Appendix H – Other Documents

Appendix H1 – Stormwater Management Plan

Zitholele Consulting
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TECHNICAL MEMORANDUM

PROJECT NAME: **Duvha WULA Amendment**

PROJECT NO: **15008**

TO: **Eskom Holdings SOC Ltd – Morongwa Molewa**

DATE: **30 May 2017**

FROM: **Ms Jyothika Heera**

EMAIL **molewaME@eskom.co.za**

SUBJECT **Duvha Power Station Stormwater Management Plan**

DOCUMENT CONTROL SHEET

Project Title: **Duvha PS Stormwater Management Plan and Water Balance.**

Project No: **15008**

Document Ref. No: 15008-45-Mem-001-Duvha PS Stw Management Plan Rev0

DOCUMENT APPROVAL

ACTION	DESIGNATION	NAME	DATE	SIGNATURE
Prepared	Civil Engineering Technologist	Jyothika Heera	30.05.2017	
Reviewed	Project Engineering Lead & Reviewer	Nevin Rajasakran	30.05.2017	
Approved	Eskom Project Manager	Morongwa Molewa	30.05.2017	

RECORD OF REVISIONS

Date	Revision	Author	Comments
22.02.2017	Draft 1	JH	Issued for comments.
30.05.2017	Draft 2	JH	Dust suppression at Coal Stockyard added.

1 INTRODUCTION

Duvha Power Station, owned and operated by Eskom is a coal fired power station located in Witbank, Mpumalanga Province. The Power Station has six power generating units with a combined capacity of 3,600MW. The location of the Power Station is shown on **Figure 1**.

Construction on the Power Station started in 1975 and the first unit was commissioned in 1984. Although this pre-dates the Environmental Conservation Act (ECA, 1989) and obviously any subsequent amendments and related legislation, the operations are environmentally compliant and they strive to maintain this. In 1993 Duvha became the first power station in the world to be retrofitted with pulse jet fabric filter plants on three of its six units. This contributes largely to the reduction of air pollution by removing 99.99% of the fly ash, which otherwise would be released into the air through the station's chimneys. This is testimony to the Power Station's commitment to greener operations and perseverance for environmental compliance.

From a water management perspective, the Power Station is located in quaternary catchment B11G which is located within the Olifants River Water Management Area. All impacted stormwater generated on-site is contained and managed on site whilst clean water is diverted around the site to a tributary which ultimately drains to the Witbank Dam. The stormwater management system at the power station complex can be delineated into three main areas as follows:

- Power Station terrace which includes the main power generating units and the power island;
- Coal stockyard and associated infrastructure;
- Ash Disposal Facility and associated infrastructure

The above areas are shown on **Figure 2.**

2 STORMWATER MANAGEMENT PLAN

The stormwater management system, grouped in the main areas as described in the previous section, is explained in the following sections. **Figure 2** shows the general arrangement of the infrastructure as discussed below.

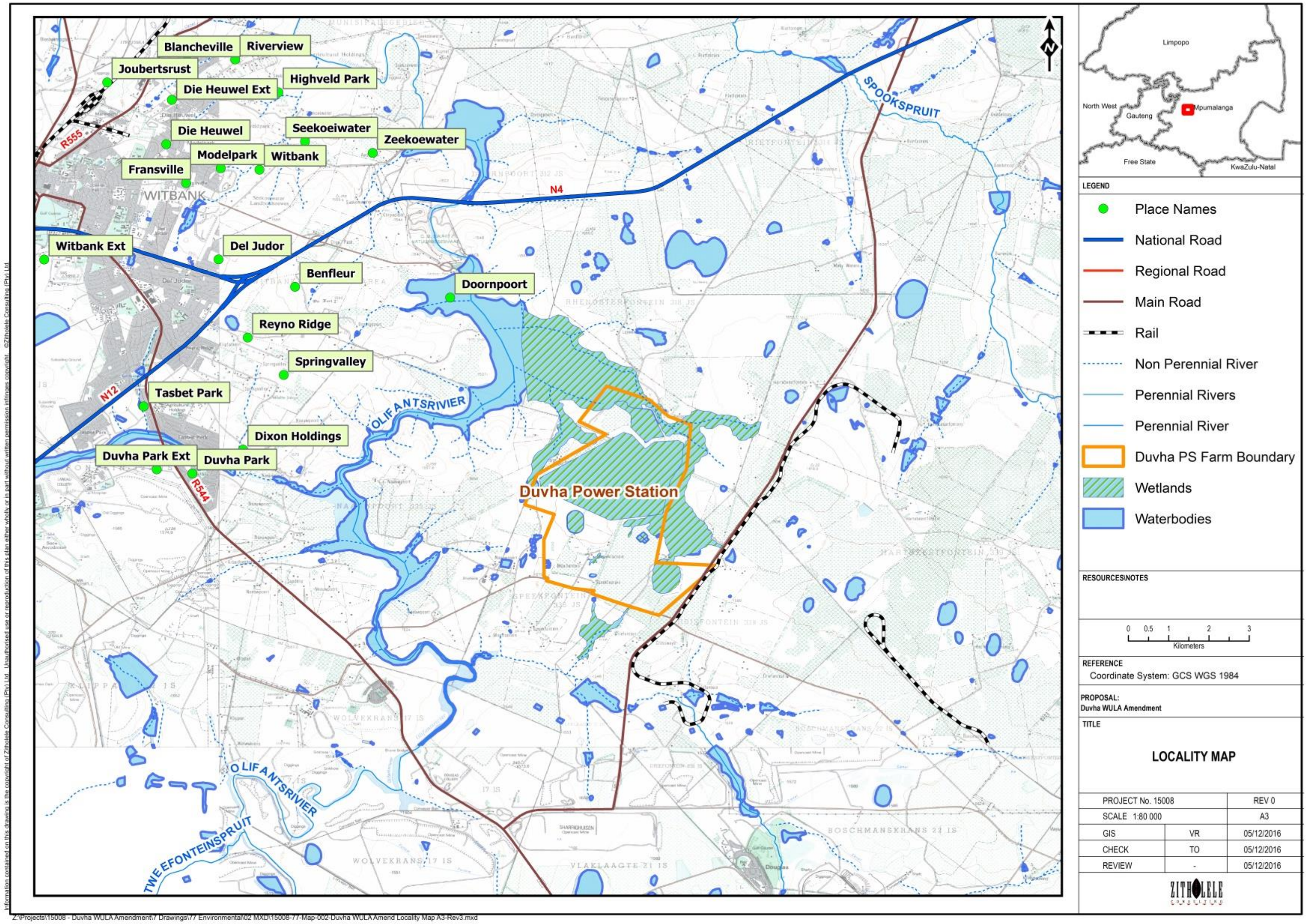


Figure 1: Locality Map of Duvha Power Station

Figure 2: Layout of Duvha Power Station

2.1 Power Station Terrace

The Power Station Terrace covers a footprint area of approximately 91 ha. Due to the nature of the operations at coal fire power stations, Duvha Power Station have opted for a more conservative approach when it comes to the discretization of dirty and clean areas within the power station terrace. This ensures that impacted stormwater does not make its way to the receiving clean environment. All areas within the terrace are declared as contaminated and this water is managed accordingly.

The Power Station is positioned on a localised high point therefore clean stormwater from the surrounding areas does not make its way onto the power station terrace. Perimeter drains along the western boundary is provided to intercept stormwater that does approach this area to be diverted to the nearby tributary.

Impacted stormwater, along with drainage from the cooling water systems and boilers, is collected in a series of concrete lined channels designed to contain a 1 in 50 year storm event without overtopping. This water eventually drains to the station drains, dirty water dams, located at the north-eastern corner of the power station terrace. These dams act as evaporation ponds. Overflow from this area is conveyed to the lower positioned Low Level Dam by gravity via a concrete lined channel. The station drains are equipped with oils and grease traps that remove them from suspension and dispose it to a licenced hazardous waste facility.

2.2 Coal Stockyard

The Coal Stockyard is located to east of the Power Station Terrace and covers a footprint area of approximately 36 ha. Concrete lined perimeter drains around the facility intercept runoff generated in this area and convey it to the stations drains (dams) located to the immediate north-east of the stockyard. As mentioned previously, these dams serve as evaporation dams and its overflow gravitates to the Low Level Dam. The perimeter drains are designed to handle a 1 in 50 year storm event without overtopping. Water from the High Level Dam (HLD) is used at the Coal Stockyard (CSY) for dust suppression purposes. Water carts are used to transport the water from the HLD to the CSY. A total flow of 576 m^3/day is used.

2.3 Ash Disposal Facility

The Ash Disposal Facility (ADF) covers a footprint area of approximately 485 ha. Duvha Power Station operates a wet ashing facility which means that the ash is mixed with water, at a ratio of water to ash of 10:1, and is hydraulically disposed to the ADF in a slurry form. The ash is allowed to settle out of solution (in the slurry) and is decanted via concrete penstocks located at various points on the facility. The penstocks, or concrete pipes, discharge to concrete lined perimeter drains located at the toe of the facility. This channel discharges to the Low Level Dam. Runoff from the side slopes of the facility are intercepted by bench drains which eventually drain to the toe perimeter drains.

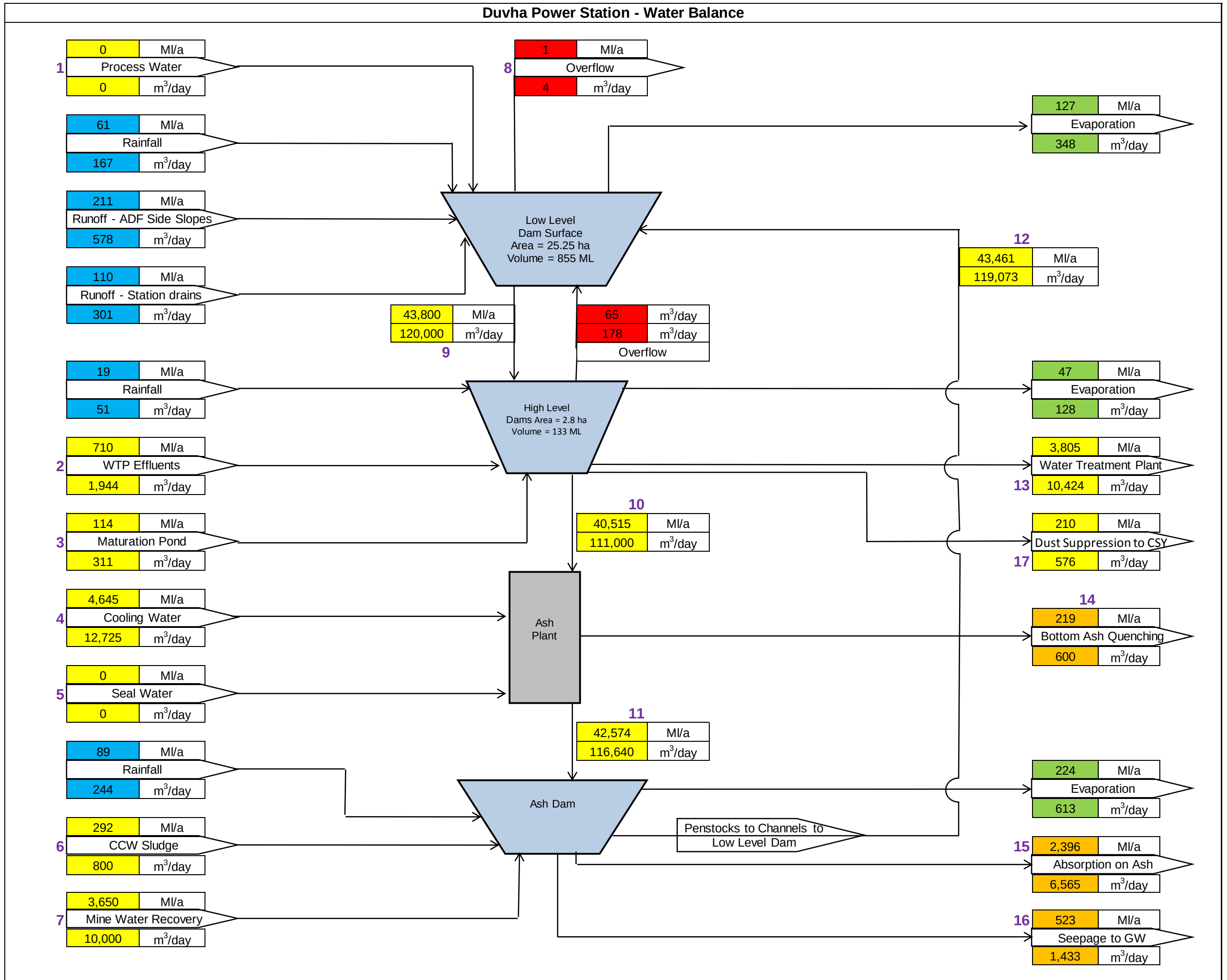
The Low Level Dam is equipped with dual silt traps that allow ash (or silt) to settle out (by gravity) before entering the dams. Each of the silt traps are designed to take full capacity coming from the ADF. The Low Level Dam, with a storage capacity of 855 Mℓ, fulfils the requirements of GN704 by only spilling once over a 50 year period. This dam is located at the lowest point of the power stations operations and inherently becomes the ultimate interception of dirty water runoff from the power station. If this dam spills, contaminated water will make its way to the Witbank Dam, therefore it is deemed essential to control the maximum water level in this dam. This is done by way of level controls that manage the water levels at a safe full supply level of 6 meters. The Low Level Dam operates in tandem with the High Level Dam by pumping water to it when it reaches its maximum storage level.

The High Level Dam is divided into four compartments and has a combined storage capacity of 133 Mℓ. It is designed to serve as a storage reservoir for water to be used in the cooling system as well as the ash plant (slurry make-up water). This dam does not have a catchment draining to it and receives water from the Low Level Dam, the Maturation Ponds and final effluent from the Water Treatment Plant located on site. Overflow from the High Level Dam discharges to a concrete lined channel draining to the Low Level Dam and innately forms a closed circuit with it.

3 STORMWATER BALANCE

The Duvha Power Station stormwater balance model is represented in **Figure 3** below. The existing pollution control dams (PCD) are in compliance with Government Notice 704. More specifically, Clause 6 (d) of the regulation indicates that:

Design, construct, maintain and operate any dirty water system at the mine or activity so that it is not to spill into any clean water system more than once in 50 years.



Dam Name	Dam Volume	% Full	Spills
Low Level Dam (LLD)	769,766	100%	1
High Level Dam (HLD)	94,450	100%	17,179
% Siltation of LLD	10%		

Figure 3: Duvha Power Station Water Balance

4 MAINTENANCE

Duvha Power Station consistently strives to ensure that the stormwater management system is effective at all times by having a maintenance plan in place. Channels are cleaned consistently to maintain its design capacity. Silt traps at the dams are operated on a rotational basis to ensure that there is always adequate capacity. Finer suspended particles do make its way into dams and they require desludging once the effective capacity is shown to be compromised. This is determined via bathymetric surveys conducted bi-annually on the dams.

5 CONCLUSION

Duvha Power Station has an effective stormwater management system is place and with proper operations and maintenance, it will ensure environmental compliance.

Ms Jyothika Heera B.Tech. (Civil Eng.)
Civil Engineering Technologist

Mr. Nevin Rajasakran PrEng PrCPM
Project Engineering Lead

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Appendix H2 – DEA Screening

SCREENING REPORT FOR AN ENVIRONMENTAL AUTHORIZATION OR FOR A PART TWO AMENDMENT OF AN ENVIRONMENTAL AUTHORISATION AS REQUIRED BY THE 2014 EIA REGULATIONS – PROPOSED SITE ENVIRONMENTAL SENSITIVITY

EIA Reference number:

Project name: Duvha Ash Dam Seepage Interception Drains in Mpumalanga Province

Project title: DEA Screening

Date screening report generated: 26/07/2019 07:48:25

Applicant: Eskom Holdings SOC Ltd

Compiler: Nemai Consulting

Compiler signature:

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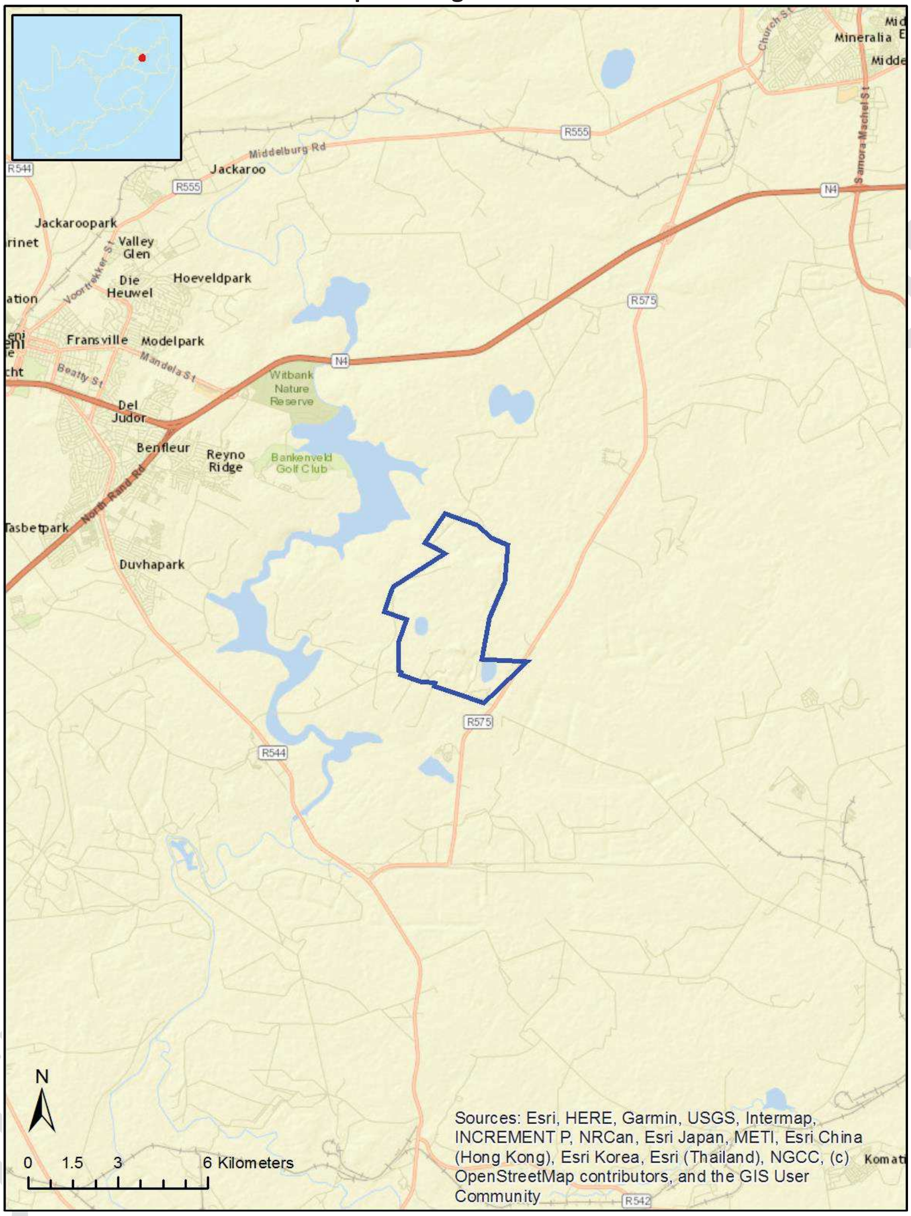
Proposed Project Location

Orientation map 1: General location

General Orientation: Duvha Ash Dam Seepage Interception Drains in Mpumalanga Province



Map of proposed site and relevant area(s)

Cadastral details of the proposed site

Property details:

No	Farm Name	Farm/Erf Number	Portion	Latitude	Longitude
1	SPEEKFONTEIN	336	00000	-25.9761	29.31667
2	DUVHA KRAGSTASIE	337	00000	-25.9527	29.3367
3	DUVHA KRAGSTASIE	337	00000	-25.94674	29.3387

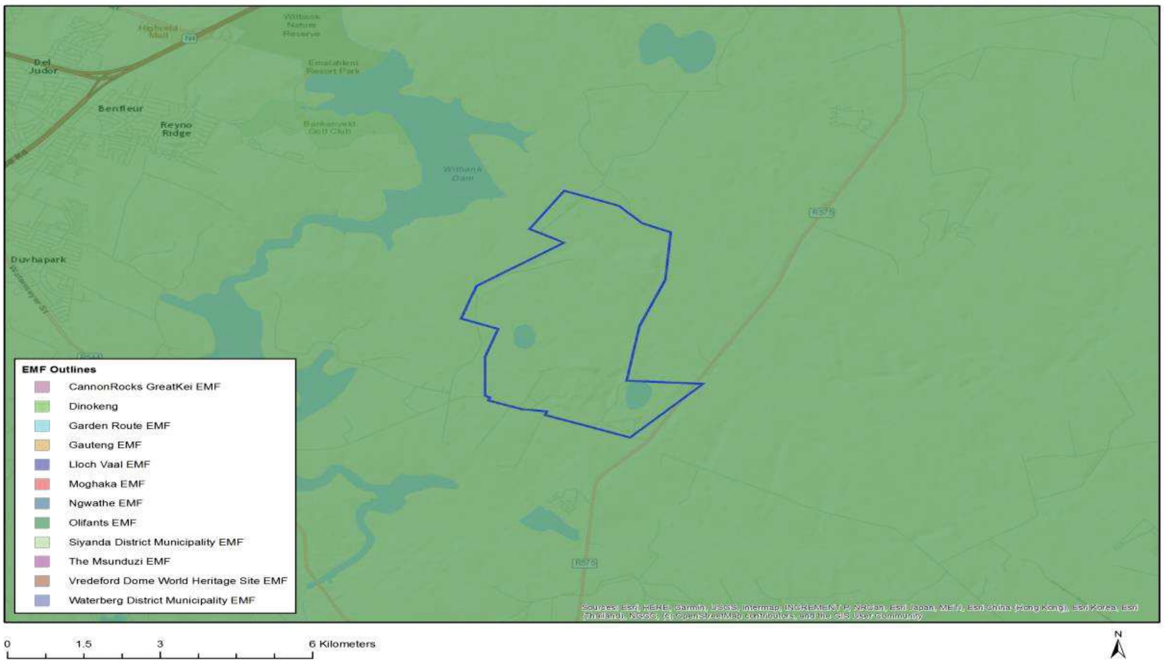
Development footprint[1] details:
No development footprint(s) specified.

Wind and Solar developments with an approved Environmental Authorisation or applications under consideration within 30 km of the proposed area

No	EIA Reference No	Classification	Status of application	Distance from proposed area (km)
1	14/12/16/3/3/2/759	Solar PV	Approved	0

[1] "development footprint", means the area within the site on which the development will take place and incudes all ancillary developments for example roads, power lines, boundary walls, paving etc. which require vegetation clearance or which will be disturbed and for which the application has been submitted.

Environmental Management Frameworks relevant to the application



Environmental Management Framework	LINK
Olifants EMF	https://screening.environment.gov.za/ScreeningDownloads/EMF/Zone_46,_67,_78,_80,_92,_103,_122,_129.pdf

Environmental screening results and assessment outcomes

The following sections contain a summary of any development incentives, restrictions, exclusions or prohibitions that apply to the proposed development site as well as the most environmental sensitive features on the site based on the site sensitivity screening results for the application classification that was selected. The application classification selected for this report is: Utilities Infrastructure|Pipelines|Waste Water|Pipelines - Waste Water.

Relevant development incentives, restrictions, exclusions or prohibitions

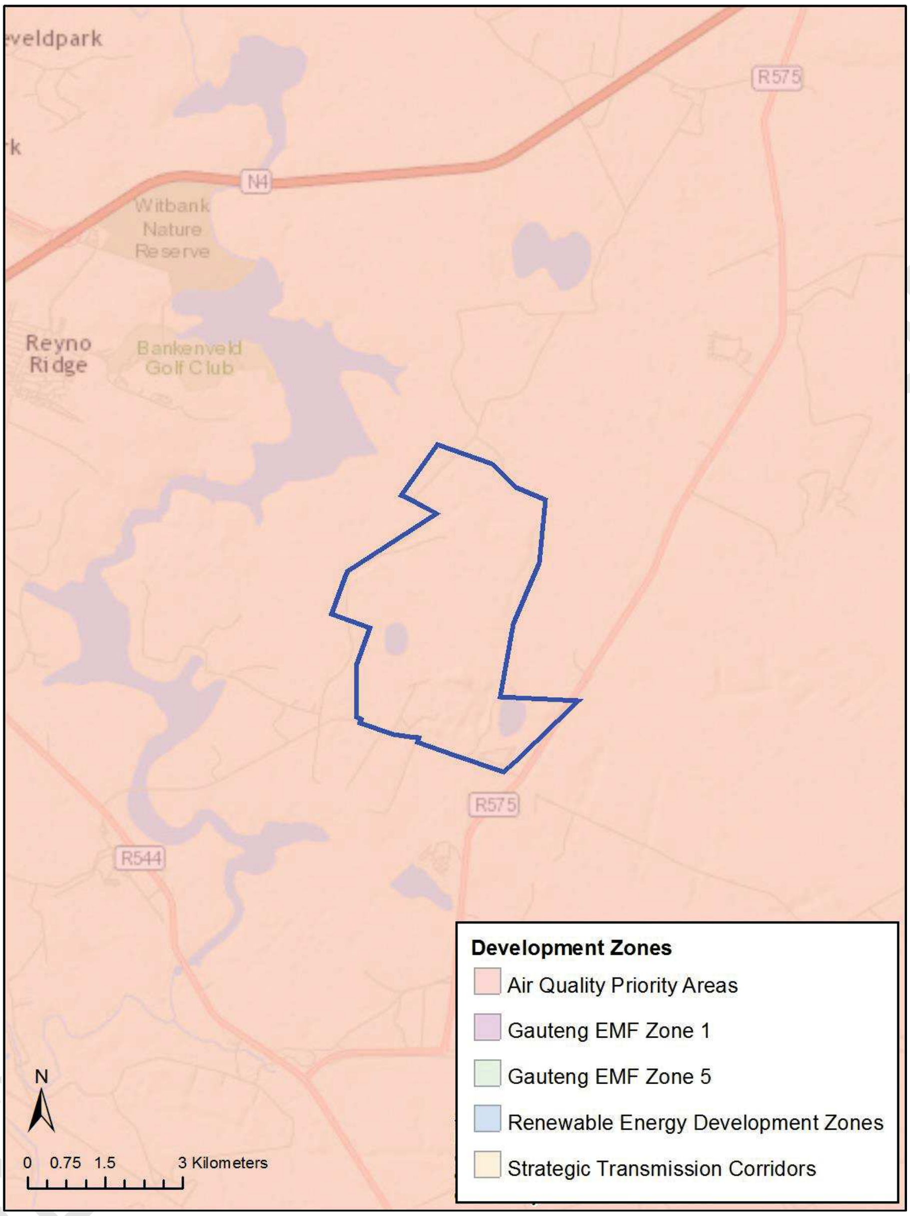
The following development incentives, restrictions, exclusions or prohibitions and their implications that apply to this site are indicated below.

Incentive, restriction or prohibition	Implication
Strategic Transmission Corridor-	https://screening.environment.gov.za/ScreeningDownloads/DevelopmentZones/GNR_350_of_13_April_2017.pdf

International corridor	
Air Quality-Highveld Priority Area	https://screening.environment.gov.za/ScreeningDownloads/DevelopmentZones/HIGHVELD_PRIORITY_AREA_AQMP.pdf

Map indicating proposed development footprint within applicable development incentive, restriction, exclusion or prohibition zones

Project Location: Duvha Ash Dam Seepage Interception Drains in Mpumalanga Province



Proposed Development Area Environmental Sensitivity

The following summary of the development site environmental sensitivities is identified. Only the highest environmental sensitivity is indicated. The footprint environmental sensitivities for the proposed development footprint as identified, are indicative only and must be verified on site by a suitably qualified person before the specialist assessments identified below can be confirmed.

Theme	Very High sensitivity	High sensitivity	Medium sensitivity	Low sensitivity
Agriculture Theme		X		
Aquatic Biodiversity Theme				X
Archaeological and Cultural		X		

Heritage Theme				
Civil Aviation Theme			X	
Defence Theme				X
Terrestrial Biodiversity Theme	X			

Specialist assessments identified

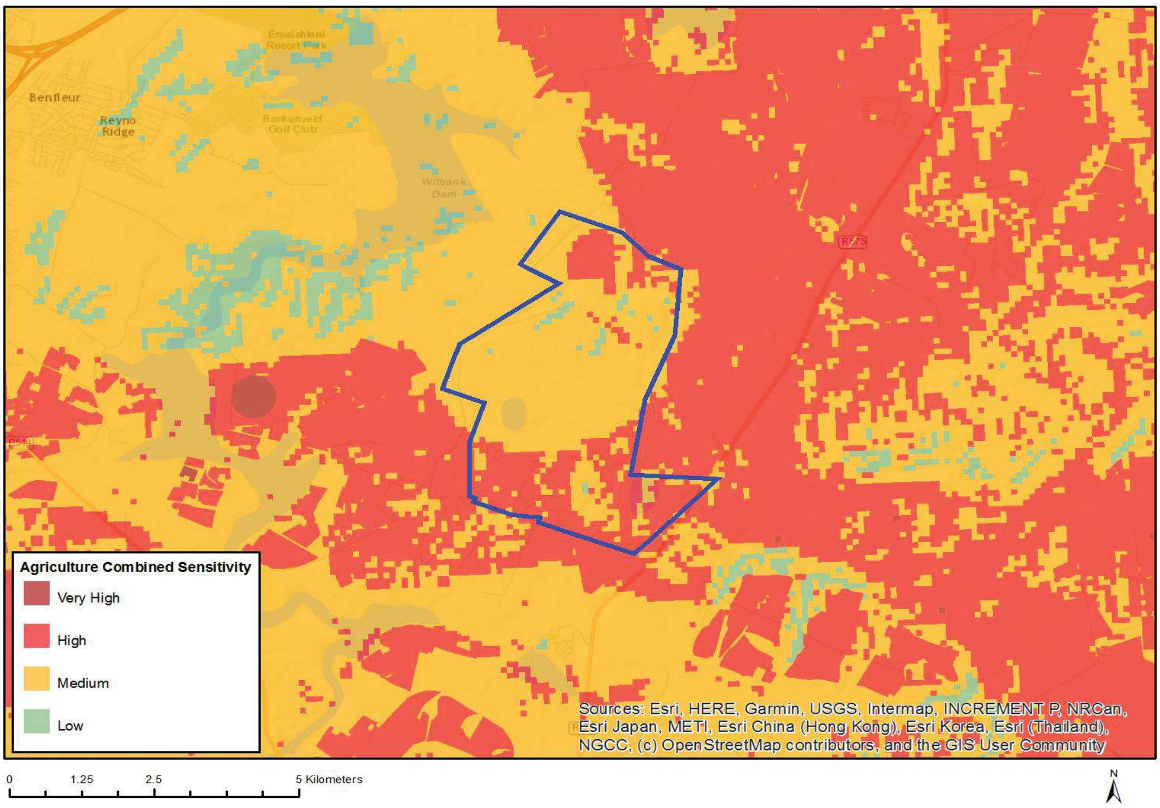
Based on the selected classification, and the environmental sensitivities of the proposed development footprint, the following list of specialist assessments have been identified for inclusion in the assessment report. It is the responsibility of the EAP to confirm this list and to motivate in the assessment report, the reason for not including any of the identified specialist study including the provision of photographic evidence of the site situation.

No	Specialist assessment	Assessment Protocol
1	Agricultural Impact Assessment	https://screening.environment.gov.za/ScreeningDownloads/Assessment/General/DraftAgricultureProtocol.pdf
2	Archaeological and Cultural Heritage Impact Assessment	https://screening.environment.gov.za/ScreeningDownloads/Assessment/General/Appendix6.pdf
3	Palaeontology Impact Assessment	https://screening.environment.gov.za/ScreeningDownloads/Assessment/General/Appendix6.pdf
4	Terrestrial Biodiversity Impact Assessment	https://screening.environment.gov.za/ScreeningDownloads/Assessment/General/Appendix6.pdf
5	Aquatic Biodiversity Impact Assessment	https://screening.environment.gov.za/ScreeningDownloads/Assessment/General/Appendix6.pdf
6	Hydrology Assessment	https://screening.environment.gov.za/ScreeningDownloads/Assessment/General/Appendix6.pdf
7	Geotechnical Assessment	https://screening.environment.gov.za/ScreeningDownloads/Assessment/General/Appendix6.pdf
8	Health Impact Assessment	https://screening.environment.gov.za/ScreeningDownloads/Assessment/General/Appendix6.pdf
9	Socio-Economic Assessment	https://screening.environment.gov.za/ScreeningDownloads/Assessment/General/Appendix6.pdf

Results of the environmental sensitivity of the proposed area.

The following section represents the results of the screening for environmental sensitivity of the proposed site for relevant environmental themes associated with the project classification. It is the duty of the EAP to ensure that the environmental themes provided by the screening tool are comprehensive and complete for the project. Refer to the disclaimer.

MAP OF RELATIVE AGRICULTURE THEME SENSITIVITY

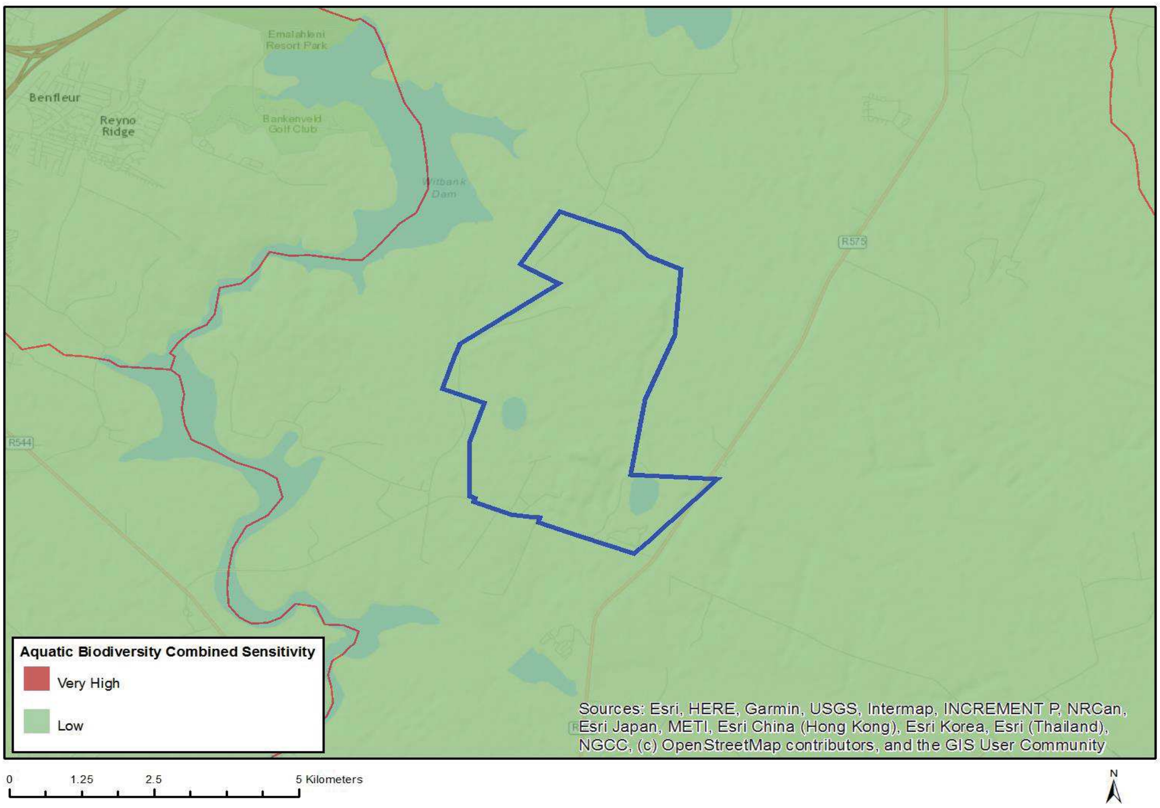


Very High sensitivity	High sensitivity	Medium sensitivity	Low sensitivity
	X		

Sensitivity Features:

Sensitivity	Feature(s)
High	Land capability;09. Moderate-High/10. Moderate-High
High	Annual Crop Cultivation / Planted Pastures Rotation;Land capability;09. Moderate-High/10. Moderate-High
High	Annual Crop Cultivation / Planted Pastures Rotation;Land capability;06. Low-Moderate/07. Low-Moderate/08. Moderate
Low	Land capability;01. Very low/02. Very low/03. Low-Very low/04. Low-Very low/05. Low
Medium	Land capability;06. Low-Moderate/07. Low-Moderate/08. Moderate

MAP OF RELATIVE AQUATIC BIODIVERSITY THEME SENSITIVITY

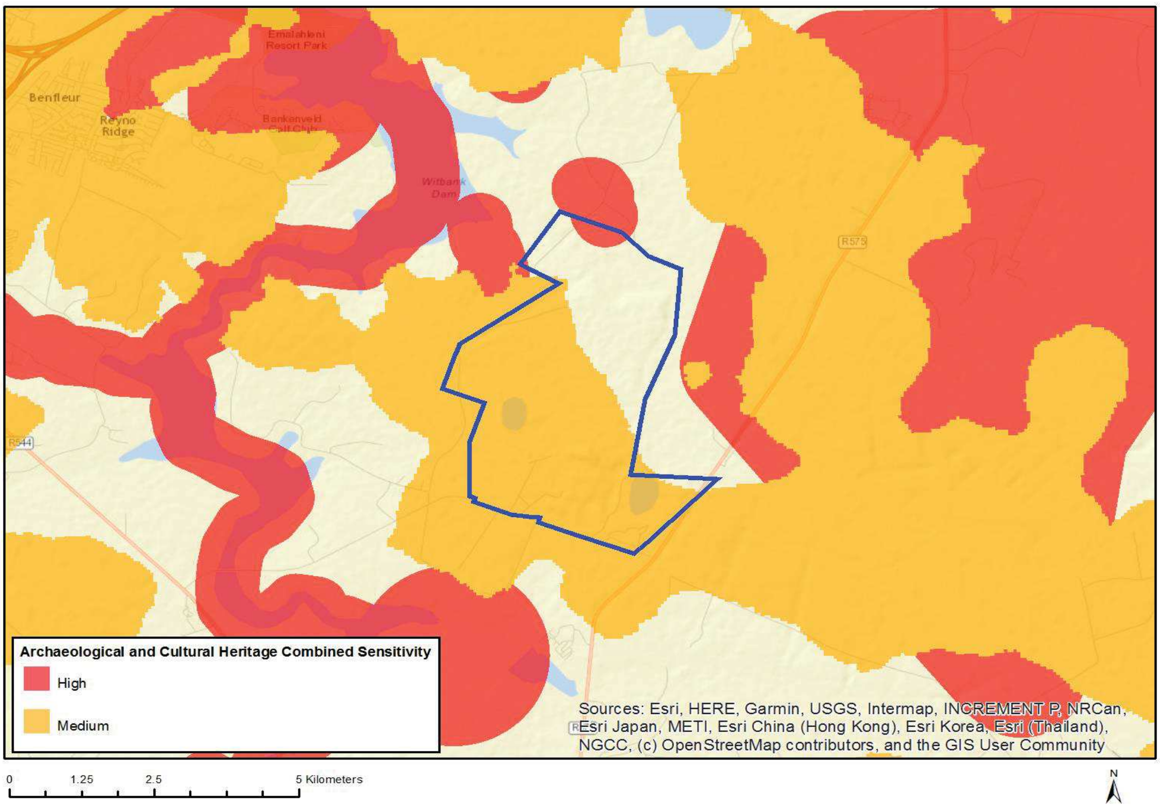


Very High sensitivity	High sensitivity	Medium sensitivity	Low sensitivity
			X

Sensitivity Features:

Sensitivity	Feature(s)
Low	Low Sensitivity Areas

MAP OF RELATIVE ARCHAEOLOGICAL AND CULTURAL HERITAGE THEME SENSITIVITY

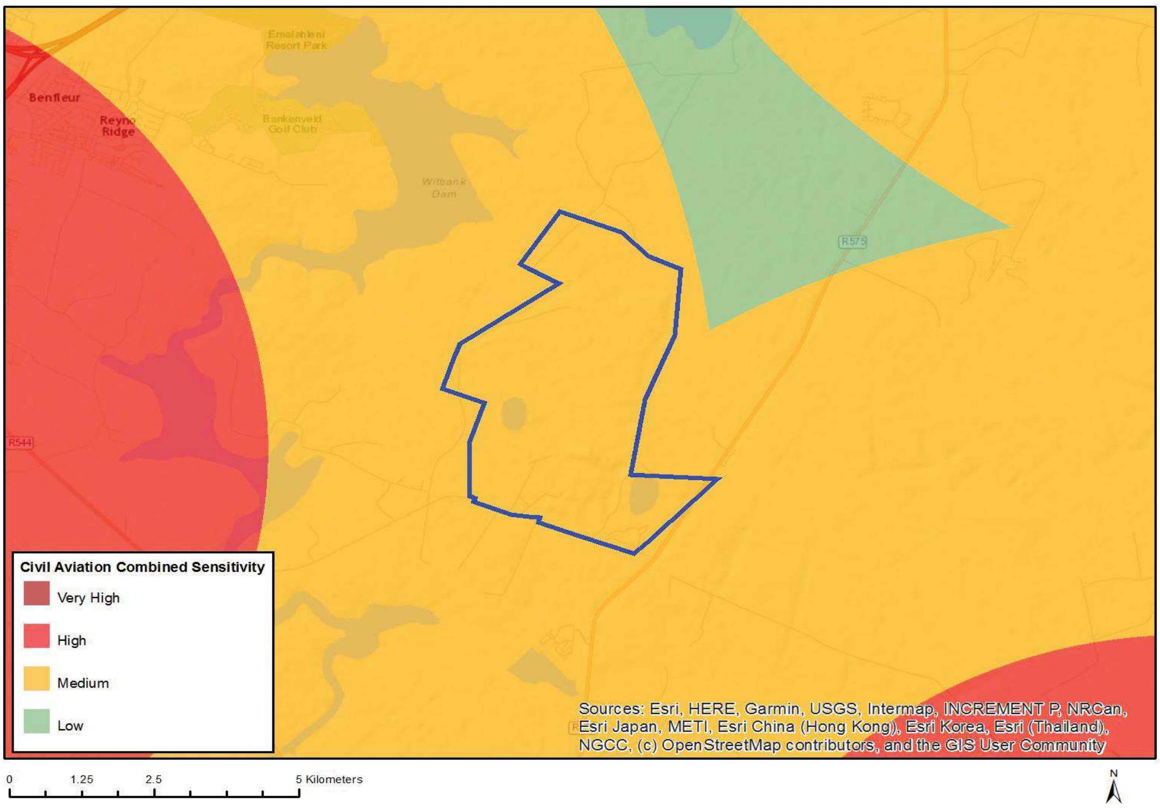


Very High sensitivity	High sensitivity	Medium sensitivity	Low sensitivity
	X		

Sensitivity Features:

Sensitivity	Feature(s)
High	Within 500 m of an important wetland
Medium	Mountain or ridge

MAP OF RELATIVE CIVIL AVIATION THEME SENSITIVITY

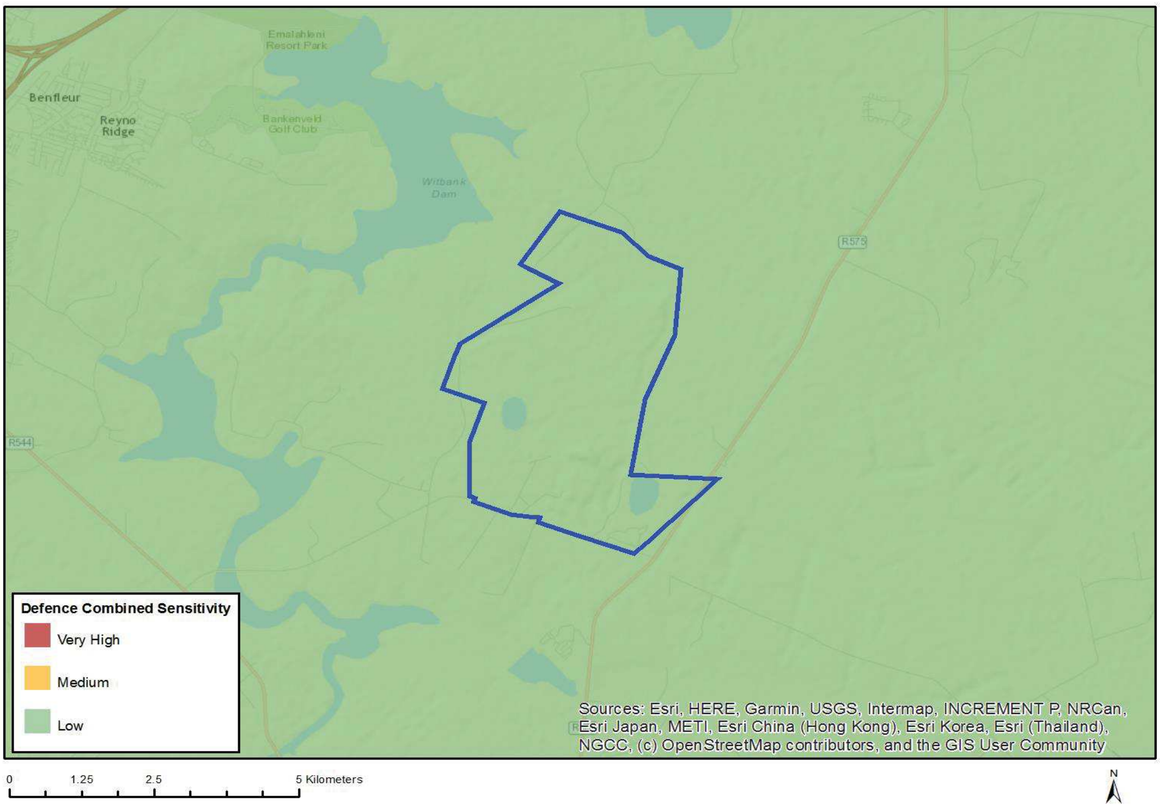


Very High sensitivity	High sensitivity	Medium sensitivity	Low sensitivity
		X	

Sensitivity Features:

Sensitivity	Feature(s)
Medium	Between 8 and 15 km of other civil aviation aerodrome

MAP OF RELATIVE DEFENCE THEME SENSITIVITY

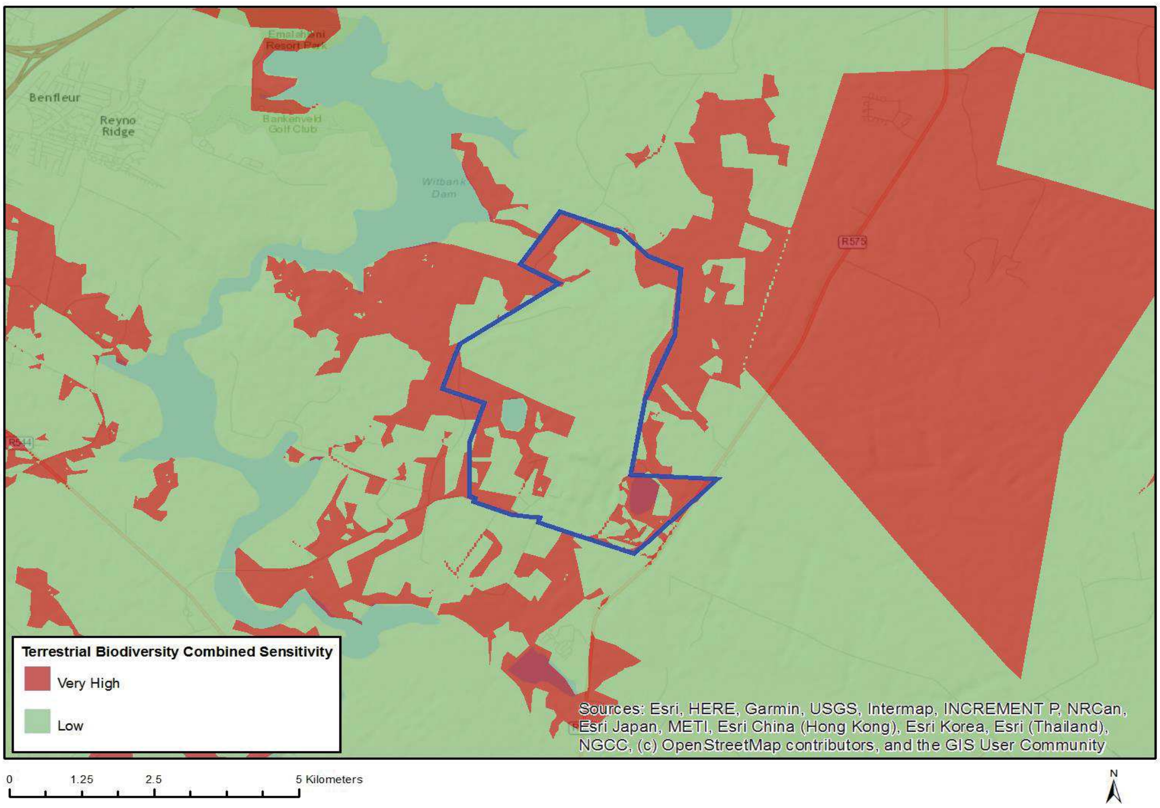


Very High sensitivity	High sensitivity	Medium sensitivity	Low sensitivity
			X

Sensitivity Features:

Sensitivity	Feature(s)
Low	Low sensitivity

MAP OF RELATIVE TERRESTRIAL BIODIVERSITY THEME SENSITIVITY



Very High sensitivity	High sensitivity	Medium sensitivity	Low sensitivity
X			

Sensitivity Features:

Sensitivity	Feature(s)
Low	None
Very High	CBA,Focus area for PAES
Very High	CBA,Protected area,Focus area for PAES

Appendix H3 – Geohydrological Investigation

GHT CONSULTING SCIENTISTS

DUVHA POWER STATION

GEOHYDROLOGICAL INVESTIGATIONS TO DETERMINE SEEPAGE LOSSES

NOVEMBER 2006

DRAFT REPORT

for

Eskom

DUVHA POWER STATION

by

GHT CONSULTING SCIENTISTS

PROJECT TEAM
L.J. van Niekerk
F.D. Fourie
M. Smit

Project no.:	202-15-ghd.457	Start Date:	July 2006
Report no.:	RVN 457.2/718	Report Date:	November 2006

GHT CONSULTING SCIENTISTS

Geo-Hydro Technologies OFS (Pty)Ltd. Trading as GHT Consulting • Reg. no. 94/05593/07 • VAT no. 493 017 5890

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28 November 2006 Our ref.: RVN 457.2/718

Duvha Power Station
Environmental Manager
Private Bag X2
Rietkuil
1097

FOR ATTENTION: Mr. Olloff Nel

Dear Sir

Duvha Power Station – Geohydrological Investigations to Determine Seepage Losses

It is our pleasure to enclose one electronic copy of the draft report: RVN 457.2/718 "DUVHA POWER STATION – GEOHYDROLOGICAL INVESTIGATIONS TO DETERMINE SEEPAGE LOSSES".

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

Yours sincerely,

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

Copies: One (1) electronic copy to Duvha Power Station

Directors: L.J. van Niekerk Pr.Sci.Nat. [M.Sc.]; D.C. Rudolph Pr.Sci.Nat. [M.Sc]

Head Office: Bloemfontein (Free State)
Offices: Springs (Gauteng); Vryheid (KwaZulu-Natal); Middelburg (Eastern Cape); Hendrina (Mpumalanga); Kimberley (Northern Cape)

Executive Summary

This report summarizes findings made during the geohydrological investigations that were undertaken at Duvha Power Station in order to assess the volumes of seepage losses from the various dam systems at the power station. These dams include: the Ash Dam, the Raw Water Dam, the Low Level Ash Water Return Dam, the High Level Ash Water Return Dams, the maturation ponds at the sewage plant and the Emergency Pan. The investigations also included an evaluation of the risks associated with contaminant migration away from these dams and recommendations for seepage interception systems where deemed necessary.

As part of the geohydrological investigations, the following actions were taken:

– *Geophysical data were recorded at positions downstream from the various dams in order to detect and delineate geological structures that may be associated with preferential pathways for groundwater migration and contaminant transport,*

– *Twenty monitoring boreholes were drilled at suitable positions after an evaluation of the geophysical data. Thirteen shallow boreholes (10 m deep) and 7 deep boreholes (15 – 30 m deep) were drilled at the chosen locations. During drilling, geological logging of the boreholes was done in order to identify the various geological units that may influence the groundwater environment,*

– *Hydraulic tests were performed on the boreholes to obtain information on the hydraulic properties of geological formations in the vicinities of the various dams,*

– *Surface water samples were taken from the different dams and submitted for chemical analyses in order to evaluate the quality of the water that could seep into the subsurface. Samples from locations where seepage occurs at surface were also submitted for analyses,*

– *Groundwater samples were taken from the newly drilled and existing monitoring boreholes and submitted for chemical analyses in order to determine the current contamination status of the groundwater in the vicinities of the various dams/reservoirs,*

– *Groundwater samples from the boreholes in the vicinity of the Raw Water Dam and Sewage Plant were submitted for isotopic analyses to determine whether the groundwater has a surface water signature that could indicate that seepage has occurred,*

– *Soil samples were taken from the shallow horizons of the newly drilled boreholes, as well as from additional surface locations appropriate to the current investigations, and submitted for chemical and granulometric analyses. The results of the granulometric analyses were used to evaluate the hydraulic properties of the soils in the vicinities of the dams/reservoirs.*

– *All the data that were gathered during the investigations were captured into an Aquabase database.*

– *A conceptual model of the geohydrological environment was developed. Based on the conceptual model, three dimensional numerical models were developed to investigate the rate and volumes of seepage that may occur from the various dams/reservoirs. The results of the numerical models were used to evaluate the risks associated with contaminant migration away from these potential pollution sources,*

– *The results of the numerical models were used to develop a conceptual design for seepage interception systems where required at the various dams.*

The results of the geohydrological investigations may be summarised as follows:

Ash Dam

The numerical modelling results indicate current seepage losses of approximately 805 m^3/day (or 2.52 m^3/ha/day) from the Ash Dam. This estimate is significantly lower than the estimate obtained by Mr. Hanekom of Eskom by means of water- and energy balance calculations. It should, however, be noted that for the water balance calculations performed by Mr. Hanekom, it was assumed that the average evaporation from the surface of Ash Dam is equal to the average evaporation measured at evaporation stations B1E001 located approximately 6.6 km away from Duvha Power Station. Mr. Hanekom showed that if the evaporation from the Ash Dam is 11% higher than at station B1E001 the seepage *volumes from the Ash Dam as suggested by his water balance calculations could be as low as 2 m^3/ha/day. It is therefore recommended that an S-pan be installed on top of the Ash Dam so that the true evaporation figures (and, consequently, seepage volumes) can be known with a greater deal of certainty.*

The contaminant plumes to the north of the Ash Dam are not expected to extend all the way to the Witbank Dam by the end of 2036 when ashing operations at Duvha Power Station will cease. The numerical modelling results suggest that even 100 years after decommissioning the impact of ashing activities on the Witbank Dam will be small and that the risks associated with these impacts will be minimal. Since there are no groundwater users downstream from the Ash Dam, the risks of contaminant impacts on groundwater users are also negligibly small.

Numerical modelling results indicate that, due to future impacts of seepage on the non-perennial rivers that occur to the north of the Ash Dam, the sulphate concentrations in these rivers could attain maximum values of between 350 and 500 mg/L during the operational phase of the Ash Dam. Such concentrations are high enough to cause the water quality to be classified as marginal. If ingested, water of a marginal quality could cause negative effects in sensitive groups. There are, however, no known users of these rivers (except cattle for drinking water) and the risks associated with the contaminant impacts are again limited.

The numerical modelling results indicate that the installation of a seepage interception trench along the north-western wall of the Ash Dam could allow large volumes of water to be recovered. Different options for the depth and length of the trench were considered during modelling and it was found that an 8 m deep trench with a length of 2 km will be the most beneficial in terms of cost savings due to water recovery over the next 30 years while the Ash Dam is in operation.

Low Level Ash Water Return Dam

The results of the numerical model show that surprisingly small volumes of seepage (~36 m^3/day) from the Low Level Ash Water Return Dam can be expected to enter the shallow weathered aquifer system and may surface at positions north of the northern wall of the dam. Comparison of the water quality at the five monitoring sites that are located north of the Low Level Ash Water Return Dam also suggest that seepage from this dam does occur, but that the volumes of seepage are small.

Since the Low Level Ash Water Return Dam is located in close proximity to the Ash Dam, the impacts of contaminant releases from the Low Level Ash Water Return Dam may be included with the impacts from Ash Dam. These health risks were shown to be very limited.

Since the volumes of seepage losses from the Low Level Ash Water Return Dam seem to be small, and since the impact of contaminants associated with seepage appears to be minimal, the benefits of installing a seepage interception system is likely to be limited. There are also practical difficulties associated with the installation of a seepage interception system. Judging from the topographic gradient, seepage from the Low Level Ash Water Return Dam is expected to take place predominantly near the north-eastern toe of the dam, east of the pump station. At this position the diverted non-perennial river flows very close to the dam wall and the access road around it. The proximity of the river to the dam wall and road leaves very little room in which to install an interception system.

Due to the factors discussed above, it is at present not recommended that a seepage interception system be installed at the Low Level Ash Water Return Dam. However, regular monitoring of the water quality and surface- and groundwater sites north of the dam should be done. Any deterioration in the water quality could indicate that larger volumes of seepage have started to impact on the environment. Under these conditions it may be beneficial to install a seepage interception system.

If future water quality monitoring reveals that contaminant impacts on the surface water and/or groundwater are occurring, a simple design for a seepage interception system could consist of a shallow unlined trench (3-4 m deep, ~300 m long) dug at a position near the north-eastern toe of the dam. The trench could be fitted with gabions to prevent it from collapsing. A sump could be formed at the position of lowest floor elevation in the trench. From this sump, seepage water could be pumped back to the dam by means of pump equipped with a level switch.

Raw Water Dam

An estimated 113 m^3 of water daily seep from the Raw Water Dam into the subsurface. This figure translates into a volume of approximately 7.9 m^3/ha/day. Approximately 81 m^3 daily seep into the shallow weathered aquifer system while approximately 32 m^3 seep into the deeper aquifer system. These volumes are relatively small when compared with the estimated volume of daily evaporation losses from the Raw Water Dam (~330 m^3).

Since the Raw Water Dam contains water of an ideal quality, no health risks associated with contaminant migration exist.

A cost-benefit analysis shows that the volumes of water intercepted by both a shallow (6 m) and deep (8 m) trench located on the south-western side of the Raw Water Dam are too small to justify the expenditures associated with the installation of the trench. It is therefore not recommended that such an expensive trench be installed. As a possible alternative a seepage interception system could be installed near the positions where seepage is noticed to occur at surface near the toes of the dam walls. Such a system could consist of an unlined trench (~4 m deep) dug parallel to the dam wall, fitted with gabions and equipped with a sump and return pump. The volumes of water intercepted by these trenches are likely to be too small to justify the installation costs purely from an economical point of view, but other possible benefits (e.g dam safety) should also be considered when evaluating the costs versus benefits.

High Level Ash Water Return Dams

An estimated 26.57 m^3 of water daily seep from the High Level Ash Water Return Dams into the subsurface. Expressed in terms of the surface area of the High Level Ash Water Return Dams, this figure translates into a volume of approximately 9.55 m^3/ha/day. Approximately 25.32 m^3 daily seep into the shallow weathered aquifer system while approximately 1.25 m^3 seep into the deeper aquifer system. These volumes are again relatively small when compared with the estimated average volume of daily evaporation losses from the High Level Ash Water Return Dams (~64 m^3).

The estimated seepage volumes were obtained by making the assumption that the floors of the High Level Ash Water Return Dams were properly prepared to reduce their permeabilities prior to the dams receiving water. However, no information on the permeabilities of the dam floors is available and it is therefore possible that the floors have higher permeabilities than those used in the numerical model. Higher dam floor permeabilities will lead to larger water losses through seepage.

As long as overflows do not occur, the only pathway available for contaminant migration away from the High Level Ash Water Return Dams is the groundwater pathway. From the numerical modelling results it can be seen that contaminant migration is expected to occur at a slow rate. By 2036 the sulphate contaminant plume will still have values of less than 200 mg/L (ideal water quality) at position located further than 300 m from the High Level Ash Water Return Dams. The absence of groundwater users down-gradient from these dams also implies that there are no receptors for the contaminants to impact on. The health risks associated with contaminant migration away from these dams can therefore be considered negligible.

A preliminary cost-benefit analysis indicate that the benefits in terms of water cost savings are minimal and do not justify the installation of a seepage interception trench. Even if the costs associated with the Waste Discharge Charge System are taken into account, it is unlikely that such a trench will be financially profitable. Since the risks associated with seepage from the High Level Ash Water Return Dams are negligible, it is not recommended that seepage interception trench be installed.

Sewage Plant

The modelling results indicate that volume of around 3 m^3 daily seeps into the subsurface from the Maturation Ponds and Buffer Pond at the Sewage Plant. When taking the surface areas of the Buffer Pond and Maturation Ponds into account, this volume of water translates into a seepage loss of approximately 4.1 m^3/ha/day.

Contaminant migration predominantly takes place in a westerly direction under the local hydraulic gradient. The rate of contaminant migration through the shallow aquifer system is expected to be slow. As a result, the lateral extent of the contaminant plume is expected to remain limited, even after 30 years of operation. However, the contaminant plume could potentially extend as far as the opencast pits of Corobrik.

The health risks due to seepage from the Maturation Ponds and Buffer Pond are associated with impacts of water with high bacterial activity. There are two pathways available along which contaminants may be transported away from the Maturation Ponds, namely the groundwater pathway and the surface water pathway where seepage daylights at positions west of the Sewage Plant. Both the groundwater and surface water is expected to migrate in the direction of the Witbank Dam under the local topographic and hydraulic gradients.

