GHT CONSULTING SCIENTISTS

Tutuka Power Station
GEOHYDROLOGICAL REPORT
PROPOSES DOMESTIC WASTE SITE EXTENSION
MAY 2010
FINAL REPORT

for

Eskom

TUTUKA POWER STATION

by

GHT CONSULTING SCIENTISTS

PROJECT TEAM
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Project no.:	002-19-ghd.574	Start Date:	February 2010
Current Phase:	Final Report	Start Date:	February 2010
Report no.:	RVN 574.1/1025	Report Date:	May 2010

GHT CONSULTING SCIENTISTS

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4 May 2010 Our ref.: RVN 574.1/1025

Zitholele Consulting (Pty) Ltd
PO Box 6002
Halfway House
1685
South Africa

FOR ATTENTION: Mr. Konrad Kruger

Dear Sir,

PROPOSES DOMESTIC WASTE SITE EXTENSION
APRIL 2010 FINAL REPORT

It is our pleasure in enclosing one electronic copy and three hard copies of the report RVN 574.1/1025 "Tutuka Power Station, Proposes Domestic Waste Site Extension - April 2010". This is a final report and includes the field work and detailed description of the hydrological as well as geohydrological assessments on the area at the Domestic Waste Site. All the issues that need immediate attention are also discussed in detail in this report.

We trust that the report will fulfil the expectations of the Power Station and we will supply any additional information if needed.

Yours sincerely,

Louis J van Niekerk (Pr.Sci.Nat.)

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Copies: 1) Three Printed copies and one electronic copy to Mr Konrad Kruger of Zitholele Consulting (Pty) Ltd

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Appendices

1 INTRODUCTION

GHT Consulting was commissioned to investigate the surface and groundwater impacts of a proposed extension of Tutuka Power Station solid waste disposal site located near Standerton, Mpumalanga, with a view to collecting sufficient geotechnical data to allow an assessment of site suitability to be made by Zitholele Consulting. The approach taken to the investigations was sub-divided into the following phases:

- Preliminary site walkover and assessment;
- Geological mapping;
- Geophysical investigations;
- Installation of monitoring bores;
- Sampling of representative soil / unsaturated zone profiles during the drilling phase;
- Hydrocensus and collection of background surface and groundwater samples for laboratory analysis; and,
- Geohydrological assessment.

Field investigations were commenced during the first week of February 2010, and subsequently completed by the 24th March 2010. All aspects of the investigation undertaken to date are reported here.

2 PHYSICAL GEOGRAPHY

2.1 Extent of investigation

The proposed site is located in a rural area on the property Pretorius Vley 374 portion 7 (Standerton Magisterial District) approximately 21 km north-northeast of Standerton (refer Appendix A, Map 1), and falls within grid references (26.773226° S, 29.323072 ° E) and (26.770405° S, 29.324294 ° E). The site is owned by Eskom. Small dolerite quarries exist in the direct vicinity of the new proposed site. Excavated material from these sites was typically used for road construction and maintenance purposes. A Locality Map is attached in Appendix A, Map 1 of this document.

Field inspections of the area within two kilometres of the property boundaries were undertaken. Detailed field investigations were, however, concentrated on the property itself, specifically the area to the west of the current domestic waste site.

2.2 Topography and surface drainage

Tutuka Power Station is located on a topographic high. The facility occurs within drainage region C11K, and can be sub-divided into secondary drainage regions comprised of smaller streams and creeks. The Domestic Waste Site area is situated in sub-catchment C11K-B and has been developed upon gradual slopes and a semi-developed drainage system (refer Appendix A, Map 2 & 3).

An east-west trending ridge that falls to more moderately sloping country defines the southern boundary of the domestic waste site area. To the east of the waste disposal site, however, surface relief is gently sloping to the non-perennial spruit. The country to the east and north of the domestic waste site falls steeply towards an un-named seasonal creek, and the perennial Racesbult Spruit, respectively. The ridge terminates along the western boundary of the property, where the country falls steeply towards perennial Leeu Spruit. The Leeu Spruit drains the area to the west of the domestic waste site to the Grootdraai Dam, an artificial impoundment constructed across the Vaal River approximately 10 km from the site.

Both the Racesbult and the Leeu Spruit are of geographical significance. The non-perennial spruit north of the waste site drains into the Racesbult Spruit which drains into the Leeu Spruit which is a major tributary of the Vaal River and therefore Grootdraai Dam. Overflow from the dam descends into the Vaal River, and ultimately enters the Vaal Dam where it is utilised for water supply purposes.

Orthophoto maps of the district confirm the presence of a recurring block type drainage pattern, characterized by stream sections orientated north-south and east-west. Drainage of this type is often structurally controlled, and thus may provide some insight into the orientation of regional and convergent stresses.

Soil cover is generally thin in the elevated areas of the property especially in the direct vicinity of the waste site, and rock outcrops are frequently observed. To the north, south and west of the waste site, however, the soil profile is deeper. These characteristics have influenced land use in the area, as most cropping are undertaken in these areas, while the only productive use for elevated country in the direct vicinity of the waste site is grazing.

2.3 Infrastructure and man-made features

Infrastructure at or in the vicinity of the current domestic waste site includes the Tutuka Power Sation complex 1.5 km to the east and Thuthukani Township 2 km to the west of the site. Site improvements initiated by the previous owner include the construction of stock fences (currently in poor to fair repair) around the lot perimeter and several dolerite quarries'.

2.4 Climate and Vegetation

Tutuka Power Station falls within the Highveld climate classification of Viterito (1987), and can thus expect warm, wet summers, and mild, dry winters, with annual equivalent evaporation depths exceeding precipitation. Winds blow predominantly from the northwest, particularly in the afternoon, although they do gust from the southwest during thunderstorm events. Regular dust storms can also be expected during periods of prolonged dry weather.

Air temperatures show significant daily and seasonal variations, with mean temperatures at their maximum in December and January, and minimum in June and July. Frosts can be expected in the 150-day period between May and September.

Temperature values for the Tutuka area are summarized in Table 1.

Table 1. Temperature values for the Tutuka area (South African Weather Bureau, 1993).

Temperature parameter	**January** **^{0}C**	**June** **^{0}C**
Maximum	31.6	21.6
Mean Daily Maximum	26.8	17.2
Mean Daily Temperature	20.2	7.8
Mean Daily Minimum	13.6	-1.6
Minimum	8.9	-6.9

Monthly rainfall records for four gauging stations in the Tutuka Power Station area show that most rainfall falls during thunderstorms in the period between October and March, while significant variations in monthly rainfall can be expected between years (refer Table 2). The area around Tutuka receives an annual rainfall of between 630 and 680 mm, although records for the last 10 years indicate that below average rainfall has been received at three of the gauging stations during this period (refer Table 3). Further, the variation in rainfall received at respective stations suggests that significant variations in the spatial distribution of rainfall can be expected, most likely a consequence of thunderstorm activity.

Rainfall has also been measured at the Tutuka Power Station using a Davis Weather Wizard 3 (refer Table 4). While some significant differences are apparent between these values and measurements taken elsewhere in the district, particularly in the earlier part of the record, these results were used for analysis purposes later in this report.

Evaporation data is also available from a site in the Standerton area (refer Table 5). The data indicates that most evaporation occurs in the months between October and March.

Table 2. Rainfall statistics for four gauging stations near Standerton (South African Weather Bureau, 2000).

Month	**Gauging station and rainfall in mm**							
	Standerton (Sandbaken)		***Standerton (Redwing)***		***Standerton (Goedgevonden)***		***Standerton***	
	Ave	***SD***	***Ave***	***SD***	***Ave***	***SD***	***Ave***	***SD***
January	118.8	53.7	117.2	59.1	108	55.4	108.4	33.9
February	90.1	49.3	87.5	64.8	87.2	61.5	79.7	61.8
March	78.7	45.2	71.7	47.6	68.7	39.3	79.1	36.6
April	35.4	31.3	34.2	27.6	40.5	36	28.4	29.9
May	16.8	21.1	17.5	24.7	16	23.5	6.8	8.4
June	6.8	13.7	7	15.7	6.3	12.2	10.1	12.8
July	7.9	16.1	7.7	14.3	7.6	18	3.8	5.5
August	8.7	14.7	11.2	21.1	8.7	15.5	7.8	11.6
September	23.1	24.5	26.3	30	24.4	31.1	23.1	36.5
October	75.9	45	75.3	43.2	71.3	46.1	103.9	41.4
November	108.8	58.8	107.8	54.6	92.5	52.8	107.1	55.5
December	105.7	46.6	107.9	46.7	101.2	59.3	102.6	23.9
TOTAL	**676.7**		**671.4**		**632.4**		**660.8**	

Note: Duration of records for each gauging site are:
Standerton (Sandbaken) 1909 to 1999;
Standerton (Redwing) 1917 to 1999;
Standerton (Goedgevonden) 1927 to 1999;
Standerton 1981 to 1995.

Table 3. Average rainfall gauged at four stations near Standerton.

Year	**Gauging station and rainfall in mm**			
	Standerton (Sandbaken)	***Standerton (Redwing)***	***Standerton (Goedgeven)***	***Standerton***
1990	486	608.9	609.4	578.6
1991	262	551.3	463.4	586.3
1992	442.5	455.5	425	510.6
1993	470.5	688	546.9	901.4
1994	339	489.5	357	583.7
1995	593.6	860.8	702.5	321.9
1996	777	762.9	536.8	580.4
1997	667	1010.7	820.2	712.6
1998	386	590.7	133.9	464.6
1999	-	473.7	-	419
AVERAGE	**491.5**	**649.2**	**510.6**	**565.9**

Table 4. Rainfall measured at Tutuka Power Station.

Month	**Rainfall received in a given year (mm)**					
	1995	***1996***	***1997***	***1998***	***1999***	***2000***
January	125	124	66	146	101	98
February	77	259	135	52	15	112
March	146	916	197	40	37	91
April	56	83	22	23	20	38
May	2	8	87	0	30	23
June	0	0	8	0	4	13
July	0	19	3	0	0	0
August	10	10	18	2	0	-
September	8	5	96	47	21	-
October	105	137	78	52	97	-
November	156	80	153	128	55	-
December	258	159	130	114	291	-
TOTAL	**943**	**1800**	**993**	**604**	**671**	**-**

Table 5. Mean monthly evaporation records for the area surrounding the Tutuka Power Station (Hydrological Information Publishing, 1985)

Month	**Class 'A' Pan Evaporation mm**	**Class 'A' Pan Coefficients**	**Bare Soil Coefficient**	**Estimated Evaporation mm**
January	191	0.84	0.9	145
February	156	0.88	0.9	123
March	158	0.88	0.9	125
April	114	0.88	0.9	90
May	99	0.87	0.9	77
Jun	81	0.85	0.9	62
July	95	0.83	0.9	71
August	138	0.81	0.9	101
September	180	0.81	0.9	131
October	203	0.81	0.9	148
November	182	0.82	0.9	135
December	199	0.83	0.9	149
Mean annual evaporation				**1357**

A water balance analysis undertaken by Rudolph, van Niekerk, and Associates (1993) indicated that while average monthly evaporation exceed precipitation in all months, consideration of maximum and minimum precipitation values indicated that precipitation surpluses could occur in the months between November and January, and thus recharge through the domestic waste site could occur.

3 GEOLOGY

The site falls within the Carboniferous to early Jurassic aged Karoo Basin, a geological feature that covers much of South Africa. Sediments in this part of Mpumalunga Province fall within the Permo-Triassic aged Northern facies of the Ecca Series (Truswell, 1977). Typically, shales define the lower and upper levels of the series, with coal measures and associated coarser detrital sediments present between. Coal measures currently mined in the area form part of the Highveld Coal Field.

Late Triassic to Middle Jurassic aged Dolerite dykes and sills are common in the Karoo Basin, and occur throughout the power station area. Previous as well as the current investigations identified the presence of a near surface, slightly weathered to fresh dolerite sill beneath surface of the study area and current domestic waste site. The extent of the sill beneath, and in the vicinity of, the dump is unknown, however.

Soil cover surrounding the site appears relatively thin, particularly in the vicinity of the study area. The type and distribution of site soils appears to be, in part, controlled by parent rock material. Soils overlying doleritic material are typically highly plastic, and dark brown to black in colour, while those on Karoo sediments are typically lighter in colour and moderate to highly reactive in character. Shrinkage cracks can, however, be expected to develop in site soils irrespective of parent material during periods of prolonged dry weather.

Dolerite dykes and sills are common in the Karoo Basin, and were typically emplaced in the period between the Late Triassic and Middle Jurassic. Dolerite dykes were observed on, and adjacent to, the site under investigation (refer Appendix A, Map 4), and were typically found to have a north-south or east-west trend, consistent with the orientation of major streams in the area. It thus seems reasonable to assume that stream orientation and dyke occurrence has been in part controlled by the occurrence pre-existing fractures such as joints. The similarity between the orientation of these inferred fractures and mapped dyke swarms in southern Africa suggests that they developed in response to a regional stress field. A possible regional control could have been the East African rift system, as suggested by Truswell (1977).

