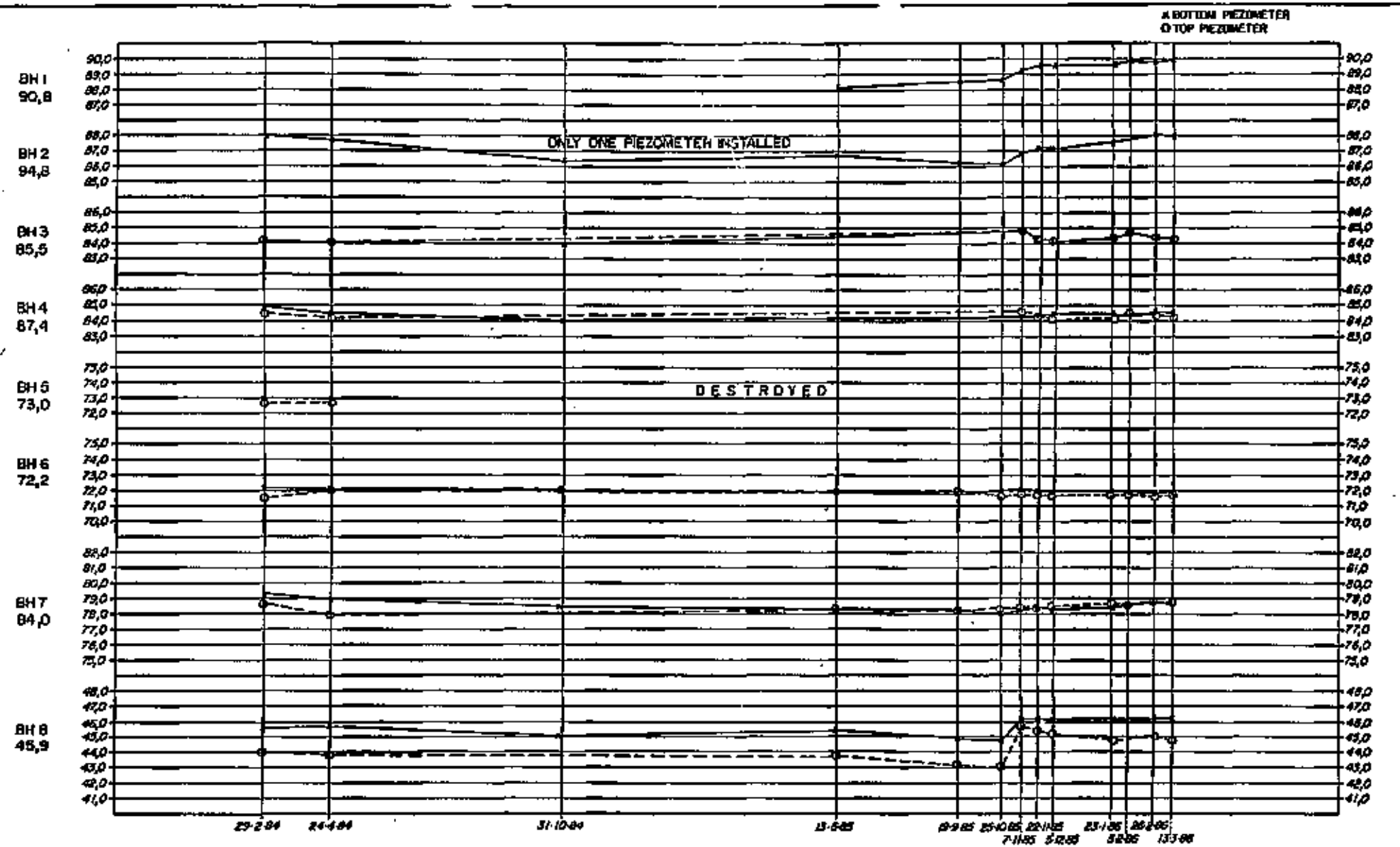
4.4.1 Water level results and interpretation

The water level results obtained from the borehole monitoring programme are summarised in the piezometric charts in Figs 12(i) and 12(ii).

The chart shows three points of interest:

i) the water levels in the two piezometers in each borehole remained very similar throughout the 25 month observation period;

ii) the movements of the water levels with time were substantially the same in all of the boreholes;



NOTE/AANTEKENINGE

ALL HEIGHTS +1600m ABOVE MEAN SEA LEVEL
i.e. 87,4 = 1687,4m

BH4 BOREHOLE ELEVATION
87,4

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TITLE/TITEL

PIEZOMETRIC LEVEL CHART
WESTERN AREA

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FIG. No.
12 (i)

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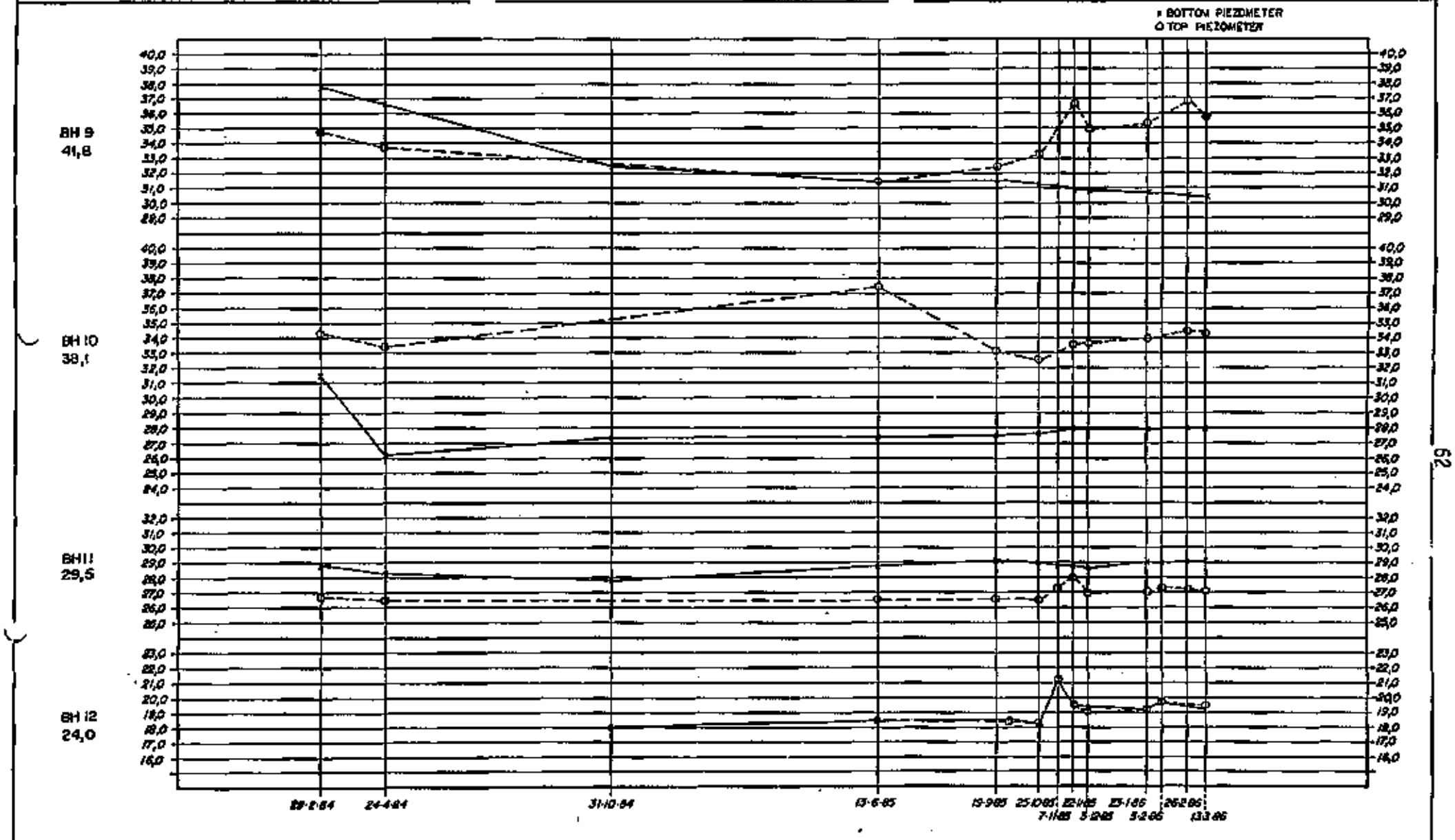

NOTES/AANTEKENINGE

ALL HEIGHTS ARE +1600m ABOVE MEAN SEA LEVEL
i.e. 87,4 = 1687,4m

BH4 BOREHOLE ELEVATION
87,4

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TITLE/TITEL
PIEZOMETRIC LEVEL CHART
EASTERN AREA

CLIENT/KLIENT
WATER RESEARCH COMMISSION

FIG. No.
12(II)

JOB No.
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iii) the water levels in the boreholes are close to ground level.

The first two points indicate that all of the piezometers on the site are measuring the same ground water body.

The exceptions to these observations are BH9 and BH10 in which the water levels in the piezometer pairs are markedly different, and the water levels in the bottom piezometers are up to 11 m below ground level. At present, the reasons for this behaviour are unknown.

The water levels in the vicinity of BHs 5,6 and 8 are very close to ground level, which accounts for the marshy areas around these boreholes. The area around BHs5 and 6 was continuously wet, while that around BH8 only became marshy in the latter part of the monitoring programme.

The water levels in the auger holes were monitored for a period of nine months from June 1985 to March 1986. During this time there was very little variation in the water levels and the averages for the period are given in Table 13.

The average water levels measured in the piezometers have been used to draw approximate piezometric maps of the ground water in the western and eastern areas of the site. These are given in Figs 13 and 14 respectively.

The map of the western area shows a drop in ground water elevation of about 16 m from west to east, which is consistent with an easterly flow direction. The

TABLE 13 – AVERAGE WATER LEVELS MEASURED IN THE AUGER HOLES

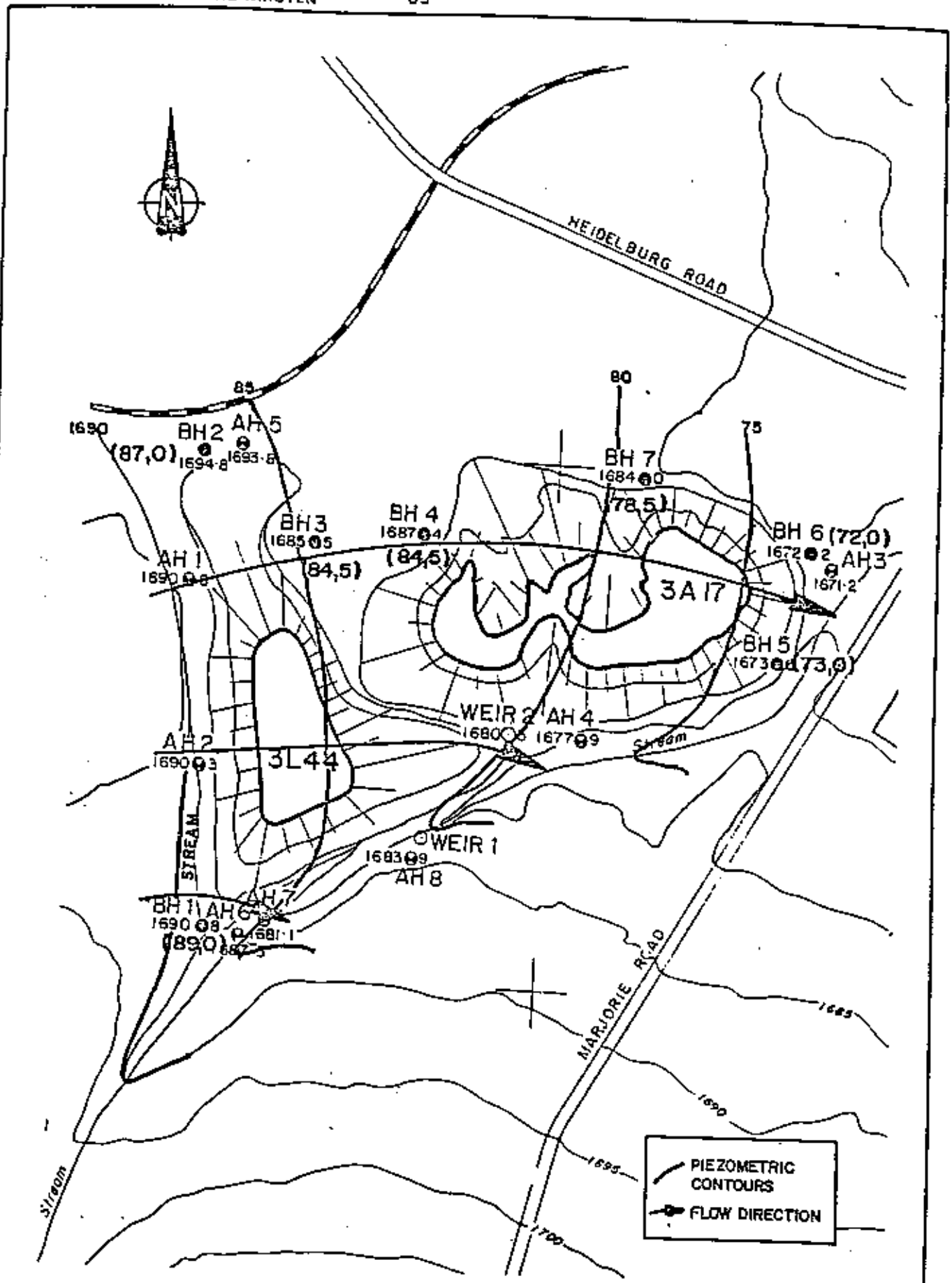
Hole No	Average water level (m above mean sea level)
1	1689,0
2	1689,0
3	1671,0
7	1684,5
8	1680,5

flow rate is, however, unknown. Shallow groundwater near the southern edge of the site flows into the stream, and the very shallow ground water contained in the soils, locally flows perpendicular to the contours, but eventually flows in an easterly direction falling 18,5 m between AH1 and AH3.

The map of the eastern area shows the ground water flowing into both the southern and the eastern streams with a drop in the ground water levels of 17,5 m and 26 m respectively. The very shallow ground water in this area also follows the contours so the flow directions are similar to that of the deeper ground water.

4.4.2 Variation in ground water quality within the study area

Piezometer levels from the boreholes were recorded over a two year period, with water samples being collected simultaneously for macro- and micro-analyses in the laboratory. These were analysed for the same constituents as the surface water samples (Section



PIEZOMETRIC MAP FOR WESTERN AREA OF CITY DEEP

	JOB Nº		FIG Nº
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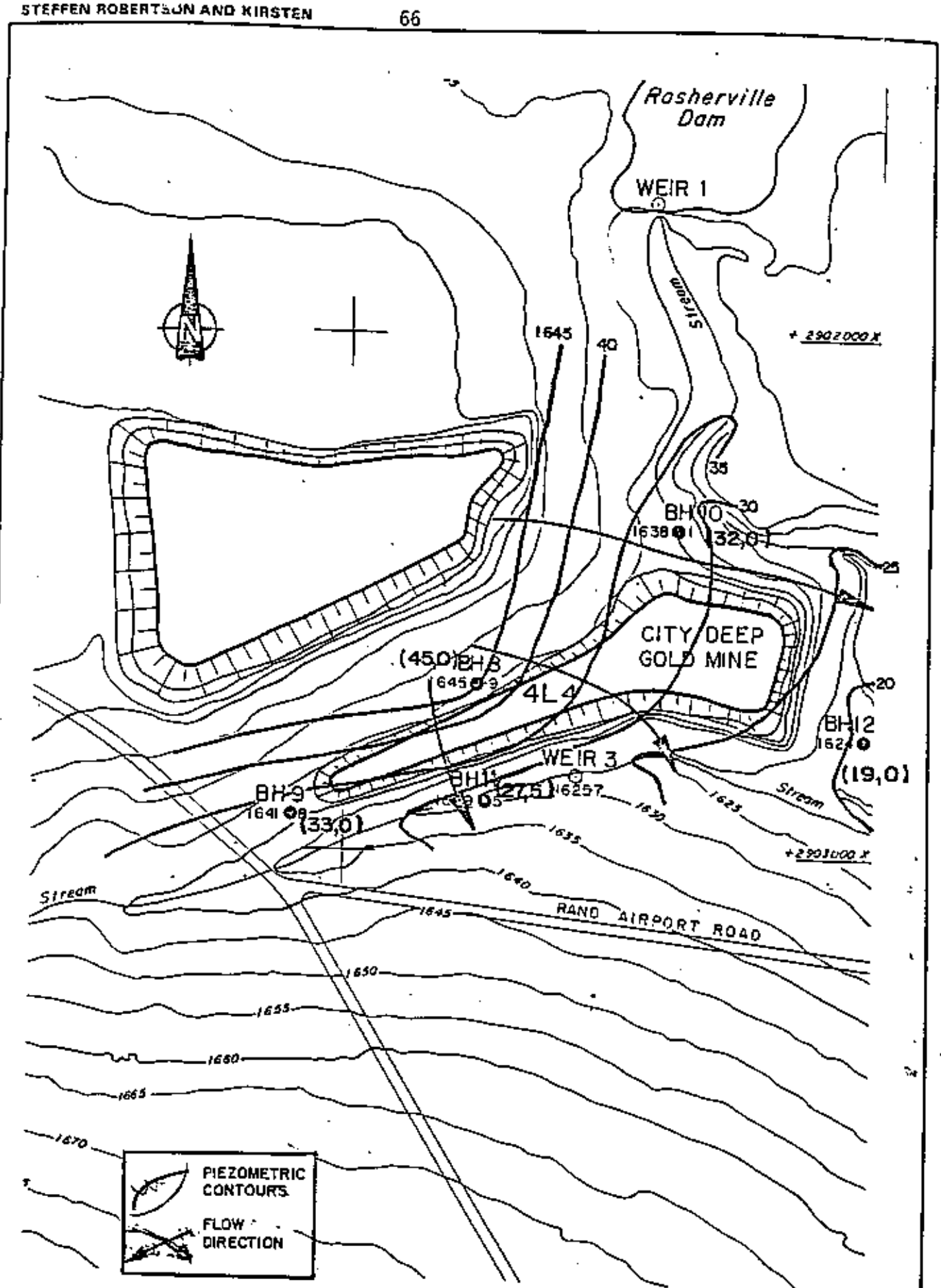

PIEZOMETRIC MAP FOR EASTERN AREA OF CITY DEEP

	JOB Nº		FIG Nº
	PT 3632	WATER RESEARCH COMMISSION	14

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3.1.2). A total of 15 sets of samples were collected during the study period. Water samples were similarly collected and analyzed from the five operational auger holes.

