

CAMDEN POWER STATION
GEOHYDROLOGICAL IMPACT ASSESSMENT:
PROPOSED ASH DAM EXTENTION AT
ESKOM CAMDEN POWER STATION
JUNE 2012
REPORT

For



Project team
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Project no.: 274-20-ghd.631
Report no.: RVN 631.1/1304

Start Date: December 2011
Report Date: May 2012

4 June 2012

Our ref.: RVN 631.1/1304

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FOR ATTENTION: Mr. Willem Howel

Dear Sir,

GEOHYDROLOGICAL IMPACT ASSESSMENT:
PROPOSED ASH DAM EXTENTION AT ESKOM CAMDEN POWER STATION
MARCH 2012 - REPORT

It is our pleasure in enclosing one electronic copy and three hard copies of the report RVN 623.1/1304 "GEOHYDROLOGICAL IMPACT ASSESSMENT PROPOSED ASH DAM EXTENTION AT ESKOM CAMDEN POWER STATION March 2012 - FINAL REPORT". This is a final report and includes the field work and detailed description of the hydrological as well as geohydrological assessments on three proposed sites. 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,

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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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1 INTRODUCTION

GHT Consulting was appointed by Zitholele Consulting (Pty) Ltd to perform geohydrological impact investigation on the local aquifer underlying proposed new ash dam sites for the extension of the current ash dam at Eskom Camden Power Station. The proposed extension of the Ash Dam is planned to have a footprint of 120 ha.

The assessment entailed geohydrological activities to determine aquifer vulnerability. The study also investigated the potential of the local underlying aquifer as a groundwater resource.

The potential for the migration of contaminants was also investigated in terms of potential preferential pathways associated with subterranean geological structures such as intrusive dolerite dyke and sill structures of post Karoo age associated with the Beaufort Group, Molteno Formation and Elliott Formations of the Karoo Supergroup. The potential of the existence of intrusive dolerite dykes in the study area, which may act as preferential pathways were also investigated by means of aerial magnetic interpretations as well as field geophysical survey methods.

A hydrocensus was also conducted to identify groundwater users in the vicinity of the site, which may be impacted upon in terms of groundwater quality which may be adversely affected by the proposed cemetery.

The locality map of the area showing the various candidate sites can be viewed in **Figure 1**. The present study focussed on Candidate Sites 1, 2 and 3.

Three maps illustrating the positions of all the current monitoring sites at Camden Power Station are presented in Figure 2 to Figure 4.

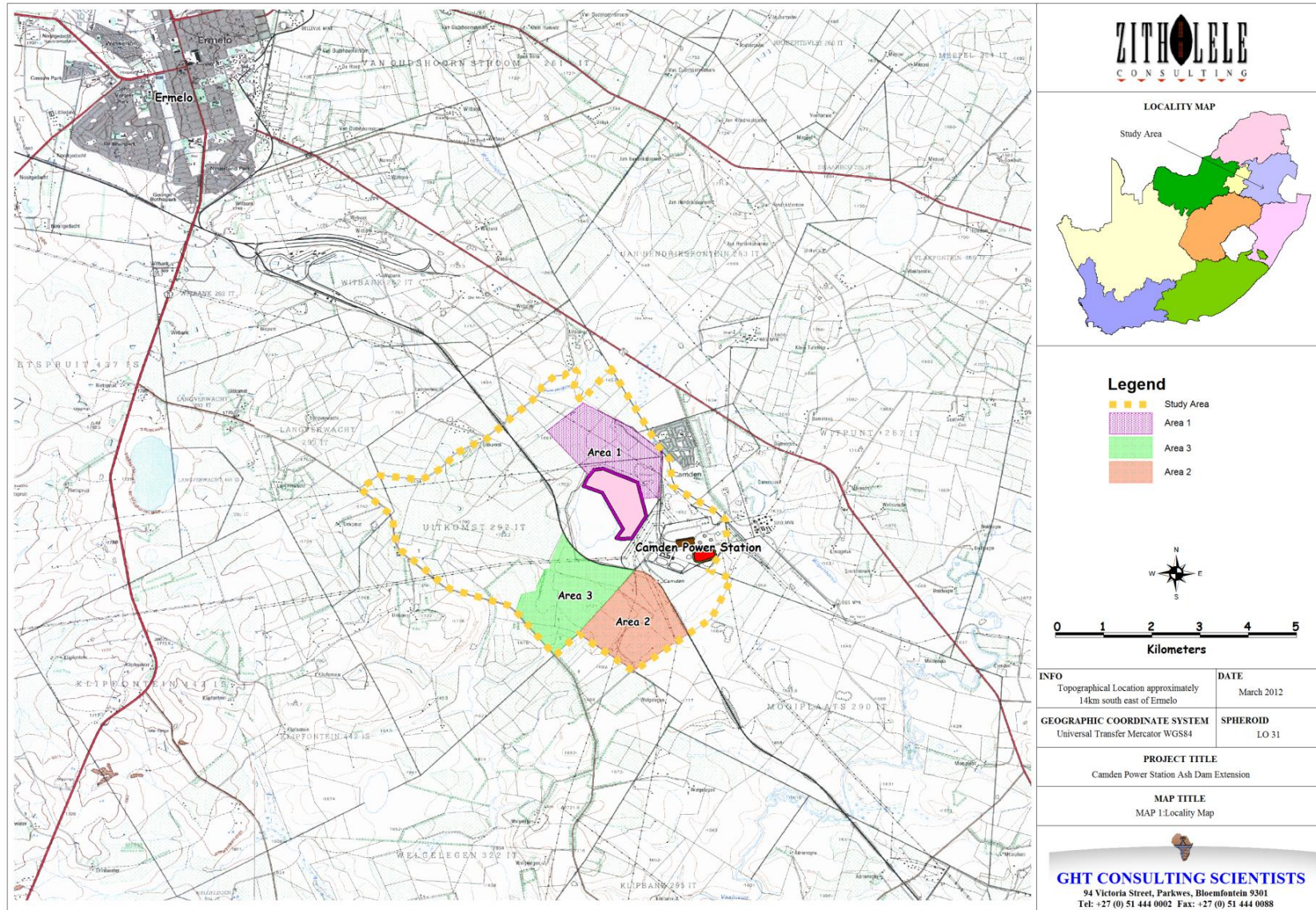


Figure 1. Locality Map

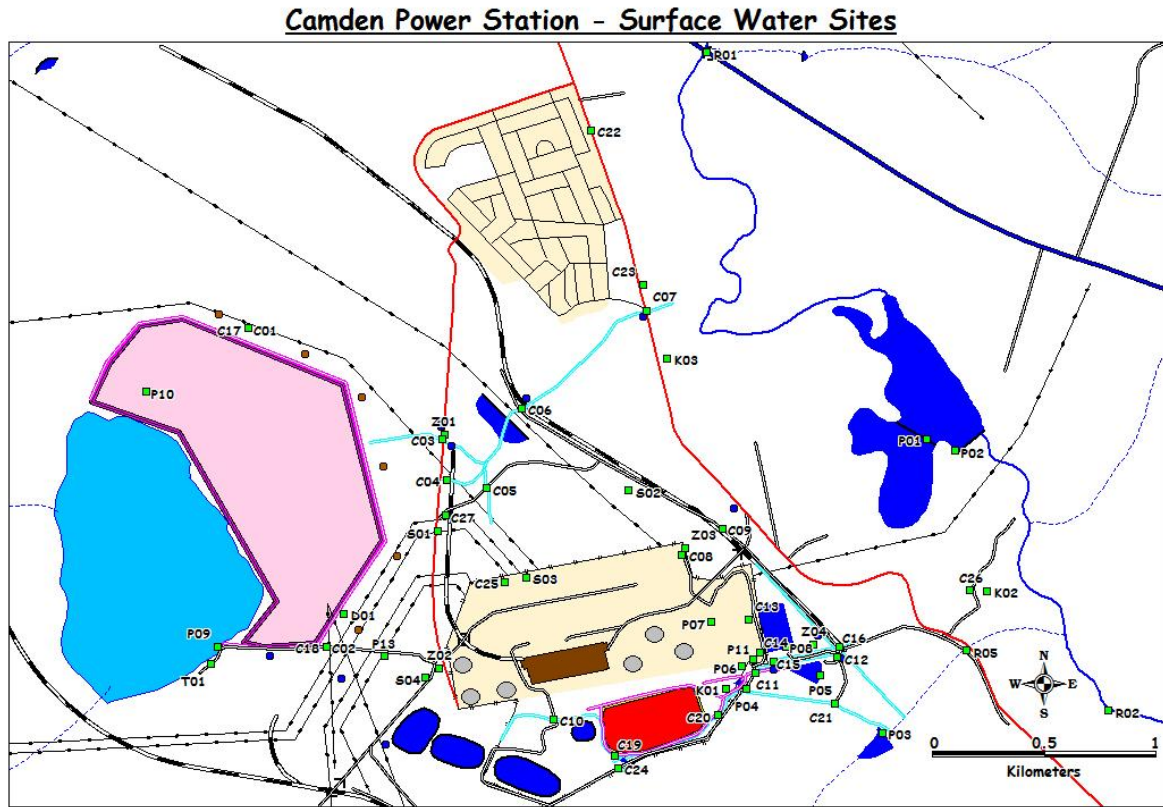


Figure 2. Camden Power Station Surface Water Monitoring Sites

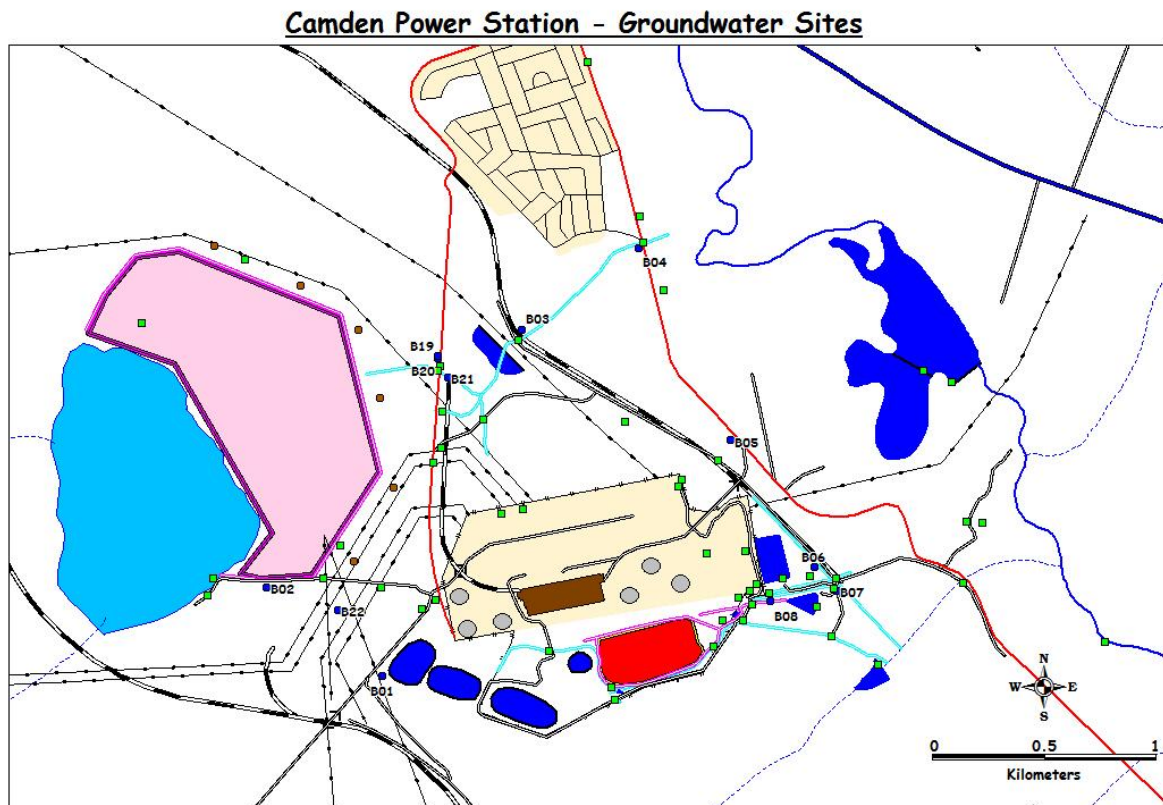


Figure 3. Camden Power Station Groundwater Monitoring Sites

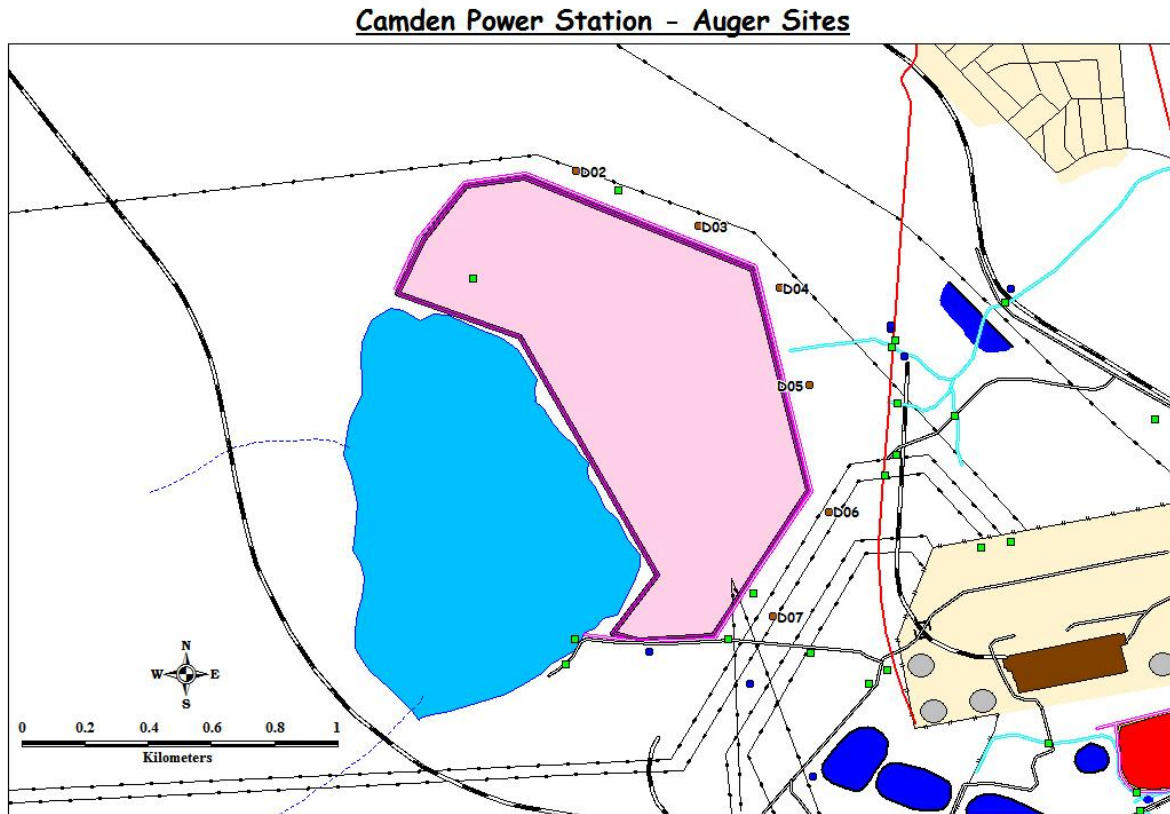


Figure 4. Camden Power Station Auger Borehole Monitoring Sites

2 PHYSICAL GEOGRAPHY

2.1 Extent of Investigation

The area under investigation is between grid references (-99 000, -2 950 000), (-88 000, -2 940 000), as shown on 1:50 000 topographic maps of the area (Camden 2630CA; Chief Director of Surveys and Mapping, 1986).

Camden Power Station, while located within a rural area approximately 14 km southeast of Ermelo in the Mpumalanga Province, the site itself is well developed, due to the presence of the power station, abandoned and new coal mine and offices, and associated infrastructure comprised of, stockyards, delivery plant, hostels, and an urban village. Prior to development, however, the site was probably a commercial stock and crop farm similar to those now present along the boundaries of the respective power station.

The candidate sites for the extension of the ash dam are located in the rural area around Camden Power Station. The property includes the farms Uitkomst 292 portion 292/18 (Proposed site 1) portion 292/2 and 290/3 (Proposed site 3) as well as the farm Mooiplaats 290 portions 290/14 and 290/20 (Proposed site 2) in the Ermelo Magisterial District.

Field inspections of the areas within three kilometres of the candidate cemetery sites were undertaken. Detailed field investigations were, however, concentrated on the areas of the candidate sites.

2.2 Topography and Surface Drainage

Topographic maps of the area show a recurring block type drainage pattern that seems particularly well developed to the east of the power station, characterized by stream sections orientated southwest-northeast and northwest-southeast. Drainage of this type is often structurally controlled, and thus may provide some insight into the orientation of regional and convergent stresses.

The Power Station lies on a slightly sloping surface with a gradient of 0.025 to the east and northeast (FD Hodgson & D Vermeulen 2002). The ash dam lies approximately 1.6 km west of the closest part of the Witpunt Spruit. This spruit flows from the northwest pass the Power Station and joining the Vaal River approximately 4.4 km southwest of the Power Station.

The Power Station lies within drainage region C11B, and can be sub-divided into secondary drainage regions comprised of smaller catchment areas and streams. The surface topography of the area is typical of the Mpumalanga Highveld, consisting in the main of a gently undulating plateau. The flood plains of the local streams are at an average elevation of approximately 1635 meters above mean sea level (mamsl).

Altitudes varies from +1680 mamsl directly west of the De Jager Pan and the Ash Dam to approximately 1635 mamsl at the Witpunt Spruit east of the Power Station. The base of the ash dam area intersects the 1675 – 1680 mamsl contour lines, with the maximum height of the dam estimated around 16 m and therefore at a maximum elevation in the vicinity of 1696 mamsl.

The natural surface drainage from the Ash Dam Complex is slightly to the northeast, whereas the surface drainage from the northern area of the Power Station is towards the northeast and from the southern area of the Power Station Area slightly more eastwards. There is however a small portion of the north eastern area of the Power Station and south eastern area of the Ash Dam that drains into the De Jager Pan northwest of the power station. The pan estimated to be in the vicinity of 92 ha in size.

Surface run-off from the area is in the order of 8% of the annual rainfall. Groundwater recharge in undisturbed areas is in the order of 3% of the annual rainfall

2.2.1 Candidate Site 1

The topography slopes from south to north-west towards a small non-perennial tributary of the Witpunt Spruit, from south-west to north-east as well as from west to east towards the Witpunt Spruit. The small tributary to the north-west is located approximately 0.3 km from candidate site 1 and discharges 0.4 km further downstream into the Witpunt Spruit. The Witpunt Spruit is approximately 1.5 km to the east of candidate site 1. The topographical contours of the site can be viewed in Figure 5. The topography of candidate site 1 area has an average slope of 0.023 V/H (V = 10 m / H = 450 m, 1:10 000 Ortho photo maps).

2.2.2 Candidate Site 2

The topography slopes from west to east, towards a small non-perennial tributary of the Witpunt Spruit. This tributary origin is located in the area of candidate site 2 and discharge 3.2 km further downstream into the Witpunt Spruit. The topographical contours of the site can be viewed in Figure 5. The topography of candidate site 2 area has an average slope of 0.043 V/H (V = 15 m / H = 370 m, 1:10 000 Ortho photo maps).

2.2.3 Candidate Site 3

The topography slopes in two major directions (south-west to north-east slope, towards the De Jager Pan and a north-east to south-west slope towards two non-perennial tributaries of the Vaal River. The southern tributary originates on the boundary of the area. Candidate site 3 is located approximately 0.2 km from the De Jager Pan and approximately 13 km upstream from the Vaal River. The topographical contours of the site can be viewed in Figure 5. The topography of candidate site 3 area has an average slope of 0.036 V/H ($V = 14 \text{ m} / H = 420 \text{ m}$, 1:10 000 Ortho photo maps).

2.1 Infrastructure and Man-made Features

Infrastructure at or in the vicinity of the candidate sites includes Camden Power Station and its associated structures (Ash dam complex, Coal stock yard) the Camden SANDF Military Base and SANDF Village. Informal settlements, farms fences and coal mines with associated structures

2.2 Climate and Vegetation

The project area falls within the highveldt climate classification of Viterito (1987), and can thus expect warm, wet summers, and mild, dry winters, with equivalent evaporation depths exceeding precipitation. Regular dust storms can also be expected during periods of prolonged dry weather. Average annual rainfall for the highveldt decreases from 900 mm in the east to 650 mm in the west, with approximately 85% falling between October and April. In the vicinity of Camden Power Stations the estimated rainfall from showers and thunderstorms is about 726 mm/year and the evaporation 1400 mm/year, based on available records for Nooitgedacht – Agriculture College (442811) a South African Weather Bureau meteorological station about 17 km to the northwest of the area (See **Figure 6.** below). The water balance in the area plays a major role in the possible impacts on especially surface water but also groundwater. It is evident that the evaporation exceeds the precipitation by a large margin. The area thus has a water deficit and a negative water balance in general.

Average daily maximum temperatures vary from 25°C in January to 16°C in June, but in extreme cases these may rise to 34 and 23°C, respectively. In comparison, average daily minima of 13 and 0°C can be expected, with temperatures falling to 5 and –10°C, respectively, on unusually cold days (See **Figure 7.** below).

Within the power station compounds and surrounds, vegetation is restricted to lawn grasses, small shrubs, and occasional trees, while crops such as maize are grown on adjoining properties. Several pasture species have also been planted on the rehabilitated areas of the ash dam.

Reeds occur across each of the sites in areas with a high groundwater table, or where surface water of shallow depth stands.

Two of the three areas are used for agricultural purposes with the main crops consisting of maize and soya beans. The third area (Proposed site 1) is mostly grasslands and mainly utilise as grazing and cattle farming.

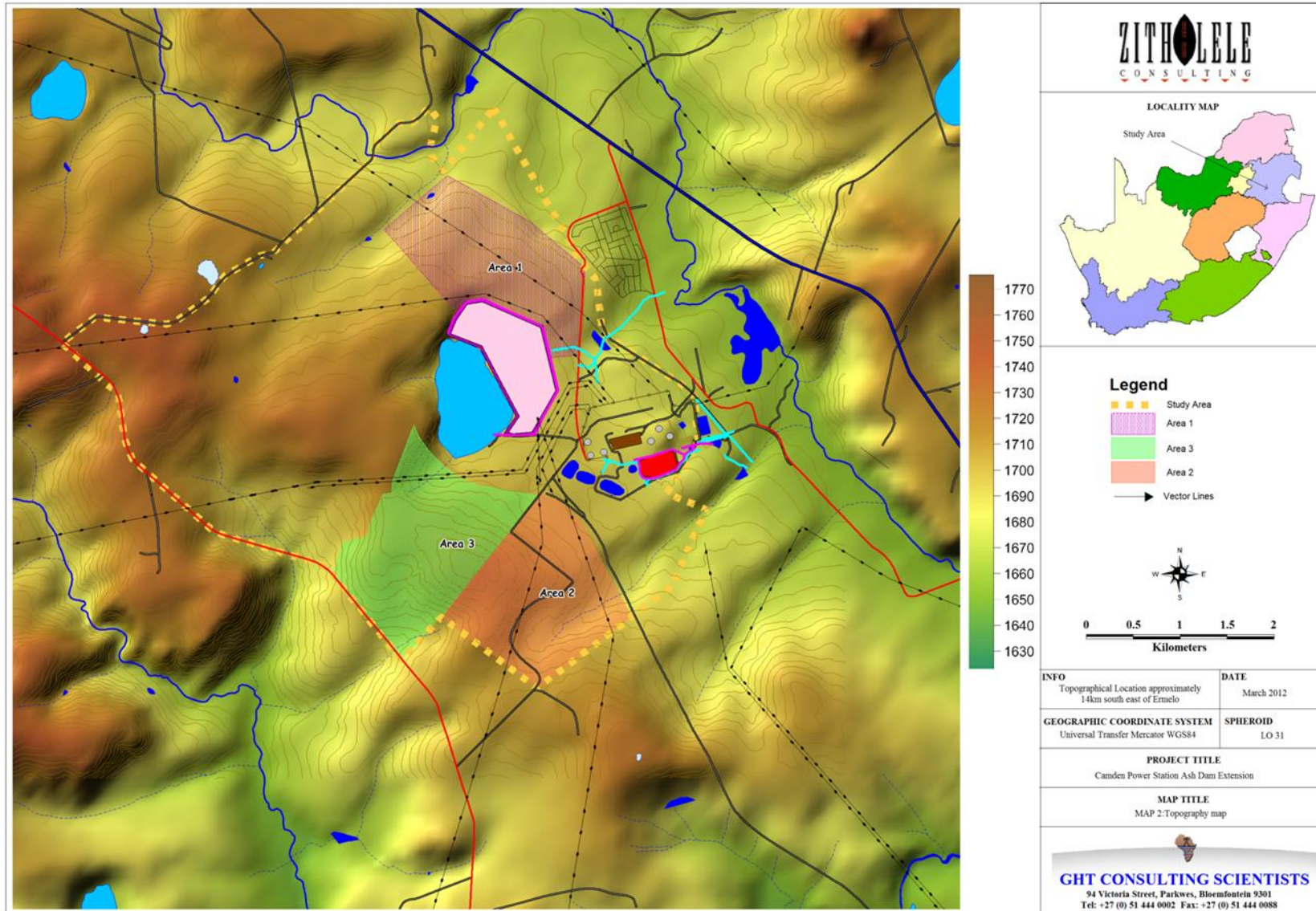


Figure 5. Topography Map of study area.