Dolerite is commonly used as road pavement material throughout South Africa, and the Standerton area is no exception. Indeed, the quarries observed in the southeastern and southwestern corners of the property were developed on larger dolerite intrusions. Dolerites exposed here are typically fractured and slight to moderately weathered, with a thin surficial covering of red clayey gravel (GC) material. The dolerites themselves behave as clayey gravels (GC) when disturbed, with the clay generally restricted to fracture surfaces. The fracture spacing within the dolerite outcrops is variable but generally appears to be between 75 and 300 mm.

4 GEOPHYSICAL INVESTIGATIONS - MAGNETIC SURVEY

During March 2010 GHT Consulting recorded magnetic data along seven traverses within the study area, to the south, west and north of the Domestic Waste Site and planned extension. The purpose of the magnetic survey was to detect and delineate magnetic structures that may influence the groundwater regime by forming preferential pathways or barriers to groundwater flow. The results of the magnetic survey were to be used to site a number of monitoring boreholes in the vicinity of the planned Domestic Waste Site extension.

4.1 Approach to the Magnetic Survey

As part of the magnetic survey at the Domestic Waste Site, the following actions were taken:

- Aerial photographs of the area under investigation were studied in order to identify any natural features that could indicate the presence of variations in the local geological conditions. Such features could include visible changes in the vegetation, the presence of rock outcrops and prominent topographical changes.

- An airborne magnetic map covering the area of interest was obtained and studied to identify large-scale magnetic features that may be indicative of the presence of geological structures in the area.

- Reports on past geohydrological investigations conducted in the area of interest were obtained and studied to allow better insight into the geological conditions that could be expected during the survey.

- Ground magnetic data were recorded along seven traverses across and in the vicinity of the planned Domestic Waste Site extension.

- The magnetic data recorded during the survey were interpreted in terms of the local geological and geohydrological conditions.

- The results of the magnetic survey were taken into account when selecting possible targets for the drilling investigative and monitoring boreholes.

4.2 Description of the magnetic method

The principles on which the magnetic technique operates are briefly described below:

Many earth materials contain magnetic minerals such as magnetite, ilmenite and pyrrhotite. When geological units contain such magnetic minerals, these units may become magnetised by the earth's magnetic field, and may then have magnetic fields associated with them. These local magnetic fields that are due to the magnetised geological units will be superimposed on the earth's regional magnetic field. Measurements taken in the vicinity of magnetised geological units will therefore show local variations or departures from the undisturbed magnetic field of the earth (called the regional field). These departures are referred to as anomalies. The shapes of the anomalies are dependent on a number of factors regarding the physical properties and dimensions of the magnetised geological units. By incorporating existing knowledge on the geological conditions at the site being surveyed, the magnetic anomalies recorded during a survey may be interpreted in terms of the local geological conditions.

The magnetic survey at the current Domestic Waste Site and planned extension was conducted by GHT Consulting using the G5 proton magnetometer manufactured by Geotron.

4.3 Study of ortho-photographs

As part of the geophysical investigations overlapping ortho-photographs of the area under investigation were studied to identify any natural features that could indicate the presence of variations in the local geological conditions. Such features could include visible changes in the vegetation, the presence of rock outcrops and prominent topographical changes. The ortho-photographs of the study area are shown in Appendix A, Map 5. Two linear features may be identified from the ortho-photos, namely a linear feature with a south-west/north-east strike to the south-west of the planned DWS extension, and a near-linear feature with an approximate west-north-west/east-south-east strike to the north of the existing DWS and planned DWS extension.

4.4 Study of airborne magnetic map

An airborne magnetic map covering the area of interest was obtained from the Council for Geoscience. The airborne magnetic map is shown in Appendix A, Map 6. A large number of prominent magnetic lineaments may be identified in the vicinity of the study area. These lineaments predominantly have west-south-west/east-north-east and north-west/south-east strikes, although some features also display south-west/north-east strikes. These lineaments are in all likelihood due to large-scale magnetic dykes.

The study area does not appear to lie on top of a dyke-like magnetic feature, although a large linear magnetic feature with a west-south-west/east-north-east strike occurs at a distance of approximately 600 m to the north of the DWS.

4.5 Ground Magnetic Survey

Magnetic data were recorded along seven traverses to the south, west and north of the existing DWS and planned DWS extension. The positions of these seven ground magnetic traverses relative to the DWS are shown in Appendix A, Map 5. Traverses T01, T02 and T03 had north-west/south-east strikes in order to investigate the possibility that the linear feature to the south-west of the DWS extension detected in the ortho-photo's is due to a thin intrusive dyke. Traverse T04 extended perpendicularly across traverses T01, T02 and T03 in order to detect possible geological features. Traverse T05 was located to the north of the DWS and extended approximately parallel to the northern fence of the DWS. Traverses T05 and T06 ran across the planned DWS extension in south/north directions.

Data were recorded at a station spacing of approximately 11 m in order to have a high spatial density to allow the detection of even thin magnetic structures. The results of the magnetic survey are displayed as profile plots in Figure 1 to Figure 7.

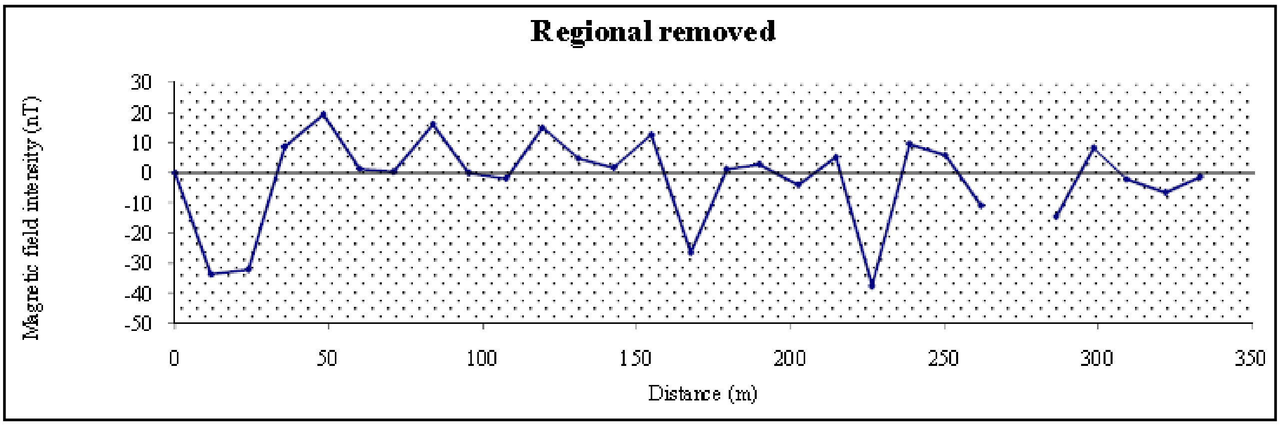

Figure 1. Profile plots of the magnetic anomalies recorded along traverse T01.

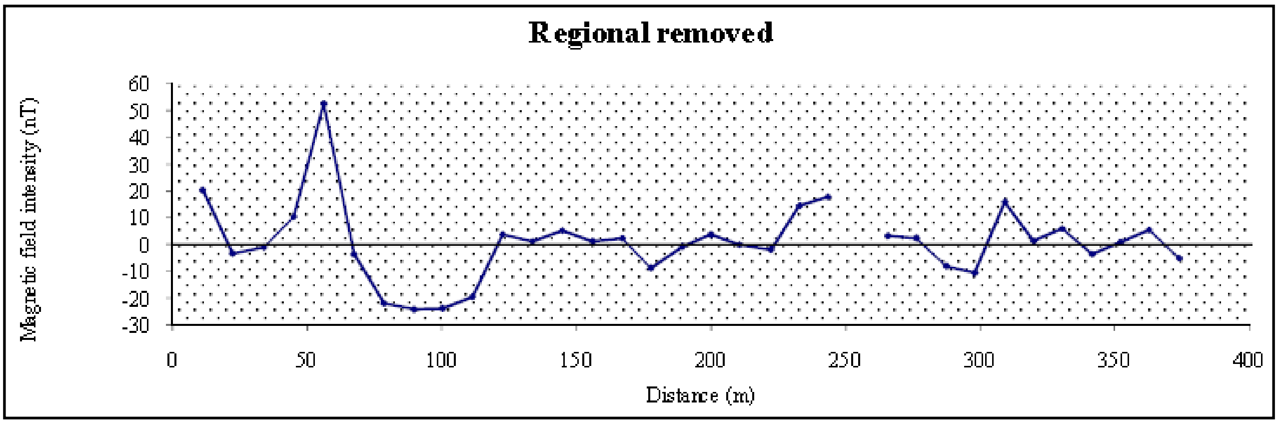

Figure 2. Profile plots of the magnetic anomalies recorded along traverse T02.

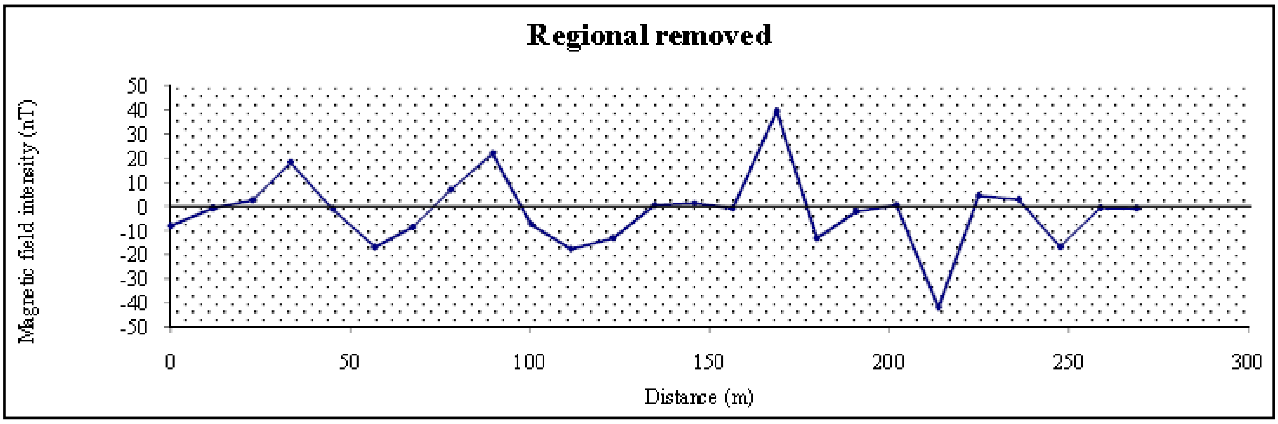

Figure 3. Profile plots of the magnetic anomalies recorded along traverse T03.

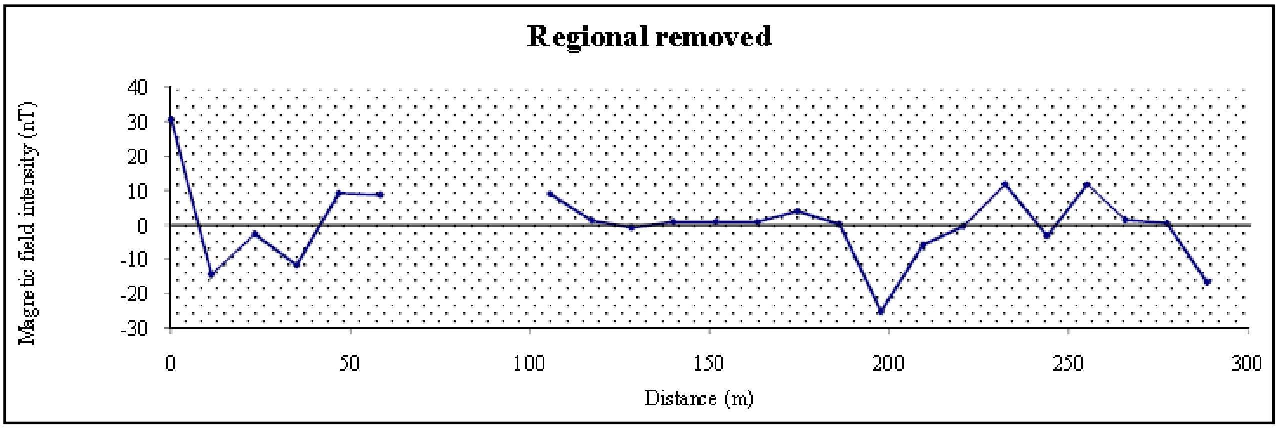

Figure 4. Profile plots of the magnetic anomalies recorded along traverse T04.