The discussion in Section 3.2.3 on the analysis of water samples is equally applicable to the ground water samples.

For ease of interpretation, the results discussed here are the mean values of pH and concentration of TDS only. These are useful indicators of the overall ground water quality, and their values are summarised in Table 14.

TABLE 14 - MEAN pH AND TDS FOR GROUND WATER SAMPLES

BH No	Top piezometer (B) pH	TDS ($mg.l^{-1}$)	Bottom piezometer (A) pH	TDS ($mg.l^{-1}$)	TDS Ratio
1	5,0	266			
2	6,8	346			
3	6,8	2305	6,2	2444	1,06
4	4,3	1159	6,9	543	0,47
5	2,5	1562	2,8	1506	0,96
6	2,7	70994	2,3	3190	0,05
7	2,8	42796	2,6	1463	0,03
8	6,3	3788	5,8	3369	0,97
9	3,7	1665	3,6	1768	1,06
10	4,7	2923	3,7	3720	1,27
11	2,4	5945	2,4	1849	0,31
12	6,6	3245	5,8	2097	0,65

Mean pH calculated from anti-log values.
Ratio of TDS concentration in bottom to top piezometers.

In order to compare the ground water data with the surface and shallow ground water data, the pH and TDS analyses from the surface sample points are retabulated along with those for the auger holes and are given in Table 15. The locations of these points, together with the auger and borehole positions, are shown in Fig 2. The mean values were obtained from a total of 54 surface water samples and 15 soil and ground-water samples.

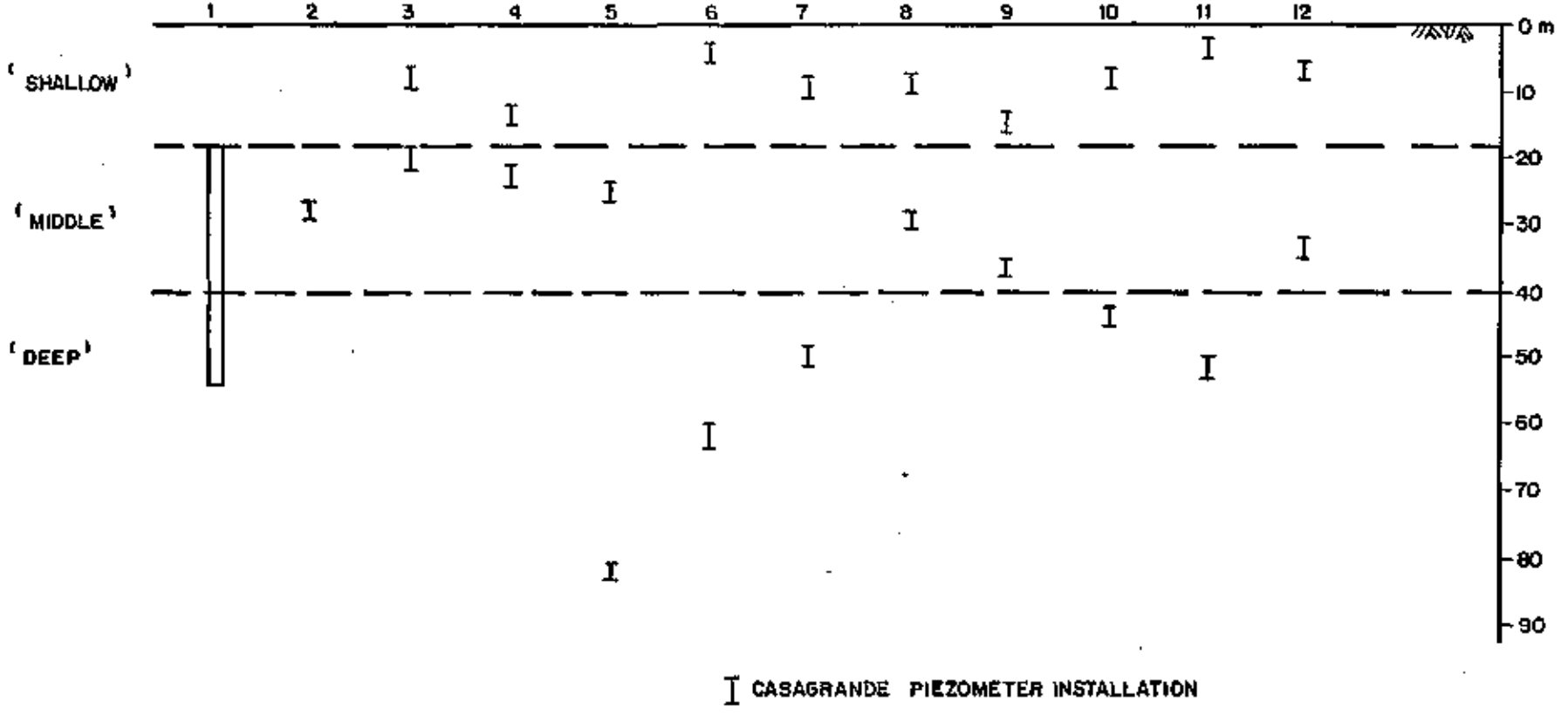
Since the geology encountered in the boreholes is fairly consistent across the site, similar attenuation properties of the rocks in each of the boreholes seems likely. Fig 15 compares the relative depths of the piezometers below ground level, and divides them into three groups based on depth. The shallow group contains nine piezometers between surface and 18 m below ground level; the middle group contains seven piezometers between 18 m and 40 m depth; and the deep group comprises five piezometers between 40 m and 90 m below ground level.

In the following discussion the quality of the water is discussed at four different levels; "the very shallow" level refers to the water sampled from the surface and from the auger holes, the "shallow", "middle" and "deep" levels refer to the three groups defined above. Reference to "very shallow", "shallow", "middle" and "deep" ground water is not intended to imply that four separate bodies of ground water exist. The terms are used to refer to four different depth ranges at which the water quality was sampled.

TABLE 15 - MEAN pH AND TDS FOR SURFACE WATER AND AUGER HOLE SAMPLES

Sample Point No	n	pH	TDS(mg.l^{-1})
S1		6,5	259
S2	54	6,7	255
S3		6,8	277
S4		6,8	266
S6		2,8	3050
S7		6,6	267
S8		2,7	820
S9*		2,3	59 890
S10		2,5	954
S11		2,5	973
S12		3,8	767
S13		3,8	792
S14*		2,3	28 223
AH1	15	4,5	304
AH2		4,5	698
AH3*		2,4	36 634
AH7		3,5	861
AH8		5,3	181

n is number of samples.
Mean pH calculated from anti-log values.
S1 to S14 : Surface water samples.
AH1 to AH8 : Auger hole samples.
* These levels are affected by toe dam seepage



DEPTHS BELOW GROUND LEVEL OF BOREHOLE PIEZOMETERS

IN CITY DEEP STUDY AREA

WATER RESEARCH COMMISSION

JOB No PT3632

FIG No 15

STEFFEN ROBERTSON AND KIRSTEN

The relative improvement in the concentration of TDS between the top and bottom piezometers in the boreholes can be inferred from the ratios of TDS concentrations in the bottom and top piezometers for each borehole which are listed in Table 14 (p 67).

The two areas of the City Deep site are discussed separately since, as with the piezometric levels, there appears to be very little correlation between them.

Western area

The variation in water quality in the western section of the study area is by no means clear, either in a horizontal or vertical direction.

However, the following observations can be made:

i) "Very shallow" ground water

These samples were obtained from auger holes 1, 2, 3, 7 and 8. Although generally of a poorer quality than the stream water, the water in the auger holes also shows a sharp deterioration in quality at the tip of sand dump 3A17. (AH3, pH = 2,4, TDS=36634).

There is slight contamination in auger holes 1 and 2, but the quality of water in AH8 is good.

In general, the pH of this water is 2 to 3 units lower than the adjacent surface water, but the TDS only shows a slight increase.

ii) "Shallow" ground water

As with the surface water and very shallow ground water, the quality of the shallow ground water deteriorates markedly towards the eastern end of the sand dump 3A17 (BH4, pH=4,3, TDS=1159; BH6, pH=2,7, TDS=70994). Both to the west of the dump, and near the eastern tip, however, the quality of the shallow ground water is worse than that of nearby surface water.

Poor quality water was also found in BH7.

iii) "Middle" ground water

The results from BHs 1 and 2, which were drilled to the west of slimes dam 3L44, show that at this depth the ground water is of relatively good quality before it reaches the mine deposits.

Of the five boreholes monitoring the middle ground water in this area, only two also monitor the shallow ground water. In BH3, the water quality does not change with depth, whereas in BH4 there is an increase in TDS of just over 50% with depth.

iv) "Deep" Ground water

Three piezometers in BHs 5, 6 and 7 measure the deep ground water under the northern and eastern parts of the western area. In two of these (BHs6 and 7) the improvement in the TDS concentrations compared to the shallow ground

water is pronounced, with both showing less than 15 % of their values at the shallower depth. The pH values, however, do not improve with depth and, within the accuracy of pH measurement, are the same as those of the shallow ground water.

In BH5 there appears to be a slight improvement in quality between the middle and deep ground water, but, as with the pH differences in BHs 6 and 7, these are so close to the accuracy of determination that the values from the bottom and the top of the piezometers should be considered to be the same.

In summary, the TDS decreases considerably between the shallow and deep ground water in BHs 6 and 7, but the pH at these sites and the pH and TDS in BH5, show no change with depth.

Eastern area

i) "Shallow" ground water

The five boreholes in the eastern City Deep area all have piezometers monitoring the shallow ground water. They show this to be moderately contaminated at all of the sites with BH11 being the worst (pH=2,4, TDS=5945).

BHs 8 and 12 have relatively neutral pH (6,3 and 6,6 respectively) and high TDS (3788 and 3245). This is also found to a lesser extent in BH10 (pH=4,7, TDS=2923).

ii) "Middle" ground water

The lower piezometers in BHs 8, 9 and 12 measure the middle ground water.

In BHs 8 and 9, the quality remains essentially unchanged from the shallow ground water, with a possible slight decrease in pH in both boreholes (5,8 and 3,6 respectively), and a slight increase in TDS in BH9 (6%). In BH12, the pH is slightly lower and the TDS better (pH=5,8, TDS=2097).

iii) "Deep" ground water

The deep ground water is monitored in BHs 10 and 11.

In BH10, both pH and TDS are worse than in the shallow ground water (pH=3,7, TDS=3720), but in BH11 the pH and TDS are essentially unchanged.

In the eastern section of the study area then, there is a slight tendency for the water quality to deteriorate with depth although there is little change from the shallow to middle levels.

5 DISCUSSION OF RESULTS AND CONCLUSIONS FROM PHASE II

5.1 Discussion of Surface Water and Ground-water Studies

The characteristics of the surface water and ground water in the City Deep area have been considered separately in Sections 3 and 4. It is necessary to consider them in combination in order to postulate mechanisms for the movement of water and pollutants in the system. Again the site is considered in two parts, the Western and Eastern areas.

5.1.1 Western area

The surface water quality south and west of sand dump 3A17 is good. Although the qualities at sites S2 and S3 (and to a lesser extent between S1 and S4) are similar, this does not strictly mean that pollutants from either of the mine deposits do not enter the surface water, since no flow measurements were made at the surface sampling sites. Since the quality of any water entering the system from the dumps would be expected to be poor however, any significant inflow would have an effect on the quality in the stream. It is concluded that such inflow is insignificant in the context of this study.

The back-up of water and low flow over Weir 2 causes pollutants present to be concentrated in the water by evaporation which, on the Witwatersrand, exceeds precipitation by about 800 mm/a. This factor, along with possible seepage from the deposits, explains the unfavourable results from surface sampling point S6.

The slight contamination measured in auger holes 1, 2, 7 and 8 is probably caused by localised seepage from

slimes dam 3L44 towards the adjacent streams. The contamination is not evident at the nearby surface sampling points because it is diluted by the much larger volumes of better quality water flowing in the streams.

It has been shown in Section 3.2.6 that the concentrations of salts in the streams is not due to storm runoff from the mine dump surfaces. The mechanism postulated for the contamination of the surface water at the eastern toe of the sand dump is illustrated in Fig 16 and described as follows:

Rainwater collects on the top of the sand dump during periods of precipitation and a large proportion infiltrates into the dump material. (Although the annual evaporation for City Deep is approximately twice the annual precipitation, these figures are misleading and precipitation, evaporation and infiltration should be considered on a daily basis. When it is raining very little evaporation will occur).

The infiltrating rain water percolates through the dump gradually increasing the thickness of the oxidized layer. Water moves along flow lines parallel to the surface eventually emerging at the base into the toe dam. The water flowing nearer the centre of the dump flows slightly eastwards entering a saturated zone which has developed because of the relatively low permeability of the natural soils and the presence of practically impermeable quartzite bedrock. Water then probably flows along the soil-rock boundary into the stream where it mixes with the surface water. The

WATER TABLE PERCHED ON SLIMES LAYER.

OXIDIZED AND PARTLY OXIDIZED SLIMES.

OXIDIZED AND PARTLY OXIDIZED SAND

BH.2.

BH.3.

BH.4.

BH.7

BH.6.

TOE DAM S14

STREAM S9

1700

1600

SOIL

WEATHERED AND SLIGHTLY WEATHERED QUARTZITE

UNWEATHERED QUARTZITE WITH WATER IN FRACTURES

BOOYSENS SHALE

METRES ABOVE MEAN SEA LEVEL

WATER RESEARCH COMMISSION

JOB NO PT 3632

FIG NO 16

SCHEMATIC DIAGRAM OF POLLUTION MECHANISM FOR WESTERN CITY DEEP

proportion of seepage from the sand dump to the ground water system which is intercepted by the stream is unknown. There are indications from the deeper piezometers which are below the stream bed that some seepage is not intercepted. Because of the probable impermeability of the underlying rock it has, however, been assumed that the load of 2 300 t/a intercepted by the stream represents the majority of the seepage from the sand dump.

A possible explanation of the anomaly between the water qualities at S9 and S14 is that the water entering the toe dam percolates through nearsurface material which has already been oxidized and leached. The water entering the stream has infiltrated through material nearer to the centre of the dump, where oxidization and leaching has been less complete, resulting in a more highly mineralized leachate.

The quality measured in AH3 is intermediate between that of S9 and S14 because the water is derived from both shallow-flowing and deep-flowing water from the dump.

A similar mechanism may apply for the slimes dam, except that the horizontal layering and low vertical permeability in the dam encourage a perched water table to form and seepage to occur towards the sides of the deposit.

5.1.2 Eastern area

Because of the paucity of reliable ground-water data for the east of the site, only a few basic conclusions can be drawn concerning the general water quality in this area.

The surface water is of poor quality when it reaches slimes dam 4L4. In the southern stream the source is probably sand dump 3A17, but in the Rosherville stream the source is unknown. Since the qualities at sampling sites S12 and S13 are similar, and reasonably good, it is assumed that pollutants from 4L4 contribute negligible load to the total export of mineral salts from the study area (see Section 5.1.1).

The generally poor ground-water quality in the eastern area of City Deep may be caused by infiltration of rainwater through the slimes dam, but, because of the internal stratifications and very low vertical permeability, this volume is thought to be small. The ground water pollution may be carried in to the area from many other sources. This is supported by the general lack of improvement, and even deterioration, in the quality of the ground water with depth. The quality of samples from the boreholes do appear to show a plume effect from the north side of the dam to the south and east sides, with the more polluted water descending in these directions to produce the poor results from the deeper piezometers in BHs 11 and 12. Water samples at more frequent depth intervals would be needed to confirm this.

5.2 Conclusions from Phase II

It has been shown that the quality of water upstream of the monitored deposits is good, but that it deteriorates in a downstream direction with a marked deterioration immediately downstream from sand dump 3A17. Evidence suggests that this dump pollutes both the stream and the ground water, since the concentration of dissolved solids increases from typically 250 $mg.l^{-1}$ at Weir 1 to 950 $mg.l^{-1}$ at Weir 3. Rainfall which

infiltrates the dump collects the products of pyrite oxidation on its way through the dump and emerges at the base as a mixture of toe seepage and seepage to a near-surface ground water system, both of which recharge the adjacent stream. It is assumed that the major part of this seepage is intercepted by the stream.

It is estimated that this dump produces approximately 2300 t/a of TDS which is exported from the study area. Including the smaller contributions from slimes dam 3L44 (40 t/a) and the contributions brought in from upstream of the study area, this figure rises to 5624 t of which 3370 t are sulphates (see Section 3.2.5).

These figures may be compared with those estimated in a desk study for the same area (Funke, 1984). The combined flows from Weirs 3 and 4 (see section 3.2.1) can be compared to the mean annual flow for 1982/83 estimated by Funke. The figures are shown in Table 16.

TABLE 16 - ANNUAL FLOW AND LOAD FROM STUDY AREA

Year	Rainfall (mm)	Runoff ($m^3 x 10^6$)	TDS (t)	SO_4 (t)
1985	705	10,491	5624[1]	3370
1982/83[2]	506	0,438	471	288

[1] Includes imported from upstream of study area

2 From Funke, 1984

As can be seen the 1985 figure is considerably greater than the figure for the drier period 1982/83. However, it is argued below, from a general hydrological basis, that the more recent runoff figure is reasonable.