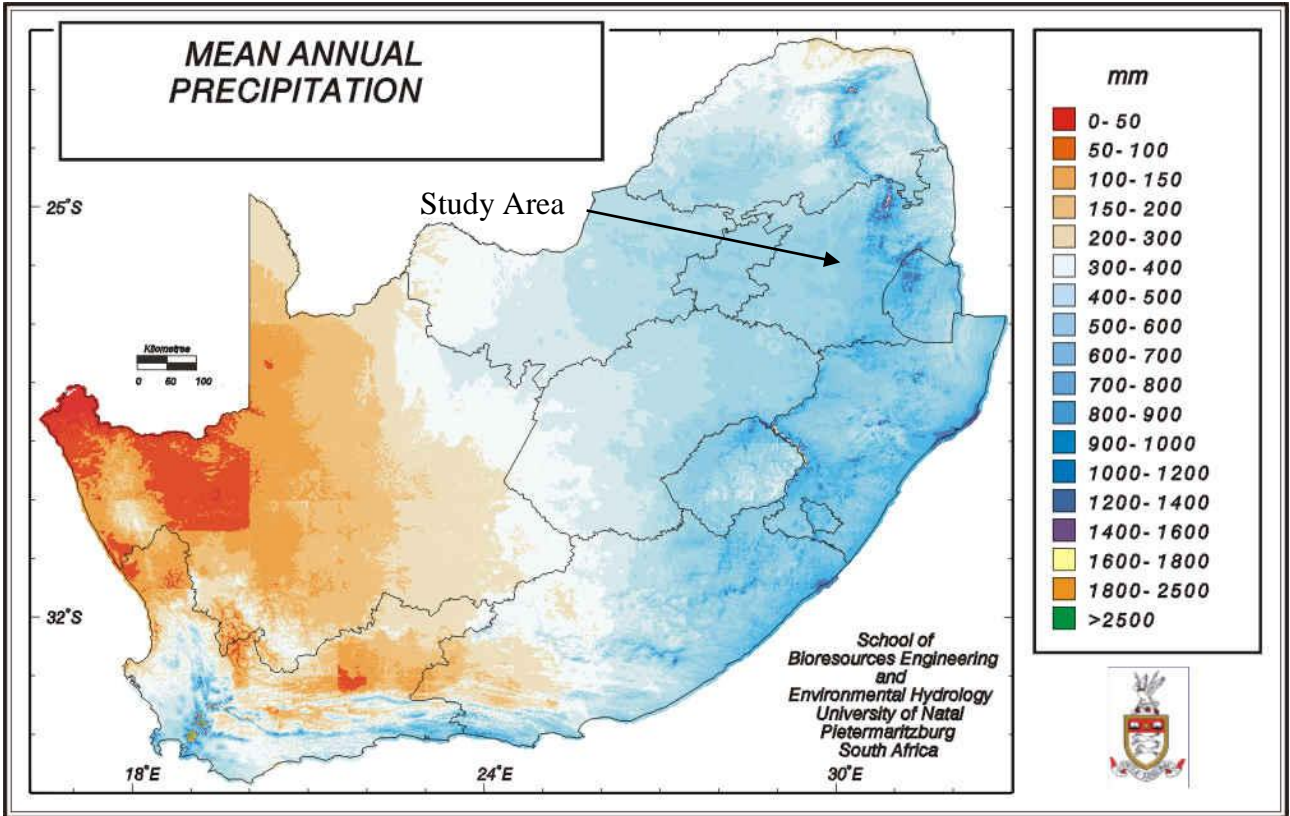


Figure 6. Mean annual precipitation of Ermelo District

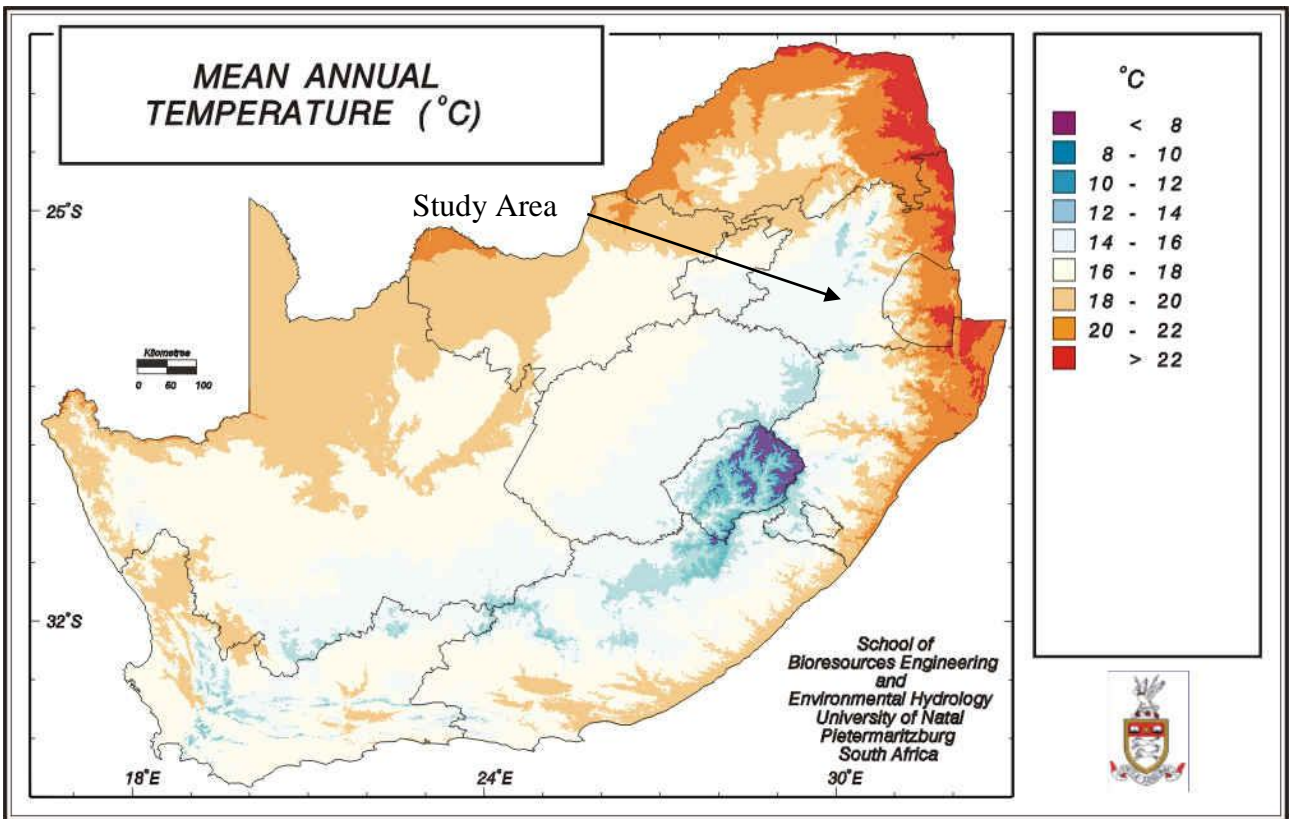


Figure 7. Mean annual temperature of Ermelo District

3 POLLUTION SOURCE INVESTIGATION

3.1 Ash Dam

The Power Stations Operations produce in excess 65 thousand tons of ash per month. From a 3 : 1 water to solids ratio, it is evident that large volumes of water are released onto the ash dams every month. Figures obtained from Eskom are that 70 - 80% of the water dumped onto the tailings will reach the return water dam. The remaining water will either be absorbed by the tailings, reach the ground-water table by infiltration or be evaporated mainly from the pool area.

According to van Niekerk (1991) up to a depth of ± 2.0 m, there is vertical movement of moisture, after which the moisture has to move horizontally, either to the centre of a ashing facility or to its side, where it can evaporate, explaining the precipitation of sulphates on the ashing facility surface. It furthermore means that there is no vertical flow past the depth of 2.0 m, hence limiting the influx of oxygen for oxidation of heavy minerals. This also correlates well with the work done on residue dump leaching procedures by James and Mrost (1971). The above-mentioned has the implication that water movement below a depth of 2 m is essentially in the horizontal direction, towards the sides of the ash dam (where it evaporates) or towards the saturated central part (pool area) of the ash dam (where it is intercepted by the drainage system).

It should, however, be stressed that the above-mentioned water movement only applies to parts of the ash dam above the phreatic surface, i.e. the unsaturated part of the slimes dam. If the saturated part of the slimes dam (i.e. the part beneath the phreatic surface) is considered, the situation changes significantly. In this region, there always exists a downward flux, due to the hydraulic gradient between the saturated part of the ash dam and the surrounding ground-water regime, as well as the chemical gradient between the two regimes.

Furthermore, van Niekerk (1991) noted that the stratification of finer and coarser layers in a slimes dam is enhanced by their water content. Generally fines tend to retain a larger portion of the available moisture than coarser materials.

3.2 Ash Permeability

On the 8 March 2012, 4 auger holes were drilled into the current ash dam to a depth of 1.2 m and representative disturbed samples taken for analyses (laboratory test results are summarized in Table 1). The localities of the auger holes are plotted on Figure 8.

Table 1. Auger hole information of ash samples.

Sites	Sample No	Longitude °E	Latitude °S	Elevation mamsl	Hole Diam (mm)	Sample Depth (m)	Hole Depth (m)	Water Level mbgl	In Situ Field Moisture (%)	Formation End of Hole	Description
Ash Profiles - Current Ash Dam											
D20	WP53	30.08062	-26.61592	1687	90	0 - 1.2	1.2	~	28.6	Ash	Dark gray ash. (Old Ash)
D21	WP54	30.07925	-26.61488	1692	90	0 - 1.2	1.2	~	31.5	Ash	Dark gray ash. (New Ash)
D22	WP55	30.07025	-26.60704	1685	90	0 - 1.2	1.2	~	55.4	Ash	Dry dark gray ash. (Old Ash)
D23	WP56	30.07474	-26.61215	1690	90	0 - 1.2	1.2	~	64.3	Ash	Wet dark gray ash. (New Ash)

The laboratory results of the sieve analyses as well as the permeability calculation sheets are attached in Appendix A. .

According to Stanley (1987), fly ash may be described as a rock floor, comprising of 0 - 10% clay fraction, with some 80% of the material falling within the silt fraction and 0 - 5% fine sand fraction.

The same were observed from the sieve analyses from the ash samples from Camden Power Station. The old ash samples (before re-commissioning) at Camden Power Station comprises of 0 - 10% clay fraction, 60% silt fraction and 0 - 20% fine sand. The new as samples (after re-commissioning) at Camden Power Station comprises of 0 - 5% clay fraction, 90% silt fraction and 0 - 5% fine sand.

The above results were used to calculate a possible flux of water through the ash dam. According to van Niekerk (1991) this is difficult to achieve, as the soil moisture characteristics of an ash dam can change significantly towards the centre (saturated pool area) of the ash dam. Van Niekerk stated that the flux of water could be ten times higher at the saturated areas. The results of all the calculation are presented in Table 2.

Table 2. Calculated permeabilities from sieve analyses results of ash samples.

Sites	Sample Depth (m)	K m/d	K m/s	Dh/Dl	Porosity (%)	Seepage Velocity m/s	Seepage Velocity m/d	Seepage Velocity m/year	Formation Tested
Ash Properties - Current Ash Dam									
D20	0 - 1.2	2.6787	3.100E-05	0.070	57%	3.807E-06	0.3290	120.0716	Dark gray ash. (Old Ash)
D21	0 - 1.2	0.0455	5.266E-07	0.095	45%	1.112E-07	0.0096	3.5060	Dark gray ash. (New Ash)
D22	0 - 1.2	0.2028	2.347E-06	0.060	46%	3.062E-07	0.0265	9.6550	Dry dark gray ash. (Old Ash)
D23	0 - 1.2	0.0407	4.711E-07	0.085	45%	8.898E-08	0.0077	2.8060	Wet dark gray ash. (New Ash)
(Average) Upper Range		0.742	8.587E-06	0.078	48%	1.078E-06	0.0932	34.01	
(Geometric mean) Lower Range		0.178	2.061E-06	0.076	48%	3.277E-07	0.0283	10.33	

An average hydraulic conductivity (K) value of 8.5×10^{-6} m/s was calculated by means of the Shephard (1989) equation. This value also compared favourably with values obtained from Steffen, Robertson and Kirsten (1990), as well as values published by James and Mrost (1965) and Mrost and Lloyd (1971). An estimated average seepage velocity (q) of 1.0×10^{-6} m/s or 34 m/year was obtained.

From the above discussions, it is evident that large quantities of contaminated water, depending on the size of the ash dam can seep into the underlying sediments to eventually reach the ground-water table. The amount of water, as well as the rate of infiltration, will furthermore depend on the under-drainage of the ash dam and the hydraulic properties of the underlying sediments respectively.

3.3 Acid Base Accounting (ABA)

With the scale of ash dams, these sites have been identified as the major sources of pollution which over-shadows the entire area.

The section therefore focuses on the evaluation of the potential of the Ashing Area to pollute water and the implications of this in terms of closure and rehabilitation. Four ash samples were taken for ABA analyses. The sample distribution is as follow:

- One sample (D20) old ash was taken on the South Eastern perimeter of the Ash Dam.
- One sample (D21) ash was taken on the South Eastern perimeter of the Ash Dam.
- One sample (D22) old ash was taken on the North Western perimeter of the Ash Dam.
- One sample (D23) new ash was taken on the South Western perimeter of the Ash Dam.

Refer to Table 1 and Figure 8 for the ash sample descriptions and locations respectively.

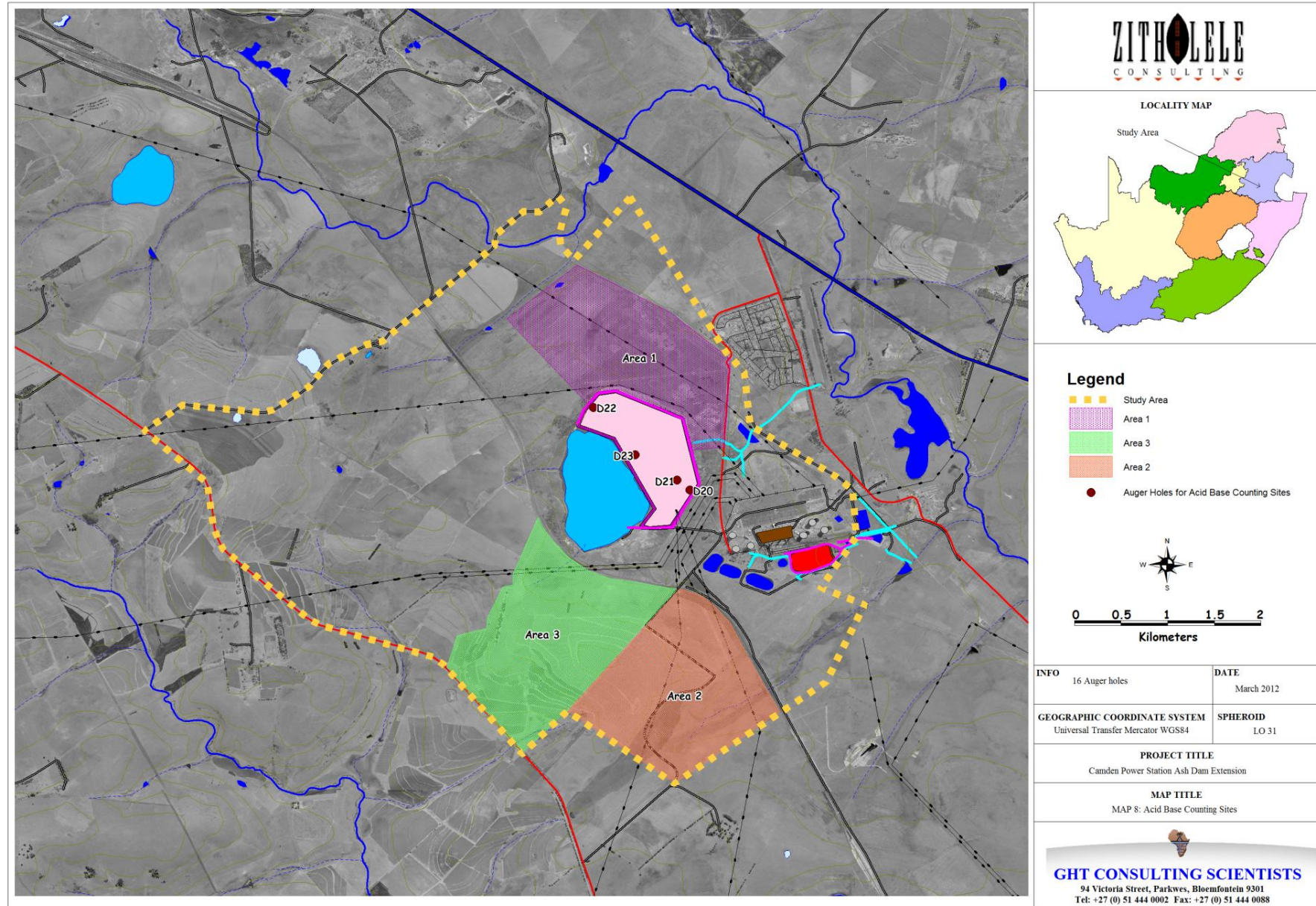
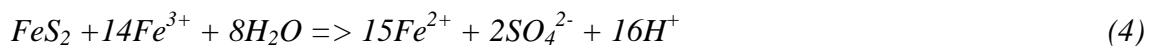
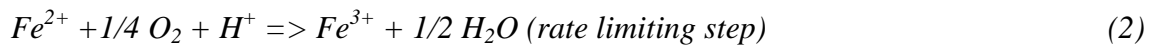


Figure 8. Auger hole positions on current ash dam.

3.3.1 Interpretation of ABA analyses

In most mining environments the onset of acid mine drainage (AMD) is as a result of the oxidation of sulphide minerals present. In ash and waste rock dumps it is often these sulphides that react with water and oxygen, usually assisted by microbiological catalysis, to generate low pH waters, with high sulphates and often associated heavy metal mobilisation.

The reactions involved are usually written with pyrite regarded as the sulphide of interest. Pyrite (FeS₂) is a common mineral often occurring as a gangue mineral associated with deposits of interest. The principal reactions involved are the following:



Reaction 1 shows oxidation of the disulphide, thus releasing ferrous iron (Fe²⁺) and two protons. In **Reaction 2** the ferrous iron is oxidised to ferric iron (Fe³⁺) which hydrolyses to form ferric hydroxide (an insoluble compound at pH greater than 3.5) and in the process as shown in **Reaction 3**, three more protons are released. Thus for every mole of pyrite five protons are released. However, since one proton is consumed for the oxidation of ferrous to ferric, only four protons are actually produced. Upon initiation of pyrite oxidation, the ferric iron can be reduced by the pyrite itself as shown in **Reaction 4**.

Acid-Base Accounting (ABA) usually refers to the so-called static methods that provide no information on the speed (or kinetic rate) with which acid generation or neutralisation will proceed, but simply determine the acid-neutralising potential (assets) and acid-generating potential (liabilities) of rock samples, and calculates the difference or net neutralising potential (equity). The net neutralising potential (NNP), and/or the ratio of neutralising potential to acid-generation potential (the neutralising potential ratio, NPR), is compared with a predetermined value, or set of values, to divide samples into categories that either require, or do not require, further determinative acid potential generation test work.

The potential for a given rock to generate and neutralize acid is determined by its mineralogical composition. This includes not only the quantitative mineralogical composition, but also individual mineral grain size, shape, texture and spatial relationship with other mineral grains. The term "potential" is used because even the most detailed mineralogical analysis, when combined with ABA, can give only a "worst case" value for potential acid production and, depending upon the NP procedure used, a "worst case", "most likely case" or "best case" value for potential neutralisation capability. The field generation and neutralisation of AMD represents the degree to which these potential values are realised in practice.

Neutralisation potential measures the sum total of carbonates, alkaline earths, and bases available to neutralize acidity and represents the most favourable condition. Calculations of maximum potential acidity and neutralisation potential are structured to equate the two measurements to a common basis for comparison. The resulting values, expressed as calcium carbonate equivalent, are compared to compute a net acid-producing or neutralising potential. Material exhibiting a net acid production potential of 5 tons/1000 tons of overburden material or more as calcium carbonate equivalent are classed as toxic or potentially toxic.

In its simplest form then Acid-Base Accounting is a way of determining via a set of procedures whether a particular sample has the potential for acid generation. Just as different methods of

accounting present different sets of books to an auditor, so different methods of conducting ABA test work will generate different sets of sample data for evaluation. Three methods commonly used to interpret ABA data are described below:

3.3.2 pH

A sample from the waste rock is subjected to ultra-oxidizing conditions by the addition of a strong oxidizing agent, such as hydrogen peroxide. This agent oxidizes all the sulphides in the sample to sulphates, liberating protons in the process. This test therefore gives a worst-case end member that could arise from oxidation. The criteria used to assess acid-generation potential are:

- Final pH > 5.5, sample is considered to be non-acidgenerating,
- $3.5 < \text{Final pH} < 5.5$, sample has a low risk of acid generation,
- Final pH < 3.5, sample has a high acid generation risk.

3.3.3 Net neutralising potential (NNP)

The NNP is simply the difference between the neutralising potential (NP) and the acid-generation potential (AP). The following criteria are used to evaluate the potential of the sample to generate acid:

- If $\text{NNP} = \text{NP} - \text{AP} < 0$, the sample has the potential to generate acid,
- If $\text{NNP} = \text{NP} - \text{AP} > 0$, the sample has the potential to neutralise acid produced.

More specifically, any sample with an $\text{NNP} < -20$ is potentially acid generating, while any sample with $\text{NNP} > 20$ is likely not to generate acid. The acid generation potential of samples with NNP values between -20 and 20 is usually considered as uncertain and other static and/or kinematic tests are performed to obtain more certainty.

3.3.4 Neutralising potential ratio (NPR)

The NPR is calculated from NP/AP . The following criteria are used to evaluate the potential for Acid Mine Drainage (AMD):

- $\text{NPR} < 1$, likely AMD generating,
- $1 < \text{NPR} < 2$, possibly AMD generating if NP is sufficiently reactive or is depleted at a faster rate than sulphides,
- $2 < \text{NPR} < 4$, not potentially AMD generating, unless significant preferential exposure of sulphides along fracture planes, or extremely reactive sulphides in combination with insufficiently reactive NP,
- $\text{NPR} > 4$, high neutralising potential, AMD very unlikely.

3.3.5 Results of ABA Tests

Four ash samples (two old and two fresh ash samples) were taken from the Ashing Area (D20, D21, D22 and 23) and submitted to the laboratory of the Institute for Groundwater Studies (UFS) for Acid-Base Accounting (ABA) tests.

To interpret the results of the analyses, the analysed chemical variables (pH, Acid Potential, Neutralisation Potential) were entered into the spreadsheet ABACUS, Acid Base Accounting Cumulative Screening, developed by Dr. Brent Usher previously from the Institute for Groundwater

Studies. This spreadsheet makes use of various accepted approaches to interpret ABA data and allows a comparison of the results from each approach. These approaches include assessments made on the basis of pH values, Net Neutralising Potential (NNP) values and Neutralising Potential Ratios (NPR) for both open and closed systems. In open systems O₂ and CO₂ are able to freely enter and leave the solution. However, in closed systems, such as positions below the water table, no gas phase is present to supply CO₂ to the system. This reduces the solubility of calcite/calcrete causing the system to have an overall higher acid potential. The sample and comparative interpretations of the ABA data for the discards is presented in Table 3.

Table 3. Sample interpretation of the Acid/Base Accounting (ABA) results.

Site	Acid Generating Potential										
	Initial pH	Final pH		NNP (Open system)		NNP (Closed system)		NPR (Open System)		NPR (Closed System)	
	Value	Value	Interpretation	Value	Interpretation	Value	Interpretation	Value	Interpretation	Value	Interpretation
D20	9.05	5.85	Lower Acid Risk	77.75	Probably Excess Neutralising Minerals	69.14	Probably Excess Neutralising Minerals	10.03	No Acid Potential	5.02	No Acid Potential
D21	12.66	7.03	Lower Acid Risk	66.13	Probably Excess Neutralising Minerals	62.16	Probably Excess Neutralising Minerals	17.66	No Acid Potential	8.83	No Acid Potential
D22	9.30	5.95	Lower Acid Risk	94.10	Probably Excess Neutralising Minerals	90.02	Probably Excess Neutralising Minerals	24.08	No Acid Potential	12.04	No Acid Potential
D23	12.98	7.45	Lower Acid Risk	69.04	Probably Excess Neutralising Minerals	64.78	Probably Excess Neutralising Minerals	17.21	No Acid Potential	8.60	No Acid Potential

Table 4. Sample interpretation of the Acid/Base Accounting (ABA) results.

Sample No.	pH values	Net Neutralising Potential
D20	Lower Acid Risk	Probably Excess Neutralising Minerals
D21	Lower Acid Risk	Probably Excess Neutralising Minerals
D22	Lower Acid Risk	Probably Excess Neutralising Minerals
D23	Lower Acid Risk	Probably Excess Neutralising Minerals
Sample No.	% S and NPR Method (Soregali and Lawrence, 1997)	ABA INDEX
D20	Too little S to create sustained acidity	0.74789
D21	Too little S to create sustained acidity	0.00391
D22	Too little S to create sustained acidity	0.00319
D23	Too little S to create sustained acidity	0.00312
Sample No.	NPR (Open System)	NPR (Closed System)
D20	No Acid Potential	No Acid Potential
D21	No Acid Potential	No Acid Potential
D22	No Acid Potential	No Acid Potential
D23	No Acid Potential	No Acid Potential
Sample No.	ABA INDEX	VERDICT
D20	-1.26163	Do Further Testing
D21	-24.08087	Very Low Risk
D22	-24.95598	Very Low Risk
D23	-25.05636	Very Low Risk

Table 4 and Figure 9 and Figure 10 are graphs of the initial and final pH values of the ash samples from the Ashing Area plotted against the NNP values calculated for an open and closed system, respectively. It can be seen that all the final pH values are greater than 5 indicating no acid potential in both the open and closed systems. All the samples have positive NNP values (probably excess neutralising materials) and are not acid generating.

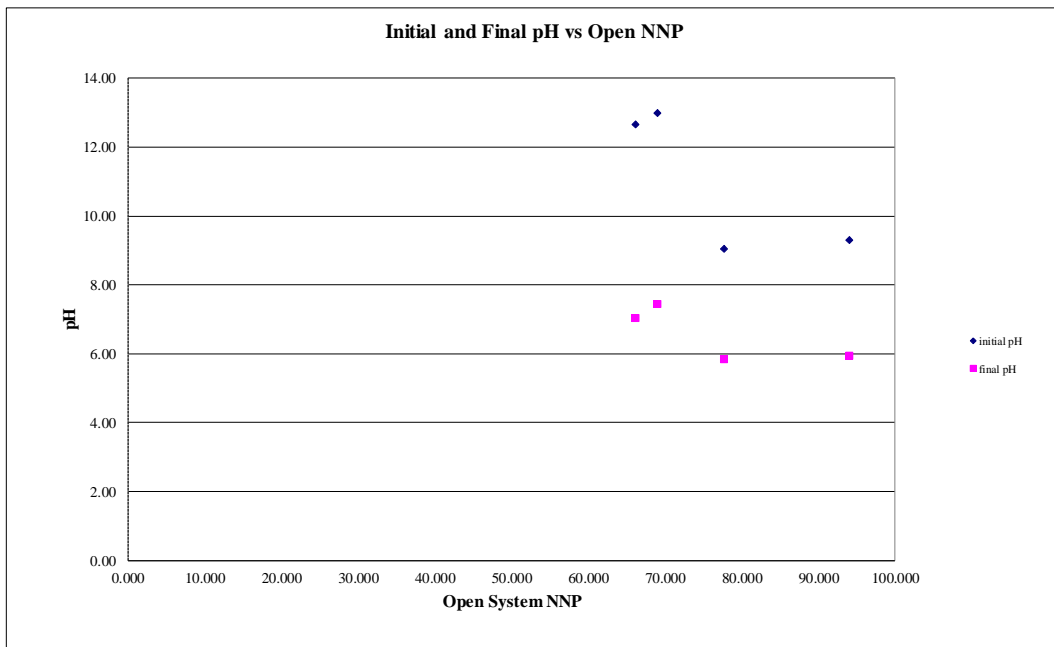


Figure 9. Initial and final pH values plotted versus NNP values (open system) for the samples from the Ashing Area.

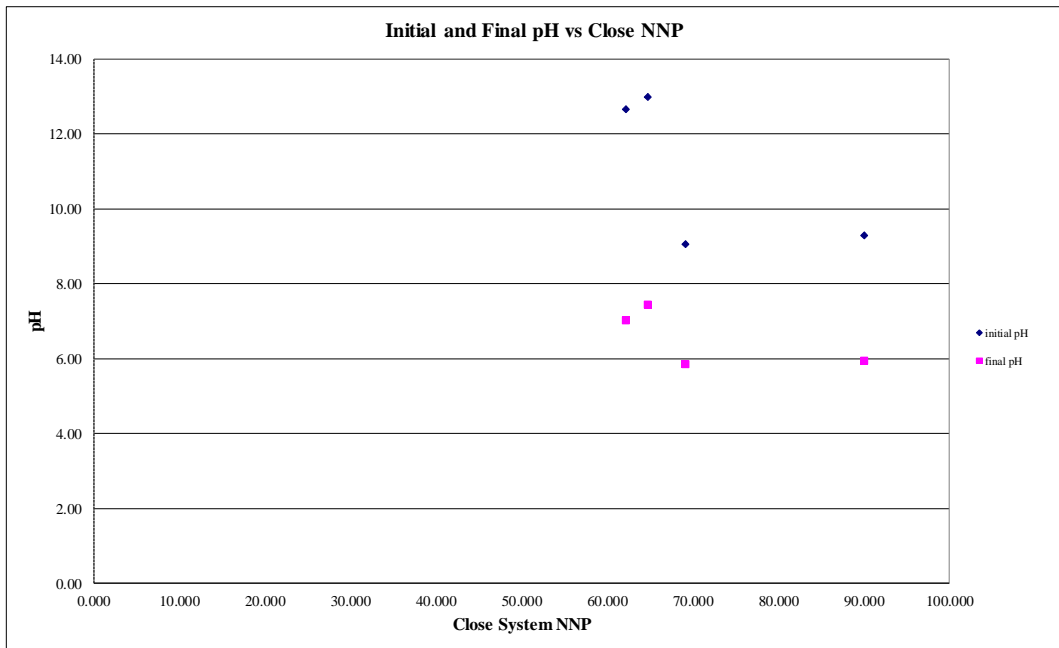


Figure 10. Initial and final pH values plotted versus NNP values (close system) for the samples from the Ashing Area.