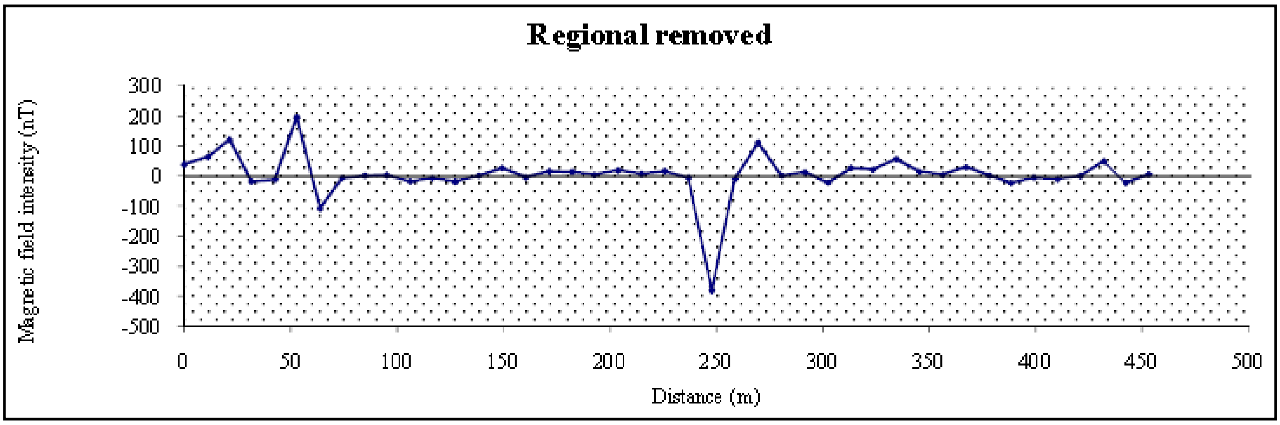

Figure 5. Profile plots of the magnetic anomalies recorded along traverse T05.

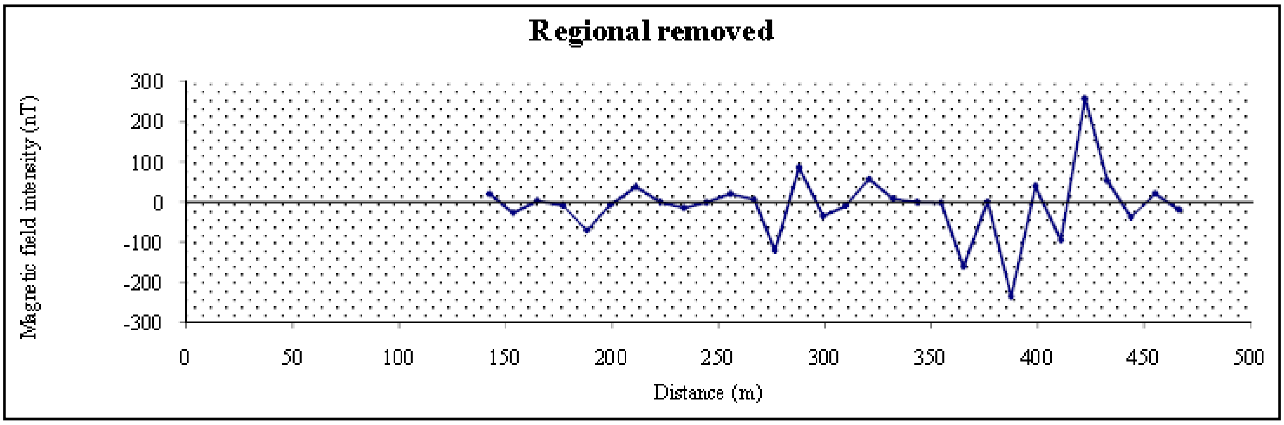

Figure 6. Profile plots of the magnetic anomalies recorded along traverse T06.

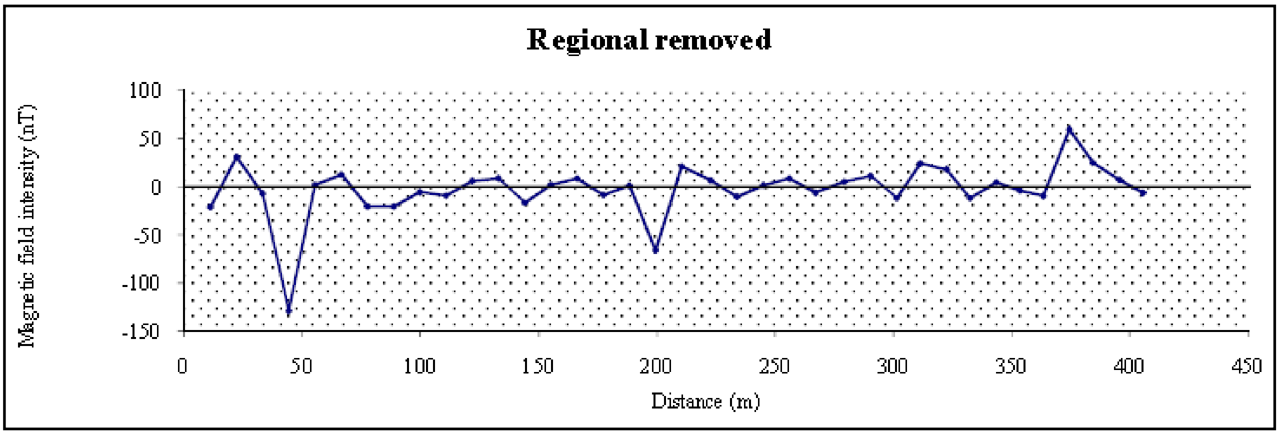

Figure 7. Profile plots of the magnetic anomalies recorded along traverse T07.

The results of the magnetic survey are briefly discussed below:

4.5.1 Traverses T01 to T04

The magnetic responses measures on traverses T01 to T04 display variable behaviour typically due to the presence of a dolerite sill. The changes in the magnetic field are generally smaller than 50 Magnetic field intensity (nT). No prominent anomalies that can be correlated between the different traverses can be identified. It therefore seems that no linear magnetic feature such as a dolerite dyke occurs in this part of the survey area (south of the DWS and planned DWS extension).

4.5.2 Traverse T05

Variability in the magnetic field is observed along traverse T05, again suggesting that this part of the survey area is underlain by a dolerite sill. Larger anomalies are observed near the start and centre of the traverse. The anomalies near the start of the survey appear to be manmade since the natural environment in this area has been disturbed by the construction of a raised dirt road. The anomaly near the centre of the traverse consists of only two anomalous values. The large amplitude and small spatial wavelength of this anomaly suggests that it is due to a near-surface source such as a buried metal object. This anomaly cannot be correlated with any certainty to anomalies on any of the other traverses.

4.5.3 Traverses T06 and T07

Traverses T06 and T07 extended across the site earmarked for the extension of the DWS. Unfortunately this area has been disturbed by human activity such as quarries and discarded metal objects. The magnetic data recorded along traverse T06 were particularly influenced by the presence of cultural noise in the form of metal objects at surface. Data recorded along the first 140 m were considered to be too noisy to be of any use. Along the remainder of the traverse, variable magnetic field strengths suggest the presence of a dolerite sill, although the variability may also be partly due to the presence of near-surface sources of noise.

Although less noisy than the data recorded along traverse T06, the data recorded on traverse T07 also display a large degree of variability. This may again be explained by the presence of both a dolerite sill and sources of magnetic noise at surface. No anomalies that can be clearly correlated between traverses T06 and T07 can be identified, suggesting the absence of linear magnetic features with west/east strikes in this part of the survey area.

4.6 Proposed targets for the installation of boreholes

Since no magnetic geological structure could be identified during the magnetic survey, it is recommended that investigative and monitoring boreholes be drilled at suitable positions selected by taking into account other considerations such as the drainage direction and the required spatial density of the monitoring network.

5 HYDROCENSUS

Four boreholes were located within 2 km of the property boundary (refer Appendix A, Map 7 and Table 6), with many of the located bores installed on, or adjacent to, dolerite dykes; several bores had been constructed along the trend of a single dyke in some instances. Groundwater here is used predominantly for stock and domestic supply purposes, with water table depths varying from approximately 9 m along ridge crests, to less than 2 m in lower-lying areas. Thus, the water table is generally a reflection of surface topography. The groundwater table has also been influence to some extent by the coal mining activities in the area. New Denmark Colliery currently supplies a lot of farmers with potable drinking water.

It is difficult to estimate the amount of groundwater extracted from site aquifers because site boreholes are not metered. Some idea of abstraction rates can, however, be gained if borehole pump capacities are considered. Generally windmill cylinder pumps were used to extract groundwater, devices which are unlikely to have an extraction rate in excess of 0.3 L/s. The largest pumps observed during the census were of the 50 mm diameter submersible and helical rotor type. Pumps of this type can generally deliver between 1 to 5 L/s, dependent on aquifer and site characteristics.

Two sample points along the Racesbult Spruit which is part of the Tutuka Power Station water monitoring system were also included and sampled during the hydrocensus survey. RSS45 is a point in the Racesbult Spruit upstream from the confluence with the non-perennial spruit which can be influenced by the Domestic Waste Site. Sample point RSS09 is downstream from the same confluence.

Table 6. Detailed description of the surface water sites and boreholes located within 2 km of the boundaries of domestic waste site.

Sites	**Date Site Visit**	**Site Description**	**Objective**	**Farm Name**	**Farmer Owner**
FBB20	23/03/2010 13:45	BH 1500m south of DWS next to fence between two ploughed fields	Background water quality	PRETORIUS VLEY 374/8	Thys Vosloo
FBB205	23/03/2010 14:30	1400m north of DWS 30m east of road in old pump house just north of Racesbult Spruit	Background water quality	SLAGKRAAL 353/2	Pieter Bosman
FBB206	23/03/2010 14:47	1700 m north of DWS & Racesbult Spruit 40m west of house, just south of gravel road	Background water quality	SLAGKRAAL 353/2	Pieter Bosman
FBB207	23/03/2010 15:18	1800m north of DWS & Racesbult Spruit 20m south of gravel road	Background water quality	SLAGKRAAL 353/5	Pieter Bosman
RSS09	24/03/2010 17:40	Racesbult Spruit north of DWS. Downstream from confluence with non-perennial spruit draining DWS area	Run-off from site	MEYERSVALLEI 354	Pieter Bosman
RSS45	24/03/2010 17:30	Racesbult Spruit north of DWS. Upstream from confluence with non-perennial spruit draining DWS area	Background water quality	SLAGKRAAL 353/5	Pieter Bosman

Sites	**Longitude °E**	**Latitude °S**	**Elevation mamsl**	**Casing Diameter mm**	**Coller Hight mm**	**Sample Depth**	**BH Depth m**	**Water Level (m below CH) / Level & Flow**	**Equipment**	**Use**	**Sampled**	**Photo nr.**	**Current State**
FBB20	29.3239	-26.7870	1609	165	0.2	Pump	~	34.65 pump	Windpump	Stock	Y	1	Working condition
FBB205	29.3155	-26.7604	1594	165	0.12	18	~	16	None	Stock	Y	2	Old powerhead removed
FBB206	29.3199	-26.7553	1598	165	0.2	~	~	~	Windpump	Stock & Domestic	N	3	Not in working condition, blocked at surface
FBB207	29.3320	-26.7558	1600	165	0.12	~	~	~	Windpump	Stock	N	4	Not in working condition
RSS09	29.3113	-26.7593	1588	~	~	Surface	~	Low Stagnant	None	Stock	Y	5	Satisfactory
RSS45	29.3273	-26.7576	1599	~	~	Surface	~	Mod. Flowing slowly	None	Stock	Y	6	Satisfactory

Photo 1.

Photo 2.

Photo 3.

Photo 4.

Photo 5.

Photo 6.

Using the values for potential sustained yields suggested by the Department of Water Affairs and Forestry (1994), available data suggests that aquifers in the area surrounding Tutuka Power Station have a low to moderate yield (<1 to 5L/s), and thus have limited development potential. Further, since groundwater in the area is not currently exploited by major users or nearby communities, and alternative water supplies are readily available for future use, aquifers here can be classified as being of "no significance" (DWA&F, 1994).

6 MONITORING SYSTEM

The total monitoring system at the domestic waste site consist of 7 monitoring boreholes, 2 surface water stream sites, 1 leachate detection site and one borrow pit filled with water. Detailed descriptions of the sites are listed in Table 7 and the localities in Appendix A, Map 8.

Table 7. Detailed description of the monitoring system sites at the domestic waste site.