Weirs 3 and 4 drain a catchment area of approximately 86 square kilometres. For an annual rainfall of 705 mm, a total volume of 60,63 $m^3 \times 10^6$ would have fallen on the area. The streams in the City Deep study area are probably fed by groundwater since flow has been recorded throughout the study period despite prolonged periods when no rain fell. The contribution to this flow from spillage by industry in the catchment is however unknown. The source of this groundwater is thought to be from the suburbs to the south of the study area flowing into the stream monitored by Weirs 1 and 3, and from the Jeppe area to the north into the Rosherville stream monitored by Weir 4 (S.L.V.Venter, 1986). By subtracting a baseflow of 4,26 $\times 10^6$ m^3 (assumed to originate from ground water, see Table 5, p 24) from the total flow recorded and ignoring evaporation, a value of 6,233 $\times 10^6$ m^3 is found representing surface runoff. This gives a percentage runoff of 10,3% which is a reasonable figure for an urban area. In a recently completed study by SRK on the runoff from the Apies River in the urbanized area of Pretoria, the direct runoff under similar rainfall conditions was found to be 22%. In contrast, the 1982/83 figure represents a total runoff of only 1,0% of the rainfall in that hydrological season (506 mm).

Since the water quality measured at Weirs 3 and 4 is very similar to that reported by the Rand Water Board (1983) (see Section 3.2.3) and used by Funke in his calculations, the large discrepancy between the loads determined in this investigation and those reported by Funke is due only to the difference in the flow values for this area.

The quality of stream water in the eastern half of the study area, whilst not as bad as in the immediate vicinity of sand dump 3A17, is still poor and is probably also due to seepage from this sand dump as there is no further deterioration in the quality as it passes dam 4IA.

The source of poor quality ground water in the eastern area is rather less certain, but it appears to enter the site from a north westerly direction and may originate from mine deposits outside the study area, such as the large slimes dam to the north, or from stormwater runoff from the large industrial area which is also to the north.

Although it has been shown (Section 3.2.6) that storm runoff serves to dilute the baseflow, it may still be the case that during storms, salts are flushed from surfaces or upper soil horizons in parts of the catchment, including from mine residues. However, the overall quality of storm runoff is better than the baseflow in which high salt concentrations exist and the major source of contamination must therefore be due to seepage from the deposits which either enters the stream directly or indirectly via the ground water which feeds the streams. This finding is not altogether surprising in view of the well established fact that the surface layers of sand and slimes residues are already substantially leached. In addition, any salts that may accumulate on the dump surfaces should be minimized by storm runoff controls from entering the stream network through direct runoff.

It is clear that seepage from sand dump 3A17 is the major source of contamination when compared to the two slimes dams in the study area. This has been established by monitoring the quality and flow in the adjacent stream. It cannot be inferred that a deposit which is not adjacent to a stream does not produce a pollution load. The mechanism of seepage

of rainfall through the deposit is the same (i.e. it is not affected by the presence or absence of a nearby stream). However, in this case the magnitude of the load emanating from the deposit is governed by the rate of seepage into ground water and the rate at which this reaches a stream network. These aspects require investigation.

6 PHASE III: MINE DEPOSIT INVENTORY AND CLASSIFICATION

6.1 Introduction

Kempe (1983), estimated that gold mine tailings cover some 8 000 ha of land on the Witwatersrand. In the 1966 lists prepared by the Chamber of Mines, 342 dams and dumps were included. Since 1966, a number of dams and dumps have been reworked in order to extract residual gold and uranium. Only three large operating mines are still in existence.

Within the confines of the project intensive routine monitoring of the pollution load from every dam and dump in the catchment would have been impractical. The deposits were therefore classified in terms of measurable physical parameters, each related to the pollution potential of the deposits. Although this approach does not give accurate quantitative estimates of the pollution load from the residues, it does provide an acceptable method which may be used to estimate the total pollution load. The estimated loads from the City Deep area have been extrapolated on this basis to give a total load for all the dams and dumps in the catchment area.

6.2 The Mine Deposit Inventory Sheet

Appendix D shows the inventory sheet used. Much of the information was obtained from the Chamber of Mines, although several categories on the sheet involved on-site observation, testing and sample collection. The series of 1:50 000 maps prepared by the Chamber of Mines in 1966, the most recent available, were used to locate the position of the deposits. Of the 342 deposits marked on the maps, 273 were visited, 237 of which fell within the Vaal catchment. At the time of sampling 53 of these had been reworked and 12 were so small

that for the purposes of this investigation they were either grouped with a larger deposit, or were ignored. Recent communication with the Department of Water Affairs Mining Section at Germiston, who are now similarly engaged with an inventory of mine deposits, has disclosed that a further 13 deposits are in the process of being reworked. These have also been omitted from the classification. Thus 160 deposits(122 slimes and 38 sand) are included in the classification. Their locations are shown in the maps in Appendix E.

6.3 Data Reduction

For the purpose of classification it was decided to reduce the inventory data to the following categories: extent of vegetation, presence of toe dams, volume, leach test results and the permeability of the residue surface. The mean values for these categories for the deposits are given in Table 17. Each of these categories have been divided into A, B and C classes. For those parameters having numerical values (the volume, leach test conductivity and pH and the results of the permeability determinations) the classes represent the 0 - 25, 25 - 75 and 75 - 100 percentile values of the data. The class limits are given in Table 18. In order for these classes to give an indication of the pollution potential; volume, conductivity and permeability values in the lower quartile and pH values in the upper quartile have each been classified as category A (i.e. low pollution potential). The high pollution potential class C has been reserved for volume, conductivity and permeability results in the upper quartile and pH values in the lower quartile. In addition, vegetated deposits and deposits with toe dams have been assigned to class A and those deposits which are without toe dams or vegetation to class C.

TABLE 17 - STATISTICS FOR MINE DEPOSITS

	Average	Standard Deviation	Coeff of Variation (%)
All deposits			
Volume/10^6 m^3	6,70	10,48	156,3
u($mS.m^{-1}$) at top (sand only)	65,71	69,97	106,5
pH at top (sand only)	3,18	2,81	237,1
u($mS.m^{-1}$) at base	206,58	129,08	62,5
pH at base	3,05	2,88	146,8
k/$10^{-3}cms^{-1}$ at base	1,63	2,54	155,9
k/$10^{-3}cms^{-1}$ at top (sand only)	4,79	7,75	161,7
Sand dumps			
Volume/10^6 m^3	5,62	5,28	93,94
u($mS.m^{-1}$) at top	65,71	69,97	106,47
pH at top	3,19	2,81	88,23
u($mS.m^{-1}$) at base	112,02	130,62	116,61
pH at base	3,33	2,96	88,96
k($10^{-3}cm.s^{-1}$) at top	4,79	7,75	161,71
k($10^{-3}cm.s^{-1}$) at base	3,74	3,24	86,55
Slimes dams			
Volume/$10^6.m^3$	7,03	11,59	164,75
u($mS.m^{-1}$) at base	230,69	117,04	50,73
pH at base	3,00	2,87	95,78
k($10^{-3}cm.s^{-1}$) at base	1,05	1,95	185,20

u = conductivity k = permeability

TABLE 18 - PERCENTILE LIMITS FOR THE NUMERICAL PARAMETERS USED IN THE MINE DEPOSIT INVENTORY

Class	A	B	C
Range	0 - 25%	25 - 75 %	75 - 100 %
Volume/10^6 m^3	0,03- 0,8	0,8 - 7,6	7,6 - 64,3
u($mS.m^{-1}$) at top(sand only)	5 - 8	8 - 121	121 - 250
pH at top (sand only)	7 - 4,1	4,10 - 3,38	3,38 - 2,15
u(mS,m^{-1}) at base	1 - 128	128 - 278	278 - 800
pH at base	7,6 - 4,05	4,05 - 2,82	2,82 - 2,19
k/$10^{-3}cms^{-1}$top(sand only)	,84 - 1,75	1,75 - 3,90	3,90 - 42,0
k/$10^{-3}cms^{-1}$base	0,03 - 32	32 - 1,60	1,60 - 17,0

u = conductivity k = permeability

In order to assign an overall classification to the deposits, those deposits with 3 or more A or C classes have been separated into the low and high pollution potential categories respectively and the remainder fall within the medium pollution potential category, Class B. These results are shown in Table 19.

Sand dump 3A17 in the study area should, strictly speaking, be classified into Class B. As a result of the detailed investigation in this area, the load from it is known, and since the major part of this load is assumed to be intercepted by the adjacent stream, it has been classified as Class C.

It should be stressed that the purpose of this form of inventory was to classify the deposits according to their pollution potential. A Class C deposit may not necessarily be a pollution threat but it will, however, be more likely to pollute than a Class A or B deposit and will thus be

TABLE 19 – MINE DUMP CLASSIFICATION IN TERMS OF POLLUTION POTENTIAL

A. Sand dumps

A Least apparent pollution threat	B Medium apparent pollution threat	C Highest apparent pollution threat
1A4	1A1	2A7
2A1	1A2	3A2
2A3	2A2	3A6
2A8	2A11	3A7
2A9	2A14	3A11
2A16	2A15	3A17
4A18	3A1	4A4
4A20	3A10	4A17
4A21	3A13	5A3
4A24	4A3	5A9
	4A7	
	4A15	
	4A19	
	5A2	
	5A5	
	5A6	
	5A11	
	6A1	

TABLE 19 - MINE DUMP CLASSIFICATION IN TERMS OF POLLUTION POTENTIAL (continued)

B. Slimes dams

A Least apparent pollution threat		B Medium apparent pollution threat		C Highest apparent pollution threat
1L2	4L23	2L4	4L30	1L1
1L5	4L24	2L9	4L44	2L1
1L6	4L25	2L10	4L47	2L2
2L5	4L27	2L11	4L48	2L3
2L6	4L28	2L12	4L50	2L7
2L8	4L31	2L14	5L1	2L24
2L15	4L33	2L16	5L2	2L29
2L17	4L35	2L20	5L4	3L4
2L22	4L36	2L21	5L5	3L44
2L23	4L38	2L27	5L8	3L46
2L25	4L39	3L1	5L10	4L14
2L31	4L40	3L6	5L23	4L37
3L2	4L41	3L7	5L24	4L39
3L3	4L42	3L8	5L25	5L27
3L5	4L43	3L10	5L26	5L28
3L9	4L45	3L12	6L11	
3L11	4L46	3L20	6L12	
3L17	5L3	3L24	6L14	
3L18	5L9	3L31		
3L19	5L11	3L35		
3L21	5L12	3L39		
3L42	5L14	3L41		
4L4	5L15	4L3		
4L8	5L16	4L6		
4L9	5L17	4L7		
4L10	5L18	4L13		
4L16	5L20			
4L17	5L21			
4L18	5L22			
4L21	5L30			
4L22	6L3			
	6L13			

higher on the list of priorities for investigation when limited funds have to be applied to remedial measures.

6.4 Numbering Scheme

The number of the deposit refers to the index number used by the Chamber of Mines. The numbers prefixed by an A refer to sand dumps, those prefixed by an L to slimes dams. The prefixes 1, 2 etc refer to the number of the index plan which contains the mine dump in question (Appendix E).

6.5 Volume

Both the surface area and the volume of the deposits were considered for inclusion in the classification. Although the volume of the deposit was chosen as being more relevant to the pollution potential of the deposit, when surface area was substituted for volume it made negligible difference to the overall classification. Volume was selected as the more suitable parameter because the percolation of water through a deposit appears to be a more important contributor to dissolved salts loading than direct run off (Section 5). The method of volume calculation is shown in Appendix F and the percentile limits which are used in the classification are shown in Table 18.

6.6 Extent of Vegetation

The inventory sheet subdivides the vegetation state into a number of categories ranging from densely bushed to bare on the sides and on the top. For the purpose of data reduction this has been separated into 3 categories: vegetated, paved and bare. Deposits which had upwards of 20% overall vegetational cover were grouped into the vegetated category, while those with less were grouped into the bare category. Rock covered deposits were placed in the paved category.

The degree of vegetation of a deposit is important when considering its pollution potential, since a well-vegetated deposit will be much more resistant to wind and water erosion leaving the upper more heavily leached (and thus less likely to pollute) layers of the deposit intact. In addition, vegetation is a good indicator of the pollution potential because pyrite oxidation, with the resultant formation of sulphuric acid (Section 1.2.2) will lead to an inhospitably low pH environment for all but the most tolerant vegetation. It is also noted that aluminium, the predominant extractable cation in mine residue samples (Hahne et al, 1976) is a prime hazard in mine deposit vegetation due to its toxicity to many plant species.

In a review by the Chamber of Mines during 1980 and 1981, it was reported that vegetation on the dams and dumps resulted solely from human agency and that chemicals often have to be added and irrigation employed. This review used spectral photography as an aid to researching the grassing of Witwatersrand sand dumps and slimes dams. The results of their spectral survey were that the vegetation cover on the flat tops of slimes dams was about equal to the surrounding veld, while that on sand dumps was inferior. In addition the vegetation on the sides of the slimes dams was more sparse than that of the surrounding veld.

It is seen that most of the deposits in the inventory meet the criterion of greater than 20 % vegetation. While it is possible that the 20 % limit is too low and that a 20 % vegetational cover may not provide much protection from erosion, it does indicate that the surface soil conditions may be reasonably hospitable and that much of the pyrite may have been oxidized and leached from the surface layers of the deposit. Although those deposits with less than 20 % vegetational cover may be expected to have results falling in

Class C (low pH, high conductivity, high permeability), such relationship was not found. It is possible that less effort has been made to re-vegetate these dumps.

6.7 Presence of Toe Dams

Efficient toe dams will considerably reduce the immediate pollution potential of a sand dump or a slimes dam by collecting runoff and seepage water and retaining it for evaporation. Many of the early deposits were constructed without taking ecological aspects into account and did not have toe dams incorporated into their construction. On modern slimes dams, excess water is drawn off through penstocks and returned for re-use while trenches are provided to drain any seepage to the penstock pumps. Although no new sand dumps were started after about 1918 (Kempe, 1983), sand treatment on established mines continued until the sixties. Although the Department of Water Affairs and the Chamber of Mines have added toe dams to those deposits judged most likely to constitute a pollution threat, about 25 % of the slimes dams and 75 % of the sand dumps inventoried are without visible toe dams. In addition, many of these deposits with toe dams are only partially protected, often because the construction of roads, buildings and stormwater pipes in close proximity to the deposits has prevented the addition of further toe dams. Those deposits which are both bare and lack toe dams may constitute a pollution threat, especially if the results of their leaching tests are also high.

6.8 Leaching Tests

The procedure followed for the leach tests was established following initial trial testing. Hand auger samples were taken to a depth of 2 m on two slimes dams and two sand dumps (including the three study deposits). These samples were

first air dried, then one part of sample was shaken with two parts of deionized water. The extracts were analysed for pH, conductivity, TDS, sulphate, iron and manganese. From the results it was decided that since no significant difference was found in the slimes samples either with depth or between top and bottom sampling position, only one sample would be taken from each slimes dam while two would be collected from each sand dump, one from the top of the dump and one from the base of the dump. In addition, only one sample per hole was collected in order to reduce the number of leach tests. The depth at which this sample was taken was selected to be at the 1 m - 1,5 m horizon since it was believed that this depth would fall just below the most heavily oxidized zone. The major immediate potential source of leachable salts in most deposits would thus be sampled.

It should be appreciated that the leach tests are not necessarily representative of the amount of salts that will be leached out of the deposits after storm events, but only of the amounts of salts which are potentially available. In the real situation the quality and quantity of the leachate will be dependent upon many factors including the permeability of the residue material, its porosity, oxygen availability, the residual sulphate, the sulphide available for oxidation and the volume of water per unit mass of residue material.

It should also be recognised that since pyrite is readily oxidisable in the presence of air, alteration of the sample may occur between the time of sampling and leach testing. Since some of the samples were allowed to stand longer than others before testing, care must be exercised in making intercomparisons between sample sites.

The conductivity values found in many of the surface and auger hole samples collected during the routine water quality monitoring far exceeded the maximum conductivity obtained in the leach tests indicating that the results from the leach tests do not necessarily provide an upper concentration limit. Nevertheless they should still give some indication of the relative pollution potential of the material.

The results of the leaching tests display a wide range of values which is indicative of the differing extents to which the mine residue material has been oxidized. Factors such as the age of the deposit, the permeability of the surface material and the head value of sulphur will cause these differences.

It can be seen from Table 17 that the mean leachate quality value from those samples collected at the bottom of the sand dumps is worse than the quality of the samples collected from the top of the sand dumps. This is the reverse of the results from the auger tests performed on the City Deep sand dump in establishing the leach test procedure. This may partly be explained by considering the point at which the sample was taken with respect to the zone of saturation. Leachate water infiltrating through the dump will collect at its base at a level governed by the permeability of the subsurface material. It is postulated that in sand dumps with relatively more permeable base materials such as 3A17, it is assumed to be the salts near the base of the dam that will have been leached into the base materials. Where the base is less permeable, these salts will not seep into the base, but will tend to emerge near the foot of the dam.

Table 17 also shows that the mean laboratory leachate quality of the samples collected from the base of the slimes dams is of worse quality than the mean quality of the samples

collected from the top and bottom of the sand dumps. This may infer that while much of the sulphide present in the surface layers of the sand dumps has already been oxidized and leached out, more of the sulphide in the slimes dam material remains unoxidized and relatively immobilised due to the lower permeability of the slimes material.

6.9 Permeability of the Residue Surface

It is assumed that those deposits with higher surface permeability are also likely to have high rates of infiltration and will accordingly also have higher rates of seepage.

The method of measuring the permeability of the uppermost 0,5 m of the deposits was not intended to give an accurate permeability value of the residue material, rather it is an approximate method intended for intercomparison.

The in situ falling head permeability tests were carried out on undisturbed material on the dumps.

Two 0,7 m holes were augered on each sand dump, one on the top approximately 20 m from the edge, the other a few metres up from the base of the dump. Since there were no differences between the leach test samples collected from the top and base of the slimes dams, only one hole was augered a few metres up from the base of the dams. Variable head permeability tests were performed on the 0,7 m sections. Due to the large number of deposits to be visited and tested, the tests were performed over a short time period. The permeabilities were calculated using the formula for an unsaturated material (Appendix G). When the mean permeability of the slimes dams was compared with the permeability of the sand dumps, it was seen that the permeability of the sand dumps was higher than that obtained from the slimes dams.