Figure 11 is a graph of the acid potential (AP) plotted against neutralising potential (NP) for samples for both open and closed systems. Both the samples plot Below the 4:1 line (Green solid line) and are therefore unlikely to be acid generating. This observation holds true for both the open and closed systems.

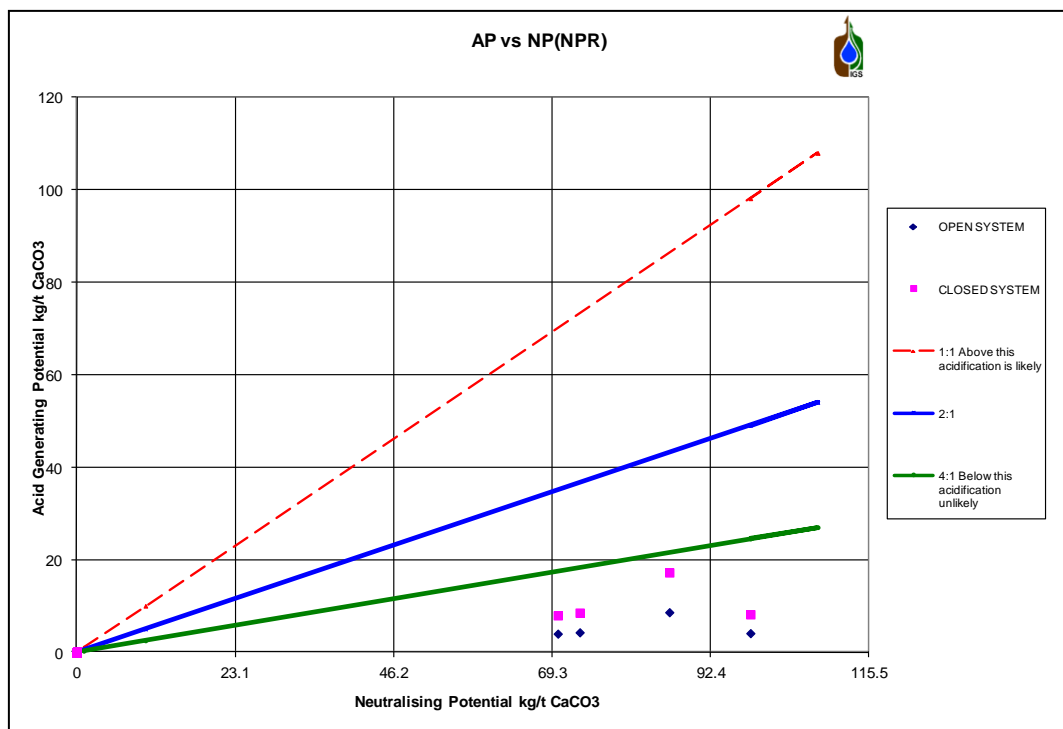


Figure 11. Acid potential (AP) plotted versus neutralising potential (NP) for the samples from the Ashing Area.

3.3.6 ABA Tests data sheets and graphs

Table 5. Water soluble constituents in kg/t

Samples	Initial pH	Ag	Al	As	Ba	Be	Ca	Cd	Cr	Co	Cu	Fe	K	Li
D20	9.1	0.0000	0.0035	0.0000	0.0008	0.0000	3.1046	0.0000	0.0000	0.0000	0.0001	0.0001	0.0376	0.0022
D21	12.7	0.0000	0.0937	0.0000	0.0022	0.0000	1.9797	0.0000	0.0034	0.0000	0.0001	0.0001	0.0268	0.0015
D22	9.3	0.0000	0.0052	0.0004	0.0004	0.0000	1.3000	0.0000	0.0002	0.0000	0.0001	0.0001	0.0205	0.0010
D23	13.0	0.0000	0.0297	0.0000	0.0021	0.0000	1.4256	0.0000	0.0026	0.0000	0.0001	0.0001	0.0280	0.0015
Samples	Initial pH	Mg	Mn	Mo	Na	Ni	Sb	Se	Sn	Sr	Pb	V	Zn	SO4
D20	9.1	0.4247	0.0003	0.0005	0.2613	0.0000	0.0001	0.0001	0.0000	0.0493	0.0000	0.0005	0.0005	9.1979
D21	12.7	0.0193	0.0001	0.0023	0.0933	0.0000	0.0002	0.0004	0.0000	0.0201	0.0000	0.0010	0.0003	3.4915
D22	9.3	0.2886	0.0002	0.0004	0.2479	0.0000	0.0002	0.0002	0.0000	0.0236	0.0000	0.0008	0.0003	3.8297
D23	13.0	0.0126	0.0000	0.0022	0.0974	0.0000	0.0001	0.0002	0.0000	0.0213	0.0000	0.0009	0.0002	1.8149

Table 6. ABA data - Constituents released due to oxidation in kg/t (water soluble subtracted)

Samples	Final pH	Ag	Al	As	Ba	Be	Ca	Cd	Cr	Co	Cu	Fe	K	Li
D20	5.9	0.0000	0.0003	0.0000	0.0015	0.0000	3.6877	0.0000	0.0002	0.0000	0.0001	0.0001	0.1285	0.0030
D21	7.0	0.0000	0.0005	0.0009	0.0026	0.0001	3.8972	0.0000	0.0013	0.0001	0.0001	0.0001	0.0614	0.0031
D22	6.0	0.0000	0.0014	0.0004	0.0012	0.0000	2.5701	0.0000	0.0003	0.0000	0.0001	0.0005	0.1104	0.0021
D23	7.5	0.0000	0.0003	0.0011	0.0024	0.0001	4.1445	0.0000	0.0016	0.0001	0.0001	0.0000	0.0519	0.0024
Samples	Final pH	Mg	Mn	Mo	Na	Ni	Sb	Se	Sn	Sr	Pb	V	Zn	SO4
D20	5.9	0.7666	0.0002	0.0001	0.6818	0.0000	0.0002	0.0001	0.0000	0.0556	0.0000	0.0012	0.0003	8.2654
D21	7.0	1.0858	0.0005	0.0009	0.5081	0.0000	0.0003	0.0004	0.0000	0.0282	0.0000	0.0029	0.0002	3.8110
D22	6.0	0.7246	0.0002	0.0001	0.7262	0.0000	0.0002	0.0001	0.0000	0.0435	0.0000	0.0018	0.0002	3.9146
D23	7.5	0.9743	0.0005	0.0010	0.5367	0.0000	0.0003	0.0004	0.0000	0.0343	0.0000	0.0029	0.0002	4.0887

Table 7. ABA data - Constituents released due to acidification (H₂SO₄) in kg/t

Samples	Final pH	Ag	Al	As	Ba	Be	Ca	Cd	Cr	Co	Cu	Fe	K	Li
D20	1.8	0.0000	12.6273	0.0014	0.0008	0.0005	5.9939	0.0000	0.0037	0.0005	0.0042	8.6524	0.3893	0.0123
D21	1.7	0.0000	11.7095	0.0010	0.0011	0.0007	6.6416	0.0001	0.0104	0.0007	0.0051	1.8847	0.1901	0.0110
D22	1.7	0.0000	14.8800	0.0033	0.0009	0.0007	5.9817	0.0001	0.0063	0.0007	0.0060	3.8205	0.3199	0.0140
D23	1.5	0.0000	9.5092	0.0075	0.0012	0.0007	6.5544	0.0001	0.0095	0.0007	0.0046	1.5042	0.1509	0.0098
Samples	Final pH	Mg	Mn	Mo	Na	Ni	Sb	Se	Sn	Sr	Pb	V	Zn	SO4
D20	1.8	5.1800	0.0796	0.0000	0.5620	0.0019	0.0008	0.0000	0.0000	0.2312	0.0010	0.0057	0.0044	0.0000
D21	1.7	4.8700	0.1332	0.0000	0.2057	0.0013	0.0004	0.0002	0.0000	0.1723	0.0008	0.0140	0.0084	0.0000
D22	1.7	6.3200	0.0811	0.0000	0.6646	0.0014	0.0012	0.0000	0.0000	0.2563	0.0009	0.0091	0.0076	0.0000
D23	1.5	4.1100	0.1320	0.0000	0.1943	0.0002	0.0010	0.0001	0.0000	0.1876	0.0008	0.0121	0.0046	0.0000

Table 8. Acid/base calculations (kg/t CaCO₃ where applicable)

Samples	Initial pH	Final pH	Acid Potential ¹ (Open System)	Acid Potential ¹ (Closed System)	Base Potential	*NNP (Open)	*NNP (Closed)
D20	9.05	5.85	8.6098	17.2195	86.3592	77.7494	69.1397
D21	12.66	7.03	3.9698	7.9396	70.1043	66.1345	62.1646
D22	9.3	5.95	4.0777	8.1555	98.1769	94.0991	90.0214
D23	12.98	7.45	4.2591	8.5181	73.2958	69.0367	64.7777

*(NNP) Net Neutralising Potential

¹Caid Potential in KG/t CaCO₂

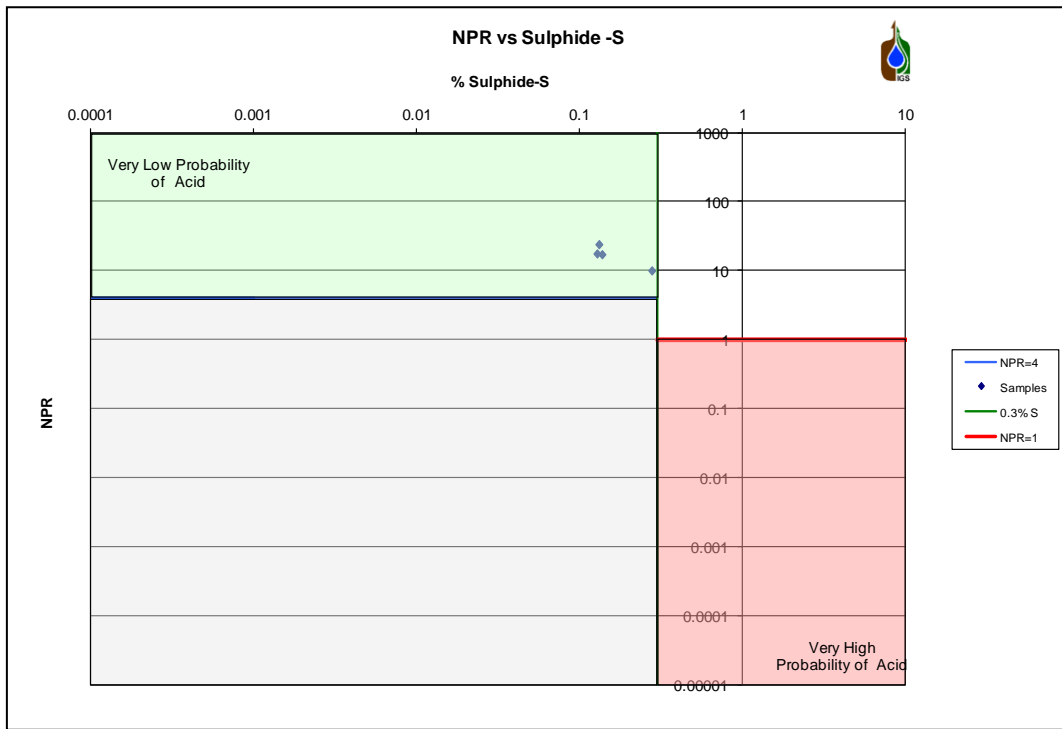


Figure 12. Neutralising Potential Ratio versus Sulphide (S)

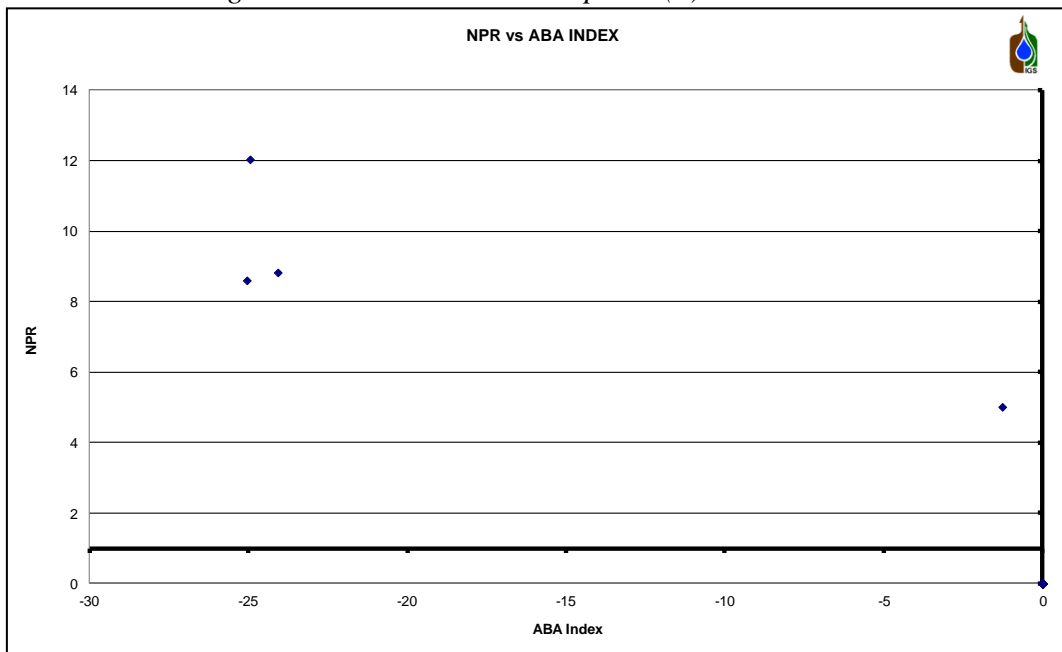


Figure 13. Neutralising Potential Ratio versus Acid/Base Accounting Index

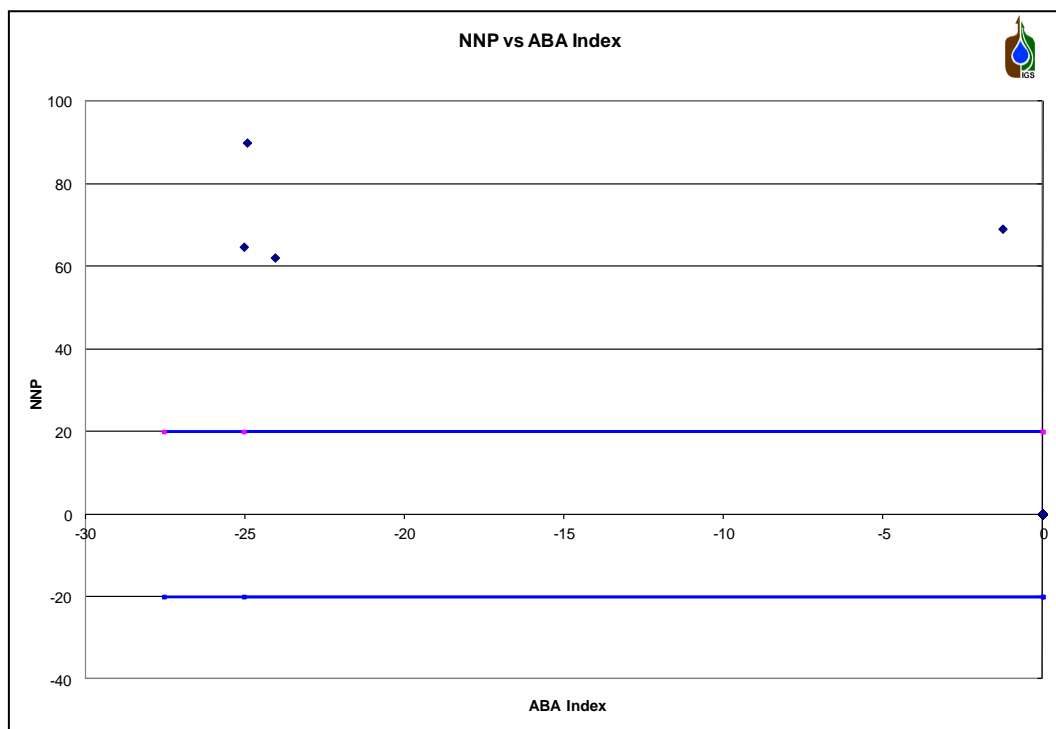


Figure 14. Net Neutralising Potential versus Acid/Base Accounting Index

3.3.1 Discussion

From the results in Table 3, Table 4 as well as the graphs in Figure 9, Figure 10 and Figure 11 the following observations can be made:

According to the pH values, none of the samples poses a risk for acid generation. All of the samples have positive NNP values and are therefore unlikely to be acid generating. These observations are confirmed by the NPR values indicated on Figure 11. All the samples plot below the 4:1 line (green solid line) and are therefore not acid generating.

The neutralising potential of the ash is very high and are able to buffer oxidation and acidification where the potential of acidification exist.

Although the information in Table 3 and the graphs in Figure 9 to Figure 11 seem to suggest that a closed system will have a larger detrimental impact in terms of acid generation, it is important to notice that no oxygen can enter a closed system to oxidise the ferrous iron to ferric iron (**Reaction 2**). The oxidation of sulphides in a closed system will therefore only continue until all the ferric iron in solution is consumed (**Reaction 4**). In the long run the environmental impact of an open system will therefore be more severe, since a constant supply of oxygen will be available to oxidise the sulphides and the ferrous iron (**Reactions 1 and 2**) thus forming ferric iron that can further oxidise the sulphides (**Reaction 4**).

3.4 X-Ray De-fraction and X-Ray frequency (XRF)

XRF and XRD analyses were performed at the Geology Department at the University of the Free State.

Major elements were analysed on a glass bead made from the powdered sample fused with lithium tetraborate using an automatic XRF spectrometer. The major elements are determined as oxide equivalents. They are: Al, Ca, Fe, K, Mg, Mn, Na, P, Si, Ti.

XRF determination of the ash reveals only the chemical constituents SiO₂ (Average 54.03%) and Al₂O₃ (Average 27.04%), which suggests that the tailings is perhaps best termed an Al silicate (Table 10). The Fe₂O₃ content of the ash is on average 7.61%, which suggests that due to the fact that the ash are reworked some oxidation has already taken place. The CaO % is at an average of 5.91%.

Table 9. Results of XRF analysis of samples.

Sample ID	XRF Analyses of samples - Oxides Wt (%)			
Analysis	D20	D21	D22	D23
SiO ₂	50.29	55.33	54.4	56.11
Al ₂ O ₃	20.46	31.54	25.64	30.53
Fe ₂ O ₃	16.62	3.75	6.88	3.19
MnO	0.04	0.05	0.03	0.05
MgO	2.21	1.75	1.99	1.33
CaO	7.2	4.93	6.64	4.87
Na ₂ O	0.29	0.09	0.36	0.07
K ₂ O	0.83	0.74	1.01	0.8
TiO ₂	1.02	1.79	1.35	1.75
P ₂ O ₅	0.50	0.55	0.61	0.52
Total	99.45	100.52	98.91	99.22

The results from the XRD (Refer to Table 10) shows that due to the presence of Mullite (silicate mineral (Al₆Al₂O₁₃)) Quarts (silicate mineral (SiO₂)), Piroxene (inosilicate mineral (Si,Al)₂O₆) and Calcite (Carbonate mineral (CaCO₃)) in almost all the samples acidification is unlikely to happen due to excess amounts of CaO available to buffer oxidation and prevent acidification.

Table 10. Results of XRD analysis of samples.

XRD	Dominant mineral (>50%)	Major minerals (20-50%)	Minor minerals (10-20%)	Accessory minerals (2-10%)	Rare minerals (<2%)
D20	Quartz	-	Mullite, pyroxene	Calcite, Magnetite	-
D21	-	Mullite, quartz	Pyroxene	Calcite	-
D22	-	Quartz, mullite	Pyroxene	Calcite	-
D23	Mullite	Quartz	Pyroxene	-	-

4 UNSATURATED ZONE SOIL CHARACTERISTICS

Eighteen auger holes were drilled to obtain natural soil samples for the determination of the soil properties in the area under investigation. The localities of all the auger holes are plotted on the map in **Figure 15**.

During a previous investigation conducted by GHT Consulting Scientists six auger holes were drilled in October 2010 on the ash stack perimeter to depths between 1.5 m and 2.0 m. These holes were lined with perforated PVC casing and concreted plinths were cast around the holes to minimise the inflow of surface water. The holes were also sealed with lockable caps.

On the 8 March 2012, twelve auger holes were drilled until the depth of refusal or maximum machine operating depth had been reached and representative disturbed samples taken for analyses.

All the soil samples obtained during both drilling phases were sent to a laboratory for sieve analyses. The permeabilities were calculated from the sieve analyses. All the information related to the different auger holes are summarized in Table 11.

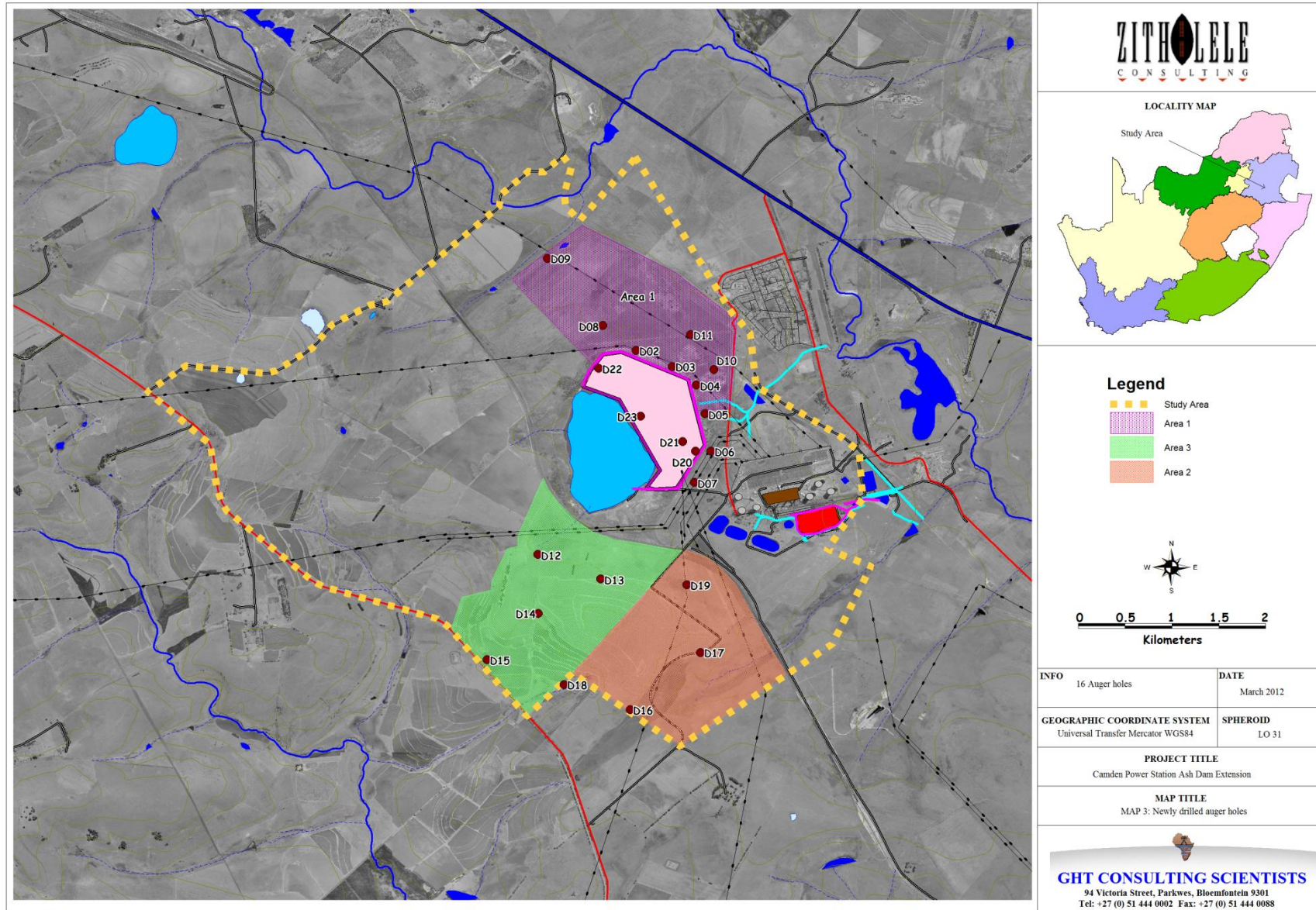


Figure 15. Auger hole location Map

4.1 Unsaturated soil aquifer profile logging.

Table 11. Auger hole information of soil samples.

Sites	Sample No	Longitude oE	Latitude oS	Elevation mamsl	Hole Diam (mm)	Sample Depth (m)	Hole Depth (m)	Water Level m bgl	In Situ Field Moisture (%)	Formation End of Hole	Description
Top Soil Profiles - Current Ash Dam Perim											
D02	A01A	30.07425°	-26.60509°	1675	90	0 - 0.5	1.5	0.21	23.1	Rock	Yellow Brown Sand.
	A01B					0.5 - 1.5			20.0		Brown Silty Sand.
D03	A02A	30.07813°	-26.60685°	1676	90	0 - 0.5	1.8	0.38	20.3	Soil	Dark Brown Sand.
	A02B					0.5 - 1.8			11.6		Yellow Brown Sand.
D04	A03A	30.08072°	-26.60882°	1673	90	0 - 1.7	1.7	0.53	30.6	Rock	Dark Brown Clayey Sand and Calcrete.
D05	A04A	30.08167°	-26.61192°	1670	90	0 - 0.5	1.8	0.25	24.6	Soil	Dark Brown Clayey Sand and Calcrete.
	A04B					0.5 - 1.8			23.4		Dark Brown Clayey Sand and Ferricrete.
D06	A05A	30.0823°	-26.61594°	1672	90	0 - 0.5	2.0	0.81	11.3	Soil	Olive Brown Sand.
	A05B					0.5 - 2.0			17.1		Yellow Brown Olive Ferricrete.
D07	A06A	30.08052°	-26.61927°	1674	90	0 - 0.5	1.8	1.32	18.8	Rock	Yellow Brown Ferricrete.
	A06B					0.5 - 1.8			20.2		Light Brown Sand and Calcrete.
Top Soil Profiles - Candidate Site 1											
D08	WP38	30.07068	-26.60243	1680	90	0 - 1.5	1.5	~	12.0	Rock	Slightly moist brown clayey sand.
D09	WP39	30.06473	-26.59525	1663	90	0 - 0.8	0.8	~	9.6	Rock	Slightly moist dark brown clayey sand.
D10	WP57	30.08474	-26.60308	1674	90	0 - 1	1	~	5.5	Rock	Slightly moist brown clayey sand.
D11	WP58	30.08010	-26.60343	1676	90	0 - 0.8	0.8	~	6.5	Rock	Dry brown clayey sand.
Top Soil Profiles - Candidate Site 2											
D12	WP44	30.06372	-26.62700	1702	90	0 - 2	2	~	15.9	Soil	Slightly moist red brown clayey sand.
D13	WP45	30.07047	-26.62963	1704	90	0 - 1.1	1.1	~	12.8	Rock	Slightly moist red brown clayey sand.
D14	WP46	30.06375	-26.63335	1704	90	0 - 0.9	0.9	~	10.5	Rock	Slightly moist light red brown clayey sand.
D15	WP47	30.05826	-26.6383	1686	90	0 - 2	2	~	20.1	Soil	Slightly moist dark red brown clayey sand.
Top Soil Profiles - Candidate Site 3											
D16	WP48	30.07363	-26.64368	1698	90	0 - 1	1	~	8.7	Rock	Moist dark brown clayey sand with vegetation.
D17	WP49	30.08119	-26.63756	1690	90	0 - 1.5	1.5	~	20.9	Rock	Moist red brown clayey sand with vegetation.
D18	WP50	30.06651	-26.64098	1681	90	0 - 1.3	1.3	~	37.0	Rock	Moist dark brown clay.
D19	WP52	30.07970	-26.63028	1682	90	0 - 2	2	~	29.7	Soil	Wet dark black sandy silt.