Sites	**Date Site Visit**	**Site Description**	**Objective**	**Farm Name**	**Farmer Owner**
DMB33	24/03/2010 07:29	BH 50m downstream & north of existing DWS	Seepage from waste site	PRETORIUS VLEY 374/7	Eskom Holding LTD
DMB34	24/03/2010 07:50	BH 90m downstream & northeast of existing DWS	Seepage from waste site	PRETORIUS VLEY 374/7	Eskom Holding LTD
DMB35	24/03/2010 08:48	BH 30m upstream and south of existing and proposes DWS and next to the entrance.	Background water quality	PRETORIUS VLEY 374/7	Eskom Holding LTD
DMB86	23/03/2010 16:00	BH 5m downstream & north of existing DWS. Shallow borehole with pizometer.	Seepage from waste site	PRETORIUS VLEY 374/7	Eskom Holding LTD
DMB87	24/03/2010 07:08	BH 50m downstream & north of proposed extension of DWS	Seepage from waste site	PRETORIUS VLEY 374/7	Eskom Holding LTD
DMB88	24/03/2010 07:11	BH 130m downstream & north of proposed extension of DWS	Seepage from waste site	PRETORIUS VLEY 374/7	Eskom Holding LTD
DMB89	24/03/2010 07:19	BH 70m downstream & west of proposed extension of DWS & north of the borrow pit	Seepage from waste site	PRETORIUS VLEY 374/7	Eskom Holding LTD
WMB37	Historical Records	BH 150m upstream & east of existing DWS - Destroyed	Drill for water supply	PRETORIUS VLEY 374/7	Eskom Holding LTD
DMT01	23/03/2010 16:20	leachate detection sump downstream at north-eastern corner of DWS	Seepage from waste site	PRETORIUS VLEY 374/7	Eskom Holding LTD
DMD25	24/03/2010 07:08	Borrow pit 370m downstream & west of DWS	Run-off and seepage from site	PRETORIUS VLEY 374/7	Eskom Holding LTD
DMS37	24/03/2010 14:40	Non-perennial Spruit 130m downstream & north of DWS	Run-off from site	PRETORIUS VLEY 374/7	Eskom Holding LTD
DMS44	24/03/2010 14:30	Non-perennial spruit 280m upstream & east of DWS	Background water quality	PRETORIUS VLEY 374/7	Eskom Holding LTD

Sites	Longitude °E	Latitude °S	Elevation mamsl	Casing Diameter mm	Coller Hight mm	Sample Depth	BH Depth m	Water Level (m below CH) / Level & Flow	Equipment	Use	Sampled	Photo nr.	Current State
DMB33	29.3249	-26.7711	1602	165	0.4	14	18	1.45	None	Monitoring	Y	7	Satisfactory
DMB34	29.3261	-26.7711	1601	165	0.4	22	24	1.11	None	Monitoring	Y	8	Satisfactory
DMB35	29.3247	-26.7738	1612	165	0.5	16	36	4.39	None	Monitoring	Y	9	Satisfactory
DMB86	29.32434	-26.77076	1602	165	0.5	6	8.5	1.28	None	Monitoring	Y	10, 11	Satisfactory
DMB87	29.32423	-26.77023	1600.5	165	0.72	3	21	1.96	None	Monitoring	Y	12	Satisfactory
DMB88	29.32376	-26.76941	1597	165	0.66	3	20	3.9	None	Monitoring	Y	13	Satisfactory
DMB89	29.32241	-26.77081	1603	165	0.44	4	20	1.59	None	Monitoring	Y	14	Satisfactory
WMB37	29.326097	-26.773779	1612.9	165	~	~	120	~	None	Monitoring	N	~	Destroyed
DMT01	29.32574	-26.77114	1604	1200	0	Surface	2.5	1 .4	Manhole	Monitoring	Y	15	Seepage visible below sump
DMD25	29.322769	-26.771659	1604		~	Surface	~	Full	None	Monitoring & Stock	Y	16	Satisfactory
DMS37	29.3244	-26.7697	1598	0	~	Surface	~	Dry	None	Monitoring & Stock	N	17	Satisfactory
DMS44	29.3282	-26.7728	1607	0	~	Surface	~	Low	None	Monitoring & Stock	Y	18	Satisfactory condition.

Photo 7.

Photo 8.

Photo 9.

Photo 10.

Photo 11.

Photo 12.

Photo 13.

Photo 14.

Photo 15.

Photo 16.

Photo 17.

Photo 18.

6.1 Current monitoring system – Existing domestic waste site

The current monitoring system comprises of four monitoring boreholes, a seepage collection sump and two surface water sites (Refer Appendix A, Map 8 and Table 7).

During the construction of the current domestic waste site only two monitoring sites were installed. A borehole DMB86 to a depth of approximately 9 m to monitor any seepage that may occur on top of the dolerite sill as well as DMT01 a seepage collection sump and inspection manhole at the end of a subsurface seepage interception trench down gradient to the north of the domestic waste site.

In July 1994 three additional monitoring boreholes were drilled from monitoring purposes. Two boreholes were drilled down-gradient from the domestic waste site outside the northern fence, while one was drilled up-gradient outside the southern fence. These boreholes were sited geophysically by means of a detailed magnetic survey. Slug tests were done on the three boreholes and the results are tabled in Table 8. This method provides an indication of aquifer permeability in the immediate vicinity of the tested borehole. The representative geological logs for these three boreholes are in Appendix B. From these it can be concluded that fresh, solid dolerite forms the largest part of the underlying formations. The locations of these monitoring boreholes can be seen in the map in Appendix A, Map 8.

Due to the presence of the un-weathered dolerite sill, no groundwater of any significance is present. No water was found in Borehole DMB33 and drilling was stopped at a depth of 18 metres. The seepage water in the formations is considered to be sufficient for monitoring purposes. Boreholes DMB34 is 24 metres deep and a small volume of water was found at depths of 4 and 21 metres. Borehole DMB35 yielded very little water in the dolerite at 12 metres and 18 metres. In this borehole, which was drilled down to a depth of 36 metres, the water was found in cracks and joints in the dolerite.

Two surface water sites were also added to the monitoring system in July 1994. These are two sample points in the non-perennial stream that originates east of the domestic waste site and flows in a north-western direction where it joins the Racesbuit Spruit north of the domestic waste site. DMS44 is the upstream sample point and DMS37 the downstream sample point.

A borehole was drilled during October 2005 to provide the security guard at the domestic waste site with sanitary facilities. This includes drinking water as well as a flush toilet. The geological environment in the area of the solid waste disposal site is dominated by massive dolerite intrusions - mainly a sill. This was confirmed by the drilling of the borehole which showed that the geological formations, except for 22 meters from a total of 120 meters, consist of dolerite only. The drilling was terminated at 120 m. Due to the thickness of the dolerite sill the possibility for exploitable groundwater is highly unlikely. No significant water strike was noted, but at a depth of 99 meters a fracture with noticeable moisture was found. It yielded only mud and no estimation of the actual yield could therefore be made. This borehole was eventually destroyed by the construction of borrow pits for dolerite gravel.

6.2 Upgrading of monitoring system – Proposed extension of domestic waste site

A total of three monitoring boreholes were installed in the period between the 16th and 17th March 2010 using a rotary percussion rig, with a view to intercepting leachate generated from any future waste operations. Three of the monitoring boreholes (DMB87 DMB88 and DMB89) were installed down gradient within the dolerite sill identified during geophysical investigations. Holes were typically cased and screened with 165 mm diameter mild steel casing as per the construction details shown in Appendix B and Table 7. The localities of the newly installed boreholes are plotted on the map in Appendix A, Map 8.

Borelogs indicate that only very small amounts of groundwater was encountered in the three new bores during drilling, with air-lift yields never exceeding 0.1 L/s (refer Appendix B and Table 7). All the water strikes were encountered on the contact between weathered dolerite and fresh hard dolerite. All the groundwater occurs within the first 5 m therefore associated with a shallow perched aquifer. The rest of the formations, below 5 m yielded no water. All boreholes were found to contain water after about 1 week after drilling, which suggests that seepage inflow from fractures of low permeability occurred in the period between borehole construction and initial bore sampling. Slug tests performed at monitoring bore sites on the 25 March 2010 also suggest that site aquifers have low permeability (refer Table 8).

7 GEOHYDROLOGY

Logging undertaken during the different drilling phases indicates that perched and regional aquifer systems are associated with the Karoo sediments at the site. The upper aquifer appears to be perched on an impermeable dolerite sill and has a relatively localized occurrence depending on the thickness of the weathered dolerite zone, while the deeper aquifer is restricted to minor fractures, cracks and joints interfaces within the fresh dolerites. While unconfirmed, it seems likely that the deeper aquifer forms part of the regional groundwater system. There is, however, little apparent difference between the SWL of the respective groundwater systems, although available evidence does suggest that the SWL is slightly deeper in the regional system.

The fluctuations in the groundwater and piezometric levels that have been observed since 1995 in the boreholes near the domestic waste site are shown in Figure 8 and Figure 9 (respectively water level depths and water level elevations). Relative stable trends in the water table depths with some seasonal fluctuations in the groundwater levels of all the existing boreholes are observed. The three new boreholes water levels were measured eight days after drilling and again on the 14 April 2010 a month after drilling. The water levels in these three newly drilled boreholes have risen since it was measured the first time (DMB87 0.38 m– 0, DMB88 – 2.22 m, DMB89 – 0.05 m) which is a clear indication of the low permeabilities of the aquifers in the area.

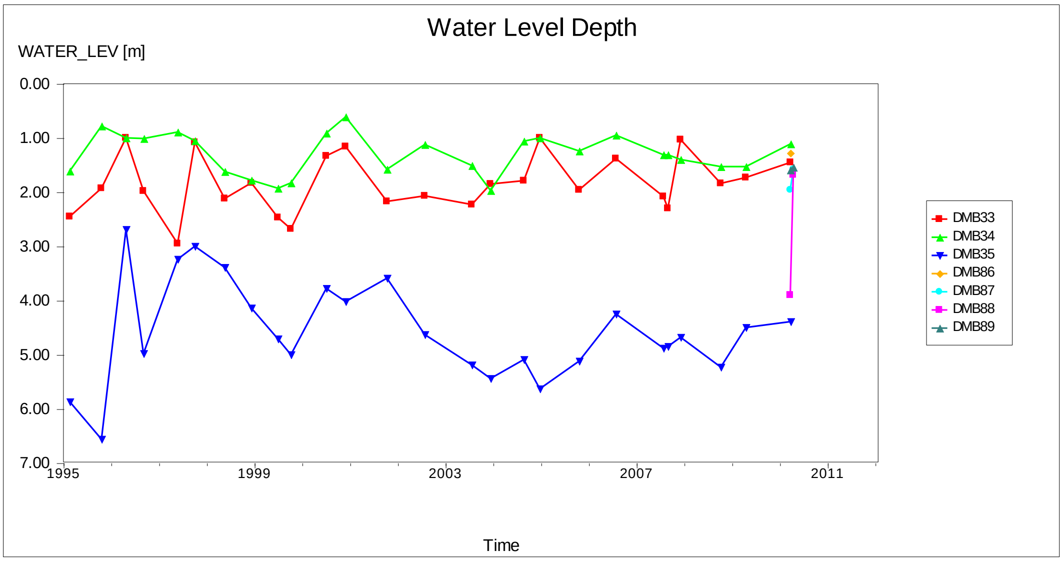

Figure 8. Water level depths of boreholes in the Domestic Waste Site Area – (mbgl).

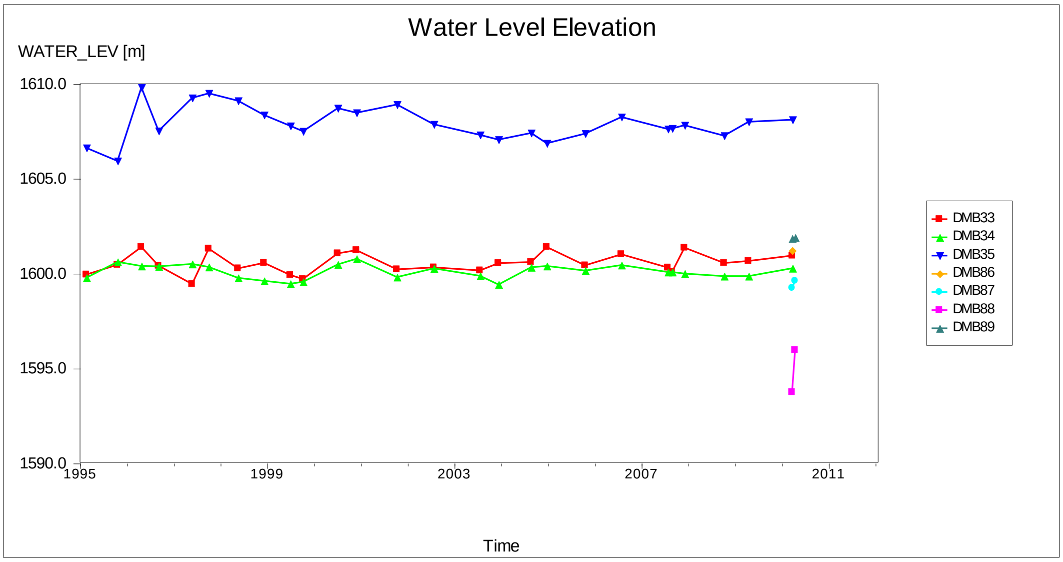

Figure 9. Water level elevation of boreholes in the Domestic Waste Site Area – (mamsl).