Even so, the values obtained for the slimes dams were perhaps on order of magnitude higher than would be expected. This may be explained by considering the grain size distribution of the residue material. Kempe (1983) gives the general particle size distribution of the sand dump material as

7 % greater than 300 μm
70 % between 75 and 300 μm
23 % less than 75 μm

while slimes have a fineness of 75 % less than 75 μm. For comparison, the results of particle size analyses on residue material from 4L16, 4L25 and 4A7 are given in Table 20. The sand dump material contains a sizeable proportion of fine material which is likely to lower its permeability considerably. The slimes samples have large proportions of material between 150 μm and 200 μm and only 5-17 % of material finer than 75 μm. It is possible that this results from the method of slimes dam construction. This usually involves spigoting in which the coarser material is deposited near the edges thereby reinforcing the walls. Thus, the surface material is not really representative of the bulk of the slimes dam, hence the high permeability.

6.10 Interpretation of the Mine Deposit Classification

Using the data obtained from the mine deposit inventory it has been possible to classify the deposits according to their apparent pollution potential. Inspecting the classification of the City Deep deposits (Table 19) it is seen that 3A17 and 3L44 fall into the category of greatest pollution threat, whilst 4L4 falls into the lowest pollution potential category. Phase II investigations have shown that 3A17 generates nearly all the dissolved solids from the study sites, whilst 3L44 contributes less than 1 % of the load.

Slimes dams 4L4 makes a negligible contribution to the load. Although the classification of 3A17 and 4L4 agrees with the Phase II results, 3L44 does not appear to constitute a considerable pollution threat. However it must be stressed that it is only because 3A17 is in such close proximity to a stream that it is possibe to monitor this considerable contribution to the load. It may be that the loads from 3L44 enter deeper lying groundwater.

TABLE 20 - PARTICLE SIZE ANALYSIS RESULTS OF SAMPLES COLLECTED FROM DEPOSITS 4A7, 4L16 AND 4L25

Sample	Depth (m)	% Passing Sieve Sizes (mm)		
		0,425	0,150	0,075
4A7	0,0 - 0,5	90	39	8
4A7	0,5 - 1,2	90	36	6
4L16	0,0 - 0,5	99	68	17
4L16	0,5 - 1,2	91	55	12
4L25	0,0 - 0,5	80	29	5
4L25	0,5 - 1,2	97	44	8

There do not appear to be any major trends in the results of the classification in that no one particular type of deposit consistently fell into the same category. The main conclusion is that the pollution potential of the deposits is now largely a function of their degree of maintenance. It would have been of value to have incorporated into the

classification the distance from each deposit to the nearest water course, as well as the age of the deposits and the present sulphide and sulphate content of the residue material. Nevertheless, the classification as it stands, provides an indication of the pollution potential of each deposit. This will allow priority attention to be paid to those dumps with the identified higher pollution potential. More detailed investigation of these dumps will then confirm whether remedial measures are necessary.

6.11 Chamber of Mines Dump Inventory

An additional survey was carried out by the Chamber of Mines (COM) Pollution Control unit during which they visited all the sand dumps and carried out an inventory based on the same criteria used by SRK, but excluding permeability and leach tests.

The tables summarising their data obtained in mid-1987 are presented in Appendix H. The SRK inventory had been carried out during 1986, so some differences may be expected.

Salient points from the COM inventory are the following:

- SRK had incorrectly assumed that two dumps 3A/11 and 5A/11 which were situated on slimes dams comprised the whole volume of the combined dumps. Correcting for this reduces the SRK estimated volume for the 38 sand dumps inventoried from 210,7 x $10^6 m^3$ to 182,2 x $10^6 m^3$ (Appendix H, Table III). This compares to the COM volume of 152,5 x 10^6 m^3 for the sand dumps inventoried by SRK.

- The COM estimate of the total volume of the sand dumps in the Vaal Barrage catchment is 308,7 x $10^6 m^3$. This

total is not shown in Appendix H, Table V, but is the sum of the Current Estimated Volume shown in Column 2.

6.12 Calculation of salt loads

Using the results from Phase II of the investigation it is possible to estimate the total load from the dumps and dams in the Vaal catchment using the calculated loads from the City Deep study area. Several methods of extrapolation are possible, each involving certain assumptions. The following common assumptions apply:

i) There is a negligible load from the slimes dams compared to the sand dumps. This was found to be true of dam 4L4 in the study area whilst 3L44, although classified as being in the highest pollution potential category (category C), was found to contribute less than 1 % of the total load. Circumstances where this assumption may not be true include cases where dams may be freshly eroded and fractured thereby increasing the vertical permeability and exposing previously unoxidized material to air. Seepage and runoff from such cases would pose a significant pollution problem.

In addition, although the load from individual slimes dams may be small, the total load contributed by them may be significant because of their total volume.

ii) None of the deposits which are in the process of being reworked contribute any load to the catchment and have been omitted from the classification. While the deposits still exist this may lead to an underestimation in the annual pollution load, especially since the reworking process may expose the less heavily leached sub surface layers of the deposits thereby increasing their pollution potential.

iii) The 237 mine deposits visited in the catchment are representative of all the deposits in the catchment.

iv) Rainfall and runoff in 1985 are typical for the area. In fact, the annual rainfall in 1985 (705 mm) is below the average (750 mm). It is considered that the load would be larger in a wetter year.

The following methods have been applied:

6.12.1 Volume corrected load

If it is assumed that the pollution load from a sand dump is proportional to the volume of the dump, the information from Phase III of the study may be coupled to that of Phase II to calculate a load as follows:

$$\text{Salt load} = 2300 \times \frac{182{,}2 \times 10^6}{12{,}41 \times 10^6} \times \frac{80}{52}$$

$$= 51950 \text{ t/a}$$

Where :

2300 : estimated salt load from 3A17

$182{,}2 \times 10^6$: corrected volume of 38 sand dumps,

$12{,}41 \times 10^6$: volume for 3A17

$\frac{80}{52}$: correction factor to convert volume of 52 dumps visited (of which 38 were considered to be significant) to the total of 80 dumps, assuming the same ratio of significant to insignificant dumps in the total of 80.

The use of the correction factor of 80/52 leads to a total volume of $280{,}3 \times 10^6 m^3$ for all the sand dumps,

whereas the COM volume is $308,7 \times 10^6 m^3$. The difference of 10% is considered acceptable.

6.12.2 Area corrected load

In the same way, the load may be calculated, assuming that the salt load is proportional to the area covered by the sand dumps:

$$\text{Salt load} = 2300 \times \frac{4,07 \times 10^6}{0,247 \times 10^6} \times \frac{80}{52}$$

$$= 58300 \text{ t/a.}$$

Where : $4,07 \times 10^6 m^2$ - corrected total area for 38 sand dumps

$0,247 \times 10^6 m^2$ - area for 3A17

6.12.3 Summary of salt load calculations

The volume and area corrected pollution loads from the mine residue deposits in the Vaal Barrage are 51 950 t/a and 58 300 t/a respectively. Taking into account the approximations and assumptions described in Section 6.12, 50 000 t/a is considered to be a reasonable approximation of the magnitude of the load.

The calculated loads are seepage loads from the sand dumps of which a presently unknown proportion will appear as streamflow. An unknown proportion of the streamflow eventually reaches the Barrage. It is known for example that the volumes flowing in the lower reaches of the Klip River are lower than in the upper reaches (Funke, 1984), possibly as a result of

agricultural abstraction and of recharge to the dolomitic aquifer traversed by the river in this area.

In summary, it is concluded that approximately 50 000 t/a of salts are discharged to the environment from the gold mine residue deposits in the Vaal barrage catchment, but that a presently unknown proportion of this reaches the Barrage.

The removal of many of the mine residue dumps, especially the sand dumps, which is in progress or being planned, could also have a significant long-term effect on the reduction of the salt loads. This factor has not been taken into account since the purpose of the study was to determine present salt loads.

These calculations have been based on a number of assumptions and combinations of assumptions. If any of these assumptions were proved to be invalid, the calculated loads could be significaintly affected. These assumptions were mentioned in the introduction to this section and are listed in Table 21.

6.12.4 Comparison with previous studies

Clausen (1969) predicted a load of 16800 t in 1970 from mine deposits in the Klip River and Suikerbosrand catchments decreasing to 6 000 t in 1980 and 3000 t in 1990. He ascribed the projected reduction in the load from mine residues to the proposed construction of toe dams, the securing of slimes dams tops against runoff and the reduction with time of the residual oxidizable pyrite, much of which had taken place by the time of this study. This study did not consider the removal

of dumps as the result of reworking. His figures were arrived at by including direct runoff from mine residue surfaces only, thus no account was taken of the potential load contributed to the ground water and stream baseflow. The last two factors have been shown to be important in the present study.

The Department of Water Affairs estimated the average salt load to the Barrage over the period 1978-1983 to be 400 000 t/a.

Stewart, Sviridov and Oliver (1979) found the total salt mass generated in the Barrage catchment for the period September 1977 to August 1978 to be 547 300 t whilst the mass generated by non-point sources alone was 315 000 t.

The present study has estimated that about 50 000 t/a of salts are discharged to the environment, mainly as seepage. The proportion of this which discharges to surface water and eventually to the Vaal Barrage has not been quantified.

Even taking into account the limitations of the assumptions, the indications are that the potential contribution to the TDS load from mine deposits is greater than previously estimated. The disparity between the load calculated in this study and values quoted previously may be due to the fact that in previous studies the role of ground water and stream baseflow has been underestimated, and that of direct runoff from the largely oxidized residue surfaces given undue prominence.

TABLE 21 – ASSUMPTIONS USED IN SALT LOAD CALCULATIONS FOR THE STUDY AREA

General assumptions :

1 The surface runoff loads during storm events are negligible. Although loads during storm events increased, the total load contributed by infrequent storm events is small.

2 The seepage load to the ground water system from slimes dams is negligible. Even small loads may, however, be significant because of the larger number of slimes dams.

3 The load of 2300 t/a from 3A17 which appears in the adjacent stream is essentially the total load from seepage to the ground water system.

4 None of the deposits which are being reworked contributes a load to the catchment.

5 The 237 mine deposits visited in the catchment are representative of all the deposits in the catchment.

6 Rainfall and runoff in 1985 were typical for the area.

Specific Assumptions:

. The pollution load is proportional to volume of the sand dumps. (Section 6.12.1)

. The pollution load is proportional to the area of the sand dumps. (Section 6.12.2)

Finally, it is important to realize that the TDS loads calculated in this investigation relate to the vicinity of the mine residues themselves. The proportion of the load which actually enters the Vaal Barrage is unknown. Whilst it is realized that in a conservative system dilution of the flow by the addition of tributaries serves to reduce only the concentration of salts and not the absolute load, this system is not conservative. Aeration of the water and the addition of better quality water serve to reduce the acidity permitting precipitation of salts such as the precipitation of iron hydroxides observed in the study area. The extent to which the load is reduced by these mechanisms is unknown.

7 CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER INVESTIGATION

7.1 Conclusions

The purpose of this investigation has been to evaluate the present contribution of mine deposits to the pollution load in the Vaal Barrage. The approach has been to monitor the flow and quality of water in a selected study area which contains three mine deposits and to extrapolate the results to the Witwatersrand area by compiling an inventory of mine deposits in the catchment. In order to assist with the planning of remedial measures, the sand and slimes dumps were classified into three categories according to their perceived pollution potential. These dumps with the higher rating have a higher priority for investigation of remedial measures.

In the selected study area, it has been established that the general quality of the stream water upstream of the monitored deposits is good but that it deteriorates significantly during its passage past sand dump 3A17. The influence of this dump persists to the eastern half of the study area where the stream water quality remains poor but does not deteriorate further. The quality of the near surface ground water follows a similar pattern. There is evidence from the quality of the ground water at depth and from the quality of water in the Rosherville stream, which does not deteriorate during its passage through the study area, that the water quality is also affected by other sources, probably nearby mine deposits and industrial areas.

Study of the variation in water quality during storm events showed that the effect of stormwater was to dilute the salt concentration in the stream baseflow. Thus direct surface runoff is not a significant source of the salts found in the stream water; these are already present in the stream

baseflow. However, the greater volumes of flow during storm events result in greater salt loads being transported than during baseflow when concentrations are higher. Part of this higher salt load during storm events may be derived from surface runoff but this could not be quantified. The likely mechanism for the contamination of stream flow from the sand dump is percolation of rainwater through the dump to the near-surface ground water and its subsequent seepage into the stream from the dump base and the near-surface ground water.

When the study was designed, it was envisaged that the major salt load would be derived from surface runoff. The study showed that seepage from the sand dump into the baseflow of the adjacent stream was the major source of the salt load contributed by the three dumps in the study area. As a result of this, the hydrogeological aspects proved to be more important than had originally been expected, and the design of the recording and monitoring systems was accordingly not detailed enough to supply the information for better quantification of the salt loads seeping from the dumps into the ground water system and from there to the streams.

Seepage, especially from sand dumps into the near-surface ground water system and recharge of streams by this ground water is now thought to be a more significant source of the salt load than storm water surface runoff.

The load of TDS and sulphate from the study area has been quantified and apportioned amongst the monitored deposits. The largest portion is derived from the sand dump.

The load of 2300 t/a of salts entering the stream from the sand dump was taken, with certain reservations, as an indication of the salt load entering the environment from this dump, and as a value which could be used in extrapolation.

The total annual load of 5620 t discharged from the study area is made up of the 2300 t from the sand dump with the balance of about 3320 t being essentially imported into the area by the stream. Contributions by the two slimes dams were considered to be small.

The annual load discharged from the study area (2 300 t from the study site and 3 320 t from upstream of the study site) is far in excess of a previously quoted value for the same area of 471 t (Funke, 1984). This is largely due to the greater volume of flow recorded for the area than was previously estimated. The proximity of a perennial stream adjacent to the sand dump enabled the pollution load produced by the dump to be monitored. In the absence of the stream the load would be transported from the dump at an unknown rate in the ground water.

The study included the compilation of an inventory of the 273 mine deposits in the Vaal Barrage catchment in order to classify them according to their pollution potential.

The pollution potential was based on measurable parameters that were considered to be significant. These were: extent of vegetation, presence of toe dams, volume, leaching tests and permeability of deposit surfaces. Three categories of deposit were identified varying in their degree of pollution potential. Of the existing deposits inspected in the catchment, 73 fell in the category of least pollution potential, 62 in the middle category and 25 in the category of highest pollution potential. No one particular deposit type was found to be a particular threat. Rather, the overriding criterion appeared to be the level of maintenance of the deposit. The classification has identified those deposits of highest pollution potential and to which priority attention should be paid when considering remedial measures.

By extrapolating the load calculated for the study area to all the dumps and dams in the catchment of the Vaal Barrage an annual figure of approximately 50 000 t was obtained as an estimate of the salt load discharged to the environment, mainly in the form of seepage to the near-surface ground water. An unknown proportion of this seepage recharges surface water systems and eventually reaches the Vaal Barrage. The effect of the removal of dumps was not studied, but is expected to have a significant long-term influence.

7.2 Recommendations for further study

Many factors influence the degree and rate of pollution from mine deposits and their ultimate contribution to the mineral load in the Vaal Barrage. In order to obtain a more reliable quantitative estimate of this contribution it would be necessary to have knowledge concerning the present rate at which the residual sulphide is being oxidized, the rate at which sulphates are leached from the mine residues and the mode and rate of the transporting medium, (i.e. whether by seepage directly to a stream, or seepage to near-surface or deep ground water and ultimately into a stream possibly remote from the source of pollution). This demands a better understanding both of the processes occurring within the deposit material (infiltration, permeability and seepage rates, depths of oxygen penetration and rates of oxidation both chemical and bacteriological) and also the direction, route and rate of movement of water from the deposits to the Vaal Barrage. It would also be necessary to investigate the apparent loss of dissolved solids from the mine deposit polluted water during its passage to the Vaal Barrage.

The following aspects should be investigated in order to achieve a better insight into these processes:-

1. More information must be obtained concerning the rates of seepage from the deposits. This would involve measurement of the distribution of moisture within sand and slimes residues. It is suggested that boreholes should be drilled through selected dams and dumps. Instrumentation should be installed to monitor changes in moisture contents and permeabilities. Estimates of the rates of seepage could then be obtained by back-analysis. At the same time, information should be obtained on sulphide and sulphate concentrations and on bacterial activity and changes in these at depths not previously investigated. The present rates of sulphide oxidation and sulphate leaching must also be investigated. Marsden (1985) has studied the variation of residual sulphide and sulphate content of mine tailings with depth and compared these values to the original head values of the residue material. It would be a useful follow up if these values were carefully monitored over several seasons so that the current rate of sulphide oxidation and sulphate removal could be estimated.

   From this the mechanisms through which pollutants enter the local ground-water system could be established and estimates made of the potential pollution load.

2. An investigation should be made into the regional ground-water regime. It is necessary to determine the direction and rate of movement of ground water in order to assess its influence, if any, on the transport of pollutants to the Vaal Barrage. The monitoring of tracers, either natural or injected, in the groundwater might be useful in this respect.

3. In the case of sand dump 3A17, it has been shown that recharge of a surface stream by seepage from a sand dump is the major source of pollution from the three dumps studied. It is believed that this mechanism has not previously been recognised as significant in the transport of salt load to a stream and it may therefore be a more general phenomenon than realised. More detailed sampling, analysis and flow rate estimation of streams during baseflow conditions in the vicinity of sand dumps will allow a better estimation of the importance of this phenomenon.

4. The loss of dissolved solids from mine polluted water should be investigated. Only a proportion of the load calculated in Section 3.2.5 may actually enter the Vaal Barrage. As the pH of the mine polluted stream recovers due to dilution and aeration, precipitation may occur resulting in reduced salt concentrations. These processes may explain the results of Funke (1984) who found that the tonnage of dissolved solids and sulphate from point sources into the Klip River exceeded the calculated tonnages at the Klip River gauging station. It would be possible to quantify the concentration of salts removed by monitoring the water quality and flow rates at a number of distances downstream.

The results of these further investigations may then be used to design empirical models which will more accurately quantify the contribution of mine residues to the salt load in the Vaal Barrage.