Profile logging and laboratory results indicate that a surficial covering, with an average depth of 1.5 m, of clayey sand (SC) of low plasticity occurs across all the candidate sites, and suggest that respective units have consistent physical characteristics across the area. Organic material, consisting predominantly of grass and crop stubble, was apparently restricted to the surficial soil unit, while the underlying material had a mottled appearance and appeared to be in situ weathered dolerite and sandstone. Field observations suggest that site soils are prone erosion, particularly in areas where surface flow is concentrated.

Particle Size Analyses and Plasticity Index and Linear Shrinkage tests confirm that the sand units are consistent in character across the area. While the percentage clay fraction (<0.002mm) is generally below 15%. This may be because this soil is still forming in response to the in situ weathering of Karoo sediments, and hence is relatively immature.

The in situ field moisture of tested disturbed samples varied between 5 % and 30%. Water was only encountered in the auger holes drilled closed to the current ash dam. No water was present in

the auger holes drilled further away at the candidate sites during the field investigation. All the holes were drilled to a depth of approximately one to two meters.

The unsaturated zone thickness in the vicinity of the current ash dam is in most cases less than 0.5 metres which is an indication of the influence of the ashing facility on the shallow perched aquifer in the direct vicinity of the ash stack.

4.2 Determination of the hydraulic conductivity of the unsaturated soil aquifer.

Hydraulic conductivity is defined as the volume of water that will move through a unit time under a unit hydraulic gradient through a unit area angles to the direction of flow. Hydraulic conductivity is usually measured in unit distance and unit time for instance, meters a day (m/d).

The permeabilities and porosities were calculated from the sieve analyses results and presented in Table 12 and Appendix A. The hydraulic conductivity for all of the soil samples was calculated by means of the Shephard (1989) and Rawls & Brakensiek (1985) methods. The porosities were calculated using the Brooks & Corey method. Table 12 indicates the averages and geometric means of the different soil properties for the areas investigated. The geometric means was used for the aquifer classification due to the differences of hydraulic conductivities of the various samples.

The results of the permeabilities calculated by means of sieve analyses indicate that most of the sites investigated have a relatively low permeabilities:

- Top soil current ash dam area – 2.8 m/d.
- Top soil Candidate Site 1 – 4.2 m/d.
- Top soil Candidate Site 2 – 1.5 m/d.
- Top soil Candidate Site 3 – 1.3 m/d.

Porosities for overlying soil profiles were calculated from the sieve analyses results with the Brooks & Corey method. These porosities are between 40% – 55%.

Field estimates of hydraulic gradient for respective sites, the Darcy flux and seepage velocities calculations as well as the pollution migration distances, for each gradient are presented in Table 12 and Table 13.

Table 12. Soil properties calculated from sieve analyses results of soil samples.

Sites	Sample Depth (m)	K m/d	K m/s	Dh/Dl	Porosity (%)	Seepage Velocity m/s	Seepage Velocity m/d	Seepage Velocity m/year	Formation Tested
Top Soil Properties - Current Ash Dam									
D02	0 - 0.5	2.633	3.047E-05	0.006	51%	3.735E-07	0.0323	11.78	Yellow Brown Sand.
	0.5 - 1.5	3.194	3.696E-05	0.006	50%	4.620E-07	0.0399	14.57	Brown Silty Sand.
D03	0 - 0.5	5.119	5.925E-05	0.006	56%	6.613E-07	0.0571	20.85	Dark Brown Sand.
	0.5 - 1.8	5.836	6.755E-05	0.006	56%	7.539E-07	0.0651	23.77	Yellow Brown Sand.
D04	0 - 1.7	1.721	1.992E-05	0.020	51%	7.811E-07	0.0675	24.63	Dark Brown Clayey Sand and Calcrete.
D05	0 - 0.5	0.760	8.796E-06	0.020	48%	3.665E-07	0.0317	11.56	Dark Brown Clayey Sand and Calcrete.
	0.5 - 1.8	0.951	1.101E-05	0.020	50%	4.404E-07	0.0380	13.89	Dark Brown Clayey Sand and Ferricrete.
D06	0 - 0.5	2.418	2.799E-05	0.020	55%	1.021E-06	0.0883	32.21	Olive Brown Sand.
	0.5 - 2.0	2.471	2.860E-05	0.020	55%	1.044E-06	0.0902	32.91	Yellow Brown Olive Ferricrete.
D07	0 - 0.5	2.738	3.169E-05	0.010	55%	5.782E-07	0.0500	18.23	Yellow Brown Ferricrete.
	0.5 - 1.8	3.069	3.553E-05	0.010	55%	6.459E-07	0.0558	20.37	Light Brown Sand and Calcrete.
(Average) Upper Range		2.810	3.252E-05	0.013	53%	6.480E-07	0.0560	20.44	
(Geometric mean) Lower Range		2.407	2.786E-05	0.012	53%	6.096E-07	0.0527	19.22	
Top Soil Properties - Candidate Site 1									
D08	0 - 1.5	3.4670	4.013E-05	0.013	52%	1.029E-06	0.0889	32.4476	Slightly moist brown clayey sand.
D09	0 - 0.8	3.1965	3.700E-05	0.020	49%	1.510E-06	0.1305	47.6213	Slightly moist dark brown clayey sand.
D10	0 - 1	4.2885	4.964E-05	0.041	54%	3.726E-06	0.3220	117.5152	Slightly moist brown clayey sand.
D11	0 - 0.8	5.8880	6.815E-05	0.018	58%	2.098E-06	0.1813	66.1675	Dry brown clayey sand.
(Average) Upper Range		4.210	4.873E-05	0.023	53%	2.091E-06	0.1807	65.94	
(Geometric mean) Lower Range		4.090	4.734E-05	0.021	53%	1.867E-06	0.1613	58.87	
Top Soil Properties - Candidate Site 2									
D12	0 - 2	0.7148	8.273E-06	0.063	51%	1.014E-06	0.0876	31.9733	Slightly moist red brown clayey sand.
D13	0 - 1.1	1.5498	1.794E-05	0.038	50%	1.345E-06	0.1162	42.4258	Slightly moist red brown clayey sand.
D14	0 - 0.9	2.7557	3.189E-05	0.033	55%	1.891E-06	0.1634	59.6342	Slightly moist light red brown clayey sand.
D15	0 - 2	1.0037	1.162E-05	0.040	49%	9.483E-07	0.0819	29.9062	Slightly moist dark red brown clayey sand.
(Average) Upper Range		1.506	1.743E-05	0.043	51%	1.300E-06	0.1123	40.98	
(Geometric mean) Lower Range		1.323	1.531E-05	0.042	51%	1.251E-06	0.1081	39.44	
Top Soil Properties - Candidate Site 3									
D16	0 - 1	4.0606	4.700E-05	0.038	53%	3.411E-06	0.2947	107.5558	Moist dark brown clayey sand with vegetation.
D17	0 - 1.5	0.5654	6.544E-06	0.055	36%	9.915E-07	0.0857	31.2683	Moist red brown clayey sand with vegetation.
D18	0 - 1.3	0.0319	3.692E-07	0.031	34%	3.394E-08	0.0029	1.0702	Moist dark brown clay.
D19	0 - 2	0.4975	5.758E-06	0.018	47%	2.188E-07	0.0189	6.8992	Wet dark black sandy silt.
(Average) Upper Range		1.289	1.492E-05	0.036	43%	1.164E-06	0.1005	36.70	
(Geometric mean) Lower Range		0.437	5.057E-06	0.033	42%	3.981E-07	0.0344	12.55	

The Darcy flux [V (m/d)] and seepage velocities [Vs (m/d)] of potential contaminants were calculated by using the following equations. The Darcy flux and seepage velocities calculations as well as the pollution migration distances for each gradient are presented in Table 13.

$$V = Ki \quad \text{Equation 1}$$

where;

V = Darcy Velocity or Flux

K = Hydraulic Conductivity

i = Hydraulic Gradient

$$V_s = \frac{V}{n_e} \quad \text{Equation 2}$$

where;

Vs = Seepage Velocity

$V = \text{Darcy Velocity or Flux}$

$n_e = \text{Effective Porosity}$

Table 13. Seepage velocity over different time steps.

Site	Pollution Migration (Lower Range) meters 1 Year	Pollution Migration (Upper Range) meters 1 Year	Pollution Migration (Lower Range) meters 5 Year	Pollution Migration (Upper Range) meters 5 Year	Pollution Migration (Lower Range) meters 10 Year	Pollution Migration (Upper Range) meters 10 Year
Top Soil Properties - Current Ash Dam	19	20	96	102	192	204
Top Soil Properties - Candidate Site 1	59	66	294	330	589	659
Top Soil Properties - Candidate Site 2	39	41	197	205	394	410
Top Soil Properties - Candidate Site 3	13	37	63	183	126	367

It is expected that potential pollutants from the ash stack will migrate relatively quickly through the unsaturated zone due to the moderate permeabilities and to a lesser extent the thickness of the zone and therefore increases the aquifer vulnerability of the shallow perched aquifer. Trenches can be constructed around the ashing facility to minimise the spreading of pollutants through the shallow perched aquifer. The shallow perched aquifer serves as recharge zone along preferential pathways for the deep exploitable aquifer (aquifer that can be utilised for production purposes). However the hydrochemical data gathered during the last two decades from the deep aquifer in the vicinity of the ash stack shows no signs of pollution.

5 GEOLOGY

5.1 General geology

The site falls within the Carboniferous to early Jurassic aged Karoo Basin, a geological feature that covers much of South Africa (Refer to **Figure 16**). Sediments in this part of Mpumalanga Province fall within the Permo-Triassic aged Northern facies of the Ecca Series, forming part of the Karoo sequence (Truswell, 1977). Sediments of the Vryheid formation comprise the local geology. The sediments of the Vryheid Formation were deposited in a fluvio-deltaic environment where swamps and marshes existed, in which peat accumulated. Shales, mudstones, siltstones and sandstones constitute the bulk of the formation, with interlayering of these sediments throughout. The coal seams have relatively high dirt content. Coal measures currently mined in the area form part of the Highveld Coal Field.

Late Triassic to Middle Jurassic aged Dolerite sills and feeder dykes are common in the Karoo Basin, which intruded the Vryheid Formation. Numerous minor faults, many of which are water bearing, interrupt the coal seams. Small fracture zones, which frequently are associated with the upper and lower contacts of sills, also are commonly water bearing, and occur throughout the power station area. Previous investigations identified the presence of a near surface, slightly weathered to fresh dolerite sill. The extent of the sill is, however, unknown.

Table 14. Table showing local lithological make up with chronological time constraints

Age	Sequence	Group	Subgroup	Formation	Symbol	Rocktypes (Sedimentary and Volcanic Rocks)	Rocktypes (Intrusive Rocks)	Surficial Deposit
Quaternary					Q			Alluvium, Scree and Ferricrete
Jurassic					Jd		Dolerite	
Permian	Karoo	Ecca		Vryheid	Pv	Grit, Sandstone, Shale, Coal Seam		

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.

The three candidate sites identified all fall within the sediments of the Vryheid Formation consisting of grit, sandstone, shale and coal seams. Dolerite intrusions form a major part of candidate site 2. Large sacrificial deposits of ferricrete are visible on the ground with outcrops visible on the north eastern side of candidate site 3.

5.2 Borehole Logs

All the boreholes used in this investigation, geological logs were discussed and plotted during previous investigations and are also available on a comprehensive database. The geological logs are attached in Appendix B.

Borehole B1 has been drilled in the upstream direction of the power station. The weathered sediments are quite thick, followed by shale with a reddish brown discoloration. This is followed by 4 m of weathered dolerite. At 16 m depth, the borehole enters into an unweathered dolerite sill of considerable thickness. Pollution from surface would therefore only penetrate to the top of the dolerite, where after it would be deflected laterally. The chemical profiles show that the borehole water is unpolluted. All values are in the range of what would be expected for natural groundwater in the area. This borehole therefore provides valuable information on the background groundwater quality for the Camden Area.

Boreholes B2 and B22 have been drilled to the south and south-east of the ash stack respectively to monitor seepage of ash water as well as migration of pollutants from a rehabilitated solid waste site and coal discard area to the southern side of the ash stack.

Borehole B2 has been drilled south of the ash stack in an area that is heavily polluted on surface. Previously, solid waste and coal discard have been disposed of around this area. The salinity in this borehole is high to very high, increasing with depth. The pH is low, decreasing with depth. The acidity is derived from oxidation of the pyrite in the coal discard. At these low pH-levels, the oxidation process is self-sustaining. This releases oxygen into the groundwater, which explains the high oxygen concentrations, even at great depth. The positive values for the redox potential of the water suggest strong oxidising conditions. The temperature is not significantly elevated, suggesting that the main oxidation process occurs outside the immediate vicinity of the borehole. This allows the groundwater to take on the temperature of the rock rather than that of the oxidation reactions.

Borehole B22 was originally intended to monitor the possible seepage of pollutants from the ash stack, rehabilitated solid waste site and coal discard area. Even though the weathering of the sediments extends down to 8 m in this area, the yield from this borehole is insignificant. Seepage, if any, would therefore be at a very low rate in this area.

Boreholes B3, B4, B19, B20 and B21 have been drilled to monitor possible seepage of ash water to the east of the ash dam along a natural drainage system.

Boreholes B19 and B21 were both drilled to shallow depths to intercept only the shallow perched aquifer on top of the shallow unweathered dolerite sill. The chemistry of these boreholes are therefore representative of the seepage water from the ashing facility. Water from the ash dam is moving through the soil and along the weathered dolerite. This flow will continue to pollute the groundwater in the upper horizon.

Borehole B20 was drilled only 4 m away from borehole B19. The shallow perched aquifer was sealed off with solid steel casing during borehole construction. The borehole was drilled to a depth of 76 m. The shallow unweathered dolerite sill (7-67 m) forces local artesian conditions and groundwater is flowing from this borehole. Water sampled from this borehole is therefore from the deep exploitable aquifer and according to the chemical results is unpolluted. It would almost be impossible for pollutants to penetrate into the sediments below this dolerite sill, because of the impermeable nature of the dolerite.

At borehole B3, the shallow unweathered dolerite sill (7-14 m) forces local artesian conditions, and groundwater has historically been flowing from this borehole. Currently, the groundwater level is still at the surface elevation. As was observed at boreholes B19 and B21 which is must closer to the ash stack the chemistry of the top 7 m is representative of the seepage water from the ashing facility. Water from the ash dam is thus moving through the soil and along the weathered dolerite. The groundwater quality in the upper horizon of this borehole is however clean. This can be ascribed to the relatively immobility of salts in the ash water, because of the initial high pH followed by precipitation of calcium carbonate. The conclusion is that power station fly ash does not pose an environmental risk under the alkaline conditions further than ± 800 m from the ash stack.

At borehole B4, penetration of pollutants is limited by the presence of the thick shale (from 2-18 m deep). It would almost be impossible for pollutants to penetrate into the sediments below this layer, because of the fine-grained nature of the shale. The hydrochemical profiling shows, as in the case of B3, that the aquifer is not polluted. No danger for pollution migration from the ash dam area therefore exists.

It can be deduced from the borehole logs, the area formed by B01, B02, B03, B04, B19, B20 and B21 is underlay by an unweathered dolerite sill at a relative depth of 7 to 32 mbgl and with thickness varying between from 9 m at B03 to 60 m at B20. This impermeable geological structure is most instances accomplished by another relative impermeable sedimentary deposit of shale occurring at a depth of between 2 m and 7 m. These two formations underlies most of the area east the ash dam complex forming an impermeable layer which assist in the containment of the polluted water. This impermeable area can further be extended to the area underneath boreholes B3, and B22 where sandstone is interlaced with shale. Some sandstone layers are however slightly weathered to course, which might result in preferred pathways for contaminants.

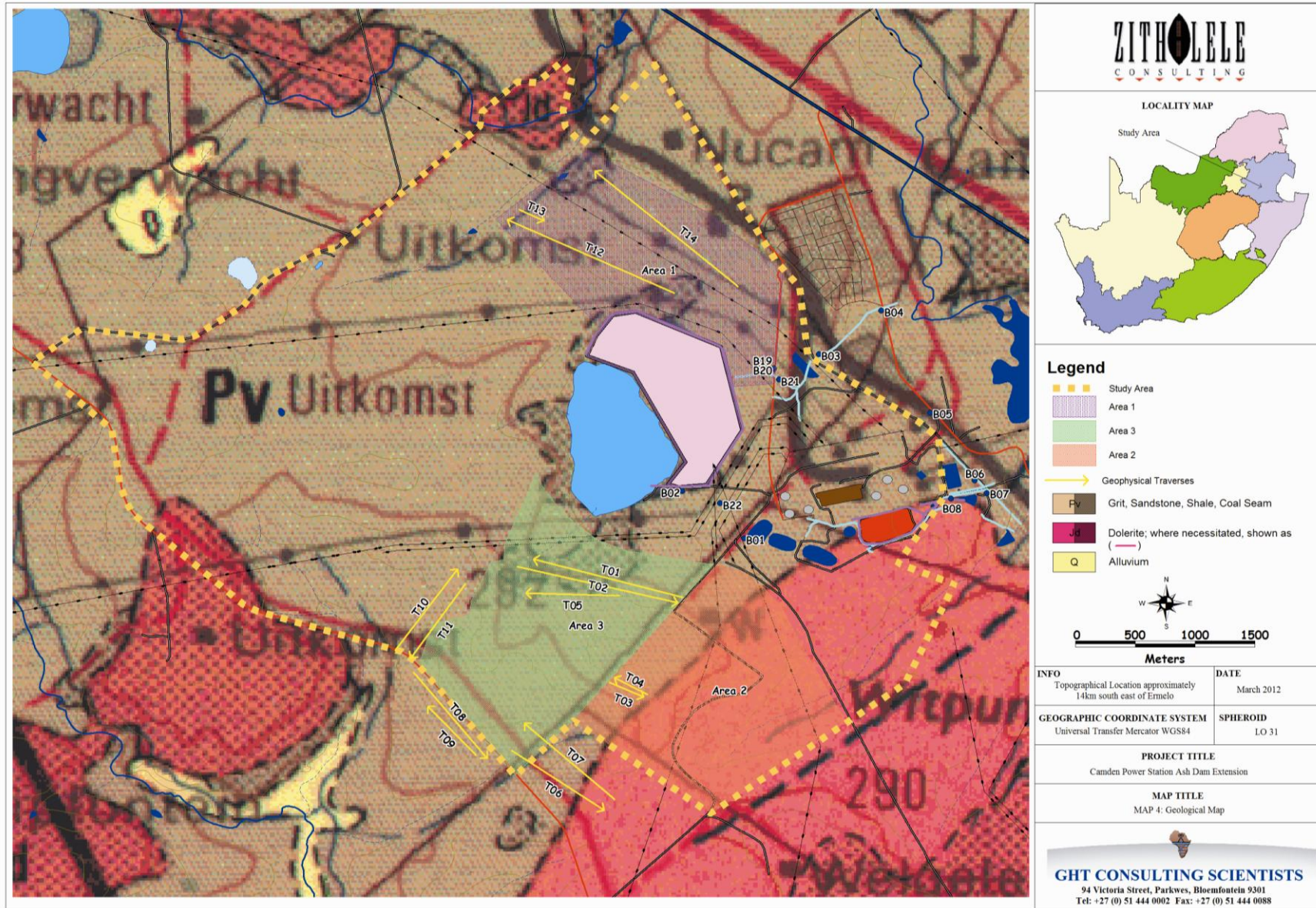


Figure 16. Geological Map with magnetic traverse.

5.3 Geophysical Investigation

This section includes the geophysical information obtained during the survey to detect possible geological features and structures, which may act as preferential pathways for groundwater flow and contaminant transport. During March 2012 GHT Consulting conducted magnetic surveys at three candidate sites considered for the extension of Camden Power Station Ash Dam. The aim of the magnetic survey was to detect and delineate magnetic structures within and near the sites that may form preferential pathways for groundwater migration and contaminant transport. The ash dam complex should ideally be placed at positions far removed from such structures.

5.3.1 Approach to the Magnetic Survey

As part of the magnetic survey at the selected sites, the following actions were taken:

- Study of ortho-photographs of the sites 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.
- Recording ground magnetic data along a number of traverses at each site.
- Process and interpreted the magnetic data in terms of the local geological and geohydrological conditions.
- Based on the interpretation of the geophysical data, detect and delineate magnetic structures within and near the site that may form preferential pathways for groundwater migration and contaminant transport.
- Indicate the most favourable position where the borehole should be drilled to monitor the pollution.

5.3.2 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.

5.3.3 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. Overlapping ortho-photographs covering the Candidate Sites are shown in **Figure 17**

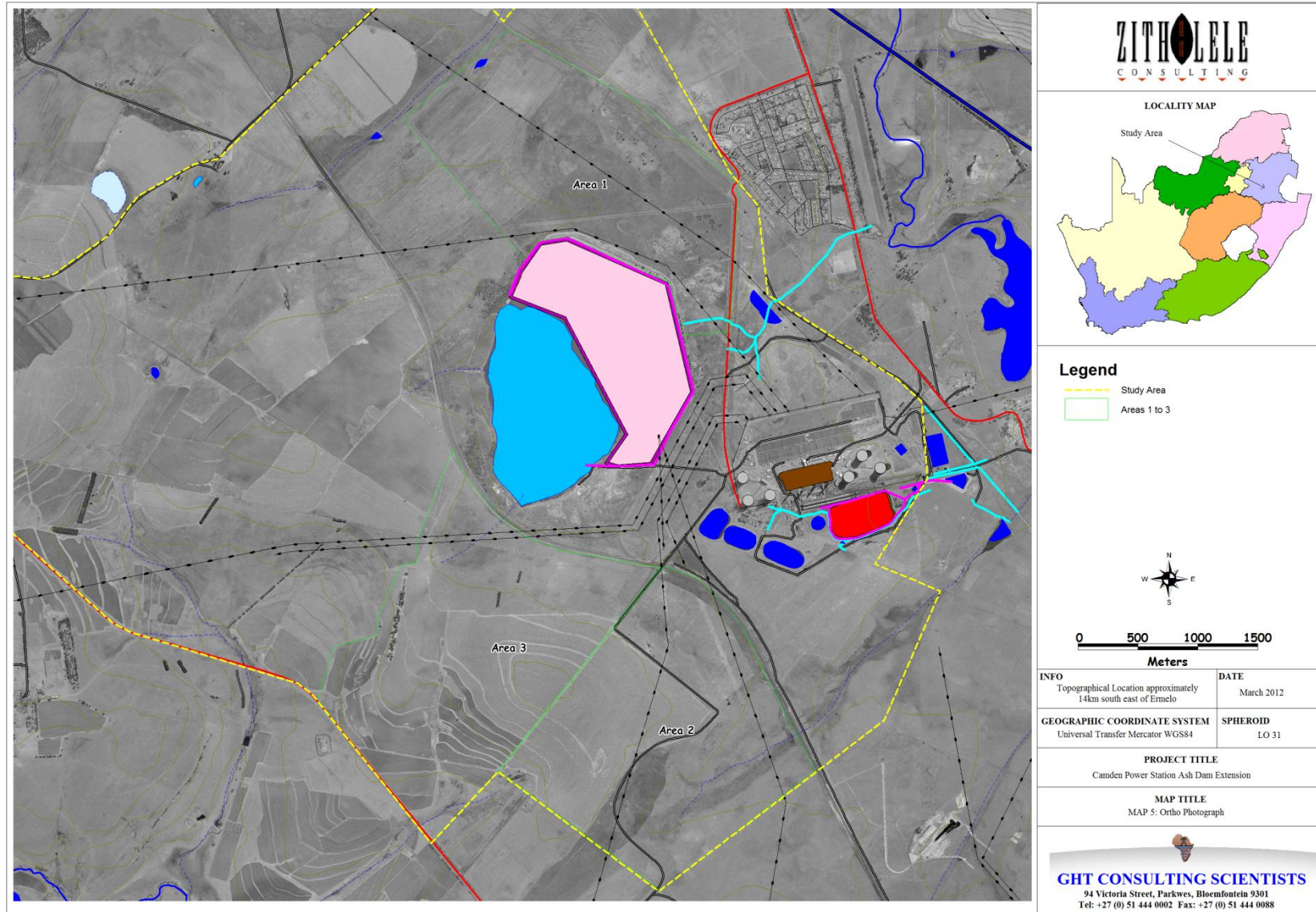


Figure 17. Ortho Photograph.

5.3.4 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 **Figure 18**. A large number of prominent magnetic lineaments may be identified in the vicinity of the three study areas. These lineaments predominantly have north-east / south-west strikes, although some features also display north-west / south-east strikes. These lineaments are in all likelihood due to large-scale magnetic dyke and sills on top of high topographical areas.

The green area on the aerial magnetic contour map denotes sedimentary rocks. Dolerite intrusions such as dykes and sill structures (red, yellow and purple areas of the map) are occurring in the vicinity of the areas under investigation.

Sedimentary rocks usually have low permeabilities (0.01 - 0.05 m/d) and storativity values (1 – 3%). Boreholes drilled into sedimentary rock formations are usually low yielding (0.1 - 0.5 L/s or 360 L/h – 1800 L/h) with the exception where bedding plane fractures are encountered within the sedimentary rocks or fractured baked contacts zones between the sedimentary rocks and magmatic dolerite intrusions such as dykes and sills.

The available aerial magnetic data available for the study area are of a low resolution, which brings about that the smaller dolerite dyke structures occurring within the area cannot be detected due to the spacing of the flight lines for the aerial magnetic survey. Therefore field geophysical survey was conducted at the proposed site to determine if smaller dolerite dyke structures do exist in the vicinity of the site.

5.4 Ground Magnetic Survey

The magnetic survey at the candidate sites were conducted by GHT Consulting using the G5 proton magnetometer manufactured by Geotron.

5.4.1 Candidate Site 1

Magnetic data were recorded along three traverses (T12, T13 and T14) with north-west / south-east strikes across Candidate Site 1. The positions of the four ground magnetic traverses relative to the candidate site are shown in **Figure 16**.

Profile plots of the ground magnetic data are presented in **Figure 19** to **Figure 21**. Large magnetic anomalies with amplitudes more than 700 nT were recorded along traverses T12 and T14, these anomalies appear due to intrusive dolerite bodies. These anomalies are likely to be a large dolerite sill.

From previous drilling phases in the area it was concluded that these sills are impermeable and that water are only encountered on the top of these sills approximately between 5 to 10 meter below surface. This shallow purged aquifer could not be used for water supply purposes due to the low yield and small amount of water stored in this aquifer.