Possible receptors for contaminant impacts are people and animals that come in contact with the contaminated water. A Corobrik quarry is located immediately west of the Sewage Plant. The opencast pits at the quarry receive large volumes of groundwater that migrate in a westerly direction. Contaminants originating at the Sewage Plant could potentially reach these pits and cause impacts on Corobrik personnel mining the pits. However, the Corobrik pits are more than 200 m away from the Sewage Plant. These pits receive large volumes of groundwater that seep into the pits *from their eastern walls. Even if contaminants from the Sewage Plant should impact on the pits, the diluting effects of the clean water seeping into the pits are expected to reduce the contaminant concentrations and reduce the likelihood of health risks. It should also be noted that groundwater is not used for drinking purposes at Corobrik or at positions further to the west towards the Witbank Dam.*

Since the Witbank Dam is located more than 2 km away from the Sewage Plant, it is highly unlikely that contaminant originating at the Sewage Plant will have any impacts on this surface water body. Groundwater that daylights at positions near the western fence of the Sewage Plant could potentially be ingested by wild animals. If the bacterial activity in the groundwater is high, contaminant impacts on these animals could occur.

The above observations suggest that the risks associated contaminant impacts from the Sewage Plant may be considered minimal. Negligible health risks to humans are expected.

Since the volumes of water that are expected to seep from the Buffer Pond and Maturation Ponds are small, a seepage interception system will have to be inexpensive to justify the recovery of water seeped from these ponds. A seepage interception trench will, however, further reduce the likelihood of contaminant impacts and may be seen as beneficial in these terms.

The groundwater table in the shallow aquifer in the vicinity of the Sewage Plant occurs at a depth of between 1.32 and 2.66 mbgl. Modelling results show that the bulk of the seepage that emanates from the Buffer Pond and Maturation Ponds will migrate at depths of less than 4 mbgl. At positions to the west of the 1st Maturation Pond, groundwater even daylights. The above observations imply that an effective seepage interception system will have to be no deeper than 4 metres.

Little room is available for the installation of a seepage interception trench. The distance between the Buffer Pond and the fence with the property of Corobrik is approximately 20 m. A possible location for the installation of the trench is along the eastern side of the fence. To minimise costs a shallow unlined interception trench, fitted with gabions and equipped with a sump and return pump, could be considered. Assuming that the trench has a depth of 4 m and a length of 200 m, the costs associated with the installation are unlikely to exceed R500 000.

Emergency Pan

An estimated 58.76 m^3 of water daily seep from the Emergency Pan into the subsurface. This figure translates into a seepage volume of approximately 2.32 m^3/ha/day. Approximately 48.70 m^3 of this water seep into the shallow weathered aquifer system while approximately 10.06 m^3 seep into the deeper aquifer system. These volumes are relatively small when compared with the estimated average volume of daily evaporation losses from the Emergency Pan (~580 m^3). The large difference in the volumes of water lost through evaporation and seepage can be understood by noting that the pan has a large surface area (~0.25 km^2) from which evaporation can take place, but a shallow depth (estimated at less than 1.5 m at maximum depth) with a resulting low hydraulic head.

Modelling results suggest that the Emergency Pan feeds the non-perennial pan that occurs north-east of it. Contaminants from the Emergency Pan migrating in the shallow aquifer system could therefore potentially impact on the water quality in the non-perennial pan.

The current sulphate concentration of the water in the Emergency Pan is 756 mg/L which renders the water quality poor and is high enough to be associated with health risk if the water is ingested. However, the water quality in the Emergency Pan has displayed a large degree of variability over the years depending on a number of factors, including the rainfall figures and whether the pan received water from the High Level Ash Water Return Dams. As long as the Emergency Pan receives water from the ashing system, it should be seen as a contaminant source that could potentially cause impacts on receptors.

Since the Emergency Pan is located within a local topographic depression, surface runoff will flow towards the pan, and it is highly unlikely that contaminant migration will take place along a surface water pathway. Contaminant migration is, however, expected to occur along the groundwater pathway. Modelling results suggest that contaminant impacts on the non-perennial pan north-east of the Emergency Pan can be expected. The modelling results suggest that the impacts will be limited over the next 30 years and that the sulphate concentration of the contaminated water impacting on the non-perennial pan will not exceed 200 mg/L (ideal water quality).

The possible receptors of contaminant impacts are animals drinking from the Emergency Pan and non-perennial pan, as well as groundwater users that occur to the north-west of the Emergency Pan. Only one private farm lies within the extent of the modelled pollution plume. Although a borehole does occur on this farm, it is not equipped with a pump and is not currently being used.

The above observations suggest that, as long as groundwater from the borehole on the private farm north of the Emergency Pan is not used for drinking purposes, the health risks associated with the storage of contaminated water in the Emergency Pan are limited. Animals drinking from the pan are the most likely receptors of contaminant impacts.

Most of the seepage from the Emergency Pan is expected to migrate in a north-easterly direction towards the non-perennial pan. If actions are taken to intercept the seepage, these actions will therefore have to focus on the area north-east of the Emergency Pan. However, the border fence with the private farm that occurs immediately north of the Emergency Pan is located very close to the northern shores of the pan, leaving little room in which to install a seepage interception system.

It should also be kept in mind that the Emergency Pan is located in a topographic depression and that the ground surface elevation increases rapidly as one moves away from the perimeter of the pan. A seepage interception trench will therefore have to be deep (>8 m) in order to effectively intercept water seeping from the Pan. Such a system will be very expensive and will not be justifiable in terms of water recovery.

Since the volumes of water lost from the Emergency Pan through seepage are relatively small and since the health risks associated with contaminant impacts appear to be limited, it is not recommended that a seepage interception system be installed at the pan. Instead it is recommended that the management of ashing activities at Duvha Power Station be reviewed and improved so that it is no longer required to use the Emergency Pan for buffer capacity when excessive volumes of water are present in the ashing system. The poor quality of the ash water that is intermittently allowed to enter the Emergency Pan has a strong detrimental effect on the water quality of this natural pan.

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APPENDICES

1 INTRODUCTION

1.1 General

GHT was commissioned by Duvha Power Station to investigate the volumes of water lost to the subsurface through seepage from the various dams of the power station. This document reports on the findings of the geohydrological investigations that were done in order to determine the seepage losses and associated risks. Recommendations regarding remedial approaches to minimise such risks are also made.

The investigations focussed on the following dams/reservoirs of Duvha Power Station:

- The Ash Dam,
- The Low Level Ash Water Return Dam,
- The High Level Ash Water Return Dams,
- The Raw Water Dam,
- The Maturation Ponds at the Sewage Plant, and,
- The Emergency Pan.

A site map indicating the various power station activities and the positions of the dams that were included in this study is given in Figure A01 of **Appendix A**.

1.2 Approach to study

As part of the geohydrological investigations into seepage losses at the various dams of Duvha Power Station, the following actions were taken:

- Geophysical data were recorded at positions downstream from the various dams in order to detect and delineate geological structures that may be associated with preferential pathways for groundwater migration and contaminant transport.
- Twenty monitoring boreholes were drilled at suitable positions after an evaluation of the geophysical data. Thirteen shallow boreholes (10 m deep) and 7 deep boreholes (15 – 30 m deep) were drilled at the chosen locations. During drilling, geological logging of the boreholes was done in order to identify the various geological units that may influence the groundwater environment.
- Hydraulic tests were performed on the boreholes to obtain information on the hydraulic properties of geological formations in the vicinities of the various dams.
- Surface water samples were taken from the different dams and submitted for chemical analyses in order to evaluate the quality of the water that could seep into the subsurface. Samples from locations where seepage occurs at surface were also submitted for analyses.
- Groundwater samples were taken from the newly drilled and existing monitoring boreholes and submitted for chemical analyses in order to determine the current contamination status of the groundwater in the vicinities of the various dams.
- Groundwater samples from the boreholes in the vicinity of the Raw Water Dam were submitted for isotopic analyses to determine whether the groundwater has a surface signature that could indicate that seepage has occurred.
- Soil samples were taken from the shallow horizons of the newly drilled boreholes, as well as from additional surface locations appropriate to the current investigations, and submitted for

chemical and granulometric analyses. The results of the granulometric analyses were used to evaluate the hydraulic properties of the soils in the vicinities of the dams.

- All the data that were gathered during the investigations were captured into an Aquabase database.
- A conceptual model of the geohydrological environment was developed. Based on the conceptual model, three dimensional numerical models were developed to investigate the rate and volumes of seepage that may occur from the various dams/reservoirs. The results of the numerical models were used to evaluate the risks associated with contaminant migration away from these potential pollution sources.
- The results of the numerical models were used to develop a conceptual design for seepage interception systems where required at the various dams.

2 REGIONAL SETTING AND CLIMATE

Duvha Power Station is located in the Mpumalanga Province of South Africa, approximately 13 km south-east of Witbank and 23 km south-west of Middelburg (see Figure 1 and Figure A02 of **Appendix A**). The power station is located east of the Witbank Dam with the Ash Dam at a minimum distance of 1.7 km from the Witbank Dam.

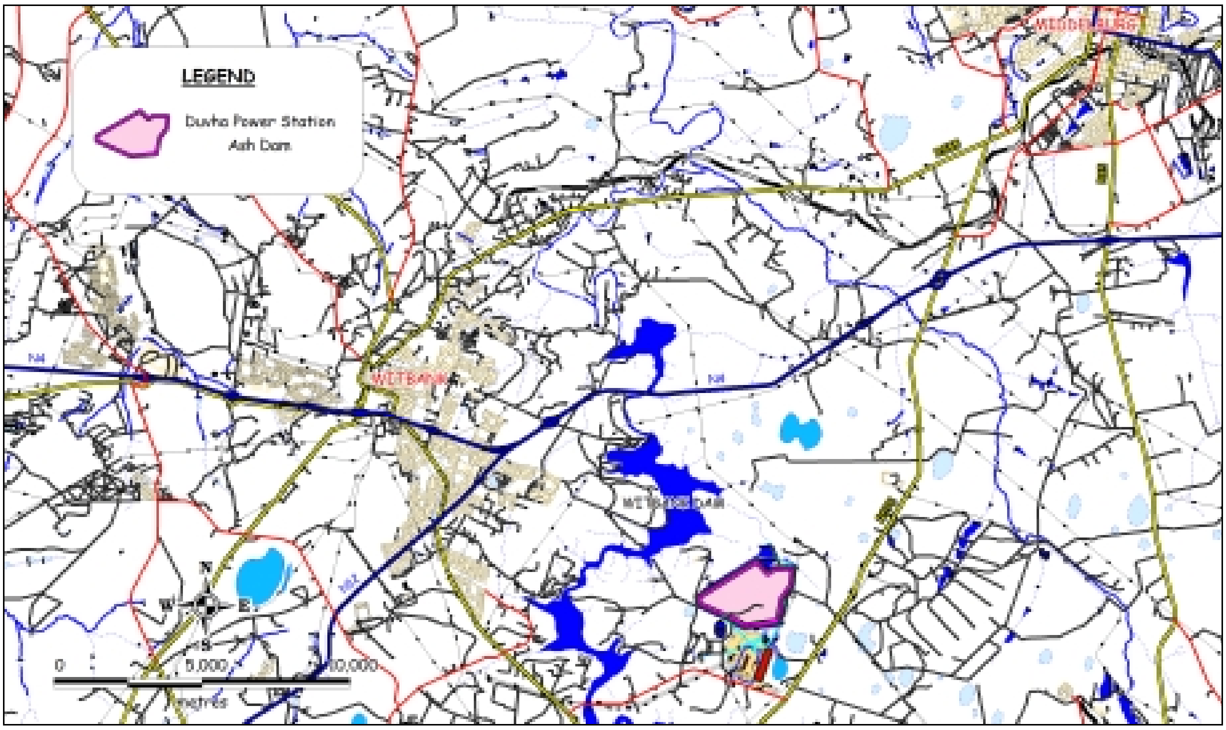

Figure 1. Regional setting of Duvha Power Station.

The power station is located in the Highveld Climatic Region. The average precipitation in the Highveld Region varies between 650 and 900 mm. Rainfall is almost exclusively in the form of showers and thunderstorms and falls mainly in the summer months from October to March. The maximum rainfall usually occurs in January. The winter months are usually dry with approximately 85% of the annual rainfall occurring in the summer months. Heavy falls of 125 to 150 mm occasionally occur in a single day.

The annual average number of thunderstorms in the highveld region varies between 75 and 100. These storms are often violent with heavy lightning and strong winds and are sometimes accompanied by hail. Between four and seven hail occurrences can be expected annually. The hailstones sometimes attain the sizes of hens' eggs or tennis balls and can cause a great deal of damage. In general winds are light, except during thunderstorms. Very occasional tornadoes do occur.

The average daily maximum temperature is roughly 27^{o}C in January and 17^{o}C in July. In extreme cases these temperatures may rise to 38^{o}Cand 26^{o}C, respectively. The average daily minima range from 13^{o}C in January to 0^{o}C in July. Temperatures as low as 1^{o}C in January and -13^{o}C in July have been recorded in extreme conditions. The period in which frost may occur usually lasts approximately 120 days from May to September. Sunshine duration is approximately 60% of the possible in summer and 80% in winter.

2.1 Rainfall Data

Duvha Power Station lies within quaternary sub-catchment B11G of rainfall zone B1C. To evaluate the local weather conditions, weather information recorded at the Landau (515 386), Witbank-Mag

(515 382) and Witbank-Mun (515 412) weather station will be used. These weather stations are situated at distances of approximately 11.3 to 14.3 km from the power station. The mean annual precipitation at theses weather stations are 689.2, 704.9 and 715.9 mm, respectively.

The average monthly rainfall for weather stations within rainfall zone B1C is summarised in Table 1. The average monthly rainfall recorded at the Landau weather station, situated the closest to Duvha Power Station, is displayed graphically in Figure 2. Data from the measurements taken during 70 years (1920 - 1989) were obtained. From the data listed in Table 1 it can be seen that the wettest months (on average) are January, November and December, whilst the driest months are August, July and June.

Table 1. Average monthly rainfall recorded at weather stations within rainfall zone B1C (1920 – 1989).

Month	**Average monthly rainfall (mm)**		
	Landau (515 386)	**Witbank-Mag (515 382)**	**Witbank-Mun (515 412)**
Jan	118.92	121.68	123.58
Feb	90.95	93.06	94.51
Mar	78.82	80.65	81.91
Apr	45.13	46.18	46.90
May	17.29	17.70	17.97
Jun	8.27	8.46	8.59
Jul	7.17	7.33	7.45
Aug	7.03	7.19	7.30
Sep	23.56	24.11	24.49
Oct	66.83	68.39	69.45
Nov	115.75	118.44	120.29
Dec	109.28	111.81	113.56

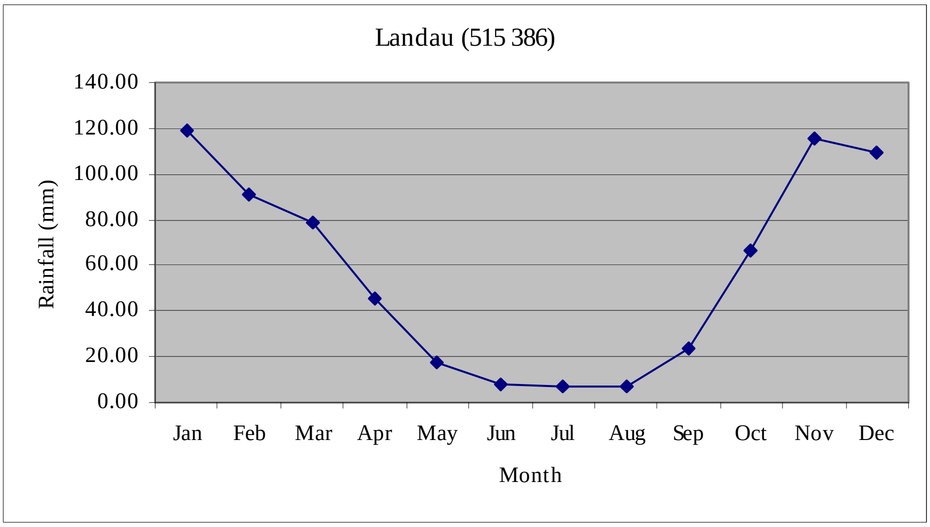

Figure 2. Average rainfall recorded at the Landau weather station (1920-1989).

2.2 Evaporation Data

Two evaporation stations are located near the western banks of the Witbank Dam. Evaporation stations B1E001 and B1E005 are situated approximately 6.6 and 5.0 km away from the activities at Duvha Power Station and fall within Evaporation Zone 4A. Evaporation data are, however, only available from station B1E001. The mean annual S-pan evaporation from station B1E001 is 1 621 mm.

The average monthly evaporation for the B1E001 evaporation station within Evaporation Zone 4A is summarised in Table 2 and displayed graphically in Figure 3. Data from the measurements taken during 15 years (1964 – 1979) were obtained. Also listed in Table 2 are the average monthly evaporation figures that can be expected for open water bodies and catchment areas in the vicinity of evaporation station B1E001. From the data listed in Table 1 and Table 2 it can be seen that the months of high evaporation correspond well with the months of high rainfall with the highest evaporation recorded during the rainy months.

Table 2. Average monthly evaporation at evaporation station B1E001 within Evaporation Zone 4A (1964 – 1979).

Month	Average monthly S-pan evaporation at station B1E001 (mm)	Conversion factors		Average monthly evaporation from catchment (mm)	Average monthly evaporation from open water bodies (mm)
		Catchment evaporation	Lake evaporation		
Jan	178.31	0.84	1.00	149.78	178.31
Feb	148.65	0.88	1.00	130.81	148.65
Mar	146.70	0.88	1.00	129.10	146.70
Apr	112.82	0.88	1.00	99.28	112.82
May	94.99	0.87	1.00	82.64	94.99
Jun	77.16	0.85	1.00	65.59	77.16
Jul	84.45	0.83	0.80	70.10	67.56
Aug	111.85	0.81	0.80	90.60	89.48
Sep	144.92	0.81	0.80	117.38	115.93
Oct	174.74	0.81	0.80	141.54	139.80
Nov	164.86	0.82	1.00	135.18	164.86
Dec	181.55	0.83	1.00	150.69	181.55

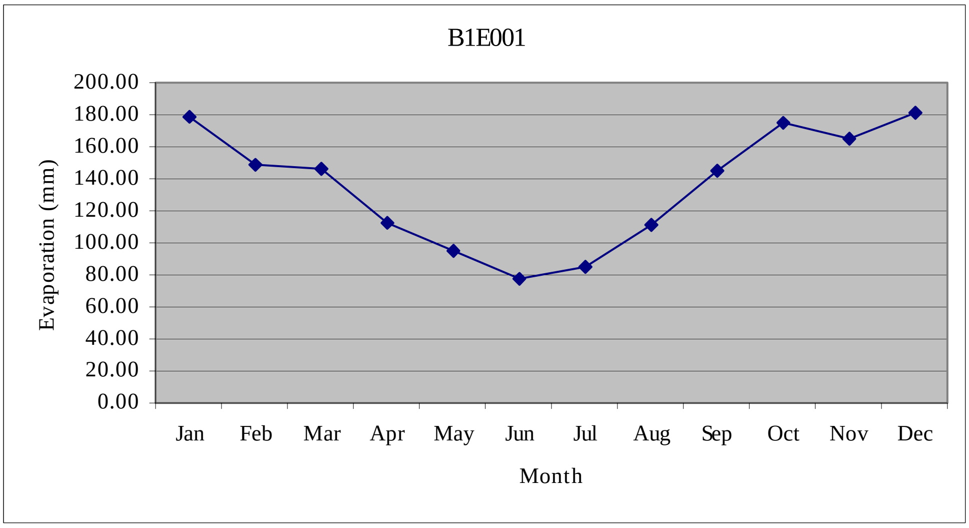

Figure 3. Average monthly S-pan evaporation at the B1E001 evaporation station (1964-1979).

The average effective monthly evaporation (evaporation – rainfall) from open water bodies near Duvha Power Station is listed in Table 3. Also listed in Table 3 are the average monthly evaporation losses estimated for the dam systems at Duvha Power Station. The evaporation losses from the Ash Dam were estimated by assuming that the evaporation from the unsaturated ash amounts to 80% the evaporation that can be expected from an open water body such as the pool area.

Table 3. Average effective monthly evaporation and estimated evaporation losses from the dam systems at Duvha Power Station.

Month	Average effective monthly evaporation for open water bodies (mm)	Estimated average monthly evaporation losses from dam systems (Ml)						
		Ash Dam	LLAWRD	Raw Water Dam	HLAWRD	Maturation Ponds	Emergency Pan	Total
Jan	59.39	157.97	16.63	8.49	1.66	0.45	15.04	200.25
Feb	57.70	153.48	16.16	8.25	1.62	0.43	14.61	194.55
Mar	67.88	180.56	19.01	9.71	1.90	0.51	17.19	228.87
Apr	67.69	180.06	18.95	9.68	1.90	0.51	17.15	228.24
May	77.70	206.67	21.76	11.11	2.18	0.58	19.68	261.98
Jun	68.89	183.25	19.29	9.85	1.93	0.52	17.45	232.29
Jul	60.40	160.66	16.91	8.64	1.69	0.45	15.30	203.65
Aug	82.45	219.32	23.09	11.79	2.31	0.62	20.88	278.01
Sep	92.37	245.70	25.86	13.21	2.59	0.69	23.40	311.45
Oct	72.96	194.08	20.43	10.43	2.04	0.55	18.48	246.01
Nov	49.10	130.62	13.75	7.02	1.37	0.37	12.44	165.57
Dec	72.28	192.26	20.24	10.34	2.02	0.54	18.31	243.70
Annual total (Ml)		2204.63	232.07	118.52	23.21	6.22	209.94	**2794.57**

3 SURFACE TOPOGRAPHY AND DRAINAGE

The natural surface topography at Duvha Power Station as it was prior to the construction of the power station is shown in Figure 4. The power station is located south-west of the Witbank Dam at a minimum distance of 1.7 km from the dam. The natural surface topography is characterised by gently undulating hills with the Witbank Dam located in a valley formed where the hills display steeper gradients. The Raw Water Dam is located at a position where the natural topography forms a local maximum. From the Raw Water Dam surface runoff drains in all directions, but predominantly to the west and south-west.

Drainage in the vicinity of the Ash Dam occurs to the north, north-east and north-west where a number of non-perennial rivers originate in local topographic depressions. These non-perennial rivers all flow into the Witbank Dam.

The Emergency Pan is situated to the east of the power station in a local topographic low. Surface runoff drains from all directions towards this perennial pan, which is also fed by a spring that occurs near its western boundary. Another non-perennial pan occurs in a local depression north of the Emergency Pan.

The natural drainage to the west of the power station is in a westerly direction.

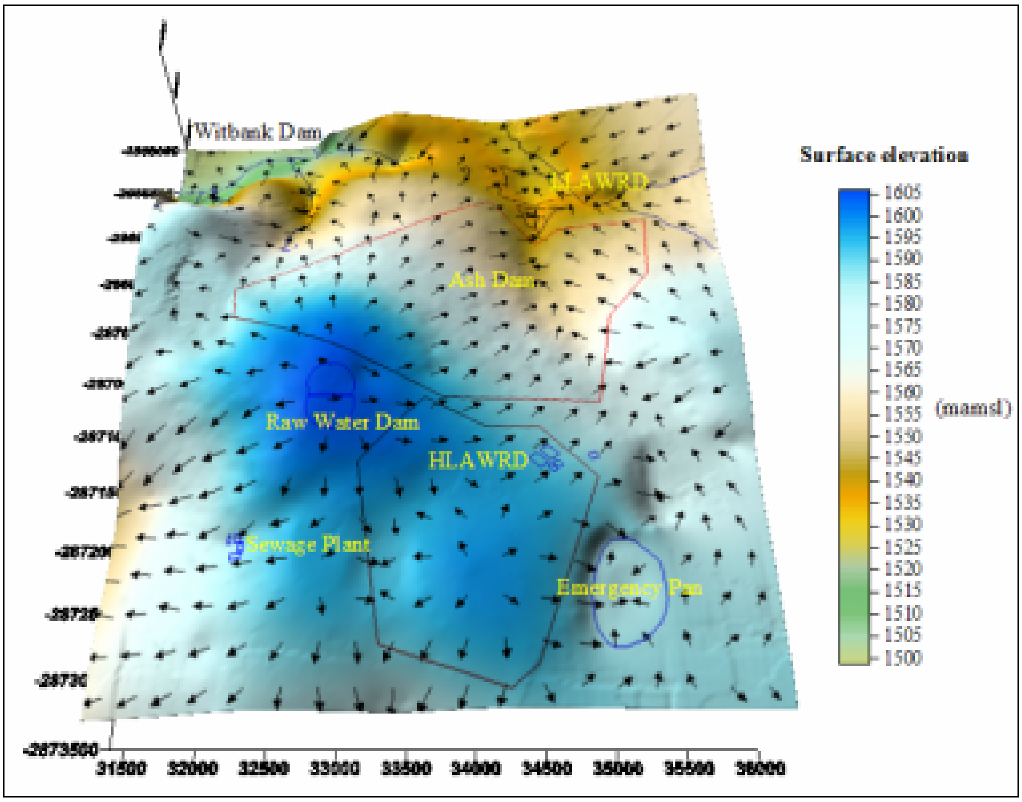

Figure 4. Surface topography and drainage prior to the commencement of power station activities.

The current surface topography and drainage directions are at Duvha Power Station are shown in Figure 5. Although the construction of the various dam systems at the power station has altered the local drainage patterns in vicinities of these dams, the regional drainage is very similar to the natural drainage that occurred prior to the construction of the power station.

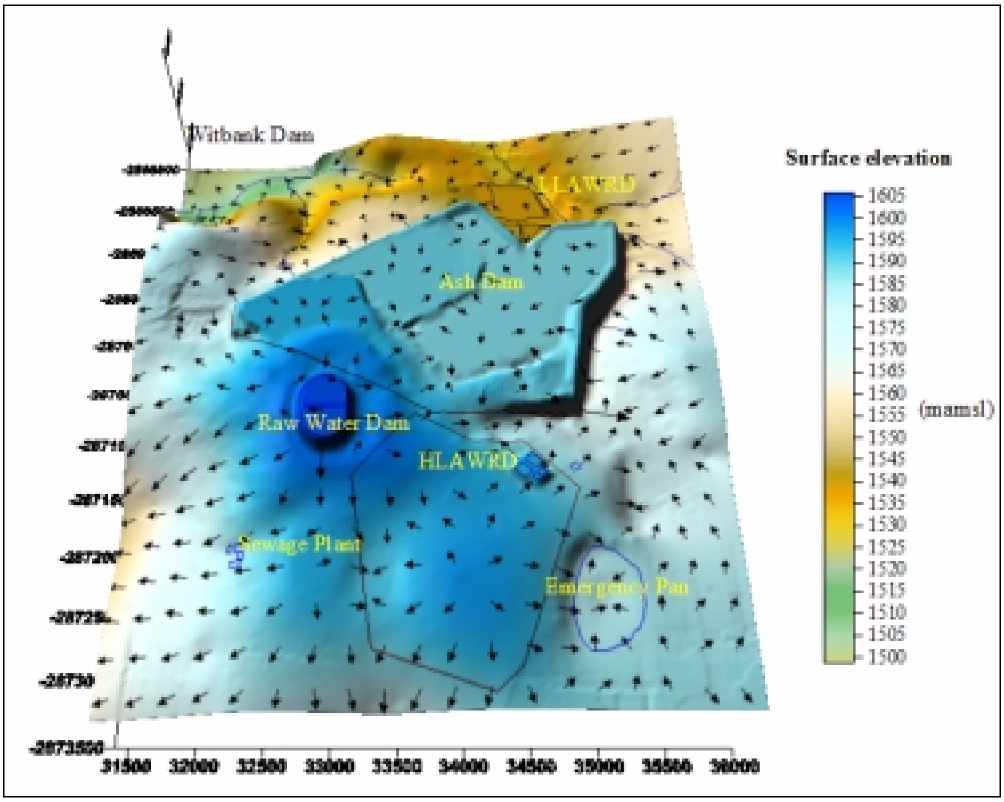

Figure 5. Current surface topography and drainage.

4 GEOLOGICAL SETTING

A regional geological map of the area surrounding Duvha Power Station is presented in Figure 6 (as well as in Figure A03 of **Appendix A**). Duvha Power Station is located near the contact between sedimentary rocks of the Karoo Supergroup and older extrusive volcanic rocks of Vaalium age in the form of rhyolites. The Karoo rocks that occur in the vicinity of the power station belong to the Ecca Group and predominantly consist of shales, sandstones, conglomerates and coal deposits.

The Ash Dam and Low Level Ash Water Return Dam are almost completely underlain by rhyolites, with the contact between the rhyolites and the Karoo rocks running approximately parallel to the south-western border of the Ash Dam. Drilling results have shown that the contact occurs more to the south and that it in fact runs underneath the Raw Water Dam. The power station itself, as well as the High Level Ash Water Return Dams, Sewage Plant and Emergency Pan, occurs on Karoo sedimentary rocks.

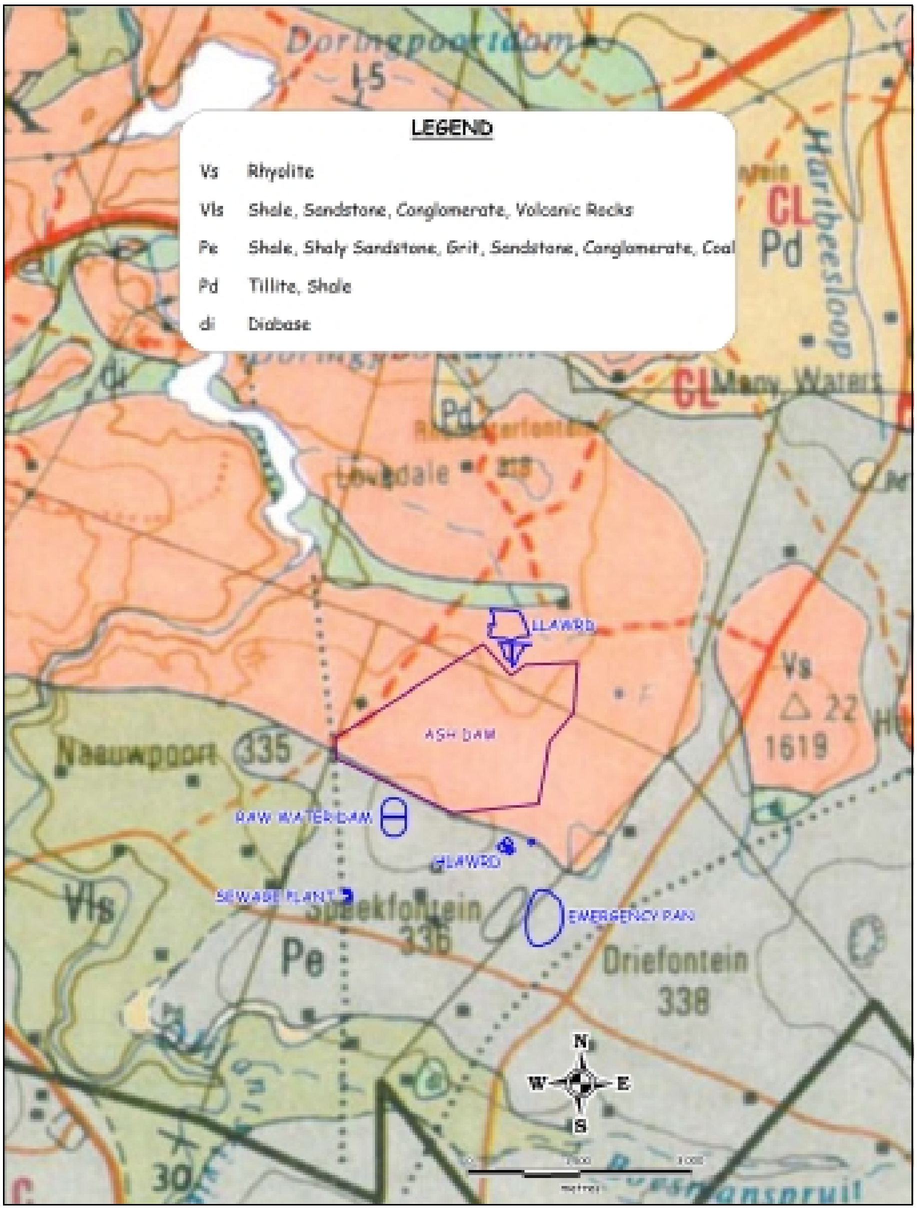

Figure 6. Geological setting of Duvha Power Station.

A large intrusive diabase body occurs to the north of the Low Level Ash Water Return Dam and partially underlies the return water dam. No outcrop of this body is, however, visible at surface.

Three boreholes that are located north of the Low Level Ash Water Return Dam intersect the diabase body.

5 GEOPHYSICAL INVESTIGATIONS

The aim of the geophysical investigations was to detect and delineate intrusive magmatic bodies that may influence groundwater migration. Magmatic bodies are often associated with baked zones near their contacts with the surrounding host rock. These baked zones are more likely to be extensively fractured and weathered and may therefore act as preferential pathways for groundwater migration and contaminant transport. Intrusive magmatic bodies may also act as barriers to groundwater flow in direction perpendicular to their strikes.

The results of the geophysical investigations interpreted in order to identify drilling targets or suitable drilling positions that would yield the geological information required for the current study.

5.1 Interpretation of airborne magnetic data

Airborne magnetic data were obtained from the Council for Geoscience and studied in order to identify large scale magnetic features that may influence the groundwater environment. A map of the airborne magnetic data is shown in Figure 7 and Figure A.10 of **Appendix A**.

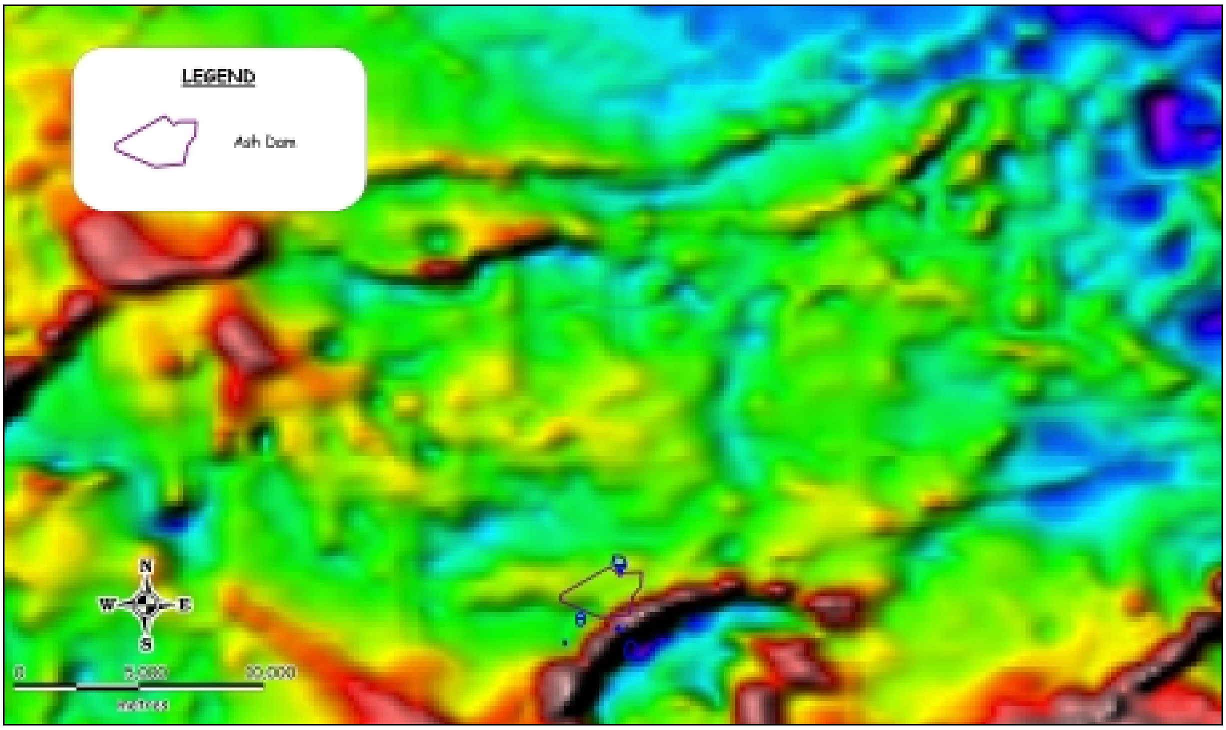

Figure 7. Airborne magnetic map of the area surrounding Duvha Power Station.

From the airborne magnetic map a large semi-circular magnetic feature that occurs to the south-west of the Ash Dam may be identified. This feature seems to underlie the Emergency Pan, and possibly the High Level Ash Water Return Dams. No other prominent magnetic features are visible in the vicinity of the power station. Note that the magnetic signature of the diabase intrusion that occurs to the north of the Low Level Ash Water Return Dam is not visible in the airborne magnetics map. Even though diabase intrusions generally give large magnetic responses, the scale of the airborne magnetics map is too large to give adequate resolution for the diabase intrusion be detected.

5.2 Ground geophysical investigations

During the ground geophysical investigations magnetic data were recorded on 14 traverses in the vicinity of the different dam systems at Duvha Power Station. . The results of the geophysical investigations were then used to select drilling positions in the vicinities of the dams.

The positions of the 14 traverses on which magnetic data were recorded during the geophysical investigations are indicated in Figure 8 (as well as in Figures A04 and A05 of **Appendix A**). The profiles of the magnetic data recorded on the various traverses are presented in **Appendix B**.

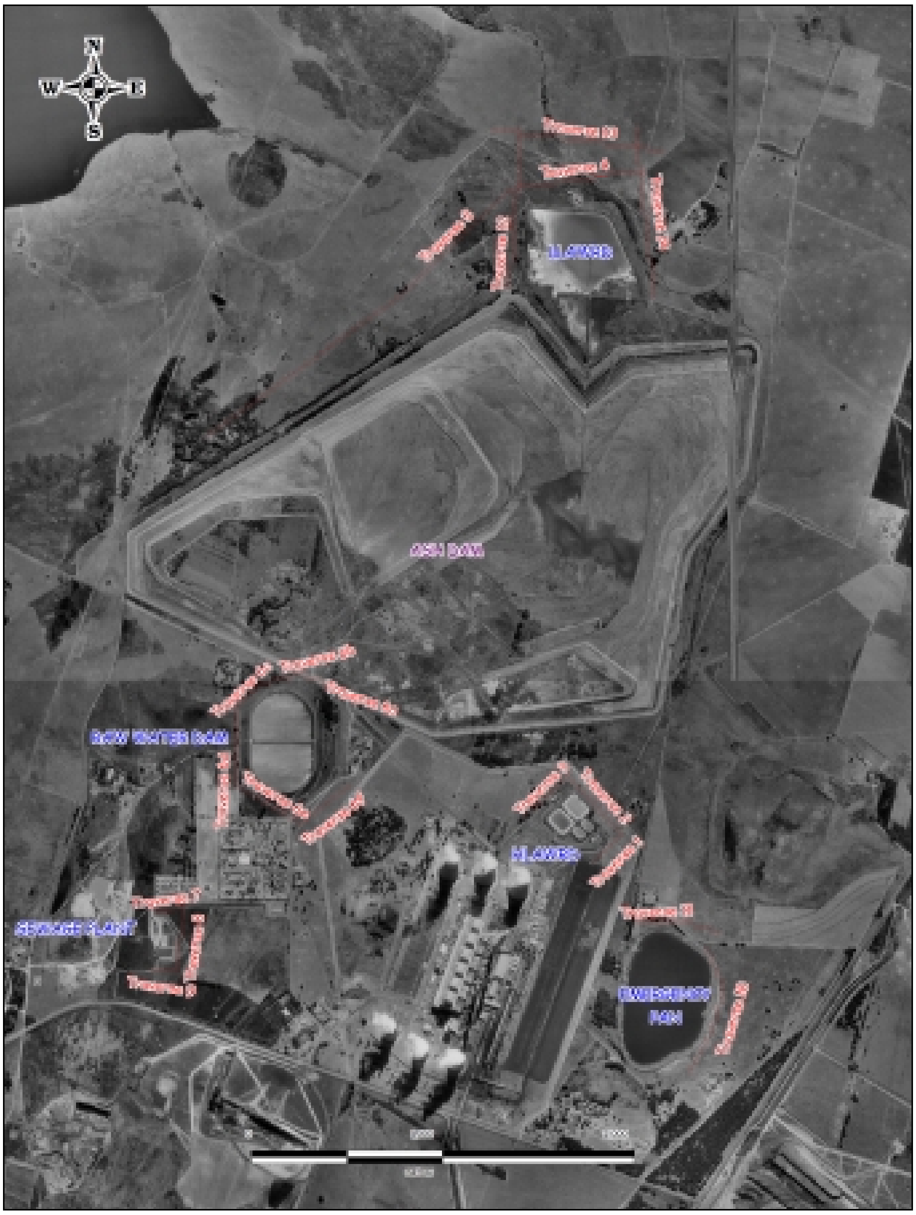

Figure 8. Positions and orientations of the magnetic traverses in relation to the dam systems at Duvha Power Station.

Where possible, magnetic data were recorded on three perpendicular traverses around the different dam systems to ensure that any linear magnetic feature that cuts through the dam systems would be detected. The choice of traverse position and direction was, however, influenced by the presence of surface infrastructure. Metal objects, such as ash transfer pipes and pump houses, have a strong magnetic signature that may mask the magnetic signatures of geological units. Power lines and wires carrying current cause electromagnetic noise that may completely dominate the magnetic readings taken during a survey. Since metal objects and electric currents are ubiquitous at a power station, it was not always possible to avoid their negative influences on the recorded data. The results of the geophysical investigations are described below:

5.3 High Level Ash Water Return Dams

Magnetic data were recorded on three traverses (Traverses 1 to 3) around the High Level Ash Water Return Dams. Traverse 1 was located south-east of the High Level Ash Water Return Dams and had an approximate south-west/north-east strike. Traverse 3 ran approximately parallel to Traverse 1, but was located north-west of the High Level Ash Water Return Dams. Traverse 2 ran perpendicular to these two traverses on the north-eastern side of the dam system.

The only prominent magnetic anomalies observed in the profiles of Traverses 1, 2 and 3 are associated with surface infrastructure. No magnetic feature of a geological origin could be identified from the data recorded on these traverses.

5.4 Low Level Ash Water Return Dam

Magnetic data were recorded on four traverses (Traverses 4, 12, 13 and 14) in the vicinity of the Low Level Ash Water Return Dam. Since an intrusive diabase body is known to occur near the dam and is expected to partially underlie the dam, the purpose of the geophysical investigations was to delineate this body.

Although the data recorded in the vicinity of the Low Level Ash Water Return Dam are likely to have been influenced by electromagnetic noise, the presence of the diabase intrusion was detected on all four traverses. Traverses 4 and 13 approximately ran along the strike of the body. The large variations in the magnetic field strength recorded on these two traverses are the typical response that may be expected from such an intrusive body. Traverses 12 and 14 ran approximately perpendicular to the expected strike of the diabase intrusion. Although the data recorded on Traverse 12 displayed large spatial variability along the entire length of the traverse, an increase in the amplitude and variability is noticed at a position 550 m from the start of the traverse. This position corresponds well with the mapped occurrence of the diabase intrusion. The data recorded on Traverse 14 were strongly influenced by man-made noise and are less useful in defining the contact with the diabase intrusion.

5.5 Ash Dam

Traverse 5 ran approximately parallel to the north-western wall of the Ash Dam. The magnetic data again displayed a large degree of spatial variability. A sharp increase in the amplitudes and variabilities of the magnetic data is, however, apparent at a distance of approximately 1 700 m from the start of the traverse. This position again corresponds well with the mapped occurrence of the diabase intrusion.

5.6 Raw Water Dam

Magnetic data were recorded on one traverse (Traverse 6) around the Raw Water Dam. Traverse 6 consisted of six shorter traverses that ran approximately parallel to the fence around the dam. Metal and electric objects occur in the vicinity of the dam. All the anomalies recorded along Traverse 6 are related to the presence of man-made noise and do not clearly indicate the presence of any geological feature in the vicinity of the dam.

5.7 Sewage Plant

Traverses 7, 8 and 9 ran around the Sewage Plant on its northern, eastern and southern sides. All the magnetic anomalies recorded on these traverses were due to the presence of metal objects at surface. No magnetic geological features could be identified from the data recorded on these three traverses.

5.8 Emergency Pan

Magnetic data were recorded on two traverses near the Emergency Pan. Traverse 10 ran along the eastern perimeter of the pan, while Traverse 11 ran approximately west/east on the northern side of the pan.

Very large magnetic variations with a low spatial frequency are apparent on Traverse 10. These variations are in all likelihood due to the large semi-circular magnetic feature identified on the airborne magnetics map (refer to Figure 7). The large wavelength of the magnetic anomalies suggest that the geological feature responsible for the magnetic response occurs at great depth and is unlikely to influence groundwater migration in the near surface.

The magnetic data recorded on Traverse 11 do not indicate the presence of a magnetic feature that could influence the groundwater environment. The lack of magnetic variation observed on Traverse 11 as compared to Traverse 10 suggests that Traverse 11 runs approximately parallel to the local strike of the magnetic feature that gives rise to the response observed along Traverse 10.

6 DRILLING OF MONITORING BOREHOLES

Twenty new monitoring boreholes were drilled at selected sites in the vicinities of the different dam systems that are included in the current seepage investigations. Both deep and shallow boreholes were drilled to allow investigation of the properties of both the shallow weathered formations and the deeper fresh rock units. The newly drilled boreholes have depths that vary from 10 to 30 metres. The positions of the newly drilled boreholes in relation to the different dam systems are shown in Figure 9 and in Figure A06 of **Appendix A**. The boreholes have been numbered according to the existing numbering system. Since 13 monitoring boreholes existed at the power station prior to the latest drilling programme, the 20 new boreholes are numbered PB14 to PB25 and AB26 to AB33. The "P" in the numbering system indicates that the specific borehole monitors groundwater of the Power Station Area, while the "A" indicates that a borehole monitors groundwater of the Ashing Area. In Figure 9 it is also indicated whether a borehole is a shallow borehole (S) with a depth of only 10 m or whether it is a deep borehole (D) with a depth greater than 15 m. Information on the 20 new boreholes is listed in Table 4.

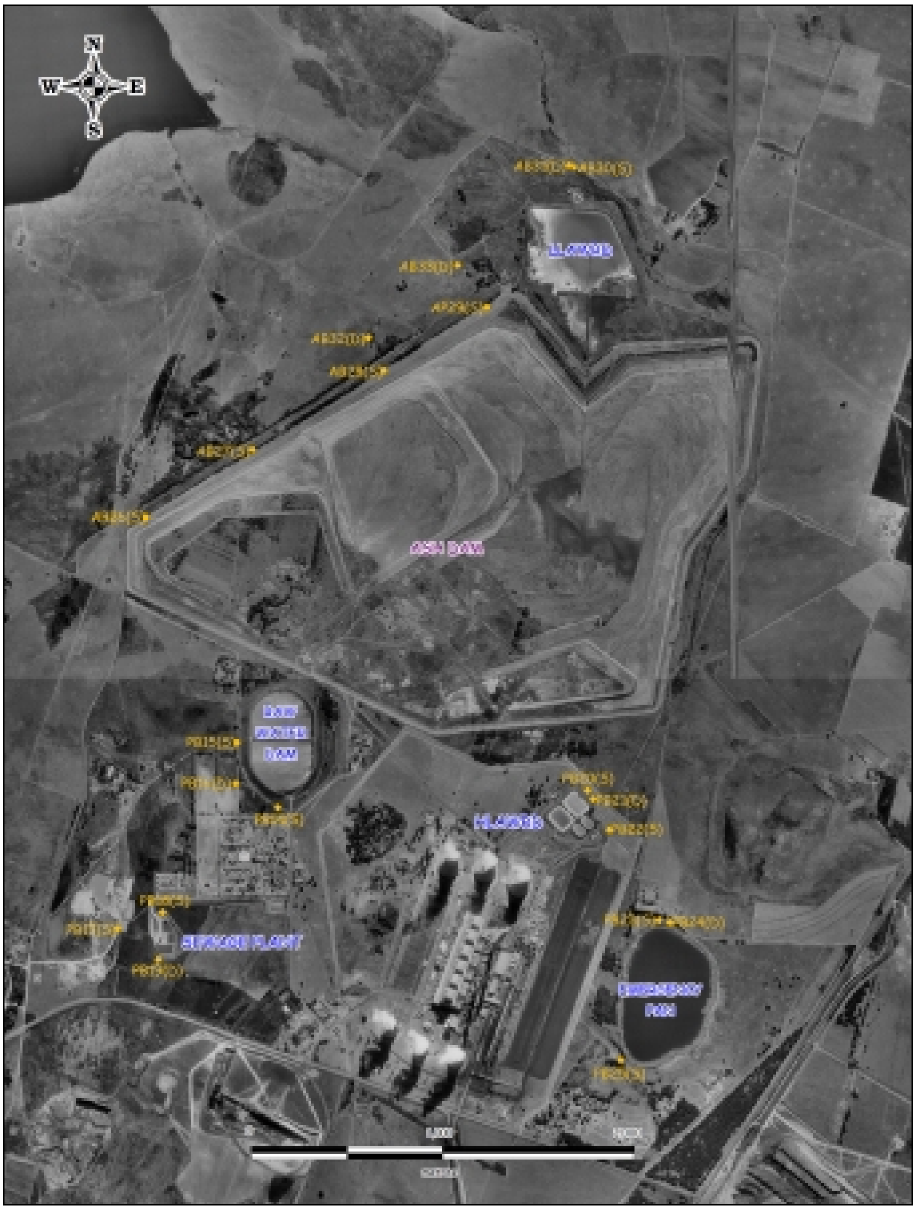

Figure 9. Positions of the 20 new monitoring boreholes at Duvha Power Station.

Table 4. Information on the 20 new boreholes.

Borehole #	Field #	Location	Latitude (°S)	Longitude (°E)	Depth (m)
PB14	BH01	South-east of Raw Water Dam	25.95350	29.32899	10
PB15	BH02	West of Raw Water Dam	25.95040	29.32685	10
PB16	BH03	South-west of Raw Water Dam	25.95236	29.32678	20
PB17	BH04	West of Sewage Plant	25.95921	29.32064	10
PB18	BH05	North of Sewage Plant	25.95843	29.32299	10
PB19	BH06	South of Sewage Plant	25.96068	29.32278	30
PB20	BH07	North-east of High Level Ash Water Return Dams	25.95265	29.34514	10
PB21	BH08	North-east of High Level Ash Water Return Dams	25.95304	29.34544	30
PB22	BH09	East of High Level Ash Water Return Dams	25.95451	29.34627	10
PB23	BH10	North of Emergency Pan	25.95877	29.34889	10
PB24	BH11	North of Emergency Pan	25.95885	29.34945	30
PB25	BH12	South of Emergency Pan	25.96538	29.34693	10
AB26	BH13	North of Ash Dam	25.93981	29.32206	10
AB27	BH14	North of Ash Dam	25.93658	29.32762	10
AB28	BH15	North of Ash Dam	25.93277	29.33445	10
AB29	BH16	North of Ash Dam	25.92981	29.33983	10
AB30	BH17	North of Low Level Ash Water Return Dam	25.92315	29.34435	10
AB31	BH18	North of Low Level Ash Water Return Dam	25.92307	29.34412	15
AB32	BH19	North of Ash Dam	25.93128	29.33364	30
AB33	BH20	North of Ash Dam	25.92781	29.33830	25

During drilling a geological borehole log was compiled for each borehole. The borehole logs include information on the geological units intersected during drilling, the depths of any water strikes and the borehole construction. The geological borehole logs of the 20 new boreholes are presented **Appendix C** and briefly discussed below:

6.1 Raw Water Dam

Boreholes PB14 to PB16 were in the vicinity of the Raw Water Dam. Since the geophysical investigations did not reveal the presence of any magnetic intrusive body that could be associated with preferential pathways for groundwater migration, these boreholes were drilled in positions to the south and west of the Raw Water Dam where the local topographic gradient is the highest. Borehole PB14 intersected coarse sandstones and soft siltstones of the Karoo Supergroup. Light brown clay was intersected at a depth of 8 metres below ground level (mbgl) and continued to the final depth of the borehole (10 mbgl).

Borehole PB15 was drilled west on the Raw Water Dam. Weathered rhyolites were encountered along the entire length of the borehole. This observation shows that the contact between the Karoo rocks and the rhyolites must lie under the Raw Water Dam.

Borehole PB16 was drilled to the south-west of the Raw Water Dam. Sandstones and siltstones were again encountered up to a depth of 10 mbgl. Light grey and olive grey clayey silts occurred at depths of between 10 and 20 mbgl. These silts are in all probability due to the decay of siltstones. The clayey material caused difficulties during drilling and it was decided to terminate drilling at a depth of 20 mbgl.

6.2 Sewage Plant

Borehole PB17 was drilled west of the Sewage Plant on the property of Corobrik. Olive brown clayey silt was encountered along the entire length of the borehole (10 m). This clayey silt is mined by Corobrik for the making of oven-baked clay bricks.

Borehole PB18 is located north of the sewage plant. Silts and fine to medium grained sandstones were intersected during drilling. The borehole was drilled to a depth of 10 m.

Borehole PB19 was drilled south of the Sewage Plant to a depth of 30 m. Silts and sandstones were again encountered. Carbonaceous shale was intersected at a depth of around 18 mbgl. Below the carbonaceous shale a four metre thick layer of low-grade coal was encountered. Fine grained sandstones underlie the coal layer. Two minor water strikes occurred at depths of around 8 and 14 mbgl.

6.3 High Level Ash Water Return Dams

Boreholes PB20, PB21 and PB22 were drilled to the north-east and east of the High Level Ash Water Return Dams, in the expected direction of groundwater flow away from the dam system. Clayey sandstones and siltstones were encountered during the drilling of these three boreholes. No water was struck during drilling. However, the drill cuttings from boreholes PB20 and PB21 were moist at shallow depths (< 5 mbgl).

6.4 Emergency Pan

Two boreholes PB23 and PB24 were drilled north of the Emergency Pan. Borehole PB23 was drilled to a depth of 10 m and intersected coarse sandstones, silts and carbonaceous shale. PB24 was drilled to a depth of 30 m and intersected the same geological units as PB23 at shallow depths. A five metre thick low-grade coal layer was intersected below the carbonaceous shales at a depth of between 15 and 20 mbgl. A minor water strike occurred within the coal layer. Shales were again encountered at depths of greater than 20 mbgl.

Borehole PB25 was drilled south of the Emergency Pan. Silty sand, siltstone and silt were intersected during drilling.

6.5 Ash Dam

Four shallow boreholes and two deep boreholes were drilled north of the Ash Dam. All of these boreholes intersected rhyolites in various states of weathering. Boreholes AB26 to AB29 were drilled close to the Ash Dam to depths of only 10 m. All these boreholes intersected weathered rhyolites along most of their lengths. High levels of weathering were particularly evident at boreholes AB27, AB28 and AB29. Minor water strikes also occurred in these boreholes. These water strikes are in all probability due to seepage from the Ash Dam.

Boreholes AB32 and AB33 were drilled further away from the Ash Dam and to greater depths in order to allow investigation of the deeper, less weathered rhyolites. Borehole AB32 was drilled to a depth of 30 m and intersected rhyolites along its entire length. Two minor water strikes occurred at depths of around 21 and 25 mbgl. Borehole AB33 was drilled to a depth of 25 m and also encountered rhyolites along its entire length. A minor water strike occurred at a depth of around 11 mbgl.

6.6 Low Level Ash Water Return Dam

Two boreholes were drilled north of the Low Level Ash Water Return Dam. Borehole AB30 was drilled to a depth of 10 m. At shallow depths alluvial clay deposits were encountered, followed by weathered rhyolites. Weathered diabase (dolerite) was struck at a depth of 6 mbgl and became fresh at a depth of around 7 mbgl.

Similar drilling results were obtained during the drilling of borehole AB31, although the dolerite was intersected at a slightly greater depth (8 mbgl). Boreholes AB30 and AB31 were constructed differently to allow hydraulic testing and sampling of both the shallow and deep aquifer systems.

7 HYDRAULIC TESTING OF BOREHOLES

None of the 20 new boreholes had a major water strike during drilling. The groundwater potential in the vicinity of Duvha Power Station therefore seems to be low. Since none of the boreholes are high-yielding, it was decided to perform slug tests, instead of injection-withdrawal test, on all the new monitoring boreholes.

Since the shallow and deep monitoring boreholes were constructed differently, both the shallow and deep aquifer systems could be tested for their hydraulic properties. The aquifer hydraulic conductivities, as estimated from the results of the slug tests performed on the different boreholes, are listed in Table 5 (also refer to **Appendix D**).

Table 5. Hydraulic conductivities of the geological formations in the vicinities of the new monitoring boreholes.

Location	Borehole #	Hydraulic conductivity (m/d)
Raw Water Dam	PB14	0.017
	PB15	0.012
	PB16	0.022
Sewage Plant	PB17	0.072
	PB18	0.029
	PB19	0.128
High Level Ash Water Return Dams	PB20	0.052
	PB21	0.006
	PB22	0.023
Emergency Pan	PB23	0.003
	PB24	0.122
	PB25	0.006
Ash Dam	AB26	0.021
	AB27	0.838
	AB28	0.599
	AB29	0.556
	AB32	0.004
	AB33	0.345
Low Level AWR Dam	AB30	0.081
	AB31	0.059

From the interpretation of the slug test results listed in Table 5, the following observations may be made:

- Boreholes PB14, PB20 and PB22 intersect shallow weathered Karoo rocks. The hydraulic conductivities estimated for the rock formations in the vicinities of these boreholes are 0.017 0.052 and 0.023 m/d, respectively. The relatively low average hydraulic conductivity of around 0.030 m/d is likely to be due to the fact that the weathered Karoo formations are clayey and silty at shallow depths.

- Boreholes PB23 and PB25 near the Emergency Pan also intersect shallow Karoo rocks, but have lower hydraulic conductivities (0.003 and 0.006 m/d). This observation shows that the hydraulic properties of the shallow Karoo formations are very variable according to location and depend on factors such as the depositional environment and the degree of weathering or decay.

- Boreholes PB16, PB19, PB21 and PB24 intersect the deeper Karoo formations. The hydraulic conductivities estimated for these boreholes are 0.022, 0.128, 0.006 and 0.122 m/d, respectively. The low hydraulic conductivities (PB16 and PB21) were recorded in boreholes that did not intersect coal and did not have water strikes, whereas the opposite is true for the boreholes with high hydraulic conductivities (PB19 and PB24). This observation shows that minor fractures within the fresh Karoo rock can cause significant increases in the hydraulic conductivities of these formations.
- Boreholes PB15 and AB26 to AB29 intersected weathered rhyolites. The degree of weathering at boreholes PB15 and AB26 was noticeably lower than at the other three boreholes. The results of the slug tests show that very high hydraulic conductivities of between 0.556 and 0.838 m/d can be expected for the highly weathered rhyolites, while lower hydraulic conductivities (~0.015 m/d) are to be expected for the less weathered rhyolites.
- Borehole AB32 intersects the deeper, un-weathered rhyolites. The low hydraulic conductivity estimated from the slug test performed on this borehole shows that the fresh rhyolites have low permeabilities and that groundwater migration through these rock will take place at a slow rate.
- The high hydraulic conductivity observed at borehole AB33 suggests that the deeper fresh rhyolites were not effectively isolated from the shallow weathered rhyolites during borehole construction.
- The hydraulic conductivities estimated for the geological units in the vicinity of boreholes AB30 and AB31 are relatively high, suggesting that the fractured and weathered dolerites intersected by these boreholes are likely to act as a preferential pathways for groundwater migration and contaminant transport.

8 SURFACE- AND GROUNDWATER SAMPLING AND ANALYSES

During the seepage investigations conducted by GHT Consulting, 13 surface water sites and 32 groundwater sites were sampled. The groundwater sites included both the existing monitoring boreholes and the newly drilled boreholes, as well as a fountain near the Emergency Pan. All the water samples were submitted to the chemical laboratories of the Institute for Groundwater Studies at the University of the Free State for chemical analyses. Eight water samples from selected boreholes near the Raw Water Dam and the Sewage Plant were also submitted for stable isotope analyses at the laboratories of the Environmental Isotope Group of iThemba Labs. The purpose of the isotope analyses was to evaluate the groundwater for surface water characteristics that could confirm that seepage from the surface water sites has occurred.

8.1 Surface water quality

The positions of the existing surface water monitoring sites at Duvha Power Station are shown in Figure 10 and Figures A07 of **Appendix A**. Information on these sites is supplied in Table 6.