The observed relationship between the groundwater table and site topography suggested that the Bayesian interpolation method could be used to estimate the depth to the water table on a regional scale. The method allows SWL contours to be generated using available SWL and surface elevation data. A representative set of SWL contours generated using measurements taken during the hydrocensus and 5 m contours from 1:10 000 topographic contour data is shown in Figure 10. The plot confirms the presence of major natural groundwater divides (essentially flow boundaries) to the northeast and north of the site, following the course of the non-perennial spruit and the Racesbult Spruit, respectively.

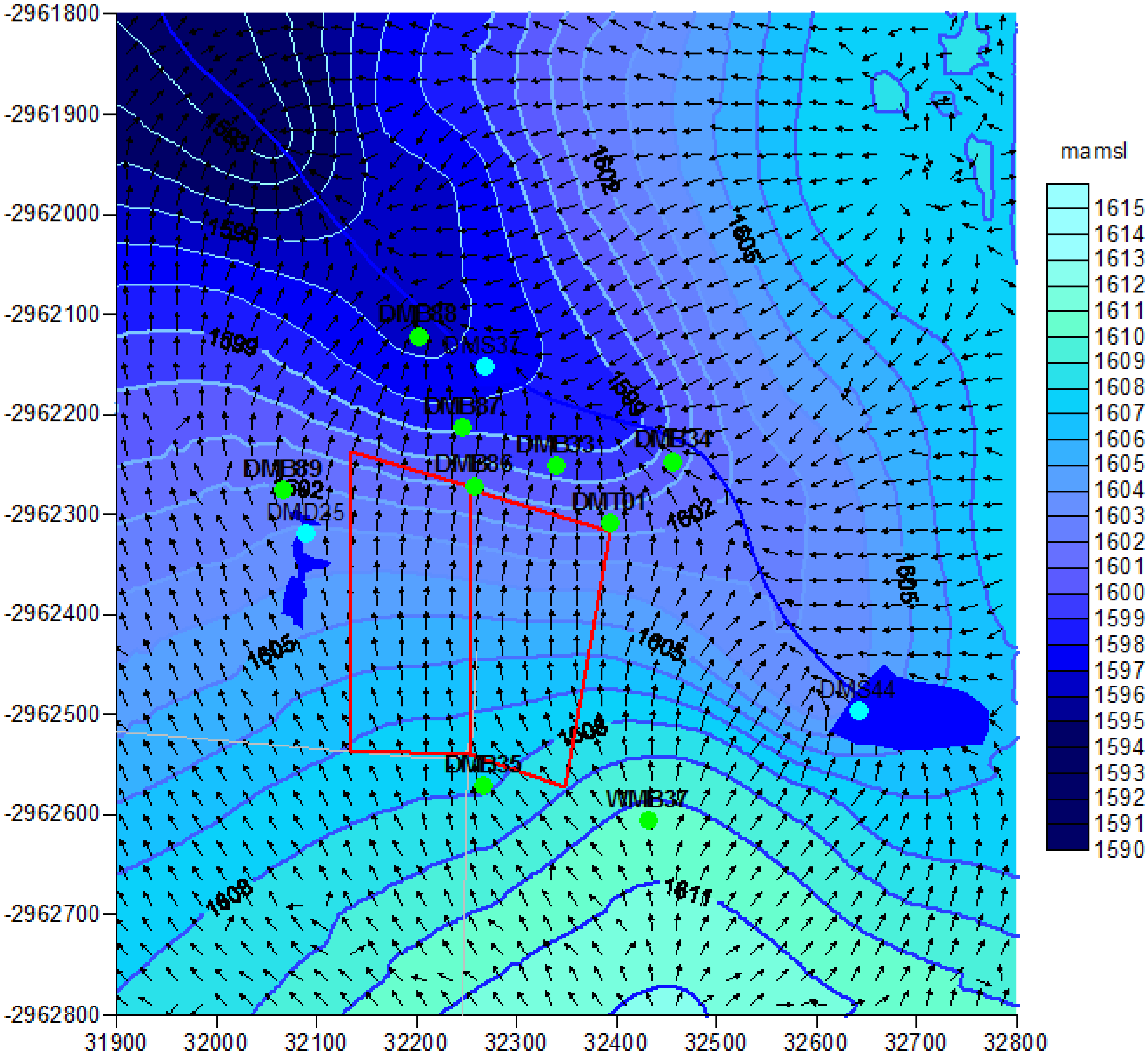

Figure 10. Groundwater level contour map in meters above mean see level.

Dolerites observed at borrow pits and outcrops were typically fractured throughout, with the presence of Fe and Mn oxides along fracture faces suggesting water movement through a permeable medium. Similar characteristics were observed throughout the top few meters of the dolerite sill intercepted by the monitoring boreholes, which implies that aquifers within these structures are essentially unconfined and purged on top of the impermeable dolerite sill. This is confirmed by the depth to groundwater table underneath the proposed extension varied from approximately 3 mbgl in the south to less than 1 mbgl in the north (Refer Figure 11). These aquifers can be recharged directly from rainfall or from surface water bodies, with the rate of recharge influenced by site hydraulic conductivity.

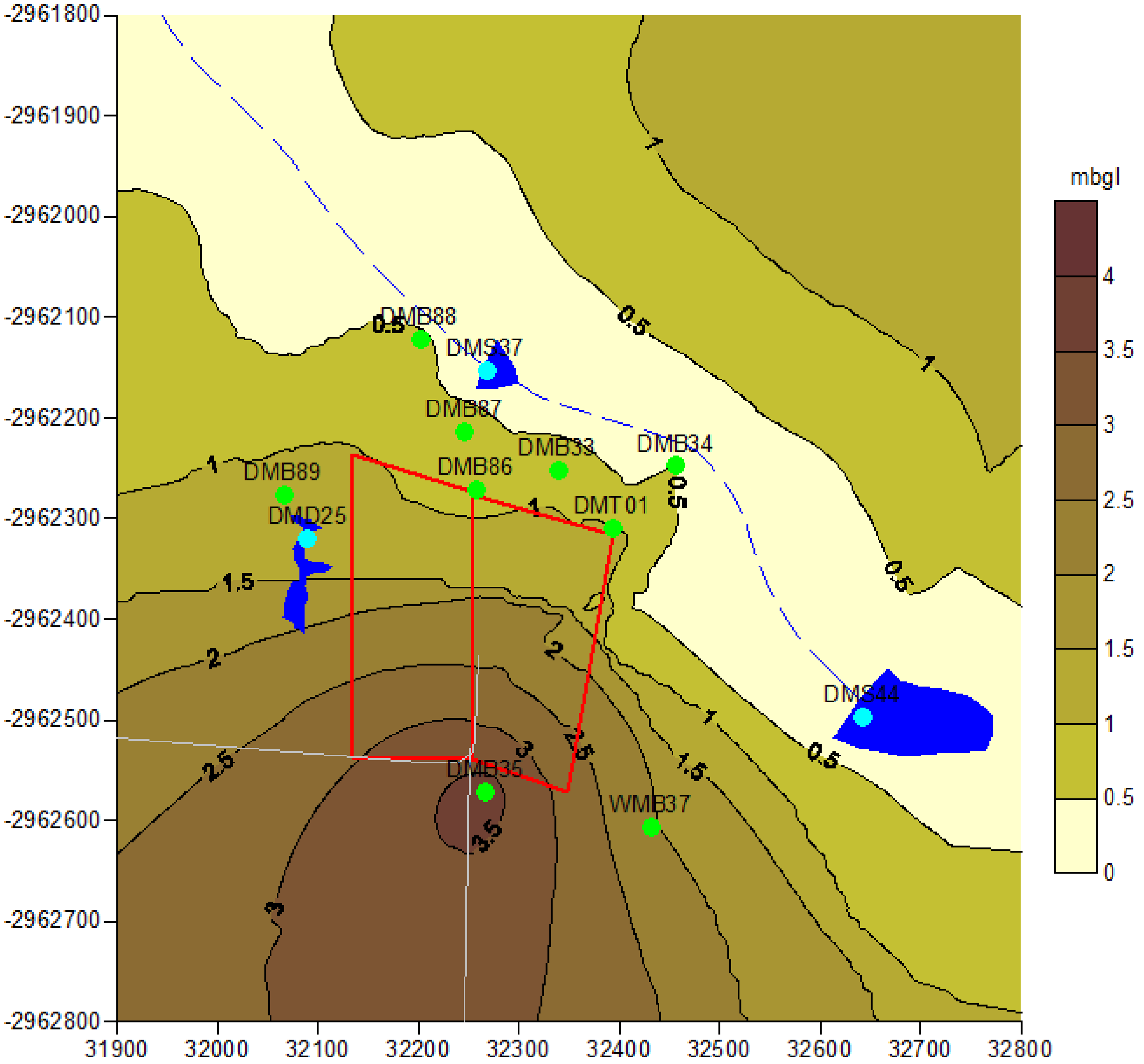

Figure 11. Unsaturated zone / depth to top of groundwater table in meters below ground level.

Slug tests were performed at all the monitoring bore sites during different detailed investigation from 1994 (refer Figure 12 to Figure 14 and Table 8). The field measurements obtained during the slug tests were analysed using the Bouwer and Rice (1976) method. This method provides an indication of aquifer permeability in the immediate vicinity of a tested borehole. In this instance, the line of best fit through slug test data was taken through later values to allow for drilling induced increases in aquifer permeability in the area immediately adjacent to the borehole.

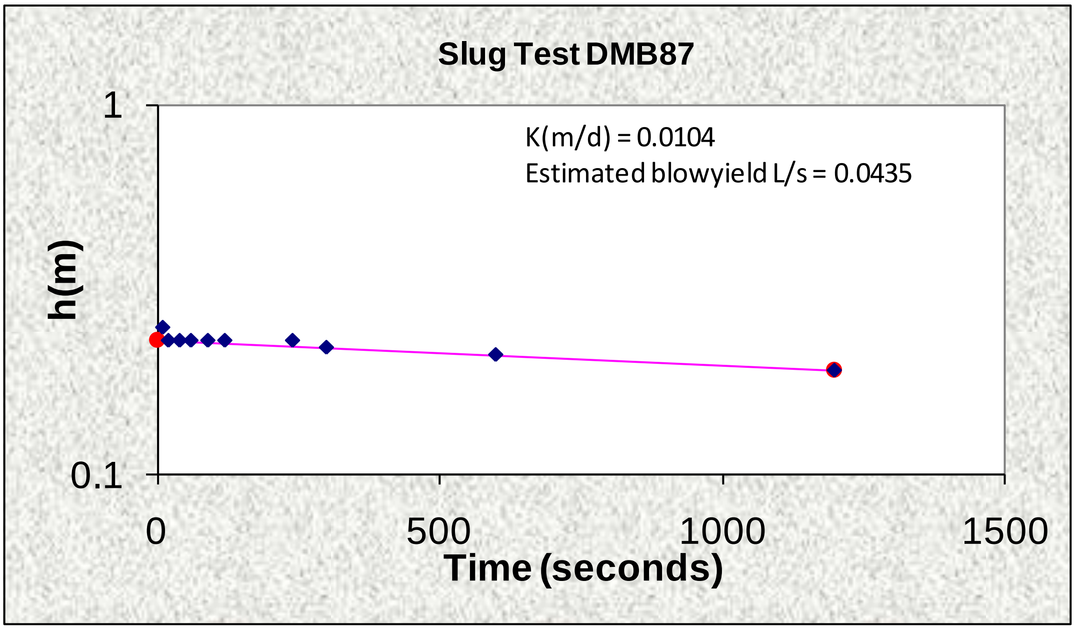

Figure 12. Slug test permebilty analysis for DMB87 with the Bouwer and Rice (1976) method.