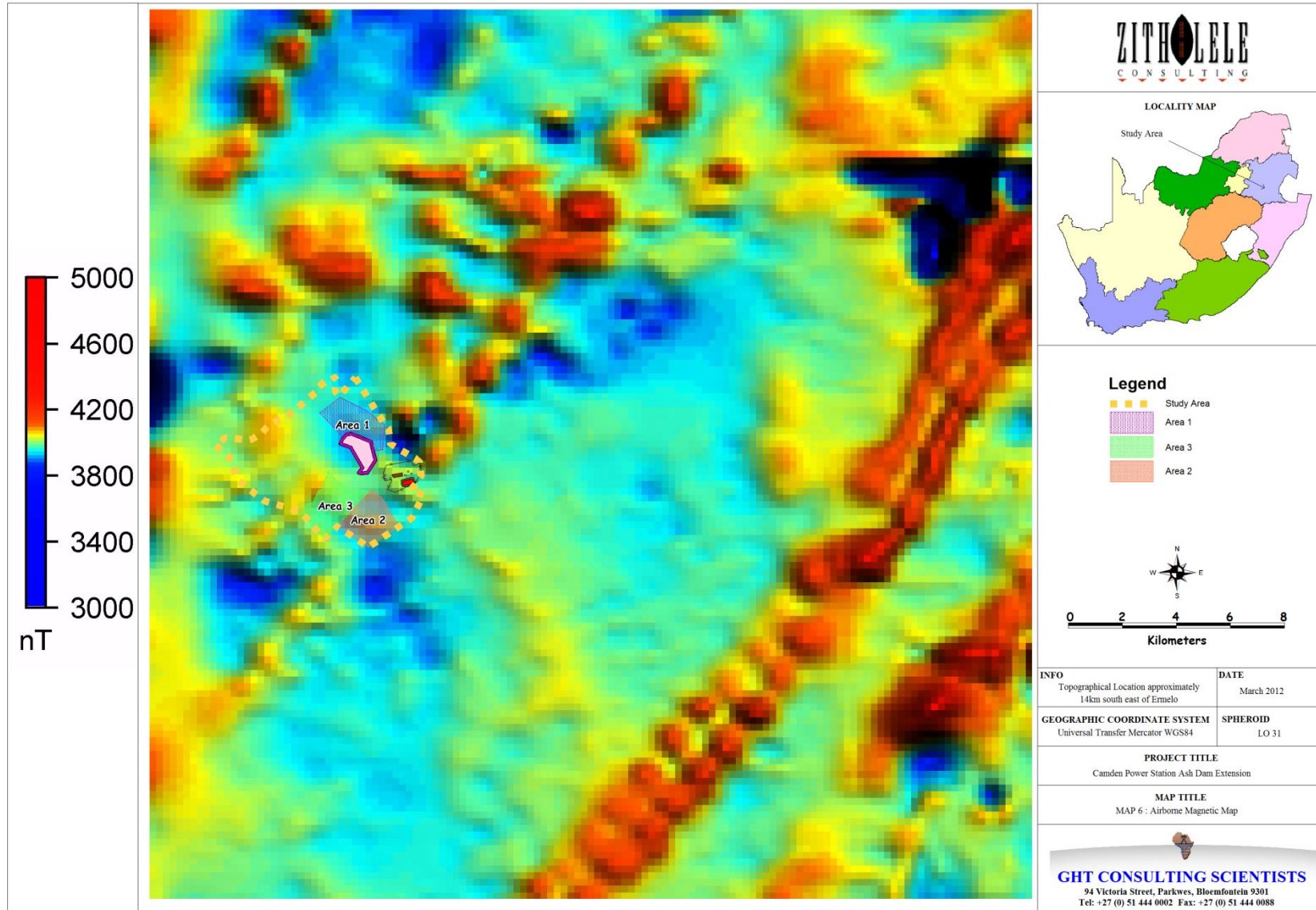


Figure 18. Airborne Magnetic Map

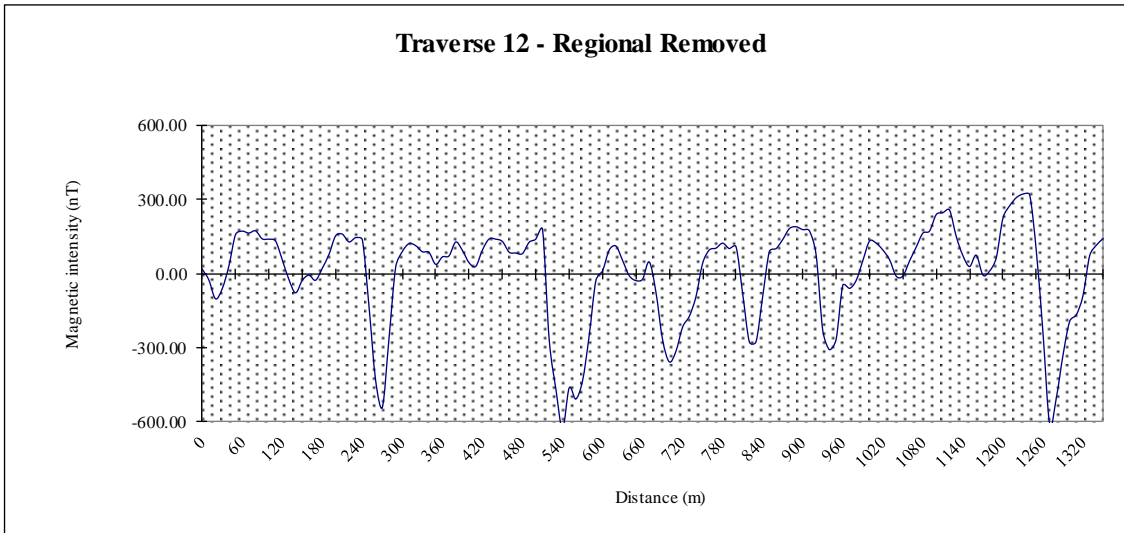


Figure 19. Magnetic profile along traverse T12.

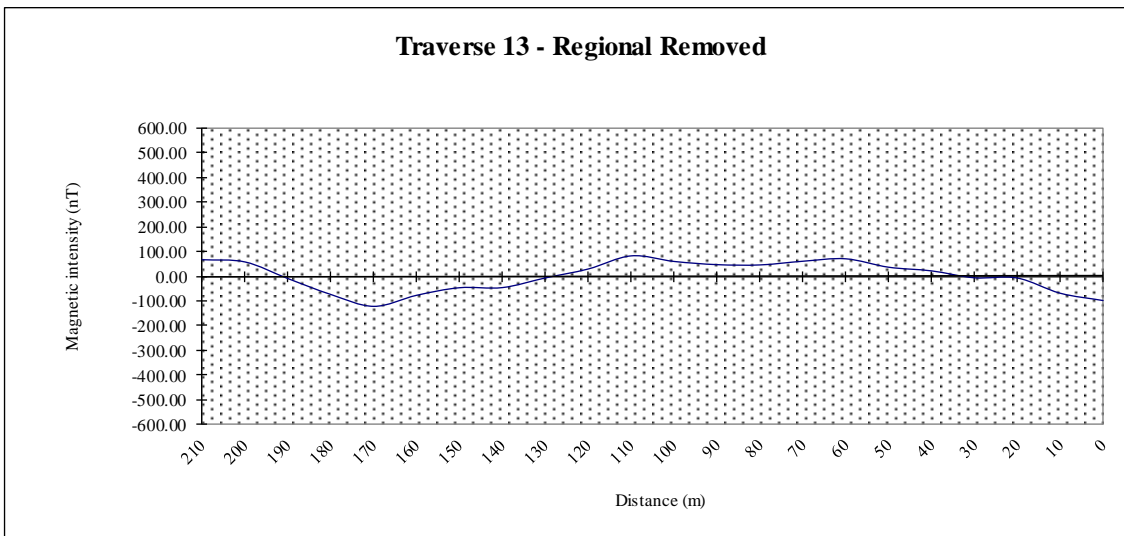


Figure 20. Magnetic profile along traverse T13.

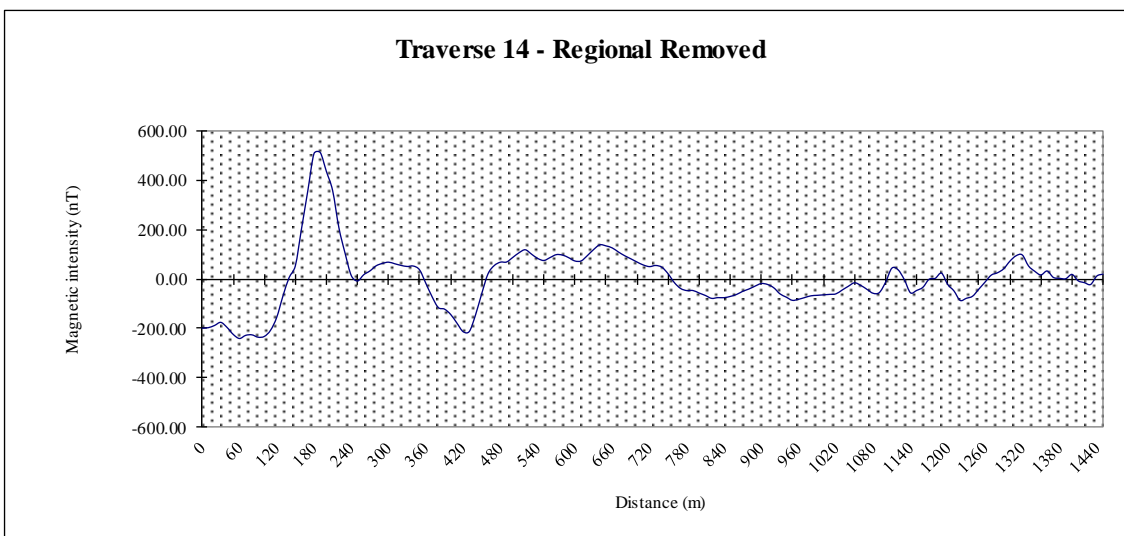


Figure 21. Magnetic profile along traverse T14.

5.4.2 Candidate Site 2

Magnetic data were recorded along four traverses (T03, T04, T06 and T08) with north-west / south-east strikes west en north-west of Candidate Site 2. The total area of Candidate Site 2 could not be covered due to the presence of power lines and other man made features in the area.

Large magnetic anomalies with amplitudes more than 700 nT were recorded along all the traverses, these anomalies appear due to intrusive dolerite bodies. These anomalies are likely to be a large dolerite sill.

From previous drilling phases in the area it was concluded that these sills are impermeable and that water are only encountered on the top of these sills approximately between 5 to 10 meter below surface. This shallow purged aquifer could not be used for water supply purposes due to the low yield and small amount of water stored in this aquifer.

The positions of the four ground magnetic traverses relative to the candidate site are shown in **Figure 16**. Profile plots of the ground magnetic data are presented in **Figure 22** to **Figure 25**.

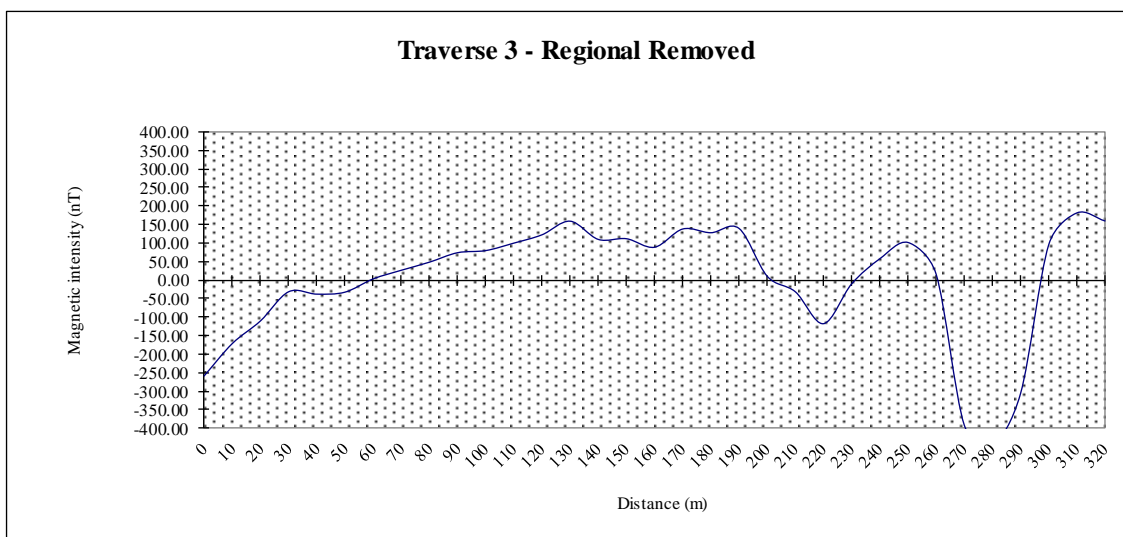


Figure 22. Magnetic profile along traverse T03.

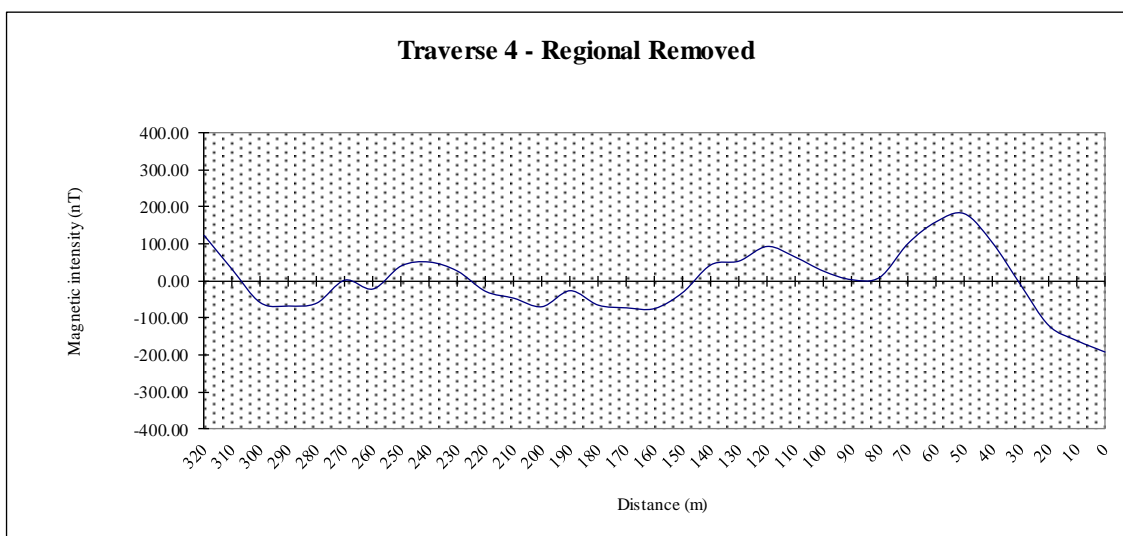


Figure 23. Magnetic profile along traverse T04.

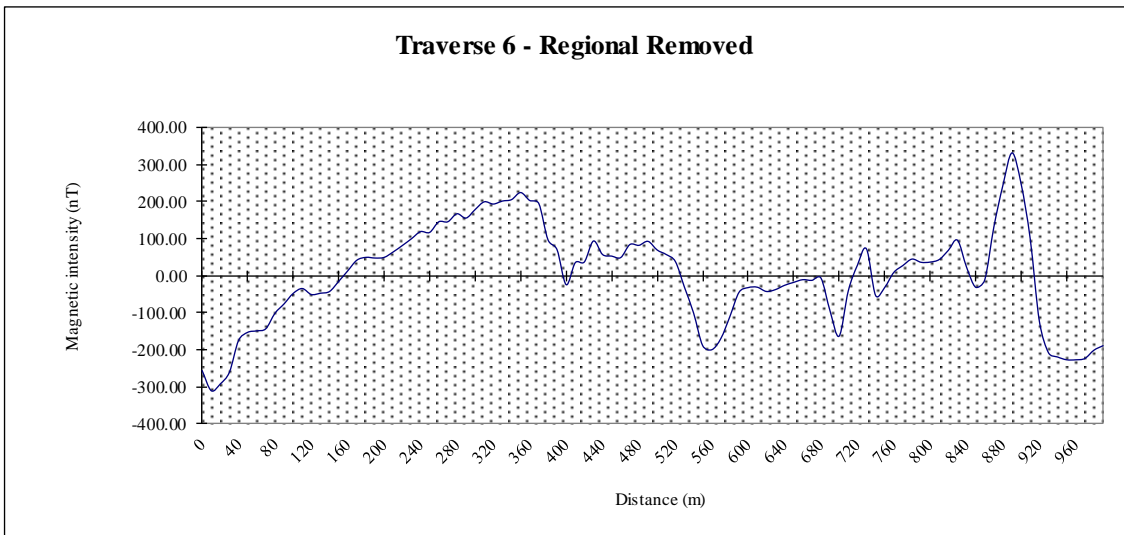


Figure 24. Magnetic profile along traverse T06.

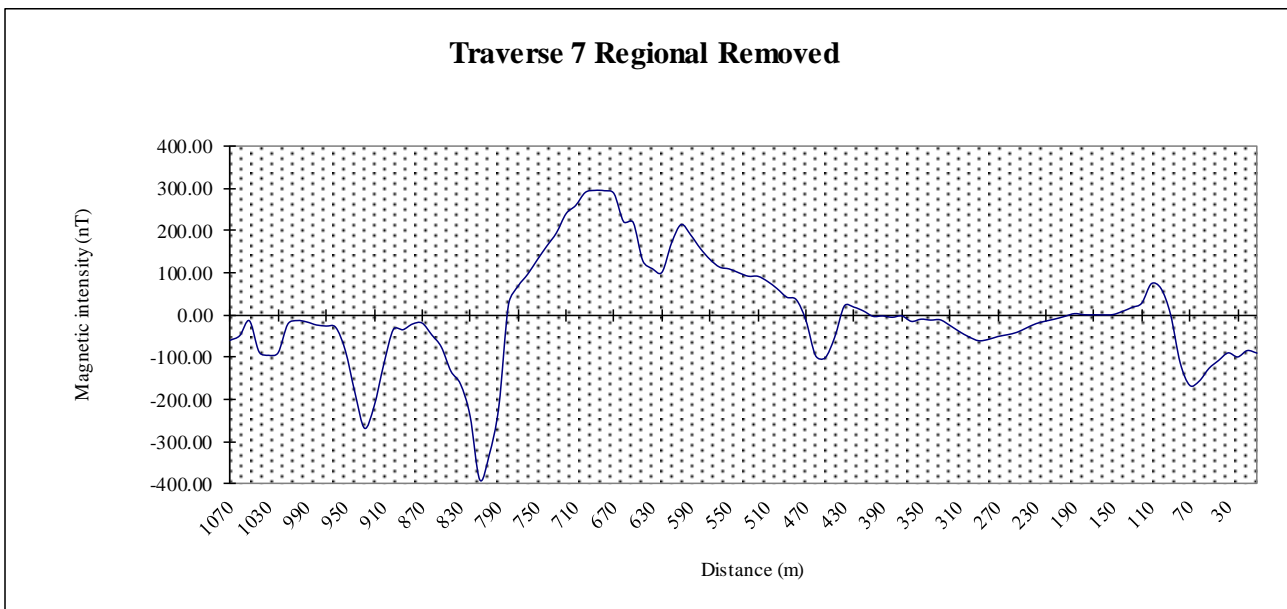


Figure 25. Magnetic profile along traverse T07.

5.4.3 Candidate Site 3

Magnetic data were recorded along seven traverses (T01, T02, T05, T08, T09, T10 and T011) with north-west / south-east and north-east / south-west strikes across the candidate site. The positions of the seven ground magnetic traverses relative to the candidate site are shown in **Figure 16**. Profile plots of the ground magnetic data are presented in **Figure 26** to **Figure 32**.

Large magnetic anomalies with amplitudes more than 700 nT were recorded along all the traverses, these anomalies appear due to intrusive dolerite bodies. These anomalies are likely to be a large dolerite sill.

From previous drilling phases in the area it was concluded that these sills are impermeable and that water are only encountered on the top of these sills approximately between 5 to 10 meter below surface. This shallow purged aquifer could not be used for water supply purposes due to the low yield and small amount of water stored in this aquifer.

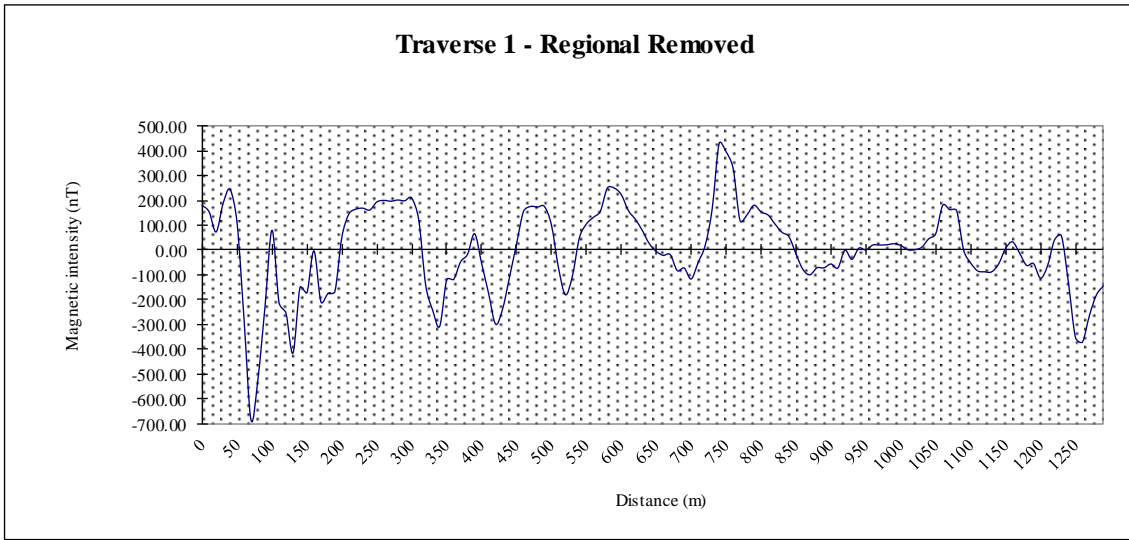


Figure 26. Magnetic profile along traverse T01.

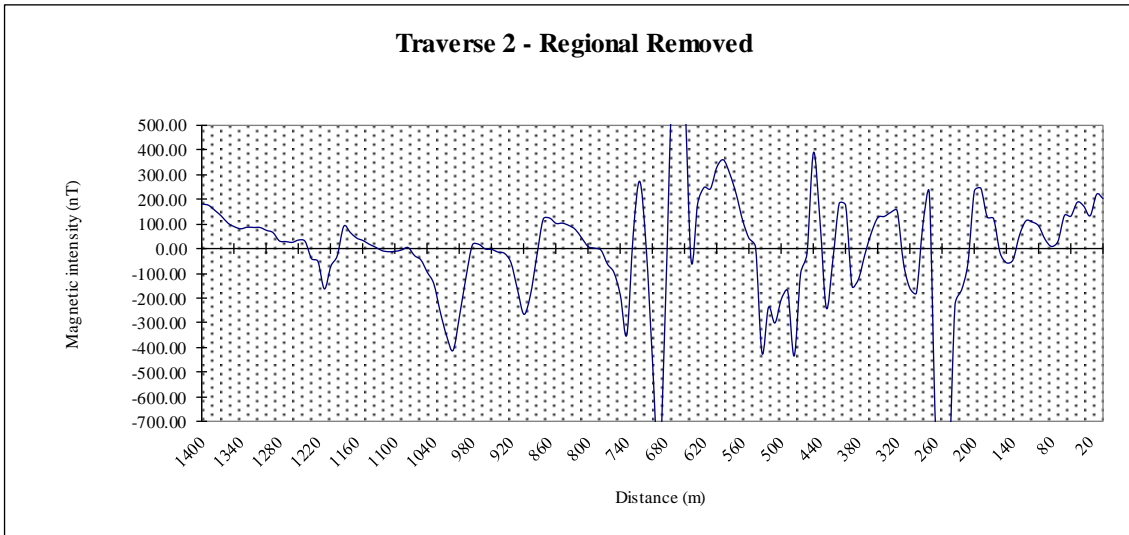


Figure 27. Magnetic profile along traverse T02.

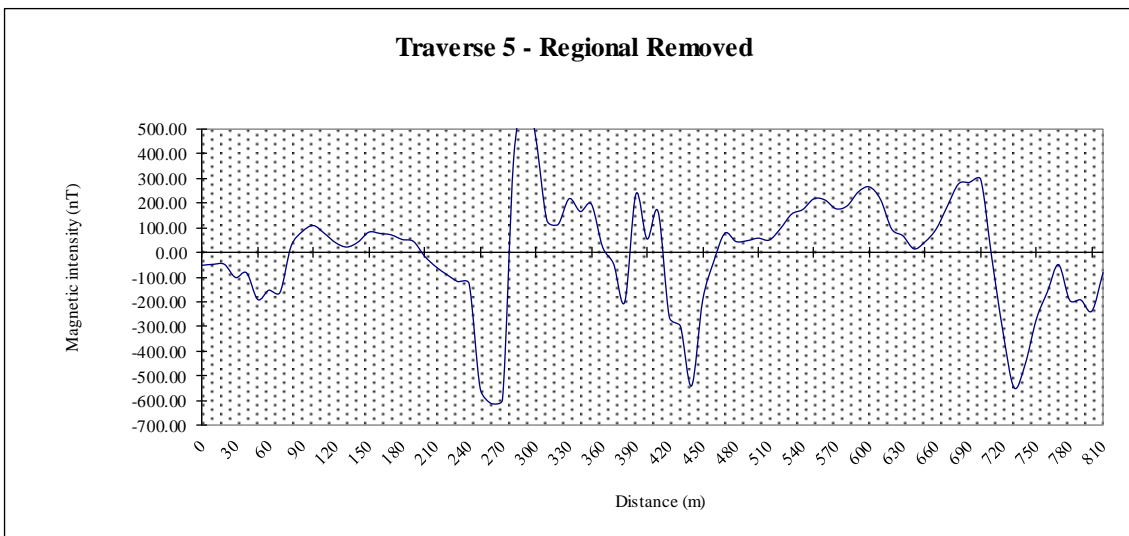


Figure 28. Magnetic profile along traverse T05.

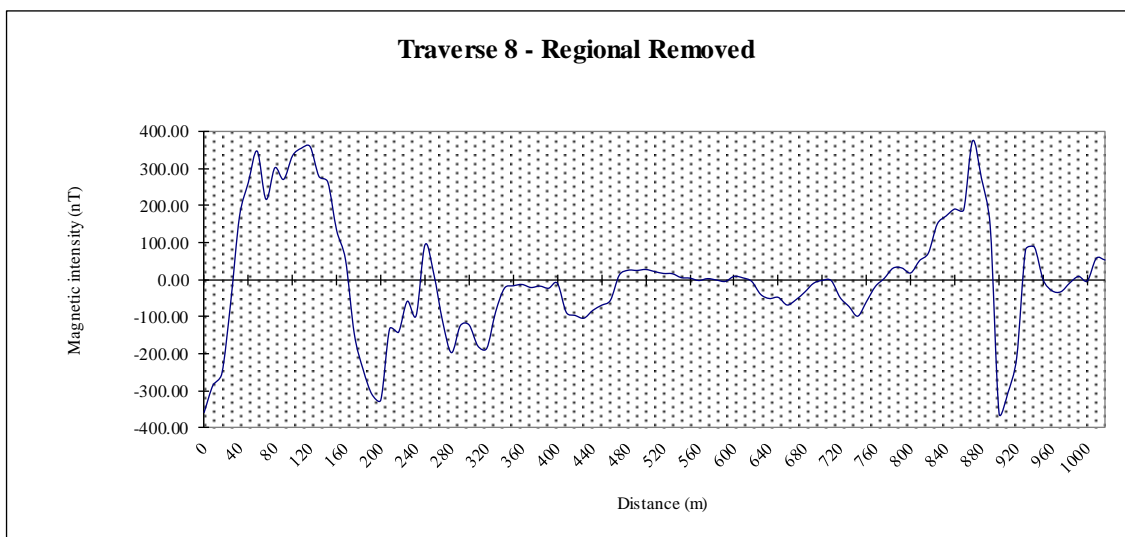


Figure 29. Magnetic profile along traverse T08.