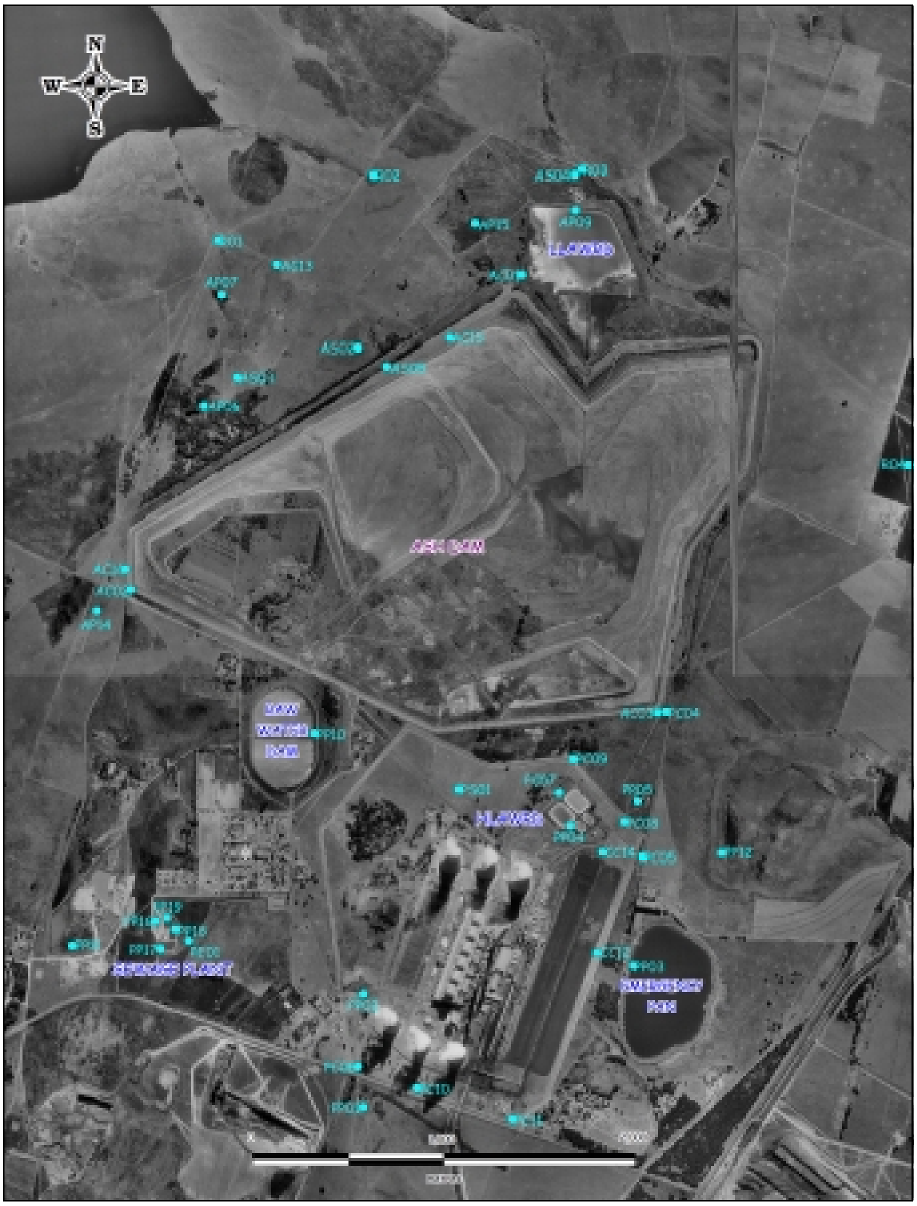

Figure 10. Surface water monitoring sites at Duvha Power Station.

Table 6. Information on surface water monitoring sites at Duvha Power Station.

Site #	Location/Description	Latitude (^oS)	Longitude (^oE)
AC01	Seepage Trench running into Low Level Ash Water Return Dam	25.92827	29.34157
AC02	Storm water canal running into vlei area south-west of Ash Dam	25.94333	29.32117
AC03	Storm water canal south of Ash Dam	25.94897	29.34905
AC13	Trench in north-western corner of Ashing Area	25.92757	29.34900
AC15	Ash Water Return Canal	25.93132	29.33783
AC16	Clean water canal west of Ash Dam	25.94231	29.32091
AP06	Dam north-west of Ash Dam, collecting drainage from Ash Dam Area	25.93459	29.32488
AP07	Dam north-west of Ash Dam	25.92928	29.32590
AP08	Witbank Dam	25.92933	29.30551
AP09	Low Level Ash Water Return Dam	25.92522	29.34438
AP13	Dam north-east of Ash Dam (upstream)	25.92798	29.36492
AP14	Non-perennial pan at south-western toe of Ash Dam	25.92798	29.36492
AP15	Seepage in pan west of the Low Level Ash Water Return Dam	25.92585	29.33914
AS02	Seepage in kraal north of Ash Dam	25.93181	29.33305
AS03	Seepage near boreholes AB01, AB02, AB03 in dug pit	25.93319	29.32672
AS04	Seepage north of Low Level Ash Water Return Dam near R03	25.92355	29.34433
AS05	Seepage next to borehole AB28	25.93277	29.33445
CC12	Clean water leaving Coal Stockyard Area	25.96051	29.34564
CC14	Runoff interception canal around Coal Stockyard	25.95574	29.34588
PC04	Dirty water canal from northern Station Drain Dams	25.94897	29.34905
PC05	Emergency canal leaving ESKOM property and running into pan PP03	25.95623	29.34777
PC06	Dirty water canal running to southern Station Drain Dams	25.96593	29.33309
PC07	Canal near pump station at High Level Ash Water Return Dams	25.95287	29.34359
PC08	Dirty water canal running to northern Station Drain Dams	25.95428	29.34696
PC09	Storm water leaving Power Station Area into natural environment	25.95119	29.34416
PC10	Clean water leaving Power Station Area	25.96695	29.33623
PC11	Clean water canal leaving Power Station Area	25.96845	29.34116
PE01	Final sewage effluent pumped to High Level Ash Water Return Dams	25.95852	29.32326
PP01	Station Drain Dams (south)	25.96811	29.33340
PP02	Duck pond near Conference/Recreation Centre	25.96249	29.33341
PP03	Emergency Pan	25.96109	29.34756
PP04	High Level Ash Water Return Dams	25.95452	29.34423
PP05	Station Drain Dams (north)	25.95335	29.34769
PP10	Raw Water Dam	25.92522	29.34438
PP11	Dam west of sewage plant	25.96022	29.31819
PP12	Non-perennial pan north-east of Power Station Area	25.95577	29.35210
PP16	Buffer pond at sewage plant	25.95904	29.32252
PP17	First maturation pond at sewage plant	25.96037	29.32280
PP18	Second maturation pond at sewage plant	25.95943	29.32356
PP19	Third maturation pond at sewage plant	25.95887	29.32313
PS01	Possible burst pipe (north-west of power station)	25.95278	29.33835
R01	Stream downstream from dam AP07 (north-west of Ash Dam)	25.92669	29.32570
R02	Stream north of Ash Dam flowing towards Witbank Dam along fence	25.92362	29.33381
R03	Stream north of LLAWRDs (Ash Water Drain)	25.92333	29.34469
R04	Non-perennial stream upstream from Ash Dam	25.93729	29.36182
R05	Non-perennial stream west of Power Station Area	25.95624	29.30105

The results the chemical analyses performed on the water samples from selected surface water sites at Duvha Power Station are listed in Table 7. The data in Table 7 are colour-coded according to the "South Africa Water Quality Guidelines, Volume 1: Domestic Use, DWA&F, First Edition 1993" and the "South Africa Water Quality Guidelines, Volume 1: Domestic Use, DWA&F, Second Edition 1996", as well as the publication "Quality of Domestic Water Supplies, DWA&F, Second Edition 1998" (see Table 8).

Table 7. Results of the chemical analyses performed on surface water samples taken during the seepage investigations.

DUVHA POWER STATION - SEEPAGE INVESTIGATIONS - SURFACE WATER QUALITY

No.	Date	pH	EC mS/m	TDS mg/L	Na mg/L	Ca mg/L	Mg mg/L	K mg/L	Cl mg/L	SO_4 mg/L	P.Alk mg/L	T.Alk mg/L	F mg/L	NO_2-N mg/L	NO_3-N mg/L	PO_4 mg/L	Fe mg/L	Mn mg/L	B mg/L
AC01	20060805	5.7	95.8	670	125	45	18	26	103	349	0	6	0.03	BDL	0.79	BDL	0.007	2.813	0.296
AC02	20060805	7.5	19.1	126	21	28	3	8	35	30	0	65	0.26	BDL	0.24	0.08	0.024	0.000	0.073
AC15*	20060805	12.1	718.0																
AC16	20060805	7.0	116.0	925	95	140	28	16	102	427	0	96	0.48	BDL	0.16	BDL	0.051	0.002	0.052
AP06	20060805	3.6	104.0	810	181	41	24	27	222	314	0	22	0.36	BDL	0.04	0.59	0.371	2.304	0.096
AP07*	20060805	6.5	67.0																
AP09	20060803	12.0	514.0	1445	113	560	0	37	88	638	0	265	1.21	0.05	1.86	BDL	0.002	0.000	0.205
AP14	20060805	6.3	42.1	259	39	15	6	27	80	56	0	29	0.17	BDL	0.33	BDL	1.187	1.129	0.039
AP15	20060804	3.4	36.4	278	53	12	7	20	80	105	0		0.12	BDL	0.34	0.58	0.443	8.957	0.073
AS02	20060804	6.2	617.0	4878	1580	124	44	43	1378	1708	0	57	0.36	BDL	0.21	BDL	0.307	4.939	0.136
AS03	20060805	7.0	115.0	888	183	36	34	18	121	397	0	83	0.18	BDL	0.15	BDL	0.064	0.098	0.069
AS04	20060804	7.5	73.3	477	28	60	36	5	108	119	0	101	BDL	BDL	0.14	BDL	0.047	0.003	0.032
PP03	20060804	6.8	180.0	1315	173	212	7	33	131	756	0	58	1.44	BDL	0.29	BDL	0.042	0.003	0.166
PP04	20060815	12.0	520.0	1506	106	590	0	35	90	676	0	267	1.19	0.06	1.73	BDL	0.000	0.000	0.147
PP10	20060816	8.0	43.3	223	21	34	20	5	15	128	0	78	0.28	BDL	0.05	0.72	0.031	0.003	0.050
PP11	20060815	5.7	10.9	58	10	4	2	4	20	17	0	4	0.28	BDL	0.13	BDL	0.036	0.135	0.039
PP12	20060815	5.7	20.4	91	19	3	2	5	35	17	0	9	0.06	BDL	0.12	BDL	9.718	0.066	0.047
PP16*	20060816	6.6	33.0																
PP17	20060816	6.9	38.5	231	33	18	8	14	28	7	0	101	0.05	2.57	0.04	BDL	0.684	0.378	0.061
PP18*	20060816	6.5	32.0																
PP19	20060816	7.2	29.2	182	29	13	6	8	30	27	0	50	0.07	0.28	2.15	6.48	0.011	0.001	0.037
R01	20060805	5.8	47.1	264	80	6	4	7	141	16	0	12	BDL	BDL	0.35	BDL	8.886	0.735	0.049
R02	20060805	6.3	35.7	338	47	10	7	8	60	35	0	107	0.16	BDL	0.64	BDL	41.369	0.373	0.134
R03	20060804	6.8	50.9	215	21	40	22	6	66	59	0	99	0.12	BDL	0.18	BDL	0.049	0.064	0.032
Detection Limits:													**0.01**	**0.01**		**0.10**			

BDL - Below Detection Limits
*** - Field measurement**

Table 8. Classification system used to evaluate water quality classes.

Quality of Domestic Water Supplies, DWA&F, Second Edition 1998	
Class 0	- **Ideal water quality** - Suitable for lifetime use.
Class 1	- **Good water quality** - Suitable for use, rare instances of negative effects.
Class 2	- **Marginal water quality** - Conditionally acceptable. Negative effects may occur in some sensitive groups
Class 3	- **Poor water quality** - Unsuitable for use without treatment. Chronic effects may occur.
Class 4	- **Dangerous water quality** - Totally unsuitable for use. Acute effects may occur.
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.

From the data listed in Table 7 the following observations may be made:

- Although the current water quality in the Seepage Trench (AC01) may be classified as good to marginal, clear signs of contaminant impacts are apparent. Most of the inorganic parameter concentrations are very high compared with the water from the clean water from the storm water canal AC02. This observation shows that the canal is indeed intercepting seepage water from the Ash Dam. However, the relatively low pH of 5.7 is puzzling since alkaline conditions are expected for seepage water from the Ash Dam.
- Since ash water is known to generally have high salt concentrations and alkaline conditions, the high pH values and electrical conductivities of the water from the Ash Water Return Canal (AC15), the Low Level Ash Water Return Dam (AP09) and the High Level Ash Water Return Dams (PP04) are to be expected. The sulphate concentrations at the two ash water return dam systems are 638 and 676 mg/L, respectively. These concentrations can be considered as representative of the sulphate concentrations in the ash water system.

- The clean water canal (AC16) on the western side of the Ash Dam has been subject to contaminant impacts. The sulphate concentration at this site (427 mg/L) is high enough to cause the water quality to be classified as marginal.
- The reason for the extremely low pH observed at dam AP06 north of the Ash Dam is unknown. The high salt concentrations at this site show that contaminants have impacted on the water quality.
- The salt concentrations in the non-perennial pan (AP14) at the south-western corner of the Ash Dam are slightly elevated, suggesting that this pan has been subject to contaminant impacts. However, this shallow pan is particularly vulnerable to evaporation losses and the observed concentrations may therefore be due to the concentrating effect of evaporation.
- A very low pH is observed at the pan west of the Low Level Ash Water Return Dam (site AP15). Low pH values have been intermittently observed at this site since December 2002. The reason for the anomalously low pH is unknown, but is not thought to be due to ashing activities.
- The standing water that occurs in the kraal area north of the Ash Dam at site AS02 has the poorest quality of all the sampled surface water sites. The origin of this water is likely to be seepage from the Ash Dam. The extremely high salt concentrations observed at this site may again be attributed to the concentrating effect of evaporation acting on standing water bodies.
- The water quality at site AS03 (dug pit north of the Ash Dam) ranges from ideal to good. However, contaminant impacts are evidenced by the high salt concentrations observed at this site. The elevated sulphate concentration suggests that this site is also influenced by seepage from the Ash Dam.
- Standing water occurs at site AS04 north of the Low Level Ash Water Return Dam right next to the non-perennial stream that flows past the dam at site R03. The quality of the water at AS04 ranges from ideal to good, but is markedly poorer than the water at site R03. This observation suggests that the water at site AS04 is due to seepage from the Low Level Ash Water Return Dam. Again it should be kept in mind that the salt concentrations in shallow standing water bodies may be significantly increased by evaporation.
- Elevated manganese concentrations are apparent at a number of surface sites near the Ash Dam. These manganese concentrations may, however, be of a natural origin. High manganese concentrations are displayed at most of the groundwater sites in the vicinity of Duvha Power Station (refer to Section 8.2). Surface water sites that are fed by groundwater are therefore also like to have elevated manganese concentrations. The low pH values observed at sites AP06 and AP15 will also increase the mobility of the trace elements, such as manganese and iron.
- Severe contaminant impacts are apparent at the Emergency Pan (PP03). This pan has in the past received water from the High Level Ash Water Return Dams (PP04). The increased sulphate concentrations observed at this shallow pan (as compared to the sulphate concentration at site PP04) may again be due to the concentrating effects of evaporation.
- The Raw Water Dam contains water of an ideal quality. However, the salt concentrations are slightly elevated when compared with some of the other clean water sites (such as PP11 and PP12).
- The dam west of the Sewage Plant (PP11) contains water of an ideal quality and no evidence for contaminant impacts is apparent from the inorganic parameter concentrations observed at this site. The slightly elevated manganese concentration observed at this site may be of a natural origin.

- Non-perennial pan PP12 also contains water of an ideal quality and little evidence for contaminants impacts from the power station can be seen. However, the high iron concentration at this site renders to water quality poor. The origin of the elevated iron concentration is at present unknown.
- In terms of the inorganic parameter concentrations, the water quality at the maturation ponds of the Sewage Plant may generally be classified as ideal. Only the iron and manganese concentrations at the first maturation pond (PP17) are slightly elevated.
- The inorganic parameter concentrations at the three river sites are generally low enough to cause the water quality to be classified as ideal. However, very high iron concentrations are observed at site R01 and R02. The elevated iron concentrations at these sites are not thought to be due to ashing activities. Since the non-perennial rivers sampled at site R01 and R02 were stagnant at the times of sampling while the river at site R03 was flowing very slowly, the concentrating effects of evaporation on open surface water bodies should also be taken into account. The salt concentrations currently observed at these sites are likely to be higher than when the rivers are flowing.

8.2 Groundwater quality

The positions of the groundwater monitoring sites at Duvha Power Station that existed prior to the drilling phase of the current investigation are shown in Figure 11 and Figures A08 of **Appendix A**. Information on these sites is supplied in Table 9.

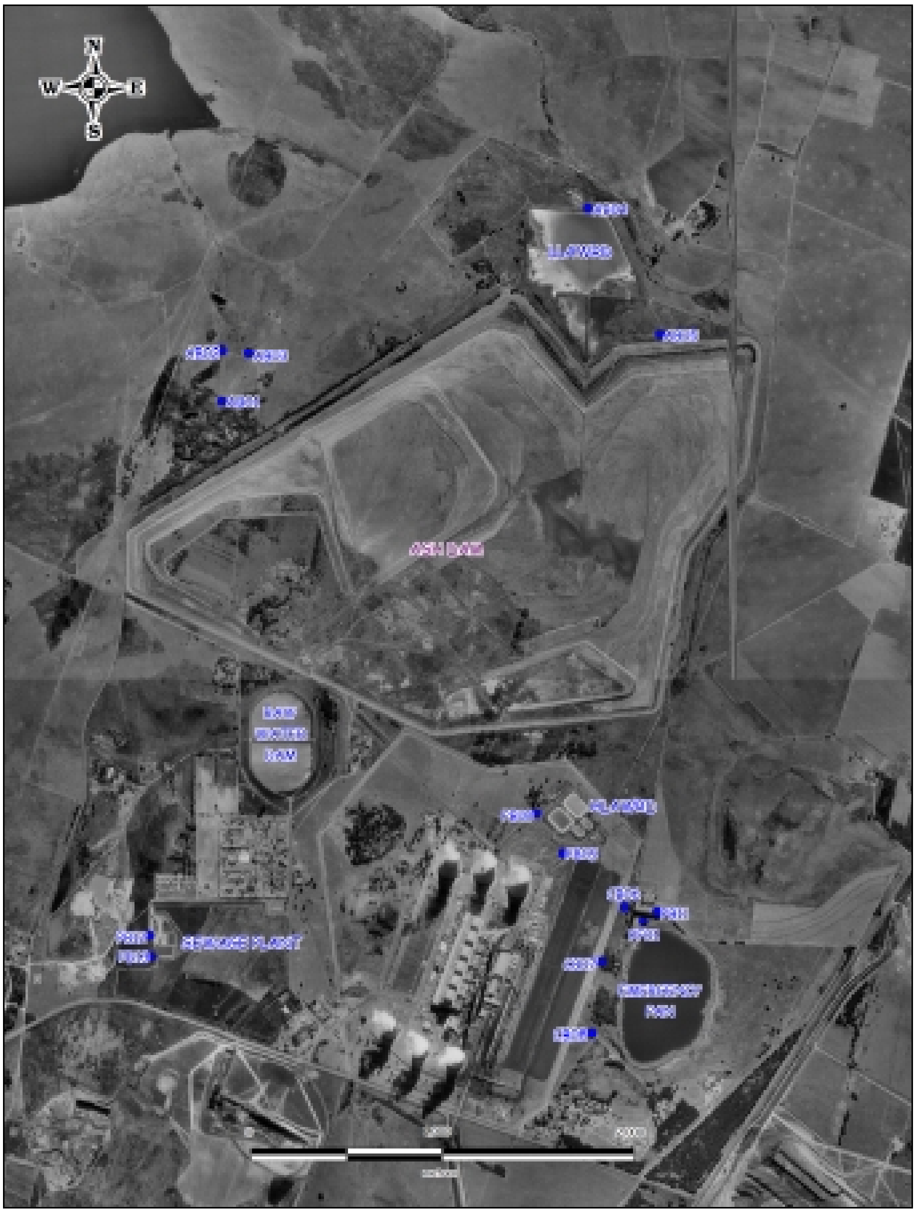

Figure 11. Groundwater monitoring sites at Duvha Power Station.

Table 9. Information on groundwater monitoring sites at Duvha Power Station.

Site #	Location/Description	Latitude (°S)	Longitude (°E)
AB01	Borehole near old farmhouse (Renosterfontein)	25.93416	29.32599
AB02	Borehole near AB01 towards Witbank Dam	25.93181	29.32606
AB03	Borehole near AB01 and AB02	25.93187	29.32738
AB04	Borehole at pump station of Low Level Ash Water Return Dam	25.92497	29.34515
AB05	Borehole north of Ash Dam near Low Level Ash Water Return Dam	25.93106	29.34893
CB06	Borehole outside Power Station Area at back of Coal Stockyard	25.95814	29.34707
CB07	Borehole outside Power Station Area at back of Coal Stockyard	25.96070	29.34594
CB08	Borehole outside Power Station Area at back of Coal Stockyard	25.96413	29.34538
PB09	Borehole upstream from High Level Ash Water Return Dams	25.95560	29.34395
PB10	Borehole downstream from High Level Ash Water Return Dams	25.95373	29.34246
PB11	Supply borehole on Mr Gouws's farm	25.95830	29.34879
PB12	Borehole at sewage works - in fenced camp at furthest corner of works	25.96053	29.32237
PB13	Borehole at sewage works - right next to road	25.95956	29.32235

The results the chemical analyses performed on the water samples from selected surface water sites at Duvha Power Station are listed in Table 10. The data in Table 10 are again colour-coded according to the “South Africa Water Quality Guidelines, Volume 1: Domestic Use, DWA&F, First

Edition 1993" and the "South Africa Water Quality Guidelines, Volume 1: Domestic Use, DWA&F, Second Edition 1996", as well as the publication "Quality of Domestic Water Supplies, DWA&F, Second Edition 1998" (see Table 8).

Table 10. Results of the chemical analyses performed on groundwater samples taken during the seepage investigations.

DUVHA POWER STATION - SEEPAGE INVESTIGATIONS - GROUNDWATER QUALITY

No.	Date	pH	EC mS/m	TDS mg/L	Na mg/L	Ca mg/L	Mg mg/L	K mg/L	Cl mg/L	SO_4 mg/L	P.Alk mg/L	T.Alk mg/L	F mg/L	NO_2-N mg/L	NO_3-N mg/L	PO_4 mg/L	Fe mg/L	Mn mg/L	B mg/L
AB01	20060805	6.7	22.0	96	42	5	2	3	39	4	0	57	0.17	BDL	0.17	BDL	0.064	0.340	0.114
AB02	20060805	6.1	54.2	273	90	7	5	2	165	3	0	18	BDL	BDL	0.29	BDL	0.061	1.107	0.077
AB04	20060803	6.8	77.7	422	75	54	33	4	68	187	0	159	BDL	BDL	0.19	BDL	0.190	0.096	0.087
AB05	20060803	7.0	25.0	102	53	7	2	3	30	5	0	86	1.63	BDL	0.12	BDL	0.132	0.198	0.082
AB26	20060814	6.4	62.4	360	99	14	9	10	80	146	0	48	0.78	BDL	0.21	BDL	0.121	1.570	0.155
AB27	20060814	6.4	88.7	525	120	25	22	21	74	259	0	65	BDL	BDL	0.59	BDL	0.057	3.555	0.205
AB28	20060814	5.9	106	714	106	71	14	26	90	405	0	8	BDL	BDL	0.19	BDL	1.202	4.040	0.235
AB29	20060814	6.9	66.4	480	112	37	5	25	98	201	0	64	0.11	BDL	0.20	BDL	0.356	2.584	0.244
AB30	20060816	6.8	68.5	336	31	79	47	2	83	93	0	218	0.16	BDL	0.19	BDL	0.316	2.561	0.044
AB31	20060816	6.7	43.7	204	15	41	21	3	65	54	0	83	0.05	BDL	1.14	BDL	0.397	0.160	0.043
AB32	20060817	6.5	29.1	135	42	3	2	16	37	33	0	46	0.75	BDL	0.05	BDL	0.041	0.658	0.047
AB33	20060817	6.2	24.9	132	35	3	6	8	42	34	0	23	0.04	0.02	0.75	BDL	0.705	0.378	0.041
CB06	20060803	6.7	7.6	23	5	5	3	3	5	2	0	33	0.13	BDL	0.14	BDL	0.245	0.114	0.048
CB07	20060803	7.3	15.7	46	11	14	6	3	4	6	0	78	0.01	0.01	0.14	BDL	0.045	0.020	0.043
CB08	20060803	6.4	9.8	28	5	5	4	3	6	2	0	37	0.06	0.99	0.42	BDL	0.019	0.176	0.041
PB09	20060816	6.0	3.4	18	6	1	1	1	6	2	0	13	BDL	0.05	0.05	BDL	0.030	0.095	0.035
PB10	20060816	6.8	9.4	29	5	10	4	3	4	2	0	50	0.03	BDL	0.11	BDL	0.058	0.148	0.037
PB12	20060816	7.8	20.5	62	15	12	7	4	20	2	0	84	0.31	0.02	0.24	BDL	0.003	0.075	0.033
PB13	20060816	6.4	18.7	72	22	3	2	4	24	13	0	54	BDL	BDL	0.80	BDL	0.032	0.120	0.034
PB14	20060815	6.0	6.2	24	8	2	2	2	8	2	0	20	BDL	BDL	0.03	2.01	0.453	0.228	0.062
PB15	20060815	6.3	9.4	44	11	3	3	8	9	7	0	39	0.05	BDL	0.32	BDL	0.213	0.570	0.058
PB16	20060815	6.0	5.2	25	8	2	1	1	9	2	0	15	BDL	BDL	0.32	BDL	0.575	0.142	0.055
PB17	20060815	5.7	9.6	47	13	2	2	2	18	8	0	15	BDL	BDL	0.33	BDL	0.203	0.113	0.055
PB18	20060815	6.3	9.4	37	10	4	2	5	12	3	0	30	BDL	BDL	0.17	BDL	0.521	0.816	0.054
PB19	20060815	6.7	15.4	59	11	13	5	5	14	6	0	56	0.11	BDL	1.07	BDL	0.003	0.138	0.055
PB20	20060816	6.0	82.1	518	116	31	13	5	60	285	0	22	0.04	0.04	0.93	BDL	2.757	1.070	0.055
PB21	20060816	6.5	76.5	439	124	12	10	8	62	223	0	54	0.04	BDL	0.13	BDL	0.159	0.382	0.052
PB22	20060816	6.0	37.8	229	72	2	1	1	21	130	0	12	BDL	BDL	0.46	BDL	0.497	0.177	0.047
PB23	20060815	6.0	18.9	106	18	8	7	4	12	55	0	16	BDL	BDL	0.52	BDL	0.562	0.415	0.048
PB24	20060815	5.4	27.1	184	33	11	9	4	16	103	0	7	BDL	BDL	2.26	BDL	0.118	0.169	0.050
PB25	20060815	6.0	5.5	26	7	3	2	1	9	3	0	15	BDL	0.04	0.44	BDL	0.291	0.068	0.048
PF01	20060803	3.8	64.0	474	36	33	9	14	30	269	0	17	BDL	BDL	0.10	0.91	81.884	0.449	0.179
Detection Limits:													**0.01**	**0.01**		**0.10**			

BDL - Below Detection Limits

From the data listed in Table 10 the following observations may be made:

- The groundwater at Duvha Power Station is generally of a good to ideal quality. Evidence for contaminant impacts is, however, observed at a number of groundwater sites. Particularly sites AB27, AB28 and AB29 north of the Ash Dam, as well as sites PB20 and PB21 down-gradient from the High Level Ash Water Return Dams, exhibit elevated salt concentrations.
- The groundwater sites that occur north of the Ash Dam and Low Level Ash Water Return Dam generally have much higher salt concentrations than the groundwater sites to the south of the Ash Dam. This observation confirms that contaminant transport is generally taking place in a direction parallel to the local topographic gradient.
- Elevated manganese concentrations are observed at almost all the groundwater sites and are most probably of a natural origin.
- The reason for the low pH at the fountain site (PF01) is likely to be due to the proximity of the coal stockpile. Acid generation is known to occur at coal stockpiles due to the oxidation of pyrites (FeS_2). The low pH at this site is most probably responsible for the mobilisation of trace metals, hence the dangerously high iron concentration observed at this site. The high sulphate concentration at PF01 also suggests that seepage from the coal stockpile is impacting on the water quality at this site.
- The reason for the elevated fluoride concentration at AB05 is not known at present.

From the data listed in Table 10 it is apparent that the sulphate concentration at a particular site can be seen as a good indicator of the contamination status of that site. To allow a fisrt idea of the distribution of the sulphate pollution plume in the vicinity of the Ash Dam, the sulphate values recorded at the different groundwater sites are contoured and plotted in Figure 12. Note that Figure 12 only plots the contoured sulphate concentrations as observed at the groundwater sites and does not take the borehole depth or sampling depth into account. Contoured values at positions far removed from the groundwater sites should also not be seen as representative of the true concentrations.

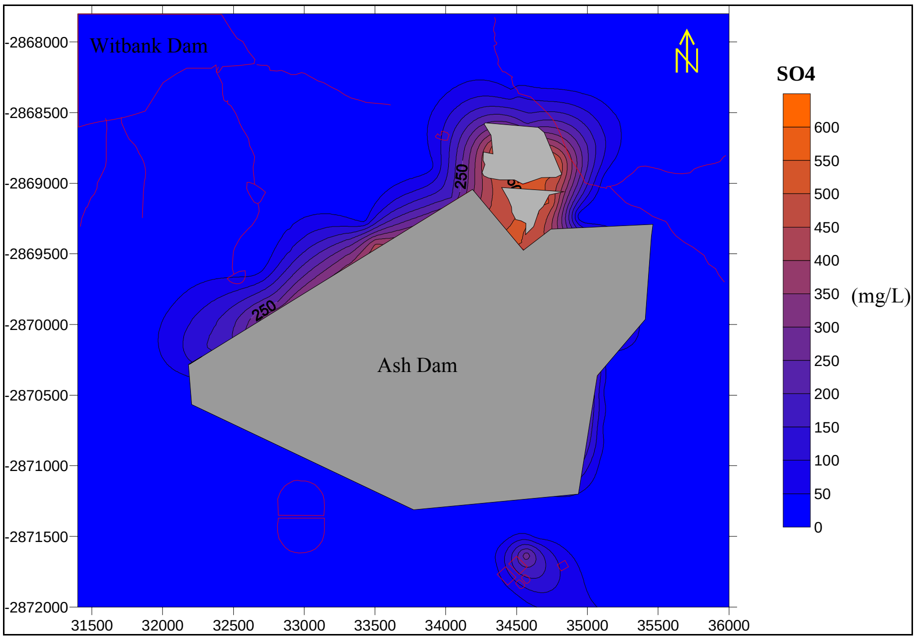

Figure 12. Contour map of the sulphate concentrations observed at the different groundwater sites.

8.3 Isotope analyses

To determine whether seepage from a contaminated surface water body is occurring, the groundwater quality in the vicinity of the surface water body can be sampled and analysed for the chemical constituents present in the surface water. The concentration of these constituents may then be evaluated against the background groundwater quality. For example, the groundwater in the immediate vicinity of the Ash Dam at Duvha Power Station displays elevated sulphate concentrations when compared with the background groundwater quality at boreholes far removed form the Ash Dam. This observation confirms that seepage from the Ash dam is impacting on the groundwater quality in the vicinity of the Ash Dam.

However, when water seeps from an uncontaminated surface water body, the chemical signature of the surface water is likely to be less apparent in the groundwater and it will therefore be more difficult to assess whether seepage is occurring by studying the concentrations of inorganic parameters in the groundwater. Isotope analyses provide a way to determine whether groundwater in the vicinity of an uncontaminated surface water body has a surface water signature. If a surface water signature is observed in the groundwater it indicates that seepage from the surface water body is likely to have occurred.

In order to investigate whether the groundwater in the vicinity of the Raw Water Dam and Sewage Plant has a surface water signature, groundwater samples were submitted for deuterium (^{2}H) and oxygen18 (^{18}O) analyses. The ratios $^{2}H/^{1}H$ and $^{18}O/^{16}O$ were determined and expressed in the so-called delta notation:

$$\delta^{18}O\ (o/oo) = \left[\frac{\left({}^{18}O/{}^{16}O\right)_{\text{sample}}}{\left({}^{18}O/{}^{16}O\right)_{\text{standard}}} - 1 \right] \times 1000$$

$$\delta^{2}H\ (o/oo) = \delta D\ (o/oo) = \left[\frac{\left({}^{2}H/{}^{1}H\right)_{\text{sample}}}{\left({}^{2}H/{}^{1}H\right)_{\text{standard}}} - 1 \right] \times 1000$$

The delta values are expressed as per mil deviation relative to a known standard, in this case standard mean ocean water (SMOW). The δD values are then plotted against the $\delta^{18}O$ values and compared with the Global Meteoric Water Line (GMWL). Deviations from the GMWL could suggest that a certain groundwater sample has an evaporation signature – indicating that it has a surface water origin.

For the seepage investigations at Duvha Power Station, five samples from groundwater sites in the vicinity of the Sewage Plant and three samples from groundwater sites in the vicinity of the Raw Water Dam were submitted for isotope analyses. The results of the analyses are presented in Table 11.

Table 11. Analytical results of isotope analyses.

Area	Site	dO ($^{o}/_{oo}$) SMOW	dD ($^{o}/_{oo}$) SMOW
Raw Water Dam	**PB14**	-1.86	-6.96
	PB15	-1.11	-2.81
	PB16	-1.46	-5.6
Sewage Plant	**PB12**	-1.89	-4.37
	PB13	-1.73	-5.84
	PB17	-2.36	-8.8
	PB18	-3.11	-13.45
	PB19	-3.36	-14.72

In Figure 13 the δD values of the groundwater samples from the Sewage Plant and Raw Water Dam are plotted against the $\delta^{18}O$ values. Samples from boreholes PB18 and PB19 show a slight deuterium excess, but do not appear to lie on an evaporation line. However, the three samples from the boreholes near the Raw Water Dam (PB14, PB15 and PB16), as well as sample PB13, lie on an evaporation line. This observation shows that the groundwater in the vicinity of the Raw Water Dam has a surface signature and indicates that seepage from the Raw Water Dam is causing artificial recharge to the groundwater system. There is less evidence for seepage from the different maturation ponds at the Sewage Plant.

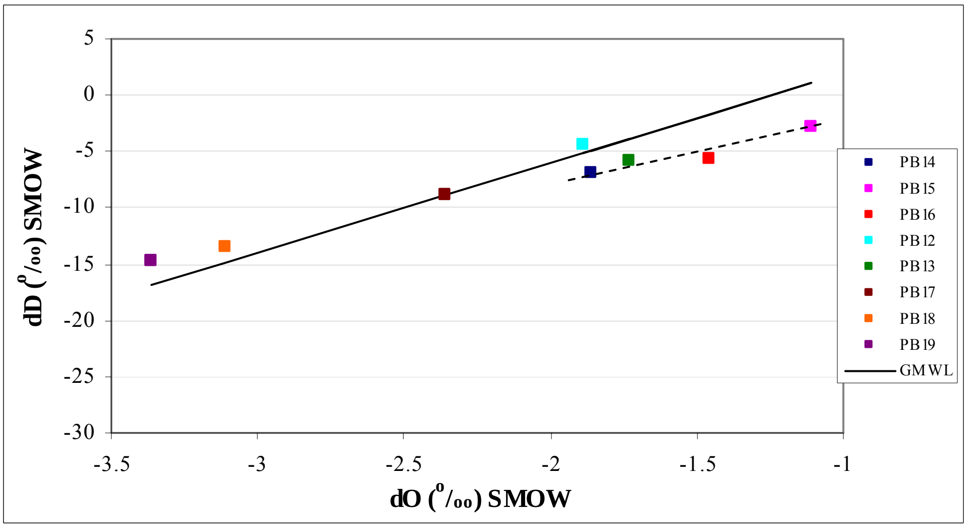

Figure 13. δD versus δ¹⁸O for the groundwater samples from the Raw Water Dam and Sewage Plant.

9 SOIL SAMPLING AND ANALYSES

The positions from which soil samples were taken for chemical and granulometric analyses are shown in Figure 14 and Figure A09 of **Appendix A**. Apart from these samples, additional soil samples were taken from the drill cuttings during the drilling of the 20 new monitoring boreholes in an attempt to gain additional information on the soil properties. The drill cuttings were generally taken during the first couple of metres of drilling where only overburden or topsoil was encountered.

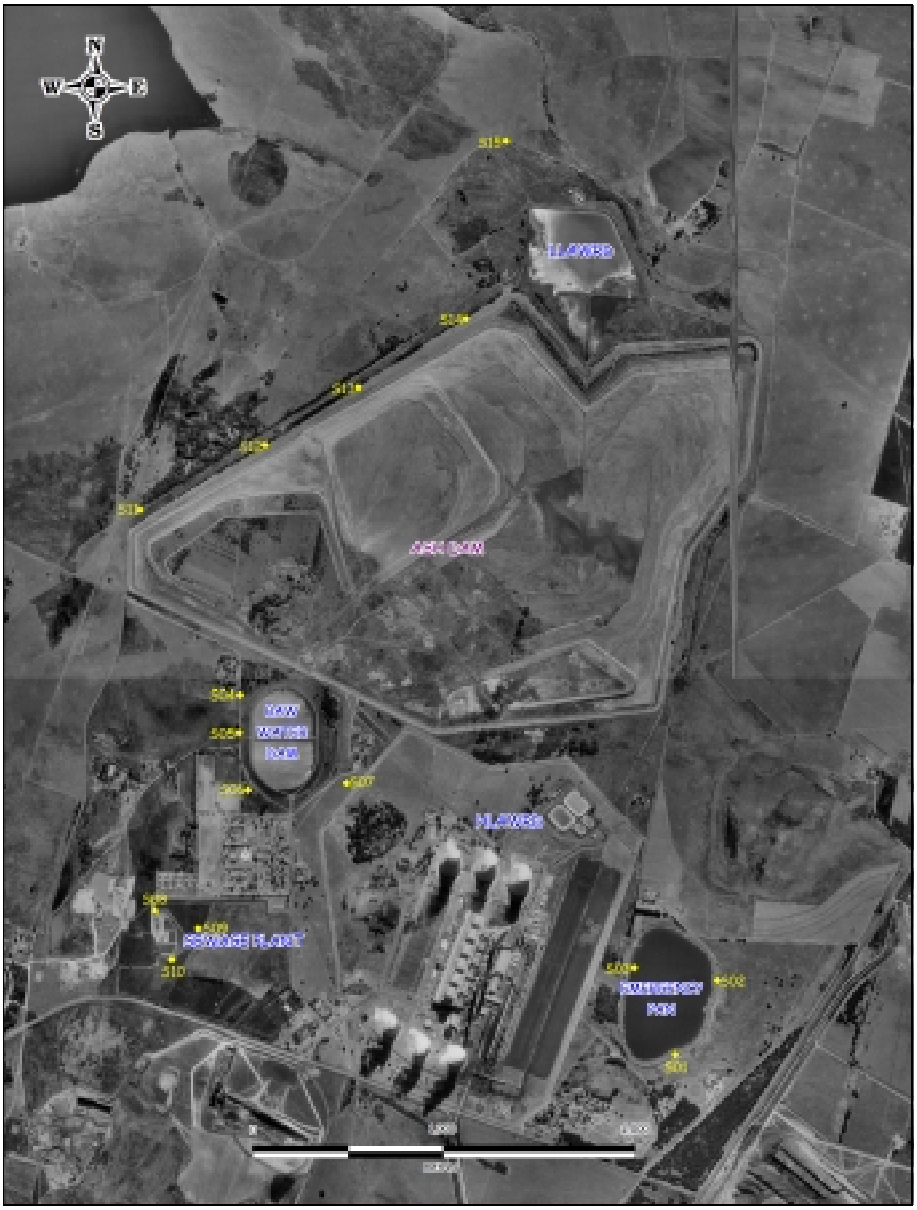

Figure 14. Soil sampling positions.

9.1 Results of chemical analyses

The results the chemical analyses performed on the soil samples are listed in Table 12. Although the drinking water standards are not applicable to soil chemistry, the data in Table 12 are again colour-coded according to the drinking water standards (replacing mg/L with mg/kg). This is done to allow a visual comparison of the chemical parameter concentrations at the various positions where soil samples were taken and should not be interpreted as representing water quality at these sites.

Table 12. Results of chemical analyses performed on soil samples taken during the seepage investigations.

DUVHA POWER STATION - SEEPAGE INVESTIGATIONS - SOIL CHEMISTRY

No.	Date	pH 1:10	EC 1:10	Na mg/kg	Ca mg/kg	Mg mg/kg	K mg/kg	Cl mg/kg	SO_4 mg/kg	P.Alk mg/kg	T.Alk mg/kg	F mg/kg	NO_2-N mg/kg	NO_3-N mg/kg	PO_4 mg/kg	B mg/kg
PB14	20060727	5.7	6.16	24	4	1	72	71	45	0	32	BDL	BDL	3.5	BDL	0.329
PB15	20060727	5.5	11.90	32	17	3	98	71	131	0	29	BDL	0.4	11.2	BDL	0.251
PB16	20060727	5.7	4.46	19	4	1	36	33	38	0	40	BDL	0.3	2.3	BDL	0.426
PB17	20060728	5.8	5.45	28	7	5	50	26	85	0	60	BDL	BDL	2.7	BDL	0.416
PB18	20060731	5.4	5.81	22	23	9	47	24	153	0	28	BDL	BDL	2.6	BDL	0.289
PB19	20060801	5.6	3.40	28	8	3	35	37	59	0	44	BDL	0.2	3.0	BDL	0.930
PB20	20060801	5.7	2.82	22	7	3	30	23	48	0	47	BDL	0.3	2.7	BDL	0.385
PB21	20060801	5.4	2.37	15	16	4	21	22	43	0	32	BDL	BDL	0.6	BDL	0.368
PB22	20060802	5.6	6.47	23	39	7	31	26	156	0	37	BDL	0.2	3.3	BDL	0.304
PB24	20060803	5.7	3.42	43	7	2	23	53	42	0	44	BDL	BDL	2.9	BDL	0.235
PB25	20060803	5.8	3.11	39	2	1	17	35	32	0	41	BDL	0.2	3.1	BDL	0.253
AB26	20060803	5.7	9.55	50	60	13	38	58	219	0	45	BDL	0.5	7.6	BDL	0.290
AB28	20060803	5.7	7.66	50	16	5	60	39	178	0	40	BDL	0.2	2.7	BDL	0.468
AB29	20060803	7.1	24.80	66	318	21	118	38	269	0	815	6.9	0.2	2.8	BDL	0.605
AB30	20060804	6.6	8.47	34	54	29	37	27	58	0	260	8.5	BDL	5.7	BDL	0.123
AB33	20060805	5.7	4.69	30	6	2	45	22	41	0	43	0.0	0.2	17.5	BDL	0.117
S12	20060816	5.9	6.62	20	36	10	47	20	101	0	113	1.9	BDL	0.3	14.6	0.922
Detection Limits:												0.1	0.1		1.0	

BDL - Below Detection Limits

From the data listed in Table 12 the following observations may be made:

- Slightly acidic conditions exist at all the sampled soil sites.
- High potassium concentrations are observed at most of the sampled soil sites. These potassium concentrations are in all likelihood due to the natural decay of the rocks forming these soils.
- The sodium, calcium and sulphate concentrations at sites AB26, AB28 and AB29 are the highest of all the soil samples. This observation suggests that seepage from the Ash Dam has impacted on the shallow soil horizons north of the Ash Dam.

9.2 Results of granulometric analyses

The results of the granulometric analyses performed on the soil samples are listed in Table 13 and Table 14. These results were used to estimate the hydraulic conductivities of the soil by means of the Shepard method. This method estimates the hydraulic conductivity of soil from the mean grain size as determined during granulometric analyses. It should be noted that the Shepard method is very sensitive to the inclusion of coarse material in the sample. The estimated hydraulic conductivities are also listed in Table 13 and Table 14.

Table 13. Soil hydraulic conductivities estimated from the results of the granulometric analyses – soil samples.

Site Location		Emergency Pan			Raw Water Reservoir				Sewage Plant			Ash Dam & Low Level Ash Water Return Dam				
Sample #		**S01**	**S02**	**S03**	**S04**	**S05**	**S06**	**S07**	**S08**	**S09**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**
Sample depth (m)		0 - 1	0 - 1	0 - 1	0 - 1	0 - 1	0 - 1	0 - 1	0 - 1	0 - 1	0 - 1	0 - 1	0 - 1	0 - 1	0 - 1	0 - 1
In situ field moisture (%)		15.3	13.6	32.0	5.2	5.5	6.6	7.0	10.2	7.5	5.8	7.8	5.9	9.2	6.2	7.9
Sieve analysis (mm)	**63.0**	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~
	53.0	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~
	37.5	~	~	~	~	~	~	~	~	~	~	~	~	~	100	~
	26.5	~	~	~	~	~	~	~	~	~	~	~	~	~	96	~
	19.0	~	~	~	~	~	~	~	100	~	~	~	~	~	93	100
	13.2	~	~	~	~	~	~	~	99	~	~	100	100	100	92	99
	4.75	~	~	100	100	100	~	~	96	100	100	92	93	98	72	90
	2.00	100	100	98	98	99	100	100	93	99	99	77	84	91	52	78
	0.425	87	91	75	81	81	84	81	70	77	80	68	75	81	41	66
	0.075	30	36	31	25	23	23	24	29	22	29	22	39	29	17	32
	0.002	8	10	2	6	4	4	6	2	6	6	2	2	4	2	2
Estimated hydraulic conductivity (m/d)		**2.09**	**1.56**	**2.37**	**2.62**	**2.71**	**2.62**	**2.45**	**2.81**	**2.81**	**2.49**	**3.27**	**1.60**	**2.18**	**63.61**	**2.67**

From the hydraulic conductivities listed in Table 13 it can be seen that the hydraulic conductivities of the soils in the vicinity of the power station generally vary between 1.56 and 3.27, with an average of 2.45 and a standard deviation of 0.47. The conductivity estimated for sample S14 is unrealistically high and does not correspond with the other soil conductivities. The high conductivity calculated for this sample may be due to laboratory errors or the inclusion of coarse surface material during sampling.

Table 14. Soil hydraulic conductivities estimated from the results of the granulometric analyses – drill cuttings.

Site Location		Raw Water Reservoir				Sewage Plant		High Level Ash Water Return Dams			Emergency Pan		Ash Dam & Low Level Ash Water Return Dam				
Sample #		**BH01**	**BH02**	**BH03**	**BH03**	**BH04**	**BH05**	**BH07**	**BH08**	**BH09**	**BH11**	**BH12**	**BH13**	**BH15**	**BH16**	**BH17**	**BH20**
Sample depth (m)		1 - 2	1 - 2	1 - 2	19 - 20	1 - 2	1 - 2	1 - 2	1 - 2	1 - 2	1 - 2	1 - 2	0 - 1	0 - 1	0 - 1	0 - 1	0 - 1
In situ field moisture (%)		2.5	3.5	8.4	22.7	18.8	12.9	19.1	11.4	11.5	7.2	3.6	9.0	13.9	12.5	18.2	11.7
Sieve analysis (mm)	**63.0**	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~
	53.0	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~
	37.5	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~
	26.5	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~
	19.0	~	100	~	~	~	100	~	~	~	~	~	100	100	100	~	100
	13.2	100	99	100	100	100	99	~	~	~	100	~	99	97	99	100	99
	4.75	97	90	99	99	94	92	100	100	100	99	100	84	62	79	95	83
	2.00	83	67	88	98	82	74	98	98	99	78	98	55	42	57	92	66
	0.425	50	33	60	92	59	55	80	76	83	44	65	39	34	42	81	54
	0.075	21	18	29	72	30	32	48	43	38	29	25	20	17	24	52	34
	0.002	10	13	20	26	20	22	26	22	24	22	10	13	9	5	23	16
Estimated hydraulic conductivity (m/d)		**8.49**	**28.64**	**4.42**	**49.43**	**4.42**	**5.53**	**0.78**	**1.34**	**1.70**	**13.72**	**3.68**	**49.95**	**162.75**	**31.66**	**0.48**	**4.74**

The hydraulic conductivities estimated from the drill cuttings vary greatly, from 0.48 to 162.75 m/d. The extremely low and high values obtained for the hydraulic conductivities indicate that the disturbed material obtained during drilling does not allow acceptable estimates of the hydraulic conductivities to be made. The values obtained from the soil samples (Table 13) will henceforth be assumed to be representative of the soil hydraulic conductivities at Duvha Power Station.

10 NUMERICAL MODELLING OF GROUNDWATER MIGRATION AND CONTAMINANT TRANSPORT

10.1 Preamble

Prior to the development of a numerical groundwater flow model, the hydrology and geohydrology of the study area must be understood conceptually. The development of a conceptual model includes designing and constructing equivalent but simplified conditions for a real world problem that are acceptable in view of the objectives of the numerical model and the associated management problems. Transferring the real world situation into an equivalent model system is a crucial step in groundwater modelling.

In order to model an aquifer system, certain assumptions have to be made. Limited geological and geohydrological data recorded at a few sites are assumed to be representative of the site geology and geohydrology. It is important to note that a numerical groundwater model is only a simplified representation of the actual system. It should therefore be regarded as only an approximation, the level of accuracy dependent on the quality of the data that are available. This implies that there are always errors associated with groundwater models due to uncertainty in site data and the capability of numerical methods to fully describe natural physical processes. Nevertheless, a numerical groundwater model is currently the best tool available to quantify groundwater flow behaviour and mass balances in order to make justifiable management decisions.

10.2 Ash Dam and Low Level Ash Water Return Dam

10.2.1 Conceptual Geohydrological Model

The distribution of geological units used in the development of the conceptual geohydrological model of the area surrounding the Ash Dam is graphically illustrated in Figure 15 and Figure 16. Figure 15 shows a plan view of the modelled area while Figure 16 shows a south/north cross-section A-A through the modelled Area.

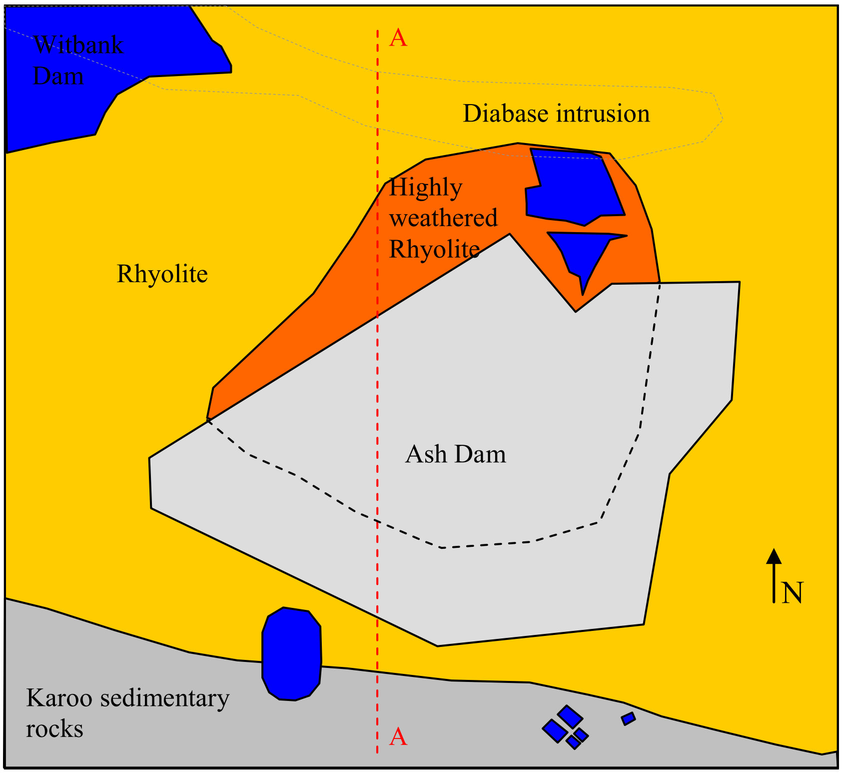

Figure 15. Conceptual geohydrological model – plan view.

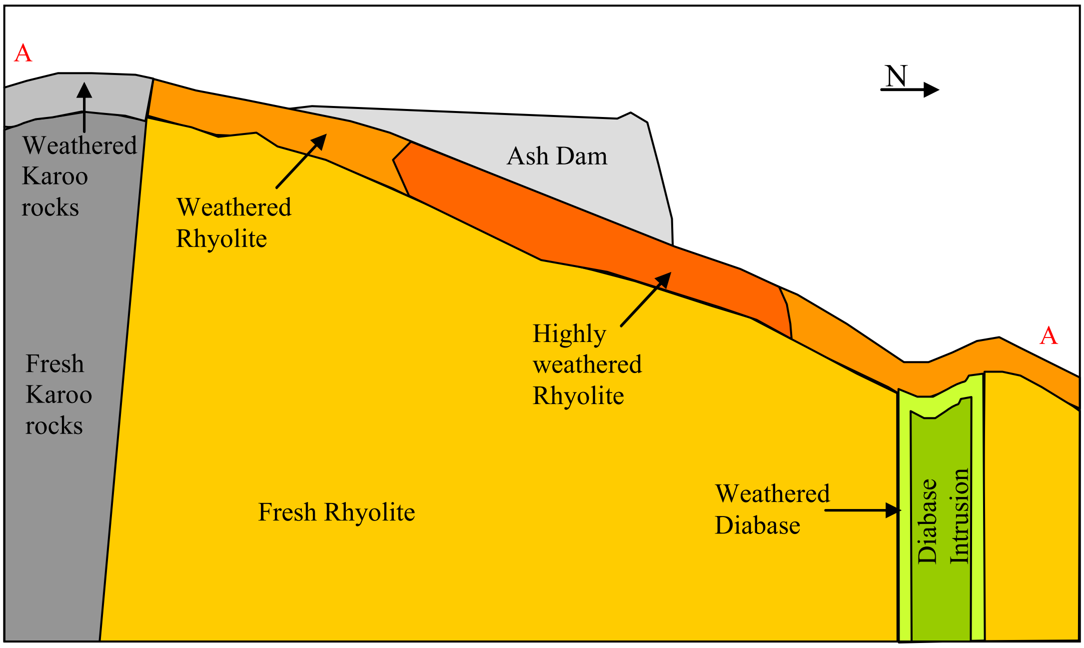

Figure 16. Conceptual geohydrological model – view along cross-section A-A (vertical scale exaggerated).

The conceptual geohydrological model on which the numerical model is based is summarised below:

- The Ash Dam is underlain by rhyolites which are volcanic extrusive rocks. These rocks are typically very dense and have low permeabilities. A low rate of groundwater flow and contaminant transport is expected to occur through the fresh rhyolites. However, preferential pathways for groundwater flow in the form of fractured zones may occur. The flow rates along such fractured zones may be very high.
- The rhyolites are weathered at surface. The depth of weathering may vary from around two to ten metres. The permeability of the weathered rhyolites is much higher than that of the fresh

rhyolite. Groundwater flow is expected to predominantly occur through the weathered rhyolites.

- Seepage from the Ash Dam will infiltrate the shallow weathered rhyolite material until the depth of the fresh rhyolites is reached. Due to the low permeability of the fresh rhyolites, flow will then predominantly take place in a lateral direction along the local topographic gradient (to the north).
- A zone of highly weathered rhyolites underlies the Ash Dam and extends to the north. Since no information is available on the extent of the weathered zone under the Ash Dam, an assumption had to be made regarding the lateral extent of this zone (refer to Figure 15).
- Karoo sedimentary rocks form a contact with the volcanic rhyolites at positions to the south of the Ash Dam. The geological borehole logging that was done during the drilling phase of this project revealed that the contact occurs further to the south than is indicated on the geological map of the area (refer to Figure A.03 in **Appendix A**). The contact between the rhyolites and Karoo rocks runs through the Raw Water Dam to the south of the Ash Dam, but occurs to the north of the High Level Ash Water Return Dams.
- The shallow Karoo rocks have also been exposed to weathering and, as a result, are more permeable than the deeper fresh Karoo rocks.
- A diabase intrusion occurs to the north of the Ash Dam. Since no information is available on the dip of this magmatic feature, it is assumed that the intrusion is steep dipping.
- The contact zone between the diabase and rhyolites has been exposed to intensive fracturing and weathering. High hydraulic conductivities are expected for this zone.
- The weathered rocks that occur near surface are henceforth referred to as the shallow aquifer system, whereas the deeper saturated geological units are referred to as the deep aquifer system.

10.2.2 Model Input – Hydraulic Parameters

For the purposes of developing a numerical model that is representative of the actual geohydrological conditions at Duvha Power Station thirteen zones of different hydraulic properties were identified. These zones and the assumed hydraulic properties are briefly discussed below:

<u>Zone 1 – Weathered rhyolite and associated topsoil</u>

Boreholes PB15 and AB26 occur in weathered rhyolites. The slug tests performed on these boreholes yielded estimates for the hydraulic conductivity of 0.012 and 0.021 m/d, respectively. However, model calibration revealed that these hydraulic conductivities are not very representative of the hydraulic conductivities of the rhyolites that occur to the north of the Ash Dam and that a hydraulic conductivity of 0.15 m/d gives a fairer representation of the hydraulic properties of these rocks. The vertical hydraulic conductivity will be assumed to be 10% of the horizontal hydraulic conductivity, as is routinely done in groundwater modelling:

K_x, K_y: 0.15 m/d

K_z: 0.015 m/d

The assumed values for the storage parameters (specific storage (S_s), specific yield (S_y), porosity (n) and effective porosity (n_e)) of the weathered rhyolite are listed below:

S_s: $1.0E^{-04}$ m^{-1}

S_y: 0.2

n: 0.25

n_e: 0.2

Zone 2 – Dry (or unsaturated) ash in the Ash Dam

The hydraulic conductivity of unsaturated materials is lower than that of saturated materials and is a non-linear function of the moisture content. As the moisture content decreases, so the hydraulic conductivity becomes lower. It can therefore be assumed that the unsaturated has a much lower hydraulic conductivity than the saturated ash. The ashing operations at the Ash Dam are also conducted in such a way so that the phreatic level within the Ash Dam is kept sufficiently low near the walls of the Ash Dam to ensure that the walls stay intact. For the purposes of the numerical model, the dry ash may therefore effectively be considered as very imperameable. The unsaturated ash will henceforth be assumed to have a hydraulic conductivity that is 1% of the saturated hydraulic conductivity. The storage properties are, however, assumed to be the same:

K_x, K_y: 0.001 m/d

K_z: 0.0001 m/d

S_s: 1.0E^{-04} m^{-1}

S_y: 0.40

n: 0.45

n_e: 0.40

Zone 3 – Saturated ash in the Ash Dam

During the current investigations a literature study on the hydraulic properties of saturated fly ash was done. The following values for the hydraulic parameters of saturated fly ash will henceforth be assumed:

K_x, K_y: 0.50 m/d

K_z: 0.05 m/d

S_s: 1.0E^{-04} m^{-1}

S_y: 0.40

n: 0.45

n_e: 0.40

Zone 4 – Weathered Karoo rocks and associated topsoil

Boreholes PB14, PB20 and PB22 intersect shallow weathered Karoo rocks. The hydraulic conductivities of the geological formations in the vicinities of these boreholes are 0.017, 0.052 and 0.023 m/d, respectively. The hydraulic parameters used to model groundwater migration in the weathered Karoo rocks are listed below:

K_x, K_y: 0.030 m/d

K_z: 0.003 m/d

S_s: 1.0E^{-04} m^{-1}

S_y: 0.20

n: 0.25

n_e: 0.20

Zone 5 – River beds

The river beds are characterised by clayey alluvial deposits. The hydraulic properties of clay will be used to model these river beds:

K_x, K_y: 0.003 m/d

K_z: 0.0003 m/d

S_s: 1.0E^{-03} m^{-1}

S_y: 0.04

n: 0.40

n_e: 0.04

Zone 6 – Highly weathered rhyolite and associated topsoil

Boreholes AB27, AB28 and AB29 intersect very weathered rhyolites. From the slug tests performed on these boreholes, the hydraulic conductivities of the highly weathered rhyolites in the vicinities of these boreholes are estimated to be 0.838, 0.599 and 0.556 m/d, respectively. The hydraulic properties used to model the highly weathered rhyolites are listed below:

K_x, K_y: 0.80 m/d

K_z: 0.08 m/d

S_s: 5.0E^{-04} m^{-1}

S_y: 0.25

n: 0.30

n_e: 0.25

Zone 7 – Fresh, un-weathered Karoo rocks

Boreholes PB15 and PB21 intersect un-weathered Karoo rocks. The hydraulic conductivities of the geological formations in the vicinities of these boreholes are 0.012 and 0.006, respectively. The hydraulic properties used to model the un-weathered Karoo rocks are listed below:

K_x, K_y: 0.010 m/d

K_z: 0.001 m/d

S_s: 1.0E^{-05} m^{-1}

S_y: 0.10

n: 0.15

n_e: 0.12

Zone 8 – Weathered dolerite

Although both boreholes AB30 and AB31 intersect weathered dolerite, the slug tests performed on these boreholes were also influenced by the shallower rhyolites and clays. Since fractured and weathered dolerite often forms preferential pathways for groundwater migration, high hydraulic conductivities are normally associated with these weathered zones. The hydraulic properties used to model the weathered Karoo rocks are listed below:

K_x, K_y: 2.0 m/d

K_z: 0.2 m/d

S_s: 1.0E^{-05} m^{-1}

S_y: 0.20

n: 0.30

n_e: 0.25

Zone 9 – Fresh, un-weathered dolerite

The hydraulic properties estimated for fresh dolerite are listed below:

K_x, K_y: 0.001 m/d

K_z: 0.0001 m/d

S_s: $5.0E^{-06}$ m^{-1}

S_y: 0.02

n: 0.05

n_e: 0.02

Zone 10 – Fresh un-weathered rhyolite

Borehole AB32 intersects fresh rhyolite. The hydraulic conductivity as estimated from the slug test performed on borehole AB32 will be used to be representative of the fresh rhyolite. The hydraulic properties estimated for fresh rhyolite are listed below:

K_x, K_y: 0.004 m/d

K_z: 0.0004 m/d

S_s: $5.0E^{-06}$ m^{-1}

S_y: 0.04

n: 0.08

n_e: 0.04

Zone 11 – Dam walls and floors

During the construction of the Raw Water Dam, High Level Ash Water Return Dams and High Level Ash Water Return Dam, consideration was given to the hydraulic conductivities of the materials that form the walls and floors of these dams. From dam safety inspection reports compiled by Daling De Lange & Van Tonder in February 2006, it seems reasonable to assume that the hydraulic conductivities of the materials forming the dam walls are lower than 0.04 m/d. The construction material was either compacted clayey hillwash or compacted clayey material from a weathered diabase intrusion. The hydraulic properties of the dam walls and floor will therefore be assumed to be similar to that of clay:

K_x, K_y: 0.01 m/d

K_z: 0.001 m/d

S_s: $1.0E^{-03}$ m^{-1}

S_y: 0.10

n: 0.40

n_e: 0.10

Zone 12

This zone represents the weathered rhyolites of Zone 1 that occurs under the Ash Dam. Adjustments to the hydraulic properties of this zone were made to ensure that the storativity (specific storage × aquifer thickness) and the transmissivity (hydraulic conductivity × aquifer thickness) of these zones are identical. The hydraulic properties of Zone 12 are:

K_x, K_y: 0.75 m/d

K_z: 0.075 m/d

S_s: 5.0E^{-04} m^{-1}

S_y: 0.2

n: 0.3

n_e: 0.25

Zone 13

This zone represents the highly weathered rhyolites of Zone 6 that occurs under the Ash Dam. Adjustments to the hydraulic properties of this zone were made to ensure that the storativity (specific storage × aquifer thickness) and the transmissivity (hydraulic conductivity × aquifer thickness) of these zones are identical. The hydraulic properties of Zone 13 are:

K_x, K_y: 4.00 m/d

K_z: 0.4 m/d

S_s: 2.5E^{-03} m^{-1}

S_y: 0.2

n: 0.3

n_e: 0.25

Zone 14 – Open water bodies

To model the influence of open water bodies, high hydraulic conductivities and storativities were assigned to the cells representing these water bodies. The hydraulic properties used to model open water bodies are listed below:

K_x, K_y, K_z: 5 m/d

S_s: 0.01 m^{-1}

S_y: 0.9

n: 0.95

n_e: 0.95

The properties of the different geohydrological zones are summarised in Table 15 and Table 16.