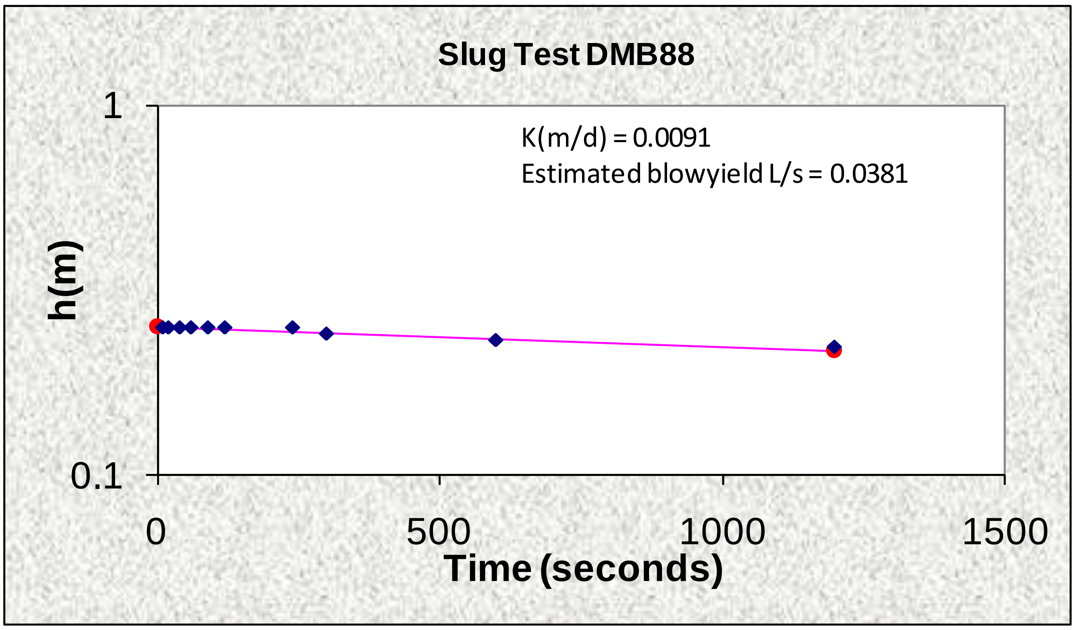

Figure 13. Slug test permebilty analysis for DMB88 with the Bouwer and Rice (1976) method.

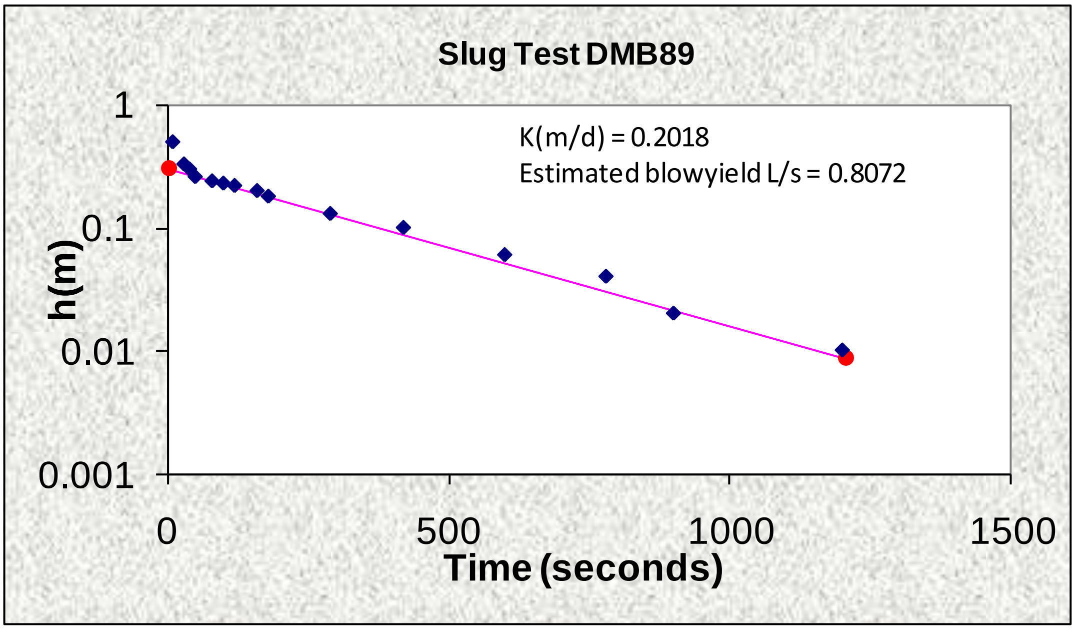

Figure 14. Slug test permebilty analysis for DMB89 with the Bouwer and Rice (1976) method.

Table 8. Results of slug testing when analysed using the Bouwer and Rice (1976) method.

Site	K m/d	K m/s	Dh/Dl	Porosity h	Real velocity of flow m/s	Real velocity of flow m/d	Yield calculated	Blowyield measured	Waters striles
Formation Tested - Fresh solid dolerite									
DMB33	0.0058	6.713E-08	0.028	0.05	3.729E-08	1.1761	~	~	dry
DMB88	0.0091	1.053E-07	0.027	0.05	5.626E-08	1.7744	0.0381	<0.01	3
Averages	0.0075	8.623E-08			4.678E-08	1.4752			
Formation Tested - Weathered fractured dolerite									
DMB34	0.1860	2.153E-06	0.013	0.1	2.691E-07	8.4863	~	<0.1	4 & 12
DMB35	0.0720	8.332E-07	0.015	0.1	1.272E-07	4.0106	~	<0.1	12 & 18
DMB87	0.0104	1.204E-07	0.027	0.1	3.215E-08	1.0139	0.0435	<0.1	2
DMB89	0.2018	2.336E-06	0.021	0.1	4.911E-07	15.4869	0.8072	0.1	4.5
Averages	0.1061	1.228E-06			2.616E-07	8.2504			

The presence of perched aquifers in the area is to be expected. Laboratory testing suggests that in situ soils are more permeable than the underlying dolerites. For example, the lowest K value measured for in situ soil/weathered dolerite was 1.2 x 10^{-7} m/s, a value an order of magnitude higher than that determined for a site aquifer within the dolerites (6.7 x 10^{-8} m/s). Thus, water will preferentially flow through the soil profile which mainly consists of weathered fractured dolerites. Further, once a moisture front reaches the weathered/fresh dolerite interface, lateral as opposed to vertical flow will predominate.

The higher permeability of weathered dolerites can also be expected to influence recharge and discharge behaviour at the site. The unconfined, relatively un-permeable character of the these rocks make them not only ideal recharge zones for regional aquifers in the Karoo, but also points for discharge in lower lying areas.

Potential flow velocities within some aquifers can be estimated by adapting Darcy's Law (1856) and considering flow effects through aquifer pores as shown below:

$$V = \frac{K(\Delta h/\Delta l)}{n} \quad \text{where,}$$

V = real flow velocity;

K = hydraulic conductivity;

$\Delta h/\Delta l$ = hydraulic gradient at site; and,

n = porosity.

Estimates of aquifer K were obtained during slug testing, while site aquifer porosity was assumed to be 5%, a typical value of porosity in fractured rocks (Driscoll, 1986). Porosities for overlying soil profiles were assumed to be 10%. Field estimates of hydraulic gradient for respective sites are shown in Table 8.

Real groundwater flow velocities calculated on the basis of estimated values are also shown in Table 8. These calculations suggest that there is little variation between field aquifer hydraulic conductivity and real groundwater flow velocities. Based on a real groundwater flow velocity of 1.5 m/y and a distance between the proposed waste disposal site and the groundwater divide in the north of between 300 m, it is estimated that it will take at least 200 years for pollutants to reach the non-perennial spruit. The rate of pollution migration would be higher, however, along more permeable dolerite in areas that have steeper hydraulic gradients.

Calculated real flow velocities through weathered dolerites were also included in Table 8 for comparison purposes. These values suggest that the rate of groundwater movement through perched aquifers has the potential to be significantly higher than through deeper aquifers within weathered rock units. It is therefore estimated that it will take at least 37 years for pollutants to reach the non-perennial spruit.

8 BACKGROUND WATER QUALITY

In order to assess background water quality, surface and groundwater samples were taken around the time of the hydrocensus. While surface water samples were taken at selected strategic sites around the proposed waste facility, an attempt was made to sample all bores located during the census although in some cases this was not possible. All water samples were sent to the laboratories of the Institute of Ground Water Studies at the University of the Free Sate in Bloemfontein for analyses.

Laboratory test results were entered into current data base for Tutuka Power Station HydroBase (HydroSolutions Inc, 1995), one of the industry standard software packages commonly used in South Africa for data storage and assessment, and chemical diagram plotting. Ion balances calculated by the programme generally show less than 5% variation, indicating that the major constituents of the water samples have been identified (refer Appendix C).

Although the concentrations of more than 20 inorganic chemical parameters in the water samples were determined during the chemical analyses, only five parameters are used as indicators of contamination in the monitoring of the pollution potential in this system. These five parameters are: the electrical conductivity (**EC**) and the major ions **Na**, **Ca**, **Cl** and **SO_4**. The suitability of these parameters to act as *indicator elements* in the evaluation of water contamination was determined by GHT during a previous investigation. The additional information on the concentrations of the other elements is required to evaluate the accuracy and reliability of the chemical analyses.

8.1 Chemical Data Presentation Formats

The results of the inorganic chemical analyses are presented in various formats in this report. These formats include Data Tables, Pollution Index Tables, MMAC plots, Time Graphs and Bar Charts. The formats used are not exhaustive and any special requirements could be incorporated if suggested by the client or if shown necessary as the monitoring program progresses. The formats of data presentation used in this report are discussed below.

8.1.1 Data Table and Water Quality Class Tables

The results of all the inorganic chemical analyses that have been performed on water samples from Tutuka Power Station during the current and previous phases of the monitoring program are available in an electronic database for review. The results of the chemical analyses of the current and historical monitoring phase are given in table format in Appendix C.

In these tables the water samples from each monitoring site are classified according to the classification system described in "Quality of Domestic Water Supplies Volume 1: Assessment Guide, Second Edition, (1998)" and "South African Water Quality Guidelines – Volume 1 Domestic Use (1993 and 1996)". For each chemical parameter under analysis, the water is classified as belonging to one of five classes, ranging from ideal to totally unacceptable. The Ion Balance Errors are included in the data tables. The drinking water standards can be perused in Table 9. A description of the health and aesthetic effects of water belonging to the various classes is given in Table 9.

Table 9. Drinking Water Standards (DWAF, 1998).

PARAMETER	CLASS 0	CLASS 1	CLASS 2	CLASS 3	CLASS 4
~ Microbiological Quality ~					
Faecal Coliforms	**0.00**	**0 - 1**	1 - 10	10 - 100	> 100
Total Coliforms	**0**	**0 - 10**	10 - 100	100 - 1 000	> 1 000
~ Physical Quality ~					
Electrical Conductivity (mS/m)	**< 70**	70 - 150	150 - 370	370 - 520	> 520
pH	**5 - 9.5**	4.5 - 5 & 9.5 - 10	4 - 4.5 & 10 - 10.5	3 - 4 & 10.5 - 11	< 3 & >11
Total Dissolved Solids [TDS] mg/L	**< 450**	450 - 1 000	1 000 - 2 400	2 400 - 3 400	> 3 400
Turbidity	**< 0.1**	0.1 - 1	1 - 20	20 - 50	> 50
~ Chemical Quality ~					
Arsenic [As] (mg/L)	**< 0.010**	0.01 - 0.05	0.05 - 0.2	0.2 - 2.0	> 2
Cadmium [Cd] (mg/L)	**< 0.003**	0.003 - 0.005	0.005 - 0.020	0.020 - 0.050	> 0.050
Calcium [Ca] (mg/L)	**0 - 80**	80 - 150	150 - 300	> 300	~
Chloride [Cl] (mg/L)	**< 100**	100 - 200	200 - 600	600 - 1 200	> 1 200
Copper [Cu] (mg/L)	**0 - 1**	1 - 1.3	1.3 - 2.0	2.0 - 15	> 15
Fluoride [F] (mg/L)	**< 0.7**	0.7 - 1.0	1 - 1.5	1.5 - 3.5	> 3.5
Iron [Fe] (mg/L)	**< 0.5**	0.5 - 1	1 - 5	5 - 10	> 10
Total Hardness	**0 - 200**	200 - 300	300 - 600	> 600	~
Magnesium [Mg] (mg/L)	**< 70**	70 - 100	100 - 200	200 - 400	> 400
Manganese [Mn] (mg/L)	**0 - 0.1**	0.1 - 0.4	0.4 - 4	4 - 10	> 10
Nitrate [N] (mg/L)	**< 6**	6 - 10	10 - 20	20 - 40	> 40
Nitrite [N] (mg/L)	**< 6**	6 - 10	10 - 20	20 - 40	> 40
Potassium [K] (mg/L)	**< 25**	25 - 50	50 - 100	100 - 500	> 500
Sodium [Na] (mg/L)	**< 100**	100 - 200	200 - 400	400 - 1 000	> 1 000
Sulphate [SO_4] (mg/L)	**< 200**	200 - 400	400 - 600	600 - 1 000	> 1 000
Boron [B] (mg/L)	**0 - 0.5**	0.5 - 2	2 - 4	4 - 6	> 6
Zinc [Zn] (mg/L)	**< 3**	3 - 5	5 - 10	10 - 20	> 20

Table 10. Classification system used to evaluate water quality classes.