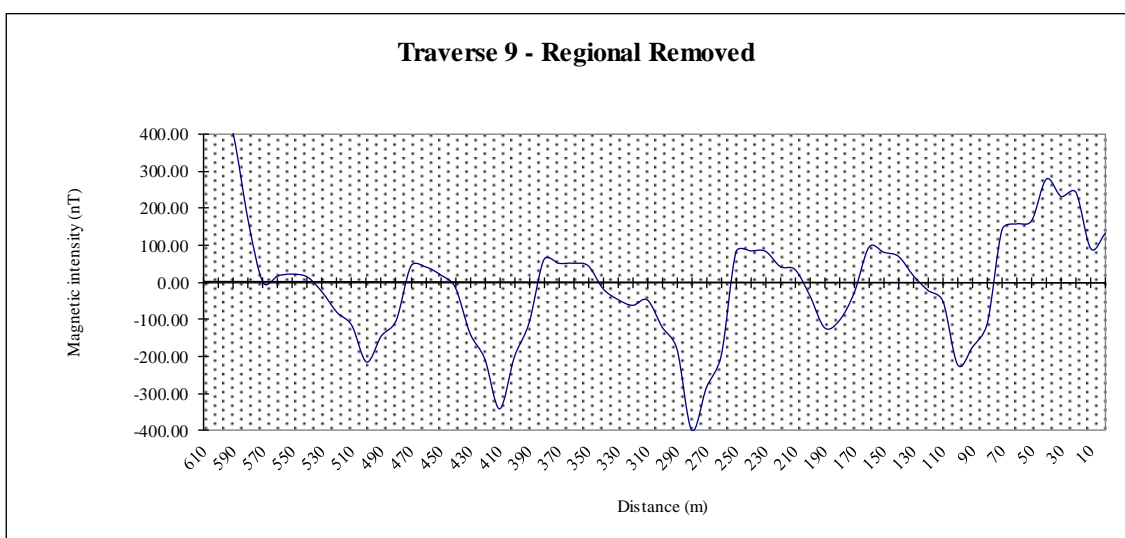


Figure 30. Magnetic profile along traverse T09.

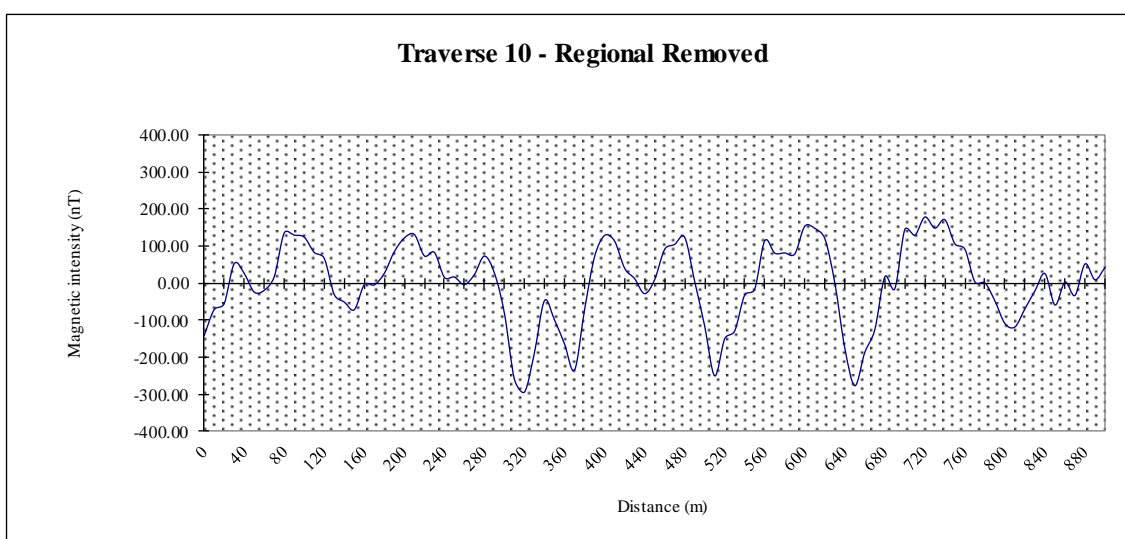


Figure 31. Magnetic profile along traverse T10.

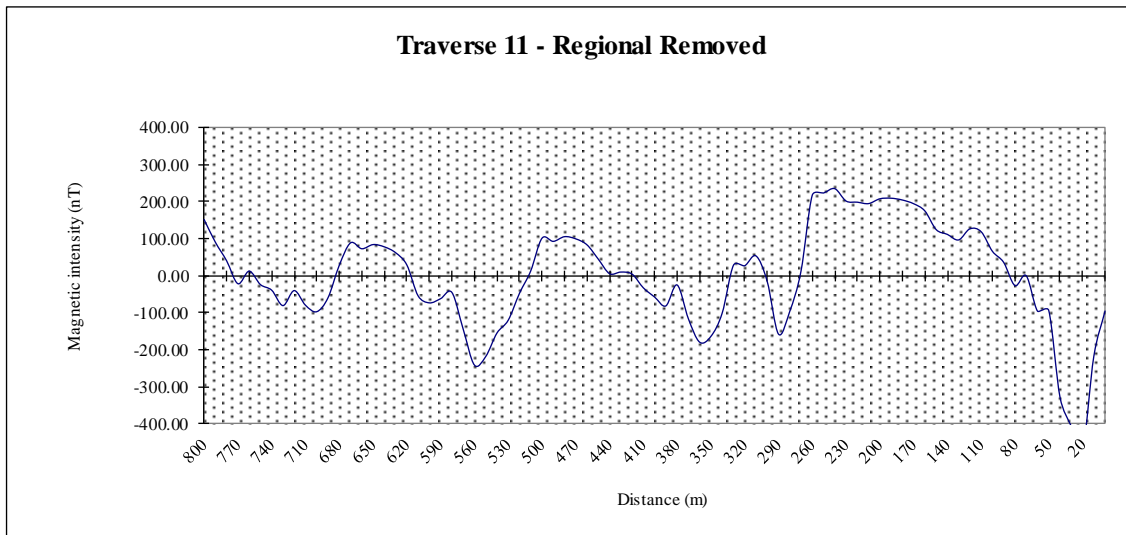


Figure 32. Magnetic profile along traverse T11.

From the geophysical survey conducted it can be concluded that large dolerite sills of low permeability are encountered at all three candidate sites. Based on the results of the magnetic survey all three candidate sites investigated appear to be the suitable for the ash dam extension.

6 GEOHYDROLOGY

The main water bearing aquifers in the vicinity of the power station are fractured rock aquifers. The term fracture refers to cracks, fissures, joints and faults, which are caused by (i) geological and environmental processes, e.g. tectonic movement; secondary stresses; release fractures; shrinkage cracks; weathering; chemical action; thermal action and (ii) petrological factors like mineral composition, internal pressure, grain size, etc.

From a hydrogeological point of view, a fractured rock mass can be considered a multi-porous medium, conceptually consisting of two major components: matrix rock blocks and fractures. Fractures serve as higher conductivity conduits for flow if the apertures are large enough, whereas the matrix blocks may be permeable or impermeable, with most of the storage usually contained within the matrix. Actually, a rock mass may contain many fractures of different scales. The permeability of the matrix blocks is in most cases of practical interest a function of the presence of micro-fractures. A rock mass which consists only of large fractures and some matrix blocks with no micro-fissures (or smaller fractures) lead to a term called purely fractured rocks. In this case, the domain takes the form of an interconnected network of fractures and the rock matrix, comprising the blocks surrounded by fractures, is impervious to flow. However, there may still be porosity. In the case where the domain is a porous medium (or a micro-scaled fractured medium) intersected by a network of interconnected fractures, the rock is termed a fractured porous rock and the domain is therefore characterized by at least two subsystems, each having a different scale of inhomogeneity (called scale effect).

6.1 Aquifer characteristics

Drilling data and work undertaken during previous investigations suggests that multiple aquifer types are represented at the site. These include:

- Unconfined aquifers present within soil horizons that have developed within colluvial and alluvial environments and the weathered upper levels of Ecca Formation sediments. These aquifers are generally perched on less permeable underlying in situ sediments;

- Unconfined aquifers along the trend of dolerite dykes. These may also act as recharge points for confined aquifers within the Eccca Formation at depth;
- Semi-confined aquifers within the Eccca Formation. These aquifers are commonly confined along essentially horizontal bedding interfaces between different lithologies, but can be locally unconfined along the trend of fractures zones, which allows the aquifers to recharge seasonally. The aquifers can therefore be regarded as a semi-confined, or leaky confined, aquifer on a regional scale if the definition of Fetter (1994) is considered;
- Deeper confined aquifers within basement lithologies.

From a pollution management viewpoint, the presence of a perched shallow aquifer is problematic due to resulting localised decreases in the bearing capacity of site profiles, and the increased potential for pollutant transport. In this instance, site aquifers are generally seasonal, which suggests that they either drain quickly (i.e. they are relatively permeable), have a low storage potential, or that stored water can be lost via evapo-transpiration processes. Contaminant movement away from pollution point sources can be reduced, or prevented entirely, through the construction of cut-off trenches and sub-soil drains to the confining layer at the base of the shallow perched aquifer.

The presence of a fracture zone is a convenient explanation for the presence of springs, located to east of the Camden Power Station ash dam and to the north of the Power Station Plant and administration buildings.

While seasonally influenced, the perched aquifer is also artificially recharged by the different structure associated with the power generation activities, the relatively impermeable Karoo sediments which act as aquifer base in some areas of the shallow perched aquifer encouraging lateral migration through the unsaturated zone in these areas. In comparison, recharge to regional aquifers occurs via preferential pathways, such as fractures, dykes, bedding planes and highly weathered bedrock areas. The regional aquifers are therefore classified as fractured rock aquifers. In general, aquifers appear unconfined to semi-confined in character.

The higher water levels observed in the immediate vicinity of the water bearing surface structures are an indication of the artificial recharge from these structures.

6.2 Recharge

Sources of water into the different aquifers may exist in the form of constant or specified flux sources. A good example of such a source is the constant water supply at the ash dam or any other dams or pans. Another source is the rainfall that recharges the aquifer.

A recharge of 2% - 3% was estimated during previous investigations for the natural area under investigation. Average annual rainfall for the region under investigation is about 726 mm per year according to data obtained from various weather stations in the area.

6.1 Groundwater Flow Direction

Due to the limited data of the boreholes located in the vicinity of the three candidate sites investigated no groundwater elevation measurements could be taken. However during the drilling of the auger holes no water was intercepted to a depth of 2 mbgl. The soil samples from all these auger holes were also only slightly moist.

Normally the groundwater table mimics the above topography if not disturbed by artificial recharge from manmade activities. Therefore, due to the lack of other groundwater level data it was decided

to use the topographical elevation data to estimate the direction of groundwater flow as indicated in **Figure 33**.

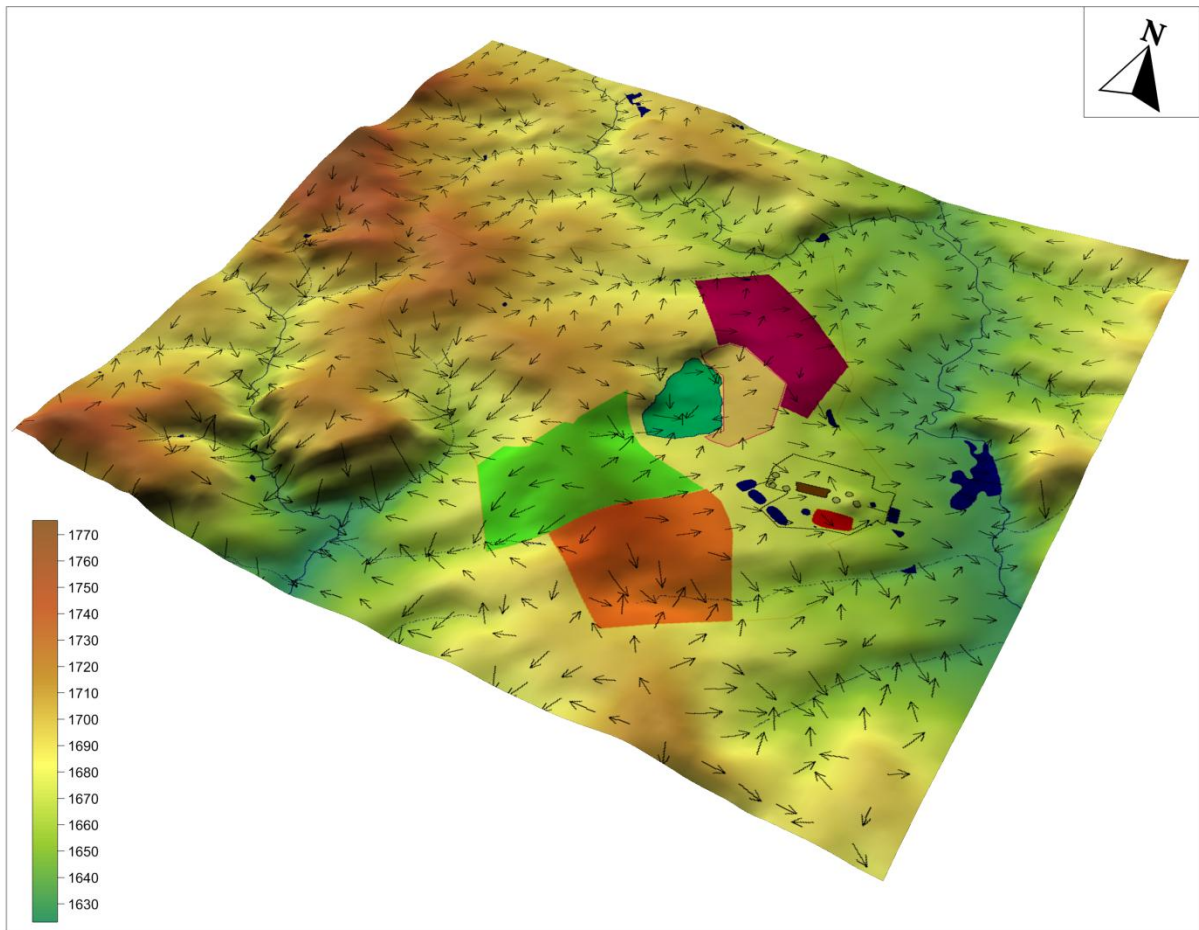


Figure 33. Direction of ground water flow.

6.1 Determination of the hydraulic conductivity of the saturated aquifer.

Slug tests were performed at all the monitoring bore sites during different detailed investigation from 2007 (refer Table 15). 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 adjacent to the borehole.

According to Muller, J. (1994) the effective porosity is of major importance with respect to the ground water seepage velocity. Muller, J (1994) also stated that the effective porosity for sandstone is between 5% and 15%. Driscoll (1986) stated that a typical value of porosity in fractured rocks is 5%. The borehole logs from Camden Power Station in the location of the Ashing Area indicate that the upper geology of study area comprises of a great deal of weathered dolerite and sandstone (Refer to Table 16 and Appendix B). Therefore an average effective porosity of 5%, for the study area, was used to calculate the seepage velocities. Porosities for overlying soil profiles were calculated from the sieve analyses results with the Brooks & Corey method. These porosities are between 40% – 55%.

Field estimates of hydraulic gradient for respective sites, the Darcy flux and seepage velocities calculations as well as the pollution migration distances, from the Ashing Area to Witpunt Spruit, for each gradient are presented in Table 15 and Table 16.

Table 15. Results of slug tests analysed using the Bouwer and Rice (1976) method.

Site	Waters strikes (m)	Blow yield measured (L/s)	K (m/d)	K (m/s)	Dh/Dl	Porosity (%)	Seepage Velocity (m/s)	Seepage Velocity (m/d)	Seepage Velocity (m/year)	Formation Tested
B01	13	0.04	0.0150	1.736E-07	0.023	5.0%	8.102E-08	0.0070	2.5550	Yellowish brown weathered dolerite.
B02	27	0.04	~	~	0.023	5.0%	~	~	~	Shale dolerite contact
B03	7	0.06	0.3100	3.588E-06	0.023	5.0%	1.674E-06	0.1447	52.8033	Reddish brown weathered dolerite.
B04	32	0.01	0.0050	5.787E-08	0.023	5.0%	2.701E-08	0.0023	0.8517	Sandstone dolerite contact
B05	9	0.01	0.0250	2.894E-07	0.023	5.0%	1.350E-07	0.0117	4.2583	Yellow coarse weathered sandstone.
B19	4	0.02	0.0020	2.315E-08	0.023	5.0%	1.080E-08	0.0009	0.3407	Grey bluish weathered dolerite.
B20	4	0.03	0.0130	1.505E-07	0.023	5.0%	7.022E-08	0.0061	2.2143	Dark grey weathered dolerite.
B21	16	0.01	0.0070	8.102E-08	0.023	5.0%	3.781E-08	0.0033	1.1923	Yellow greyish weathered dolerite
B22	18	0.03	0.0240	2.778E-07	0.023	5.0%	1.296E-07	0.0112	4.0880	Very fine laminated coal.
(Average) Upper Range		0.028	0.050	5.802E-07	0.023	5.0%	2.707E-07	0.023	8.538	
(Geometric mean) Lower Range		0.026	0.055	6.310E-07	0.023	5.0%	2.945E-07	0.025	9.286	

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 average K value measured for in situ soil/weathered dolerite was 3.3×10^{-5} m/s, a value an order of magnitude higher than that determined for a site aquifer within the dolerites (5.8×10^{-7} 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 be predominating.

The higher permeability of weathered dolerites can also be expected to influence recharge and discharge behaviour at the site. The unconfined, relatively permeable characters of 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. The Darcy flux [V (m/d)] and seepage velocities [Vs (m/d)] of potential contaminants were calculated by using the following equations.

$$V = Ki \tag{Equation 1}$$

where;

V = Darcy Velocity or Flux

K = Hydraulic Conductivity

i = Hydraulic Gradient

$$V_s = \frac{V}{n_e} \tag{Equation 2}$$

where;

Vs = Seepage Velocity

V = Darcy Velocity or Flux

ne = Effective Porosity

Table 16. Seepage velocity over different time steps..

Site	Pollution Migration (Lower Range) meters 1 Year	Pollution Migration (Upper Range) meters 1 Year	Pollution Migration (Lower Range) meters 5 Year	Pollution Migration (Upper Range) meters 5 Year	Pollution Migration (Lower Range) meters 10 Year	Pollution Migration (Upper Range) meters 10 Year
Saturated deep aquifer	9.3	8.5	46	43	93	85

Seepage velocities calculated on the basis of estimated values are also shown in these tables. These calculations suggest that there is little variation between field aquifer hydraulic conductivity and seepage velocities. Based on a seepage velocity of 9 m/y and a distance between the ash stack and the groundwater divide in the east of between 1 500 m, it is estimated that it will take at least 160 years for pollutants to reach the perennial Witpunt Spruit. The rate of pollution migration would be higher, however, along more permeable dolerite in areas that have steeper hydraulic gradients.

Calculated seepage velocities through higher permeability soils (present at Candidate Site 1) were also included 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 23 years for pollutants to reach the perennial Witpunt Spruit.

6.2 Hydrocensus Information and Field Observations

A hydrocensus was conducted around the candidate sites to identify potential groundwater users in the vicinity of these sites that may be adversely affected should contamination occur due to the proposed Ash dam extension (Refer to **Figure 34**). Seven boreholes and a fountain were located. Due to equipment fitted and the lack of water in some of the boreholes, samples were only taken at two boreholes and the fountain. Seven surface sites were also identified, of these five samples were taken. Samples from two of the auger holes that were drilled as part of the seepage investigation of Camden Power Station’s ash dam were also taken. **Table 17** below list all the sites identified with their description and current state.

It should be noted that two of the boreholes that have been located, FBB23 and FBB26 are situated in two of the candidate sites. These boreholes must be plugged, according to the standards set by the Department of Water Affairs, before ashing commence. When a pollution source is placed over an uncapped borehole the borehole creates an artificial preferred pathway to the deeper aquifers in which the pollutants can move more freely. The first of these (FBB23) is located in candidate site 1 approximately 400m north of the current Camden Power Station ash dam. This Borehole is currently is not in use and fitted with a wind pump which is not operational and severely neglected. The second borehole (FBB26) is located 100m north of the farm workers dwellings in the northern area of candidate site 2. This borehole is for domestic use and is fitted with a hand pump that is in a good working condition.

Water for domestic use at most of the farms in the area is pumped via a pipeline from which the water is then tapped to the different farm holdings. Water for livestock comes mainly from the smaller tributaries and farm dams in the area.

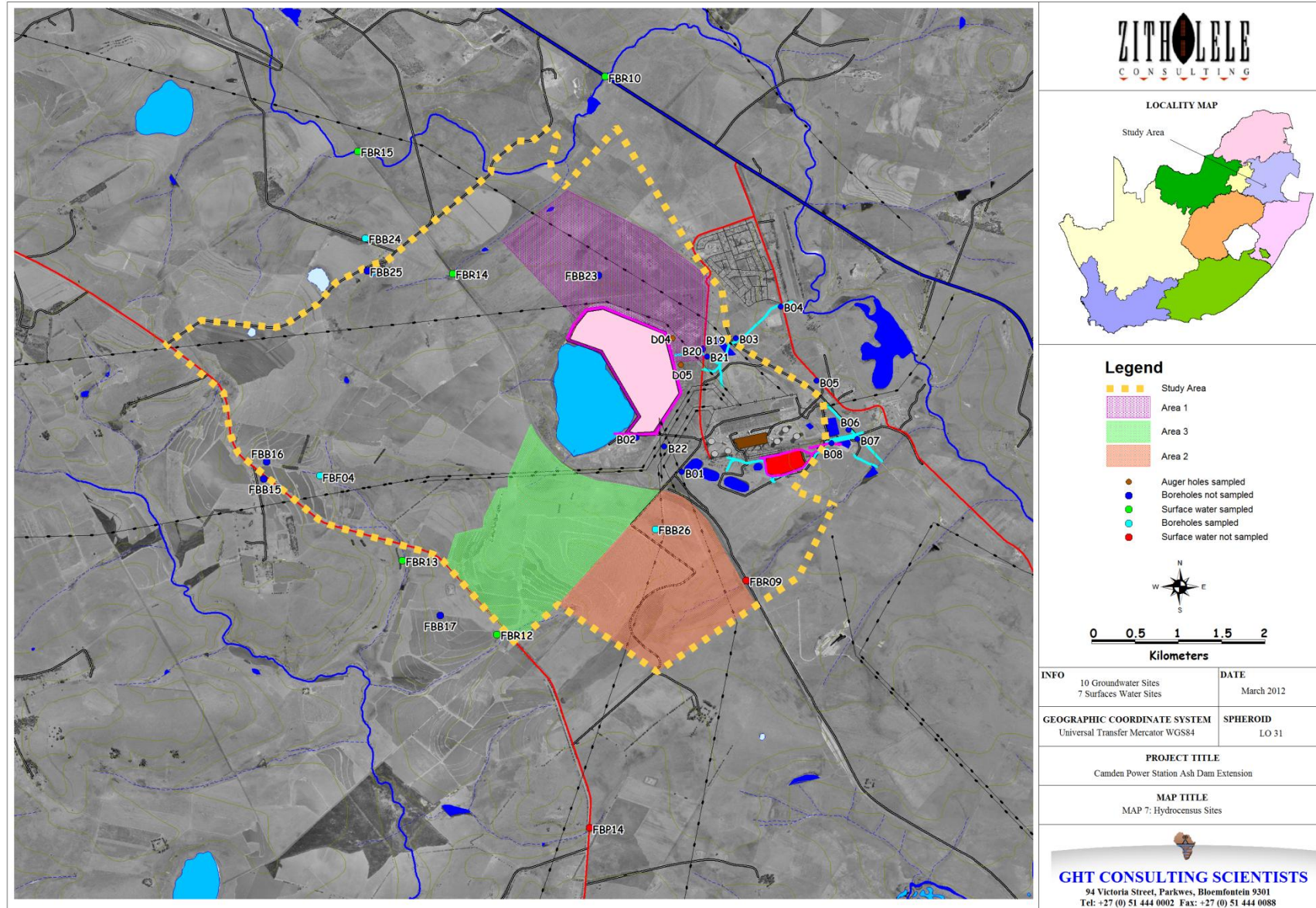


Figure 34. Hydrocensus Map

Table 17. Current state tables of sites identified during the hydrocensus.

Number on map	Site Description	Longitude (°E)	Latitude (°S)	Farm Name	Site Type	Equipment	Use: Agricultural Livestock Domestic	Status : G In Use U Unused	Date	WL	Time	Sampled	Sample Depth (m)	Field Photo Nr.	Current Condition
FBB15	Background groundwater site. 10m from gravel road. Small pump house. Water usage: 1400L/day.	30.03317	-26.62515	Uitkomst 292/2	Borehole	Submersible Pump	L	G	3/8/2012	~	11:11	N	~	1	Good working condition.
FBB16	Background groundwater site. 120m on road towards the fountain FBF04 at old wind pump in corn field.	30.03351	-26.62320	Uitkomst 292/2	Borehole	Wind Pump	~	U	3/8/2012	~	11:16	N	~	2	Not in working condition.
FBB23	Background groundwater site. Old disused wind pump in field north west of power station between power lines.	30.07210	-26.60151	Uitkomst 292/18	Borehole	Wind Pump	~	U	3/7/2012	8.55	11:10	N	~	3, 4	Not in working condition.
FBB24	Background groundwater site. 400m north west of farmhouse next to tank.	30.04499	-26.59719	Uitkomst 292/19	Borehole	None	~	U	3/8/2012	5.53	08:24	Y	10	5	Not in working condition.
FBB25	Background groundwater site. 250m south west of farm house.	30.04525	-26.60101	Uitkomst 292/19	Borehole	None	~	U	3/8/2012	4.7	08:45	N	~	6	Not in working condition.
FBB26	Background groundwater site. 100m north of workers house at old wind pump	30.07875	-26.63106	Mooiplaats 290/14	Borehole	Hand pump	L,D	G	3/8/2012	~	12:42	Y	Pumped	7	Good working condition.
FBF04	Background groundwater site. Fountain located 270m south west from where the 2 thick rows of trees meets.	30.03974	-26.62477	Uitkomst 292/2	Fountain	~	L	G	3/8/2012	Low	11:37	Y	Surface	8	Flowing Slow. Overgrown. Satisfactory condition
FBP14	Background surface water site. Farm dam 40m East from road.	30.07109	-26.66577	Welgelegen 322/1	Dam	~	~	~	3/8/2012	Damp	11:49	N	Surface		Damp Satisfactory condition.
FBR09	Background surface water site. 1km South of Power Station. Next to rail road.	30.08935	-26.63702	Mooiplaats 290/14	River	~	~	~	3/8/2012	Dry	12:20	N	Surface		Dry Satisfactory condition.
FBR10	Background surface water site. 4km North West of PS. On road to Ermelo.	30.07288	-26.57844	Jan Hendriksfontein 263/9	River	~	~	~	3/8/2012	Low	14:40	Y	Surface	9	Flowing Slow. Satisfactory condition.
FBR12	Background surface water site. 700m Southeast from CWP28.	30.06027	-26.64335	Uitkomst 292/10	River	~	~	~	3/8/2012	Low	11:44	Y	Surface	10	Stagnant pools. Satisfactory condition.
FBR13	Background surface water site. 200m South from road. Stream flows into dam. Visible from road.	30.04927	-26.63473	Uitkomst 292/2	River	~	~	~	3/8/2012	Low	11:05	Y	Surface	11	Stagnant pools. Satisfactory condition.
FBR14	Background surface water site. Sampled at culvert between dam and railway tracks.	30.05516	-26.60131	Uitkomst 292/19	River	~	~	~	3/8/2012	Low	08:03	Y	Surface	12	Flowing Slowly. Satisfactory condition.
FBR15	Background surface water site. Sampled at culvert at railway tracks.	30.04411	-26.58709	Uitkomst 292/14	River	~	~	~	3/8/2012	Low	08:10	Y	Surface	13	Flowing Slowly. Satisfactory condition.
D04	Monitoring shallow groundwater contamination of ash dam.	30.08072	-26.60882	Camden Power Station 329	Auger	None	Monitoring	G	3/8/2012	1.46	13:45	Y	2	14	Satisfactory condition.
D05	Monitoring shallow groundwater contamination of ash dam.	30.08167	-26.61192	Camden Power Station 329	Auger	None	Monitoring	G	3/8/2012	1.44	13:40	Y	2	15	Satisfactory condition.