Table 15. Hydraulic conductivities of the geohydrological zones.

Zone	Kx [m/d]	Ky [m/d]	Kz [m/d]
1	0.15	0.15	0.015
2	0.001	0.001	0.0001
3	0.5	0.5	0.05
4	0.03	0.03	0.003
5	0.003	0.003	0.0003
6	0.8	0.8	0.08
7	0.01	0.01	0.001
8	2	2	0.2
9	0.001	0.001	0.0001
10	0.004	0.004	0.0004
11	0.01	0.01	0.001
12	0.75	0.75	0.075
13	4	4	0.4
14	5	5	5

Table 16. Storage properties of the geohydrological zones.

Zone	Ss [1/m]	Sy []	Eff. Por. []	Tot. Por. []
1	0.0001	0.2	0.2	0.25
2	0.0001	0.4	0.4	0.45
3	0.0001	0.4	0.4	0.45
4	0.0001	0.2	0.2	0.25
5	0.001	0.04	0.04	0.4
6	0.0005	0.25	0.25	0.3
7	1E-5	0.1	0.12	0.15
8	0.0005	0.2	0.25	0.3
9	5E-6	0.02	0.02	0.05
10	5E-6	0.04	0.04	0.08
11	0.001	0.1	0.1	0.4
12	0.0005	0.2	0.25	0.3
13	0.0025	0.2	0.25	0.3
14	0.01	0.9	0.95	0.95

For the numerical model, a grid consisting of 210 × 230 cells (each cell 20 × 20 m) was constructed. Three layers were incorporated into the model. Layer 1 represents the dam systems, topsoil and shallow aquifer system. Layer 2 also represents the shallow aquifer system, but extends under the various dams to allow the investigation of seepage from these dams. Layer 3 represents the deep aquifer system. The distribution of the 13 geohydrological zones described above in each of these layers is shown in Figure 17, Figure 18 and Figure 19.

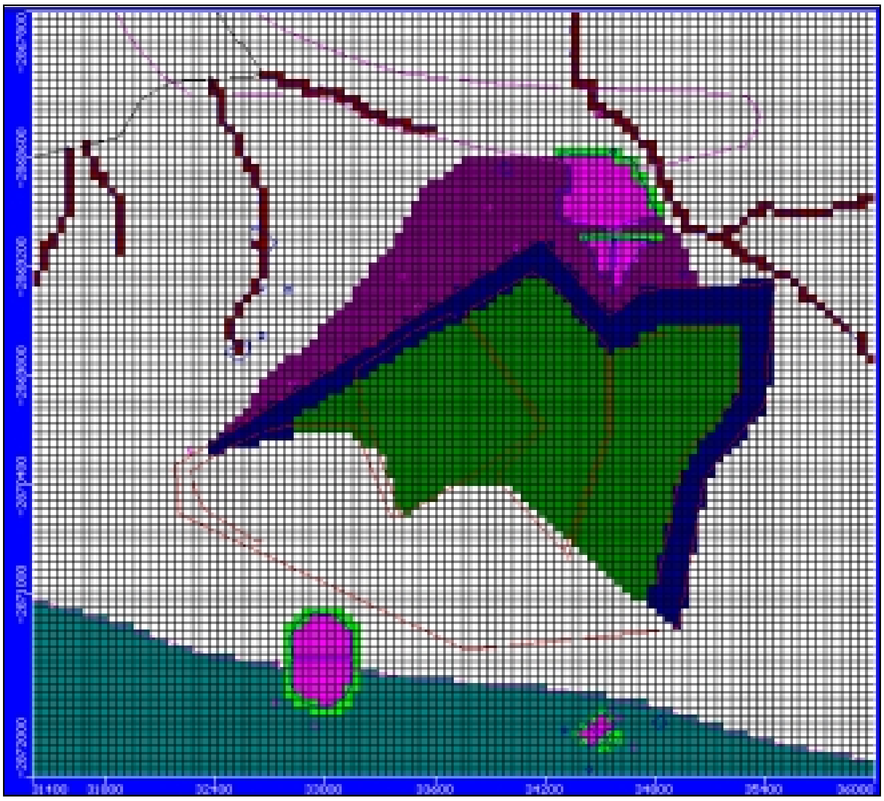

Figure 17. Geohydrological zone distribution in Layer 1.

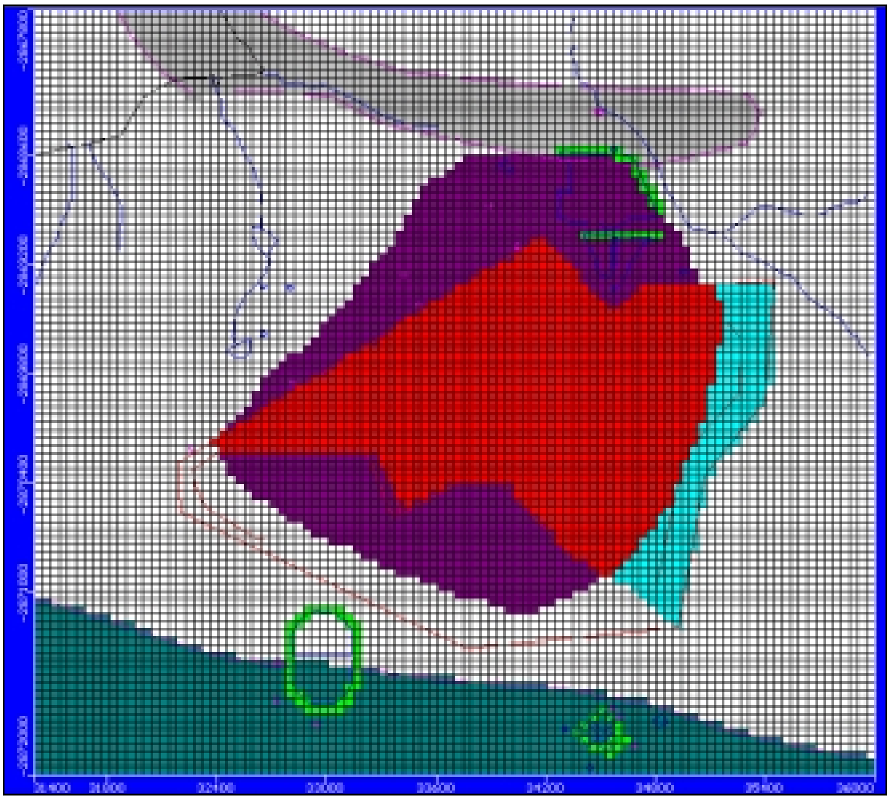

Figure 18 Geohydrological zone distribution in Layer 2.

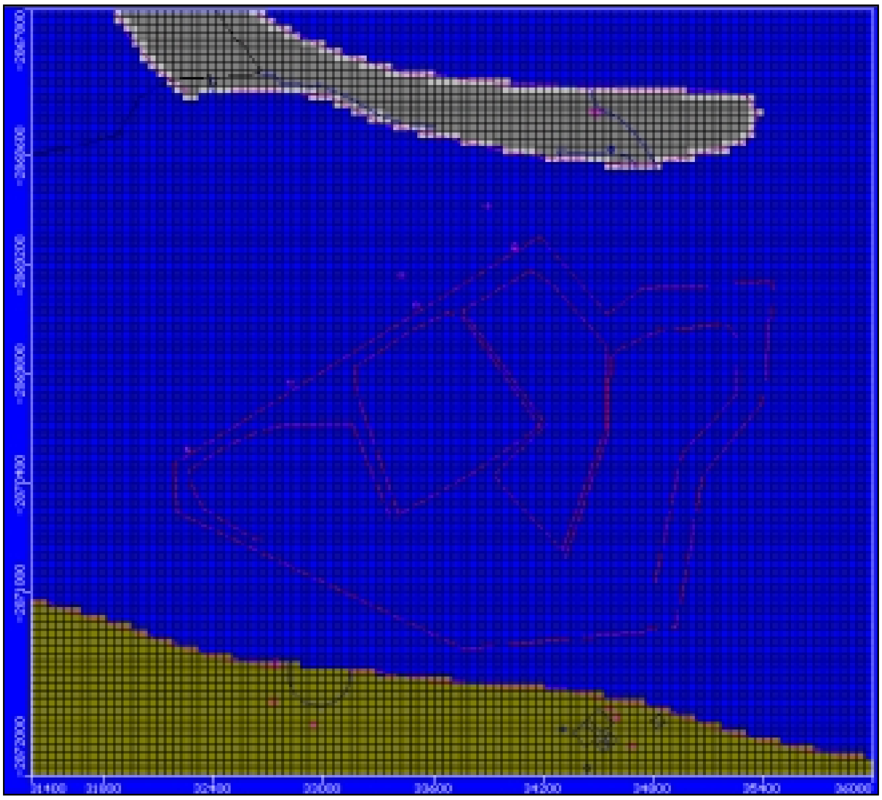

Figure 19. Geohydrological zone distribution in Layer 3.

10.2.3 Model Input – Groundwater Elevation

It is known that the groundwater table generally emulates surface topography. The piezometric elevations measured in the 33 monitoring boreholes (both shallow and deep) at Duvha Power Station were used to estimate the piezometric elevations at positions removed from these boreholes. This was done by Bayesian interpolation. The estimated natural groundwater elevations (as before the commencement of ashing operations) in the vicinity of the Ash Dam at Duvha Power Station are shown in Figure 20. Also shown in Figure 20 (yellow arrows) are the groundwater flow directions as inferred from the groundwater elevations.

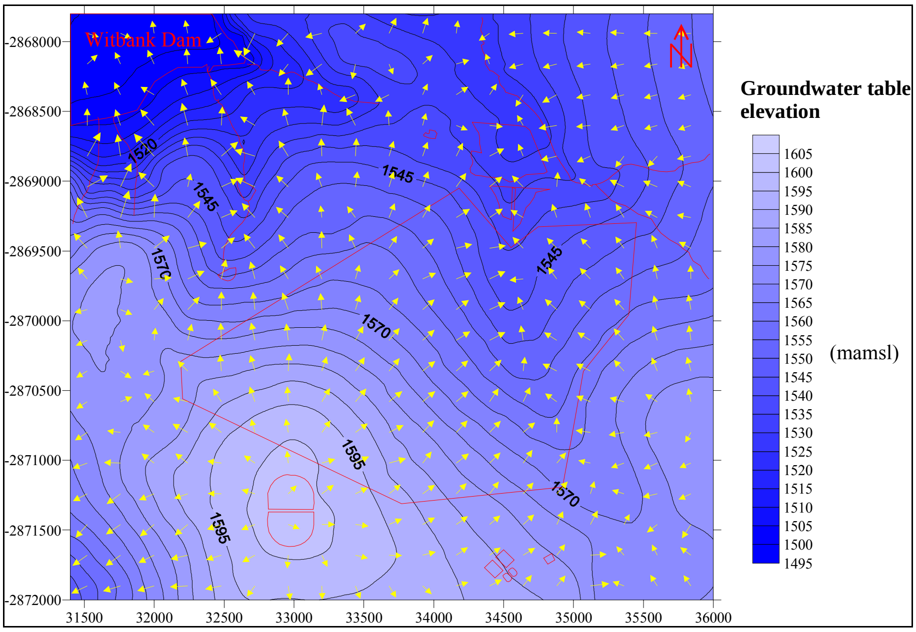

Figure 20. Estimated groundwater elevations in the vicinity of the Ash Dam at Duvha Power Station.

10.2.4 Model Calibration

In order to assess the degree to which the model input parameters are representative of the actual field parameters, the model outputs may be compared with the actual measured values. In Figure 21 the observed and calculated heads at the different boreholes around the Ash dam for the current time (end 2006) are plotted. The calculated heads are seen to give good approximations of the actual heads. In Figure 22 the hydraulic heads modelled are plotted against the observed heads. A regression coefficient of 0.992 suggests that the hydraulic properties assigned to the different geohydrological zones give a fair representation of the actual field parameters.

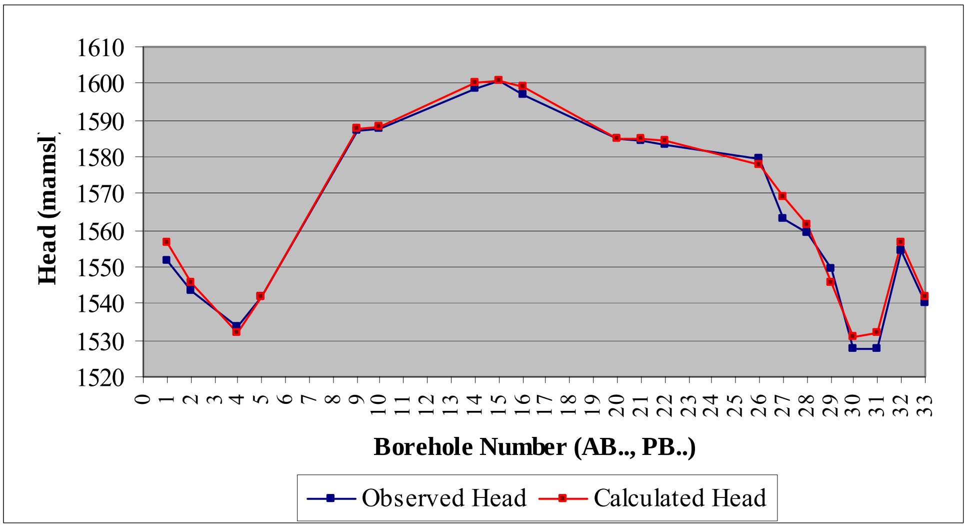

Figure 21. Observed and Calculated Heads at the various boreholes – end 2006.

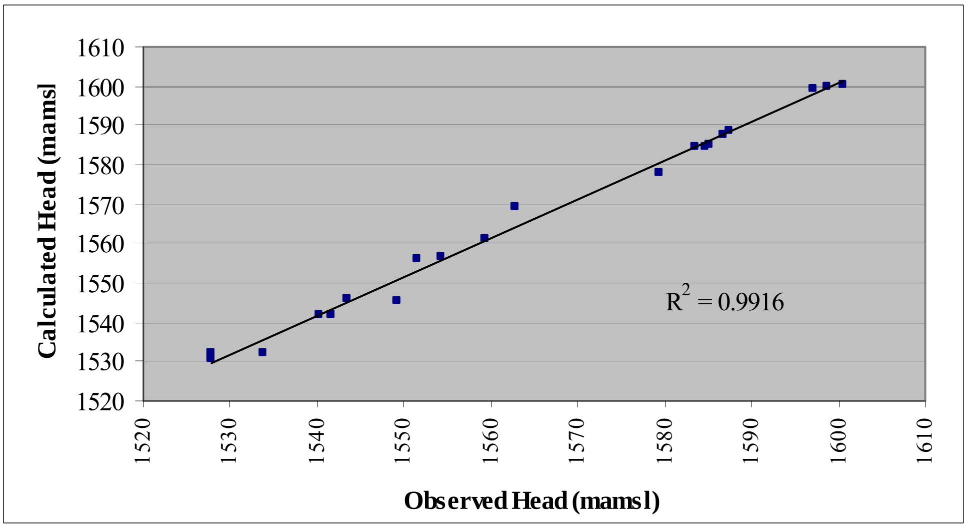

Figure 22. Model calibration: Calculated vs. Observed Head – end 2006.

In Figure 23 the observed and calculated sulphate concentrations at the different borehole around the Ash dam for the current time (end 2006) are plotted. The calculated concentrations are seen to give reasonable approximations of the actual concentrations. In Figure 24 the modelled sulphate concentrations are plotted against the observed concentrations. A regression coefficient of 0.975 is obtained, again indicating that the hydraulic properties assigned to the different geohydrological zones are good approximations of the actual properties.

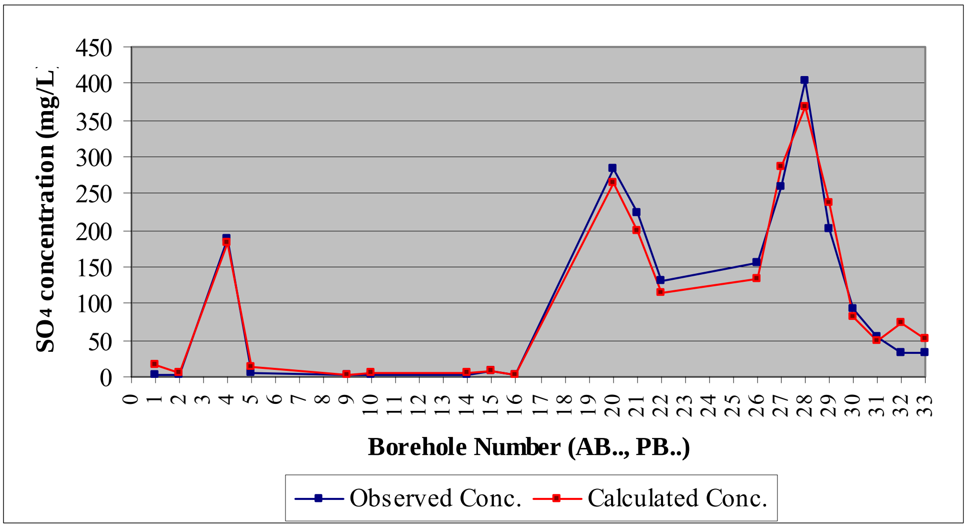

Figure 23. Observed and Calculated SO_4 concentrations at the various boreholes – end 2006.

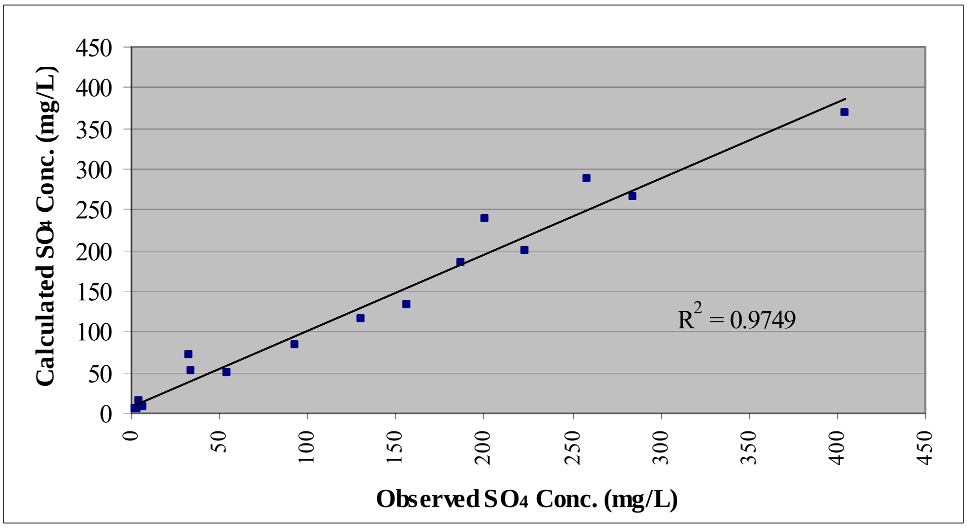

Figure 24. Model calibration: Calculated vs. Observed SO_4 concentration – end 2006.

10.2.5 Model Results

The results of the numerical modelling of groundwater flow and contaminant transport in the vicinity of the Ash Dam and Low Level Ash Water Return Dam are described below. Before the volumes of seepage water that can be expected are investigated, the migration of contaminants from these dams is discussed.

10.2.5.1 Contaminant migration in the shallow aquifer system

The modelled sulphate concentrations as observed in Layer 2, representing the shallow aquifer, are shown in Figure 25 to Figure 29 as coloured contour plots for the following times: end 2011, end 2016, end 2021, end 2026 and end 2036 (when the Ash Dam is expected to reach its maximum height).

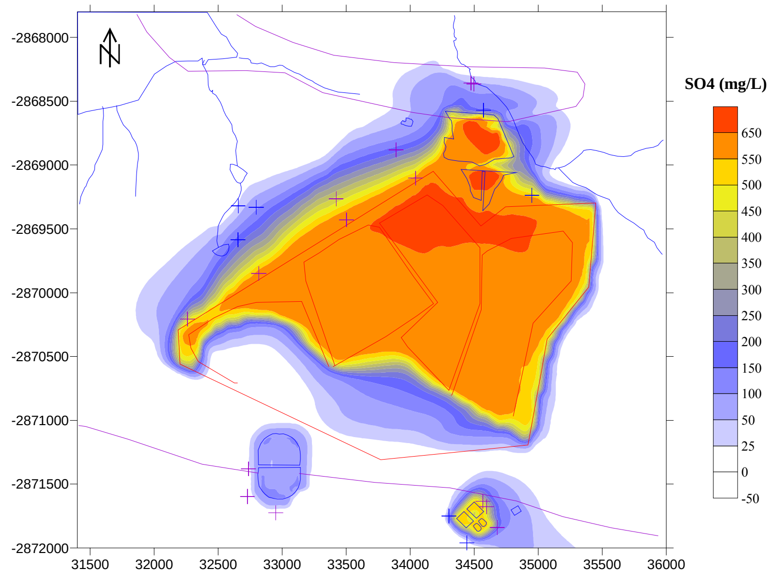

Figure 25. Modelled SO_4 concentrations in the shallow aquifer – end 2011.

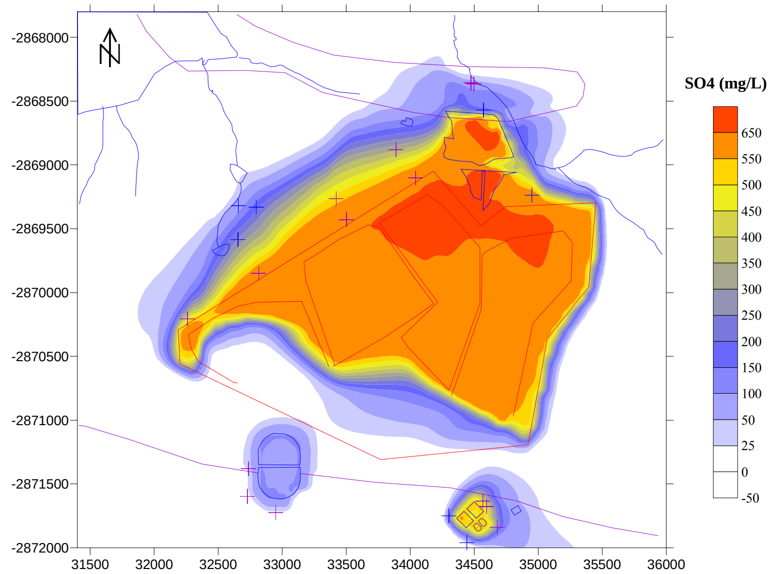

Figure 26. Modelled SO_4 concentrations in the shallow aquifer – end 2016.

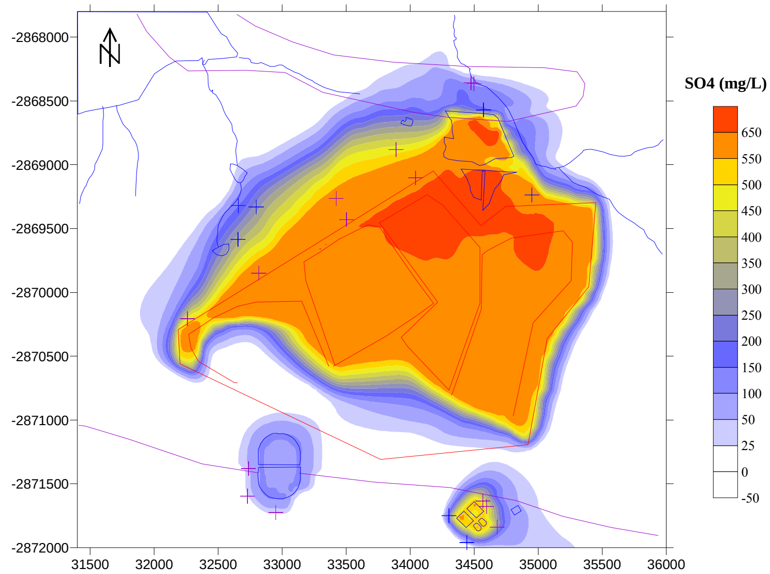

Figure 27. Modelled SO_4 concentrations in the shallow aquifer – end 2021.

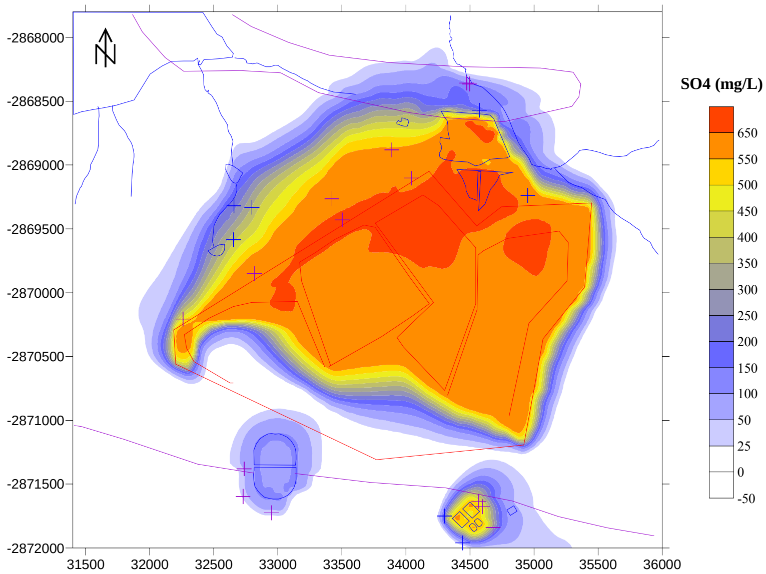

Figure 28. Modelled SO_4 concentrations in the shallow aquifer – end 2026.

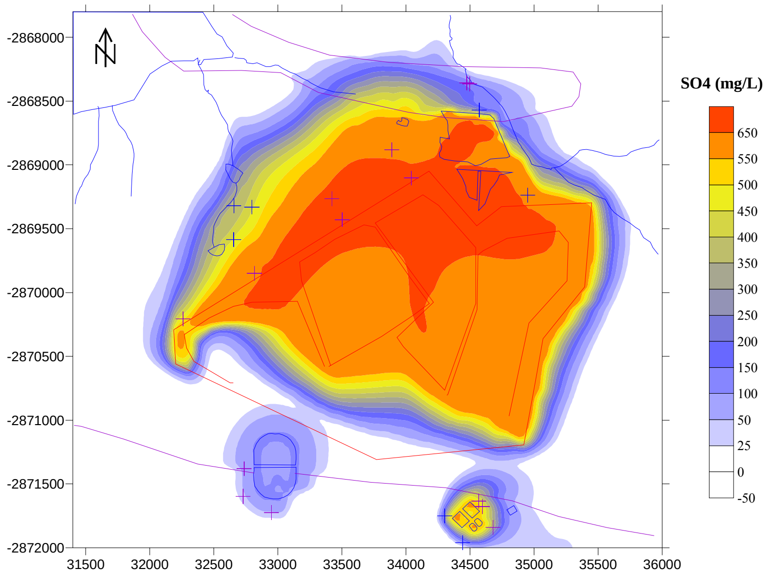

Figure 29. Modelled SO_4 concentrations in the shallow aquifer – end 2036.

From the coloured contour plots in Figure 25 to Figure 29 the following observations may be made:

- As expected, contaminant migration in the shallow aquifer system is seen to predominantly take place to the north, along the topographic and groundwater gradients.
- Groundwater migration and contaminant transport are the most rapid through the highly weathered rhyolites.
- Although the rate of contaminant migration is expected to be more rapid through the highly weathered rhyolites, contaminant migration away from the Ash Dam takes place at a relatively slow rate. The spatial extent of the contaminant plume remains limited – even at the end of ashing operations in 2036.
- Contaminant impacts are expected on the non-perennial streams that occur to the north of the Ash Dam and Low Level Ash Water Return Dam. The quality of the water in these streams is probably already affected by seepage from the dam systems.

10.2.5.2 Contaminant migration in the deep aquifer system

The modelled sulphate concentrations as observed in Layer 3, representing the deep aquifer system, are shown in Figure 30 to Figure 34 as coloured contour plots for the following times: end 2011, end 2016, end 2021, end 2026 and end 2036 (when the Ash Dam is expected to reach its maximum height).

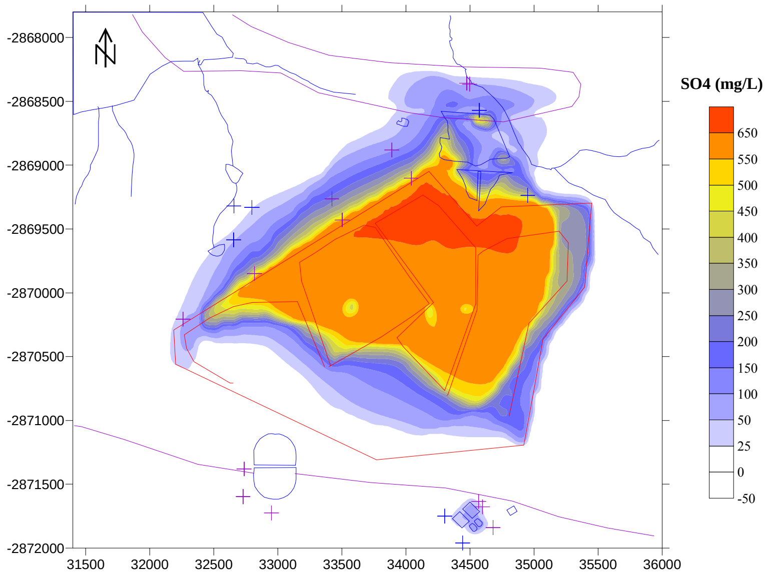

Figure 30. Modelled SO_4 concentrations in the deep aquifer system – end 2011.

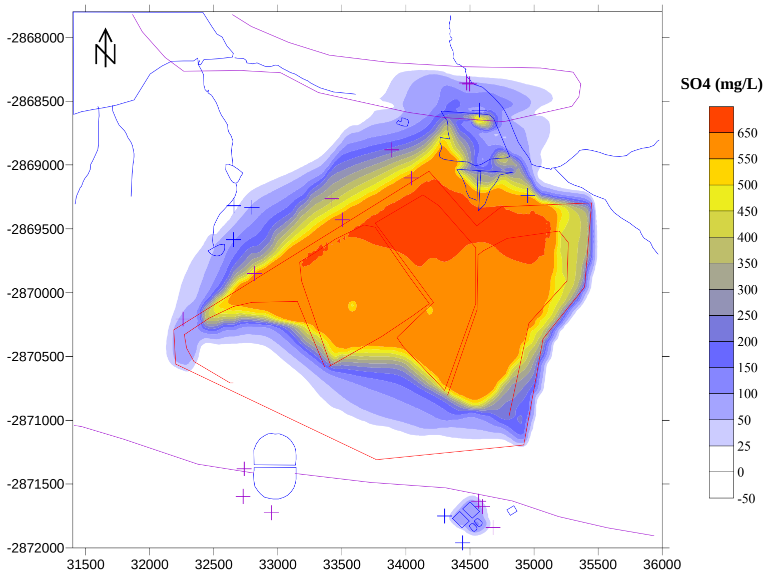

Figure 31. Modelled SO_4 concentrations in the deep aquifer system – end 2016.

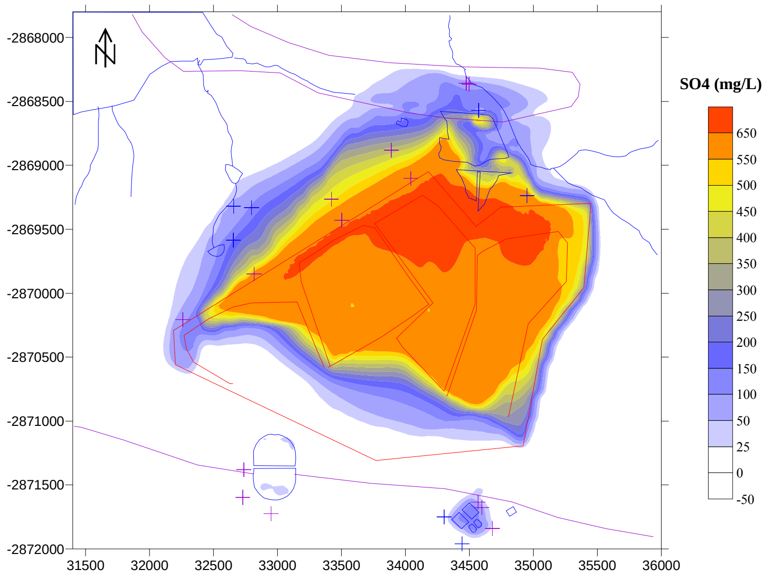

Figure 32. Modelled SO_4 concentrations in the deep aquifer system – end 2021.

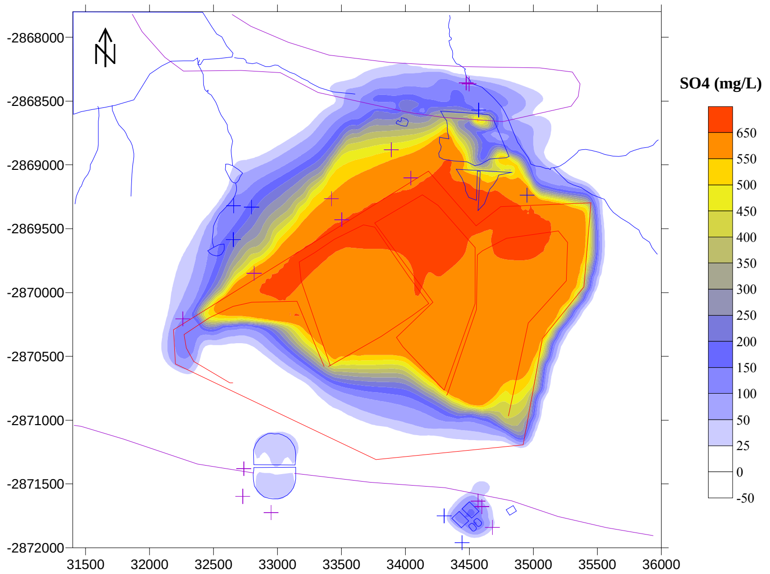

Figure 33. Modelled SO_4 concentrations in the deep aquifer system – end 2026.

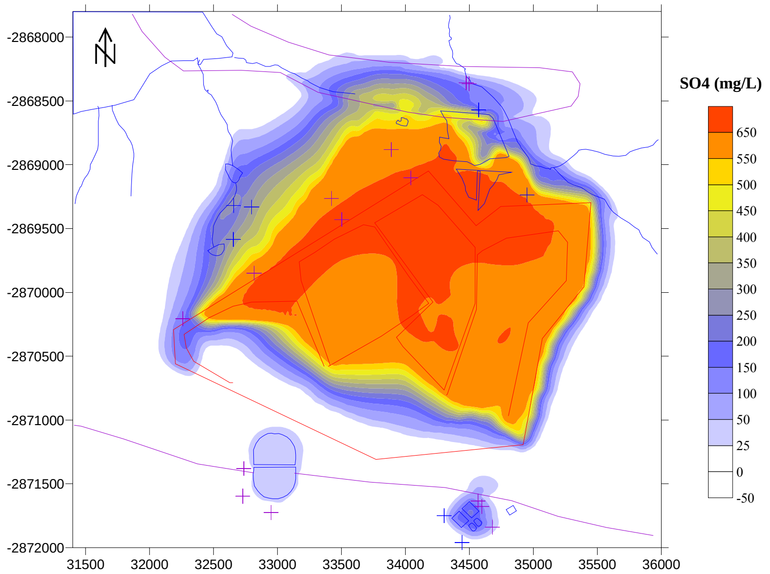

Figure 34. Modelled SO_4 concentrations in the deep aquifer system – end 2036.

From the coloured contour plots in Figure 30 to Figure 34 the following observations may be made:

- The contaminant plume in the deep aquifer system is expected to have a similar spatial extent than the plume in the shallow aquifer system.
- Some mobilisation of contaminants along the weathered diabase intrusion is expected to occur.

10.2.5.3 Seepage volumes from the Ash Dam

The estimated daily volumes of water that will seep from the Ash Dam into the subsurface are listed in Table 17 and displayed graphically in Figure 35. The estimated daily volumes of seepage that enter the shallow weathered and deep aquifer systems are also listed in Table 17.

Table 17. Estimated daily volumes of seepage from the Ash Dam.

Seepage from Ash Dam (m^3/day)			
Year	**Total**	**Into Shallow Aquifer**	**Into Deep Aquifer**
end 2006	805	796	9
end 2011	1109	1095	14
end 2016	1433	1410	22
end 2021	1708	1678	30
end 2026	1942	1905	37
end 2031	2156	2111	45
end 2036	2340	2289	52

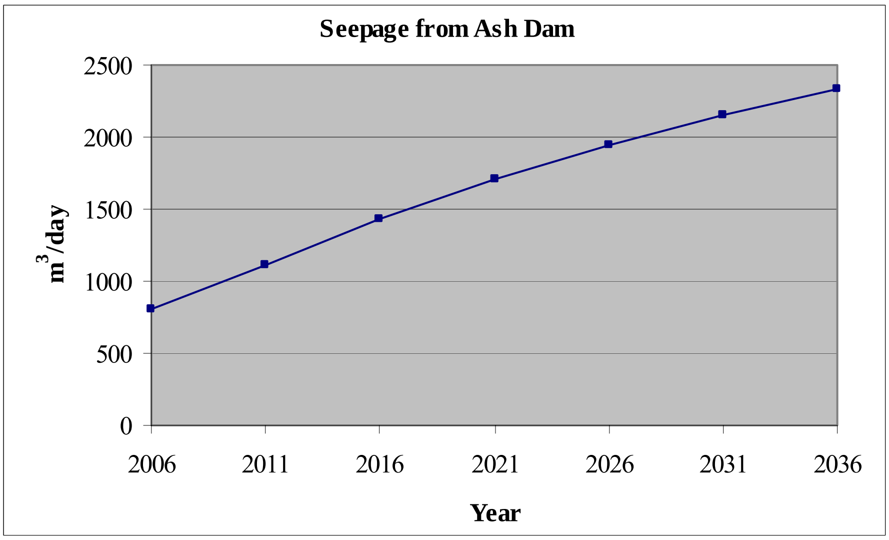

Figure 35. Estimated daily seepage volumes from the Ash Dam.

Since both the topographic and local groundwater gradients in the vicinity of the Ash Dam are predominantly to the north, most of the seepage is expected to occur at positions north of the Ash Dam. During the field investigations seepage was indeed observed at positions to the north of the Ash Dam, as far as 350 m away from the Ash Dam. The estimated volumes of seepage water entering the shallow weathered aquifer system to the north of the Ash Dam are listed in Table 18 and displayed graphically in Figure 36.

Table 18. Estimated daily volumes of seepage from the Ash Dam into the weathered aquifer system north of the Ash Dam.

Seepage into shallow aquifer north of Ash Dam (m^3/day)	
Year	**Total**
end 2006	427
end 2011	589
end 2016	719
end 2021	824
end 2026	912
end 2031	987
end 2036	1052

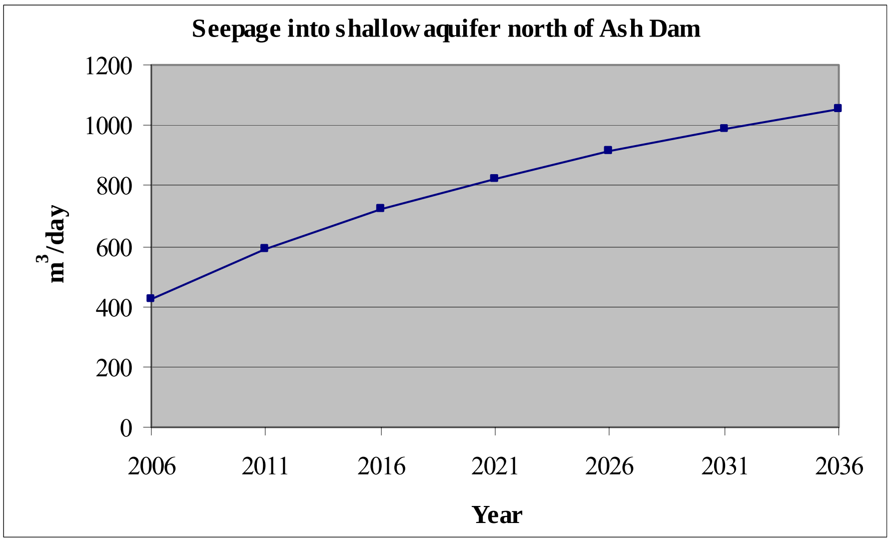

Figure 36. Estimated daily seepage volumes into the weathered aquifer north of the Ash Dam.

The estimated volumes of seepage listed in Table 17 do not take into account the fact that some of this seepage is intercepted by an interception trench that runs parallel to the north-western wall of the Ash Dam and discharges into the Low Level Ash Water Return Dam. The volumes of seepage that migrate to the north are also reduced by two rows of densely spaced Blue Gum Eucalyptus trees that occur on either side of the interception trench. Transpiration from these trees will result in decreased seepage volumes affecting the aquifer system to the north of the Ash Dam.

During field investigations it was noted that the shallow seepage interception trench currently intercepts approximately 1 L/s of seepage water. This volume translates into a daily volume of around 86 m^3 or approximately 20% of the estimated volume of water currently seeping into the shallow aquifer system north of the Ash dam. Fully grown Blue Gum Eucalyptus trees can transpirate as much as 200 L/day. Assuming that, on average, five such trees occur per area of 20 m×20 m, the daily water losses due to transpiration amounts to approximately 60 m^3. With these estimates the volumes of water seeping into the shallow aquifer system north of the interception trench and rows of trees are estimated in Table 19 and shown graphically in Figure 37. The seepage volumes estimated in Table 19 indicate that the interception trench and trees may cause reductions of between 26% and 37% in the volumes of water that migrate through the shallow aquifer system towards the Witbank Dam. These estimates are, however, based on a number of assumptions and should therefore be seen as only first estimates.

Table 19. Estimated daily volumes of seepage into the weathered aquifer system north of the interception trench and trees.

Seepage into shallow aquifer system north of interception trench and trees (m^3/day)		
Year	**Without trench&trees**	**With trench&trees**
end 2006	362	229
end 2011	509	347
end 2016	649	459
end 2021	765	552
end 2026	862	630
end 2031	949	699
end 2036	1029	763

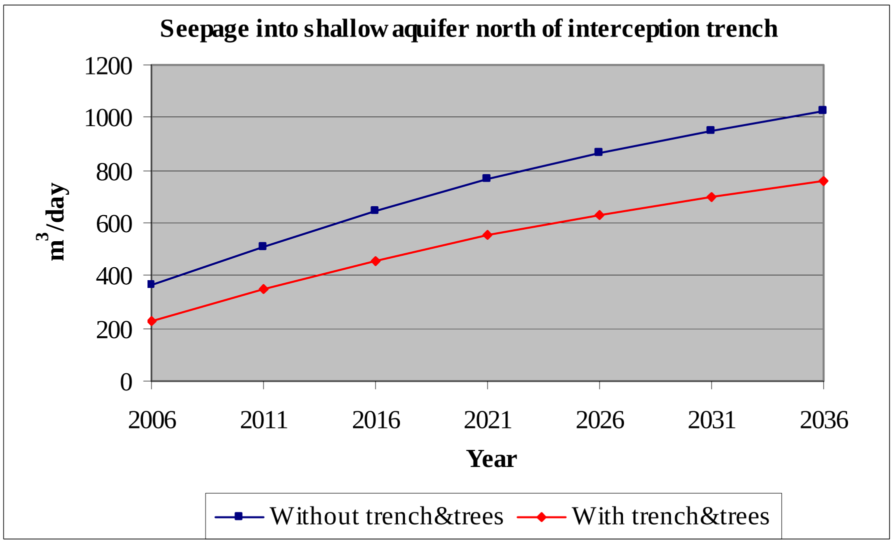

Figure 37. Estimated daily seepage volumes into the weathered aquifer north of the interception trench and trees.

10.2.5.4 Seepage volumes from the Low Level Ash Water Return Dam

The estimated daily volumes of water that will seep from the Low Level Ash Water Return Dam (including the silt trap) into the subsurface are listed in Table 20. It is seen that a modelled daily volume of around 36.26 m^3 seeps from this dam. Seepage predominantly takes place into the shallow weathered aquifer with only small volumes seeping through to the deeper aquifer system.

The low volumes of seepage from the Low Level Ash Water Return Dam can be understood by noting that this dam is located within a local topographic depression. Groundwater elevations in the areas to the west and east of the return water dam where local topographic highs occur are generally higher than the operational water level of the return water dam (1532 mamsl). The hydraulic gradients to the west and east of the return water dam therefore point towards the dam. As a result, groundwater flow is generally towards the return water dam, and not away from it. Seepage is therefore expected to predominantly take place to the north and north-east of the dam where the topographic low formed by the valley in which the dam is located extends in a north-westerly direction.

Table 20. Estimated seepage volumes from Low Level Ash Water Return Dam.

Seepage from LLAWRD (m^3/day)		
Total	**Into Shallow Aquifer**	**Into Deep Aquifer**
36.26	34.45	1.81

10.2.6 Risk Assessment

10.2.6.1 Sources, pathways and receptors

In order for a health risk to exist, three components are required, namely:

- A contaminant source. The concentration of the contaminant in the source should be sufficiently high to pose a health risk, either through once-off exposure or through the cumulative effects of long-term exposure,
- A pathway for contaminant migration.
- Receptors that may be exposed to the contaminants and on which the contaminants might impact.

To evaluate the risks associated with seepage from the Ash Dam and the Low Level Ash Water Return Dam, each of these three components is discussed below.

Contaminant sources

The water contained in the ash water system has a high salt concentration with a total dissolved solids (TDS) concentration of approximately 1 500 mg/L and a sulphate concentration of around 650 mg/L (refer to Table 7, for the chemical analyses performed on water samples from the Low Level Ash Water Return Dam (site AP09) and the High Level Ash Water Return Dams (site PP04)). The colour scheme employed in Table 7 to rate the water quality according to the South African Drinking Water Standards indicates that the pH, electrical conductivity (EC), calcium and sulphate concentrations of the ash water are particularly high, resulting in the ash water quality to be classified as poor to dangerously poor. These observations show that there are significant risks associated with the contaminant sources.

Pathways

The pathways for contaminant transport in the vicinity of the Ash Dam and Low Level Ash Water Return Dam are seepage through the shallow aquifer system, seepage through the deep aquifer system and transport along the non-perennial stream.

The numerical modelling results show that the deep aquifer system does not present a significant pathway for groundwater migration and contaminant transport. The hydraulic conductivities of the fresh rhyolites are generally very low. Fractures within the rhyolites may cause significant increases in the hydraulic conductivity on a local scale, but these fractures do not seem to have a large impact on the hydraulic conductivity on a regional scale.

The shallow weathered rhyolites form a prominent pathway for groundwater migration and contaminant transport. Seepage occurs to the north, and at a distance of 350 m, from the Ash Dam. The high hydraulic conductivities of the weathered rhyolites suggest that significant volumes of seepage can be expected to migrate through these rocks and their associated soils.

Seepage from the Ash Dam and the Low Level Ash Water Return Dam could impact on the non-perennial streams that occur in the vicinity of these dams. Impacts on these streams may occur through both surface runoff and base flow. Although these impacted streams may themselves be considered receptors of contaminant impacts, they also act as pathways along which contaminated water may be transported. All the non-perennial streams in the vicinity of the Ash Dam and the Low Level Ash Water Return Dam eventually run into the Witbank Dam.

<u>Receptors</u>

There are no groundwater users between the Ash Dam and the Witbank Dam. The risks associated with the ingestion of contaminated groundwater are therefore negligible. However, groundwater migration takes place in the direction of the Witbank Dam. Contaminated groundwater reaching this dam may impact negatively on the water quality in the dam, as well as on users of this water.

The non-perennial rivers that occur to the north of the Ash Dam could also be subject to contaminant impacts. The water from these rivers are not used by humans, but drinking water for cattle is supplied from the western river that runs into dams AP06 and AP07 (see Figure 10). In addition, cattle and wild animals could potentially drink from the other non-perennial rivers. Contaminated water that reaches the non-perennial rivers could also end up in the Witbank Dam. The Witbank Dam and users of its water should therefore be seen as possible receptors of contaminant impacts.

10.2.6.2 The groundwater pathway

From the numerical modelling results (refer to Section 10.2.5) it can be seen that the pollution plumes to the north of the Ash Dam and Low Level Ash Water Return Dam are not expected to extend all the way to the Witbank Dam by the end of 2036 when ashing operations at Duvha Power Station will cease. It would therefore seem that the groundwater pathway through the both the shallow and deep aquifer systems will be of less importance when considering contaminant impacts on the Witbank Dam and its water users. However, the Ash Dam will remain a source of contamination long after decommissioning. After ashing operations cease, a hydraulic mound will remain in the Ash Dam that will continue to force seepage from the Ash Dam into the subsurface. This mound will gradually decrease in size with a corresponding decrease in hydraulic head. The spatial extent that the pollution plumes could attain 50 and 100 years after decommissioning is illustrated in Figure 38 to Figure 41. (Note that these plumes were modelled by neglecting the water losses associated with transpiration from the two rows of trees and the losses due to the existing interception trench north of the Ash Dam. The modelled plumes shown in the figures below may therefore be seen as worst case estimates.)

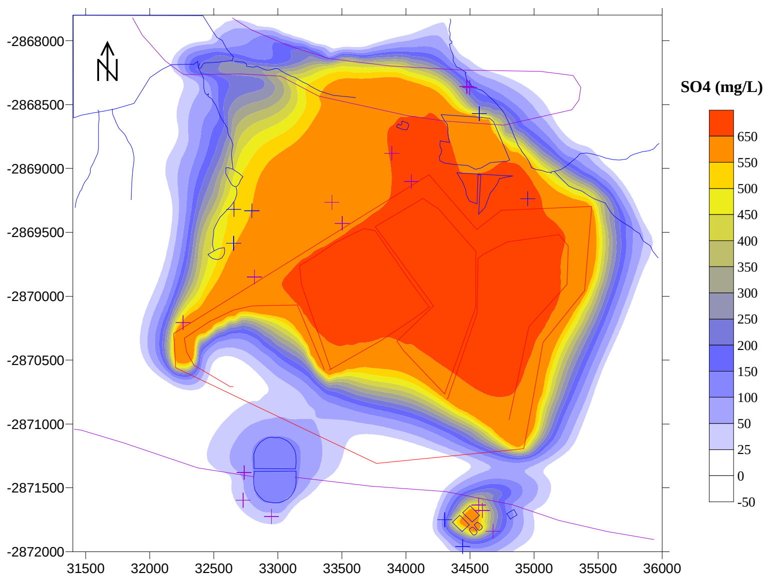

Figure 38. Modelled SO_4 concentrations in the shallow aquifer system, 50 years after decommissioning – end 2086.

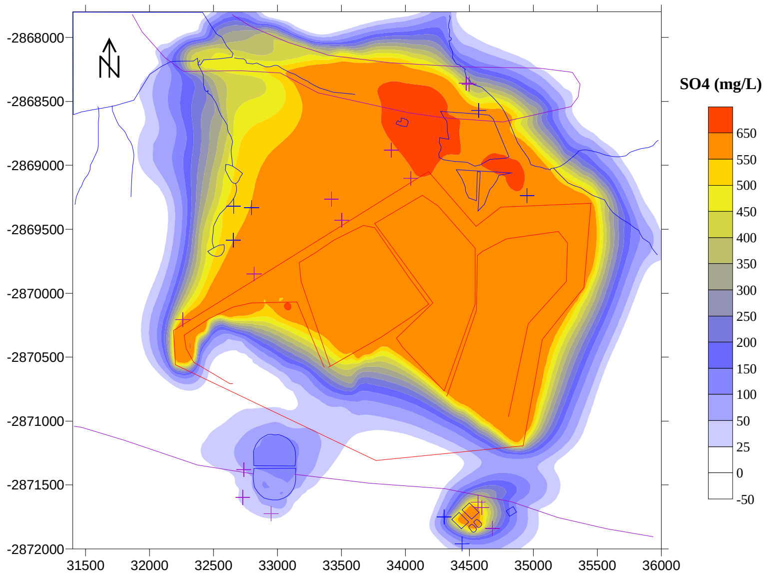

Figure 39. Modelled SO_4 concentrations in the shallow aquifer system, 100 years after decommissioning – end 2136.

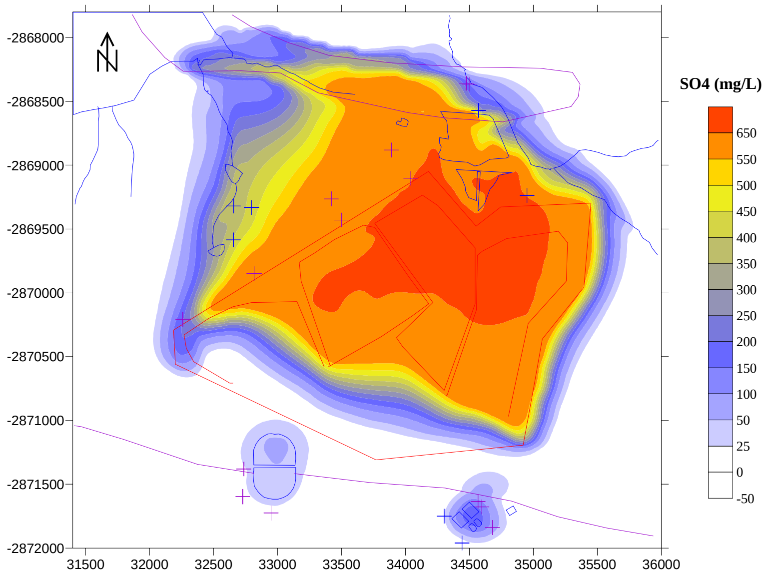

Figure 40. Modelled SO_4 concentrations in the deep aquifer system, 50 years after decommissioning – end 2086.

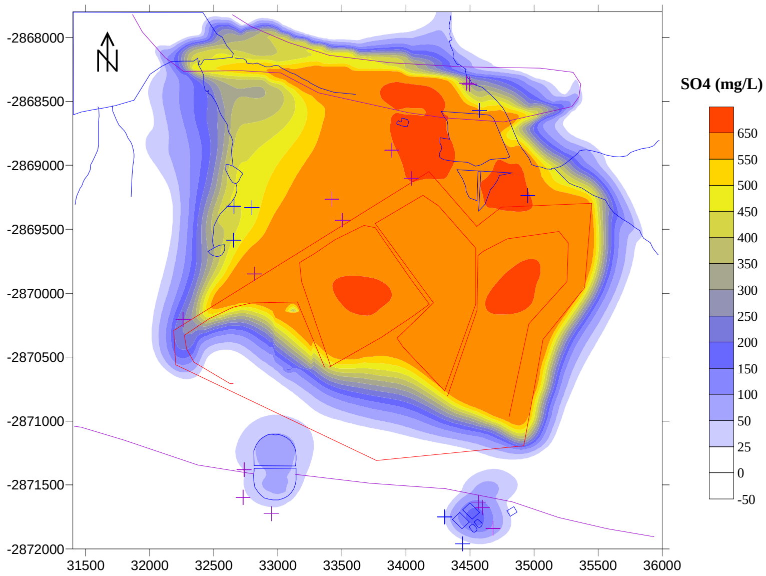

Figure 41. Modelled SO_4 concentrations in the deep aquifer system, 100 years after decommissioning – end 2136.

From the contours of the sulphate concentrations shown in Figure 38 to Figure 41, the following observations can be made:

- The pollution plumes in both aquifer systems are expected to continue their migration to the north in the years after decommissioning. Contaminant migration will also occur along the weathered zones of the intrusive diabase body in the direction of the Witbank Dam.
- By 2086 the contaminants that are mobilised along the diabase intrusion are expected to impact on the Witbank Dam. However, the sulphate concentrations of the groundwater that reaches the Witbank Dam will still be less than 500 mg/L, and the groundwater will therefore still be classified as water of an good to marginal quality according to the South African Drinking Water Standards. (The current sulphate concentration of the water from the Witbank Dam is approximately 145 mg/L).

The above observation show that the risks associated with contaminant impacts along the groundwater pathways may be considered relatively small. The estimated daily salt loads that will reach the Witbank Dam along the groundwater pathway are listed in Table 21.

Table 21 Estimated salt loads transported to the Witbank Dam along the groundwater pathway.

Salt loads to Witbank Dam along groundwater pathway	
Year	**Salt load kg/day**
end 2086	9.1
end 2136	26.4

10.2.6.3 The non-perennial river pathway

Seepage that reaches the non-perennial rivers in the vicinity of the Ash Dam and Low Level Ash Water Return Dam could potentially impacts on the water quality of the Witbank Dam. Apart from elevated iron concentrations at sites R01 and R02 (refer to Table 7) the current water quality at the non-perennial river sites may be classified as ideal. The current sulphate concentrations at these sites are 16, 35 and 59 mg/L, respectively. Numerical modelling results indicate that, due to future impacts of seepage on these surface water bodies, these concentrations could attain maximum values of between 350 and 500 mg/L during the operational phase of the Ash dam. Such concentrations are high enough to cause the water quality to be classified as marginal. If ingested, water of a marginal quality could cause negative effects in sensitive groups.

In order to estimate the magnitude of the impact that could occur on the Witbank Dam due to contaminant transport along the non-perennial rivers, the salt loads that are expected to be carried by these rivers to the Witbank Dam are estimated in Table 22. The estimated salt loads listed in Table 22 are seen to be small and the impact of these salts on the quality of the water in the Witbank will therefore be minimal. It should, however, be appreciated that, due to the relatively slow rate of groundwater migration and contaminant transport, the Ash Dam is likely to have impacts on the Witbank Dam long after ashing activities have ceased.

Table 22. Estimated salt loads transported to the Witbank Dam along the non-perennial river pathway.

Salt loads to Witbank Dam	
Year	**Salt load kg/day**
end 2006	2.6
end 2011	3.5
end 2016	5.2
end 2021	8.0
end 2026	13.5
end 2031	22.7
end 2036	34.4
end 2066	43.3
end 2086	45.9
end 2136	49.3

10.2.7 Conceptual design of seepage interception systems

10.2.7.1 Ash Dam

The results of the field investigations and numerical modelling show that seepage losses from the Ash Dam predominantly take place through the highly weathered rhyolites that occur along the north-western wall of the Ash Dam. Currently two interception systems are in place along the north-western wall of the Ash Dam. A shallow, unlined interception trench with a depth of around 3 m runs along the entire length of the wall and discharges into the Low Level Ash Water Return Dam. Two rows of densely spaced Blue Gum Eucalyptus trees (on either side of the interception trench) also contribute to seepage interception through the mechanism of transpiration.

The existing interception trench constantly carries water, indicating that it is intercepting seepage from the Ash Dam. However, since the depth of weathering in the rhyolites north of the Ash Dam is generally greater than 3 m, the interception trench is only effective in intercepting seepage that occurs at very shallow depths. In order to effectively intercept the seepage, it is recommended that an interception trench with a depth of at least 6 m be installed. It is recommended that this trench be constructed to the north of the existing interception trench, so that the trees that occur on the sides of the existing trench need not be removed. The new trench should, however, still be located close to the Ash Dam in order to minimise the impacts of the seepage on the groundwater regime. It is therefore recommended that the trench be installed 10 – 20 m north of the northern row of trees. The approximate location of the proposed trench is shown in Figure 42.

Figure 42. Location of the proposed seepage interception trench north of the Ash Dam.