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S J J GELDENHUIS Sci Nat J R HOWARD PhD

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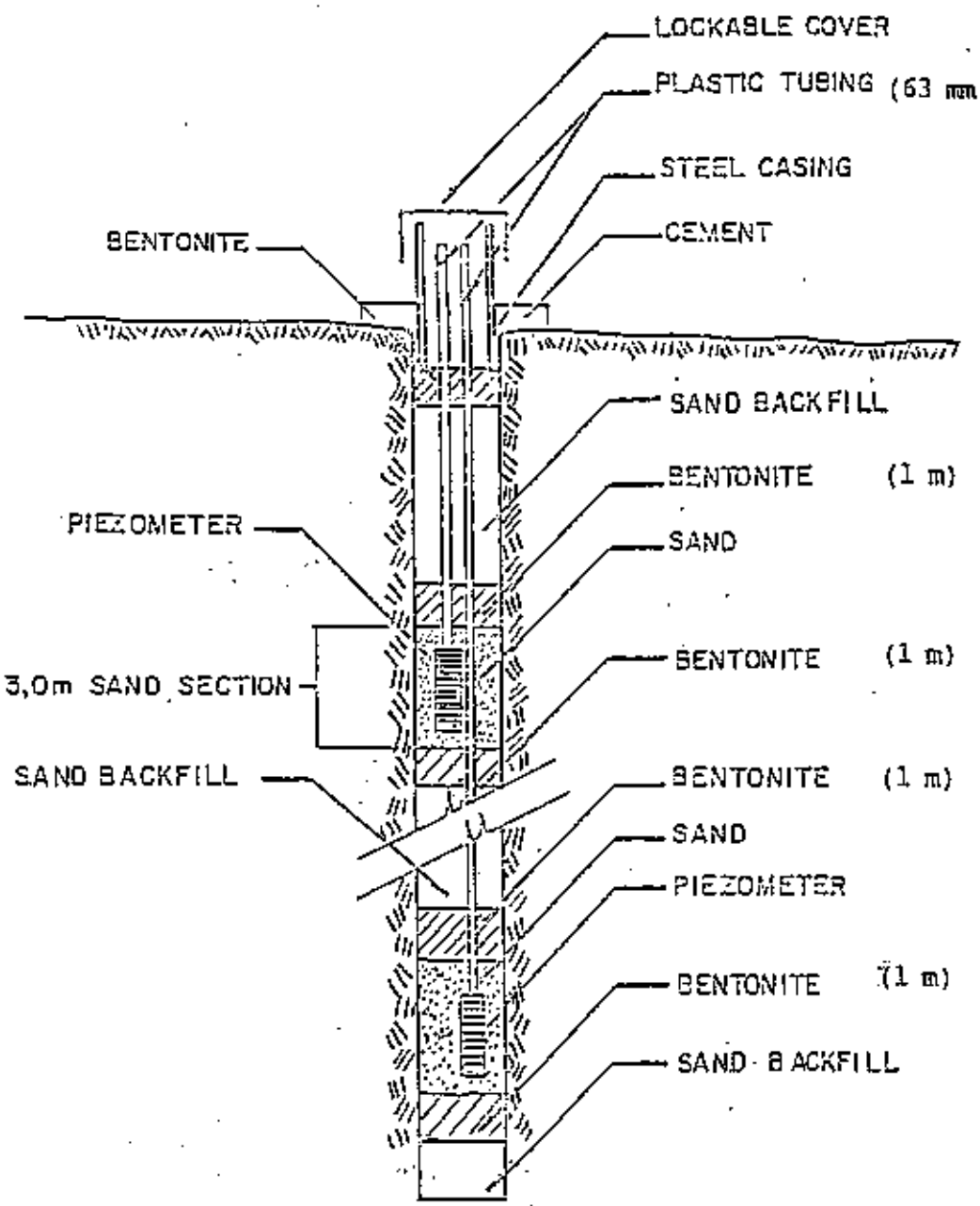
A P P E N D I X A

SCHEMATIC REPRESENTATION

OF A

MULTIPLE CASAGRANDE PIEZOMETER INSTALLATION

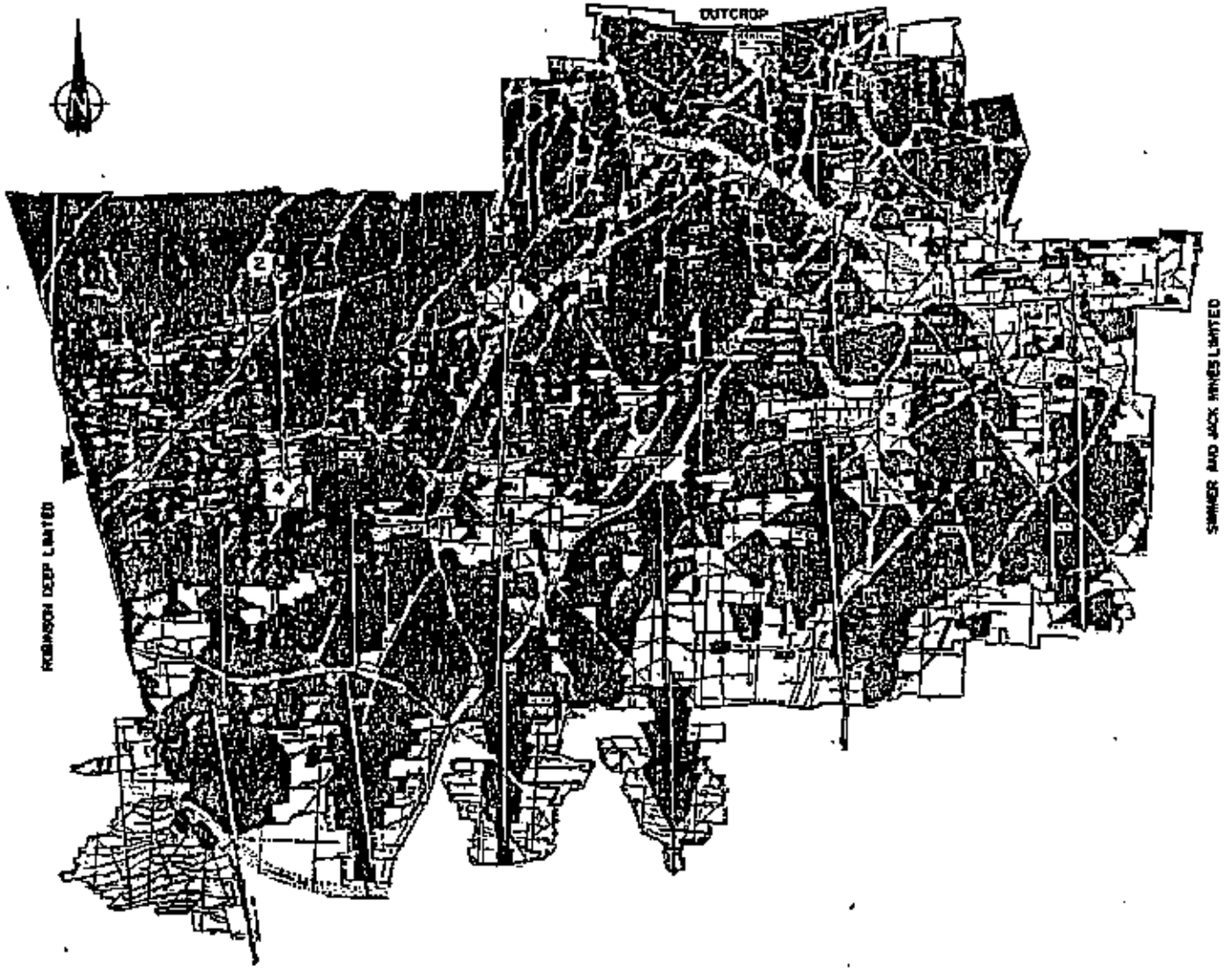


SCHEMATIC REPRESENTATION MULTIPLE CASAGRANDE PIEZOMETER INSTALLATION

	JOB Nº		FIG Nº
	PT 3632	WATER RESEARCH COMMISSION	APPENDIX A

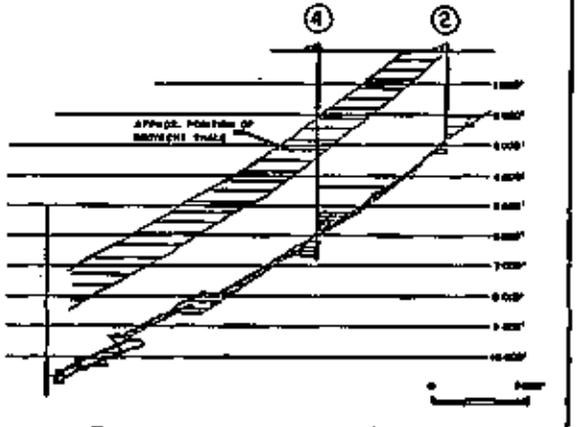
A P P E N D I X B

PLAN OF UNDERGROUND WORKINGS AT CITY DEEP



LEGEND

- ③ SHAFTS
- SHAFTS INCLINE
- DYKES
- MINED
- NOT MINED



TRANSVERSE SECTION THROUGH ④ SHAFT LOOKING WEST

KINDLY SUPPLIED BY RAND MINES LTD.

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CONSULTING ENGINEERS RAADGEWENDE INGENIEURS

CITY DEEP LIMITED

PLAN OF UNDERGROUND WORKINGS

WATER RESEARCH COMMISSION

APPENDIX B

APPENDIX C

PERCUSSION DRILLING RECORDS, CITY DEEP

STEFFEN ROBERTSON AND KIRSTEN INC.
Geotechnical and Mining Engineers.
15th Floor, 20 Anderson Street, Johannesburg.
P.O. Box 6856, Johannesburg, 2000.
Telephone 834-6061. Telex 8-9763.

PERCUSSION DRILLING RECORD

SHEET No. 1/2

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 3L44 SW corner
LOGGED BY DW
DRILLER DWA

JOB No. PT 3532
HOLE No. BH 1
ELEVATION
WATER TABLE
DATE STARTED Jan '94

PENETRATION (MINUTES)	WATER STRUCK	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
				sand. Weathered quartzite.
	▽	22		
				Moist, light greyish-brown to buff, gravelly, medium and fine sand. Weathered quartzite.
		33		
				Dry, light orange, silty sandy fine gravel. Weathered quartzite.
		34		
				As 22,0 to 33,0m.
		36		
				Moist, light grey, silty, coarse, medium and fine sand. Weathered quartzite.
		44		
				As 22,0 to 33,0m.
		48		
				Dry, very light grey, gravelly fine sand. Weathered quartzite.
		51		
				Moist, buff to light grey, gravelly coarse, medium and fine sand. Weathered quartzite.

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PERCUSSION DRILLING RECORD

SHEET No. 1/1

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 3L44 SW corner
LOGGED BY DW
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 1
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER TABLE	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
		1m		Very moist, light orange, silty, medium sand. Colluvium.
		2		Slightly moist, orange speckled white, gravelly silty m-f sand. Colluvium and pebble marker.
		3		As above, but yellow and generally finer. Colluvium and residual quartzite.
		8		Dry, light yellow to buff, sandy silt with some fine gravel. Residual quartzite.
		9		Moist, light brown, gravelly sandy silt. Residual quartzite.
		12		As above, but dry.
		15		As 8,0 to 9,0m, but pink.
		16		Moist, light dusky red, gravelly silty, coarse sand. Residual quartzite.
		19		As above, but very moist.
				Moist, buff, gravelly coarse, medium and fine

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PERCUSSION DRILLING RECORD

SHEET No. 2/1

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 3L44 NW corner
LOGGED BY MFH
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 2
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER TABLE	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
				Reddish- brown, fine-medium sand. Transported and residual material.
		3,5		
				Pale pinkish-grey rock flour and coarse rock chips. Acid intrusive or weathered quartzite ?
		12,5		
				Yellowish-brown rock flour with apparently fibrous texture. Weathered intrusive ?
		17		
				Pale yellowish-grey rock flour. Sericitic quartzite quartzite.

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PERCUSSION DRILLING RECORD

SHEET No. 1/3

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 3144 SW corner
LOGGED BY DW
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 1
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER TABLE	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
		55		Moist, buff to light grey, gravelly coarse, medium and fine sand. Weathered quartzite.

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PERCUSSION DRILLING RECORD

SHEET No. 3/1

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 3144 NE corner
LOGGED BY MEH
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 3
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER STRUCK	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
		0m		Moist, light yellowish-orange, fine-coarse sand. Weathered quartzite.
		2		Pale grey, fine-coarse sand. Fresh quartzite.
		3		Pale pinkish-grey and yellowish-grey, fine-coarse sand. Slightly weathered quartzite.
		6		Pink and grey slightly weathered quartzite.
PIEZOMETER INSTALLED AT 10m.	▽	8 9		Pink, white and grey, coarse sand. Slightly weathered, coarse grained quartzite.
		19		Grey rock flour and fine-coarse sand. Fresh quartzite.

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PERCUSSION DRILLING RECORD

SHEET No. 2/2

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 3L44 NW corner
LOGGED BY MFH
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 2
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER STRUCK	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
				As 17 to 20m.
		21		Pale pinkish-grey rock flour. Weathered sericitic quartzite.
	▽	28		
		29		Pale yellowish-greenish-grey to dark greenish-grey, rock flour with quartzite chips. Weathered quartzite.
PIEZOMETER INSTALLED AT 29.1m.		38		Reddish-brown sand and dark greenish-grey quartzite mixed. Weathered quartzite.
		40		

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PERCUSSION DRILLING RECORD

SHEET No. 4/1

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 3A17 NW corner
LOGGED BY MFH
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 4
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER STRUCK	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
		0m		Dark yellowish-green becoming light reddish-orange with depth, fine sand with chips of black slate and other foreign material. Highly weathered quartzite ?
		8		Pale reddish-grey, mainly rock flour and fine sand. Weathered quartzite.
	▽	12		Pale yellowish-brown sand. Weathered quartzite.
PIEZOMETER INSTALLED AT 14,9m.		16		
PIEZOMETER INSTALLED AT 23,55m.	▽	20		Samples missing
		27		

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PERCUSSION DRILLING RECORD

SHEET No. 3/2

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 3L44 NE corner
LOGGED BY MFH
DRILLER DWA

JOB No. PT3632
HOLE No. BH 3
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER TABLE	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
PIEZOMETER INSTALLED AT 22,05m.				Grey rock flour and fine-coarse sand. Fresh quartzite.
		23		Pale reddish-grey, coarse sand. Slightly weathered quartzite.
		24		

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PERCUSSION DRILLING RECORD

SHEET No. 5/2

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 3A17 SE corner
LOGGED BY MFH
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 5
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER STRUCK	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
		21		Very pale pinkish-grey, fine-coarse sand with some rock flour. Fresh quartzite.
				As 20 to 21m, but almost white in colour. Fresh quartzite.
		24		
	(damp) ▽	27		Dark greenish-grey rock flour and fine-coarse sand with quartzite chips. Fresh quartzite.
PIEZOMETER INSTALLED AT 27,8m.				
		33		Pale grey (almost white) rock flour with fine-coarse sand and quartzite chips. Fresh quartzite.
		36,5		Very pale yellowish-grey rock flour and fine-coarse sand. Fresh quartzite.
		39		AS 36,5 to 39m, but pinkish-grey.

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PERCUSSION DRILLING RECORD

SHEET No. 5/1

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 3A17 SE corner
LOGGED BY MFH
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 5
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER TABLE	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
		0m		Brown, medium sand. Weathered quartzite.
		6		Very pale yellowish-grey, medium sand with some rock flour. Slightly weathered-fresh quartzite.
		11		Very pale pinkish-grey, medium-coarse sand with some rock flour. Slightly weathered quartzite, some grains weathered.
		19		Very pale grey, fine-coarse sand. Fresh quartzite.

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PERCUSSION DRILLING RECORD

SHEET No. 5/4

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 3A17 SE corner
LOGGED BY MFH
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 5
ELEVATION
WATER TABLE
DATE STARTED Jan '94

PENETRATION (MINUTES)	WATER STRUCK	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
	▽	80		Pale yellowish-grey rock flour with minor coarse sand and small amounts of mica. Fresh, slightly sericitic quartzite.
PIEZOMETER INSTALLED AT 84,7m.				Yellowish-greenish-grey; coarse sand with minor rock flour. Fresh, coarse grained quartzite.
		90		

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PERCUSSION DRILLING RECORD

SHEET No. 5/3

CLIENT WPC
PROJECT CITY DEEP MINE DUMPS
SITE 3A17 SE corner
LOGGED BY MEH
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 5
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER TABLE	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
				Very pale yellowish-grey, fine-medium sand with rock flour. Solid, fresh quartzite.
		48		Greenish-yellow and grey, fine- coarse sand. Fresh quartzite.
		60		Pale greenish-yellow with some grey, coarse sand. Fresh, coarse grained quartzite.
		63		Pale yellowish-green and grey, mainly rock flour with mica/sericite flakes. Fresh, micaceous/sericitic, shaly quartzite.
		78		

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PERCUSSION DRILLING RECORD

SHEET No. 6/2

CLIENT ** WRC
PROJECT CITY DEEP MINE DUMPS
SITE 3A17 E side
LOGGED BY MFH
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 6
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER TABLE	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
				Solid, fresh quartzite.
		24		
				Yellow, fine-coarse sand and rock flour with some mica flakes. Weathered quartzite.
		25		
				Pale yellow, mainly rock flour and sand. Intact quartzite.
		34		
				Pale greenish-yellow rock flour. Solid, fresh quartzite. Becomes greenish-grey and then pale yellowish-green with depth.
		54		
				Yellow, grey and greenish-yellow, coarse sand. Fresh quartzite.
		55		
				Pale greenish-yellow, becoming yellowish-green below 60m, rock flour and fine-coarse sand. Solid, fresh quartzite.
		63		

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PERCUSSION DRILLING RECORD

SHEET No. 6/1

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 3A17 E side
LOGGED BY MFH
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 6
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER TABLE	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
		0m		Dark yellowish-brown, fine and coarse sand. Weathered quartzite.
		3		
PIEZOMETER INSTALLED AT 5,0m.				Yellow rock flour and weathered, fine-coarse sand. Weathered quartzite.
		11		Reddish-grey, fine-coarse sand with some rock flour. Weathered quartzite.
		14		Yellowish-grey rock flour and fine-coarse sand. Slightly weathered quartzite.
		19		Pale yellowish-grey rock flour and fine sand.