Photo 1. – Borehole FBB15.



Photo 2. – Borehole FBB16.



Photo 3. – Borehole FBB23.



Photo 4. – Broken wind pump at FBB23.



Photo 5. – Borehole FBB24.



Photo 6. – Borehole FBB25.



Photo 7. – Borehole FBB26.



Photo 8. – Fountain FBF04.



Photo 9. – Stream FBR10.



Photo 10. – Stream FBR12.



Photo 11. – Stream FBR13.



Photo 11. – Stream FBR14.



Photo 13. – Stream FBR15.



Photo 14. – Auger hole D05.



Photo 15. – Auger hole D04.

Table 18. Current state tables of groundwater monitoring sites.

Number on map	Site Description	Longitude (°E)	Latitude (°S)	Farm Name	Site Type	Equipment	Use (Agricultural, Domestic)	Status (G In Use, U Unused)	Date	WL	Time	Sampled	Sample Depth (m)	Field Photo Nr.	Current Condition
B01	Monitoring groundwater quality south-west of PS for background purposes.	30.08139	-26.62417	Camden Power Station 329	Borehole	None	Monitoring	G	25/01/2012	3.75	11:45	Y	14	~	Satisfactory condition.
B02	Monitoring groundwater contamination from Ash dam and Domestic Waste Site.	30.07672	-26.62014	Camden Power Station 329	Borehole	None	Monitoring	G	25/01/2012	~	12:45	N	5	~	B02 historically has very high Fe, Mn, SO ₄ , Al and a very low Ph. Borehole is currently under water.
B03	Monitoring groundwater contamination east of ash dam and north of power station.	30.08775	-26.60911	Camden Power Station 329	Borehole	None	Monitoring	G	25/01/2012	Artesian	10:25	Y	6	~	B03 has above recommended standard Fe levels.
B04	Monitoring groundwater contamination east of ash dam and north of power station downstream from B03.	30.08775	-26.60911	Camden Power Station 329	Borehole	None	Monitoring	G	25/01/2012	1.99	08:00	Y	8	~	B04 has above recommended standard Fe levels.
B05	Monitoring groundwater quality north-east of PS.	30.09761	-26.61372	Camden Power Station 329	Borehole	None	Monitoring	G	25/01/2012	0.98	08:10	Y	8	~	Satisfactory condition.
B19	Monitoring groundwater contamination east of ash dam and north of power station.	30.08428	-26.61003	Camden Power Station 329	Borehole	None	Monitoring	G	25/01/2012	0.93	10:45	Y	14		B19 has above recommended standard Mn levels.
B20	Monitoring groundwater contamination east of ash dam and north of power station.	30.08427	-26.61012	Camden Power Station 329	Borehole	None	Monitoring	G	25/01/2012	Artesian	10:50	Y	15		B20 has a very high Ph.
B21	Monitoring groundwater contamination east of ash dam and north of power station.	30.08472	-26.61012	Camden Power Station 329	Borehole	None	Monitoring	G	25/01/2012	5.07	11:15	Y	16		B21 has above recommended standard Mn levels.
B22	Monitoring groundwater contamination SPOeast of ash dam and north of power station.	30.07977	-26.62143	Camden Power Station 329	Borehole	None	Monitoring	G	25/01/2012	1.41	12:16	Y	21		B22 has above recommended standard Fe levels.
D01	Duged trenches north of C02 next to road. Inspect regularly & monitoring water quality.	30.07990	26.61853	Camden Power Station 329	Duged Trench	None	Monitoring	G	25/01/2012	Mod	12:50	Y	2		D01 has above recommended standard water quality due to elevated EC and Mg.
D02	Monitoring shallow groundwater contamination of ash dam.	30.07425	-26.60509	Camden Power Station 329	Auger	None	Monitoring	G	25/01/2012	~	13:10	N	2		Unable to gain access due to extremely high water level of canals C17 and C01.
D03	Monitoring shallow groundwater contamination of ash dam.	30.07813	-26.60685	Camden Power Station 329	Auger	None	Monitoring	G	25/01/2012	0.98	13:11	Y	2		D03 has very high EC, Na, Cl, SO ₄ and Mn.
D06	Monitoring shallow groundwater contamination of ash dam.	30.08230	-26.61594	Camden Power Station 329	Auger	None	Monitoring	G	25/01/2012	1.52	13:20	Y	2		D06 has very high EC, Ca, Mg, Na, SO ₄ , Mn, Al and a very low Ph.
D07	Monitoring shallow groundwater contamination of ash dam.	30.08052	-26.61927	Camden Power Station 329	Auger	None	Monitoring	G	25/01/2012	1.1	12:10	Y	2		Satisfactory condition.

Table 19. Current state tables of surface dwater monitoring sites.

Number on map	Site Description	Longitude (°E)	Latitude (°S)	Farm Name	Site Type	Equipment	Use (Agricultural, Domestic)	Status (G In Use, U Unused)	Date	WL	Time	Sampled	Sample Depth (m)	Field Photo Nr.	Current Condition
C01	Seepage north of road.Road filling act as clean-dirty water separation.Inspect and monitoring water quality.	30.07560	-26.60570	Camden Power Station 329	Canal	None	Monitoring	G	25/01/2012	Stagnant	13:09	Y	Surface		High Water level.High pollution levels and salt precipitation due to seepage from ash dam complex and associated structures. C01 also has a above recommended standard Mn.
C02	Canal with ash and return water pipes.Inspect and monitoring water quality.	30.07910	-26.62000	Camden Power Station 329	Canal	None	Monitoring	G	25/01/2012	High	12:28	Y	Surface		High Water level.High pollution levels and salt precipitation due to seepage from ash dam complex and associated structures.C02 also has very high SO4 and Mn.
C03	Clean water run-off canal collecting water from ashing area.Monitoring water quality.	30.08430	-26.61070	Camden Power Station 329	Canal	None	Monitoring	G	25/01/2012	Low	11:11	Y	Surface		Low Water level.Water flow has increased due to large amounts of standing water in the ash water return canals. C03 also has elevated EC, Na and SO4.
C04	Clean water canal east of ash dam .	30.08450	-26.61250	Camden Power Station 329	Canal	None	Monitoring	G	25/01/2012	Low	11:25	Y	Surface		C04 has above recommended standard SO4 levels.
C05	Clean water run-off canal downstream from C25.Monitoring water quality.	30.08630	-26.61290	Camden Power Station 329	Canal	None	Monitoring	G	25/01/2012	Low	13:26	Y	Surface		Satisfactory condition.
C06	Clean water canal east of ash dam.	30.08790	-26.60930	Camden Power Station 329	Canal	None	Monitoring	G	25/01/2012	Low	10:23	Y	Surface		Low Water level.Water flow has increased due to large amounts of standing water in the ash water return canals. C06 also has elevated EC, Na and SO4.
C07	Clean water canal SE of village.	30.09350	-26.60490	Camden Power Station 329	Canal	None	Monitoring	G	25/01/2012	Low	07:58	Y	Surface		Low Water level.Water flow has increased due to large amounts of standing water in the ash water return canals. C07has above recommended standard SO4 levels.
C27	Clean water canal NW of PS.	30.08433	26.61406	Camden Power Station 330	Canal	None	Monitoring	G	25/01/2012	Dry	13:21	N	Surface		Satisfactory condition. C27 historically has elevated EC, SO4, Al and a very high Ph.
p09	Large pan west of Ash Dam used as ash water return dam - De Jager Pan.	30.07420	-26.62000	Camden Power Station 329	Dam	None	Monitoring	G	25/01/2012	Very high	12:40	Y	Surface		Water level dangerously high.The integrity of the ash dam maybe at risk due to the high water level.
P13	Shallow dam east of De Jager Pan	30.08171	26.62036	Camden Power Station 330	Dam	None	Monitoring	G	25/01/2012	Low	12:01	Y	Surface		P13 has above recommended standard EC, Ca, SO4, Mn and a low Ph.
S01	Clean water run-off canal collecting water from ashing area.Monitoring water quality.	30.08410	-26.61480	Camden Power Station 329	Seepage	None	Monitoring	G	25/01/2012	Low	11:28	Y	Surface		Ash spill visible. S01 has very high EC, Ca, Mg, Na, SO4 and B.
S04	Seepage west of PS next to road.	30.08357	26.62142	Camden Power Station 330	Seepage	None	Monitoring	G	25/01/2012	Low	11:59	Y	Surface		S04 has above recommended standard Ca and SO4
T01	Pump out sump for seepage interception system of historic waste site.Inspect and monitoring water quality.	30.07390	-26.62080	Camden Power Station 329	Drain	None	Monitoring	G	25/01/2012	~	09:06	N	Surface		Under the water of De Jager Pan.

7 SURFACE- AND GROUNDWATER QUALITY – INORGANIC PARAMETERS

Surface- and groundwater samples taken during the current investigation were submitted to Clean Stream Laboratories for analyses of the different parameter concentrations. The results of the analyses are presented in this section by various graphical means and observations regarding the contamination status of the surface- and groundwater are made.

The results of all the inorganic chemical, hydrocarbon and bacteriological analyses that have been performed on water samples from Camden Power Station during the current and previous investigations are available in an electronic database for review.

In the following tables the water samples from all the sampled sites are classified according to the South African National Standard (SANS 241: 2006 Edition 6.1 and SANS 241-1:2011 Edition 1). A description of the various Classes is given in Table 22.

Table 20. South African National Standard (SANS 241: 2006 Edition 6.1).

Determinand	Unit	Class I (recommended operational limit)	Class II (max. allowable for limited duration)	Class II water consumption period, ^a max.
Physical and organoleptic requirements				
Colour (aesthetic)	mg/L pt	< 20	20-50	No limit ^b
Conductivity at 25 °C (aesthetic)	mS/m	< 150	150-370	7 years
Dissolved solids (aesthetic)	mg/L	< 1 000	1 000-2 400	7 years
Odour (aesthetic)	TON	<5	5-10	No limit ^b
pH value at 25 °C (aesthetic/operational)	pH units	5,0 - 9,5	4,0 - 10,0	No limit ^c
Taste (aesthetic)	FTN	< 5	5-10	No limit
Turbidity (aesthetic/operational/indirect health)	NTU	< 1	1-5	No limit ^d
Chemical requirements — macro-determinand				
Ammonia as N (operational)	mg/L	< 1,0	1,0-2,0	No limit ^d
Calcium as Ca (aesthetic/operational)	mg/L	< 150	150-300	7 years
Chloride as Cl ⁻ (aesthetic)	mg/L	< 200	200-600	7 years
Fluoride as F ⁻ (health)	mg/L	< 1,0	1,0-1,5	1 year
Magnesium as Mg (aesthetic/health)	mg/L	< 70	70- 100	7 years
(Nitrate and nitrite) as N (health)	mg/L	< 10	10-20	7 years
Potassium as K (operational/health)	mg/L	< 50	50- 100	7 years
Sodium as Na (aesthetic/health)	mg/L	< 200	200-400	7 years
Sulfate as SO ₄ ⁼ (health)	mg/L	< 400	400-600	7 years
Zinc as Zn (aesthetic/health)	mg/L	< 5,0	5,0- 10	1 year

Determinand	Unit	Class I (recommended operational limit)	Class II (max. allowable for limited duration)	Class II water consumption period," max.
Chemical requirements — micro-determinand				
Aluminium as Al (health)	mg/L	< 300	300-500	1 year
Antimony as Sb (health)	mg/L	< 10	10-50	1 year
Arsenic as As (health)	mg/L	< 10	10-50	1 year
Cadmium as Cd (health)	mg/L	<5	5- 10	6 months
Total Chromium as Cr (health)	mg/L	< 100	100-500	3 months
Cobalt as Co (health)	mg/L	< 500	500-1 000	1 year
Copper as Cu (health)	mg/L	< 1 000	1 000-2 000	1 year
Cyanide (recoverable) as CW (health)	mg/L	<50	50-70	1 week
Iron as Fe (aesthetic/ operational)	mg/L	< 200	200-2 000	7 years ^b
Lead as Pb (health)	mg/L	< 20	20-50	3 months
Manganese as Mn (aesthetic)	mg/L	< 100	100-1000	7 years
Mercury as Hg (health)	mg/L	< 1	1-5	3 months
Nickel as Ni (health)	mg/L	< 150	150- 350	1 year
Selenium as Se (health)	mg/L	< 20	20-50	1 year
Vanadium as V (health)	mg/L	< 200	200- 500	1 year
Chemical requirements — organic determinand				
Dissolved organic carbon as C (aesthetic/health)	mg/L	< 10	10-20	3 months ^e
Total trihalomethanes (health)	mg/L	< 200	200-300	10 years ^f
Phenols (aesthetic/health)	mg/L	< 10	10-70	No limit ^b

^a The limits for the consumption of class II water are based on the consumption of 2 L water per day by a person of mass 70 kg over a period of 70 years, Columns 4 and 5 shall be applied together.

^b The limits given are based on aesthetic aspects.

^c No primary health effect- low pH values can result in structural problems in the distribution system.

^d These values can indicate process efficiency and risks associated with pathogens.

^e When dissolved organic carbon is deemed of natural origin, the consumption period can be extended.

^f This is a suggested value because trihalomethanes have not been proven to have any effect on human health.

Table 21. South African National Standard (SANS 241-1:2011 Edition 1).

Determinand	Risk	Unit	Standard limits ^a (Class I)
Physical and aesthetic determinands			
Free chlorine	Chronic health	mg/L	≤ 5
Monochloramine	Chronic health	mg/L	≤ 3
Colour	Aesthetic	mg/L Pt-Co	≤ 15
Conductivity at 25 °C	Aesthetic	mS/m	≤ 170
Odour or taste	Aesthetic	-	Inoffensive
Total dissolved solids	Aesthetic	mg/L	≤ 1 200
Turbidity ^b	Operational	NTU	≤ 1
	Aesthetic	NTU	≤ 5
pH at 25 °C ^c	Operational	pH units	≤ 5 to ≥ 9,7
Chemical determinands — macro-determinands			
Nitrate as N ^d	Acute health - 1	mg/L	≤ 11
Nitrite as N ^d	Acute health - 1	mg/L	≤ 0,9
Sulfate as SO ₄ ²⁻	Acute health - 1	mg/L	≤ 500
	Aesthetic	mg/L	≤ 250
Fluoride as F ⁻	Chronic health	mg/L	≤ 1,5
Ammonia as N	Aesthetic	mg/L	≤ 1,5
Chloride as Cl ⁻	Aesthetic	mg/L	≤ 300
Sodium as Na	Aesthetic	mg/L	≤ 200
Zinc as Zn	Aesthetic	mg/L	≤ 5
Chemical determinands — micro-determinands			
Antimony as Sb	Chronic health	mg/L	≤ 20
Arsenic as As	Chronic health	mg/L	≤ 10
Cadmium as Cd	Chronic health	mg/L	≤ 3
Total chromium as Cr	Chronic health	mg/L	≤ 50
Cobalt as Co	Chronic health	mg/L	≤ 500
Copper as Cu	Chronic health	mg/L	≤ 2 000
Cyanide (recoverable) as CN ⁻	Acute health - 1	mg/L	≤ 70
Iron as Fe	Chronic health	mg/L	≤ 2 000
	Aesthetic	mg/L	≤ 300
Lead as Pb	Chronic health	mg/L	≤ 10
Manganese as Mn	Chronic health	mg/L	≤ 500
	Aesthetic	mg/L	≤ 100
Mercury as Hg	Chronic health	mg/L	≤ 6
Nickel as Ni	Chronic health	mg/L	≤ 70
Selenium as Se	Chronic health	mg/L	≤ 10
Uranium as U	Chronic health	mg/L	≤ 15
Vanadium as V	Chronic health	mg/L	≤ 200
Aluminium as Al	Operational	mg/L	≤ 300

Determinand	Risk	Unit	Standard limits ^a (Class I)
Chemical determinands-organic determinands			
Total organic carbon as C	Chronic health	mg/L	≤10
Trihalomethanes			
Chloroform	Chronic health	mg/L	≤ 0,3
Bromoform	Chronic health	mg/L	≤ 0,1
Dibromochloromethane	Chronic health	mg/L	≤ 0,1
Bromodichloromethane	Chronic health	mg/L	≤ 0,06
Microcystin as LR ^e	Chronic health	mg/L	≤1
Phenols	Aesthetic	mg/L	≤10

^a The health-related standards are based on the consumption of 2 L of water per day by a person of a mass of 60 kg over a period of 70 years.

^b Values in excess of those given in column 4 may negatively impact disinfection.

^c Low pH values can result in structural problems in the distribution system.

^d This is equivalent to nitrate at 50 mg NO₃/L and nitrite as 3 mg NO₂/L.

^e Microcystin only needs to be measured where an algal bloom (> 20 000 cyanobacteria cells per millilitre) is present in a raw water source. In the absence of algal monitoring, an algal bloom is deemed to occur where the surface water is visibly green in the vicinity of the abstraction, or samples taken have a strong musty odour.

Table 22. Classification system used to evaluate water quality classes.

SABS South Africa National Standard: Drinking Water, SANS 241-2:2011 Edition 1

Class 1	- Recommended standard limit - Suitable for lifetime use.
ARS	- Above recommended standard limit - Unsuitable for lifetime human consumption.

SABS South Africa National Standard: Drinking Water, SANS 241:2006 Edition 6.1

Class 1	- Recommended operational limit - Suitable for lifetime use.
Class 2	- Maximum allowable limit - Suitable for limited duration use only.
AMA	- Above maximum allowable limit - Unsuitable for human consumption.

* (Ae) - Aesthetic standards.

South Africa Water Quality Guidelines, Volume 1: Domestic Use, DWA&F, First Edition 1993 & Second Edition 1996

NR	- Target water quality range - No risk.
IR	- Good water quality - Insignificant risk. Suitable for use, rare instances of negative effects.
LR	- Marginal water quality - Allowable low risk. Negative effects may occur in some sensitive groups
HR	- Poor water quality - Unsuitable for use without treatment. Chronic effects may occur.

7.1 Surface- and Groundwater Quality – Hydrocensus Sites

In this section the results of the chemical analyses of the water samples taken during the hydrocensus is discussed (refer to Table 24 below). At the time of the sampling event, most of the streams in the study area were characterised as low, and slow flowing. It is therefore fair to assume that the dilution effect of continuous stream flow was negligibly small during the months preceding the sampling event.

Table 23. Water Quality of Hydrocensus Sites.

Site No.	Date	pH	EC mS/m	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	SO ₄ mg/L	F mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NH ₄ -N mg/L	Fe mg/L	Mn mg/L	B mg/L	Al mg/L	Cr mg/L
Groundwater Sites																		
FBB24	2012/03/08	6.74	24	13	5	14	8.5	10	3	0.07	0.01	0.05	6.27	0.9300	0.1910	0.0810	0.0060	0.0060
FBB26	2012/03/08	6.84	21	21	11	8	3.3	8	1	0.01	0.01	12.39	0.09	0.0500	0.0160	0.0670	0.0100	0.0100
FBF04	2012/03/09	7.27	28	25	13	9	1.8	9	8	0.02	0.01	14.67	0.13	0.0350	0.0140	0.0660	0.0370	0.0150
Surface Water Sites																		
*FBR10	2012/03/10	6.16	54	52	26	24	6.2	9	251	0.16	0.01	0.15	0.13	0.0210	1.0640	0.1040	0.0140	0.0060
*FBR12	2012/03/11	6.63	26	22	11	14	4.8	19	48	0.09	0.01	0.19	0.60	0.2920	0.0150	0.0820	0.1940	0.0060
*FBR13	2012/03/12	7.28	48	44	25	28	2.6	28	127	0.11	0.01	0.05	0.12	0.0280	0.0230	0.0730	0.0190	0.0060
*FBR14	2012/03/13	7.49	67	58	38	44	4.1	44	23	0.39	0.01	0.05	0.30	0.1360	1.7310	0.1150	0.0270	0.0060
*FBR15	2012/03/14	6.13	55	51	31	23	2.6	18	233	0.14	0.01	1.63	0.22	0.0240	0.5270	0.0980	0.0050	0.0060

* Surface water sites supposed to contain clean water.

The surface water quality at all sites except FBR13 exceeds the recommended allowable drinking water standard due to the presence of iron and manganese.

The manganese concentrations observed at FBR15 and FBR10 are most likely due to mining activities upstream. The elevated iron in sample FBR12 and the manganese concentration in sample FBR14 might be due to the geology as there is no definite pollution source nearby. Agricultural impacts are visible in the elevated nitrate concentrations of groundwater sites FBB26 and FBF04. The above recommended allowable drinking water standard of Borehole FBB24 due to the presence of ammonia is the result of decomposing rodents and other debris that fell into the uncapped borehole. The elevated iron might be geological as there is not enough information available.

The quality of stream sample FBR13 was the only clean surface water site of which the quality was within the recommended standard.

7.1 Surface- and Groundwater Quality – Monitoring Sites

The impact of Camden Power Station's current Ash Dam Complex on the shallow purge aquifer is visible in the chemical analysis of the water quality of the auger hole and shallow pit sites as presented in Table 25. The chemical concentrations of these sites are above the recommended allowable drinking water standard quality and are due to the seepage from the ash dam as well as the ash water return canals that are not sloped adequately to promote flow of the water back to the De Jager Pan which is used as a ash water return dam.

From the chemical concentrations in Table 24 it is evident that the Ash Dam Complex has very limited impact on the deep exploitable aquifer. The groundwater in the vicinity of B02 has been polluted to a large extent, however this borehole is situated directly in a hold waste site and is sometimes covered by water from De Jager Pan.

The current Ash Dam Complex has a negative impact on all the surface water bodies downstream from the area. Elevated chemical concentrations are observed at nearly all the clean surface water sampling sites as depicted in Table 26. This is due to the mismanagement of the current ashing area as well as inadequate dirty water drainage systems in the vicinity of this facility.

Table 24. Water Quality of Groundwater Sites.

Site No.	Date	pH	EC mS/m	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	SO4 mg/L	F mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NH ₄ -N mg/L	Fe mg/L	Mn mg/L	B mg/L	Al mg/L	Cr mg/L
B01	20101007	7.85	78	59	51	45	1.0	30	127	0.09	0.01	0.05	0.53	0.2600	0.4600	0.2760	0.0400	0.0060
B01	20110118	7.04	108	95	62	47	1.4	24	221	0.10	0.01	0.05	0.30	0.0670	0.1910	0.0060	0.0100	0.0060
B01	20110531	8.03	69	36	52	48	2.5	27	109	0.02	0.01	0.05	0.23	0.1000	0.1850	0.2760	0.0110	0.0060
B01	20110825	7.85	47	23	30	40	0.8	24	53	0.18	0.18	0.36	0.02	0.0060	0.0540	0.0160	0.0060	0.0020
B01	20120125	7.58	99	81	73	53	1.4	74	234	0.02	0.01	0.05	0.47	0.0480	0.4980	0.1610	0.0150	0.0060
B02	20101007	4.10	168	70	74	21	5.8	15	1021	0.04	0.10	0.50	0.38	226.6	12.92	0.9330	55.920	0.0060
B02	20110531	4.51	247	114	127	26	8.2	14	1865	2.56	0.10	0.50	0.17	261.4	19.50	1.1420	146.500	0.0060
B03	20101007	6.54	41	38	17	16	3.1	20	99	0.08	0.01	1.51	0.44	0.3500	0.1100	0.1980	0.0200	0.0060
B03	20110118	6.89	41	40	15	13	2.6	16	94	0.03	0.01	0.80	0.30	0.8000	0.0250	0.0020	0.0130	0.0060
B03	20110531	6.79	43	45	19	18	4.9	18	103	0.06	0.01	1.26	0.27	0.1000	0.0250	0.2360	0.0250	0.0060
B03	20110825	7.50	45	48	21	16	2.9	14	109	0.18	0.13	2.20	0.05	0.0060	0.0090	0.0130	0.0060	0.0020
B03	20120125	6.84	42	40	17	21	3.5	14	104	0.03	0.01	0.95	0.64	1.7990	0.0350	0.1670	0.0200	0.0060
B04	20101007	6.81	38	12	5	58	2.3	34	2	0.39	0.01	0.05	0.62	0.3500	0.2500	0.2610	0.0200	0.0060
B04	20110118	7.14	57	33	12	36	3.1	18	11	0.40	0.01	0.05	0.54	0.2880	0.0270	0.0300	0.0160	0.0060
B04	20110531	7.03	33	13	5	55	3.9	15	1	0.46	0.01	0.05	0.45	0.2000	0.1480	0.2730	0.0070	0.0060
B04	20110825	7.59	34	15	6	53	1.9	12	1	0.42	0.13	0.30	0.05	0.0060	0.1510	0.0990	0.0060	0.0020
B04	20120125	7.04	35	14	5	56	2.6	35	4	0.31	0.01	0.05	0.95	0.5500	0.0190	0.2180	0.0350	0.0060
B05	20101007	7.11	31	20	10	37	3.5	4	6	0.08	0.01	0.05	0.21	0.5700	0.1300	0.1780	0.0200	0.0060
B05	20110128	7.31	32	19	10	36	3.1	5	12	0.08	0.01	0.05	0.20	0.1010	0.0230	0.0010	0.0130	0.0060
B05	20110531	7.57	32	18	10	39	4.4	5	3	0.13	0.01	0.05	0.13	0.7000	0.0640	0.1890	0.0440	0.0060
B05	20110825	7.87	34	23	12	36	2.8	4	7	0.18	0.14	0.21	0.02	0.0060	0.0010	0.0120	0.0060	0.0020
B05	20120125	8.02	33	19	9	39	3.3	4	5	0.06	0.01	0.05	0.24	0.1450	0.0210	0.1430	0.0190	0.0060
B19	20101007	6.75	138	84	46	118	5.5	168	399	0.14	0.10	0.50	0.48	0.1600	3.3900	0.3310	0.0100	0.0060
B19	20110118	6.79	122	78	44	94	5.0	156	330	0.13	0.01	0.05	0.56	0.0360	2.9550	0.0840	0.0190	0.0060
B19	20110531	7.02	110	71	43	101	6.1	160	266	0.01	0.10	0.50	0.49	0.1000	1.6410	0.2530	0.0120	0.0060
B19	20110825	7.74	115	65	45	94	4.4	120	274	0.18	0.16	0.37	0.02	0.0060	1.4330	0.1080	0.0060	0.0020
B19	20120125	7.00	95	50	38	91	3.8	176	221	0.07	0.01	0.05	0.60	0.0270	0.2960	0.1990	0.0150	0.0060
B20	20101007	9.88	37	1	0	76	1.2	22	11	0.01	0.01	0.05	1.89	0.2700	0.2400	0.4910	0.1200	0.0060
B20	20110118	9.98	37	4	1	66	1.3	23	11	0.00	0.01	0.05	2.12	0.1250	0.0130	0.2680	0.0800	0.0060
B20	20110531	10.30	39	1	0	81	3.3	24	5	0.00	0.01	0.05	1.46	0.1000	0.0050	0.5010	0.0610	0.0060
B20	20110825	10.11	40	2	0	81	0.7	20	9	0.18	0.16	0.35	1.25	0.0060	0.0010	0.3850	0.0170	0.0020
B20	20120125	10.08	39	1	0	80	1.2	24	10	0.00	0.01	0.06	2.36	0.0920	0.0030	0.5230	0.0600	0.0060
B21	20101007	6.88	142	85	26	160	15.7	117	407	0.05	0.09	0.50	0.70	0.0600	2.2300	1.5470	0.0100	0.0060
B21	20110118	6.83	106	66	21	118	9.2	90	302	0.13	0.29	0.05	0.83	0.0530	1.4060	0.9300	0.0110	0.0060
B21	20110531	6.94	94	54	17	111	10.5	88	250	0.92	0.01	0.05	0.87	0.2000	0.8730	1.0310	0.0150	0.0060
B21	20110825	7.83	134	89	25	164	14.0	90	363	0.21	0.17	0.41	0.03	0.0060	1.7450	1.6130	0.0060	0.0020
B21	20120125	8.28	123	69	24	169	13.2	119	332	0.26	0.10	0.50	0.58	0.0520	0.2040	1.5170	0.0150	0.0060
B22	20101007	6.70	19	7	4	26	2.6	17	4	0.32	0.01	0.05	0.13	0.1100	0.2000	0.1660	0.0200	0.0060
B22	20110118	6.83	17	8	4	23	2.5	16	1	0.35	0.03	0.05	0.24	0.0820	0.0450	0.0190	0.0130	0.0060
B22	20110531	6.98	20	8	5	26	4.1	16	1	0.27	0.01	0.05	0.14	4.5000	0.1440	0.1640	0.0100	0.0060
B22	20110825	7.91	21	12	7	24	2.3	12	1	0.32	0.14	0.37	0.02	0.6820	0.1890	0.0300	0.1090	0.0020
B22	20120125	6.99	21	13	3	26	2.7	14	3	0.35	0.10	0.05	0.31	1.2440	0.0550	0.1510	0.0390	0.0060

* Surface water sites supposed to contain clean water.