The construction of such a trench should be done similarly to the sub-soil cut-off drains that were installed at Matla Power Station. The design of these drains is described in the report “Matla Power Station, New Ash Dam, Ash Water Seepage Investigation” (N Barnard, 1999, Report No. 23CBML008). The proposed construction of the interception trench at Duvha Power Station is described below:

- The ground is excavated to the desired depth (6 to 8 m).
- An impermeable barrier in the form of a 1 mm thick high density polyethylene (HDPE) liner is installed on the southern face of the trench.
- A layered filter system consisting of an HDPE geonet, a type 14 geotextile and 50 mm deep geocells filled with river sand is installed immediately below the HDPE liner to form an inclined filter. This filter will transport the seepage water to a slotted drain pipe contained in a stone filter pack. The stone filter pack is also wrapped in a type 14 geotextile.
- The slotted drain pipe will transport the seepage water to a collector drain pipe along which the seepage water will be gravitated in the direction of the Low Level Ash Water Return Dam. Since the depth of the trench will exceed the lowest level of the Low Level Ash Water Return Dam, water will have to be collected in a sump near the Low Level Ash Water Return Dam from which it can be pumped into the dam.
- The trench is backfilled with fine ash to prevent any damage to the HDPE liner. The fine ash is in turn covered with backfilled overburden.

The designs of the interception trench and seepage barrier system are illustrated graphically in Figure 43 and Figure 44 (based on drawings by N Barnard).

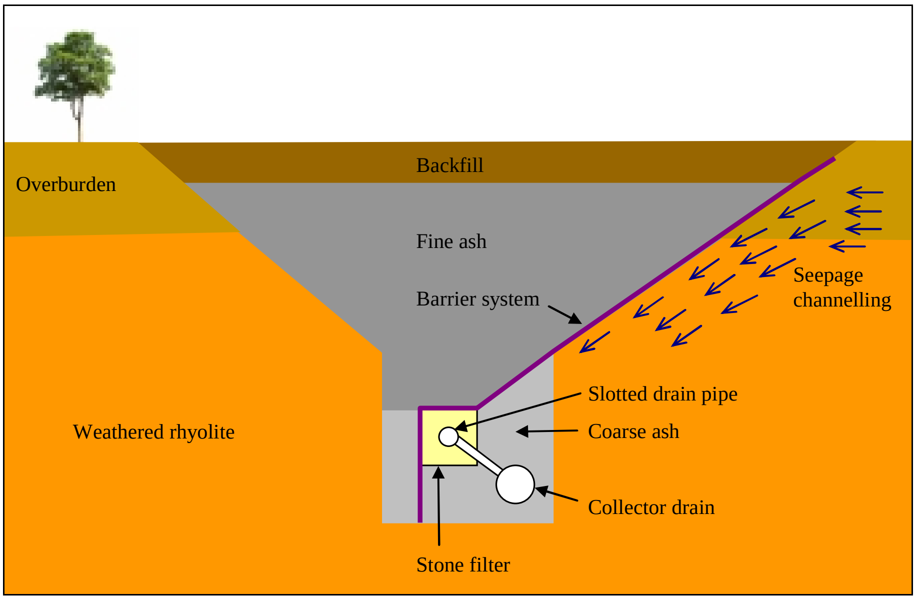

Figure 43. Conceptual design of the interception trench.

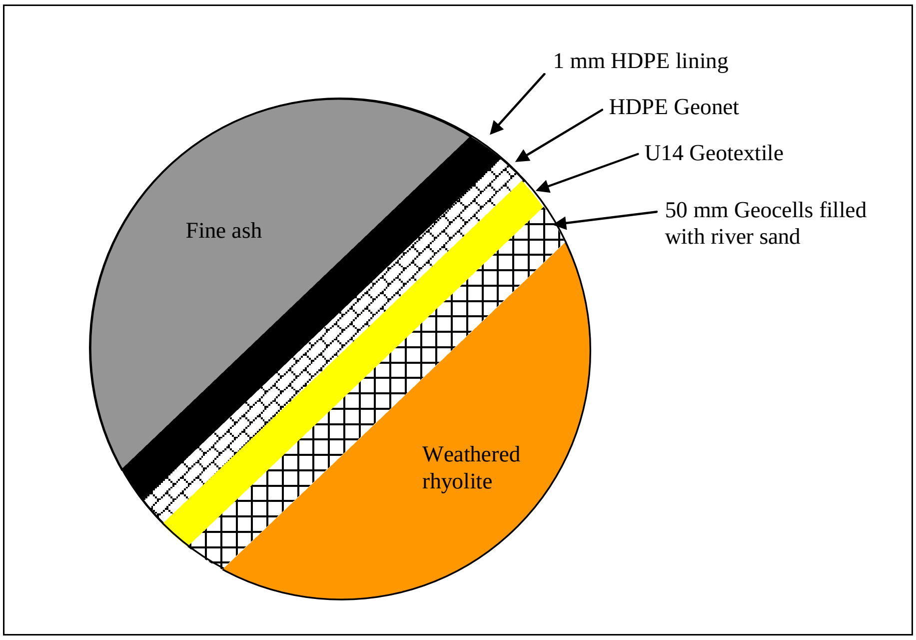

Figure 44. Design of the seepage barrier system.

<u>Estimated Installation Costs</u>

Based on a cost estimate obtained from Mr. Wilhelm van Wyk of Roshcon, the costs involved with the installation of seepage interception trench are listed in Table 23. These costs should be seen as only first estimates, since a site visit by the engineer will be required before a more accurate cost estimate can be made. The costs for the installation of both a 6 and 8 m deep trench are listed in Table 23. Also compared are the costs associated with a 2.4 km long trench running along the entire length of the Ash Dam, and a shorter trench of only 1.6 km length that is installed only at the positions where highly weathered rhyolites were encountered during drilling. These different options for the construction of the trench are later evaluated in terms of the costs and benefits.

Table 23. Cost estimate for the installation of a seepage interception trench north of the Ash dam.

Length of trench (km)	Depth of trench (m)	Estimated cost (R)
1.6	6	7,285,400
1.6	8	8,640,226
2.4	6	10,928,100
2.4	8	12,960,339

Preliminary Cost-Benefit Analysis

Assuming a 60% efficiency for the interception trench (that is, 60% of seepage water that reaches the trench is intercepted), the volumes of water that are expected to be intercepted by the seepage trench are listed in Table 24. Again different depths and lengths are considered for the trench. Also listed in Table 24 are the estimated cost benefits associated with the lower volumes of make-up water that will need to be purchased to replace the water lost through seepage. The cost estimates in Table 24 are based on the assumption that water costs will increase from R1 150/Ml in 2006 to R2 300/Ml in 2011 (these cost estimates were obtained from Duvha Power Station), and at 7% per annum thereafter.

Table 24. Estimated volumes of seepage that will be intercepted by the trench and the associated cost benefits in terms of water recovery.

Trench design	Year	Estimated daily volume intercepted (m^3/day)	Cumulative volume intercepted (m^3)	Estimated make-up water costs (R/m^3)	Daily water cost savings (R/day)	Cumulative water cost savings (R)	Estimated installation costs (R)	Net present value of trench (R)
1.6 km long, 6 m deep	end 2006	123		1.15	141.42		**7,285,400**	8,083,606
	end 2011	170	266,963	2.30	390.05	484,966		
	end 2016	207	610,771	3.23	668.37	1,450,771		
	end 2021	237	1,016,447	4.52	1,074.04	3,040,722		
	end 2026	263	1,472,773	6.35	1,667.01	5,541,936		
	end 2031	284	1,971,836	8.90	2,529.65	9,371,388		
	end 2036	303	2,507,651	12.48	3,782.04	**15,130,806**		
1.6 km long, 8 m deep	end 2006	164		1.15	188.56		**8,640,226**	11,851,782
	end 2011	226	355,950	2.30	520.06	646,622		
	end 2016	276	814,361	3.23	891.16	1,934,361		
	end 2021	317	1,355,263	4.52	1,432.06	4,054,296		
	end 2026	350	1,963,698	6.35	2,222.68	7,389,247		
	end 2031	379	2,629,114	8.90	3,372.87	12,495,184		
	end 2036	404	3,343,534	12.48	5,042.72	**20,174,408**		
2.4 km long, 6 m deep	end 2006	154		1.15	176.78		**10,928,100**	8,283,157
	end 2011	212	333,703	2.30	487.56	606,208		
	end 2016	259	763,464	3.23	835.46	1,813,463		
	end 2021	297	1,270,559	4.52	1,342.56	3,800,903		
	end 2026	328	1,840,967	6.35	2,083.76	6,927,419		
	end 2031	355	2,464,795	8.90	3,162.06	11,714,235		
	end 2036	379	3,134,563	12.48	4,727.55	**18,913,507**		
2.4 km long, 8 m deep	end 2006	205		1.15	235.70		**12,960,339**	12,654,671
	end 2011	283	444,938	2.30	650.08	808,277		
	end 2016	345	1,017,951	3.23	1,113.95	2,417,951		
	end 2021	396	1,694,079	4.52	1,790.07	5,067,870		
	end 2026	438	2,454,622	6.35	2,778.35	9,236,559		
	end 2031	474	3,286,393	8.90	4,216.08	15,618,980		
	end 2036	505	4,179,418	12.48	6,303.40	**25,218,010**		

In order to evaluate the financial benefits of the trench against the installation costs, the last column in Table 24 lists the net present value (NPV) of the trench. To calculate the NPV the initial installation cost of the trench is considered as an investment, while the water cost savings are considered as returns on the investment. An annual interest (discount) rate of 7% was assumed for the NPV calculations in Table 24. It can be seen that, of the different trench designs, the deeper trenches (8 m deep) are more economically profitable than the shallow trenches (6 m deep).

It should, however, be stressed that there are additional benefits (financial and other) to the installation of an interception trench. Within the next two years the Waste Discharge Charge System (WDCS) will be implemented through which the "polluter pays" principle will be enforced. As waste generating facilities that have environmental impacts, all the Eskom power stations will by subject to the WDCS and will be held financially responsible for the salt loads that are released to the environment.

The WDCS is only in its initial stages and the costs per tonnage of salts have not been finalised. A pilot study focussing on the water quality of the Witbank Dam is to be launched in 2007. This study will aim to ensure that the sulphate concentration of the Witbank Dam remains below 150 mg/L and will yield information on how a pricing system should be structured. Initial estimates range from R3 000 to R11 000 per ton of salt that is released to the dam. Lesser costs will also be incurred for the salt loads that impact on the groundwater quality in the vicinity of contaminant sources (such as ash dams).

Although modelling results suggest that the impact of seepage from the Ash Dam at Duvha Power Station on the Witbank Dam is limited, Duvha Power Station will be held financially responsible for the salt loads that are released to the subsurface. The seepage interception trench will therefore also be beneficial in terms of the cost savings associated with the WDCS. These costs will only be quantifiable once more information on the WDCS and its application to Duvha Power Station becomes available. Once the necessary adjustments to the NPV's listed in Table 24 are made by incorporating the cost savings associated with the WDCS, the trenches will be even more profitable.

The financial viability of the interception trench will also be affected by the annual interest rate. To illustrate how the profitability of the trench could vary, the NPV's for different interest rates are calculated in Table 25. Again, only the cost benefits associated with water cost savings are taken into account. For the calculations in Table 25 it was assumed that the cost of water also increases annually according to the listed interest rate.

Table 25. Net Present Values of seepage interception trench for different annual interest rates.

Trench design	**Net present value of trench (R)**							
Interest rate (% / annum)	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1.6 km long, 6 m deep	14,739,836	13,145,385	11,697,380	10,380,047	9,179,523	8,083,606	7,081,532	6,163,792
1.6 km long, 8 m deep	20,726,755	18,600,821	16,670,148	14,913,704	13,313,005	11,851,782	10,515,683	9,292,030
2.4 km long, 6 m deep	16,603,445	14,610,381	12,800,375	11,153,709	9,653,054	8,283,157	7,030,565	5,883,390
2.4 km long, 8 m deep	23,748,387	21,090,969	18,677,629	16,482,073	14,481,200	12,654,671	10,984,548	9,454,981

The NPV's calculated in Table 25 show that at low interest rates, the trenches are more profitable financially than at high interest rates. It is also clear that the deeper trenches are more profitable than the shallower trenches.

10.2.7.2 Low Level Ash Water Return Dam

The results of the numerical model show that surprisingly small volumes of seepage (~36 m^3/day) from the Low Level Ash Water Return Dam can be expected to enter the shallow weathered aquifer system and may surface at positions north of the northern wall of the dam. Comparison of the water quality at the five monitoring sites that are located north of the Low Level Ash Water Return Dam also suggest that seepage from this dam does occur, but that the volumes of seepage are small. The sulphate concentration at borehole AB04, located immediately north of the dam wall, is at present only 187 mg/L, even though ashing operations have been taking place since 1978. The sulphate concentrations at the new boreholes AB30 and AB31 are 93 and 54 mg/L, respectively. The fact that these boreholes are located only 200 m north from the northern wall of the Low Level Ash Water Return Dam again suggests that limited seepage has occurred from this dam. Although the water at surface site AS04 displays an elevated sulphate concentration of 119 mg/L compared with the sulphate concentration of the water in the nearby non-perennial river (59 mg/L, site R03), the increased concentration may be attributed to evaporation effects that are more pronounced on stagnant water bodies.

It should, however, be kept in mind that the relatively low sulphate concentrations observed in the groundwater may also be due to the precipitation of sulphates as the groundwater migrates through the aquifer systems. The groundwater quality observed at the borehole should therefore not be seen as the only indicator of the occurrence and volumes of water that seep from the Low Level Ash Water Return Dam.

Since the volumes of seepage losses from the Low Level Ash Water Return Dam seem to be small, and since the impact of contaminants associated with seepage appears to be minimal, the cost benefits of installing a seepage interception system is likely to be limited. There are also practical difficulties associated with the installation of a seepage interception system. Judging from the topographic gradient, seepage from the Low Level Ash Water Return Dam is expected to take place predominantly near the north-eastern toe of the dam, east of the pump station. At this position the diverted non-perennial river flows very close to the dam wall and the access road around it. The proximity of the river to the dam wall and road leaves very little room in which to install an interception system.

Due to the factors discussed above, it is at present not recommended that a seepage interception system be installed at the Low Level Ash Water Return Dam. However, regular monitoring of the water quality and surface- and groundwater sites north of the dam should be done. Any deterioration in the water quality could indicate that larger volumes of seepage have started to impact on the environment. Under these conditions it may be beneficial to install a seepage interception system.

If future water quality monitoring reveals that contaminant impacts on the surface water and/or groundwater are occurring, a simple design for a seepage interception system could consist of a shallow unlined trench (3-4 m deep, ~300 m long) dug at a position near the north-eastern toe of the dam (see Figure 45). The trench could be fitted with gabions to prevent it from collapsing. A sump could be formed at the position of lowest floor elevation in the trench (near the elbow of the trench). From this sump, seepage water could be pumped back to the Low Level Ash Water Return Dam by means of pump equipped with a level switch. Such a system will, however, cause hydraulic gradients towards the trench which could increase the volumes of water seeped from the dam. The estimated costs of installing such a trench amount to approximately R700 000.

Figure 45. Position of possible seepage interception trench at the Low Level Ash Water Return Dam.

10.3 Raw Water Dam

10.3.1 Conceptual Model

Drilling results showed that the contact between the volcanic rhyolites and the Karoo sedimentary rocks must lie under the Raw Water Dam (refer to Section 6.1). Since the volcanic rocks are much older than the sedimentary rocks, the contact between these rock types is not associated with a baked zone as would be the case if the Karoo rocks were penetrated by younger magmatic bodies. The permeabilities of the rocks near the contact are therefore not expected to be higher than further away from the contact. Borehole PB15 was drilled within weathered felsites near the inferred contact with the sedimentary rocks. The low hydraulic conductivity of the earth materials at this site (K ~ 0.012 m/d) at this site also suggests that the contact zone does not act as a preferential pathway for groundwater migration.

The sedimentary rocks at borehole PB14 south-east of the Raw Water Dam consist of coarse grained sandstones associated with clayey material and siltstones up to a depth of around 8 m. Dark brown clay occurs below the sandstones. A similar geological section is observed at borehole PB16, but thick layers of clayey silt occur at depths greater than 10 m. The hydraulic tests performed on these two boreholes suggest that both the shallower and deeper Karoo formations have relatively low hydraulic conductivities (0.017 and 0.022 m/d, respectively). However, the coarse grained sandstones that occur at shallow depths are could potentially have much larger conductivities at positions with a lower clay content.

The conceptual model of the geohydrological conditions at the Raw Water Dam is summarised below:

- The shallow weathered rhyolites generally have low permeabilities. However, at positions of more extensive weathering these permeabilities may be dramatically enhanced (hydraulic conductivities as high as 0.838 m/d were recorded within the highly weathered rhyolites north of the Ash Dam).
- Due to a high clay content, the shallow Karoo rocks also have relatively low permeabilities. However, if a lower clay content occurs at a certain position, the coarseness of the sandstones may lead to marked increases in the hydraulic conductivity.

- The deeper fresh rhyolites fine grained and very dense. Low permeabilities are expected for these rocks.
- The deeper Karoo formations are very clayey are not expected to transmit large volumes of water. These units essentially form a thick impermeable layer that will limit the vertical migration of water from the Raw Water Dam.
- Water that seeps from the Raw Water Dam is expected to predominantly migrate vertically through the shallower, more permeable horizons formed by the weathered rhyolites and Karoo sandstones. When reaching the deeper fresh rhyolites and clayey Karoo deposits, the vertical migration will be impeded and groundwater motion is expected to predominantly take place in a horizontal direction. Seepage therefore primarily takes place through the shallow weathered materials and the hydraulic properties of these materials are the controlling factors when evaluating the seepage losses that could occur.

Note that the above conceptual model was developed by using the geological and geohydrological information obtained from only three boreholes. It is quite possible that this information could reflect only local conditions and that it may not be representative of the average geological/geohydrological conditions over the entire model area. Such limitations inherent to the conceptual model should be kept in mind when evaluating the results of the numerical model.

10.3.2 Model Input –Hydraulic Parameters

The same hydraulic parameters as was used for the larger Ash Dam and Low Level Ash Water Return Dam model was used for the numeric model of the Raw Water Dam (refer to Section 10.2.2). However, during model calibration different hydraulic conductivities were assigned to the weathered rhyolites and Karoo rocks that constitute the shallow aquifer system in order to evaluate the volumes of water that could potentially seep from the Raw Water Dam. These conductivities and the resulting seepage volumes are discussed in Sections 10.3.4 and 10.3.5. It was also found that the hydraulic conductivities of the dam walls and floors had to be lowered to allow acceptable agreement between the observed and modelled water levels in the three boreholes near the Raw Water Dam.

The properties of the different geohydrological zones are summarised in Table 26 and Table 27.

Table 26. Hydraulic conductivities of the geohydrological zones.

Zone	Kx [m/d]	Ky [m/d]	Kz [m/d]
1	0.65	0.65	0.065
2	0.65	0.65	0.065
3	0.001	0.001	0.0001
4	0.01	0.01	0.001
5	0.04	0.04	0.004
6	5	5	5
7	0.001	0.001	0.0001

Table 27. Storage properties of the geohydrological zones.

Zone	Ss [1/m]	Sy []	Eff. Por. []	Tot. Por. []
1	0.0001	0.2	0.2	0.25
2	0.0001	0.2	0.2	0.25
3	0.001	0.1	0.1	0.4
4	1E-5	0.1	0.12	0.15
5	5E-5	0.04	0.04	0.08
6	0.01	0.9	0.95	0.95
7	0.001	0.1	0.1	0.4

For the numerical model, a grid consisting of 100 × 100 cells (each cell 20 × 20 m) was constructed. Four layers were incorporated into the model. Layers 1, 2 and 3 represent the dam system, topsoil and shallow aquifer system. Layer 4 represents the deep aquifer system. The distribution of the seven geohydrological zones used to model the Raw Water Dam is shown in Figure 46 to Figure 50.

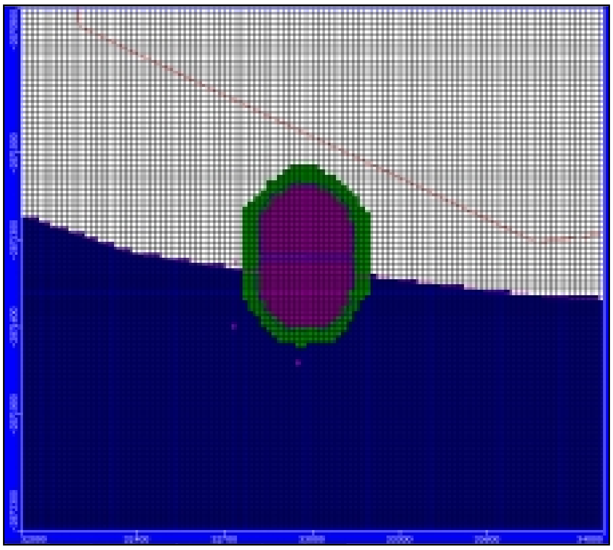

Figure 46. Geohydrological zone distribution in Layer 1.

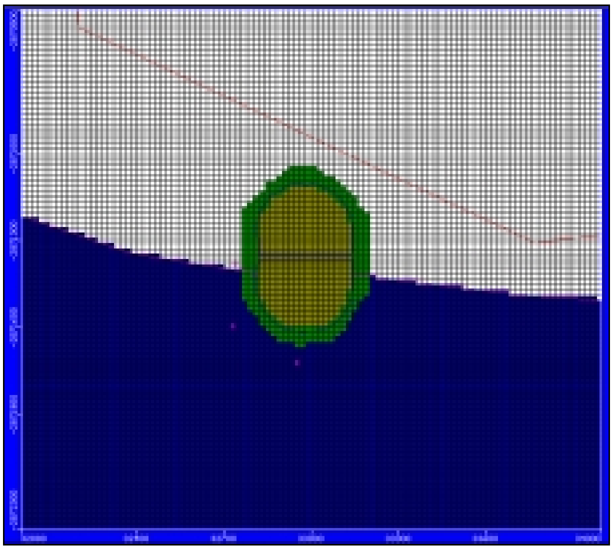

Figure 47 Geohydrological zone distribution in Layer 2.

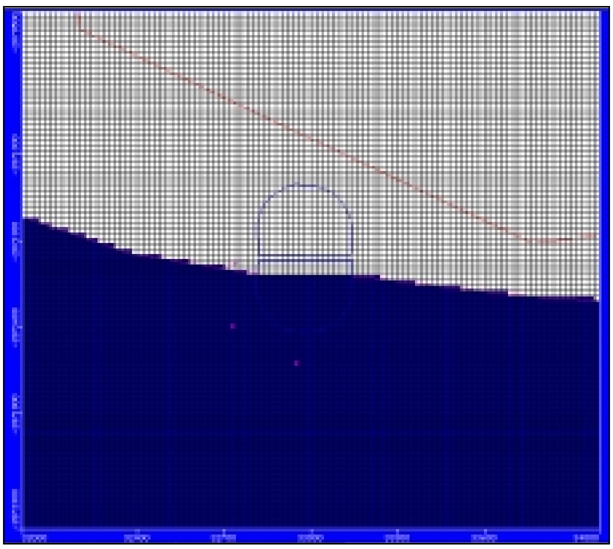

Figure 48. Geohydrological zone distribution in Layer 3.

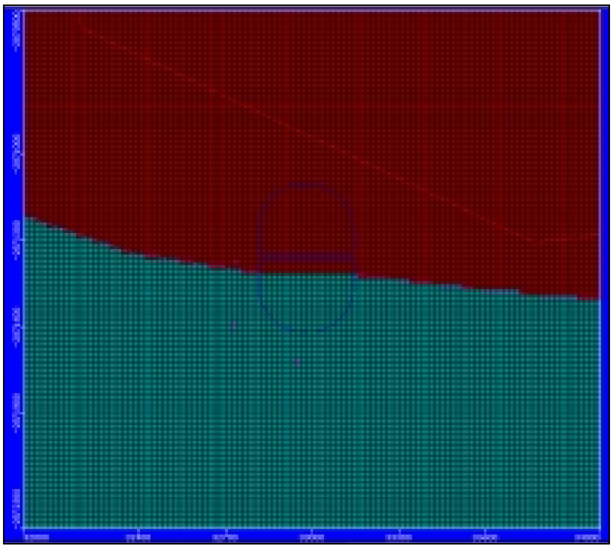

Figure 49. Geohydrological zone distribution in Layer 4.

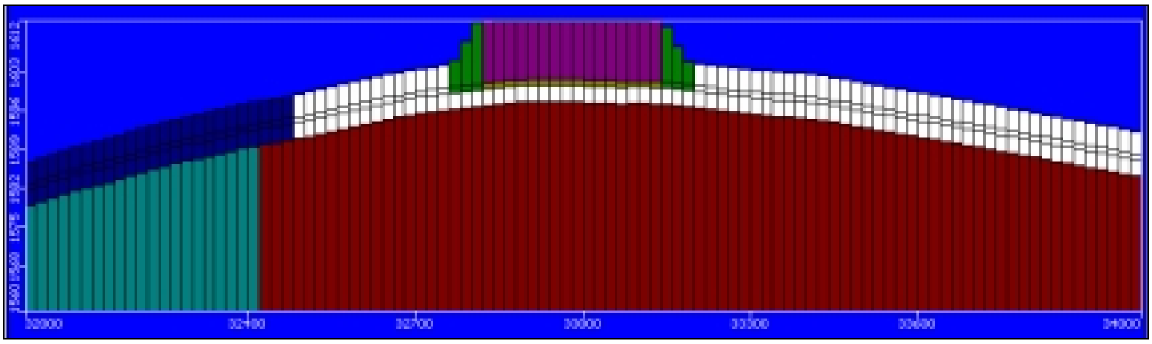

Figure 50. West-east cross-section through model domain to illustrate the geohydrological zone distribution.

10.3.3 Model Input – Groundwater Elevation

The estimated groundwater elevations in the vicinity of the Raw Water Dam are shown in Figure 51. Also shown in Figure 51 (yellow arrows) are the groundwater flow directions as inferred from the groundwater elevations. Since the Raw Water Dam is located on the crest of a local topographic high, groundwater migration is expected to take place in all directions away from the dam. The steepest gradients occur to the south-west, north-west and north-east of the dam. The rate of groundwater motion is expected to be the highest at these positions.

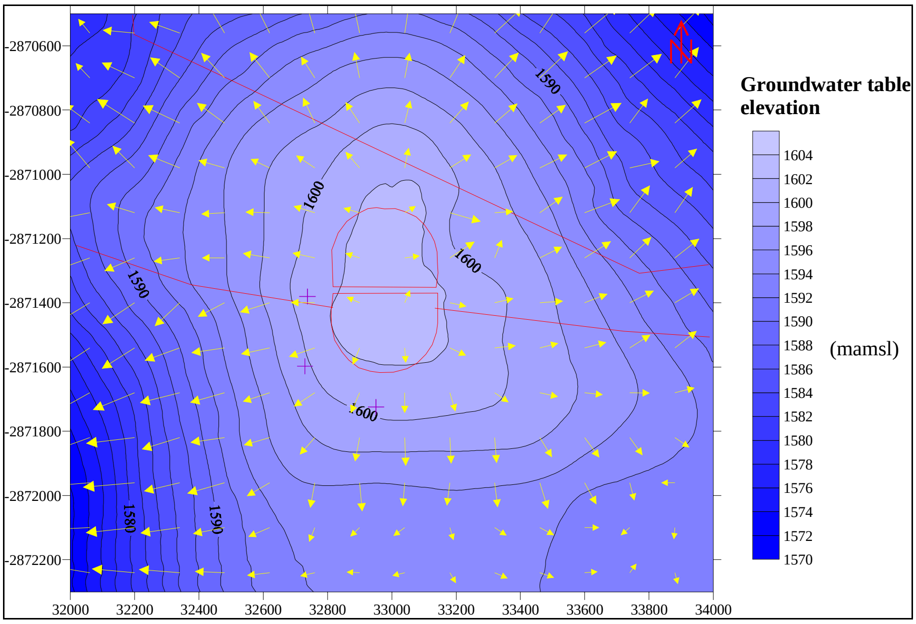

Figure 51. Estimated groundwater elevations in the vicinity of the Raw Water Dam at Duvha Power Station.

10.3.4 Model calibration

For the model calibration, the numerical model developed for the Raw Water Dam was run under steady state conditions. The modelled water levels at the three monitoring boreholes were then compared with the observed water levels. Adjustments to the hydraulic parameters were made until the best correlation between the modelled and observed water levels was achieved. The best correlation was found when the shallow weathered aquifer system (both the rhyolites and the Karoo rocks) was assigned a horizontal hydraulic conductivity of 0.65 and a vertical conductivity of 0.065 m/day. These conductivities are much higher than those determined from the slug tests performed on the three boreholes near the Raw Water Dam. As explained earlier, the geohydrological conditions at the three boreholes may reflect only local conditions and may not be representative of the average geological/geohydrological conditions over the entire modelled area.

In Figure 52 the observed and calculated (modelled) heads at the three boreholes near the Raw Water Dam are plotted for a horizontal hydraulic conductivity of 0.65 and a vertical conductivity of 0.065 m/day. The calculated heads are seen to give fair approximations of the actual heads. In Figure 53 the hydraulic heads modelled are plotted against the observed heads and a regression coefficient of 0.994 is attained. It should, however, be kept in mind that only three groundwater level measurements were used to calibrate the model.

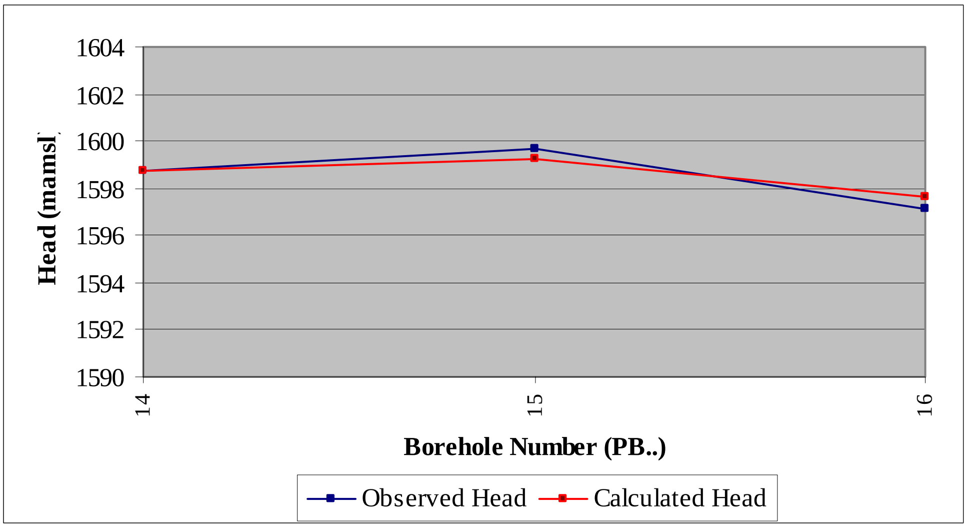

Figure 52. Observed and calculated heads at the boreholes near the Raw Water Dam.

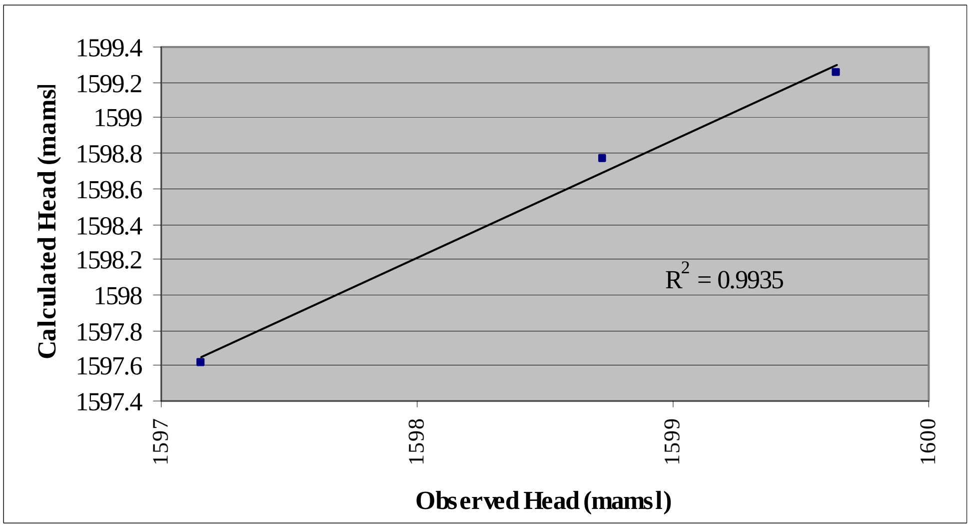

Figure 53. Calculated vs. observed heads at the boreholes near the Raw Water Dam.

10.3.5 Model Results

For the present model, it was assumed that the water level in the Raw Water Dam will be held at a constant elevation of 1610.5 mamsl (1.5 m below full supply level, ~80% of the dam capacity) while operations at the power station continues. A steady state numerical model was run to estimate the volumes of seepage from the Raw Water Dam that enter the subsurface.

10.3.5.1 Seepage volumes from the Raw Water Dam

The estimated daily volumes of water that will seep from the Raw Water Dam into the subsurface are listed in Table 28. The estimated daily volumes of seepage that enter the shallow weathered and deep aquifer systems are listed separately. Although the best fit between observed and modelled hydraulic heads was found for an average horizontal hydraulic conductivity of 0.65 m/day for the weathered aquifer system, the seepage that could be expected for other hydraulic conductivities are listed Table 28. This is done in order to allow insight into the influence of the average hydraulic conductivity on the volumes of seepage that could occur.

Table 28. Estimated daily volumes of seepage from the Raw Water Dam.

Shallow aquifer system		**Seepage from Raw Water Dam (m^3/day)**		
Horizontal hydraulic conductivity (m/day)	**Vertical hydraulic conductivity (m/day)**	**Into Shallow Aquifer**	**Into Deep Aquifer**	**Total**
0.15	0.015	29.25	39.40	68.65
0.30	0.03	49.66	36.52	86.18
0.50	0.05	70.12	33.34	103.46
0.60	0.06	76.73	32.26	108.99
0.65	**0.065**	**81.32**	**31.65**	**112.97**
0.70	0.07	83.98	30.61	114.59
0.80	0.08	89.17	29.54	118.71

From Table 28 it is seen that, for a horizontal hydraulic conductivity of 0.65 m/day and a vertical conductivity of 0.065 m/day for the shallow aquifer system, an estimated 113 m^3 of water daily seep from the Raw Water Dam into the subsurface. Approximately 81 m^3 seep into the shallow weathered aquifer system while approximately 32 m^3 seep into the deeper aquifer system. These volumes are relatively small when compared with the estimated volume of daily evaporation losses from the Raw Water Dam (~330 m^3).

10.3.6 Conceptual design of seepage interception systems

It should be noted that the water level depths in the three boreholes near the Raw Water Dam range from 2.48 to 5.24 mbgl, even though these boreholes occur close to the dam (66 – 118 m away). The results of the numerical model also suggest that seepage in the immediate vicinity of the Raw Water Dam is predominantly vertical through the weathered material that underlies the dam. This observation implies that the groundwater levels will become rapidly deep as one moves away from the dam. Seepage from the dam could, however, be expected to surface near the toes of the dam walls where the topographic gradient undergoes a rapid change. These observations are illustrated in Figure 54 where the surface topography and steady state water level along a west/east cross-section through the Raw Water Dam are plotted. The implications are that any seepage interception system should occur close to the dam wall and should be installed a relatively deep depth (> 4 m) to ensure that it is effective in intercepting seepage from the dam.

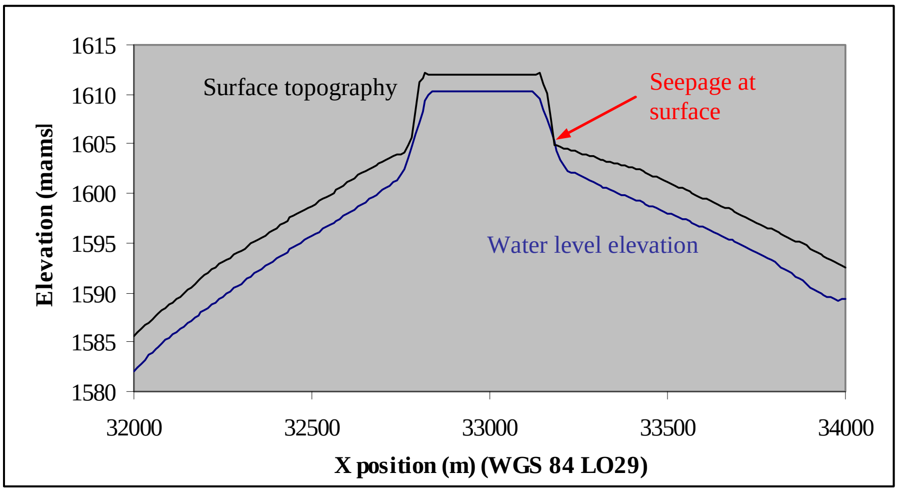

Figure 54. West/east cross-section through the Raw Water Dam showing the topographic elevation and water level elevation.

The numerical model suggests that seepage from the Raw Water Dam into the shallow aquifer system is expected to take place in all directions as can be seen in Figure 55 where the path lines of individual water molecules through the shallow aquifer are plotted. The model also shows that seepage can be expected to surface almost anywhere along the perimeter of the dam wall. However, seepage in the past predominantly surfaced on the western and south-western perimeter of the dam wall, where a seepage interception has already been installed. To evaluate the efficacy of a seepage interception system and to evaluate the costs against benefits that can be obtained from such a system, it will henceforth be assumed that the interception trench with a total length of 450 m will be installed near the western and south-western perimeters of the dam wall, as shown in Figure 56.

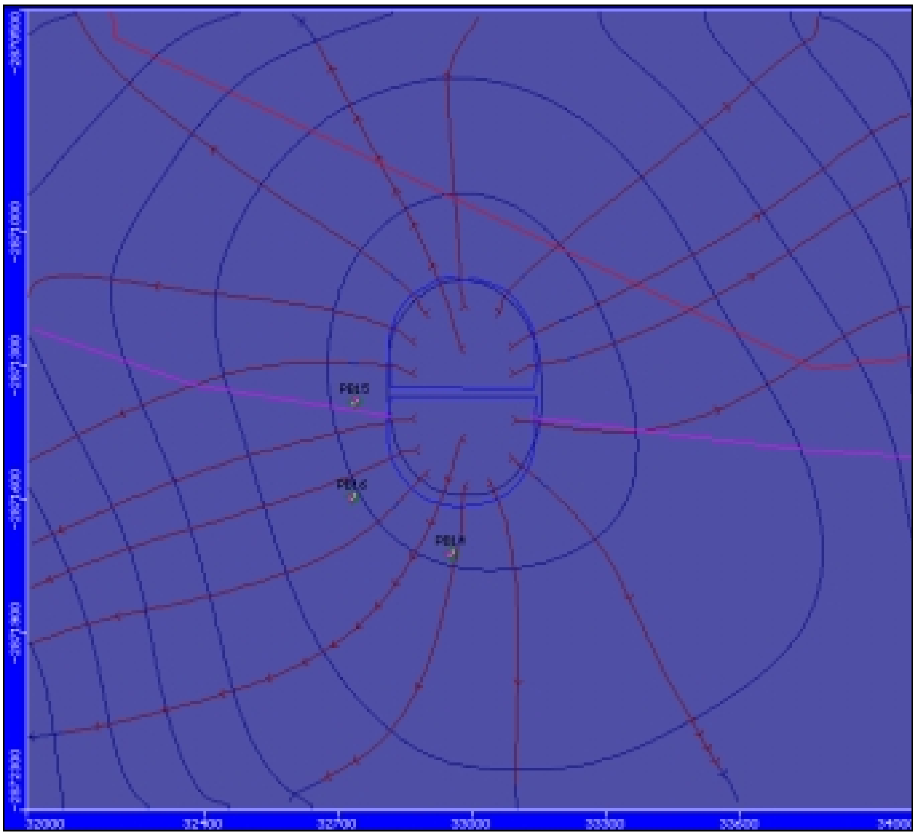

Figure 55. Path lines indicating groundwater flow directions away from the Raw Water Dam.

Figure 56. Possible location and orientation of a seepage interception trench on the western and south-western perimeter of the Raw Water Dam.

Estimated Installation Costs

It is proposed that a seepage interception trench with a design similar to the trench described in Section 10.2.7 be installed at the Raw Water Dam. Water that seeps into the trench will need to be collected in a sump from which it can be pumped back to the Raw Water Dam. The estimated costs associated with the installation of a 6 and 8 m deep trench, each with a total length of 450 m, are listed in Table 29.

Table 29. Estimated costs of installation of a seepage interception trench at the Raw Water Dam.

Length of trench (km)	Depth of trench (m)	Estimated cost (R)
0.45	6	2,049,019
0.45	8	2,430,064

Preliminary Cost-Benefit Analysis

The installation of the seepage interception trench will lead to water cost savings. To evaluate these savings against the initial costs of installation it will again be assumed that the interception trench is 60% efficient so that 60% of the seepage water that reaches the trench is intercepted. The cost-benefit analysis for an interest rate of 7% is performed in Table 30.

Table 30. Estimated volumes of seepage that will be intercepted by the trench at the Raw Water Dam and the associated cost benefits in terms of water recovery.

Trench design	Year	Estimated daily volume intercepted (m^3/day)	Cumulative volume intercepted (m^3)	Estimated make-up water costs (R/m^3)	Daily water cost savings (R/day)	Cumulative water cost savings (R)	Estimated installation costs (R)	Net present value of trench (R)
0.45 km long, 6 m deep	end 2006	8.7		1.15	10.01		**2,049,019**	-1,414,975
	end 2011	8.7	15,886	2.30	20.02	27,404		
	end 2016	8.7	31,773	3.23	28.08	71,296		
	end 2021	8.7	47,659	4.52	39.38	132,858		
	end 2026	8.7	63,545	6.35	55.24	219,202		
	end 2031	8.7	79,431	8.90	77.48	340,303		
	end 2036	8.7	95,318	12.48	108.66	**639,423**		
0.45 km long, 8 m deep	end 2006	13.1		1.15	15.02		**2,430,064**	-1,478,997
	end 2011	13.1	23,829	2.30	30.03	41,106		
	end 2016	13.1	47,659	3.23	42.12	106,945		
	end 2021	13.1	71,488	4.52	59.08	199,287		
	end 2026	13.1	95,318	6.35	82.86	328,803		
	end 2031	13.1	119,147	8.90	116.21	510,455		
	end 2036	13.1	142,976	12.48	162.99	**959,135**		

From the NPV's listed in Table 30 it can be seen that the volumes of water intercepted by both the shallow and deep trench are too small to justify the expenditures associated with the installation of the trench. It is therefore not recommended that such an expensive trench be installed.

Alternatively, seepage interception systems could be installed near the positions where seepage is noticed to occur at surface near the toes of the dam walls. Such a system could again consist of an unlined trench (~ 4 m deep) dug parallel to the dam wall, fitted with gabions and equipped with a sump and return pump. Care will, however, have to be taken that the stability of the dam walls is not affected when installing the trench. Consultation with engineers experienced in this kind of problem will be required. The estimated costs associated with the installation of such a trench are approximately R230 000 per 100 m length of the trench. The volumes of water intercepted by these trenches are likely to be too small to justify the installation costs purely from an economical point of view, but other possible benefits (e.g dam safety) should also be considered when evaluating the costs versus benefits.

10.4 High Level Ash Water Return Dams

10.4.1 Conceptual Model

The conceptual geohydrological model developed for the High Level Ash Water Return Dams is similar to the model developed for the Raw Water Dam. However, the High Level Ash Water Return Dams are completely underlain by Karoo rocks. The conceptual model for these dams is based on the following assumptions:

- The shallower Karoo formations have been exposed to higher degrees of weathering and, as a result, are more permeable than the deeper Karoo formations. The shallow, weathered earth material is treated as a separate aquifer system from the deeper, less weathered material.
- Although the permeabilities of the shallow formations are higher than those of the deeper formations, the high clay content in the weathered material results in relatively low permeabilities.
- Water from the High Level Ash Water Return Dams will predominantly seep through the shallow weathered material and will be migrate in a north-easterly direction following the local groundwater gradient.

10.4.2 Model Inputs – Hydraulic Parameters

The same values for the hydraulic properties were assigned to the different zones as for the model developed for the Ash Dam and Low Level Ash Water Return Dam (refer to Section 10.2.2). As for the model of the Raw Water Dam, the horizontal hydraulic conductivity of the shallow weathered Karoo formations was varied during model calibration (refer to Sections 10.4.4 and 10.4.5).

The properties of the different geohydrological zones are summarised in Table 31 and Table 32.

Table 31. Hydraulic conductivities of the geohydrological zones.

Zone	Kx [m/d]	Ky [m/d]	Kz [m/d]
1	0.75	0.75	0.075
2	0.001	0.001	0.0001
3	5	5	5
4	0.006	0.006	0.0006
5	0.001	0.001	0.0001

Table 32. Storage properties of the geohydrological zones.

Zone	Ss [1/m]	Sy []	Eff. Por. []	Tot. Por. []
1	0.0001	0.2	0.2	0.25
2	0.001	0.1	0.1	0.4
3	0.001	0.95	0.95	0.95
4	1E-5	0.1	0.12	0.15
5	0.001	0.1	0.1	0.4

For the numerical model, a grid consisting of 91 × 91 cells was constructed. Four layers were incorporated into the model. Layers 1, 2 and 3 represent the dam walls and floors, topsoil and shallow aquifer system. Layer 4 represents the deep aquifer system. The distribution of the seven geohydrological zones used to model the High Level Ash Water Return Dams is shown in Figure 57 to Figure 60.

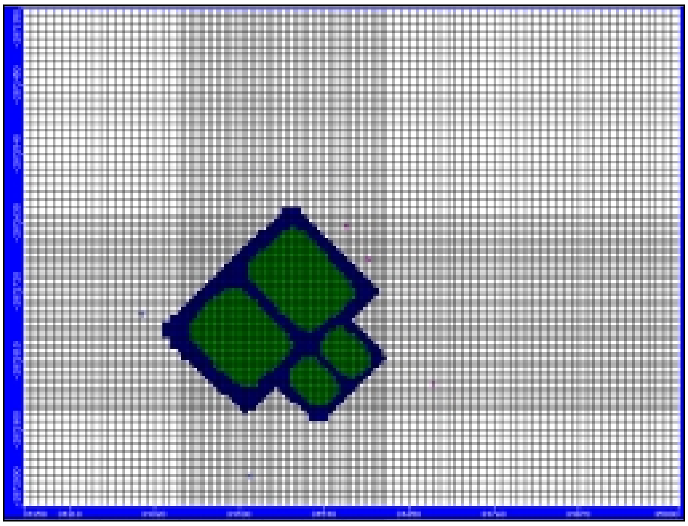

Figure 57. Geohydrological zone distribution in Layer 1.

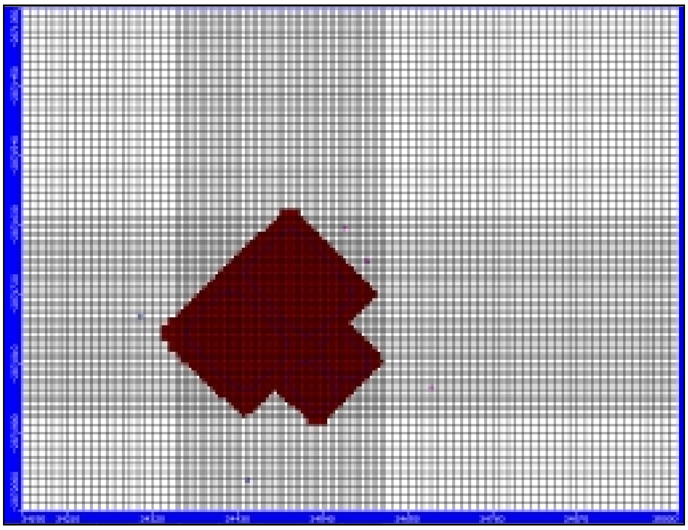

Figure 58 Geohydrological zone distribution in Layer 2.

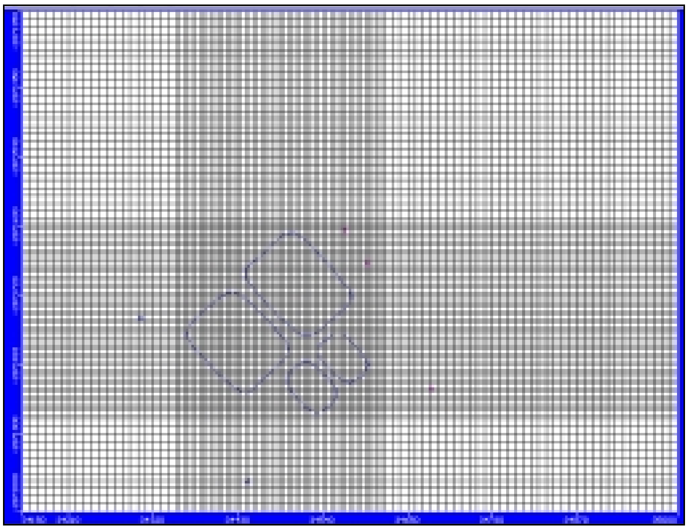

Figure 59. Geohydrological zone distribution in Layer 3.

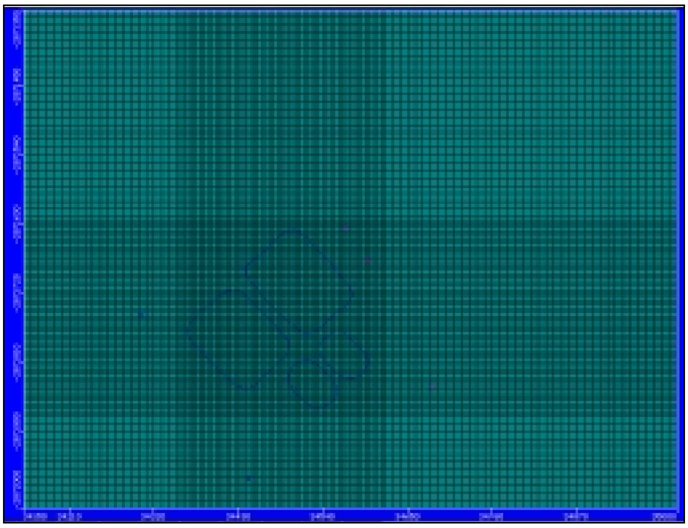

Figure 60. Geohydrological zone distribution in Layer 4.

10.4.3 Model Inputs – Groundwater Elevation

The estimated natural groundwater elevations (as prior to ashing activities) in the vicinity of the High Level Ash Water Return Dams are shown in Figure 61. The natural flow directions are indicated with yellow arrows. Groundwater flow is seen to predominantly occur to the north-east.

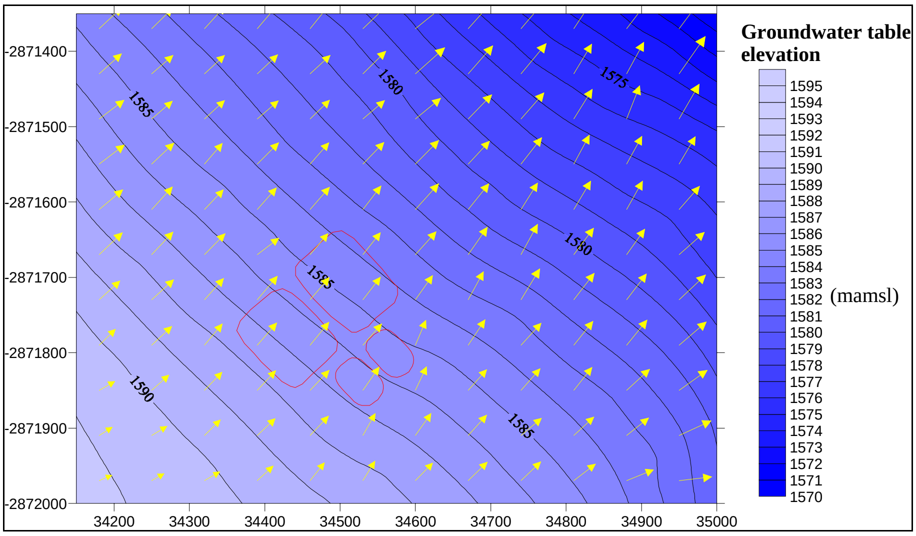

Figure 61. Estimated natural groundwater elevations in the vicinity of the High Level Ash Water Return Dams.

10.4.4 Model Calibration

For the model calibration, the numerical model developed for the High Level Ash Water Return Dams was run under steady state conditions. The modelled water levels at the five monitoring boreholes in the vicinity of these dams were then compared with the observed water levels. Adjustments to the hydraulic parameters of the shallow weathered aquifer system were made until the best correlation between the modelled and observed water levels was achieved. The best correlation was found when the shallow weathered aquifer system was assigned a horizontal hydraulic conductivity of 0.75 and a vertical conductivity of 0.075 m/day (refer to Figure 62). These conductivities are much higher than those determined from the slug tests performed on the three new boreholes near the High Level Ash Water Return Dams (PB20, PB21 and PB22). This observation suggests that the geohydrological conditions at the three boreholes may reflect only local conditions and may not be representative of the average geological/geohydrological conditions over the entire modelled area.

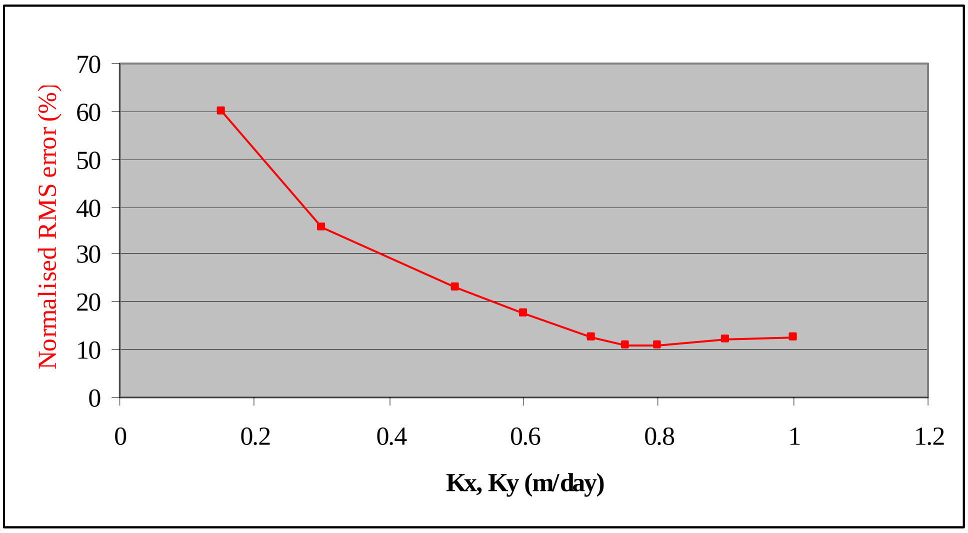

Figure 62. Normalised RMS errors between the modelled and observed water levels in the boreholes near the High Level Ash Water Return Dams as plotted against the horizontal hydraulic conductivity of the shallow weathered aquifer system.

The observed and modelled heads are shown in Figure 63. The calculated heads are seen to give fair approximations of the actual heads. In Figure 64 the modelled hydraulic heads are plotted against the observed heads and a regression coefficient of 0.927 is obtained, suggesting that the model input parameters give a good description of the actual field values.

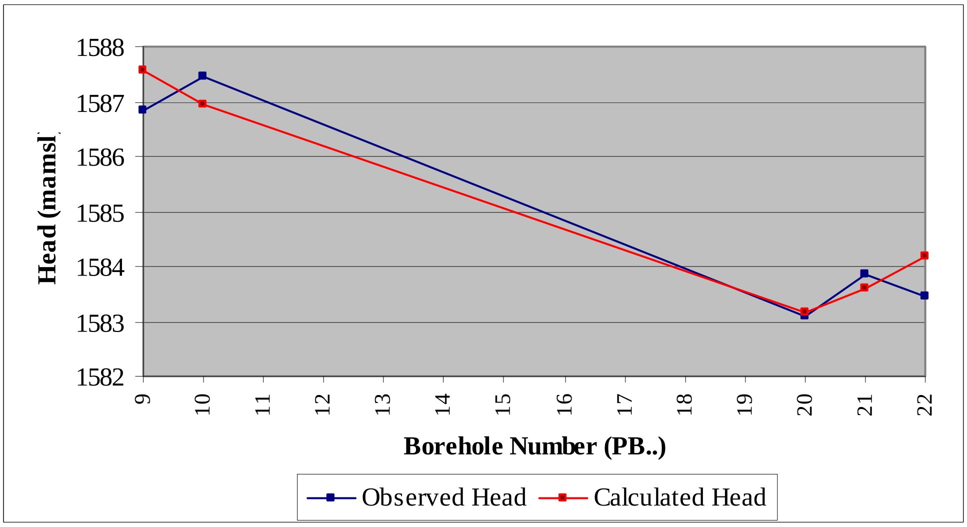

Figure 63. Observed and calculated heads at the boreholes near the High Level Ash Water Return Dams.

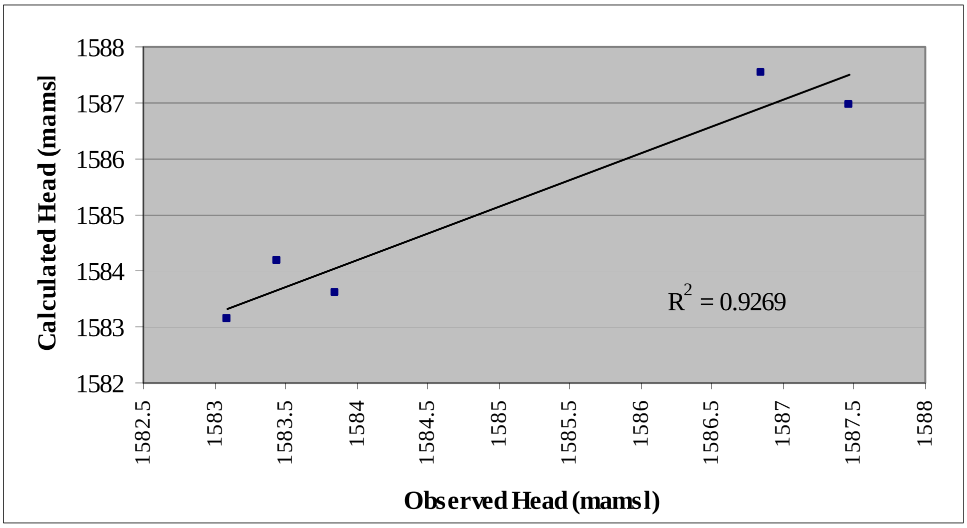

Figure 64. Calculated vs. observed heads at the boreholes near the High Level Ash Water Return Dams.

10.4.5 Model Results

10.4.5.1 Seepage volumes from the High Level Ash Water Return Dams

The estimated daily volumes of water that will seep from the High Level Ash Water Return Dams into the subsurface are listed in Table 33. The estimated daily volumes of seepage that enter the shallow weathered and deep aquifer systems are listed separately. Although the best fit between observed and modelled hydraulic heads was found for an average horizontal hydraulic conductivity of 0.75 m/day for the weathered aquifer system, the seepage that could be expected for other hydraulic conductivities are listed Table 33 and plotted in Figure 65. This is done in order to allow insight into the influence of the average hydraulic conductivity on the volumes of seepage that could occur.

From Table 33 it is seen that, for a horizontal hydraulic conductivity of 0.75 m/day and a vertical conductivity of 0.075 m/day for the shallow aquifer system, an estimated 26.57 m^3 of water daily seep from the High Level Ash Water Return Dams into the subsurface. Approximately 25.32 m^3 seep into the shallow weathered aquifer system while approximately 1.25 m^3 seep into the deeper aquifer system. These volumes are relatively small when compared with the estimated average volume of daily evaporation losses from the High Level Ash Water Return Dams (~64 m^3).

Table 33. Estimated seepage volumes from the High Level Ash Water Return Dams

Shallow aquifer system		**Seepage from High Level Ash Water Return Dams (m^3/day)**		
Horizontal hydraulic conductivity (m/day)	**Vertical hydraulic conductivity (m/day)**	**Into Shallow Aquifer**	**Into Deep Aquifer**	**Total**
0.15	0.015	12.37	2.25	14.62
0.30	0.03	18.23	1.86	20.09
0.50	0.05	22.34	1.48	23.82
0.60	0.06	23.76	1.35	25.11
0.70	0.07	24.88	1.28	26.16
0.75	**0.075**	**25.32**	**1.25**	**26.57**
0.80	0.08	25.70	1.23	26.93
0.90	0.09	26.30	1.15	27.45
1.00	0.1	26.77	1.06	27.83

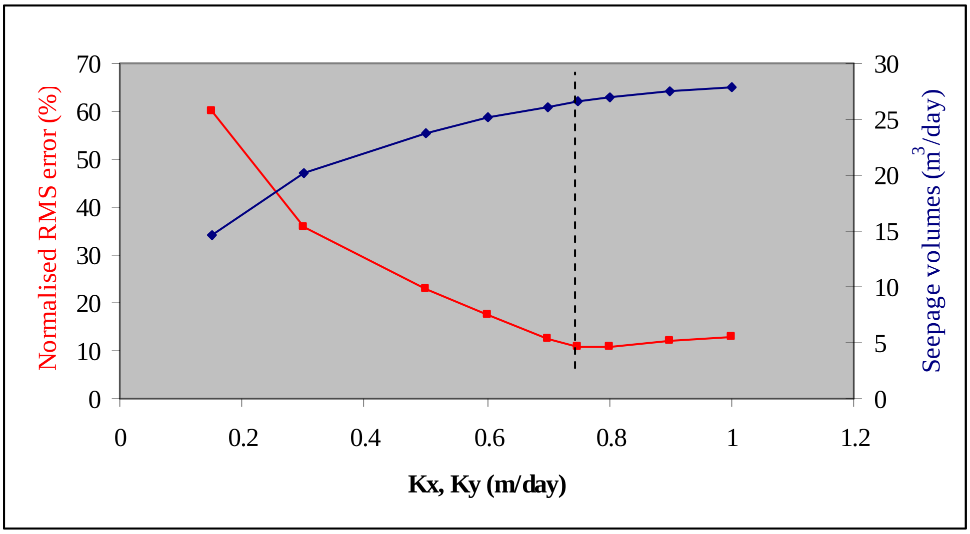

Figure 65. Estimated seepage volumes from the High Level Ash Water Return Dams for different horizontal hydraulic conductivities of the shallow weathered aquifer system.