CLASS	DESCRIPTION	EFFECTS
CLASS 0	**Ideal water quality**	**Drinking Health:** No effects, suitable for many generations. **Drinking Aesthetic:** Water is pleasing. **Food preparation:** No effects. **Bathing:** No effects. **Laundry:** No effects.
CLASS 1	**Good water quality**	**Drinking Health:** Suitable for lifetime use. Rare instances of sub-clinical effects. **Drinking Aesthetic:** Some aesthetic effects may be apparent. **Food Preparation:** Suitable for lifetime use **Bathing:** Minor effects on bathing or on bath fixtures. **Laundry:** Minor effects on laundry or on fixtures.
CLASS 2	**Marginal water quality**	**Drinking Health:** May be used without health effects by the majority of individuals of all ages, but may cause effects in some individuals in sensitive groups. Some effects possible after lifetime use. **Drinking Aesthetic:** Poor taste and appearance are noticeable. **Food preparation:** May be used without health or aesthetic effects by the majority of individuals. **Bathing:** Slight effects on bathing or on bath fixtures. **Laundry:** Slight effects on laundry or on fixtures.
CLASS 3	**Poor water quality**	**Drinking Health:** Poses a risk of chronic health effects, especially in babies, children and the elderly. **Drinking Aesthetic:** Bad taste and appearance may lead to rejection of the water. **Food preparation:** Poses a risk of chronic health effects, especially in children and the elderly. **Bathing:** Significant effects on bathing or on bath fixtures. **Laundry:** Significant effects on laundry or on fixtures.
CLASS 4	**Unacceptable water quality**	**Drinking Health:** Severe acute health effects, even with short-term use. **Drinking Aesthetic:** Taste and appearance will lead to rejection of the water. **Food preparation:** Severe acute health effects, even with short-term use. **Bathing:** Serious effects on bathing or on bath fixtures. **Laundry:** Serious effects on laundry or on fixtures.

Monitoring Sites

Surface Water (DMS37, DMS44, DMD25, DMT01)

Water from sites DMS37 and DMS44 are mostly classed as Good (Class 1) to Marginal (Class 2) due to elevated EC values and elevated concentrations of Na, Ca, Mg, Cl and SO_4. The latest analyses show an improvement at site DMS44 which can be classed as an Ideal (Class 0) water quality. Seepage water intercepted at the sump DMT01 is classified as Poor (Class 3) due to elevated concentrations of NH_4. Water from the borrow pit DMD25 is classified as Ideal (Class 0).

Groundwater (DMB33, DMB34, DMB35, DMB86, DMB87, DMB88, DMB89, DMB37)

The groundwater of the Domestic Waste Site Area is generally of a good (Class 1) to poor (Class 3) quality. The poor water quality is derived from the elevated nitrate (NO_3-N) concentrations at site DMB35 (up-gradient from the site). The nitrates and NH_4 may possibly be derived from decomposing processes of organic matter. Classification of water from the newly drilled borehole ranges from Marginal (Class 2) to Poor (Class 3) due to the concentrations of NH_4.

Background Sites

Surface Water (Upstream site of the Racesbult Spruit - RSS45)

The water qualities of the sampling site RSS45 upstream from the confluence of the Racesbult Spruit and the tributary that flows past the Domestic Waste Site range from Ideal (Class 0) to Poor

(Class 3). The historical classification of Class 3 in 1991 was due to high SO_4 concentrations. The latest chemical analyses allows for the classification of Ideal (Class 0).

Surface Water (Downstream site of the Racesbult Spruit – RSS09)

The water qualities of the sampling site RSS09 downstream from the confluence of the Racesbult Spruit and the tributary that flows past the Domestic Waste Site range from Ideal (Class 0) to Poor (Class 3), with one classification during 1999 as Dangerous (Class 4). The last two chemical analyses both allow for the classification of Ideal (Class 0).

Groundwater (FBB20, FBB205)

The groundwater qualities of site FBB20 and FBB205 respectively ranges from Marginal (Class 2) to Good (Class 0) at sites FBB20 and FBB205. This is mainly due to the concentrations of NO_3.

8.1.2 MMAC Plots and Time graphs

Monitoring is undertaken so that changes in water quality over time can be identified. Such changes may be particularly evident in areas affected by surface activities, which could enhance water degradation. For this investigation the evaluation of previous and the current monitoring period has again been condensed and plotted in a format referred to as the Maximum, Minimum, Average and Current plot (MMAC). The results from a number of sample sites can be plotted in a single diagram for comparison. The MMAC plots can be perused in Appendix D.

A diagram of an MMAC plot is shown in Figure 15 and serves to explain the meaning of each element in the presentation. Instead of only an average value, twice the standard deviation, given as one value above and one value below the average is supplied. The standard deviation allows an idea of the usual range of values measured for the particular constituent at the particular site. A small standard deviation indicates a stable sample, while a large value represents a high variation in values. The maximum and minimum values ever recorded at the site are indicated in these plots by horizontal lines.

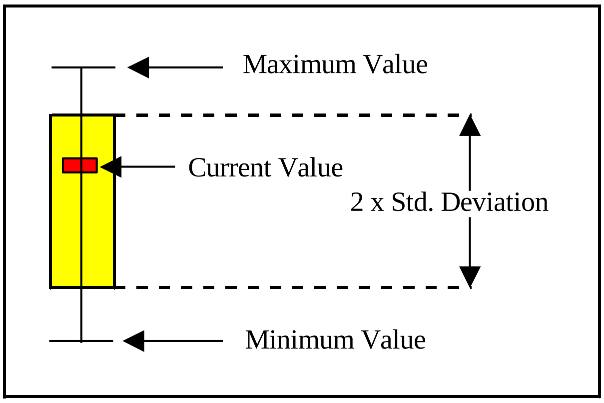

Figure 15. Maximum, Minimum, Average and Current Plot (MMAC).

In this way, a visual comparison may be made between the different sampling points for each monitoring period. At the same time, the history of each sampling point can be assessed. For example, if the red rectangle in the diagram was an actual data point, the current value would be higher than the average. If this is the case for other indicator parameters, and the condition persists through a number of monitoring events, then progressive degradation is indicated.

It must be noted that on the plots included in Appendix D, only the sampling sites that were sampled during the last monitoring phase were included. The geohydrological software package

'WISH' (Institute of Groundwater Studies, UFS, 2005) was used to evaluate the data. The Department of Water Affairs and Forestry drinking water standard for human consumption can be described as follows:

- The Target Water Quality Range (TR) for a particular constituent is indicated by the lower horizontal line on the figures. Concentrations below this value correspond to levels at which the presence of the particular constituent would have no known adverse or anticipated effects on the fitness of the water assuming long-term continuous use. If the quality is within the TR one can immediately concluded that water quality in that particular case is not an issue to the water use concerned. However, if the water quality falls outside the TR it does not mean that the water is unsuitable for a particular use, but rather that the particular situation must be more thoroughly assessed by referencing the comprehensive guidelines.

- The upper horizontal line of the standard indicates the Maximum Allowable Limit (AL). This is the limit above which remedial action should be implemented. It does not mean that the water is unsuitable for a particular use, but rather that the particular situation must be more thoroughly assessed by referencing the comprehensive guidelines.

General observations

The MMAC plots indicate that there is considerable variability in the content of indicator elements within surface water at the site. This response is to be expected when site drainage characteristics are considered. It must also be kept in mind that water is re-circulated between different sites at the power station. Surface water quality in the drainage system has the potential, therefore, to be affected by several factors including:

- Dilution effects from sudden rain storms;

- Concentration effects due to evaporation;

- Solution/dissolution effects as a result of water moving along the drain bed;

- Changes in mineral speciation over time with water movement through the system.

Mostly stable and decreasing trends are observed in the concentrations of most of the indicator element of all three historical groundwater sites (DMB33, DMB34 and DMB35). Increasing trends in most of the indicator element concentrations (Cl, Ca, Mg and EC values) are apparent at DMB33.

8.2 Nitrate analyses

High NO_3-N concentrations were observed at 4 boreholes (DMB33, DMB34, DMBB35 and DMB88) in the area during this and previous investigations. During a previous study conducted by GHT Conssulting samples from DMB33, DMB34 and DMB35 ^{15}N isotope analyses were done to determine the origin of the samples. The results are in the following table.

Table 11. Nitrogen analyses results

Sites	NH^4-N	NO^3-N	%o AIR ^{15}N	Comments
B33	<0.20	1.70	none	
B34	<0.20	4.70	none	
B35	0.36	26.00	+7.60	Organic nitrogen - natural

Although the nitrate concentration at B35 remains unacceptably high the nitrogen was found to have a Nitrogen isotope signature correlating with organic nitrogen and is considered to be natural. It is therefore likely that this NO_3 concentration originates from natural sources, rather than the waste site. As this conclusion is based on a single sample, it is recommended that monitoring continue, especially since the concentrations show an increasing trend.

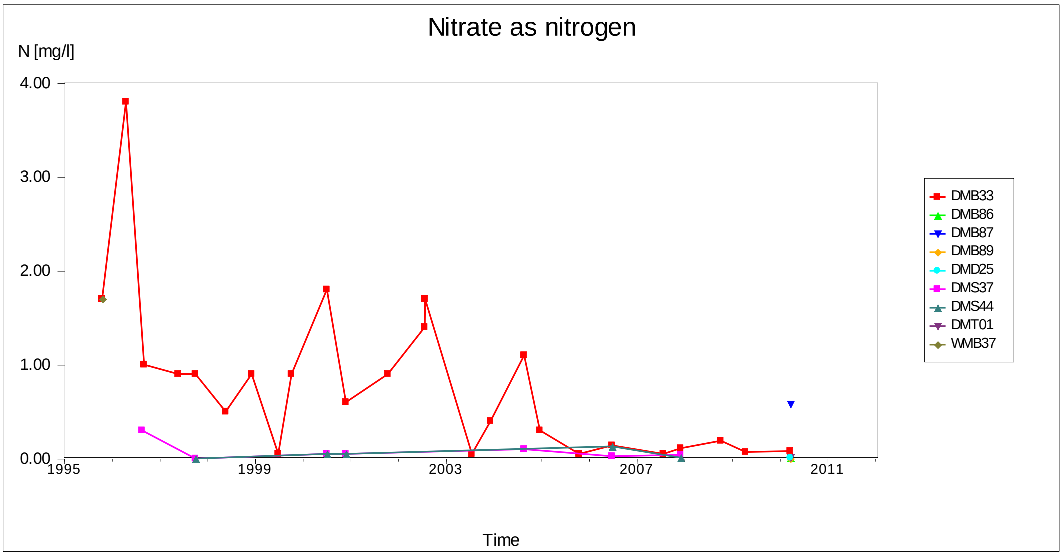

Figure 16. Temporal trends of NO_3-N concentration in 9 boreholes.

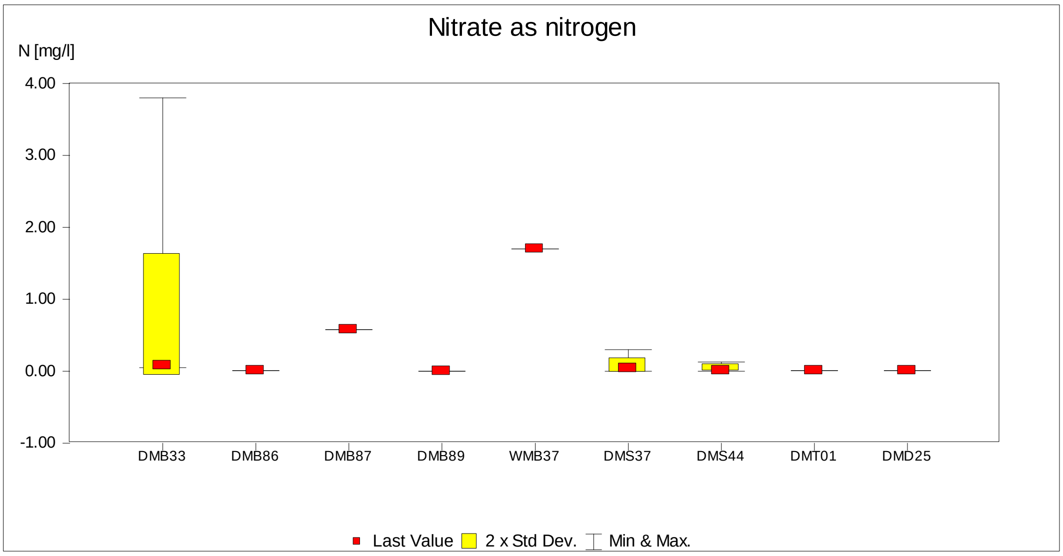

Figure 17. MMAC Plot of NO_3-N concentration in 9 boreholes.