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PERCUSSION DRILLING RECORD

SHEET No. 6/4

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 3A17 E side
LOGGED BY MFH
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 6
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER TABLE	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
				flour with some sand.
		92		Solid quartzite.
				Grey silt and sericite flakes.
				Shaly or sericitic quartzite.
		96		Greenish-yellow rock flour and sand.
				Solid quartzite.
		99		Pale yellowish-grey rock flour and sand.
		100		Solid quartzite.

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PERCUSSION DRILLING RECORD

SHEET No. 6/3

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 3A17 E side
LOGGED BY MFH
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 6
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER STRUCK	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
PIEZOMETER INSTALLED AT 64.1m.	▽	65		Coarse yellow and greenish-grey sand. Fresh, coarse grained quartzite.
		67		Pale yellowish-green, mainly rock flour and fine sand. Solid, fresh quartzite.
		71		Dark greenish- grey rock flour and fine sand with some sericite flakes. Fresh, sericitic quartzite.
		74		Greenish-yellow, mainly rock flour with some fine-medium sand. Fresh quartzite.
		86		Dark greenish-grey, mainly rock flour and sericite flakes. Sericitic quartzite.
		89		Greenish-yellow, coarse sand.
		90		Coarse grained quartzite.
				Pale yellowish-green and grey, mainly rock

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PERCUSSION DRILLING RECORD

SHEET No. 7/2

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 3A17 N side
LOGGED BY MFH
DRILLER OWA

JOB No. PT 3632
HOLE No. BH 7
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER STRUCK	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
		48		Dry, pale bluish to greenish-grey rock flour and coarse sand. Fresh quartzite.
	▽	50		As 40 to 48m, but yellowish-grey in colour.
PIEZOMETER INSTALLED AT 51.9m.		51		Moist, yellowish-grey rock flour and fine-coarse sand. Fresh quartzite.
		53		Pale grey rock flour and fine-coarse sand. Fresh quartzite.
		54		Brownish-grey coarse sand. Coarse grained quartzite.
		55		Pale orange, becoming pale yellowish-grey, rock flour and fine-coarse sand. Fresh quartzite.
		60		

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PERCUSSION DRILLING RECORD

SHEET No. 1/1

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 3A17 N side
LOGGED BY MFH
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 7
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER TABLE	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
		0m		Yellow, fine grained sand. Slimes.
		6		Pale reddish-brown, becoming grey towards 12m fine-coarse quartz sand. Slightly weathered, becoming fresh with depth coarse grained quartzite.
PIEZOMETER INSTALLED AT 10.8m.		12		Very pale pinkish-grey rock flour and fine-coarse sand. Solid, fresh quartzite.
		29		Coarse, pinkish-grey sand with some rock flour. Solid, coarse grained quartzite.
		31		Very pale pinkish-grey, fine-coarse sand and rock flour. Solid, unweathered quartzite.
		40		

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PERCUSSION DRILLING RECORD

SHEET No. 8/2

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 414 N side
LOGGED BY MEH
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 8
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER STRUCK	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
				Pinkish-grey coarse sand. Fresh, coarse grained quartzite.
		23		
				Reddish-grey coarse sand. Slightly weathered, coarse grained quartzite.
		26		
				Pinkish-grey, coarse grained sand Slightly weathered, coarse grained quartzite.
	▽	28		
		29		
PIEZOMETER INSTALLED AT 30,0m.				Dark reddish-grey, medium-coarse sand with magnetite grains. Weathered quartzite.
		32		
				Pale pinkish-grey, coarse sand. Fresh-slightly weathered, coarse grained quartzite.
		36		

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PERCUSSION DRILLING RECORD

SHEET No. 8/1

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 4L4 N side
LOGGED BY MFH
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 8
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER TABLE	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
		0m		Reddish-brown, slightly clayey sand with coarse gravel. Colluvial material.
		1		Pale yellowish-orange, fine sand. Weathered quartzite.
		5		Reddish-brown, fine-coarse sand. Weathered, coarse grained quartzite.
PIEZOMETER INSTALLED AT 10,0m.				
		17		Pale pinkish-brown, coarse sand. Slightly weathered, coarse grained quartzite.

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PERCUSSION DRILLING RECORD

SHEET No. 9/2

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 4L4 SW corner
LOGGED BY MFH
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 9
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER STRUCK	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
				Greensih-grey, fine-coarse sand with a little rock flour. Fresh, coarse grained quartzite.
		27		
				Pink and grey coarse sand. Coarse grained quartzite.
		28		
	▽	30		Greenish-grey, fine-coarse sand with some rock flour. Fresh, coarse grained quartzite.
PIEZOMETER INSTALLED AT 31,85m.				
		36		

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PERCUSSION DRILLING RECORD

SHEET No. 9/1

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 4L4 SW corner
LOGGED BY MFH
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 9
ELEVATION
WATER TABLE
DATE STARTED Jan 84

PENETRATION (MINUTES)	WATER TABLE	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
		0m		Mostly sand with some fragments of completely weathered quartzite. Transported and residual.
		1		Reddish-brown, fine-medium sand with some coarse chips and rock flour. Weathered quartzite.
		8,5		Pinkish-grey and grey, fine-coarse sand. Slightly weathered, coarse grained quartzite.
PIEZOMETER INSTALLED AT 10,35m.		12,5		Greenish-grey, fine-coarse sand with some rock flour. Fresh, coarse grained quartzite.
		15		Slightly yellowish-greenish-grey, fine-coarse sand with some rock flour. Slightly weathered quartzite.
		18		Greenish-grey, fine-coarse sand with a little rock flour. Fresh, coarse grained quartzite.

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PERCUSSION DRILLING RECORD

SHEET No. 1/1

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 4L4 S side
LOGGED BY MFH
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 11
ELEVATION
WATER TABLE
DATE STARTED Jan 84

PENETRATION (MINUTES)	WATER TABLE	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
		0m		Dark brown, slightly clayey, fine-coarse sand and minor gravel. Transported.
		1		Dark reddish-brown, medium sand. Residual quartzite.
		2		Pale pinkish-brown and pinkish-grey rock flour with fine-coarse sand. Fresh quartzite.
PIEZOMETER INSTALLED AT 4,75m.		6		Pale grey rock flour with quartzite chips. Fresh, medium grained quartzite.
		14		Pale yellowish-grey rock flour with fine-coarse sand and quartzite chips. Fresh, slightly sericitic quartzite.
		18		Grey and pale yellowish-grey gravel with some rock flour. Fresh quartzite.

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PERCUSSION DRILLING RECORD

SHEET No. 10/1

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 4L4 N side
LOGGED BY MEH
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 10
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER STRUCK	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
		0m		Pale reddish-grey, rock flour and fine-coarse sand. Weathered quartzite.
		3		Pale grey and pink, mainly coarse sand with some rock flour. Slightly weathered quartzite.
		7		As 3 to 7m, but grey and with some rock chips present. Fresh quartzite.
PIEZOMETER INSTALLED AT 9,85m.		13		Pale grey, mainly rock flour with some sand and rock chips. Fresh, solid quartzite.
		15		Pale grey rock flour and fine-coarse sand. Fresh quartzite.
	▽	50		
PIEZOMETER INSTALLED AT 45,5m.		52		

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PERCUSSION DRILLING RECORD

SHEET No. 12/1

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 4L4 SE corner
LOGGED BY
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 12
ELEVATION
WATER TABLE
DATE STARTED Jan '94

PENETRATION (MINUTES)	WATER STRUCK	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
		0m		
		1		Dry, yellowish-light brown, fine-coarse sand with some transported gravels.
1				Dry, reddish-brown, fine-medium sand. Slightly weathered quartzite.
PIEZOMETER INSTALLED AT 7,15m.	▽	7		
		8		Slightly moist, very light pinkish-grey rock flour and fine-coarse sand. Fresh quartzite.
		19		Slightly moist, light yellowish-brown to grey, fine-coarse sand and rock flour. Weathered quartzite.
		22		Moist, light yellowish-grey rock flour with fine-medium sand and quartzite chips. Fresh quartzite.

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PERCUSSION DRILLING RECORD

SHEET No. 1 1/2

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 4L4 S side
LOGGED BY MFH
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 11
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER STRUCK	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
				As 18 to 20m.
		24		Pale greenish-yellowish-grey, coarse sand, quartzite chips and minor rock flour. Fresh, coarse grained quartzite.
		27		Very pale grey (almost white), rock flour and fine-coarse sand. Fresh quartzite. Sericitic ?
		28		Pale yellowsih- and greenish-grey, rock flour, sand and quartzite chips. Fresh, solid quartzite.
		48		Yellowish-grey, fine-coarse sand. Slightly weathered (?) quartzite.
PIEZOMETER INSTALLED AT 52,7m.	▽	49 50		Pale greenish-grey, mainly rock flour with scattered quartzite chips. Fresh quartzite.
		60		

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PERCUSSION DRILLING RECORD

SHEET No. 12/2

CLIENT WRC
PROJECT CITY DEEP MINE DUMPS
SITE 4L4 SE corner
LOGGED BY JMB
DRILLER DWA

JOB No. PT 3632
HOLE No. BH 12
ELEVATION
WATER TABLE
DATE STARTED Jan '84

PENETRATION (MINUTES)	WATER TABLE	DEPTH (METRES)	PROFILE	MATERIAL DESCRIPTION
				As 22 to 26m.
		27		Moist, light yellowish-grey rock flour with fine-medium sand and quartzite chips. Similar to 22 to 27m, but with more rock flour. Fresh quartzite.
		31		Moist, light greyish-white rock flour with a little medium-coarse sand. Fresh quartzite.
PIEZOMETER INSTALLED AT 35,05m.		40		

APPENDIX D

MINE DUMP INVENTORY FORM

WATER RESEARCH COMMISSION APPENDIX D FILE K5/136/2/1

RESEARCH OF THE CONTRIBUTION OF MINE DUMPS TO MINERAL POLLUTION IN THE VAAL BARRAGE

PHASE 3 - INVENTORY OF MINE DUMPS IN THE CATCHMENT OF THE VAAL BARRAGE

BY STEFFEN ROBERTSON & KIRSTEN (PRETORIA) INC

REF PT 3632

Mine dump index no. _____

A. General and administrative

A1) Sand ..... Slimes ..... Other .....

A2) Mine .....

A3) Group .....

A4) Freehold .....

A5) Surface Right Permit .....

A6) Dates of operation: Opened ..... Closed .....

Period ..... Age .....

A7) Average Annual Rainfall .....mm

A8) Dump to be reworked? ..... When .....

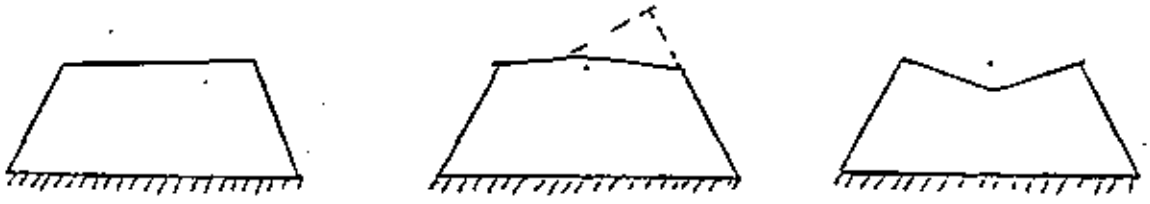
B. Physical data

B1) Area: Top .....m^2 Sides .....m^2

B2) Volume: .....m^3

B3) Topography of dump: Class ..... Remarks .....

Class 1 Class 2 Class 3



B4) Vegetation: Dump: Top; Class ..... Remarks .....

Sides; Class ..... Remarks .....

Surround: Class ..... Remarks .....

Class A: Densely Bushed Class B: Sparcely Bushed

Class C: Grassed Class D: Bare

Class E: Paved

B5) Stormwater Control: Internal: Class ..... Remarks .....
External: Class ..... Remarks .....

E = Existing N = Not existing

Class X: Good Class Y: Satisfactory Class Z: Bad

B6) Existing toe dam .....

B7) Erosion of dump: Class ..... Remarks .....

Class A: Little Class B: Fairly Class C: Badly

ETCOM VALUES

	TEST 1(TIME)	TEST 2(TIME)	TEST 3(TIME)	MEAN VAL ( )
BOTTOM OF DUMP				
MIDDLE OF DUMP				
TOP OF DUMP				

B9) Terrain Geology: Sand ..... Silt ..... Clay .....
Remarks .....

B10) Distance to watercourse from centre of gravity of dump:

Horizontal .....

Vertical .....

Barrage .....

C. <u>Sketch of existing stormwater control</u>

D. Mineral Pollutants and Permeability

D1) Sample no: .....

D2) Location of sample: .....

D3) Leach Test:

	0,5m	1,5m	Bottom
pH			
TDS			
SO_4			
Class			

D4) Permeability: Falling headtest

Depth of hole: .....

Time,T(min)										
Depth of water,hw										

Particle size analysis: 0,425mm .....% passing

0,150mm .....% passing

0,075mm .....% passing

A P P E N D I X E

LOCATION OF MINE DUMPS

IN

VAAL CATCHMENT AREA

JOB N9		FIG N9
PT 3632	WATER RESEARCH COMMISSION	APPENDIX E

Drawing B175746

08-84

STEFFEN ROBERTSON AND KIRSTEN

	JOB Nº		FIG Nº
	PT 3632	WATER RESEARCH COMMISSION	1A

Drawing 81/5/46

08-84

	JOB Nº		FIG Nº
	PT 3632	WATER RESEARCH COMMISSION	1L

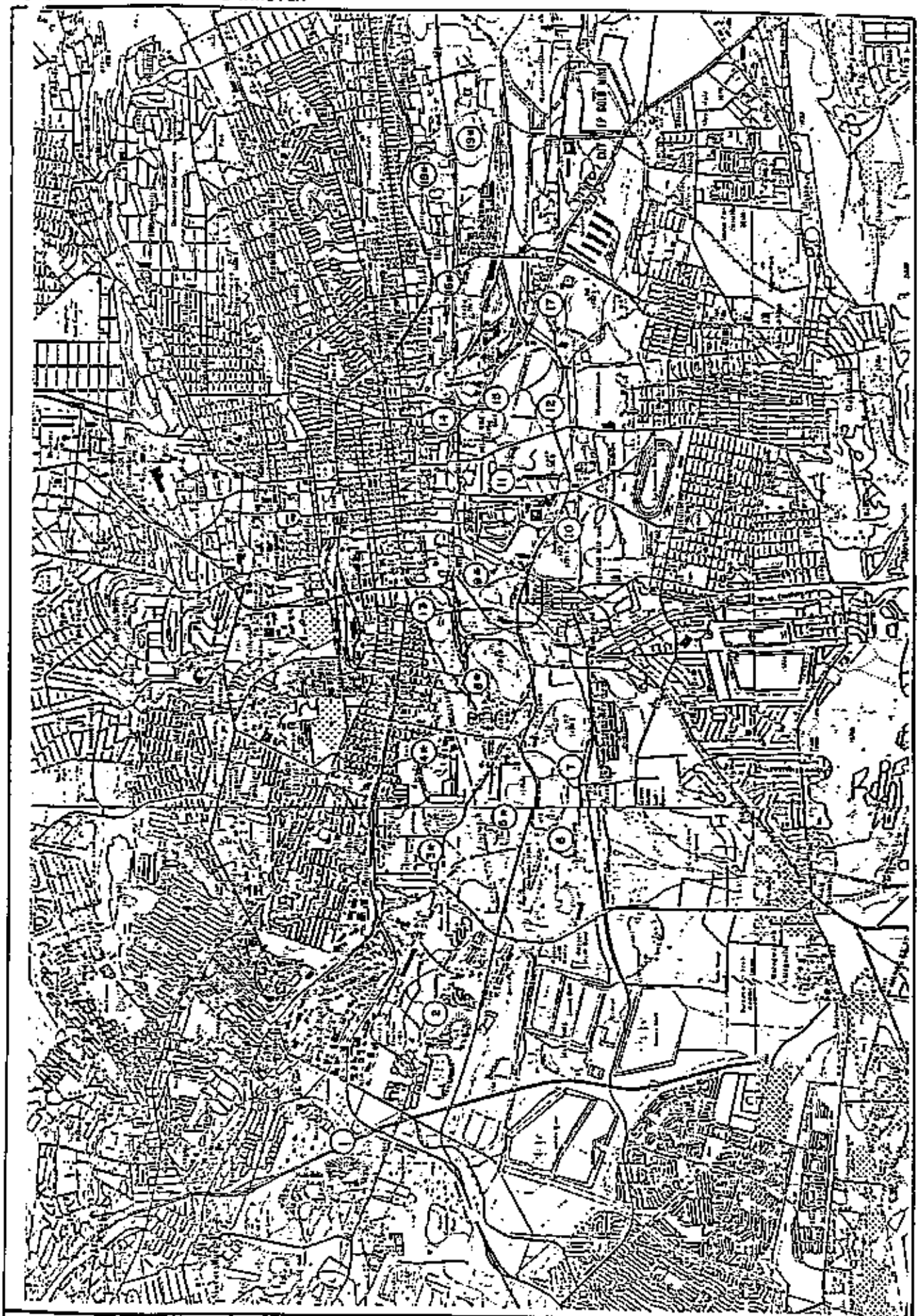
	JOB Nº		FIG Nº
	PT 3632	WATER RESEARCH COMMISSION	2A