The estimated seepage volumes listed in Table 33 were obtained by making the assumption that the floors of the High Level Ash Water Return Dams were properly prepared to reduce their permeabilities prior to the dams receiving water. However, no information on the permeabilities of the dam floors is available and it is therefore possible that the floors have higher permeabilities than those used in the numerical model. Higher dam floor permeabilities will lead to larger water losses through seepage. To illustrate this, the numerical model was rerun by assigning the dam floors hydraulic conductivities equal to those of the shallow aquifer system. Model calibration was again done by comparing the modelled and observed water levels in the five boreholes near the High Level Ash Water Return Dams. It was found that the best fit between the modelled and observed water level data was obtained when the horizontal hydraulic conductivities were 0.30 m/day. In this case the modelled volume of water that seeps from the High Level Ash Water Return Dams was estimated to be 138.63 m^3/day. This estimate is more than five times higher than the estimated seepage volume of 26.57 m^3/day listed in Table 33. This observation shows that the volumes of seepage that can be expected are sensitive to the permeability of the dam floors. The accuracy of the numerical model is therefore also limited by the lack of data on the hydraulic properties of the dam floors.

10.4.5.2 Contaminant migration in the shallow aquifer system

The modelled sulphate concentrations as observed in Layer 2, representing the shallow aquifer, are shown in Figure 66 to Figure 70 as coloured contour plots for the following times: end 2011, end 2016, end 2021, end 2026 and end 2036.

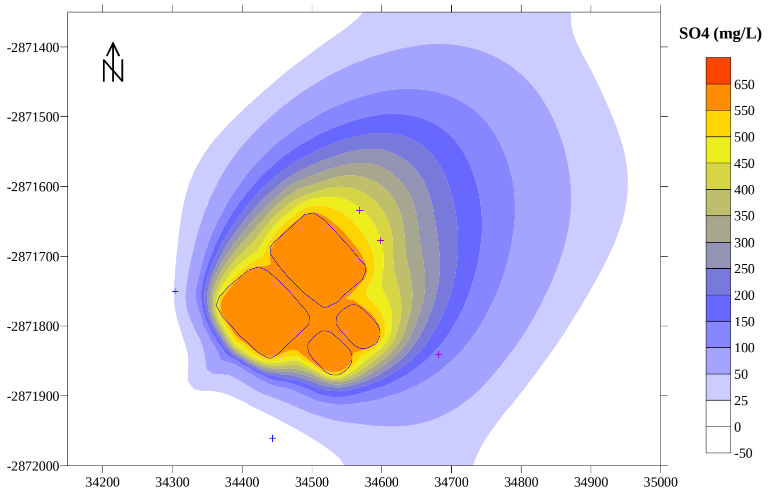

Figure 66. Modelled SO_4 concentrations in the shallow aquifer – end 2011.

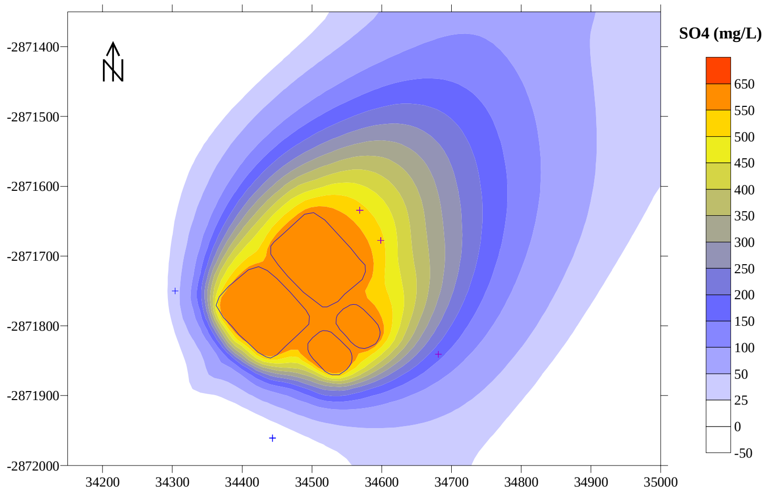

Figure 67. Modelled SO_4 concentrations in the shallow aquifer – end 2016.

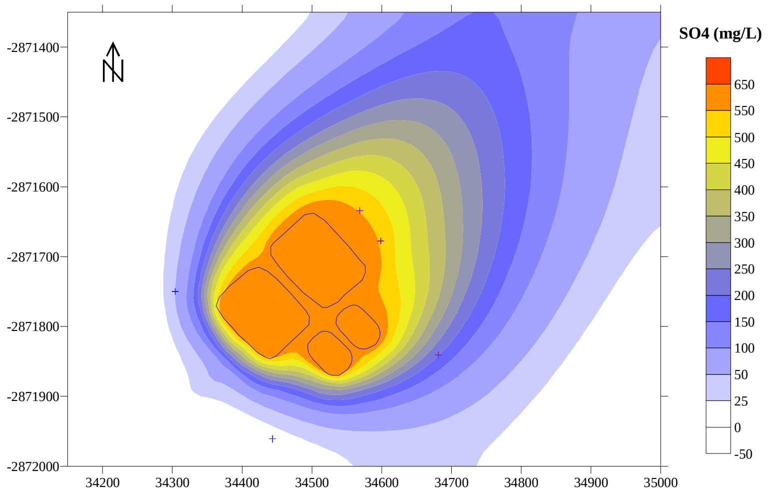

Figure 68. Modelled SO_4 concentrations in the shallow aquifer – end 2021.

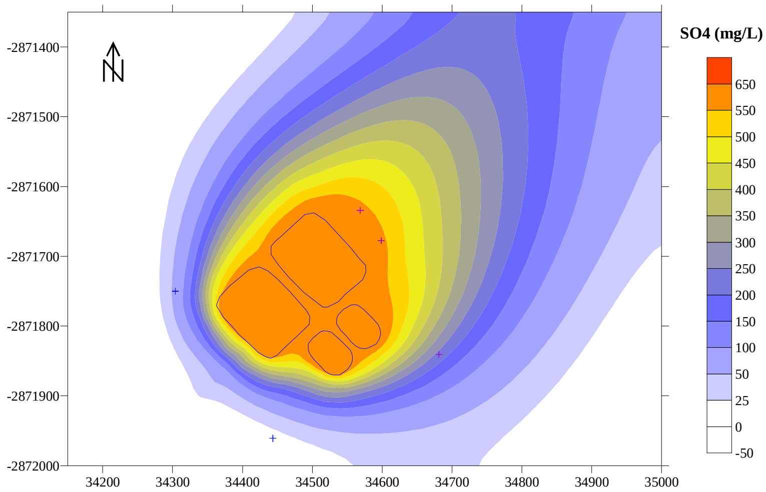

Figure 69. Modelled SO_4 concentrations in the shallow aquifer – end 2026.

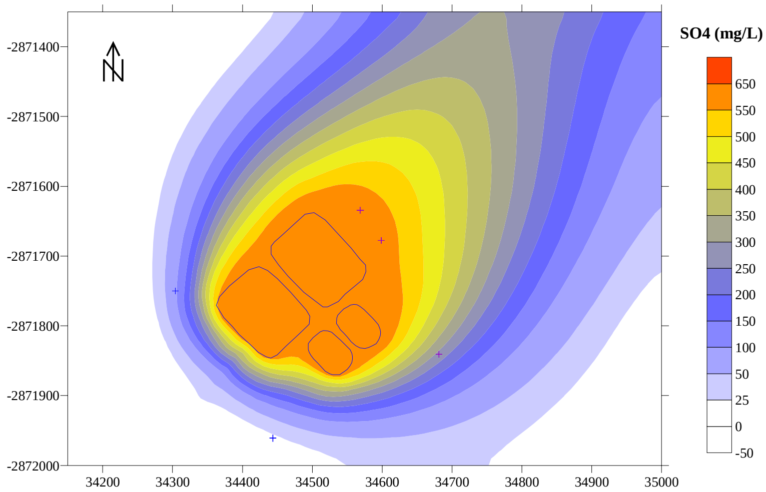

Figure 70. Modelled SO_4 concentrations in the shallow aquifer – end 2036.

From the coloured contour plots in Figure 66 to Figure 70 the following observations may be made:

- As expected, contaminant migration is seen to predominantly take place to the north-east, following the local topographic and groundwater gradients.
- The rate of contaminant migration is seen to be relatively slow. Even by the end of 2036 the sulphate concentrations at distances greater than 300 m from the High Level Ash Water Return Dams are still expected to be less than 400 mg/L.
- Limited contaminant migration is also seen to occur to the south-east, south-west and north-west. This migration is due to both the local hydraulic gradients formed by the raised water levels in the dams, and the effects of contaminant dispersion.

10.4.5.3 Contaminant migration in the deep aquifer system

The modelled sulphate concentrations as observed in Layer 4, representing the deep aquifer, are shown in Figure 71 to Figure 75.

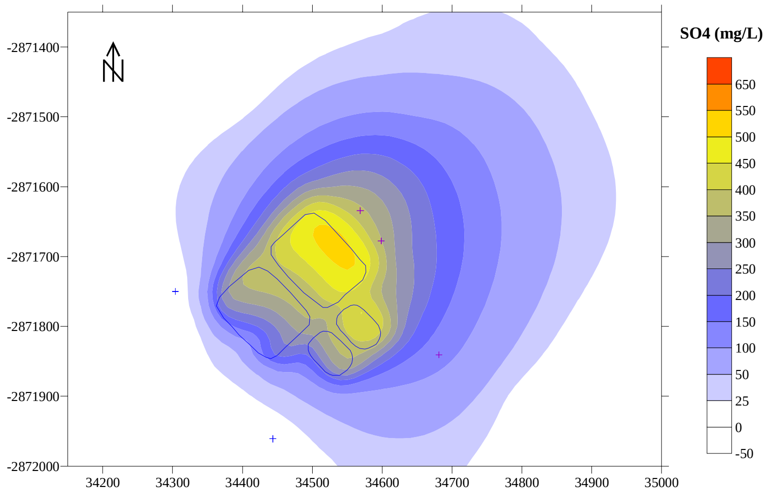

Figure 71. Modelled SO_4 concentrations in the deep aquifer – end 2011.

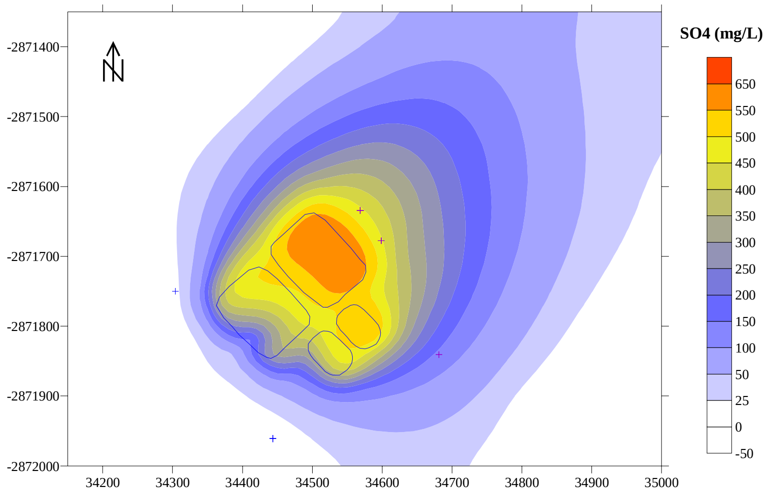

Figure 72. Modelled SO_4 concentrations in the deep aquifer – end 2016.

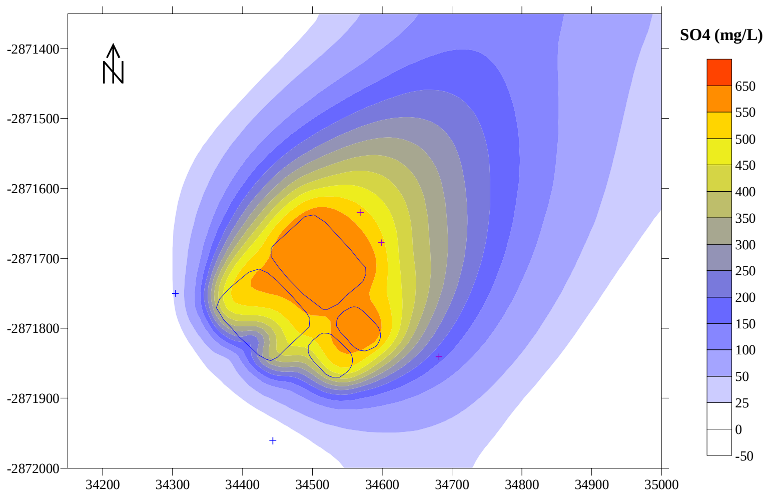

Figure 73. Modelled SO_4 concentrations in the deep aquifer – end 2021.

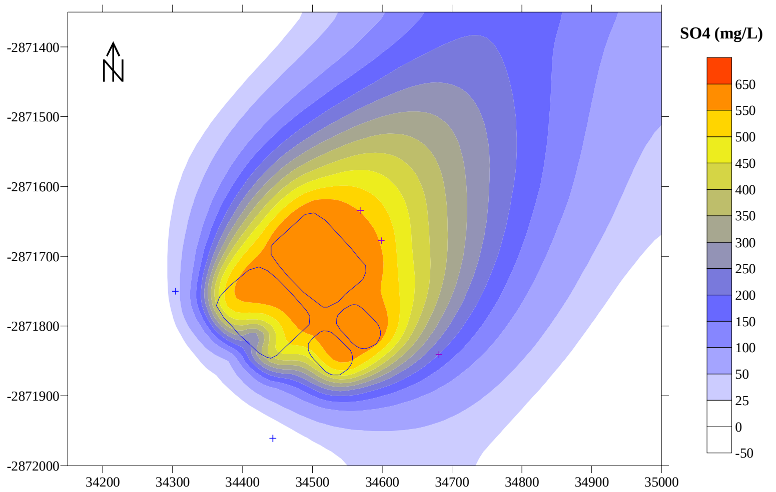

Figure 74. Modelled SO_4 concentrations in the deep aquifer – end 2026.

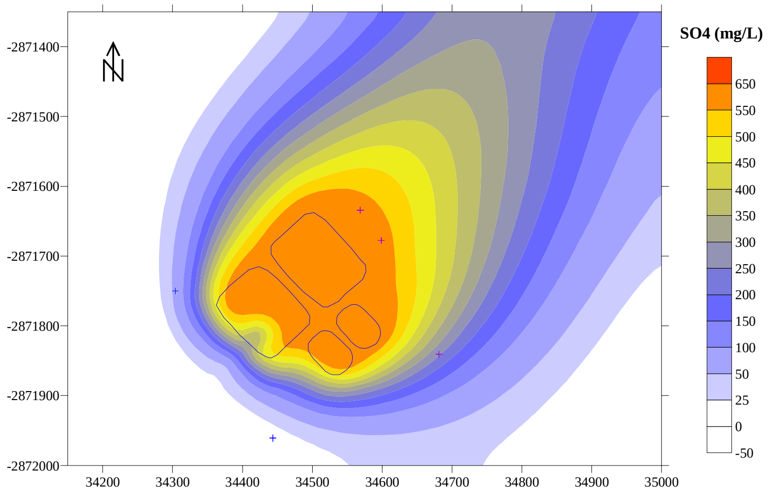

Figure 75. Modelled SO_4 concentrations in the deep aquifer – end 2036.

From the coloured contour plots in Figure 71 to Figure 75 the following observations may be made:

- Similar contaminant migration patterns are observed as through the weathered aquifer system, although the contaminant plume spreads more slowly through the deeper formations.
- The contaminant concentrations in the immediate vicinity of the dams (particularly at the northernmost dam) are seen to increase over time as increasing volumes of seepage enter the deep aquifer system.
- Based on the sulphate concentrations, by the end of 2036 groundwater from the deep aquifer system will still be of a good quality (sulphate concentration < 400 mg/L) at position greater than 300 m away from the dam.

10.4.6 Risk Assessment

The only pathway available for contaminant migration away from the High Level Ash Water Return Dams is the groundwater pathway. From the contour plots of the sulphate concentrations observed in the shallow and deep aquifer systems, (refer to Sections 10.4.5.1 and 10.4.5.3) it can be seen that contaminant migration is expected to occur at a slow rate. By 2036 the sulphate contaminant plume will still have values of less than 400 mg/L (ideal water quality) at position located further than 300 m from these dams. The absence of groundwater users down-gradient from the High Level Ash Water Return Dams also implies that there are no receptors for the contaminants to impact on. The health risks associated with contaminant migration away from these dams can therefore be considered negligible.

10.4.7 Conceptual design of seepage interception systems

Groundwater migration and contaminant transport away from the High Level Ash Water Return Dams are seen to predominantly take place towards to north-east. The proposed position of a seepage interception trench is shown in Figure 76. The proposed trench has a total length of approximately 330 m with a design similar to that described in Section 10.2.7.1.

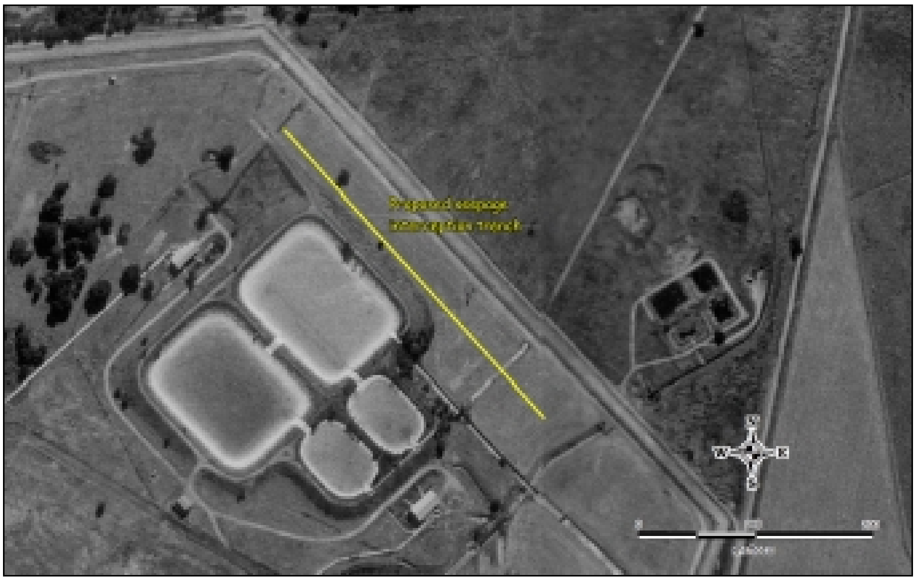

Figure 76. Position of proposed interception trench at the High Level Ash Water Return Dams.

Estimated Installation Costs

The estimated costs of installing a 330 m long seepage interception trench equipped with a sump and return pump are listed in Table 34. The costs are again estimated for two trenches with depths of 6 and 8 m.

Table 34. Estimated installation costs of a seepage interception trench near the High Level Ash Water Return Dams.

Length of trench (km)	Depth of trench (m)	Estimated cost (R)
0.33	6	1,552,614
0.33	8	1,832,047

Preliminary Cost-Benefit Analysis

As before, the benefits of installing an interception trench are compared with the installation costs by means of a preliminary cost-benefit analysis (see Table 35). Only the benefits in terms of water cost savings are taken into account. An annual interest (discount) rate of 7% is assumed to calculate the Net Present Values of the two different trench designs. It is again assumed that the trench is 60% effective in intercepting seepage.

Table 35. Estimated volumes of seepage that will be intercepted by the trench at the High Level Ash Water Return Dams and the associated cost benefits in terms of water recovery.

Trench design	Year	Estimated daily volume intercepted (m^3/day)	Cumulative volume intercepted (m^3)	Estimated make-up water costs (R/m^3)	Daily water cost savings (R/day)	Cumulative water cost savings (R)	Estimated installation costs (R)	Net present value of trench (R)
0.33 km long, 6 m deep	end 2006	5.6		1.15	6.49		**1,552,614**	-1,141,455
	end 2011	5.6	10,302	2.30	12.98	17,771		
	end 2016	5.6	20,604	3.23	18.21	46,234		
	end 2021	5.6	30,905	4.52	25.54	86,155		
	end 2026	5.6	41,207	6.35	35.82	142,146		
	end 2031	5.6	51,509	8.90	50.24	220,676		
	end 2036	5.6	61,811	12.48	70.46	**414,647**		
0.33 km long, 8 m deep	end 2006	8.5		1.15	9.74		**1,832,047**	-1,215,309
	end 2011	8.5	15,453	2.30	19.47	26,656		
	end 2016	8.5	30,905	3.23	27.31	69,350		
	end 2021	8.5	46,358	4.52	38.31	129,232		
	end 2026	8.5	61,811	6.35	53.73	213,219		
	end 2031	8.5	77,263	8.90	75.36	331,015		
	end 2036	8.5	92,716	12.48	105.70	**621,970**		

From the NPV's listed in Table 35 it is clear that the benefits in terms of water cost savings are minimal and do not justify the installation of a seepage interception trench. The volumes of water that seep from the High Level Ash Water Return Dams into the shallow aquifer system are too small to result in significant cost savings. Even if the costs associated with the WDSC are taken into account, it is unlikely that the trench will be financially profitable.

It is at present not recommended that a seepage interception trench be installed at the High Level Ash Water Return Dams, for the following reasons:

- The volumes of water that seep into the subsurface appear to be limited.
- The rate of contaminant migration away from the dams is also limited.
- There are no receptors on which contaminants may impact and the health risks associated with these contaminants are negligible.
- The financial benefits associated with water recovery are outweighed by the installation costs of the interception trench.

10.5 Sewage Plant

10.5.1 Conceptual Model

The conceptual geohydrological model for the area surrounding the sewage plant is based on the following observations and assumptions:

- The sewage plant is completely underlain by rocks of the Karoo Supergroup. The shallow soils have high hydraulic conductivities of between 2.5 and 2.8 m/day (refer to Table 13).
- The soils are underlain by silts and fine to medium grained sandstones. Hydraulic tests performed on the boreholes intersecting the sandstones suggest that the sandstones have low hydraulic conductivities (~ 0.03 m/day). However, in areas where the sandstones have been exposed to higher levels of weathering or fracturing, the conductivities may be significantly enhanced.
- The sandstones are underlain by shales, carbonaceous shales and coal layers. Although these layers are expected to be dense and to have low permeabilities, fracturing may cause increases

in the hydraulic conductivities. A conductivity of 0.128 m/day was measured in borehole PB19.

- West of the sewage plant clayey silts are found. These silts are mined by Corobrik for the production of baked clay bricks. The silts extend downwards from shallow depths to depths of at least 10 m. For the conceptual model it is assumed that the silts occur in a large lens of which the contact with the sandstones, silts and shales occurs to the west of the sewage plant.
- Water from the maturation ponds at the sewage plant will predominantly seep through the shallow weathered material and will migrate in a westerly direction following the local topographic and groundwater gradients. However, the lower permeabilities of the clayey silts that occur to the west of the sewage plant will cause resistance to groundwater flow and, as a result, lead to the groundwater day lighting at positions west of the sewage plant. Groundwater emerging at surface is indeed observed on the Corobrik property.

10.5.2 Model Inputs – Hydraulic Parameters

For the purposes of developing a numerical model that is representative of the actual geohydrological conditions in the vicinity of the sewage plant six zones of different hydraulic properties were identified. These zones and their hydraulic properties are listed in Table 36 and Table 37 and briefly discussed below.

Table 36. Hydraulic conductivities of the geohydrological zones.

Zone	Kx [m/d]	Ky [m/d]	Kz [m/d]
1	0.7	0.7	0.07
2	0.01	0.01	0.001
3	5	5	5
4	0.1	0.1	0.01
5	0.05	0.05	0.005
6	0.5	0.5	0.05

Table 37. Storage properties of the geohydrological zones.

Zone	Ss [1/m]	Sy []	Eff. Por. []	Tot. Por. []
1	0.001	0.25	0.25	0.3
2	0.001	0.1	0.1	0.4
3	0.01	0.9	0.9	0.95
4	0.0001	0.2	0.25	0.3
5	0.0001	0.1	0.1	0.3
6	0.001	0.25	0.25	0.3

Zone 1 – Weathered Karoo rocks (sandstones) and associated topsoil

During model calibration (refer to Section 10.5.4) it was found that a horizontal hydraulic conductivity of 0.70 m/day yielded the best fit between the observed and modelled water levels in the boreholes near the sewage plant. This relatively high hydraulic conductivity should be seen as an averaged conductivity obtained from the conductivities of the topsoil (2.5 – 2.8 m/day) and the sandstones (0.029 m/day). As before the vertical hydraulic conductivity was assumed to be 10% of the horizontal hydraulic conductivity.

Zone 2 – Dam walls and floors

As before, it was assumed that the hydraulic properties of the dam walls and floor are similar to that of clay.

Zone 3 – Open water bodies

To model the influence of open water bodies, high hydraulic conductivities and storativities were assigned to the cells representing these water bodies.

Zone 4 – Deeper unweathered Karoo rocks (sandstones, shales, coal)

A relatively high horizontal hydraulic conductivity of 0.1 m/day was assigned to the fresh sandstone and coal layers in order to take account of the influence of small scale fractures.

Zone 5 – Deep silty deposits west of the sewage plant

Low horizontal hydraulic conductivities (0.05 m/day) were assigned to the silty deposits that occur at depth.

Zone 6 – Shallow silty deposits west of the sewage plant and associated topsoil

The shallow clayey silts have been exposed to higher levels of weathering than the deeper material. Although the silts are expected to have low hydraulic conductivities (~0.05 m/day), the presence of weathered material and topsoil at shallow depths is likely to lead to significant increases in the average hydraulic conductivity of the shallow silts. Model calibration indicated that an average hydraulic conductivity of approximately 0.4 m/day yields the best agreement between observed and modelled groundwater levels.

For the numerical model, a grid consisting of 100 × 127 cells was constructed. Four layers were incorporated into the model. Layers 1 to 3 represent the dam systems, topsoil and shallow aquifer system. Layer 4 represents the deep aquifer system consisting of the deeper fresh Karoo formations. The distribution of the six geohydrological zones described above in each of these layers is shown in Figure 77 to Figure 80.

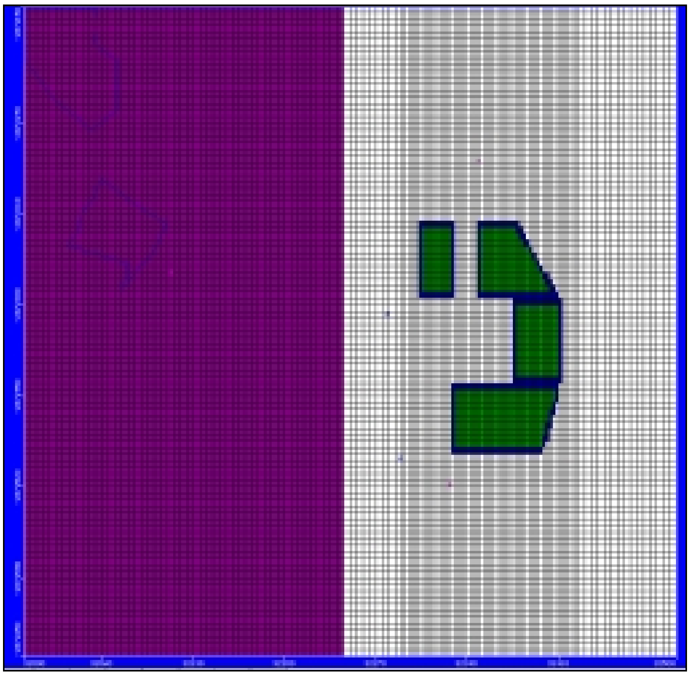

Figure 77. Geohydrological zone distribution in Layer 1.

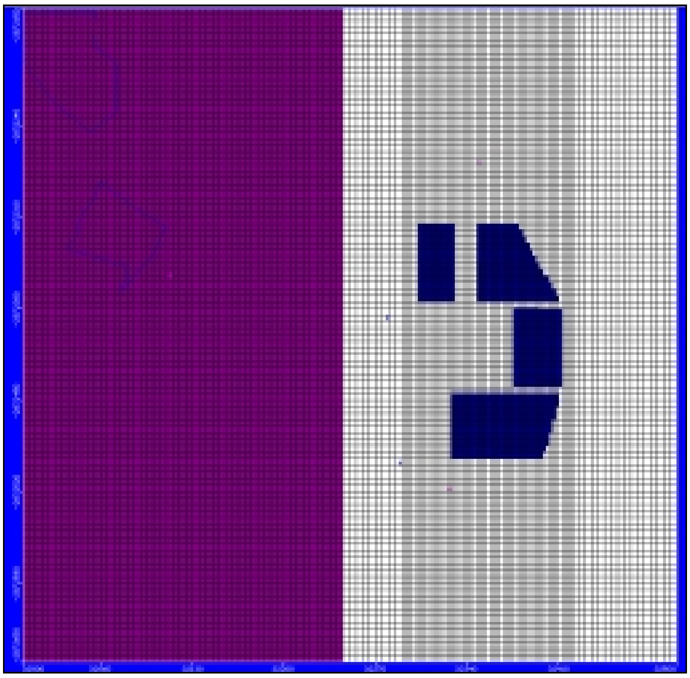

Figure 78 Geohydrological zone distribution in Layer 2.

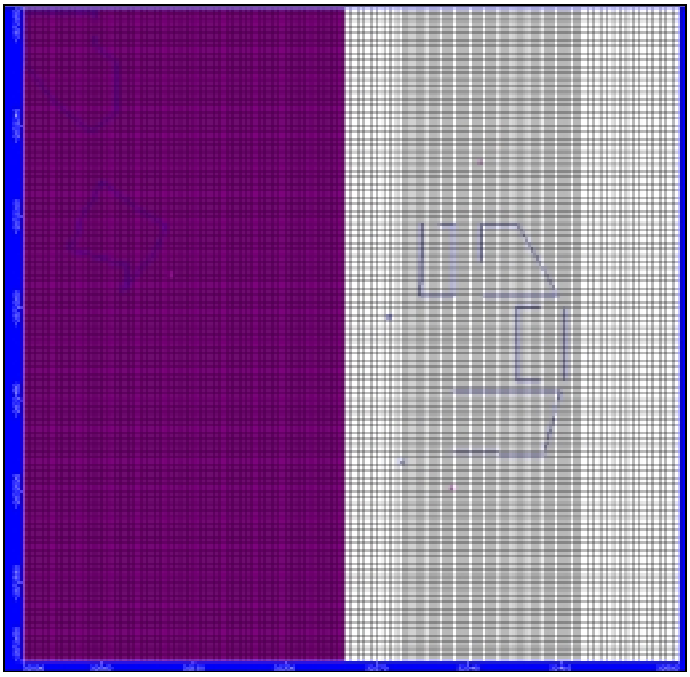

Figure 79 Geohydrological zone distribution in Layer 3.

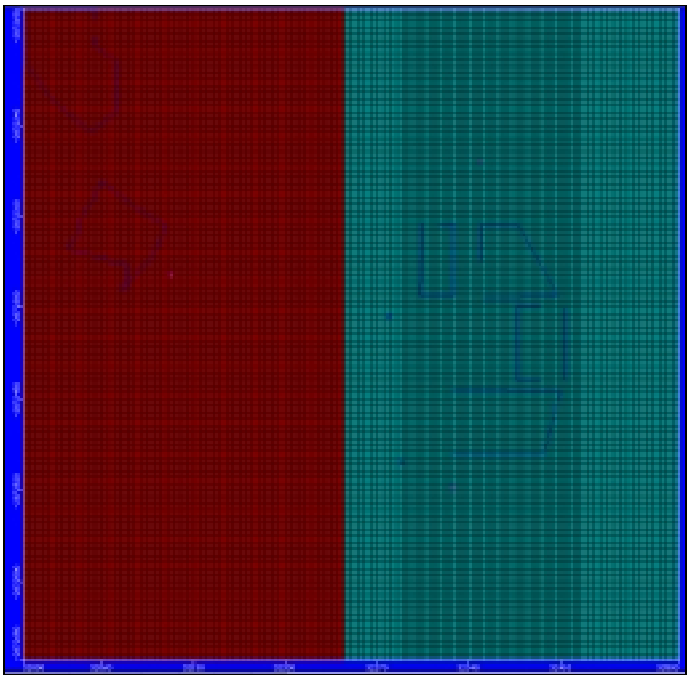

Figure 80. Geohydrological zone distribution in Layer 4.

10.5.3 Model Input – Groundwater Elevation

The estimated natural groundwater elevations in the vicinity of the Sewage Plant are shown in Figure 81. The natural flow directions are indicated with yellow arrows. Groundwater flow is seen to predominantly occur to the west.

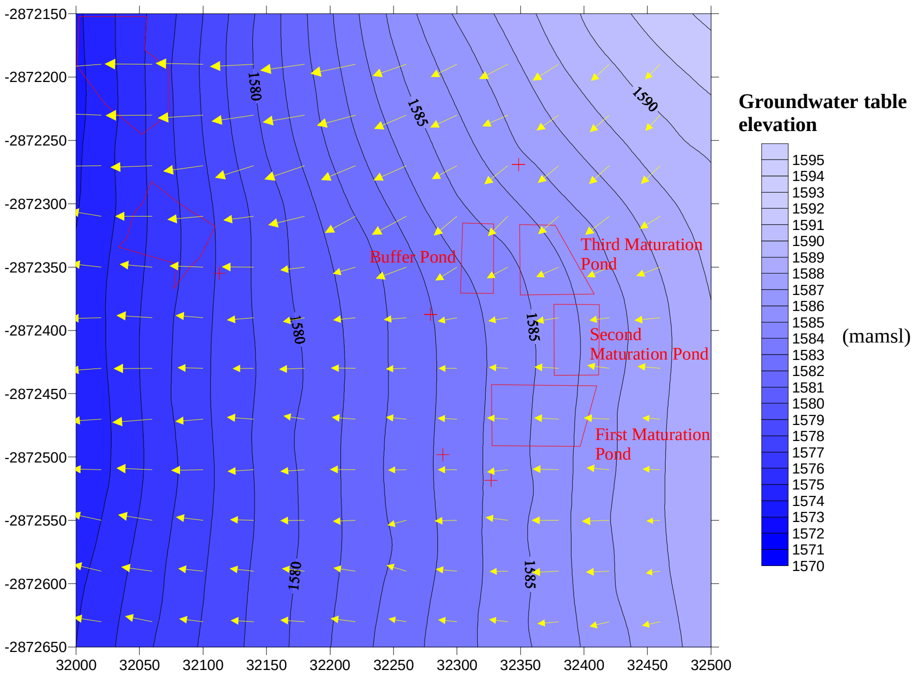

Figure 81. Estimated groundwater elevations in the vicinity of the Sewage Plant at Duvha Power Station.

10.5.4 Model Calibration

In order to assess the degree to which the model input parameters are representative of the actual field parameters, the model outputs may be compared with the actual measured values. In Figure 82 the observed and calculated heads at the borehole intersecting the shallow aquifer system around are plotted. The calculated heads are seen to give good approximations of the actual heads at all the boreholes except borehole PB13. The poor correlation between the observed and modelled groundwater elevations at PB13 is due to the fact that no information on the construction of this borehole is available. It is possible that the water level in PB13 does not represent the hydraulic head in the shallow aquifer system.

In Figure 83 the hydraulic heads modelled are plotted against the observed heads. A regression coefficient of 0.821 is calculated for the data. This poor regression is due to the large difference between the modelled and observed water levels at PB13. If the data from this borehole is excluded a regression coefficient of 0.979 is obtained, suggesting that the hydraulic properties assigned to the different geohydrological zones give a fair representation of the actual field parameters.

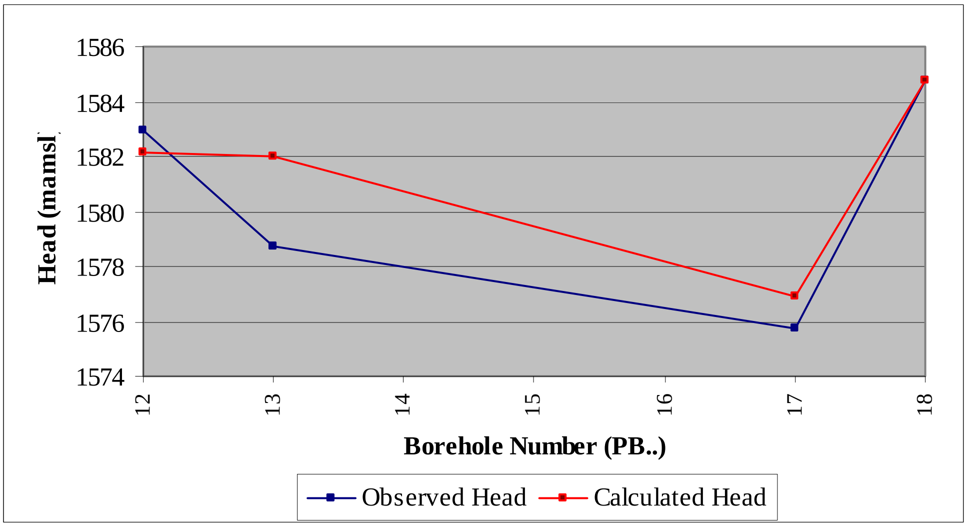

Figure 82. Observed and Calculated Heads at the various boreholes.

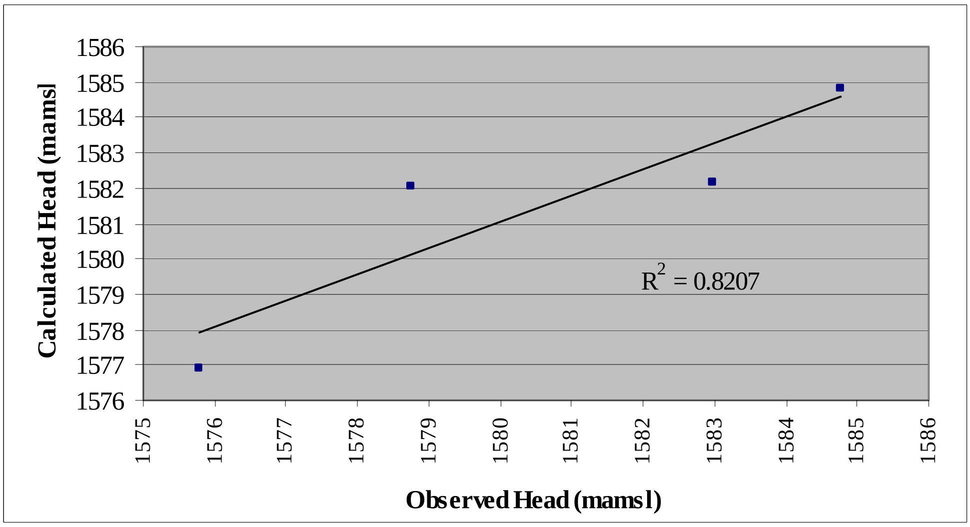

Figure 83. Model calibration: Calculated vs. Observed Heads.

10.5.5 Model Results

The results of the numerical modelling of groundwater flow and contaminant transport in the vicinity of the Ash Dam and Low Level Ash Water Return Dam are described below. Before the volumes of seepage water that can be expected are investigated, the migration of contaminants from these dams is discussed.

10.5.5.1 Contaminant migration in the shallow aquifer system

For the purposes of investigating contaminant transport away from the maturation ponds, the total dissolved solids (TDS) concentrations recorded at the surface and groundwater sites near the Sewage Plant were used. The TDS concentrations were used because this parameter displays the largest variation between the surface and groundwater sites (refer to Table 38). Although TDS is not a conservative parameter, using it as an indicator parameter for contamination may allow insight into the rate and direction of contaminant transport. For the numerical model a TDS concentration of 200 mg/L was assigned to the surface water sites at the Sewage Plant.

Table 38. Results of chemical analyses performed on water samples from sites at/near the Sewage Plant.

DUVHA POWER STATION - SEEPAGE INVESTIGATIONS - WATER QUALITY AT THE SEWAGE PLANT

No.	Description	pH	EC mS/m	TDS mg/L	Na mg/L	Ca mg/L	Mg mg/L	K mg/L	Cl mg/L	SO_4 mg/L	P.Alk mg/L	T.Alk mg/L	F mg/L	NO_2-N mg/L	NO_3-N mg/L	PO_4 mg/L	Fe mg/L	Mn mg/L	B mg/L
PB12	Monitoring borehole	7.8	20.5	62	15	12	7	4	20	2	0	84	0.31	0.02	0.24	BDL	0.003	0.075	0.033
PB13	Monitoring borehole	6.4	18.7	72	22	3	2	4	24	13	0	54	BDL	BDL	0.80	BDL	0.032	0.120	0.034
PB17	Monitoring borehole	5.7	9.6	47	13	2	2	2	18	8	0	15	BDL	BDL	0.33	BDL	0.203	0.113	0.055
PB18	Monitoring borehole	6.3	9.4	37	10	4	2	5	12	3	0	30	BDL	BDL	0.17	BDL	0.521	0.816	0.054
PB19	Monitoring borehole	6.7	15.4	59	11	13	5	5	14	6	0	56	0.11	BDL	1.07	BDL	0.003	0.138	0.055
PP16*	Buffer Pond	6.6	33.0																
PP17	1st Maturation Pond	6.9	38.5	231	33	18	8	14	28	7	0	101	0.05	2.57	0.04	BDL	0.684	0.378	0.061
PP18*	2nd Maturation Pond	6.5	32.0																
PP19	3rd Maturation Pond	7.2	29.2	182	29	13	6	8	30	27	0	50	0.07	0.28	2.15	6.48	0.011	0.001	0.037
Detection Limits:													**0.01**	**0.01**		**0.10**			

BDL - Below Detection Limits
*** - Field measurement**

The modelled TDS concentrations as observed in Layer 2, representing the shallow aquifer system, are shown in Figure 84 to Figure 88 as coloured contour plots for the following times: end 2011, end 2016, end 2021, end 2026 and end 2036. (Note that the TDS concentrations contoured in Figure 84 to Figure 88 represent the values above the background TDS concentration.)

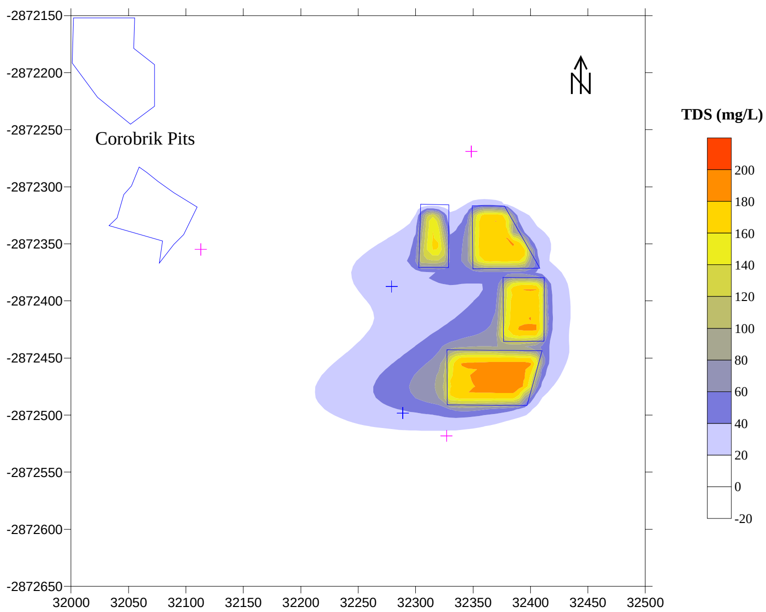

Figure 84. Modelled TDS concentrations in the shallow aquifer – end 2011.

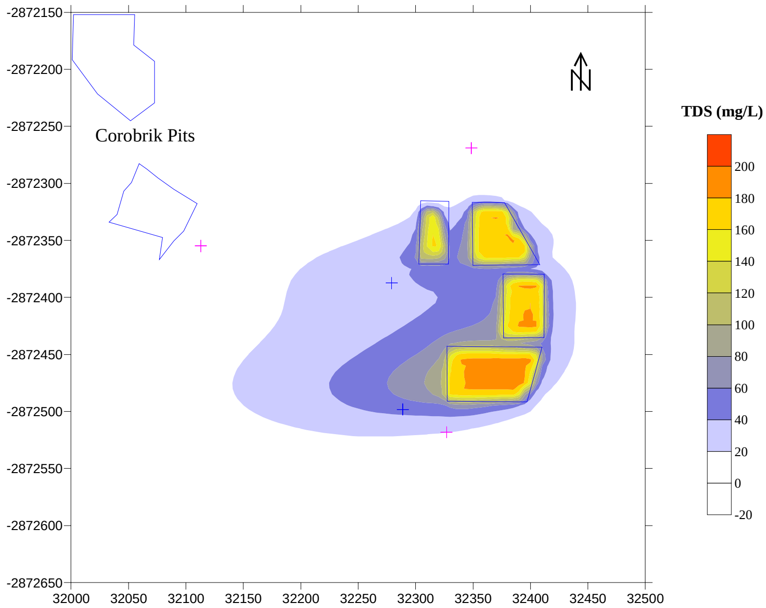

Figure 85. Modelled TDS concentrations in the shallow aquifer – end 2016.

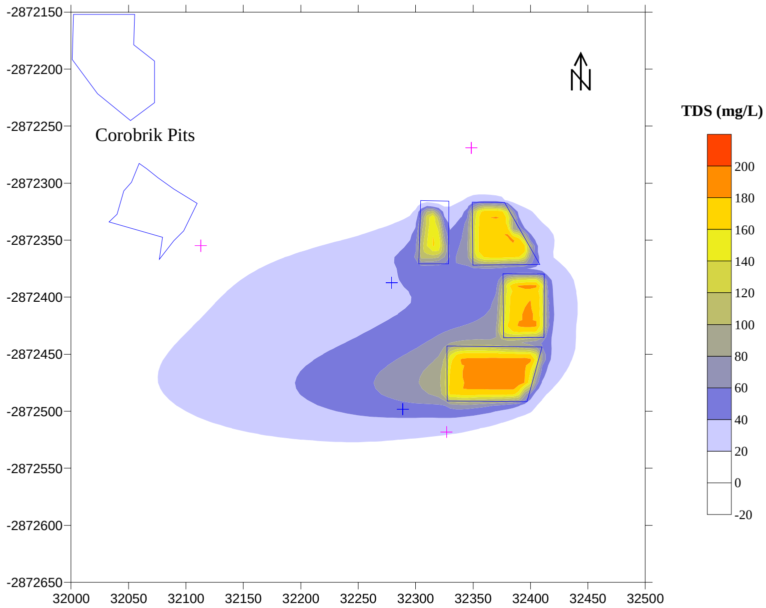

Figure 86. Modelled TDS concentrations in the shallow aquifer – end 2021.

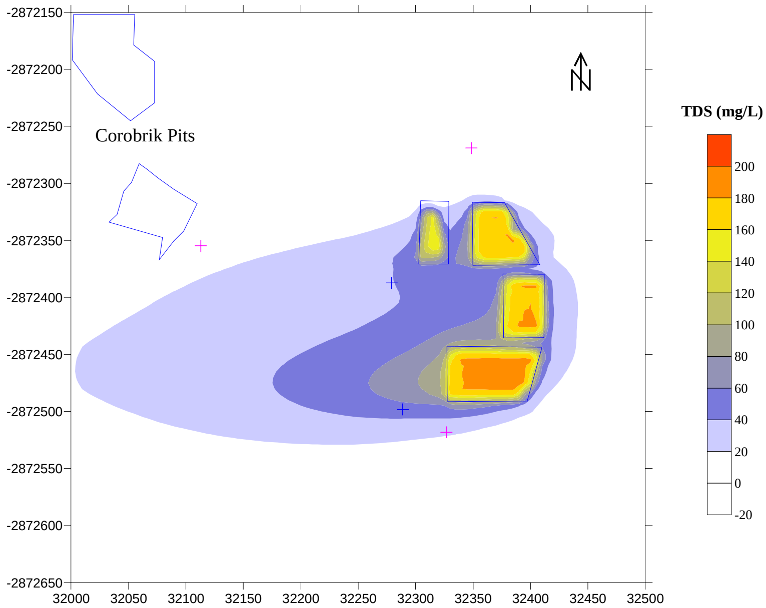

Figure 87. Modelled TDS concentrations in the shallow aquifer – end 2026.

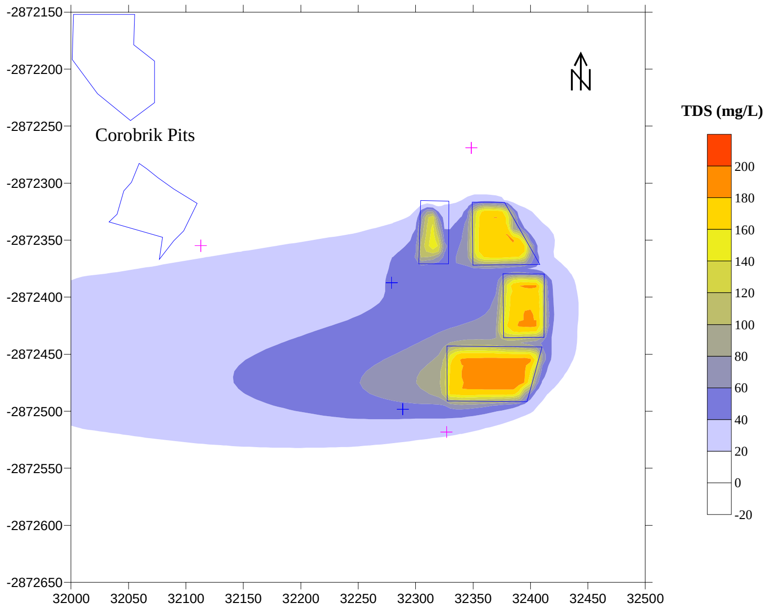

Figure 88. Modelled TDS concentrations in the shallow aquifer – end 2036.

From the coloured contour plots in Figure 84 to Figure 88 the following observations may be made:

- As expected, contaminant migration is seen to predominantly take place in a westerly direction under the local hydraulic gradient.
- The rate of contaminant migration through the shallow aquifer system is expected to be slow. As a result, the lateral extent of the contaminant plume is expected to remain limited, even after 30 years of operation. However, the contaminant plume could potentially extend as far as the opencast pits of Corobrik.

10.5.5.2 Contaminant migration in the deep aquifer system

The modelled sulphate concentrations as observed in Layer 3, representing the deep aquifer system, are shown in Figure 89 to Figure 93 as coloured contour plots for the following times: end 2011, end 2016, end 2021, end 2026 and end 2036.

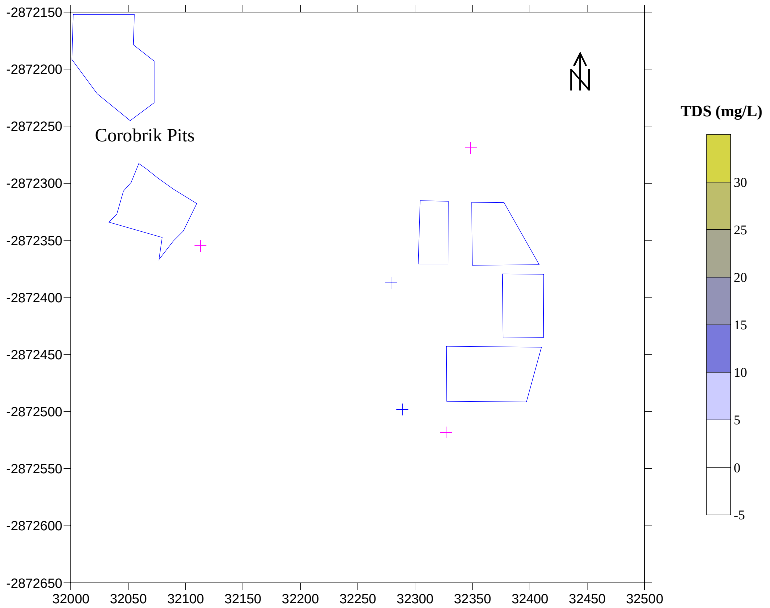

Figure 89. Modelled TDS concentrations in the deep aquifer system – end 2011.

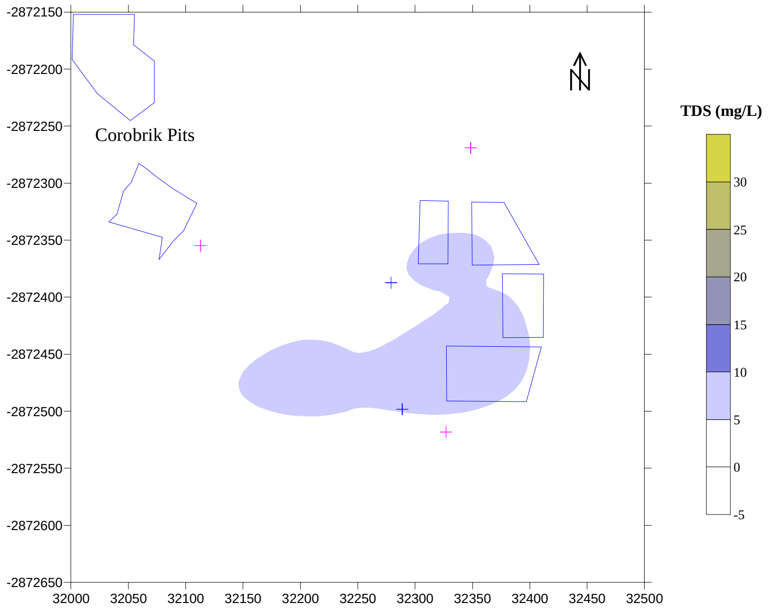

Figure 90. Modelled TDS concentrations in the deep aquifer system – end 2016.

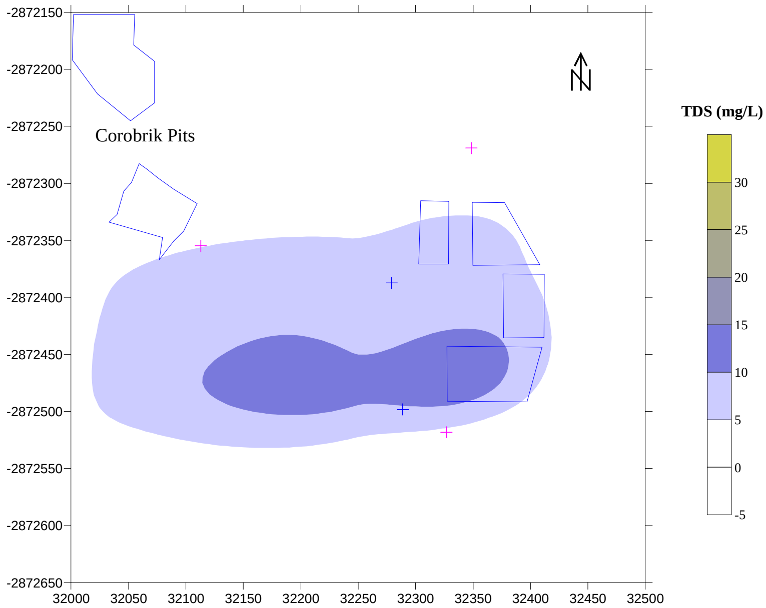

Figure 91. Modelled TDS concentrations in the deep aquifer system – end 2021.

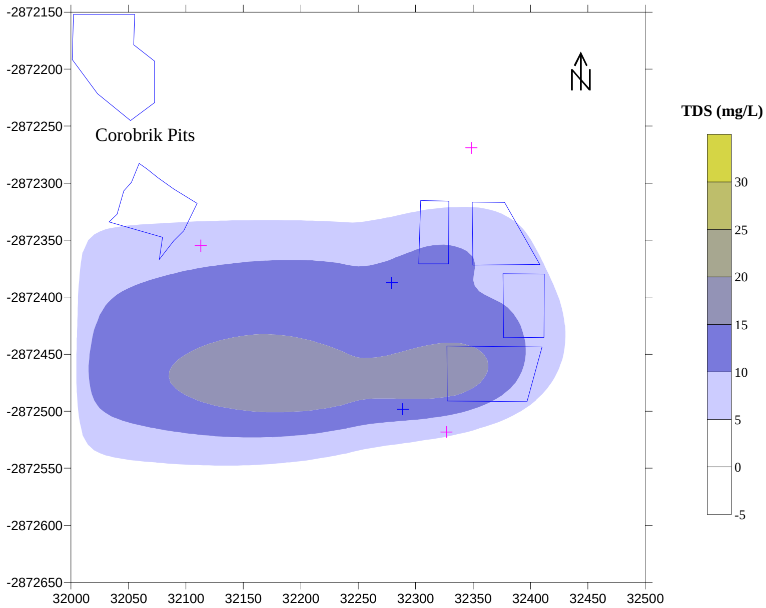

Figure 92. Modelled TDS concentrations in the deep aquifer system – end 2026.

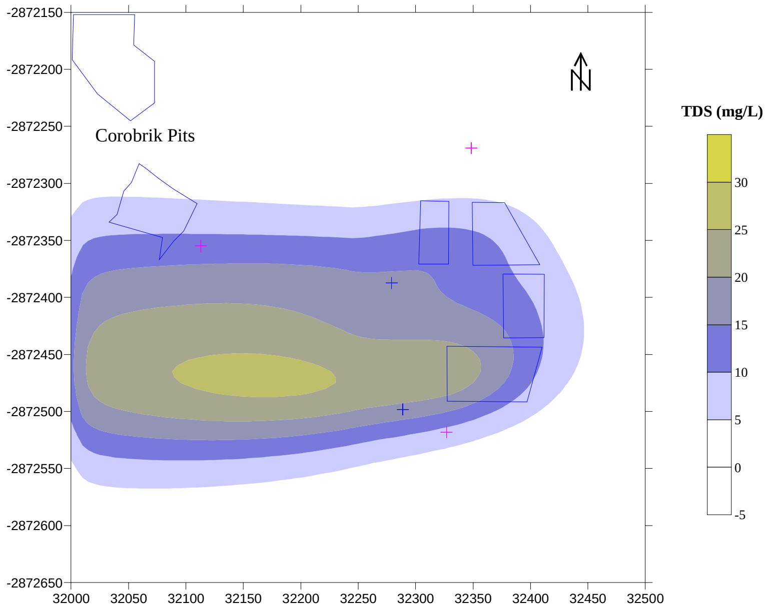

Figure 93. Modelled TDS concentrations in the deep aquifer system – end 2036.

From the coloured contour plots in Figure 89 to Figure 93 the following observations may be made:

- Groundwater migration and contaminant transport in the deep aquifer system is expected to predominantly take place towards the west in the direction of the Witbank Dam.
- Although the contaminant plume could extend as far as the opencast workings of Corobrik by 2021, the contaminant levels in the deep aquifer system are expected to remain very low.

10.5.5.3 Seepage volumes from the Sewage Plant

The estimated daily volumes of water that will seep from the Buffer Pond and Maturation Ponds at the Sewage Plant into the subsurface are listed in Table 39. The estimated daily volumes of seepage that enter the shallow weathered and deep aquifer systems are also listed in Table 39.

Table 39. Estimated daily volumes of seepage from the Buffer Pond and Maturation Ponds.

Seepage from Sewage Plant (m^3/day)		
Total	**Into Shallow Aquifer**	**Into Deep Aquifer**
3.09	2.70	0.39

From Table 39 it is seen that an estimated volume of around 3.1 m^3 daily seeps into the subsurface. When taking the surface areas of the Buffer Pond and Maturation Ponds into account, this volume of water translates into a seepage loss of approximately 4.1 m^3/ha/day.

Since both the topographic and local groundwater gradients in the vicinity of the Sewage Plant are predominantly to the west, most of the seepage is expected to occur at positions west of the Maturation Ponds.

10.5.6 Risk Assessment

From the chemical data listed in Table 38 it can be seen that, in terms of the inorganic parameter concentrations, the water contained in the Buffer Pond and Maturation Ponds is of an ideal to good quality. The risks due seepage from these ponds are therefore rather associated with impacts of water with high bacterial activity. Bacterial activity in groundwater is, however, not a conservative parameter and can therefore not be modelled with standard mass transport models.

There are two pathways available along which contaminants may be transported away from the Maturation Ponds, namely the groundwater pathway and the surface water pathway where seepage daylights at positions west of the Sewage Plant. Both the groundwater and surface water is expected to migrate in the direction of the Witbank Dam under the local topographic and hydraulic gradients.

Possible receptors for contaminant impacts are people and animals that come in contact with the contaminated water. A Corobrik quarry is located immediately west of the Sewage Plant. The opencast pits at the quarry receive large volumes of groundwater that migrate in a westerly direction. Contaminants originating at the Sewage Plant could potentially reach these pits and cause impacts on Corobrik personnel mining the pits. However, the Corobrik pits are more than 200 m away from the Sewage Plant. These pits receive large volumes of groundwater that seep into the pits from their eastern walls. Even if contaminants from the Sewage Plant should impact on the pits, the diluting effects of the clean water seeping into the pits are expected to reduce the contaminant concentrations and reduce the likelihood of health risks. It should also be noted that groundwater is not used for drinking purposes at Corobrik or at positions further to the west towards the Witbank Dam.

Since the Witbank Dam is located more than 2 km away from the Sewage Plant, it is highly unlikely that contaminant originating at the Sewage Plant will have any impacts on this surface water body.

Groundwater that daylights at positions near the western fence of the Sewage Plant could potentially be ingested by wild animals. If the bacterial activity in the groundwater is high, contaminant impacts on these animals could occur.