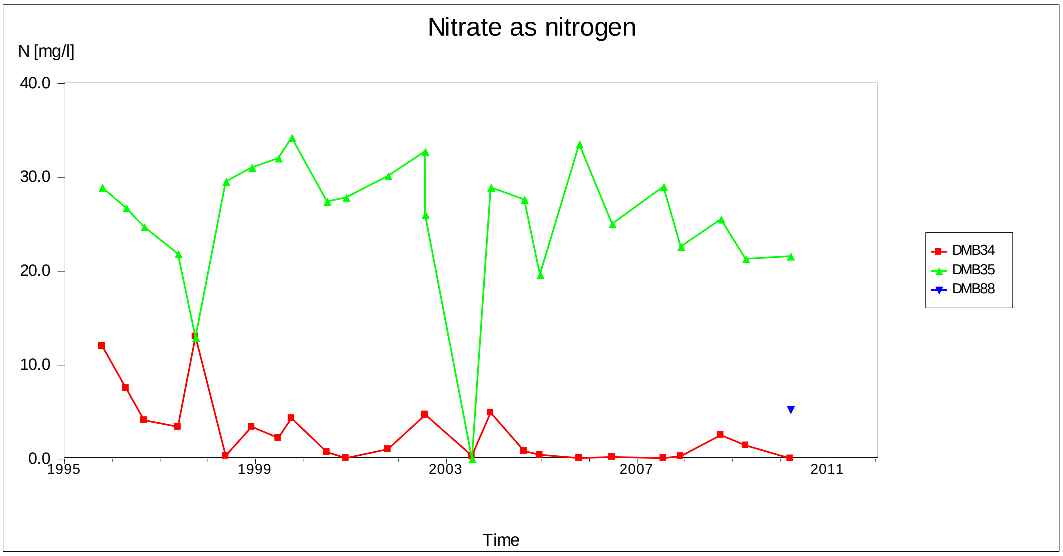

Figure 18. Temporal trends of NO_3-N concentration in 3 boreholes.

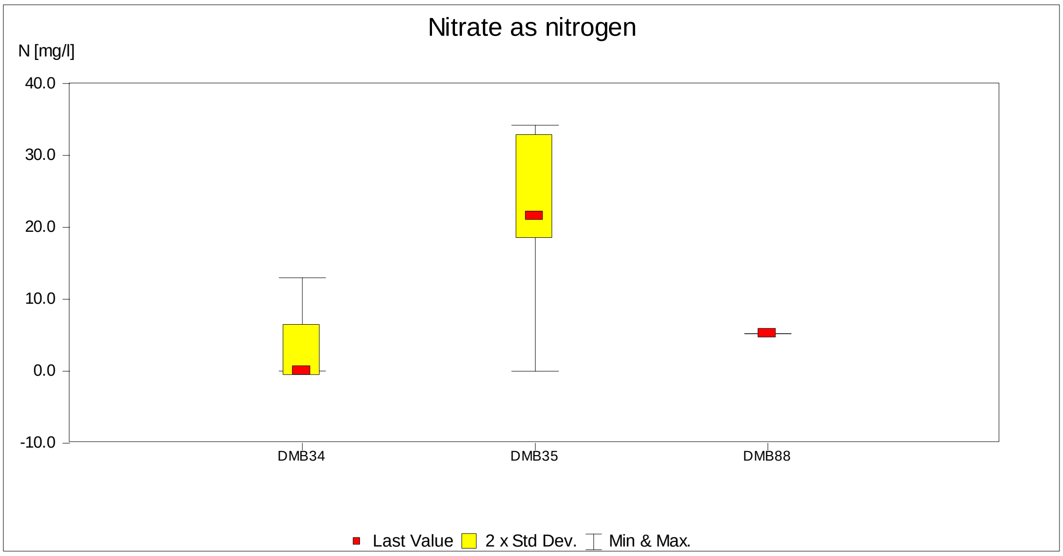

Figure 19. MMAC Plot of NO_3-N concentration in 3 boreholes.

9 DISCUSSION

9.1 Geohydrological assessment

While groundwater is used mainly for stock watering and to a lesser extent for domestic purposes by farmers in the area surrounding the domestic waste site, the number of people dependent on the resource is limited to residents on adjoining farms. This appears highly unlikely to change in the near future due to the proximity of large, reliable surface water bodies such as The Leeu Spruit, Vaal River and Grootdraai Dam to the nearby communities of Thuthukani, Standerton, and Sakhile as well as large industries such as Tutuka Power Station and New Denmark Collieries.

There is a significant risk of shallow perched aquifer contamination and a slight risk of pollution to migrate to the of adjacent surface water body, the non-perennial stream to the east and north of the site, during waste disposal operations if site drainage is not considered during the design stage, and indeed there is evidence to suggest that past waste disposal activities have already degraded site water quality to the north of the current domestic waste site. In this instance, surface drains could perhaps best control the migration of leachate. Ponding within these drains and any associated dams constructed within in situ material should be prevented as testing undertaken to date suggests that site soils are not suited for use as a liner material.

Available data suggests that the thick deep fresh dolerite sill is relatively impermeable at the site. Indeed, the weathered 1 to 5 m of this sill appears less permeable. Thus, excavations associated with waste disposal activities could extend to the soil/weathered rock interface, equating to the depth of excavation refusal for normal plant associated with waste disposal in rural areas. Surface drains could also be constructed to this depth to intercept any water perched on the fresh dolerite sill. These drains must be constructed up-gradient as well as down-gradient of the waste site. The drain up-gradient, south of the waste site must be constructed in such a way to intercept all clean water ingress into the waste site. The down-gradient drain must have the capability to intercept possible leachate that could be generated by the waste site operations as was done during the construction of the current waste site.

While laboratory testing suggests that site soils are unsuited for use as liner material, they can be used as a waste cover. For rehabilitation purposes, however, the final cover layer should predominantly comprise of topsoil.

The sudden change in the orientation of the water table adjacent to the non-perennial stream, which act as a groundwater divide east and north of the site and the relatively high hydraulic gradient within aquifers adjacent to the divide suggests that the risk of aquifer pollution on adjoining properties due to solid waste disposal is remote. Further, increases in surface elevation along the ridge south of the site suggest that there will be no impacts on groundwater quality in areas to the south and west of the domestic waste site either.

9.2 Monitoring considerations

Table 12. Parameters to be determined during biannual detection and investigative monitoring as recommended by the DWA&F (1994) and previous monitoring reports done by GHT Consulting.

Chemical Parameter	Testing Frequency	
	Biannual Monitoring	Investigative Monitoring
Alkalinity (Total Alkalinity)	x	x
Ammonia (NH3 as N)	x	x
Calcium (Ca)	x	x
Chemical Oxygen Demand (COD)	x	x
Chloride (Cl)	x	x
Electrical Conductivity (EC)	x	x
Fluoride (F)	x	x
Magnesium (Mg)	x	x
Nitrate (as N) (NO3-N)	x	x
pH	x	x
Potassium (K)	x	x
Sodium (Na)	x	x
Sulphate (SO4)	x	x
Total Dissolved Solids (TDS)	x	x
Boron (B)	x	x
Iron (Fe)	x	x
Manganese Mn)	x	x
Cadmium (Cd)		x
Chromium (Hexavalent) (Cr^{6+})		x
Chromium (Total) (Cr)		x
Cyanide (CN)		x
Free and Saline Ammonia as N (NH4-N)		x
Lead (Pb)		x
Mercury (Hg)		x
Phenolic Compounds (Phen)		x

Site water quality monitoring is an essential requirement at any solid waste disposal site. Both surface and groundwater quality will have to be regularly assessed in the vicinity of any facility developed on Pretorius Vley 374. While seven dedicated monitoring bores have already been installed, it is recommended that groundwater quality and water level fluctuations within these bores be monitored quarterly.

Although the concentrations of 17 inorganic chemical parameters in the water samples must be determined during the chemical analyses, only five parameters are used as indicators of contamination in the monitoring of the pollution potential in this system. These five parameters are: the electrical conductivity (**EC**) and the major ions **Na**, **Ca**, **Cl** and **SO_4**. The suitability of these parameters to act as *indicator elements* in the evaluation of water contamination was determined by GHT during a previous investigation. The additional information on the concentrations of the other elements is required to evaluate the accuracy and reliability of the chemical analyses.

The most common way to evaluate the reliability of an analysis is to perform an Ion Balance Calculation. For any water analysis, the total cation and anion concentrations should balance. The difference between these concentrations is referred to as the Ion Balance Error. A negative value indicates that anions predominate in the analysis, whereas a positive value shows that cations are more abundant. For the analysis to be considered reliable, the ion balance error should not be greater than 5% of the total ion concentration. A value greater than this figure indicates that some major constituents have not been analysed for or that there is an analytical error. Some trace elements are not included in the ion balance calculation. However, these may still be important as pollution indicators and may be used to identify point sources of pollution.

DWA&F (1994) documentation and previous investigation by GHT Consulting states that detection monitoring should be undertaken bi-annually and samples tested for the parameters shown in Table 12. The chemical analyses to be done on water samples during investigative monitoring are also stipulated in the above table.

Detection monitoring should also be undertaken at the three surface water sites and leachate detection sump sampled during routine monitoring investigations. Additionally, any water impoundments constructed at the site as part of a waste disposal facility, such as sedimentation or storm surge ponds, should also be sampled. Parameters of interest and their respective sampling frequencies are shown in Table 12.

Should detection monitoring indicate that water quality has degraded over time, an increase in the sampling frequency and the number of parameters as per investigative monitoring will be required. Specialist geohydrological advice should also be sought.

10 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations have been made on the basis of field investigations and laboratory test results:

Groundwater is used predominantly for stock use in the surrounding area, although there is also some rural domestic water use. This appears unlikely to change in the near future due to the proximity of large, reliable surface water bodies, such as Leeu Spruit, Vaal River and Grootdraai Dam to the nearby communities of Bohlokong and Bethlehem.

Available evidence suggests that aquifers in the area surrounding the domestic waste site be classified as “Low / No significance”;

Available evidence suggests that groundwater quality in the to the north of the proposed facility has already been slightly degraded by past domestic waste disposal activities;

Geohydrological assessment of the site using WASP (Parsons and Jolly, 1994) suggests the site be classified “marginal” to “suitable” for solid waste disposal, with available data suggesting that aquifer pollution on adjoining properties is highly unlikely;

The control of surface run-off and sub-surface seepage with a view to preventing the pollution of adjacent surface water bodies is of major importance at the site. As a minimum requirement, ponding within these drains and any associated dams constructed within in situ soils should be prevented as testing undertaken to date suggests that site soils are not suited for use as a liner material. Bare site soils are also at risk of erosion, particularly if flow velocities within channels constructed in the profiles are excessive. A better option would be the construction of interception drains to the soil/weathered rock interface around the perimeter of the site to prevent and control the rapid migration of pollutants through perched aquifers towards the non-perennial spruit;

Available data suggests that the underlying dolerite sill is relatively impermeable at the site. Thus, excavations associated with waste disposal activities could extend to the soil/weathered rock interface, equating to the depth of excavation refusal for normal plant associated with waste disposal in rural areas;

Site soils are unsuited for use as a liner material to prevent the migration of contaminants, but can be used as a waste cover. The final covering layer should predominantly comprise topsoil, however, to aid with site rehabilitation;

Detection monitoring must be performed as per frequency and parameter list as determined by previous investigation done by GHT Consulting in the vicinity of Tutuka Power Station. It is recommended that groundwater be monitored at seven sites and surface water at three. The leachate detection sump most also be included in the monitoring program.

Additional sampling will also be required in those areas where surface water impoundments are constructed as part of any waste disposal operations. Should detection monitoring indicate that water quality has degraded over time, an increase in the sampling frequency and the number of parameters to be determined during laboratory testing will be required. Specialist geohydrological advice should also be sought.

Louis van Niekerk (Pr. Nat. Sci.)

11 REFERENCES

Darcy, H. 1856. *Les fontaines publiques de la ville de Dijon.* V. Dalmont, Paris, 647pp. In: Kruseman, G.P. & de Ridder, N.A. 1991. *Analysis and evaluation of pumping test data*. International Institute for Land Reclamation and Improvement, Amsterdam, 377pp.

Department of Water Affairs and Forestry. 1994. *Waste Management Series. Minimum requirements for waste disposal by landfill.*

Department of Water Affairs and Forestry, 1996. *South African Water Quality Guidelines (second edition).* Volume 1: Domestic Use.

Dreyer, C. 2000. *Archaeological impact assessment at Kuypsheim 901, Bethlehem.* Report prepared for Geo Hydro Technologies – Free State, Bloemfontein.

Driscoll, F.G. 1986. *Groundwater and wells*. Johnson Filtration Systems, Minnesota. In:
Parsons, R. & Jolly, J. 1994. *The development of a systematic method for evaluating site suitability for waste disposal based on geohydrological criteria*. WRC Report No. 485/1/94, Pretoria.

Parsons, R. & Jolly, J. 1994. *The development of a systematic method for evaluating site suitability for waste disposal based on geohydrological criteria*. WRC Report No. 485/1/94, Pretoria.

Truswell, J.F. 1977. *The geological evolution of South Africa.* Purnell and Sons, Cape Town, 218pp.

VSA GeoConsultants. 2000. *Aquabase – Version 2.1.* South Africa.