STEFFEN ROBERTSON AND KIRSTEN

	JOB Nº		FIG Nº
	PT 3632	WATER RESEARCH COMMISSION	2L

Ozalid : 81/5748

08-84



	JOB Nº		FIG Nº
	PT 3632	WATER RESEARCH COMMISSION	3A

STEFFEN ROBERTSON AND KIRSTEN

	JOB Nº		FIG Nº
	PT3632	WATER RESEARCH COMMISSION	3L

Drawing 81/5746

08-84

	JOB Nº		FIG Nº
	PT3632	WATER RESEARCH COMMISSION	4A

STEFFEN ROBERTSON AND KIRSTEN

JOB Nº		FIG Nº
PT3632	WATER RESEARCH COMMISSION	4L

Ozalid d1/5746

06-04

	JOB Nº		FIG Nº
	PT 3632	WATER RESEARCH COMMISSION	5A

	JOB N9		FIG N9
	PT 3632	WATER RESEARCH COMMISSION	5L

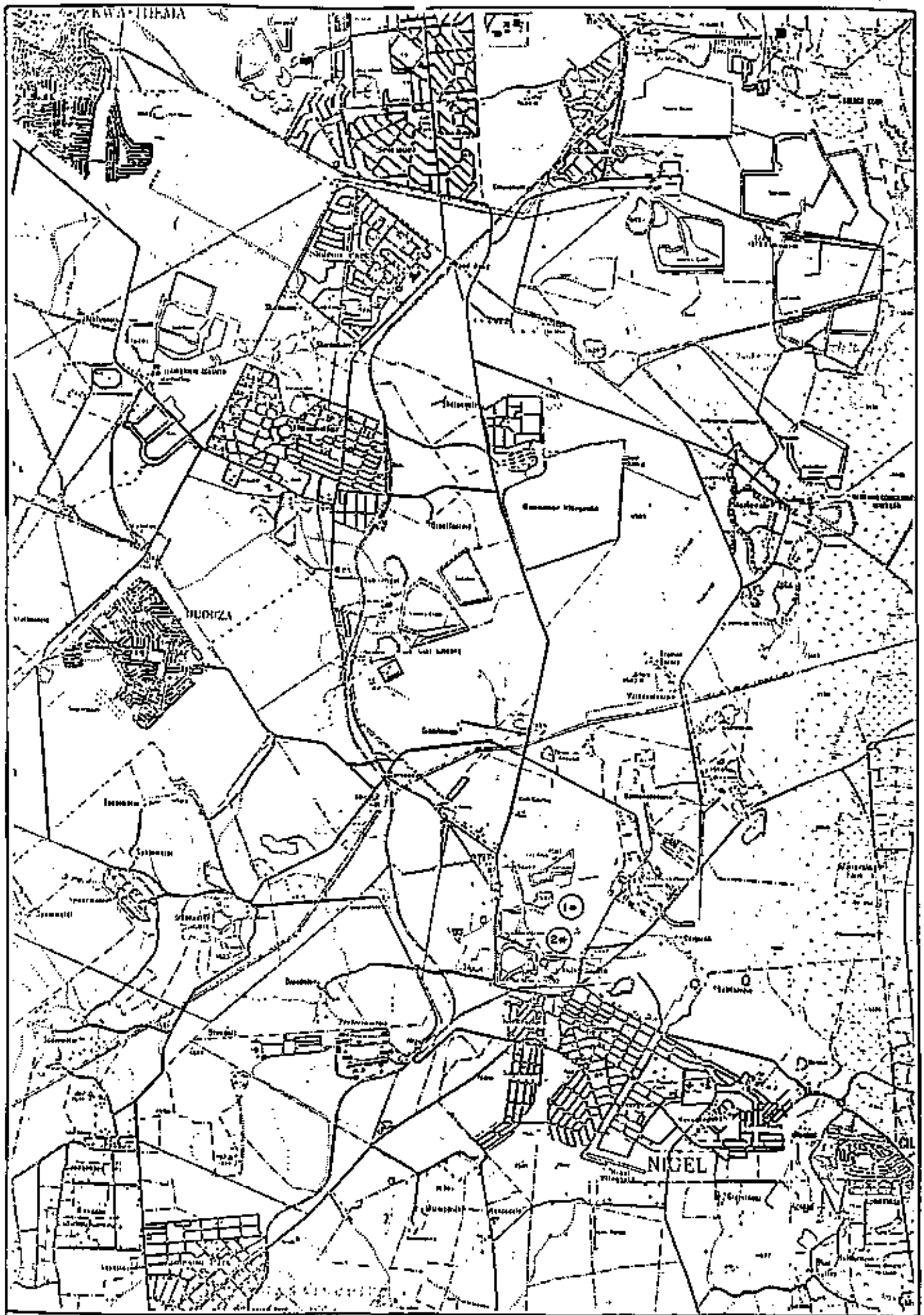
	JOB Nº		FIG Nº
	PT3632	WATER RESEARCH COMMISSION	6A

STEFFEN ROBERTSON AND KIRSTEN

	JOB Nº		FIG Nº
	PT3632	WATER RESEARCH COMMISSION	6L

Ozalid 81/5746

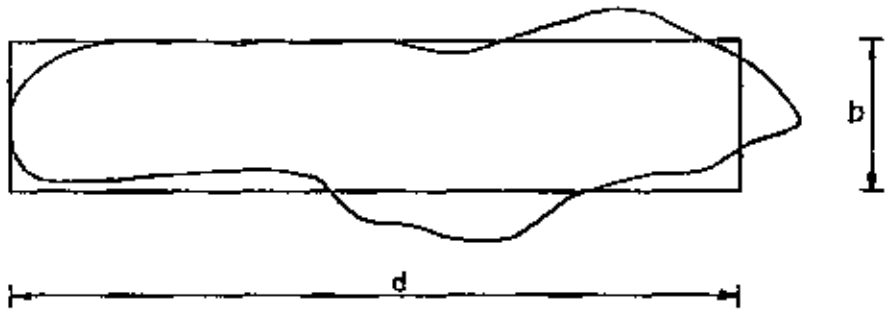
08-84



	JOB NO		FIG NO
	PT3632	WATER RESEARCH COMMISSION	7A

A P P E N D I X F

METHOD OF CALCULATION USED FOR VOLUME OF DUMP ESTIMATIONS



A_T = AREA OF TOP
A_S = AREA OF SIDES
} OBTAINED FROM CHAMBER OF MINES TABLES 1966.

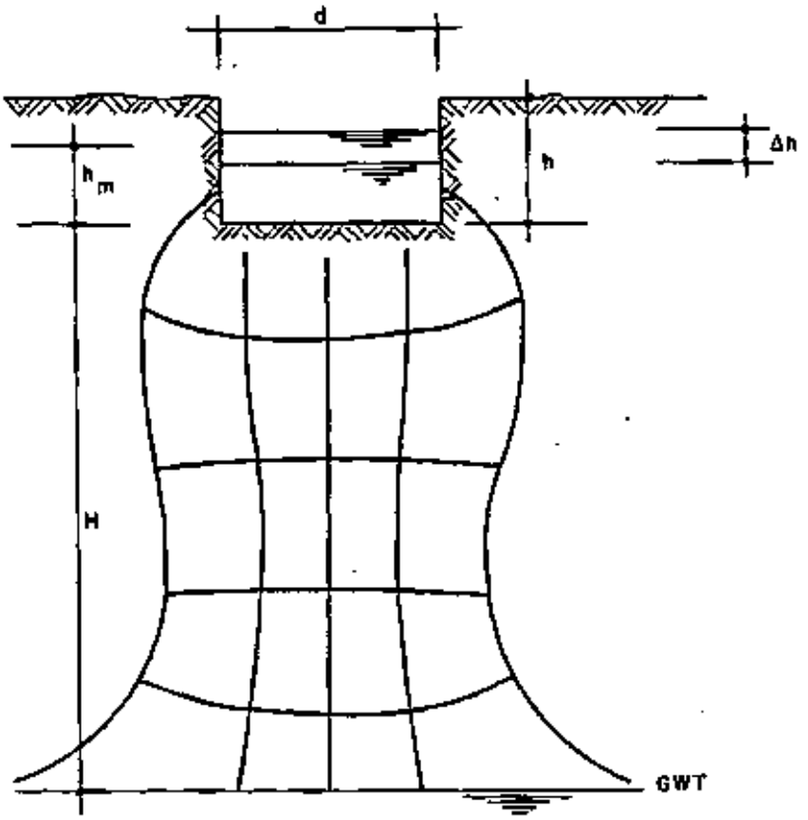
$$\text{VOLUME} = \left(\frac{48-\frac{d}{b}}{47}\right)\left(\frac{1}{6}\left(\sqrt{A_S \cdot 0{\cdot}707 + A_T} - \sqrt{A_T}\right)\left(0{\cdot}707\,A_S + 2A_T + \sqrt{0{\cdot}707\,A_T \cdot A_S + A_T^2}\right)\right)$$

VOLUME OF DUMP ESTIMATIONS

APPENDIX G

CALCULATION OF PERMEABILITY

FROM FALLING HEAD TESTS



CIRCULAR EXCAVATION
(VERTICAL WALLS)

Valid if : $H > 7h_m$

$h > \frac{d}{4}$

FROM MODEL TESTS :

(VALID FOR FALLING HEAD TESTS)

$$k = \frac{\Delta h}{\Delta t} \frac{d}{28h_m}$$

	JOB Nº		FIG Nº
	PT 3632	WATER RESEARCH COMMISSION	APPENDIX G

A P P E N D I X H

CALCULATIONS AND INVENTORIES PROVIDED BY THE CHAMBER OF MINES

CHAMBER Nº 3/A/17 3/L/45

MENNIES Nº 74

MINE Nº ..... DATE. 4-12-75

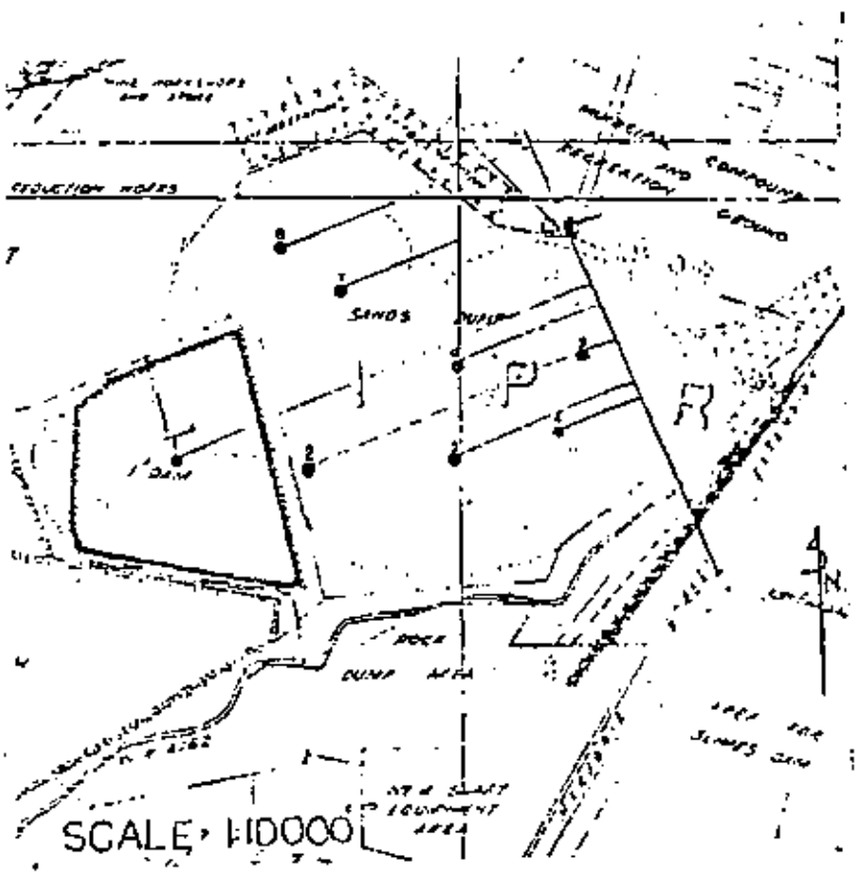


Fig 2

Borehole depth m	Sulphur & Moisture %															
	Hole number															
	1		2		3		4		5		6		7		8	
	S	M	S	M	S	M	S	M	S	M	S	M	S	M	S	M
0 - 4,3	0,98	5,76	0,94	5,19	0,77	5,17	0,81	5,29	0,7	6,55	0,54	4,57	0,21	4,62	0,21	6,05
4,3 - 8,8	1,26	7,02	1,47	4,10	0,63	4,53	1,29	3,40	1,42	4,50	1,88	5,16	0,37	6,18	0,26	6,93
8,8 - 13,4	1,68	3,85	1,52	4,22	1,81	3,97	1,55	3,97	1,11	4,91	1,91	4,15	1,03	5,26	0,50	8,26
13,4 - 18,0	1,45	3,76			1,50	3,97	1,63	3,68	1,65	4,93	1,96	4,29	0,71	6,18	1,49	6,38
18,0 - 22,6	1,33	5,44			1,92	3,48	1,36	1,97	1,53	4,98	1,79	5,26	0,23	7,22	1,52	8,91
22,6 - 27,1	1,19	4,24			2,02	3,44	1,11	3,27	1,39	4,68	1,91	4,50	0,86	5,73	*1,44	21,79
27,1 - 31,7	1,24	4,10			1,66	3,61	1,08	5,01	1,03	4,20	1,60	3,37	1,27	5,61		
31,7 - 36,3	0,31	4,69			1,81	3,35	1,46	4,63	1,16	4,78	1,70	3,83	1,51	4,94		
36,3 - 40,8	0,56	11,81			2,07	3,52	1,60	3,99	1,49	4,53	1 82	3,48	1,44	4,81		
40,8 - 45,4	0,86	16,06			1,89	3,16	1,74	3,97	1,51	4,35	1,72	3,41	1,32	5,63		
45,4 - 50,0	0,98	20,71			1,89	4,29	1,55	3,85	1,44	4,55	1,60	3,41	Sample lost			
50,0 - 54,6	1,06	22,38			1,77	3,68	1,55	15,46	*0,92	21.94	1,56	4,23	*1,58	16,36		
54,6 - 59,1	*0,86	18,57			*1,77	16,87	*1,77	25,97			1,55	3,03				
59.1 - 63,7											* -	15,28				
63,7 - 68,3																
68,3 - 71,3																

* Hole 1 Sample depth to 56,1
3 56,1
4 57,0
5 54,9
6 61,0
7 52,6
8 24.4

TABLE 11 SIZES AND VEGETATION CHARACTERISTICS OF WITWATERSRAND SAND DEPOSITS

Cat. 1 - High pollution potential
2 - Medium pollution potential
3 - Low pollution potential

17TH JUNE 1987

TAL 98 SAND DEPOSITS
94 SAND DEPOSITS REMAIN
4 SAND DEPOSITS COMPLETELY REMOVED

NAME	INDEX NO	HEIGHT	ANGLE	ACRES INDEX VALUE	ACRES REMAINING	REMARKS	CAT.	VEGETATED	TOR DAMS
East Champ d'or	1A/1	3m	22°	2 Acres	2 Acres		3	Good 75% Yes	Nil
East Champ d'or	1A/2	5m	18°	1 Acre	1 Acre		3	Good 65% Yes	Nil
East Champ d'or	1A/3	4m	26°	11 Acres	3 Acres	Removing Deposit	1	Nil	Nil
East Champ d'or	1A/4	3m	15°	17 Acres	1 Acre	Removed	2	Fair 30% Yes	Nil
East Champ d'or	1A/5	-	-	10 Acres	1 Acre	Removed	3	Nil	Nil
Lui[illegible]eds Vlei	1A/6	-	-	-	-	Removed	3	Nil	Nil
Luipaards Vlei	1A/7	60m	27°	30 Acres	30 Acres		3	Good 90% Yes	Nil
Luipaards Vlei	1A/8	4m	18°	3 Acres	3 Acres		3	Good 70% Yes	Nil
Luipaards Vlei	1A/9	24m	20°	20 Acres	16 Acres	Removing	1	Nil	Nil
[illegible]ssacker Outcrops	1A/10	21m	22°	5 Acres	5 Acres		1	Nil	Nil
	1A/11	20m	26°	4 Acres	4 Acres		1	Nil	Nil
West Rand Cons.	1A/12	110m	28°	90 Acres	85 Acres	Removed 5 Acres West	2	Fair 50% Yes	Nil
est Rand Cons.	1A/13	-	-	11 Acres	-	Removed	-	Nil	Nil
[illegible]. and Cons.	1A/14	50m	26°	38 Acres	38 Acres		3	Good 70% Yes	Nil
Randfontein Estates	1A/15	-	-	-	-	Removed	-	Nil	Nil
andfontein Estates	1A/16	-	26°	8 Acres	1 Acre	Removed 7 Acres	3	Nil	Nil
Randfontein Estates	1A/17	-	-	18 Acres	-	Removed	-	Nil	Nil
andfontein Estates	1A/18	10m	26°	18 Acres	1 Acre	Removed	-	Portion	Yes
Randfontein Estates	1A/19	5m	16°	19 Acres	1 Acre	Removing	3	Nil	Yes
Water Flows	1A/20	120m	28°	188 Acres	10 Acres	Removing	2	Good 70% Yes	Nil
nto Hartebeestfontein	1A/21	6m	29°	10 Acres	1 Acre	Small Deposit	3	Nil	Nil
dam 1A/20, 1A/21 and 1A/22 (Luipaardsvlei)	1A/22	7m	29°	1 Acre	1 1/2Acre	Small Deposit	3	Nil	Nil

ML/dvdv/80

TABLE II CONTD.