The above observations suggest that the risks associated contaminant impacts from the Sewage Plant may be considered minimal. Negligible health risks to humans are expected.

10.5.7 Conceptual design of seepage interception systems

Since the volumes of water that are expected to seep from the Buffer Pond and Maturation Ponds are small, a seepage interception system will have to be inexpensive to justify the recovery of water seeped from these ponds. A seepage interception trench will, however, further reduce the likelihood of contaminant impacts and may be seen as beneficial in these terms.

The groundwater table in the shallow aquifer in the vicinity of the Sewage Plant occurs at a depth of between 1.32 and 2.66 mbgl. Modelling results show that the bulk of the seepage that emanates from the Buffer Pond and Maturation Ponds will migrate at depths of less than 4 mbgl, as shown in Figure 94. At positions to the west of the 1st Maturation Pond, groundwater even daylights. The above observations imply that an effective seepage interception system will have to be no deeper than 4 metres.

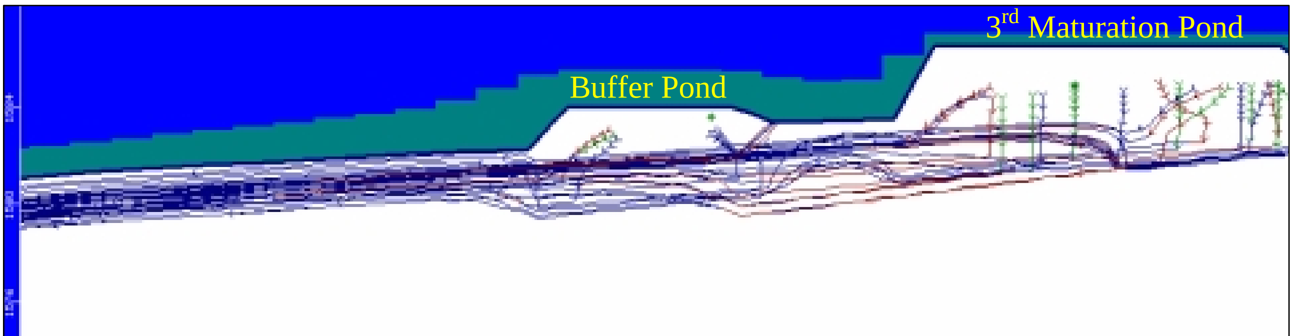

Figure 94. Flow lines as viewed along a cross-section through the Buffer Pond and 3rd Maturation Pond.

Little room is available for the installation of a seepage interception trench. The distance between the Buffer Pond and the fence with the property of Corobrik is approximately 20 m. A possible location for the installation of the trench is shown Figure 95. To minimise costs a shallow unlined interception trench, fitted with gabions and equipped with a sump and return pump, could be considered. Assuming that the trench has a depth of 4 m and a length of 200 m, the costs associated with the installation are unlikely to exceed R500 000.

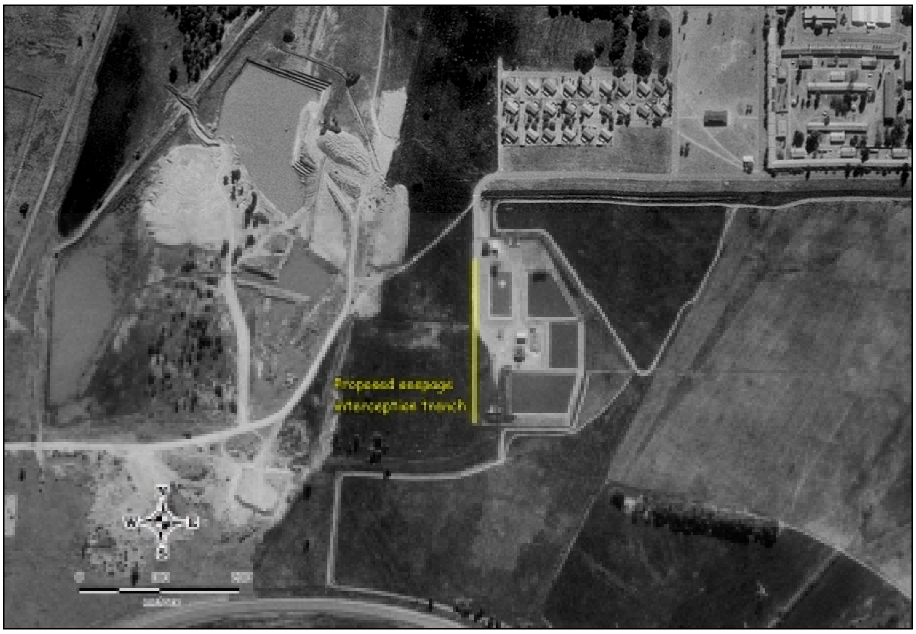

Figure 95. Proposed Seepage Interception Trench at the Sewage Plant.

Preliminary Cost-Benefit Analysis

As before, the benefits of installing an interception trench are compared with the installation costs by means of a preliminary cost-benefit analysis (see Table 40). Only the benefits in terms of water cost savings are taken into account. An annual interest (discount) rate of 7% is assumed to calculate the Net Present Values of the two different trench designs. It is again assumed that the trench is 60% effective in intercepting seepage.

Table 40. Estimated volumes of seepage that will be intercepted by the trench at the Sewage Plant and the associated cost benefits in terms of water recovery.

Trench design	Year	Estimated daily volume intercepted (m^3/day)	Cumulative volume intercepted (m^3)	Estimated make-up water costs (R/m^3)	Daily water cost savings (R/day)	Cumulative water cost savings (R)	Estimated installation costs (R)	Net present value of trench (R)
0.20 km long, 4 m deep	end 2006	1.9		1.15	2.13		**500,000**	-364,958
	end 2011	1.9	3,384	2.30	4.26	5,837		
	end 2016	1.9	6,767	3.23	5.98	15,185		
	end 2021	1.9	10,151	4.52	8.39	28,297		
	end 2026	1.9	13,534	6.35	11.77	46,687		
	end 2031	1.9	16,918	8.90	16.50	72,480		
	end 2036	1.9	20,301	12.48	23.14	**136,188**		

From the NPV's listed in Table 40 it is clear that the benefits of the seepage interception trench in terms of water recovery and water cost savings are limited. The volumes of water that seep from the Buffer Pond and Maturation Ponds into the shallow aquifer system are too small to result in significant cost savings.

10.6 Emergency Pan

10.6.1 Conceptual Model

The conceptual geohydrological model for the area surrounding the Emergency Pan is based on the following observations and assumptions:

- The Emergency Pan is completely underlain by rocks of the Karoo Supergroup. The shallow soils have high hydraulic conductivities of between 1.5 and 2.4 m/day (refer to Table 13).
- The soils are underlain by medium to coarse grained sandstones and silts forming the shallow aquifer system. Hydraulic tests performed on the shallow aquifer indicate that low hydraulic conductivities (< 0.01m/day) can be expected. However, the coarseness of the sandstones observed in the vicinity of the Emergency Pan (especially north of the pan) suggests that much higher conductivities could occur in places.
- Since the Emergency Pan is a naturally occurring pan, it is to be expected that lower hydraulic conductivities will be associated with the fine deposits (clayey and silty materials) that form the bed of the pan.
- The sandstones and silts are underlain by carbonaceous shales and coal layers. Although these layers are expected to be dense and to have low permeabilities, fracturing may cause increases in the hydraulic conductivities. A minor water strike associated with fracturing was indeed recorded within a coal layer intersected by borehole PB24. The relatively high conductivity of 0.122 m/day measured in this borehole is in all likelihood due to the presence of such preferential pathways.

10.6.2 Model Inputs – Hydraulic Parameters

For the purposes of developing a numerical model that is representative of the actual geohydrological conditions in the vicinity of the sewage plant three zones of different hydraulic properties were identified. These zones and their hydraulic properties are listed in Table 41 and Table 42 and briefly discussed below.

Table 41. Hydraulic conductivities of the geohydrological zones.

Zone	Kx [m/d]	Ky [m/d]	Kz [m/d]
1	0.3	0.3	0.03
2	0.075	0.075	0.0075
3	0.05	0.05	0.005

Table 42. Storage properties of the geohydrological zones.

Zone	Ss [1/m]	Sy []	Eff. Por. []	Tot. Por. []
1	0.0001	0.2	0.2	0.25
2	0.001	0.1	0.1	0.4
3	0.0001	0.15	0.15	0.2

Zone 1 – Weathered Karoo rocks (sandstones) and associated topsoil

During model calibration it was found that a horizontal hydraulic conductivity of 0.30 m/day yielded the best fit between the observed and modelled water levels in the boreholes near the Emergency Pan. This relatively high hydraulic conductivity should be seen as an averaged conductivity obtained from the conductivities of the topsoil (1.5 – 2.4 m/day) and the sandstones and silts (~0.006 m/day). As before the vertical hydraulic conductivity was assumed to be 10% of the horizontal hydraulic conductivity.

Zone 2 – Shallow aquifer system under the Emergency Pan

Due to the deposition of fine clayey and silty materials in the pan, the hydraulic conductivity of the material underlying the pan can be expected to be lower than the average conductivity of the weathered Karoo rocks and associated topsoil. Model calibration suggested that a value of 0.075 m/day gives a reasonable average conductivity for the silty and clayey deposits and weathered Karoo rocks underlying the pan.

Zone 3 – Deeper unweathered Karoo rocks (sandstones, shales, coal)

A relatively high horizontal hydraulic conductivity of 0.05 m/day was assigned to the fresh sandstone and coal layers in order to take account of the influence of small scale fractures.

For the numerical model, a grid consisting of 100 × 100 cells was constructed. Three layers were incorporated into the model. Layers 1 and 2 represent the Emergency Pan, topsoil and shallow aquifer system. Layer 3 represents the deep aquifer system consisting of the deeper fresh Karoo formations. The distribution of the three geohydrological zones described above in each of these layers is shown in Figure 96, Figure 97 and Figure 98.

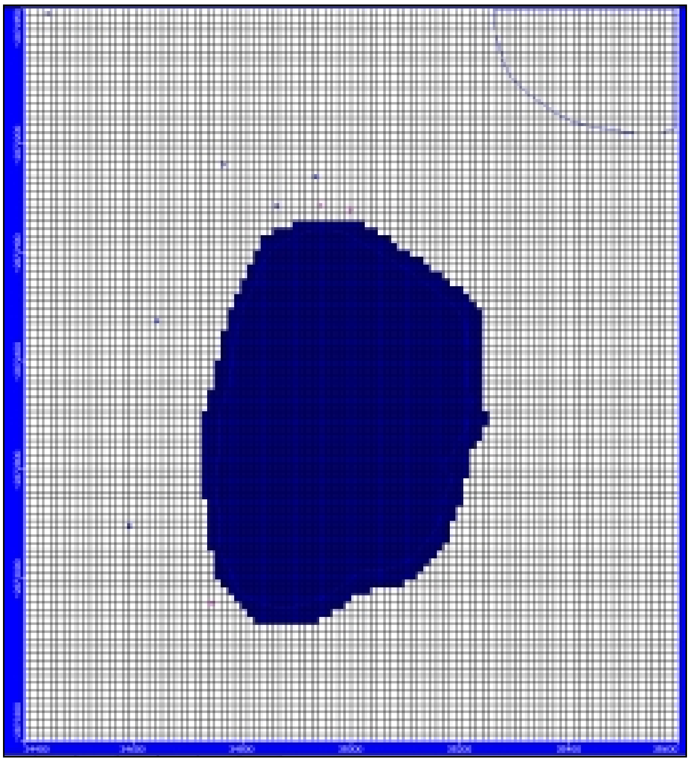

Figure 96. Geohydrological zone distribution in Layer 1.

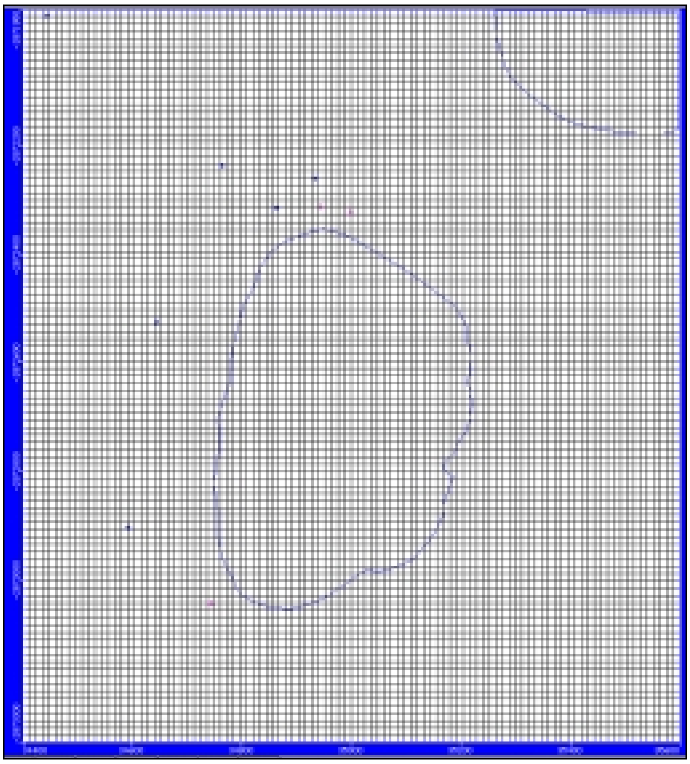

Figure 97   Geohydrological zone distribution in Layer 2.

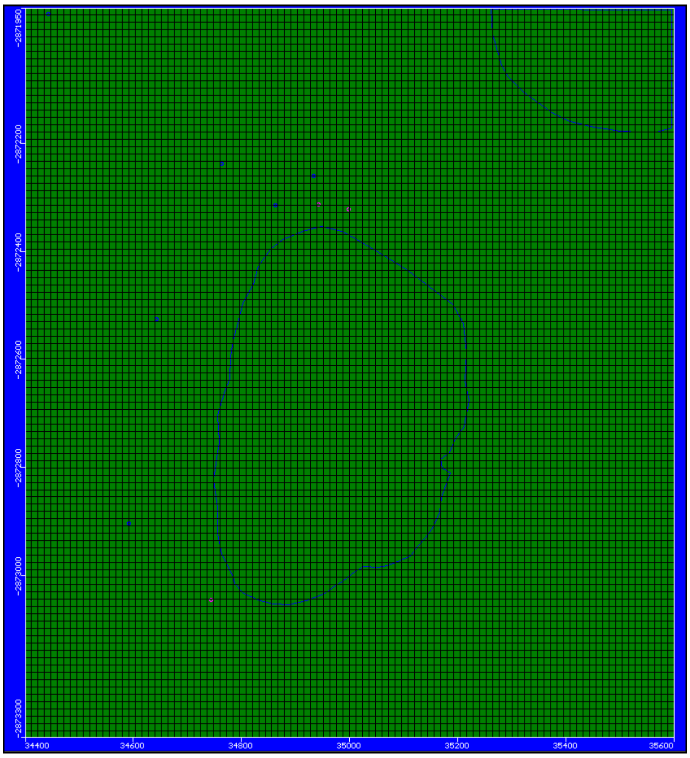

Figure 98   Geohydrological zone distribution in Layer 3.

10.6.3 Model Inputs – Groundwater Elevations

The estimated natural groundwater elevations in the vicinity of the Emergency Pan are shown in Figure 99. The natural flow directions are indicated with yellow arrows. Groundwater flow is seen to flow from all directions towards the pan. A watershed with an approximate south-east/north-west strike occurs north-east of the Emergency Pan. North-east of the watershed, groundwater flow is expected to occur in the direction of a non-perennial pan that is located within a local topographic depression.

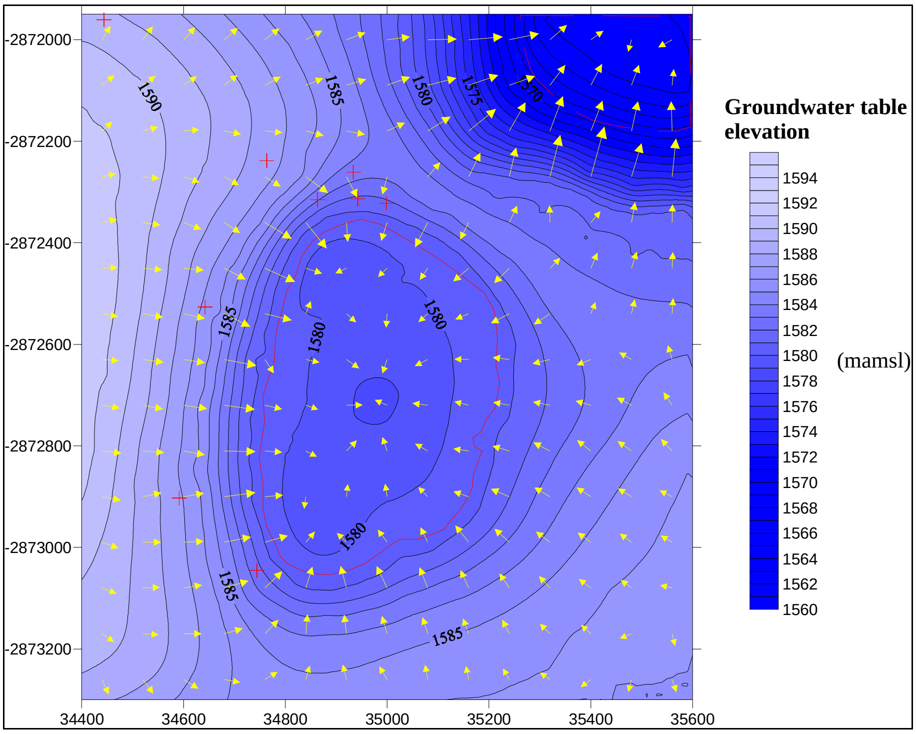

Figure 99. Estimated groundwater elevations in the vicinity of the Emergency Pan at Duvha Power Station.

10.6.4 Model Calibration

In order to assess the degree to which the model input parameters are representative of the actual field parameters, the model outputs may be compared with the actual measured values. In Figure 100 the observed and modelled heads (using the hydraulic parameters listed Table 41 and Table 42) in at the boreholes in the vicinity of the Emergency Pan are plotted. The calculated heads are seen to give fairly good approximations of the actual heads at the boreholes. In Figure 101 the hydraulic heads modelled are plotted against the observed heads. A regression coefficient of 0.840 is calculated for the data.

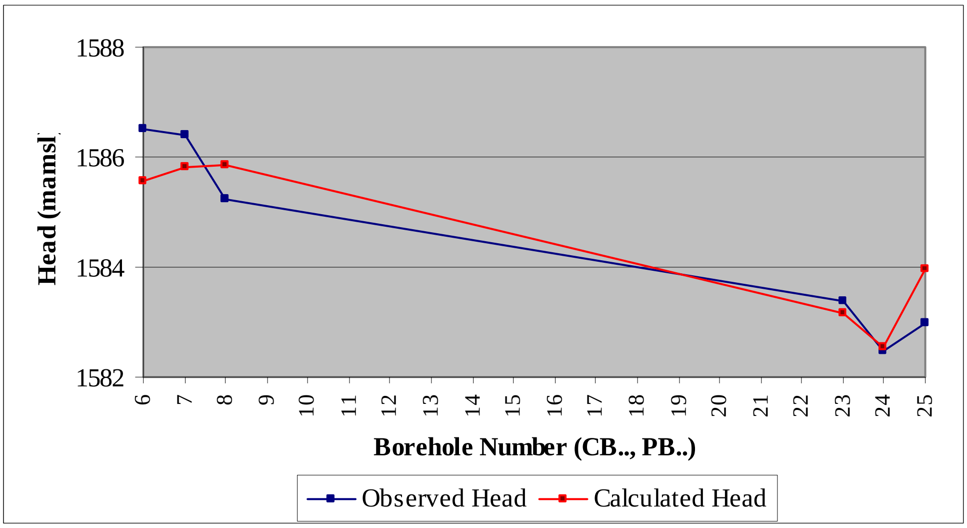

Figure 100.Observed and Calculated Heads at the various boreholes near the Emergency Pan.

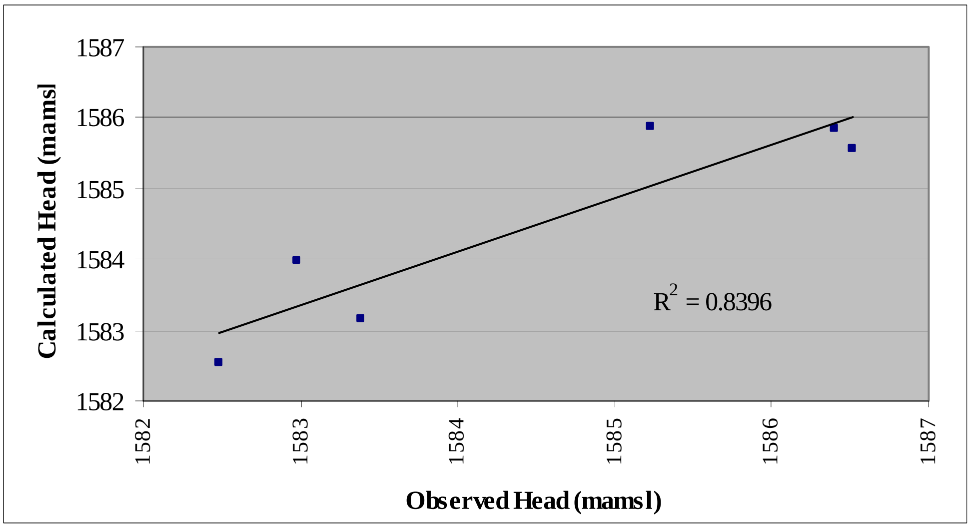

Figure 101.Model calibration: Calculated vs. Observed Head.

In Figure 102 the observed and calculated sulphate concentrations at the different borehole around the Ash dam for the current time (end 2006) are plotted. The calculated concentrations are seen to give reasonable approximations of the actual concentrations. In Figure 103 the modelled sulphate concentrations are plotted against the observed concentrations. A regression coefficient of 0.971 is obtained, indicating that the hydraulic properties assigned to the different geohydrological zones are good approximations of the actual properties.

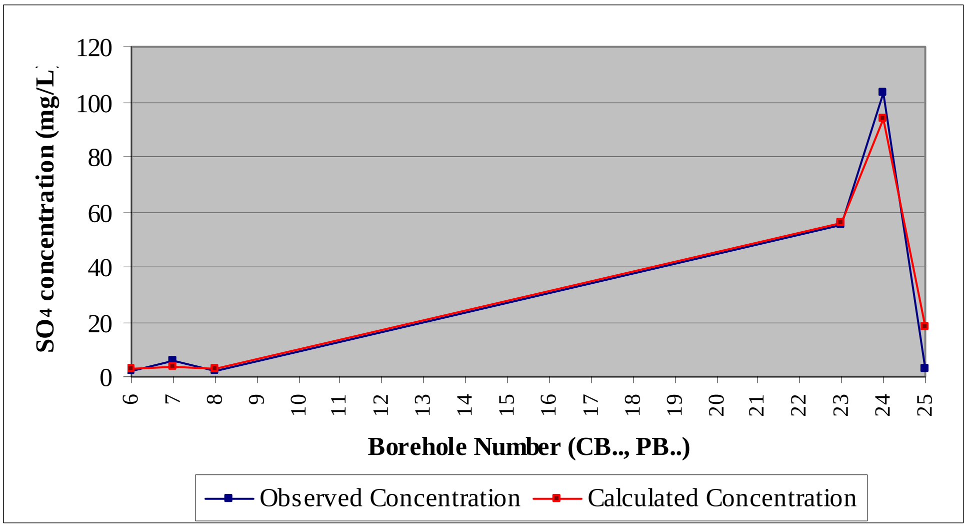

Figure 102.Observed and Calculated SO_4 concentrations at the various boreholes – end 2006.

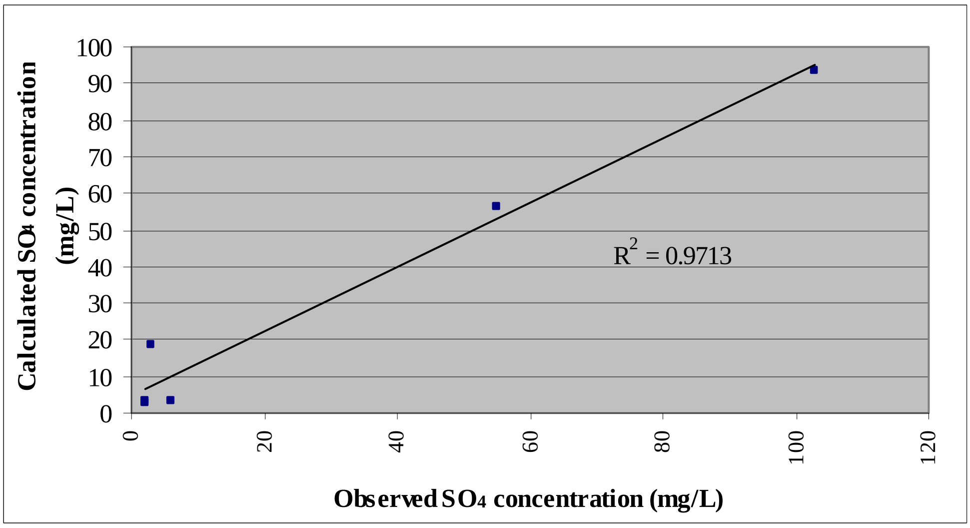

Figure 103.Model calibration: Calculated vs. Observed SO_4 concentration – end 2006.

10.6.5 Model Results

10.6.5.1 Seepage volumes from the Emergency Pan

The estimated daily volumes of water that seep from the Emergency Pan into the subsurface are listed in Table 43. The estimated daily volumes of seepage that enter the shallow weathered and deep aquifer systems are listed separately.

From Table 43 it is seen that, for a horizontal hydraulic conductivity of 0.30 m/day and a vertical conductivity of 0.030 m/day for the shallow aquifer system, an estimated 58.76 m^3 of water daily seep from the Emergency Pan into the subsurface. This figure translates into a seepage volume of approximately 2.32 m^3/ha/day. Approximately 48.70 m^3 of this water seep into the shallow weathered aquifer system while approximately 10.06 m^3 seep into the deeper aquifer system. These volumes are relatively small when compared with the estimated average volume of daily evaporation losses from the Emergency Pan (~580 m^3). The large difference in the volumes of water lost through evaporation and seepage can be understood by noting that the pan has a large surface area (~0.25 km^2) from which evaporation can take place, but a shallow depth (estimated at less than 1.5 m at maximum depth) with a resulting low hydraulic head.

Table 43. Estimated seepage volumes from the Emergency Pan.

Seepage from Sewage Plant (m^3/day)		
Total	**Into Shallow Aquifer**	**Into Deep Aquifer**
58.76	48.70	10.06

10.6.5.2 Contaminant migration in the shallow aquifer system

The modelled sulphate concentrations as observed in Layer 2, representing the shallow aquifer, are shown in Figure 104 to Figure 108 as coloured contour plots for the following times: end 2011, end 2016, end 2021, end 2026 and end 2036.

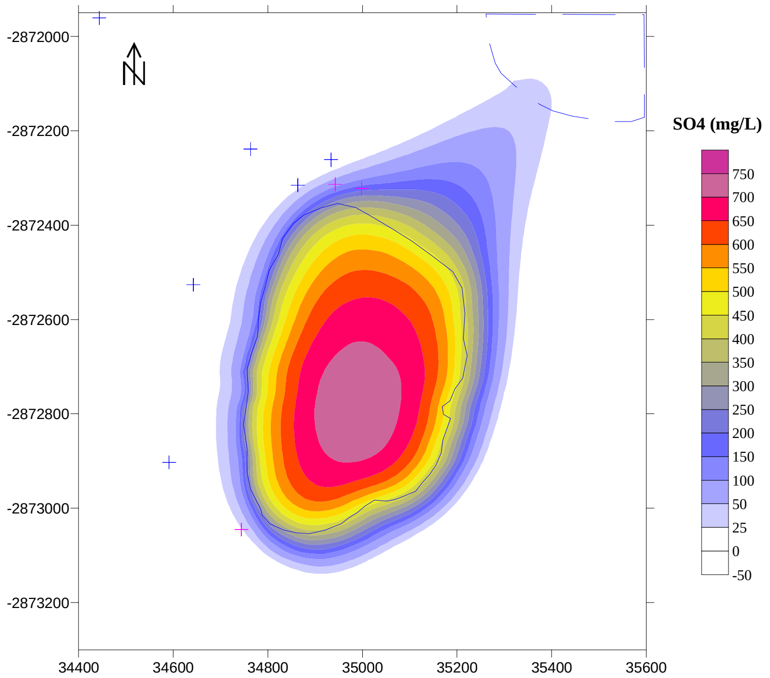

Figure 104. Modelled SO_4 concentrations in the shallow aquifer – end 2011.

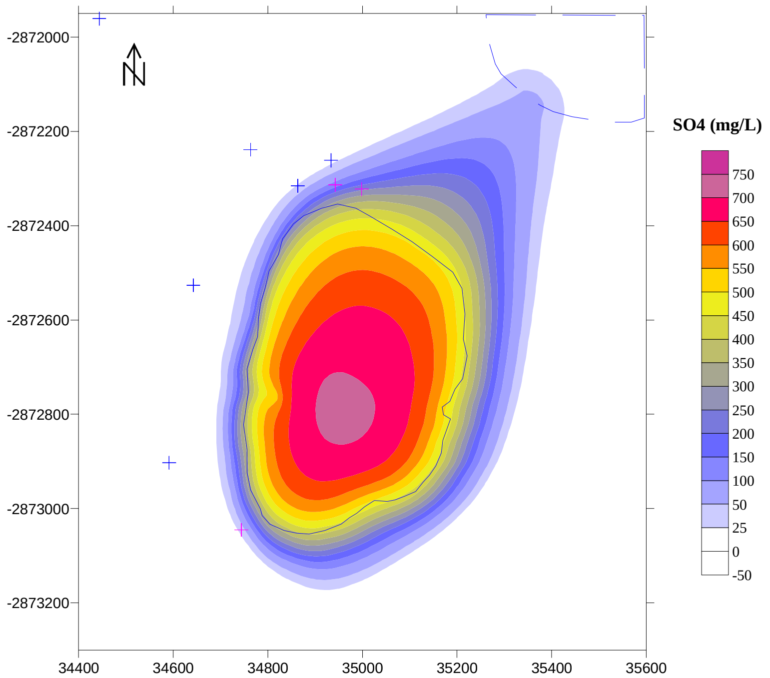

Figure 105.Modelled SO_4 concentrations in the shallow aquifer – end 2016.

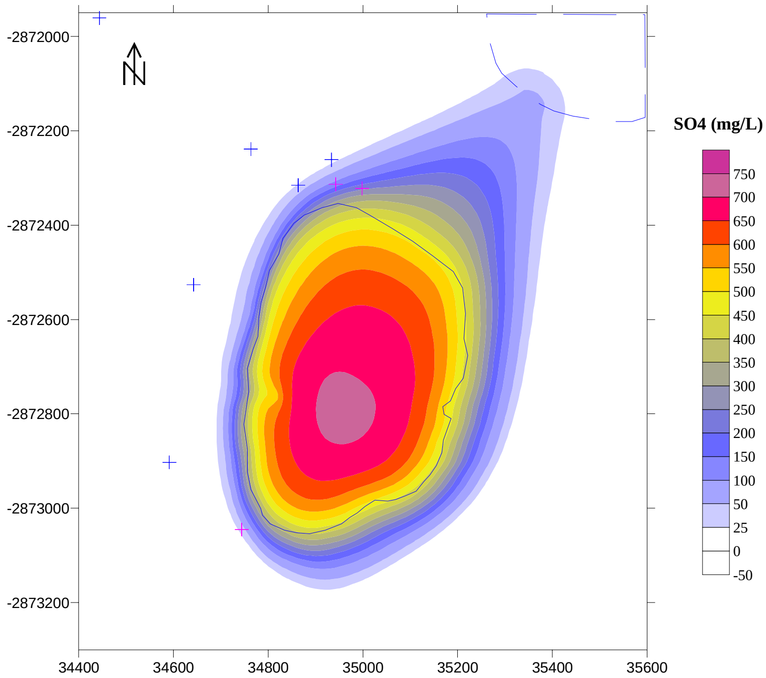

Figure 106.Modelled SO_4 concentrations in the shallow aquifer – end 2021.

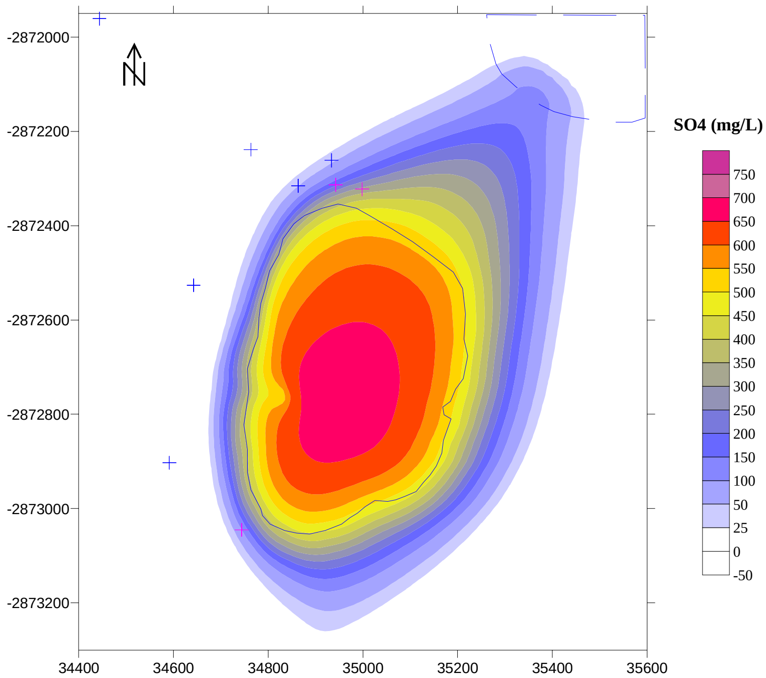

Figure 107.Modelled SO_4 concentrations in the shallow aquifer – end 2026.

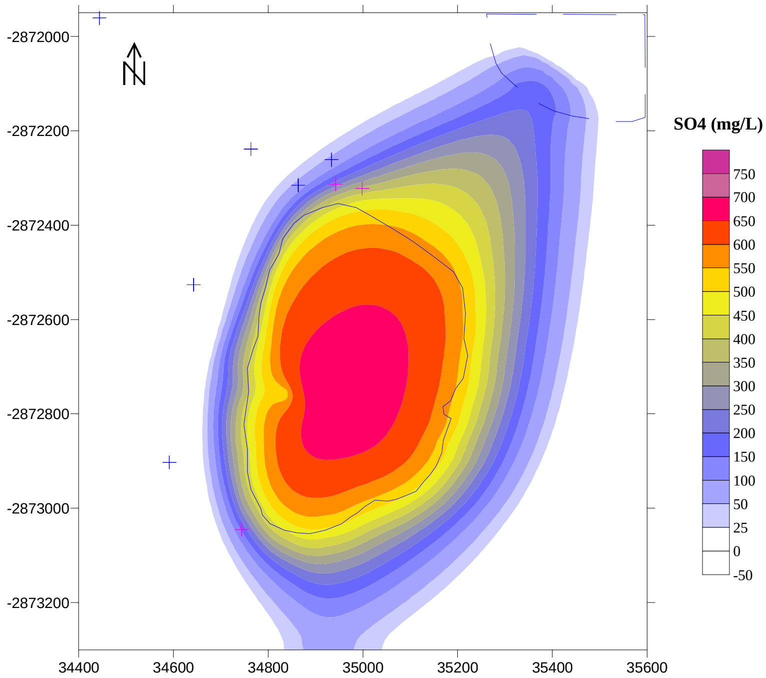

Figure 108.Modelled SO_4 concentrations in the shallow aquifer – end 2036.

From the coloured contour plots in Figure 104 to Figure 108 the following observations may be made:

- Modelling results suggest that the Emergency Pan feeds the non-perennial pan that occurs north-east of it. Contaminants from the Emergency Pan migrating in the shallow aquifer system could therefore potentially impact on the water quality in the non-perennial pan. However, the sulphate concentration of the water impacting on the non-perennial pan is expected to remain below 200 mg/L and should therefore not lead to any serious health risks.
- Limited contaminant migration is also expected to occur in directions radially away from the Emergency Pan through the process of diffusion.

10.6.5.3 Contaminant migration in the deep aquifer system

The modelled sulphate concentrations as observed in Layer 3, representing the deep aquifer, are shown in Figure 109 to Figure 113.

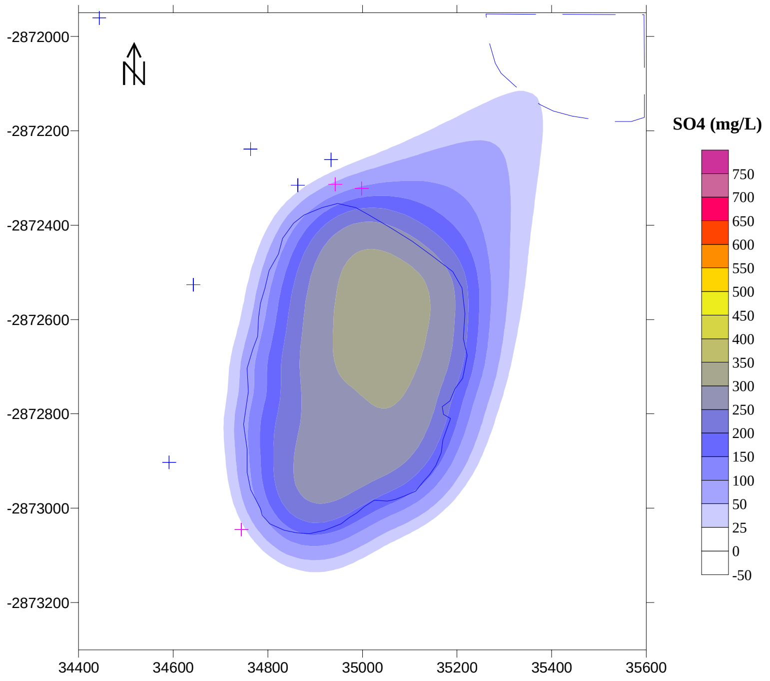

Figure 109. Modelled SO_4 concentrations in the deep aquifer – end 2011.

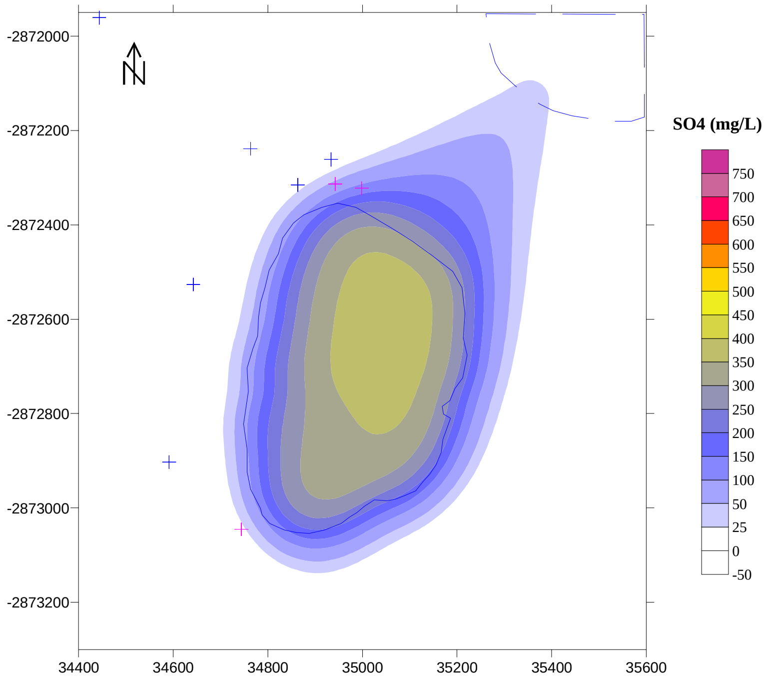

Figure 110.Modelled SO_4 concentrations in the deep aquifer – end 2016.

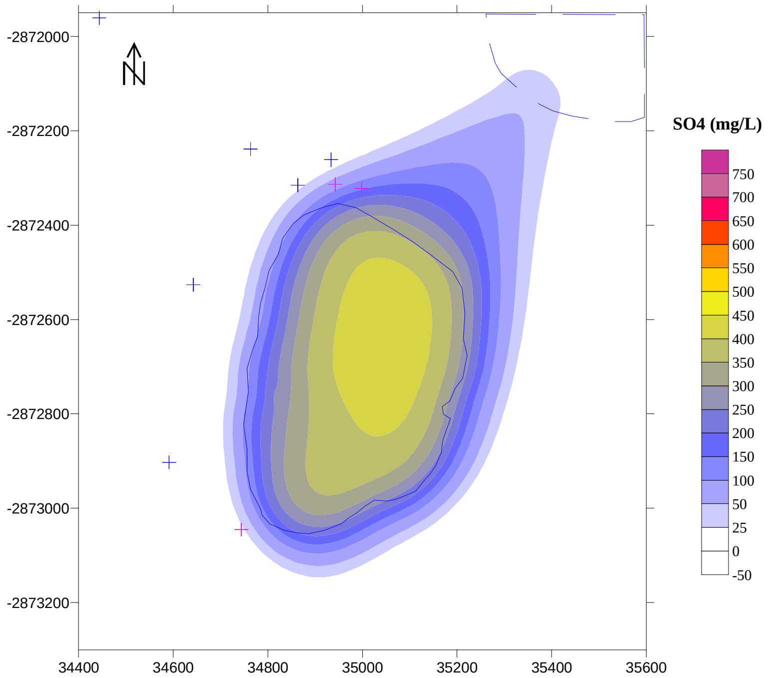

Figure 111.Modelled SO_4 concentrations in the deep aquifer – end 2021.

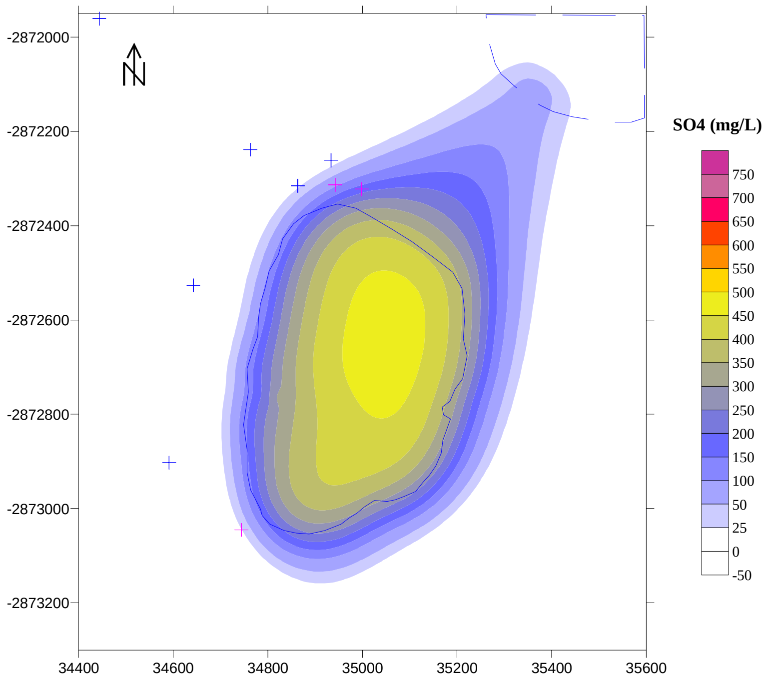

Figure 112.Modelled SO_4 concentrations in the deep aquifer – end 2026.

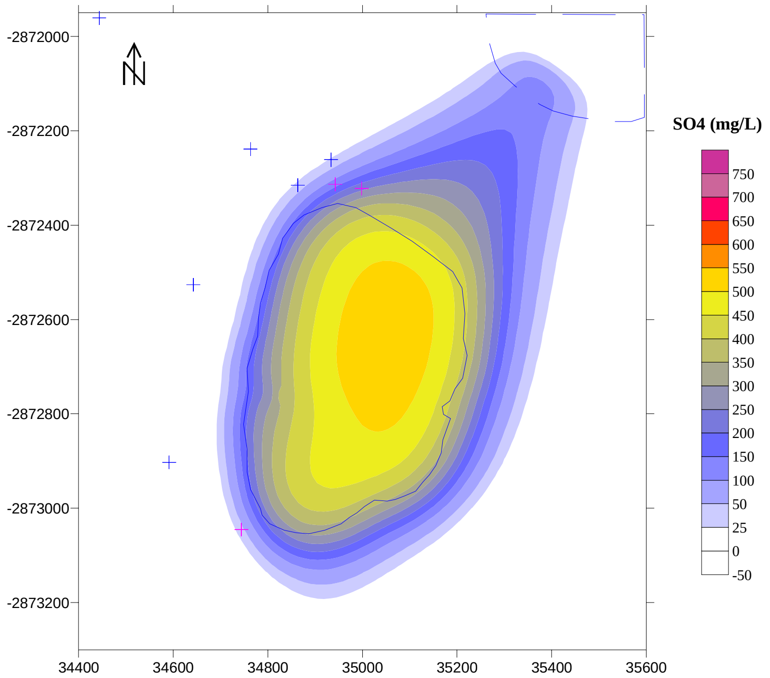

Figure 113.Modelled SO_4 concentrations in the deep aquifer – end 2036.

From the coloured contour plots in Figure 109 to Figure 113 the following observations may be made:

- Groundwater migration and contaminant transport in the deep aquifer system exhibit similar behaviour than in the shallow aquifer system, although the levels of contamination are expected to be lower.
- Limited contaminant migration in directions to the east, west and south of the Emergency Pan is expected to occur in the deep aquifer system.

10.6.6 Risk Assessment

The current sulphate concentration of the water in the Emergency Pan is 756 mg/L which renders the water quality poor and is high enough to be associated with health risk if the water is ingested. However, the water quality in the Emergency Pan has displayed a large degree of variability over the years depending on a number of factors, including the rainfall figures and whether the pan received water from the High Level Ash Water Return Dams. As long as the Emergency Pan receives water from the ashing system, it should be seen as a contaminant source that could potentially cause impacts on receptors.

Since the Emergency Pan is located within a local topographic depression, surface runoff will flow towards the pan, and it is highly unlikely that contaminant migration will take place along a surface water pathway. Contaminant migration is, however, expected to occur along the groundwater pathway. The modelled contaminant plumes in the aquifer systems (refer to Sections 10.6.5.2 and 10.6.5.3) were based on the assumption that the Emergency Pan contains water with a constant sulphate concentration of 750 mg/L. As such, these modelled contaminant plumes may be seen as giving overestimations of the true sulphate concentrations in the aquifer systems. However, the modelling results suggest that contaminant impacts on the non-perennial pan north-east of the Emergency Pan can be expected. The modelling results suggest that the impacts will be limited over the next 30 years and that the sulphate concentration of the contaminated water impacting on the non-perennial pan will not exceed 200 mg/L (ideal water quality).

The possible receptors of contaminant impacts are animals drinking from the Emergency Pan and non-perennial pan, as well as groundwater users that occur to the north-west of the Emergency Pan. Only one private farm lies within the extent of the modelled pollution plume. Although a borehole does occur on this farm, it is not equipped with a pump and is not currently being used.

The above observations suggest that, as long as groundwater from the borehole on the private farm north of the Emergency Pan is not used for drinking purposes, the health risks associated with the storage of contaminated water in the Emergency Pan are limited. Animals drinking from the pan are the most likely receptors of contaminant impacts.

10.6.7 Potential for seepage interception

As seen from the contour plots in Sections 10.6.5.2 and 10.6.5.3, most of the seepage from the Emergency Pan is expected to migrate in a north-easterly direction towards the non-perennial pan. If actions are taken to intercept the seepage, these actions will therefore have to focus on the area north-east of the Emergency Pan. However, the border fence with the private farm that occurs immediately north of the Emergency Pan is located very close to the northern shores of the pan, leaving little room in which to install a seepage interception system.

It should also be kept in mind that the Emergency Pan is located in a topographic depression and that the ground surface elevation increases rapidly as one moves away from the perimeter of the pan. A seepage interception trench will therefore have to be deep (>8 m) in order to effectively intercept water seeping from the Pan. Such a system will be very expensive and will not be justifiable in terms of water recovery.

Since the volumes of water lost from the Emergency Pan through seepage are relatively small and since the health risks associated with contaminant impacts appear to be limited, it is not recommended that a seepage interception system be installed at the pan. Instead it is recommended that the management of ashing activities at Duvha Power Station be reviewed and improved so that it is no longer required to use the Emergency Pan for buffer capacity when excessive volumes of water are present in the ashing system. The poor quality of the ash water that is intermittently allowed to enter the Emergency Pan has a strong detrimental effect on the water quality of this natural pan.

11 CONCLUSIONS AND RECOMMENDATIONS

Geohydrological investigations were undertaken at Duvha Power Station in order to estimate the volumes of water lost through seepage from the different dam systems at the power stations. As part of the geohydrological investigations, three-dimensional numerical models for the different dam systems were developed. These models were used to estimate the volumes of water that can be expected to seep from the different dam systems and to evaluate the risks associated with contaminant transport away from the dams. The investigations consisted of:

- Geophysical investigations at appropriate positions in the vicinity of the dam systems in order to identify and delineate magmatic intrusions that could influence groundwater migration and contaminant transport,
- A drilling programme during which 20 new monitoring boreholes were drilled at positions appropriate to the current investigations. Geological borehole logs were compiled during drilling in order to record information on the subsurface geology and geohydrology.
- Testing of the hydraulic properties of the geological units intersected by the boreholes in order to obtain information on the potential rate of groundwater migration and contaminant transport through these units.
- Groundwater, surface water and soil sampling. Water and soil samples were submitted to a recognised laboratory for chemical analyses in order to obtain information on the current salt loads and contamination statuses.
- Interpretation of the results of granulometric analyses performed on soil samples to obtain information on the soil hydraulic properties.
- Interpretation of stable isotope analyses performed on groundwater from boreholes near dam systems containing water with low salt concentrations (the Raw Water Dam and the Maturation Ponds at the Sewage Plant). The isotope analyses were performed in order to evaluate whether the groundwater at these sites has a surface water signature, indicating that seepage from the surface water body may have occurred.
- Development of three-dimensional numerical models to evaluate the rate and direction of groundwater flow and contaminant transport away from the dam systems. The volumes of water that seep from the dam systems were also estimated from the numerical modelling results.
- Assessing the risks associated with contaminant impacts on the groundwater and surface water bodies that could potentially be threatened by activities at the power station.
- Conceptually designing seepage interception systems where such systems are deemed necessary. The costs associated with the installation were evaluated against the benefits that may be obtained from these interception systems.

The results of the geohydrological investigations into seepage losses and the associated risks of contaminant impacts are summarised below:

<u>Ash Dam</u>

Seepage volumes

The volumes of water that are expected to seep from the Ash Dam are to a large extent determined by the lateral extent of a zone of highly weathered rhyolites that occurs to the north of the Ash Dam and extends under it. The zone of highly weathered rhyolites was intersected during the drilling of boreholes AB27, AB28 and AB29. Unfortunately no information is available on the lateral extent of this zone at positions located under the Ash Dam.

In a previous interim modelling report (GHT Report RVN 457.1/681), the lateral extent of the zone of highly weathered rhyolites was assumed to be limited to an area near the north-western wall of the Ash Dam. With this assumption the current volume of water lost through seepage was estimated at 270 m^3/day (or approximately 0.84 m^3/ha/day). However, according to water- and energy balance calculations performed for Duvha Power Station by Mr. Dirk Hanekom of Eskom, this estimate was too low and seepage losses as high as 6 – 8 m^3/ha/day were expected.

The current numerical model constructed for the Ash Dam assumed a much larger lateral extent for the zone of highly weathered rhyolites, underlying most of the Ash Dam. With this assumption the numerical modelling results indicate current seepage losses of approximately 805 m^3/day (or 2.52 m^3/ha/day). This estimate is still significantly lower than the estimate obtained by Mr. Hanekom.

It should, however, be noted that for the water balance calculations performed by Mr. Hanekom, it was assumed that the average evaporation from the surface of Ash Dam is equal to the average evaporation measured at evaporation stations B1E001. The mean annual S-pan evaporation from station B1E001 is 1 621 mm. Mr Hanekom showed that if the evaporation from the Ash Dam is 11% higher than at station B1E001 (corresponding to a mean annual S-pan evaporation of 1 800 mm) the seepage volumes from the Ash Dam as suggested by his water balance calculations could be as low as 2 m^3/ha/day.

The modelling results further indicate that, as the level of the Ash Dam increases up to its final height (attained in 2036), the hydraulic head in the Ash Dam will also increase causing ever larger volumes of water to seep into the subsurface. By the end of 2036 the volumes of water daily lost through seepage could be as high as 2 340 m^3 (or around 7.31 m^3/ha/day). Most of the seepage will migrate through the shallow weathered aquifer system and flow will predominantly take place to the north along the groundwater gradient.

Contaminant migration and risk assessment

The contaminant plumes to the north of the Ash Dam are not expected to extend all the way to the Witbank Dam by the end of 2036 when ashing operations at Duvha Power Station will cease. The numerical modelling results suggest that even 100 years after decommissioning the impact of ashing activities on the Witbank Dam will be small and that the risks associated with these impacts will be minimal. Since there are no groundwater users downstream from the Ash Dam, the risks of contaminant impacts on groundwater users are also negligibly small.

Numerical modelling results indicate that, due to future impacts of seepage on the non-perennial rivers that occur to the north of the Ash Dam, the sulphate concentrations in these rivers could attain maximum values of between 350 and 500 mg/L during the operational phase of the Ash Dam. Such concentrations are high enough to cause the water quality to be classified as marginal. If ingested, water of a marginal quality could cause negative effects in sensitive groups. There are, however, no known users of these rivers (except cattle for drinking water) and the risks associated with the contaminant impacts are again limited.

Seepage interception

The numerical modelling results indicate that the installation of a seepage interception trench along the north-western wall of the Ash Dam could allow large volumes of water to be recovered. Different options for the depth and length of the trench were considered during modelling and it was found that an 8 m deep trench with a length of 2 km will be the most beneficial in terms of cost savings due to water recovery over the next 30 years while the Ash Dam is in operation.

Additional recommendations

The accuracy of the numerical model developed for the Ash Dam was limited by a number of uncertainties. One factor that strongly influences the results of the numerical model is the lateral extent of the zone of highly weathered rhyolites that partially underlies the Ash Dam. To allow better delineation of this zone, it is recommended that a number of boreholes be drilled through the ash at different locations on the Ash Dam in order to investigate the geological formations that underlie the dam. The boreholes will have to be constructed in such a way that they not form preferential pathways for contaminant migration from the Ash Dam into the aquifer systems. Although this is likely to be a costly exercise, the information thus obtained may be very useful if greater certainty regarding the volumes of water lost through seepage is required.

Another uncertainty is the volumes of water lost through evaporation from the Ash Dam. It is quite possible that the conditions on top of the Ash Dam differ greatly from the conditions at evaporation station B1E001. As discussed above, an 11% increase in the average annual evaporation figures could have a dramatic impact on the estimates of the volumes of water seeped to the subsurface as obtained from a water balance. It is therefore recommended that an S-pan be installed on top of the Ash Dam so that the true evaporation figures (and, consequently, seepage volumes) can be known with a greater deal of certainty.

Low Level Ash Water Return Dam

Seepage volumes

The results of the numerical model show that surprisingly small volumes of seepage (~36 m^3/day) from the Low Level Ash Water Return Dam can be expected to enter the shallow weathered aquifer system and may surface at positions north of the northern wall of the dam. The low volumes of seepage from the Low Level Ash Water Return Dam can be understood by noting that this dam is located within a local topographic depression. Groundwater elevations in the areas to the west and east of the return water dam where local topographic highs occur are generally higher than the operational water level of the return water dam (1532 mamsl). The hydraulic gradients to the west and east of the return water dam therefore point towards the dam. As a result, groundwater flow is generally towards the return water dam, and not away from it. Seepage is therefore expected to predominantly take place to the north and north-east of the dam where the topographic low formed by the valley in which the dam is located extends in a north-westerly direction.

Contaminant migration and risk assessment

Comparison of the water quality at the five monitoring sites that are located north of the Low Level Ash Water Return Dam suggest that seepage from this dam does occur, but that the volumes of seepage are small. The sulphate concentration at borehole AB04, located immediately north of the dam wall, is at present only 187 mg/L, even though ashing operations have been taking place since 1978. The sulphate concentrations at the new boreholes AB30 and AB31 are 93 and 54 mg/L, respectively.

Since the Low Level Ash Water Return Dam is located in close proximity to the Ash Dam, the impacts of contaminant releases from the Low Level Ash Water Return Dam and the associated health risks were considered along with the impacts from Ash Dam. As discussed, the health risks are very limited.

Seepage interception

Since the volumes of seepage losses from the Low Level Ash Water Return Dam seem to be small, and since the impact of contaminants associated with seepage appears to be minimal, the benefits of installing a seepage interception system is likely to be limited. There are also practical difficulties associated with the installation of a seepage interception system. Judging from the topographic gradient, seepage from the Low Level Ash Water Return Dam is expected to take place predominantly near the north-eastern toe of the dam, east of the pump station. At this position the diverted non-perennial river flows very close to the dam wall and the access road around it. The proximity of the river to the dam wall and road leaves very little room in which to install an interception system.

Due to the factors discussed above, it is at present not recommended that a seepage interception system be installed at the Low Level Ash Water Return Dam. However, regular monitoring of the water quality and surface- and groundwater sites north of the dam should be done. Any deterioration in the water quality could indicate that larger volumes of seepage have started to impact on the environment. Under these conditions it may be beneficial to install a seepage interception system.

If future water quality monitoring reveals that contaminant impacts on the surface water and/or groundwater are occurring, a simple design for a seepage interception system could consist of a shallow unlined trench (3-4 m deep, ~300 m long) dug at a position near the north-eastern toe of the dam. The trench could be fitted with gabions to prevent it from collapsing. A sump could be formed at the position of lowest floor elevation in the trench. From this sump, seepage water could be pumped back to the dam by means of pump equipped with a level switch.

Raw Water Dam

Seepage volumes

An estimated 113 m^3 of water daily seep from the Raw Water Dam into the subsurface. This figure translates into a volume of approximately 7.9 m^3/ha/day. Approximately 81 m^3 daily seep into the shallow weathered aquifer system while approximately 32 m^3 seep into the deeper aquifer system. These volumes are relatively small when compared with the estimated volume of daily evaporation losses from the Raw Water Dam (~330 m^3).

Risk assessment

Since the Raw Water Dam contains water of an ideal quality, no health risks associated with contaminant migration exist.

Seepage interception

A cost-benefit analysis shows that the volumes of water intercepted by both a shallow (6 m) and deep (8 m) trench located on the south-western side of the Raw Water Dam are too small to justify the expenditures associated with the installation of the trench. It is therefore not recommended that such an expensive trench be installed. As a possible alternative a seepage interception system could be installed near the positions where seepage is noticed to occur at surface near the toes of the dam walls. Such a system could consist of an unlined trench (~4 m deep) dug parallel to the dam wall, fitted with gabions and equipped with a sump and return pump. The volumes of water intercepted by these trenches are likely to be too small to justify the installation costs purely from an economical point of view, but other possible benefits (e.g dam safety) should also be considered when evaluating the costs versus benefits.

High Level Ash Water Return Dams

Seepage volumes

An estimated 26.57 m^3 of water daily seep from the High Level Ash Water Return Dams into the subsurface. Expressed in terms of the surface area of the High Level Ash Water Return Dams, this figure translates into a volume of approximately 9.55 m^3/ha/day. Approximately 25.32 m^3 daily seep into the shallow weathered aquifer system while approximately 1.25 m^3 seep into the deeper aquifer system. These volumes are again relatively small when compared with the estimated average volume of daily evaporation losses from the High Level Ash Water Return Dams (~64 m^3).

The estimated seepage volumes were obtained by making the assumption that the floors of the High Level Ash Water Return Dams were properly prepared to reduce their permeabilities prior to the dams receiving water. However, no information on the permeabilities of the dam floors is available and it is therefore possible that the floors have higher permeabilities than those used in the numerical model. Higher dam floor permeabilities will lead to larger water losses through seepage.

A cost-benefit analysis shows that the volumes of water that could potentially be intercepted by either a shallow (6 m) or deep (8 m) trench are too small to justify the expenditures associated with the installation of such a trench. Even if the costs associated with the WDSC are taken into account, it is unlikely that an interception trench will be financially profitable.

Contaminant migration and risk analysis

As long as overflows do not occur, the only pathway available for contaminant migration away from the High Level Ash Water Return Dams is the groundwater pathway. From the numerical modelling results it can be seen that contaminant migration is expected to occur at a slow rate. By 2036 the sulphate contaminant plume will still have values of less than 200 mg/L (ideal water quality) at position located further than 300 m from the High Level Ash Water Return Dams. The absence of groundwater users down-gradient from these dams also implies that there are no receptors for the contaminants to impact on. The health risks associated with contaminant migration away from these dams can therefore be considered negligible.

Seepage interception

A preliminary cost-benefit analysis indicate that the benefits in terms of water cost savings are minimal and do not justify the installation of a seepage interception trench. Even if the costs associated with the Waste Discharge Charge System are taken into account, it is unlikely that such a trench will be financially profitable. Since the risks associated with seepage from the High Level Ash Water Return Dams are negligible, it is not recommended that seepage interception trench be installed.

<u>Sewage Plant</u>

Seepage volumes

The modelling results indicate that volume of around 3 m^3 daily seeps into the subsurface from the Maturation Ponds and Buffer Pond at the Sewage Plant. When taking the surface areas of the Buffer Pond and Maturation Ponds into account, this volume of water translates into a seepage loss of approximately 4.1 m^3/ha/day.