Table 25. Water Quality of Auger Hole & Shallow Pit Sites.

Site No.	Date	pH	EC mS/m	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	SO4 mg/L	F mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NH ₄ -N mg/L	Fe mg/L	Mn mg/L	B mg/L	Al mg/L	Cr mg/L
T01	20070613	3.05	531	528	340	69	6.6	13	4799	14.94	0.62	0.05	3.26	75.0000	27.8000	1.0400	382.0000	0.0100
T01	20070906	2.93	534	574	361	86	8.2	14	5430	2.50	0.46	0.05	0.34	86.1500	33.7000	1.1490	479.8000	0.0160
D01	20110118	7.04	192	304	59	113	20.9	80	922	0.13	0.10	0.50	0.30	0.0390	0.0290	1.7310	0.0140	0.0060
D01	20110531	9.34	170	174	6	187	38.6	141	594	0.54	0.10	0.54	0.34	0.0000	0.0590	2.0670	0.2190	0.0250
D01	20110825	7.62	194	212	25	191	26.6	139	706	0.24	0.01	0.06	2.45	0.5680	1.3070	2.1700	0.0060	0.0020
D01	20120125	7.46	234	275	109	161	13.4	237	1050	0.10	0.10	0.50	0.39	0.0330	0.0250	3.1130	0.0190	0.0060
D02	20101112	3.35	55	27	13	29	2.3	69	162	0.08	0.01	0.01	0.21	3.7920	6.5860	0.1500	0.3620	0.0060
D03	20101112	4.23	203	181	48	205	6.8	180	928	1.41	0.10	0.31	0.18	0.1130	0.2120	2.0980	4.7940	0.0060
D03	20110118	6.71	254	243	63	267	40.7	242	787	0.12	0.10	0.50	6.88	0.4950	1.6380	1.2360	0.0270	0.0060
D03	20120125	6.47	274	219	68	358	26.1	323	919	0.10	0.10	0.50	3.50	0.1450	1.2510	1.4090	0.0140	0.0060
D04	20101112	7.26	348	535	96	201	17.6	161	1910	0.24	0.01	0.50	0.36	0.0260	11.7610	3.2800	0.0120	0.0060
D04	20110118	7.09	365	556	149	251	30.6	147	2083	0.13	0.09	0.40	0.51	0.0390	11.5400	2.3730	0.0020	0.0060
D04	20110825	7.59	393	532	173	305	24.9	183	2029	0.18	0.10	0.31	0.02	0.0060	5.5040	2.1650	0.0060	0.0020
D04	20120125	6.89	331	453	138	234	20.3	132	1732	0.10	0.10	0.50	0.60	0.0450	4.3300	2.9880	0.0100	0.0060
D04	20120308	6.72	354	495	158	269	23.5	172	2102	0.27	0.10	0.50	0.82	0.1150	4.5140	3.1670	0.0120	0.0060
D05	20101112	7.59	236	177	38	281	37.9	168	914	0.28	0.86	0.09	1.96	0.1790	1.1320	2.1850	0.1530	0.0060
D05	20110118	7.07	159	117	34	173	20.6	130	524	0.19	0.10	1.43	0.31	0.0620	0.7370	1.1780	0.0420	0.0060
D05	20110825	7.67	219	191	40	239	27.5	178	775	0.28	0.10	1.00	0.02	0.0060	3.4650	1.4020	0.0060	0.0020
D05	20120125	7.14	92	72	17	114	16.8	71	221	0.27	0.01	0.20	0.27	0.0940	0.0270	1.0150	0.0760	0.0060
D05	20120308	7.12	142	121	31	159	25.6	121	376	0.33	0.10	0.50	0.45	0.0250	0.7050	1.5070	0.0270	0.0060
D06	20101112	6.15	396	453	177	286	56.5	69	2632	0.88	0.16	5.84	1.54	0.1590	29.3000	1.5270	0.3270	0.0060
D06	20110118	5.80	366	499	244	214	11.8	92	2594	0.27	0.10	0.50	0.85	0.1060	23.2350	1.4860	0.1130	0.0060
D06	20110531	5.67	406	425	240	235	11.6	97	2497	0.24	0.10	0.50	0.53	0.1000	37.8870	1.3250	0.2040	0.0060
D06	20110825	4.32	390	449	273	253	9.8	92	2505	0.18	0.01	0.06	1.20	0.0060	31.6810	1.2850	22.3620	0.0020
D06	20120125	4.31	390	504	260	225	8.9	92	2575	0.41	0.10	0.50	0.62	0.0690	16.5510	1.8660	17.5200	0.0060
D07	20101112	5.66	21	16	9	16	5.5	13	80	0.03	0.01	0.27	1.03	0.0760	0.8650	0.3700	0.1070	0.0060
D07	20110118	7.31	82	23	6	144	30.3	9	92	0.34	0.03	1.13	0.31	0.0820	0.1630	0.2760	0.0990	0.0060
D07	20110531	7.30	83	20	9	139	20.9	6	66	0.25	0.14	0.53	0.80	0.1000	0.4820	0.3460	0.2420	0.0060
D07	20110825	7.20	83	57	12	97	26.2	47	267	0.22	0.15	0.35	0.02	0.0060	0.1850	0.5050	0.3490	0.0020
D07	20120125	6.24	77	61	16	64	12.6	14	293	0.05	0.01	0.30	0.27	0.0680	0.3460	0.6970	0.0620	0.0060

* Surface water sites supposed to contain clean water.

Table 26. Water Quality of Surface Water Sites.

Site No.	Date	pH	EC mS/m	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	SO4 mg/L	F mg/L	NO ₂ -N mg/L	NO ₃ -N mg/L	NH ₄ -N mg/L	Fe mg/L	Mn mg/L	B mg/L	Al mg/L	Cr mg/L
P09	20101007	11.00	204	204	1	197	37.6	143	699	1.26	0.13	0.91	0.35	0.0500	0.0500	2.1740	0.7000	0.0480
P09	20110118	10.70	188	177	3	193	31.7	143	660	0.84	0.10	0.62	0.36	0.0420	0.0520	1.8040	0.4630	0.0500
P09	20110531	7.59	178	191	1	180	36.9	132	568	1.05	0.10	0.87	0.23	0.0000	0.0060	1.8320	0.7670	0.0410
P09	20110825	10.67	172	157	1	178	33.3	122	612	1.34	0.29	1.24	0.09	0.0060	0.0010	1.7560	1.0590	0.0020
P09	20120125	10.50	170	167	3	198	34.6	118	630	0.38	0.10	0.98	0.26	0.0410	0.0320	1.9080	0.8880	0.0350
*P13	20110118	4.98	93	128	35	14	4.6	11	505	0.29	0.10	0.50	0.23	0.0500	4.7770	0.1820	0.3910	0.0060
*P13	20110825	4.31	162	225	68	25	12.1	22	969	0.18	0.01	0.06	0.47	0.0060	11.9890	0.3460	27.0350	0.0020
*P13	20120125	5.78	115	161	54	27	6.3	12	659	0.11	0.10	0.50	0.25	0.0530	2.3050	0.4130	0.1500	0.0060
*C01	20101007	7.50	283	179	32	401	72.1	305	808	0.18	0.10	0.50	0.12	0.0700	0.0700	7.8840	0.0100	0.0060
*C01	20110118	7.16	149	124	8	157	28.9	127	448	0.88	0.10	0.50	0.30	0.0790	0.0240	1.9080	0.0150	0.0060
*C01	20110825	7.21	154	91	5	199	38.8	100	405	0.38	0.14	0.31	2.59	0.0060	0.2270	3.3010	0.0060	0.0020
*C01	20120125	7.87	157	108	8	217	31.0	183	398	0.10	0.10	0.50	0.38	0.1080	0.0240	3.3080	0.0210	0.0060
*C02	20101007	6.23	311	498	146	137	32.6	92	1923	0.27	0.10	0.50	0.45	0.0900	6.2000	2.1810	0.0500	0.0060
*C02	20110118	6.96	159	171	29	117	22.8	92	662	0.10	0.10	0.50	0.30	0.2590	0.6510	1.8380	0.0150	0.0060
*C02	20110531	8.97	161	124	4	191	44.5	154	517	0.49	0.10	0.50	0.37	0.0000	0.0270	2.4690	0.2920	0.0150
*C02	20110825	7.64	195	254	24	136	30.5	80	748	0.67	0.14	0.31	0.02	0.0060	2.4740	1.7580	0.0060	0.0020
*C02	20120125	6.28	160	174	4	168	27.6	97	638	0.14	0.10	0.50	0.67	0.0440	0.5680	1.7880	0.0730	0.0060
*C03	20101007	7.79	226	189	24	292	49.0	224	709	0.20	0.10	0.50	0.17	0.0800	0.0700	4.0370	0.0100	0.0060
*C03	20110118	7.69	172	155	6	182	31.9	143	587	0.82	0.10	0.50	0.29	0.0420	0.0240	2.4450	0.0710	0.0100
*C03	20110531	8.05	170	146	8	203	39.5	160	543	0.35	0.10	0.50	0.34	0.0000	0.0520	2.9140	0.0480	0.0060
*C03	20110825	7.88	159	103	7	194	39.5	104	435	0.36	0.14	0.35	0.02	0.0060	0.0020	2.9130	0.0060	0.0020
*C03	20120125	7.92	258	294	40	284	32.1	281	974	0.10	0.10	0.50	0.54	0.0370	0.4780	3.8380	0.0150	0.0060
*C04	20101007	7.28	162	166	38	141	17.1	102	602	0.28	0.10	0.50	0.19	0.1300	0.1800	1.0600	0.0100	0.0060
*C04	20110118	7.00	113	121	35	61	5.9	48	419	0.31	0.01	0.06	0.18	0.0580	0.0740	0.5040	0.0090	0.0060
*C04	20110531	6.86	166	190	56	118	9.4	99	631	0.20	0.10	0.50	0.76	0.1000	0.0470	0.8140	0.0080	0.0060
*C04	20110825	7.58	197	228	61	135	9.7	99	751	0.24	0.14	0.71	0.02	0.0060	4.4070	0.7170	0.0060	0.0020
*C04	20120125	6.96	170	206	58	136	11.6	117	673	0.10	0.10	0.50	0.30	0.0420	0.0290	1.2950	0.0140	0.0060
*C05	20101007	7.63	110	106	27	87	13.5	70	374	0.49	0.01	0.05	0.19	0.0900	0.0400	0.9260	0.0300	0.0060
*C05	20110118	6.59	65	60	23	38	2.8	22	210	0.17	0.01	0.05	0.22	1.9610	0.0160	0.2210	0.0400	0.0060
*C05	20110531	11.50	224	240	1	173	35.2	133	585	0.90	0.10	0.49	0.34	0.0000	0.0060	1.8220	0.6350	0.0350
*C05	20110825	7.60	202	214	83	121	14.7	106	792	0.53	0.13	0.31	0.02	0.0060	0.0010	1.4300	0.0060	0.0020
*C05	20120125	6.69	45	37	8	36	4.6	19	134	0.22	0.01	0.05	0.22	0.0930	0.0220	0.4910	0.0580	0.0060
*C06	20101007	7.75	244	212	35	313	47.4	213	840	0.19	0.10	0.50	0.23	0.1400	0.1400	3.9850	0.0100	0.0060
*C06	20110118	7.46	167	151	7	184	31.8	138	569	0.18	0.10	0.50	0.16	0.0710	0.0090	2.3270	0.0390	0.0060
*C06	20110531	8.21	1674	132	5	200	39.8	152	490	0.41	0.10	0.50	0.27	0.1000	0.0140	3.0130	0.1590	0.0060
*C06	20110825	8.09	165	125	11	196	38.0	108	487	0.37	0.13	0.31	0.02	0.0060	0.0200	2.8850	0.0060	0.0020
*C06	20120125	7.76	203	237	44	225	26.1	133	804	0.10	0.10	0.50	0.19	0.0550	0.2570	2.6380	0.0200	0.0060
*C07	20101007	7.96	252	214	39	319	49.2	217	860	0.25	0.10	0.50	0.22	0.1000	0.0700	3.8930	0.0200	0.0060
*C07	20110118	7.80	167	150	7	183	31.5	138	563	0.52	0.10	0.50	0.14	0.0460	0.0090	2.3250	0.0180	0.0060
*C07	20110531	8.04	167	140	7	199	39.0	154	502	0.50	0.10	0.50	0.23	0.1000	0.0250	2.9170	0.1320	0.0060
*C07	20110825	8.05	165	119	10	194	36.7	102	475	0.38	0.13	0.30	0.02	0.0060	0.0340	2.8130	0.0060	0.0020
*C07	20120125	7.95	190	210	44	197	23.3	186	696	0.10	0.10	0.50	0.20	0.0530	0.1480	2.3650	0.0200	0.0060
*C27	20101007	7.31	88	92	13	75	13.1	54	287	0.54	0.01	0.05	0.36	0.1200	0.7200	0.7690	0.0600	0.0060
*C27	20110118	7.58	114	125	38	64	5.5	40	481	0.39	0.04	0.05	0.28	0.0620	0.2030	0.6180	0.0200	0.0060
*C27	20110531	11.00	186	213	1	182	37.4	139	562	0.77	0.10	0.46	0.28	0.0000	0.0050	1.9260	0.3260	0.0240
*S01	20110118	7.20	114	136	39	58	5.4	40	491	0.37	0.01	0.50	0.19	0.0850	0.1720	0.6140	0.0160	0.0060
*S01	20110531	11.70	290	345	0	160	31.5	124	566	1.42	0.10	0.82	0.23	0.0000	0.0050	1.0060	0.2260	0.0680
*S01	20110825	10.06	206	315	1	166	23.0	114	943	1.35	0.28	0.99	0.46	0.0060	0.0010	1.1280	0.5210	0.0030
*S01	20120125	7.67	278	321	144	195	10.9	94	1523	0.10	0.10	0.50	0.30	0.0310	0.0300	2.4120	0.0270	0.0060
*S04	20101007	5.27	239	410	128	72	17.8	41	1777	3.41	0.10	1.21	1.64	0.2100	15.4900	0.6260	1.1000	0.0060
*S04	20110118	6.73	88	84	41	40	3.1	16	309	0.49	5.83	0.11	0.33	1.8000	4.0000	0.1290	0.1000	0.0060
*S04	20110825	7.65	242	291	52	214	29.7	142	1071	0.82	0.01	0.06	0.02	0.0060	0.0040	1.7750	0.0060	0.0020
*S04	20120125	7.79	137	199	60	75	10.4	122	505	0.10	0.10	0.50	0.28	0.0690	0.0320	0.7280	0.0250	0.0060

* Surface water sites supposed to contain clean water.

8 IMPACT ASSESSMENT

The following section is based on information obtained from the current investigations done on the three candidate sites.

8.1 Potential Contaminant Impacts

An average hydraulic conductivity (K) value of 8.5×10^{-6} m/s was calculated from the results of the sieve analyses which were done on ash samples from Camden Power Station. An estimated average seepage velocity (q) of 1.0×10^{-6} m/s or 34 m/year was obtained. From these results, it is evident that large quantities of contaminated water, depending on the size of the ash dam can seep into the underlying sediments to eventually reach the ground-water table. The amount of water, as well as the rate of infiltration, will furthermore depend on the under-drainage of the ash dam and the hydraulic properties of the underlying sediments respectively.

The areas most vulnerable to this type of contamination are those with a high water table, and those with high rainfall. The rainfall of the Camden Power Station area is moderate (726 mm/a) and therefore the area should be potentially more vulnerable to groundwater contamination or water quality impacts. From the information gathered from current monitoring sites in the vicinity of the ashing area, during the field investigations, it could be concluded that the groundwater tables at the proposed sites are between 2 and 4 mbgl, which increases the aquifer vulnerability. All three the proposed candidate sites are situated on the topographic heights and therefore it might be possible that the water table could be deeper at these sites. A recharge of 2% - 3% of the rainfall was estimated during previous investigations for the natural area under investigation.

It was found in previous studies that Power Station Ashing Facilities is mainly a source of inorganic contamination. Potential contaminants include but are not limited to sulphate, calcium, sodium, chloride, iron, manganese, boron and aluminium.

From the results of the Acid Base Accounting investigation done on ash samples from Camden Power Station none of the ash samples poses a risk for acid generation. All of the samples have positive net neutralising potential values and are therefore unlikely to be acid generating. The neutralising potential of the ash is very high and are able to buffer oxidation and acidification where the potential of acidification exist.

The results from the XRD analyses shows that due to the presence of Mullite (silicate mineral (Al₆Ai₂O₁₃)) Quarts (silicate mineral (SiO₂)), Piroxene (inosilicate mineral (Si,Al)₂O₆) and Calcite (Carbonate mineral (CaCO₃)) in almost all the samples acidification is unlikely to happen due to excess amounts of CaO available to buffer oxidation and prevent acidification.

8.2 Assessment of Flag Conditions

The flag conditions of the three candidate sites were evaluated and the following conclusions were made.

8.2.1 Candidate Site 1

The surface drainage at Candidate Site 1 is basically in two directions, both towards the Witpunt Spruit. The one surface drainage slopes from south to north-west towards a small non-perennial tributary of the Witpunt Spruit which was sampled at point FBR14. This stream is currently unpolluted and is located approximately 0.3 km from Candidate Site 1 and discharges 0.4 km further downstream into the Witpunt Spruit. The second drainage is from south-west to north-east

and then from west to east towards the tributary of the Witpunt Spruit currently under influenced of the current ashing facility. Sample points along this stream are part of Camden Power Station monitoring system and are sampled on a regular basis. This tributary flows into the Witpunt Spruit approximately 1.5 km to the east of Candidate Site 1.

The results of the top soil permeabilities calculated at Candidate Site 1 reveal a moderate permeability of 4.2 m/d. Porosity for the overlying soil profiles were calculated and are 53%. It is expected that potential pollutants from an ash stack will migrate relatively quickly, 0.2 m/day or 59 m/year, through the unsaturated zone due to the moderate permeabilities and to a lesser extent the thickness of the zone and therefore increases the aquifer vulnerability of the shallow perched aquifer.

Due to the limited data of the boreholes located in the vicinity of Candidate Site 1 only three groundwater elevation measurements could be taken. These levels are between 5 and 8.5 mbgl. However during the drilling of the auger holes no water was intercepted to a depth of 2 mbgl. Borehole FBB23 which is equipped with an old damaged hand / wind pump is situated directly in the middle of this area.

It can be deduced from the geophysical investigation that the Candidate Site 1 area is underlay by an unweathered dolerite sill. When evaluating the borehole logs from previous investigations in the vicinity of the current ash dam it can be conclude the dolerite sills in the area are at a relative depth of 7 to 15 mbgl and with thickness varying between from 9 m to 60 m. This impermeable geological structure is most instances accomplished by another relative impermeable sedimentary deposit of shale occurring at a depth of between 2 m and 7 m. These two formations underlies most of the areas forming an impermeable layer which assist in the containment of the polluted water. Some sandstone layers are however slightly weathered to course, which might result in preferred pathways for contaminants.

8.2.2 Candidate Site 2

The topography slopes from west to east, towards a small non-perennial tributary of the Witpunt Spruit. This stream was sampled at FBR09 during previous monitoring phases but was dry during this investigation. This unpolluted tributary originates in the area of Candidate Site 2 and discharge 3.2 km further downstream into the Witpunt Spruit.

The results of the top soil permeabilities calculated at Candidate Site 2 reveal a relative low permeability of 1.5 m/d. Porosity for the overlying soil profiles were calculated and are 51%. It is expected that potential pollutants from an ash stack will migrate relatively quickly, 0.1 m/day or 39 m/year, through the unsaturated zone due to the moderate to low permeabilities and to a lesser extent the thickness of the zone and therefore increases the aquifer vulnerability of the shallow perched aquifer.

Due to the limited data of the boreholes located in the vicinity of Candidate Site 2 no groundwater elevation measurements could be taken. However during the drilling of the auger holes no water was intercepted to a depth of 2 mbgl. A borehole, labelled FBB26, equipped with a hand / wind pump that is in a good working order is situated in the middle of the area. This borehole is used as a production hole for livestock and domestic purposes. The sample collected during the hydrocensus reveal only elevated concentrations of nitrate which probably originated from agriculture activities.

It can be deduced from the geophysical investigation that the Candidate Site 2 area is underlay by an unweathered dolerite sill. When evaluating the borehole logs from previous investigations in the vicinity of the current ash dam it can be conclude the dolerite sills in the area are at a relative depth of 7 to 15 mbgl and with thickness varying between from 9 m to 60 m. This impermeable

geological structure is most instances accomplished by another relative impermeable sedimentary deposit of shale occurring at a depth of between 2 m and 7 m. These two formations underlie most of the areas forming an impermeable layer which assist in the containment of the polluted water. Some sandstone layers are however slightly weathered to course, which might result in preferred pathways for contaminants.

8.2.3 Candidate Site 3

The drainage of Candidate Site 3 slopes in two major directions (south-west to north-east towards the De Jager Pan and a north-east to south-west towards two non-perennial tributaries of the Vaal River. The southern tributary originates on the boundary of the area. The two unpolluted tributaries were sampled at FBR12 and FBR13 and are less than 0.3 km from the site. Candidate Site 3 is located approximately 0.2 km from the De Jager Pan and approximately 13 km upstream from the Vaal River. De Jager Pan is used as a ash water return dam from the start of the Power Station.

The results of the top soil permeabilities calculated at Candidate Site 3 reveal a relative low permeability of 1.3 m/d. Porosity for the overlying soil profiles were calculated and are 42%. It is expected that potential pollutants from an ash stack will migrate relatively slowly, 0.03 m/day or 13 m/year, through the unsaturated zone due to the low permeabilities and to a lesser extent the thickness of the zone and therefore increases the aquifer vulnerability of the shallow perched aquifer.

Due to the limited data of the boreholes located in the vicinity of Candidate Site 3 no groundwater elevation measurements could be taken. However during the drilling of the auger holes no water was intercepted to a depth of 2 mbgl.

It can be deduced from the geophysical investigation that the Candidate Site 3 area is underlay by an unweathered dolerite sill. When evaluating the borehole logs from previous investigations in the vicinity of the current ash dam it can be conclude the dolerite sills in the area are at a relative depth of 7 to 15 mbgl and with thickness varying between from 9 m to 60 m. This impermeable geological structure is most instances accomplished by another relative impermeable sedimentary deposit of shale occurring at a depth of between 2 m and 7 m. These two formations underlie most of the areas forming an impermeable layer which assist in the containment of the polluted water. Some sandstone layers are however slightly weathered to course, which might result in preferred pathways for contaminants.

9 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are based on the information supplied in this report:

- **Candidate Site 1**

- Candidate Site 1 is the most suitable area for constructing a new ash dam
- If Candidate Site 1 is used, the ash dam must be built on the eastern side of this area as far away as possible from the stream north-west of the area.
- It is also advisable that the entire ash dam must be constructed on the west to east slopes of the drainage area.
- Borehole FBB23 must be sealed properly with a cement bentonite mixture to prevent pollutants to enter the groundwater regime directly.
- Trenches can be constructed around the ashing facility to minimise the spreading of pollutants through the shallow perched aquifer.
- The shallow perched aquifer serves as recharge zone along preferential pathways for the deep exploitable aquifer (aquifer that can be utilised for production purposes). However the hydrochemical data gathered during the last two decades from the deep aquifer in the vicinity of the ash stack shows little or no signs of pollution.

- **Candidate Site 2.**

- Candidate Site 2 got two major fatal flaws, the production borehole FBB26 and the origin of a tributary of the Witpunt Spruit which drains eventually into the Vaal River.
- If this area is used, the ash dam must be built on the northern side of this area as far away as possible from the stream draining east of the area.
- Borehole FBB26 must be sealed properly with a cement bentonite mixture to prevent pollutants to enter the groundwater regime directly.
- Trenches can be constructed around the ashing facility to minimise the spreading of pollutants through the shallow perched aquifer.
- The shallow perched aquifer serves as recharge zone along preferential pathways for the deep exploitable aquifer (aquifer that can be utilised for production purposes). However the hydrochemical data gathered during the last two decades from the deep aquifer in the vicinity of the ash stack shows little or no signs of pollution.

- **Candidate Site 3.**

- Candidate Site 3 got one major fatal flaw, the origin of a tributary of a stream which drains eventually into the Vaal River.
- If this area is used, the ash dam must be built on the north-eastern side of this area as far away as possible from the stream draining west of the area.
- The close proximity of production borehole FBB17 is also a reason of concern.
- Trenches can be constructed around the ashing facility to minimise the spreading of pollutants through the shallow perched aquifer. T
- The shallow perched aquifer serves as recharge zone along preferential pathways for the deep exploitable aquifer (aquifer that can be utilised for production purposes). However the hydrochemical data gathered during the last two decades from the deep aquifer in the vicinity of the ash stack shows little or no signs of pollution.

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4 Junie 2012

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Date