NAME	INDEX NO	HEIGHT	ANGLE	ACRES INDEX VALUE	ACRES REMAINING	REMARKS	CAT.	VEGETATED	TOE DAMS
ns Main Reef	2A/1	25m	26°	20 Acres	12 Acres	-	1	Nil	Nil
ons. Main Reef	2A/2	25m	26°	15 Acres	15 Acres	East Slope Not Ver.	1	Nil	Nil
nd Leases	2A/3	30m	26°	11 Acres	13 Acres	-	3	Good 80% Yes	Nil
Rand Leases	2A/4	3m	24°	3 Acres	3 Acres	-	3	Good 80% Yes	Nil
nd Leases	2A/5	20m	27°	13 Acres	6 Acres	Being Removed	2	Nil	Nil
Durban Roodepoort Deep	2A/6	20m	26°	21 Acres	21 Acres	-	3	Good 70% Yes	Nil
Durban Roodepoort Deep	2A/7	50m	27°	45 Acres	45 Acres	-	3	Good 65% Yes	Nil
rban Roodepoort Deep	2A/8	20m	26°	20 Acres	20 Acres	Rock Cladded	3	Fair 50% Yes	Nil
Durban Roodepoort Deep	2A/9	10m	26°	6 Acres	2 Acres	Being Removed	3	Nil	Nil
rban Roodepoort Deep	2A/10	2m	12°	5 Acres	5 Acres	-	3	Fair 50% Yes	Nil
Durban Roodepoort Deep	2A/11	15m	22°	6 Acres	6 Acres	-	2	Good 60% Yes	Nil
..lford.	2A/12	8m	26°	1 Acre	½ Acre	Being Removed	3	Good 65% Yes	Nil
Wilford	2A/13	3m	24°	2 Acres	2 Acres	-	3	Nil	Nil
Wilford	2A/14	3m	24°	-	4 Acres	-	3	Fair 50% Yes	Yes
Ilford	2A/15	20m	24°	-	6 Acres	Princess Sandveins Being Removed	3	Good 65% Yes	Yes
CMR	3A/1	70m	29°	74 Acres	74 Acres	-	3	Good 70% Yes	Yes
..oestar	3A/2	95m	29°	50 Acres	50 Acres	-	2	Good 60% Yes	Nil
ayfair	3A/3	40m	28°	30 Acres	20 Acres	Being Removed	3	Good 70% Yes	Nil
Mayfair	3A/4	30m	25°	25 Acres	25 Acres	-	3	Good 70% Yes	Yes
..own Mines	3A/5	30m	27°	31 Acres	31 Acres	-	3	Fair 50% Yes	Nil
Crown Mines D Sand	3A/6	85m	28°	50 Acres	40 Acres	Being Removed	2	Good 65% Yes	Nil
Crown Mines C Sand	3A/7	80m	28°	96 Acres	80 Acres	Being Removed	3	Good 75% Yes	Nil
rown Mines	3A/8	90m	27°	108 Acres	25 Acres	Being Removed	3	Good 75% Yes	Nil
Robinson Deep	3A/9	20m	24°	12 Acres	4 Acres	Being Removed	1	Nil	Nil
..llage H.R.	3A/9A	15m	22°	1 Acre	1 Acre	H2	2	Good 70% Yes	Nil
obinson Deep	3A/10	80m+	27°	84 Acres	84 Acres	-	1	Poor 40% Yes	Nil
Robinson Deep	3A/11	60m	27°	53 Acres	53 Acres	-	2	Fair 50% Yes	Nil
..llage H.R.	3A/12	8m	24°	12 Acres	12 Acres	-	3	Fair 50% Yes	Nil
Village H.R.	3A/13A	50m	28°	-	0	Cladded with soil Top-star drive-in	3	Good 70% Yes	Nil

NAME	INDEX NO	HEIGHT	ANGLE	INDEX VALUE	ACRES REMAINING	REMARKS	CAT.	VEGETATED	TOE DAMS
Village M.R.	3A/13	15m	24°	46 Acres	Flat 40 Acres	H2	3	Good 70% Yes	Nil
Village M.R.	3A/14	2m	-	26 Acres	4 Acres	H2	3	Good 70% Yes	Nil
Village M.R.	3A/15	15m	26°	13 Acres	10 Acres	Being Removed	2	Soil & Grass Yes	Nil
Village M.R.	3A/15A	2m	Flat-low	23 Acres	2 Acres	Removed	2	Nil	Nil
Village M.R.	3A/16	30m	28°	25 Acres	20 Acres	Being Removed	2	Poor 40% Yes	Nil
Deep	3A/17	90m	28°	88 Acres	80 Acres	Being Removed	2	Good 70% Yes	East
Deep	3A/18	-	-	27 Acres	-	ADJ TO H2	-	Nil	Nil
Deep	3A/19	60m	26°	97 Acres	95 Acres	Being Removed	2	Good 70% Yes	Nil
Jack	4A/1	$\frac{1}{2}$m	-	20 Acres	1 Acre	Being Removed	3	Nil	Yes
Jack	4A/2	50m	25°	86 Acres	60 Acres	Being Removed	1	Poor 40% Yes	Nil
Jack	4A/3	4m	Flat	10 Acres	6 Acres	H2	3	Good 60% Yes	Nil
Jack	4A/4	60m	28°	33 Acres	25 Acres	Being Removed	1	Poor 10% Yes	Nil
	4A/5	1m	27°	1 Acre	$\frac{1}{4}$ Acre	Being Removed	3	Nil	Nil
Steinbein	4A/6	60m	27°	46 Acres	44 Acres	-	2	Good 70% South Yes	Yes
Kleinhuys Deep	4A/7	40m	26°	29 Acres	29 Acres	-	2	Good 70% Yes	Yes
Kleinhuys Deep	4A/8	15m	21°	16 Acres	8 Acre	Being Removed	2	Nil	Nil
Kleinhuys JHB	4A/9	50m	16°	34 Acres	34 Acres	-	3	Good 70% North South Yes	East
Kleinhuys Deep	4A/10	4m	24°	2 Acres	1 Acre	Being Removed	3	Fair 40% Yes	Nil
Kleinhuys Deep	4A/11	40m	29°	38 Acres	38 Acres	-	3	Fair 50% Yes	Nil
P	4A/12	45m	28°	27 Acres	24 Acres	Being Removed	3	Nil	Nil
Riverbase G.H.	4A/13	10m	28°	1 Acre	1 Acre	-	1	Nil	Nil
Deep	4A/14	90m	30°	61 Acres	59 Acres	Being Removed	2	Poor 45% Yes	Nil
Consolidated	4A/15	25m	23°	13 Acres	7 Acres	Being Removed	1	Fair 55% Yes	Nil
G.H.	4A/16	10m	22°	23 Acres	23 Acres	Under Treatment	1	Nil	Yes
G.H.	4A/17	60m	27°	61 Acres	61 Acres	-	2	Good 75% Yes	Nil
G.H.	4A/18	50m	26°	36 Acres	36 Acres	30% Grassed	2	Poor 30% Yes	Yes
G.H.	4A/19	6m	28°			SAR Marshalling Yard	3	Poor 30% Yes	Nil
P.H.	4A/20	20m	25°	14 Acres	14 Acres		3	Good 75% Yes	Nil
P.H.	4A/21	80m	28°	22 Acres	22 Acres		3	Good 60% Yes	Nil

1 JUNE 1987

TABLE II CONTD.

NAME	INDEX NO	HEIGHT	ANGLE	ACRES INDEX VALUE	ACRES REMAINING	REMARKS	CAT.	VEGETATED	TOE DAMS
R.P.M.	4A/22	80m	28°	64 Acres	64 Acres	-	3	Good 70% Yes	Nil
R.P.M.	4A/23	80m	30°	65 Acres	65 Acres	-	3	Good 60% Yes	Nil
R.P.M.	4A/24	15m	26°	6 Acres	6 Acres	-	3	Fair 55% Yes	Nil
ew Kleinfontein	5A/1	-	-	-	-	Removed	-	-	-
akpan	5A/2	40m	29°	64 Acres	50 Acres	Being Removed	1	Fair 50% Yes	Nil
New Kleinfontein	5A/3	60m	27°	52 Acres	48 Acres	Being Removed	1	Rock clad	Nil
elnfontein	5A/4	70m	28°	54 Acres	49 Acres	Being Removed	1	Rock clad	Nil
w Van Ryn	5A/5	30m	25°	40 Acres	24 Acres	Being Removed	2	Fair 30% Yes	Nil
New Van Ryn	5A/6	50m	28°	44 Acres	40 Acres	Being Removed	2	Rock clad	Nil
ew Modder	5A/7	50m	27°	52 Acres	48 Acres	Being Removed	2	Good 70% Yes	Nil
akeview	5A/8	50m	27°	37 Acres	37 Acres	-	1	West only Yes 30%	Nil
Modder B	5A/9	75m	28°	49 Acres	49 Acres	-	2	Nil	Nil
C.S.I.R.	5A/10	80m	27°	76 Acres	76 Acres	-	1	Good 70% Yes	Nil
ew Modder	5A/11	30m	25°	25 Acres	25 Acres	Rock Clad	3	Nil	Nil
Geduld Prop	6A/1	24m	25°	29 Acres	6 Acres	Being Removed	2	Nil	Nil
S.A. Igel	7A/1	15m	27°	19 Acres	4 Acres	Being Removed	2	Nil	Nil
Sub Nigel	7A/2	10m	26°	2 Acres	1 Acre	Being Removed	2	Nil	Nil

/dvdw/300

TABLE NO 111 COMPARISON OF SRK & COM VOLUME ESTIMATES

DEPOSIT	SRK VOLUME 10^6	COM VOLUME m^3	REMARKS
1A/1	0,08+	0,02	
2	0,03	0,01	
6	1,82+	0,01	
2A/1	2,32+	0,78	
2	1,51	1,03	
3	0,95	0,76	
7	7,32	5,90	
8	2,29	1,24	
9	0,38+	0,05	
11	0,36	0,23	
14	-	-	
15	-	-	
16	0,98+	1,04	
3A/1	16,02	13,56	
2	6,48	9,16	*This is sand
6	7,92	6,34	on slime with
7	20,34+	15,65	21,45 ha of side/
10	14,12	16,28	coo. Volume of
*11	21,20*	7,94	36/17 (88ha) =
13	5,72	2,08	13,41 cherefore
17	12,41+	15,66	volume here must
			be much lower
4A/3	0,92+	0,10	
4	4,76+	3,05	
7	3,38	2,98	
15	1,48+	0,16	
17	12,41	9,66	

DEPOSIT	SRK VOLUME 10^6	COM VOLUME m^3	REMARKS
18	5,63	4,36	
19	-	-	
20	1,37	0,81	
21	2,69	2,65	
24	0,38	0,25	
5A/2	9,55+	6,01	
3	6,99+	7,08	
5	4,63+	1,98	
6	5,46+	5,20	
9	7,27	8,09	
**(1	17,37**	2,08	**This is a small sand dune on top of slime area approx 10ha in of similar dimensions to 5A/5 the volume of which is ca 3,9
6A/1	4,13+	0,31	
	210,57	152,45	33 Deposits
2A/14	0,94	0,94	Taking COM
15	0	0	Values
4A/19	0	0	SAES. year4
	210,71	152,49	38 Deposits
*5A/11 = 7,94	13,25		Taking COM
**5A/11 = 2,08	15,29		Values
	182,16	152,49	Volume of 38 Deposits

+ These are now being removed

HL/dvdv/70

TABLE NO IV COMPARISION OF WEIGHTED VOLUMES, CALCULATED BY SRK, THE CON, UTILISING SRK'S HAZARD RATINGS

INDEX NO	SRK POLLUTION CLASSIFICATION	CON POLLUTION CLASSIFICATION	SRK WEIGHTED VOLUME USING SRK RATING	CON WEIGHTED VOLUME USING CON RATING	CON WEIGHTED VOLUME USING SRK RATING
1A/1	B	A	0,04	0,01	0,01
2	B	A	0,01	0,00	0,00
4	A	B	0,45	0,01	0,00
2A/1	A	C	0,58	0,78	0,19
2	B	C	0,75	1,03	0,51
3	A	A	0,24	0,19	0,19
7	C	A	7,32	1,47	5,90
8	A	A	0,57	0,31	0,31
9	A	A	0,09	0,01	0,01
11	B	B	0,19	0,11	0,11
15	A	B	0,24	0,52	0,26
3A/1	B	A	8,01	3,39	6,78
2	C	B	6,48	4,58	9,16
6	C	B	7,92	3,17	6,34
7	C	A	20,34	3,51	15,66
10	B	C	7,06	16,28	8,14
11	C	B	*7,94	3,97	7,94
13	B	A	3,86	0,52	1,04
17	C	B	12,41	7,83	15,66
4A/3	B	A	0,46	0,02	0,04
4	C	C	4,74	3,05	3,05
7	B	B	1,59	1,49	1,49
15	B	C	2,74	0,16	0,18
17	C	B	12,41	4,73	9,46
5A/18	A	B	1,40	2,18	1,09
20	A	A	0,34	0,20	0,20
21	A	A	0,47	0,66	0,66
24	A	A	0,09	0,06	0,06
5A/2	B	C	4,77	6,01	3,00
3	C	C	6,99	7,01	7,01
5	B	B	2,31	0,99	0,99
6	B	B	2,72	2,60	2,60
9	C	B	7,27	4,04	8,09
11	B	A	*1,04	0,52	1,04
5A/1	B	B	2,06	0,15	0,15
			133,22	82,16	117,32

A = Rated low pollution hazard

B = Rated medium pollution hazard

C = Rated high pollution hazard

*This is a relatively small sand deposit on top of a slime deposit hence since the CON were aware of this their volume estimate is stated.

ML:kdw/60

Estimated weighted volume for

INDEX NO	CURRENT ESTIMATED VOLUME 10^6 m^3	ESTIMATED PERMANENT DEPOSITS 10^6 m^3	DEPOSITS REMOVED OR BEING REMOVED 10^6 m^3	REMARKS
1A/1	0,02	0,01		
2	0,01	0,00		
3	0,04		0,04	
4	0,01		0,01	
5	0,02		0,01	
6	0,00		0,00	
7	3,79	0,95		
8	0,04	0,01		
9	0,95		0,95	
10	0,21	0,21		
11	0,17	0,17		
12	19,11		9,56	
13	00,00		0,00	
14	4,67	1,17		
15	0,00		0,00	
16	0,02		0,01	
17	0,00		0,00	
18	0,00		0,00	
19	0,00		0,00	
20]				
21]				Water flows into Hartebeestfontein
22]				
		2,52	10,58	

TABLE NO V CONT. CHAMBER OF MINES ESTIMATES MAY 1987

INDEX NO	CURRENT ESTIMATED VOLUME 10^6 m^3	Estimated weighted volume for: ESTIMATED PERMANENT DEPOSITS 10^6 m^3	Estimated weighted volume for: DEPOSITS REMOVED OR BEING REMOVED 10^6 m^3	REMARKS
2A/1	0,78		0,78	
2	1,03	1,03		
3	0,76	0,19		
4	0,03	0,01		
5	0,30		0,15	
6	1,31	0,33		
7	5,90	1,48		
8	1,24	0,31		Rock cladded
9	0,05		0,01	
10	0,04	0,01		
11	0,23	0,11		
12	0,01		0,00	
13	0,02	0,01		
14	0,04	0,01		
15	0,28		0,07	
16	1,04		0,52	
		3,49	1,53	

TABLE NO V COAL CHAMBER OF MINES ESTIMATES MAY 1987

Estimated weighted volume for

INDEX NO	CURRENT ESTIMATED VOLUME 10^6 m^3	ESTIMATED PERMANENT DEPOSITS 10^6 m^3	DEPOSITS REMOVED OR BEING REMOVED 10^6 m^3	REMARKS
4A/1	0,00		0,00	
2	8,21		8,21	N2
3	0,10		0,02	
4	3,05		3,05	
5	0,00		0,00	
6	6,64	3,32		
7	2,98	1,49		
8	0,32		0,16	
9	4,06	1,02		
10	0,01		0,00	
11	4,36	1,09		
12	3,00		0,75	
13	0,02	0,02		
14	11,62		5,81	
15	0,36		0,36	
16	0,80		0,80	Under treatment
17	9,46	4,73		
18	4,36	2,18		
19	0,00	0,00		SATS Marshalling yard
20	0,81	0,20		
21	2,65	0,66		
22	11,76	2,93		
23	12,58	3,15		
24	0,25	0,06		
		20,85	19,16	

TABLE NO 5 CONT CHAMBER OF MINES ESTIMATES MAY 1987

Estimated weighted volume for

INDEX NO	CURRENT ESTIMATED VOLUME 10^6 m^3	ESTIMATED PERMANENT DEPOSITS 10^6 m^3	DEPOSITS REMOVED OR BEING REMOVED 10^6 m^3	REMARKS
3A/1	13,56	3,39		
2	9,16	4,58		
3	1,96		0,49	
4	2,08	0,52		
5	2,76	0,69		
6	6,34		3,17	
7	15,66		3,92	
8	3,08		0,77	
9	0,16		0,16	
9A	0,02	0,01		
10	16,28	16,28		
11	7,94	3,97		
12	0,33	0,08		
13	2,08	0,52		M2 Highway
13A	0,00	0,00		Top Star drive-in
14	0,03	0,01		M2 Highway
15	0,46		0,23	
15A	0,01		0,01	
16	1,67		0,84	
17	15,66		7,83	
18	0,00		0,00	
19	15,90		7,95	
		30,05	25,37	

TABLE NO V CONT. CHAMBER OF MINES ESTIMATES MAY 1987

Estimated weighted volume for

INDEX NO	CURRENT ESTIMATED VOLUME 10^6 m^3	ESTIMATED PERMANENT DEPOSITS 10^6 m^3	DEPOSITS REMOVED OR BEING REMOVED 10^6 m^3	REMARKS
5A/1	0,00		0,00	
2	6,01		6,01	
3	7,01		7,01	
4	7,87		7,87	
5	1,98		0,99	
6	5,20		2,60	
7	6,38		3,19	
8	4,63	4,63		
9	8,09	4,05		
10	14,32	3,58		
11	2,08	0,52		
		12,78	27,67	

TABLE NO V CONT. CHAMBER OF MINES ESTIMATES MAY 1987

Estimated weighted volume for

INDEX NO	CURRENT ESTIMATED VOLUME 10^6 m^3	ESTIMATED PERMANENT DEPOSITS 10^6 m^3	DEPOSITS REMOVED OR BEING REMOVED 10^6 m^3	REMARKS
6A/1	0,31		0,16	
7A/1	0,16		0,08	
2	0,02		0,01	
		0,00	0,25	
TOTAL		69,69	84,56	

Since 3A/17 -12,4 x $10^6 m^3$ produces 2 300 t/a of TDS

TDS from Permanent deposits $\frac{69,69}{12,41}$ X 2300 = 12 916 tons/annum

TDS from Removed or being removed deposits $\frac{84,56}{12,41}$ X 2300 = 15 671 tons/annum

28 587 tons/annum