Contaminant migration and risk assessment

For the purposes of investigating contaminant transport away from the maturation ponds, the total dissolved solids (TDS) concentrations recorded at the surface and groundwater sites near the Sewage Plant were used. The TDS concentrations were used because this parameter displays the largest variation between the surface and groundwater sites. Although TDS is not a conservative parameter, using it as an indicator parameter for contamination may allow insight into the rate and direction of contaminant transport.

Contaminant migration predominantly takes place in a westerly direction under the local hydraulic gradient. The rate of contaminant migration through the shallow aquifer system is expected to be slow. As a result, the lateral extent of the contaminant plume is expected to remain limited, even after 30 years of operation. However, the contaminant plume could potentially extend as far as the opencast pits of Corobrik.

The health risks due to seepage from the Maturation Ponds and Buffer Pond are associated with impacts of water with high bacterial activity. There are two pathways available along which contaminants may be transported away from the Maturation Ponds, namely the groundwater pathway and the surface water pathway where seepage daylights at positions west of the Sewage Plant. Both the groundwater and surface water is expected to migrate in the direction of the Witbank Dam under the local topographic and hydraulic gradients.

Possible receptors for contaminant impacts are people and animals that come in contact with the contaminated water. A Corobrik quarry is located immediately west of the Sewage Plant. The opencast pits at the quarry receive large volumes of groundwater that migrate in a westerly direction. Contaminants originating at the Sewage Plant could potentially reach these pits and cause impacts on Corobrik personnel mining the pits. However, the Corobrik pits are more than 200 m away from the Sewage Plant. These pits receive large volumes of groundwater that seep into the pits from their eastern walls. Even if contaminants from the Sewage Plant should impact on the pits, the diluting effects of the clean water seeping into the pits are expected to reduce the contaminant concentrations and reduce the likelihood of health risks. It should also be noted that groundwater is not used for drinking purposes at Corobrik or at positions further to the west towards the Witbank Dam.

Since the Witbank Dam is located more than 2 km away from the Sewage Plant, it is highly unlikely that contaminant originating at the Sewage Plant will have any impacts on this surface water body. Groundwater that daylights at positions near the western fence of the Sewage Plant could potentially be ingested by wild animals. If the bacterial activity in the groundwater is high, contaminant impacts on these animals could occur.

The above observations suggest that the risks associated contaminant impacts from the Sewage Plant may be considered minimal. Negligible health risks to humans are expected.

Seepage interception

Since the volumes of water that are expected to seep from the Buffer Pond and Maturation Ponds are small, a seepage interception system will have to be inexpensive to justify the recovery of water seeped from these ponds. A seepage interception trench will, however, further reduce the likelihood of contaminant impacts and may be seen as beneficial in these terms.

The groundwater table in the shallow aquifer in the vicinity of the Sewage Plant occurs at a depth of between 1.32 and 2.66 mbgl. Modelling results show that the bulk of the seepage that emanates from the Buffer Pond and Maturation Ponds will migrate at depths of less than 4 mbgl. At positions to the west of the 1st Maturation Pond, groundwater even daylights. The above observations imply that an effective seepage interception system will have to be no deeper than 4 metres.

Little room is available for the installation of a seepage interception trench. The distance between the Buffer Pond and the fence with the property of Corobrik is approximately 20 m. A possible location for the installation of the trench is along the eastern side of the fence. To minimise costs a shallow unlined interception trench, fitted with gabions and equipped with a sump and return pump, could be considered. Assuming that the trench has a depth of 4 m and a length of 200 m, the costs associated with the installation are unlikely to exceed R500 000.

Emergency Pan

Seepage volumes

An estimated 58.76 m^3 of water daily seep from the Emergency Pan into the subsurface. This figure translates into a seepage volume of approximately 2.32 m^3/ha/day. Approximately 48.70 m^3 of this water seep into the shallow weathered aquifer system while approximately 10.06 m^3 seep into the deeper aquifer system. These volumes are relatively small when compared with the estimated average volume of daily evaporation losses from the Emergency Pan (~580 m^3). The large difference in the volumes of water lost through evaporation and seepage can be understood by noting that the pan has a large surface area (~0.25 km^2) from which evaporation can take place, but a shallow depth (estimated at less than 1.5 m at maximum depth) with a resulting low hydraulic head.

Contaminant migration and risk assessment

Modelling results suggest that the Emergency Pan feeds the non-perennial pan that occurs north-east of it. Contaminants from the Emergency Pan migrating in the shallow aquifer system could therefore potentially impact on the water quality in the non-perennial pan.

The current sulphate concentration of the water in the Emergency Pan is 756 mg/L which renders the water quality poor and is high enough to be associated with health risk if the water is ingested. However, the water quality in the Emergency Pan has displayed a large degree of variability over the years depending on a number of factors, including the rainfall figures and whether the pan received water from the High Level Ash Water Return Dams. As long as the Emergency Pan receives water from the ashing system, it should be seen as a contaminant source that could potentially cause impacts on receptors.

Since the Emergency Pan is located within a local topographic depression, surface runoff will flow towards the pan, and it is highly unlikely that contaminant migration will take place along a surface water pathway. Contaminant migration is, however, expected to occur along the groundwater pathway. Modelling results suggest that contaminant impacts on the non-perennial pan north-east of the Emergency Pan can be expected. The modelling results suggest that the impacts will be limited over the next 30 years and that the sulphate concentration of the contaminated water impacting on the non-perennial pan will not exceed 200 mg/L (ideal water quality).

The possible receptors of contaminant impacts are animals drinking from the Emergency Pan and non-perennial pan, as well as groundwater users that occur to the north-west of the Emergency Pan. Only one private farm lies within the extent of the modelled pollution plume. Although a borehole does occur on this farm, it is not equipped with a pump and is not currently being used.

The above observations suggest that, as long as groundwater from the borehole on the private farm north of the Emergency Pan is not used for drinking purposes, the health risks associated with the storage of contaminated water in the Emergency Pan are limited. Animals drinking from the pan are the most likely receptors of contaminant impacts.

Seepage interception

Most of the seepage from the Emergency Pan is expected to migrate in a north-easterly direction towards the non-perennial pan. If actions are taken to intercept the seepage, these actions will therefore have to focus on the area north-east of the Emergency Pan. However, the border fence with the private farm that occurs immediately north of the Emergency Pan is located very close to the northern shores of the pan, leaving little room in which to install a seepage interception system.

It should also be kept in mind that the Emergency Pan is located in a topographic depression and that the ground surface elevation increases rapidly as one moves away from the perimeter of the pan. A seepage interception trench will therefore have to be deep (>8 m) in order to effectively intercept water seeping from the Pan. Such a system will be very expensive and will not be justifiable in terms of water recovery.

Since the volumes of water lost from the Emergency Pan through seepage are relatively small and since the health risks associated with contaminant impacts appear to be limited, it is not recommended that a seepage interception system be installed at the pan. Instead it is recommended that the management of ashing activities at Duvha Power Station be reviewed and improved so that it is no longer required to use the Emergency Pan for buffer capacity when excessive volumes of water are present in the ashing system. The poor quality of the ash water that is intermittently allowed to enter the Emergency Pan has a strong detrimental effect on the water quality of this natural pan.

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

28 November 2006

Date

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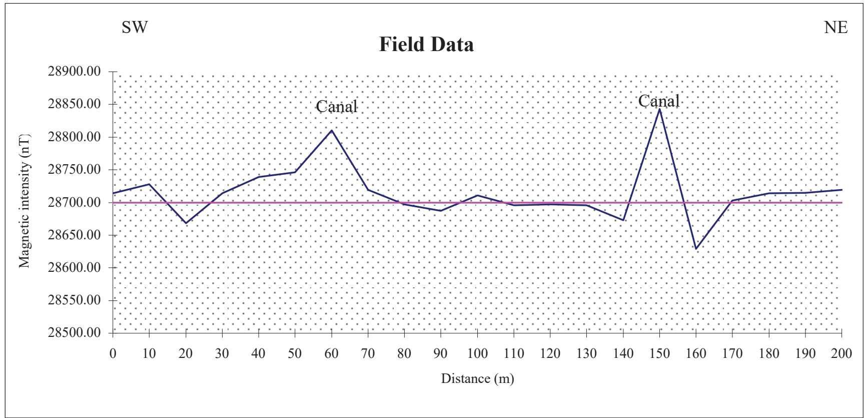
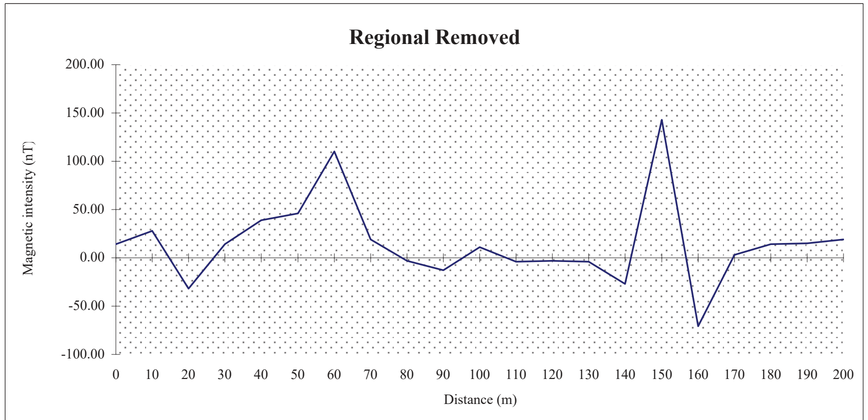
MAGNETIC PROFILES





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Profile Number:	Traverse 1	**End Stn:**	**200**	25.95459 S	29.34693 E
Station Spacing:	10 m				
Survey Area	South-east of HLAWRD	**Operator:**			
Date of Survey:	06 July 2006	F Fourie			

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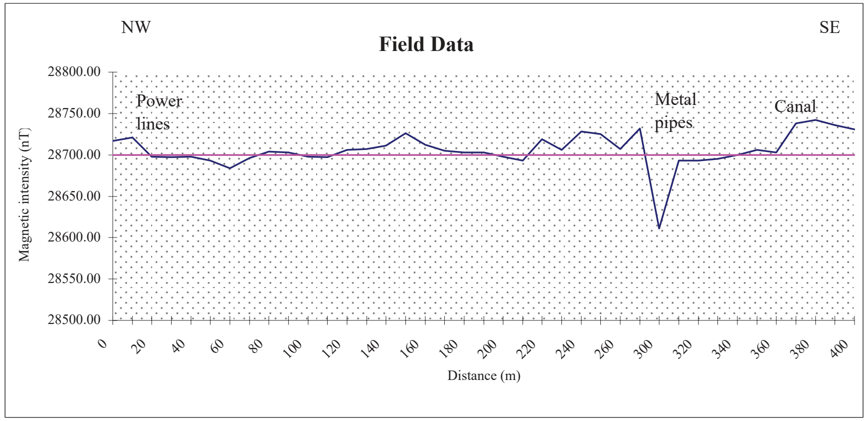

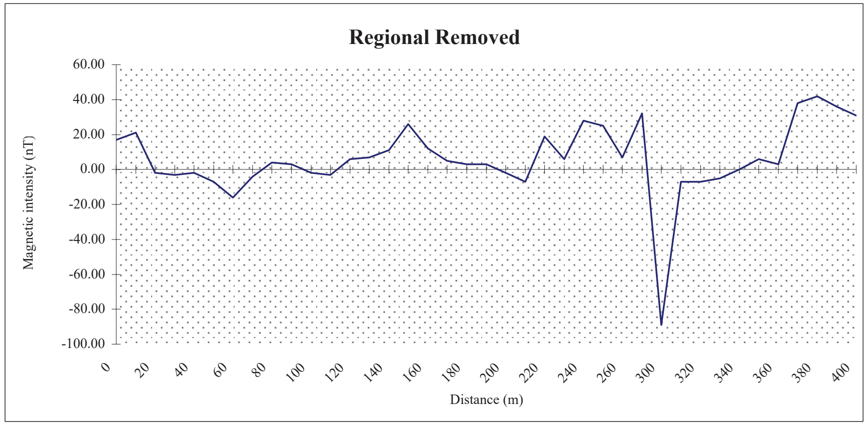

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Profile Number:	Traverse 2		**200**	25.95318 S	29.34554 E
Station Spacing:	10 m	**End Stn:**	**400**	25.95459 S	29.34693 E
Survey Area	North-east of HLAWRD	**Operator:**			
Date of Survey:	06 July 2006	F Fourie			

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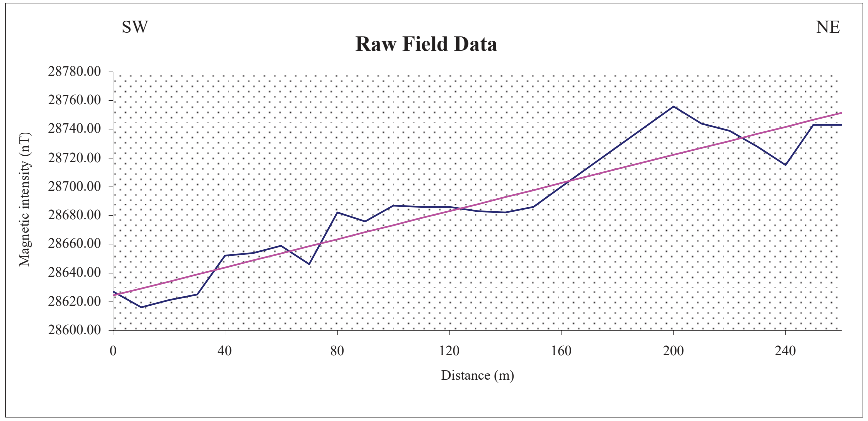

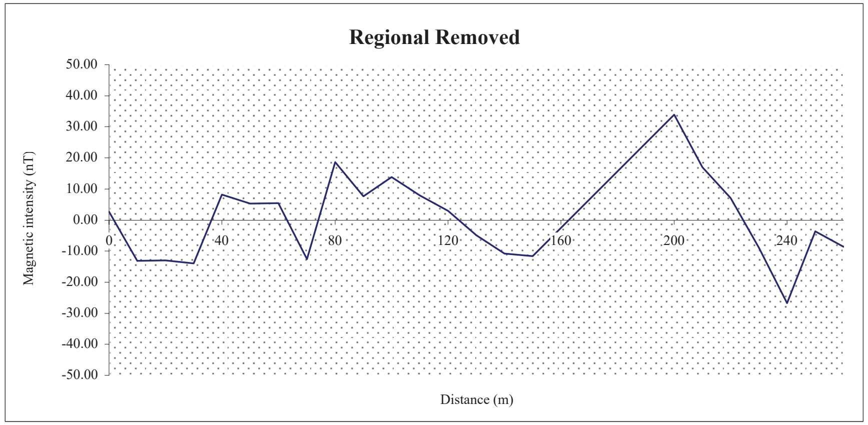

Project:	Duvha PS - Seepage Investigation	**Profile Direction:**	South-west to north-east			
Project Number:	202-15-ghd.457	**Start Stn:**	**0**	25.95351 S	29.34225 E	
Profile Number:	Traverse 3	**End Stn:**	**260**	25.95182 S	29.34410 E	
Station Spacing:	10 m					
Survey Area	North-west of HLAWRD	**Operator:**				
Date of Survey:	06 July 2006	F Fourie				

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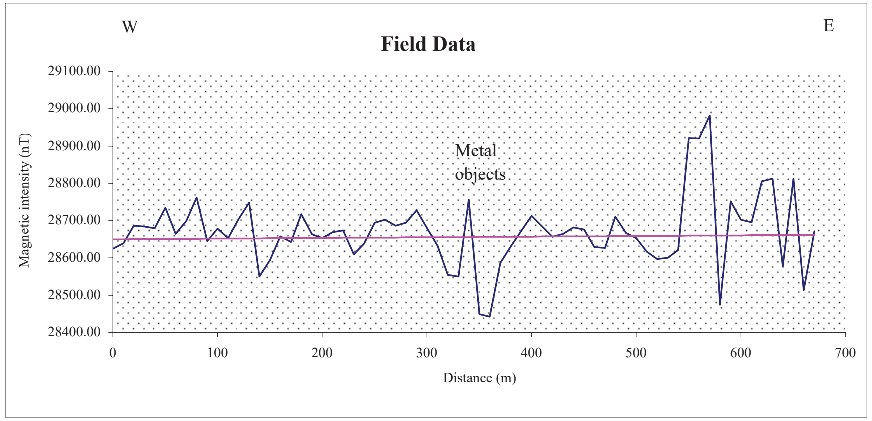

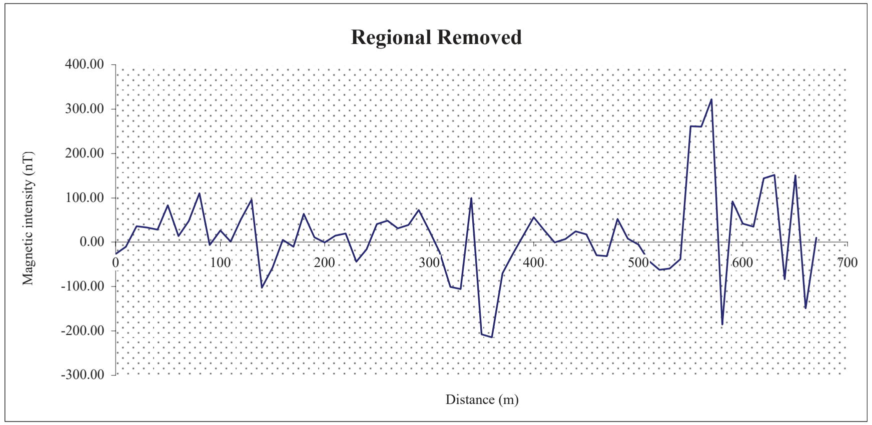

Project:	Duvha PS - Seepage Investigation	**Profile Direction:**				
Project Number:	202-15-ghd.457		**Start Stn:**	**0**	25.92409 S	29.34106 E
Profile Number:	Traverse 4			**70**	25.92389 S	29.34175 E
Station Spacing:	10 m			**270**	25.92348 S	29.34382 E
Survey Area	North of LLAWRD	**Operator:**		**470**	25.92333 S	29.34590 E

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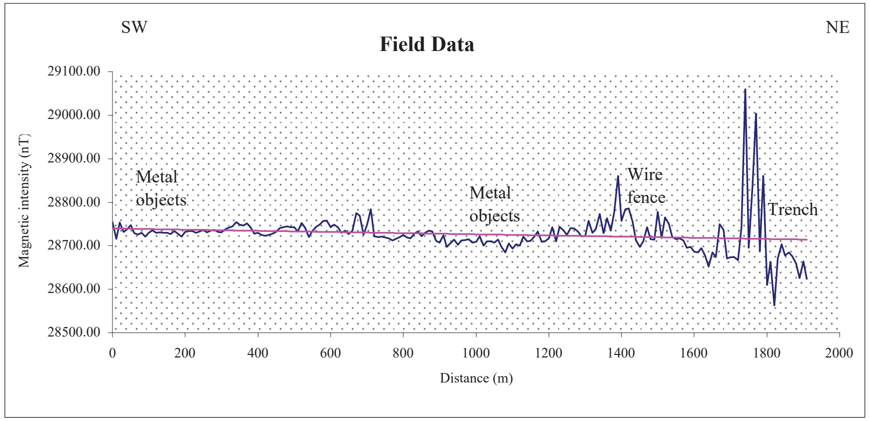

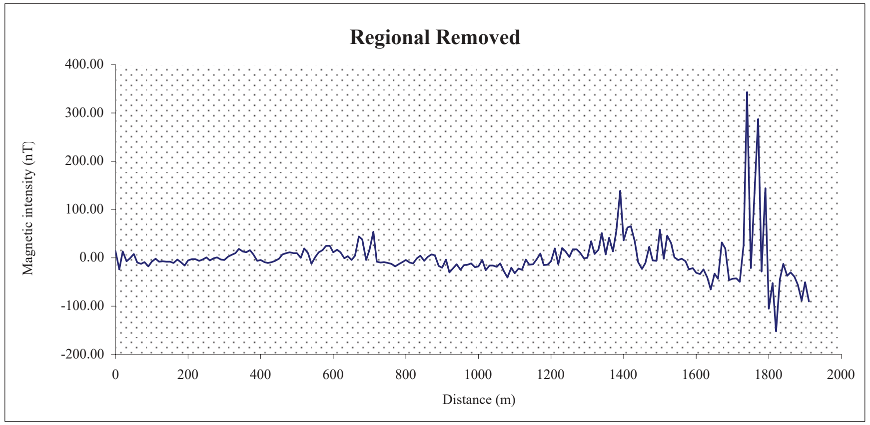

Project:	Duvha PS - Seepage Investigation	**Profile Direction:**	South-west to North-east		
Project Number:	202-15-ghd.457	**Start Stn:**	**0**	25.93584 S	29.32519 E
Profile Number:	Traverse 5		**580**	25.93254 S	29.33015 E
Station Spacing:	10 m		**980**	25.93028 S	29.33365 E
Survey Area	North-west of Ash Dam	**Operator:**	**1580**	25.92629 S	29.33842 E
Date of Survey:	07 July 2006	F Fourie **End Stn:**	**1910**	25.92409 S	29.34106 E

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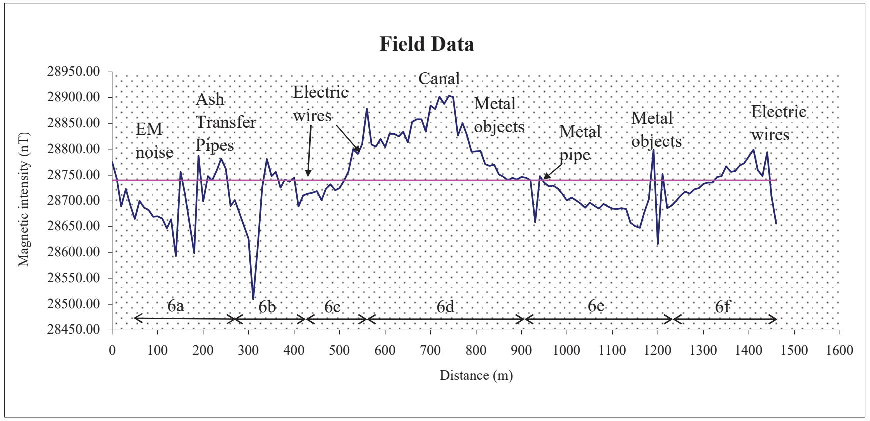

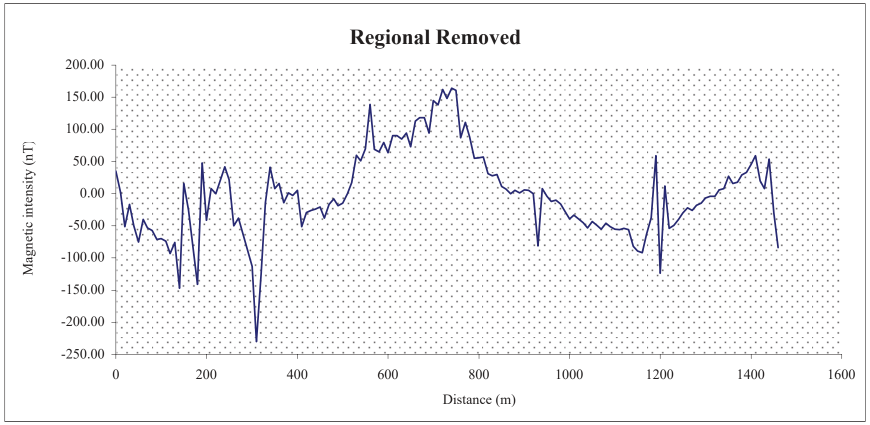

Project:	Duvha PS - Seepage Investigation	**Profile Direction:**	Varied		
Project Number:	202-15-ghd.457	**Start Stn:**	**0**	25.94799 S	29.33242 E
Profile Number:	Traverse 6		**400**	25.94753 S	29.32812 E
Station Spacing:	10 m		**880**	25.95230 S	29.32675 E
Survey Area	Around Raw Water Dam	**Operator:**	**1220**	25.95411 S	29.33015 E
Date of Survey:	08 July 2006	F Fourie **End Stn:**	**1460**	25.95225 S	29.33284 E

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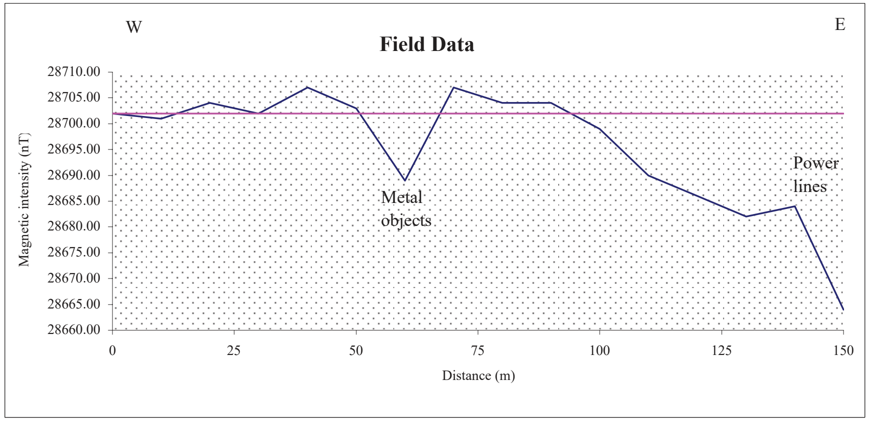

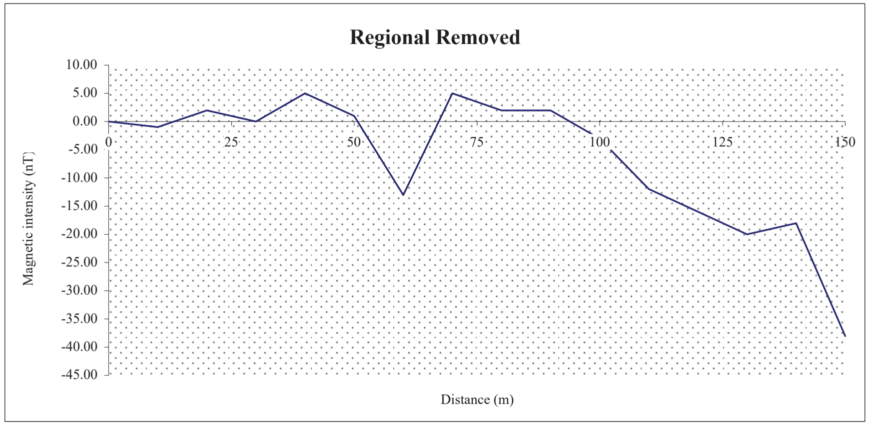

Project:	Duvha PS - Seepage Investigation	**Profile Direction:**	West to east		
Project Number:	202-15-ghd.457	**Start Stn:**	**0**	25.95810 S	29.32412 E
Profile Number:	Traverse 7	**End Stn:**	**150**	25.95827 S	29.32249 E
Station Spacing:	10 m				
Survey Area	North of sewage plant	**Operator:**			
Date of Survey:	08 July 2006	F Fourie			

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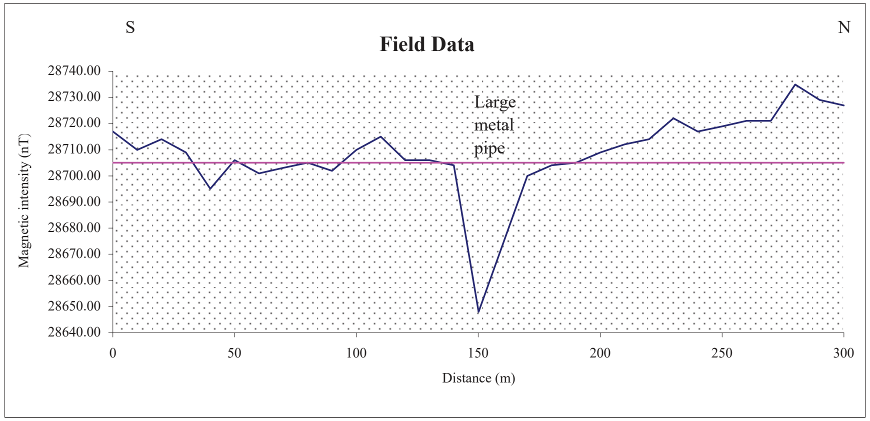

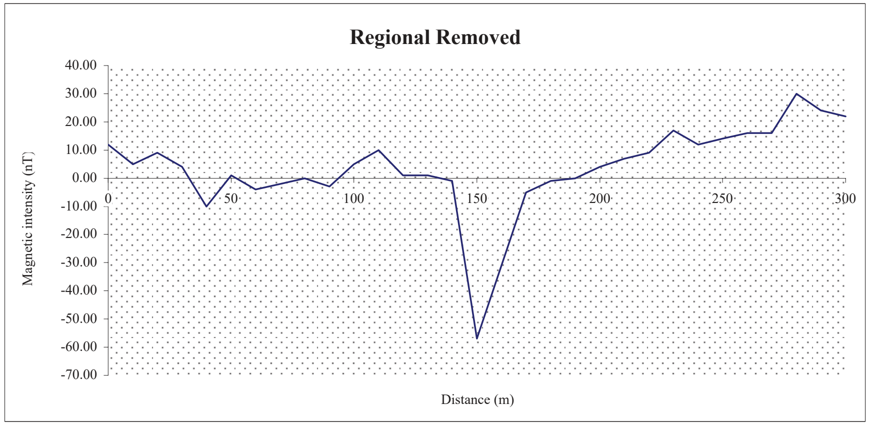

Project:	Duvha PS - Seepage Investigation	**Profile Direction:**	South to north		
Project Number:	202-15-ghd.457	**Start Stn:**	**0**	25.96116 S	29.32366 E
Profile Number:	Traverse 8	**End Stn:**	**300**	25.95810 S	29.32412 E
Station Spacing:	10 m				
Survey Area	East of sewage plant	**Operator:**			
Date of Survey:	08 July 2006	F Fourie			

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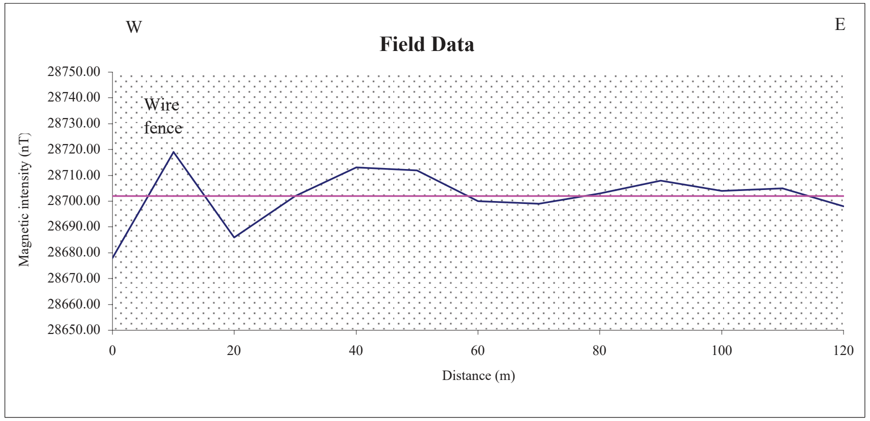
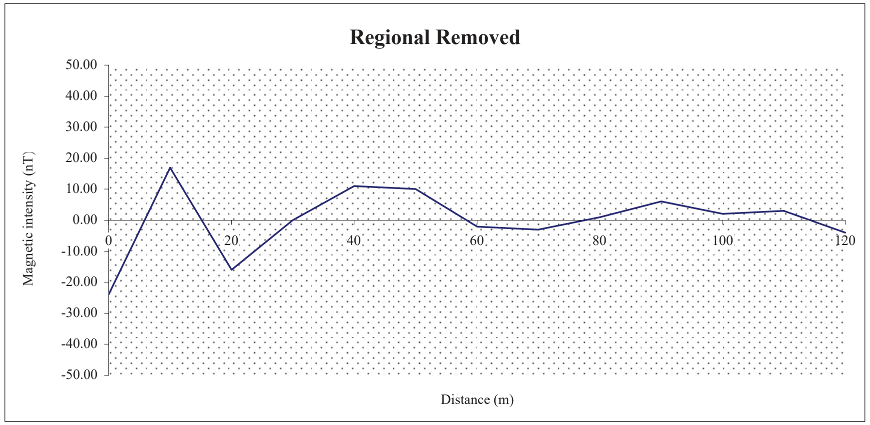
MAGNETIC PROFILES





Project:	Duvha PS - Seepage Investigation	**Profile Direction:**	West to east		
Project Number:	202-15-ghd.457	**Start Stn:**	**0**	25.96099 S	29.32234 E
Profile Number:	Traverse 9	**End Stn:**	**120**	25.96116 S	29.32366 E
Station Spacing:	10 m				
Survey Area	South of sewage plant	**Operator:**			
Date of Survey:	08 July 2006	F Fourie			

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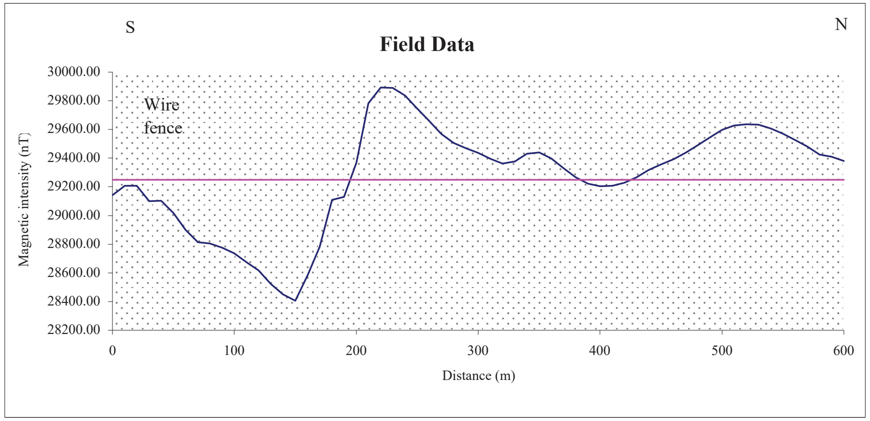
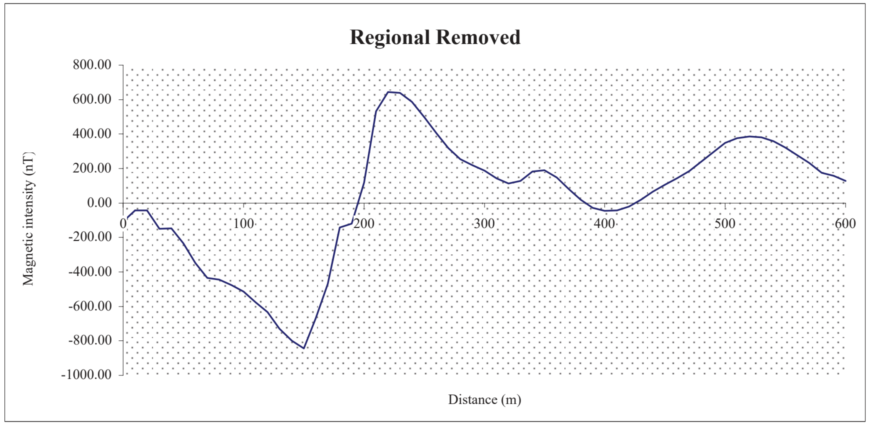
MAGNETIC PROFILES





Project:	Duvha PS - Seepage Investigation	**Profile Direction:**	South to north		
Project Number:	202-15-ghd.457	**Start Stn:**	**0**	25.96584 S	29.35047 E
Profile Number:	Traverse 10		**200**	25.96396 S	29.35163 E
Station Spacing:	10 m		**400**	25.96188 S	29.35232 E
Survey Area	East of Emergency Pan	**Operator:** **End Stn:**	**600**	25.95988 S	29.35134 E
Date of Survey:	28 July 2006	F Fourie			

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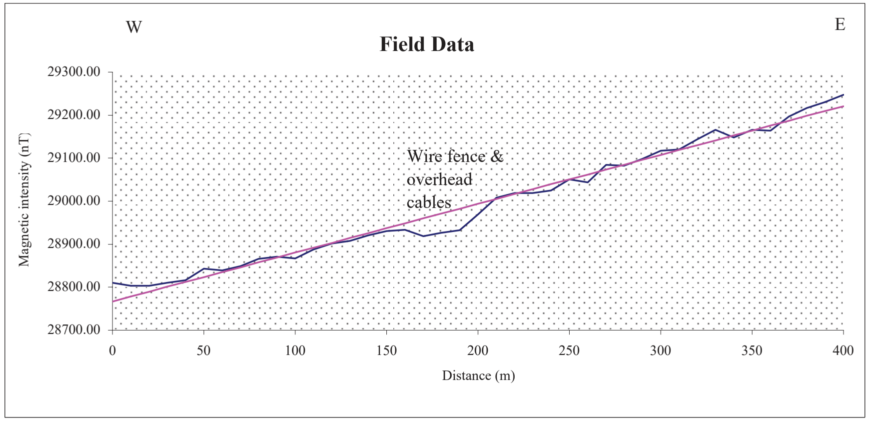
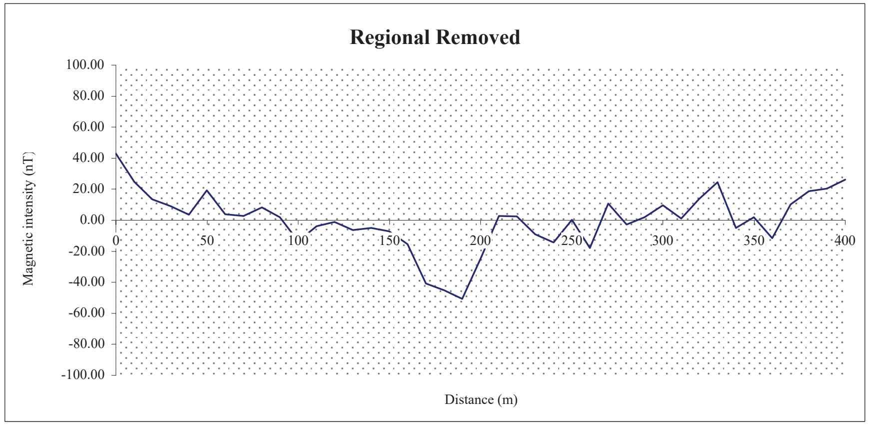
MAGNETIC PROFILES





Project:	Duvha PS - Seepage Investigation	**Profile Direction:**	West to east		
Project Number:	202-15-ghd.457	**Start Stn:**	**0**	25.95876 S	29.34762 E
Profile Number:	Traverse 11		**200**	25.95864 S	29.34994 E
Station Spacing:	10 m	**End Stn:**	**400**	25.95922 S	29.35213 E
Survey Area	North of Emergency Pan	**Operator:**			
Date of Survey:	28 July 2006	F Fourie			

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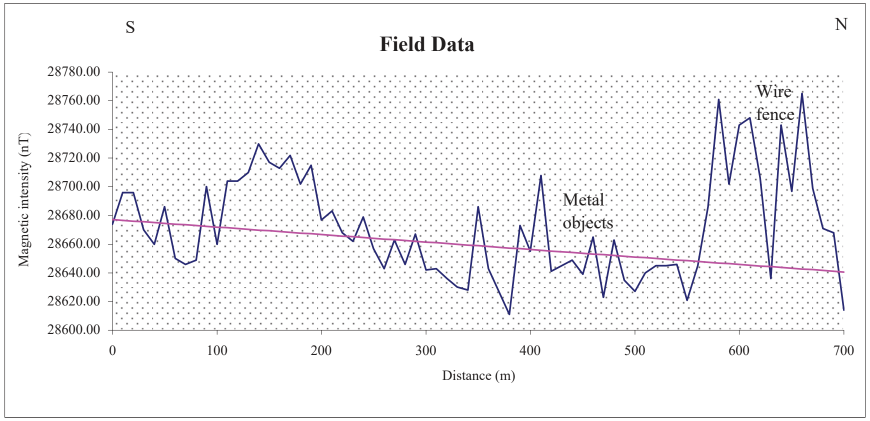
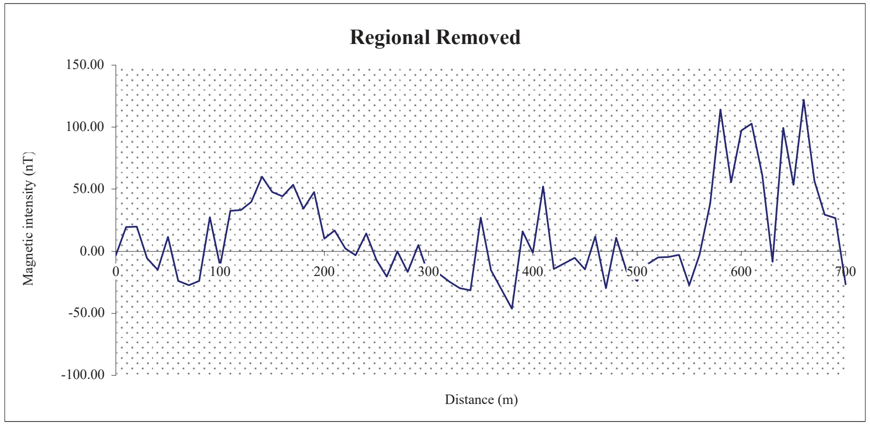
MAGNETIC PROFILES





Project:	Duvha PS - Seepage Investigation	**Profile Direction:**	South to north		
Project Number:	202-15-ghd.457	**Start Stn:**	**0**	25.92884 S	29.34100 E
Profile Number:	Traverse 12		**200**	25.92671 S	29.34114 E
Station Spacing:	10 m		**400**	25.92460 S	29.34132 E
Survey Area	West of LLAWRD	**Operator:**	**600**	25.92243 S	29.34156 E
Date of Survey:	15 August 2006	M Smit **End Stn:**	**700**	25.91360 S	29.34166 E

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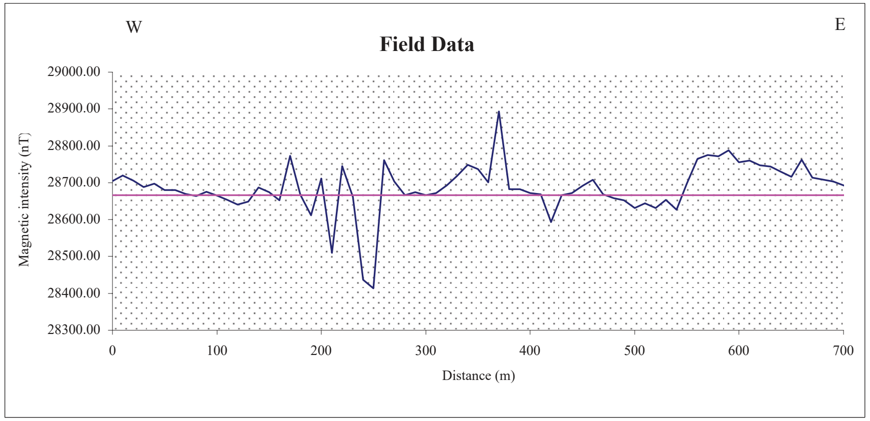
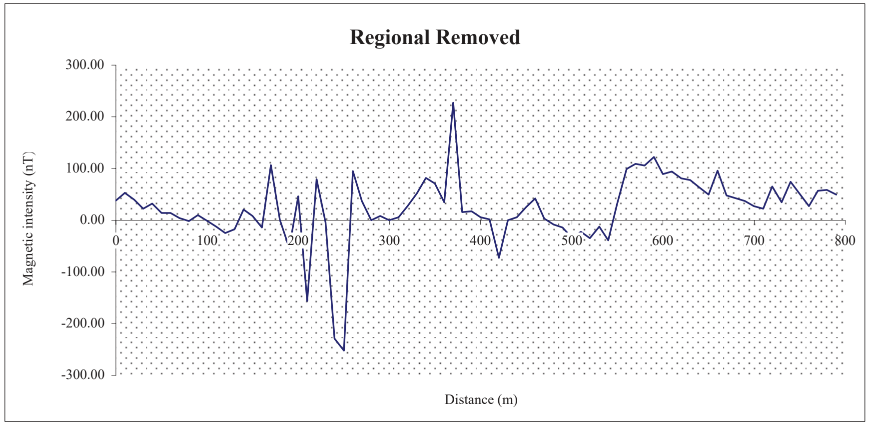
MAGNETIC PROFILES





Project:	Duvha PS - Seepage Investigation	**Profile Direction:**	West to east			
Project Number:	202-15-ghd.457		**Start Stn:**	**0**	25.92132 S	29.34003 E
Profile Number:	Traverse 13			**200**	25.92156 S	29.34240 E
Station Spacing:	10 m			**400**	25.92182 S	29.34472 E
Survey Area	North of LLAWRD	**Operator:**		**600**	25.92205 S	29.34698 E
Date of Survey:	15 August 2006	M Smit	**End Stn:**	**790**	25.92231 S	29.34905 E

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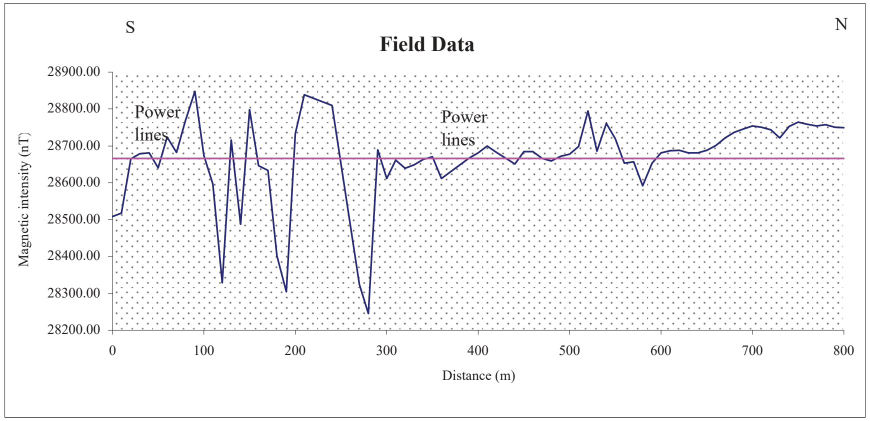
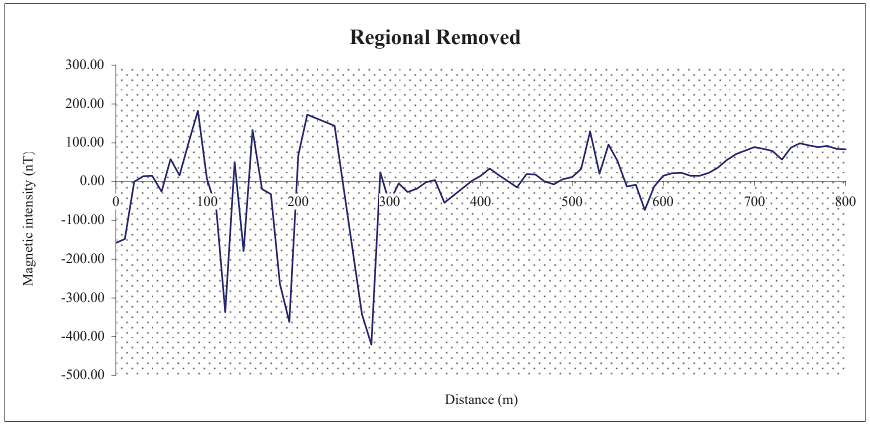
MAGNETIC PROFILES





Project:	Duvha PS - Seepage Investigation	**Profile Direction:**	South to north			
Project Number:	202-15-ghd.457		**Start Stn:**	**0**	25.92428 S	29.34859 E
Profile Number:	Traverse 14			**200**	25.92720 S	29.34825 E
Station Spacing:	10 m			**400**	25.92512 S	29.34799 E
Survey Area	East of LLAWRD	**Operator:**		**600**	25.92311 S	29.34778 E
Date of Survey:	15 August 2006	M Smit	**End Stn:**	**800**	25.92113 S	29.34753 E

Borehole Construction and Geological Log

BASIC SITE INFORMATION: ***Site Identifier:*** 2529CD00014 ***Number:*** PB14 ***Site type:*** Borehole

Distr./Farm No.: 336JS ***Site Name/Des.:*** BH SOUTH-EAST OF RAW WATER DAM

Region Type: ***Region Descr.:***

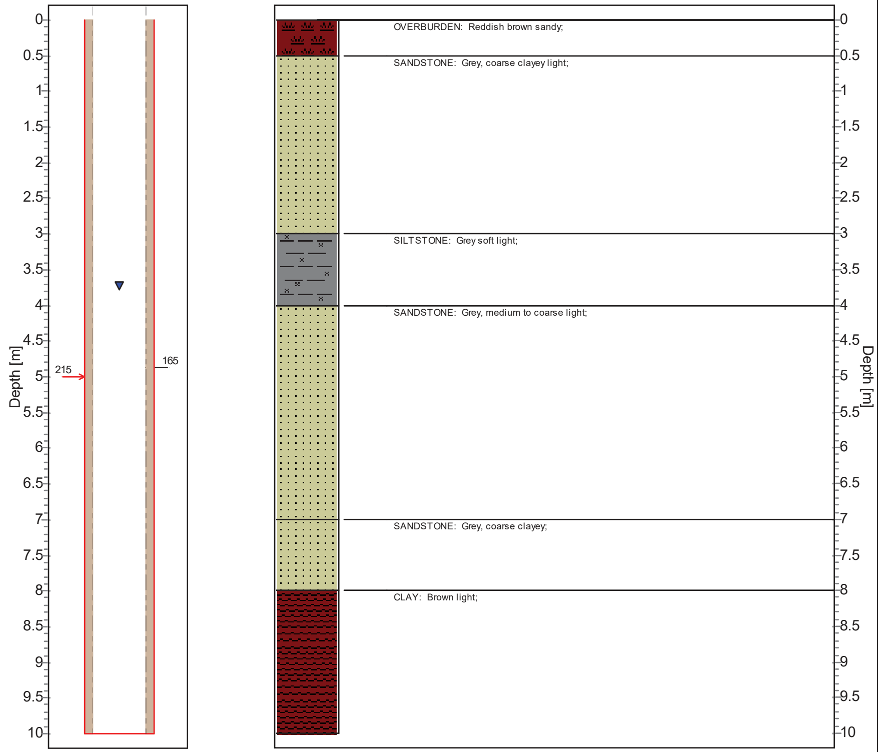
Longitude [°]:	-25.953500	***Reg./BB.:***		***Topo-set.:***	At or in waste disposal	***Depth [m]:***	10.00
Latitude [°]:	29.328990	***G-Nr.:***	BH01	***Site status:***	In use	***Col. ht. [m]:***	0.28
Altitude [m]:	1604.00			***Site purp.:***	Observation	***Diam. [mm]:***	165
Coord. acc.:	Accurate to within 1 000 units			***Use applic.:***	Industrial - power generation	***Drain. reg.:***	B11G
Coord. meth.:	Global Positioning System			***Equipment:***	No equipment	***Rep. inst.:***	GHT

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)

Construction and Geohydrological Legend

Hole		Hole diameter [mm]	165	Drill cuttings	
Casing (plain / perforated, sloted)		Casing diameter [mm]	152		
Screen / Mesh Screen		Waterlevel measured: 15/08/06			
Piezometer		Piezometer (Nr. & Diameter [mm])	0:50		

Construction Lithology



COMMENT: User name and adress

Borehole Construction and Geological Log

BASIC SITE INFORMATION: ***Site Identifier:*** 2529CD00015 ***Number:*** PB15 ***Site type:*** Borehole

Distr./Farm No.: 336JS ***Site Name/Des.:*** BH WEST OF RAW WATER DAM

Region Type: ***Region Descr.:***

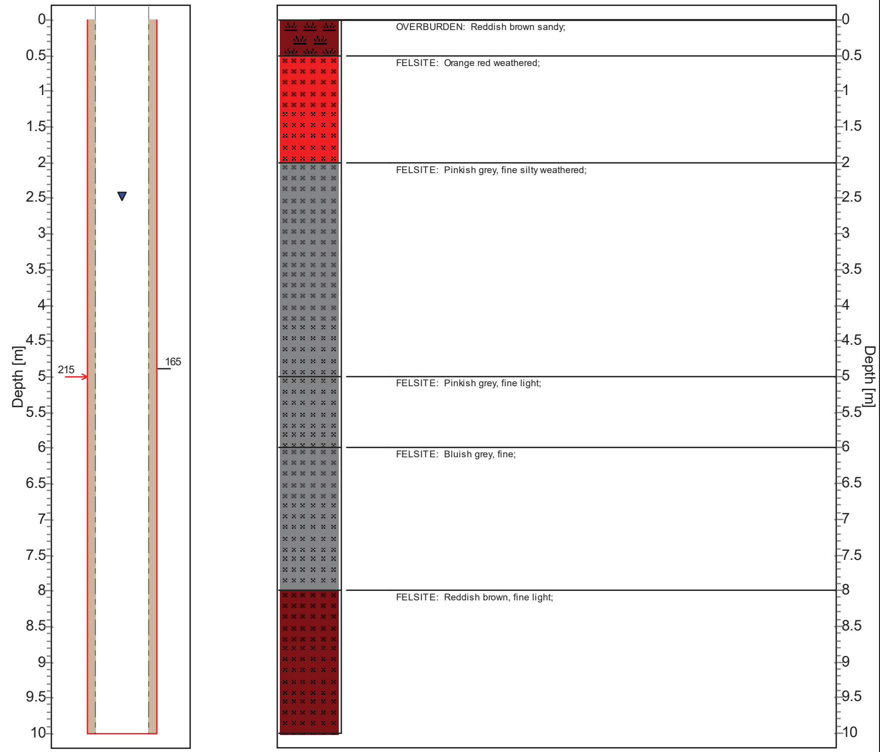
Longitude [°]:	-25.950400	***Reg./BB.:***		***Topo-set.:***	At or in waste disposal	***Depth [m]:***	10.00
Latitude [°]:	29.326850	***G-Nr.:***	BH02	***Site status:***	In use	***Col. ht. [m]:***	0.22
Altitude [m]:	1603.00			***Site purp.:***	Observation	***Diam. [mm]:***	165
Coord. acc.:	Accurate to within 1 000 units			***Use applic.:***	Industrial - power generation	***Drain. reg.:***	B11G
Coord. meth.:	Global Positioning System			***Equipment:***	No equipment	***Rep. inst.:***	GHT

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)

Construction and Geohydrological Legend

Hole		Hole diameter [mm]	165	Drill cuttings	
Casing (plain / perforated, sloted)		Casing diameter [mm]	152		
Screen / Mesh Screen		Waterlevel measured: 15/08/06			
Piezometer		Piezometer (Nr. & Diameter [mm])	0:50		

Construction Lithology



COMMENT: User name and adress

Borehole Construction and Geological Log

BASIC SITE INFORMATION: ***Site Identifier:*** 2529CD00016 ***Number:*** PB16 ***Site type:*** Borehole

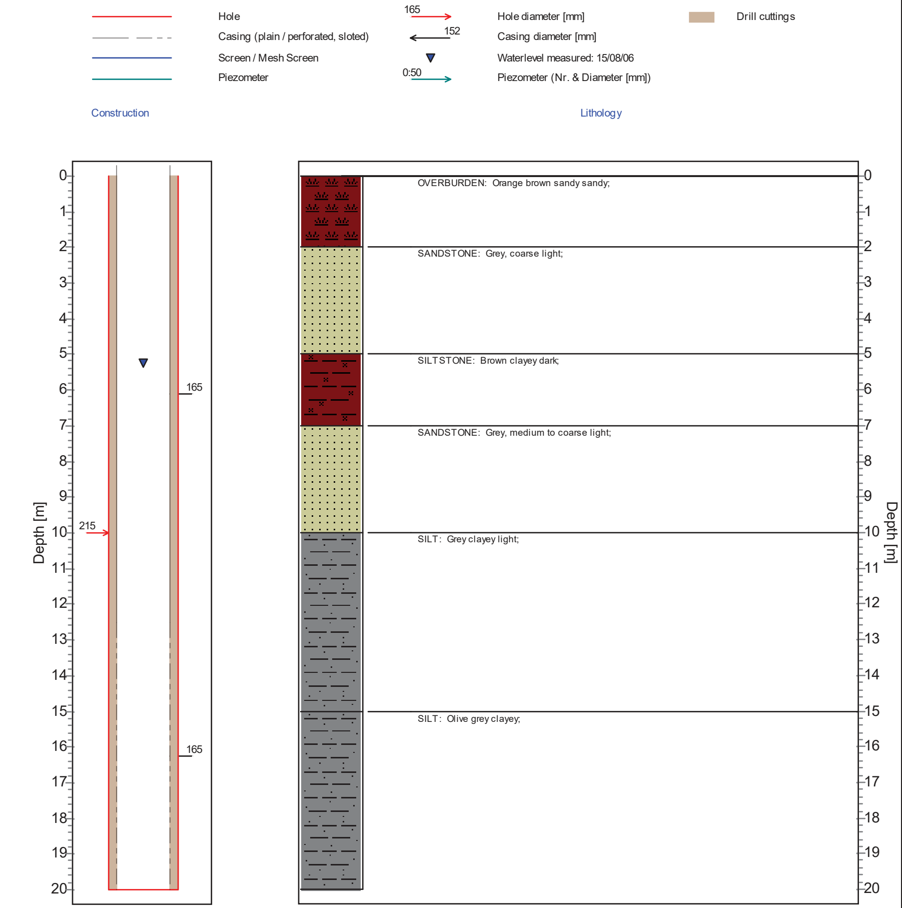
Distr./Farm No.: 336JS ***Site Name/Des.:*** BH SOUTH-WEST OF RAW WATER DAM

Region Type: ***Region Descr.:***

Longitude [°]:	-25.952360
Latitude [°]:	29.326780
Altitude [m]:	1602.50
Coord. acc.:	Accurate to within 1 000 units
Coord. meth.:	Global Positioning System
Reg./BB.:	
G-Nr.:	BH03
Topo-set.:	At or in waste disposal
Site status:	In use
Site purp.:	Observation
Use applic.:	Industrial - power generation
Equipment:	No equipment
Depth [m]:	20.00
Col. ht. [m]:	0.31
Diam. [mm]:	165
Drain. reg.:	B11G
Rep. inst.:	GHT

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)

Construction and Geohydrological Legend



COMMENT:

User name and adress

Borehole Construction and Geological Log

BASIC SITE INFORMATION: ***Site Identifier:*** 2529CD00017 ***Number:*** PB17 ***Site type:*** Borehole

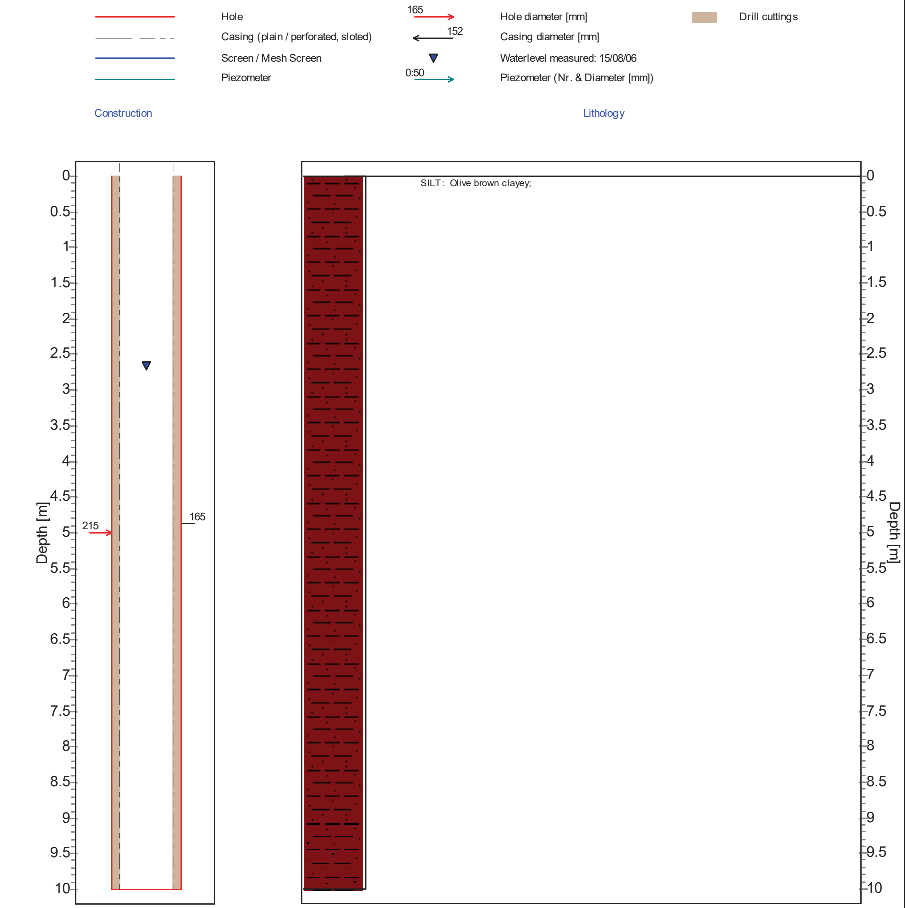
Distr./Farm No.: 336JS ***Site Name/Des.:*** BH WEST OF SEWAGE PLANT

Region Type: ***Region Descr.:***

Longitude [°]:	-25.959210
Latitude [°]:	29.320640
Altitude [m]:	1577.75
Coord. acc.:	Accurate to within 1 000 units
Coord. meth.:	Global Positioning System
Reg./BB.:	
G-Nr.:	BH04
Topo-set.:	At or in waste disposal
Site status:	In use
Site purp.:	Observation
Use applic.:	Industrial - power generation
Equipment:	No equipment
Depth [m]:	10.00
Col. ht. [m]:	0.28
Diam. [mm]:	165
Drain. reg.:	B11G
Rep. inst.:	GHT

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)

Construction and Geohydrological Legend



COMMENT:

User name and adress

Borehole Construction and Geological Log

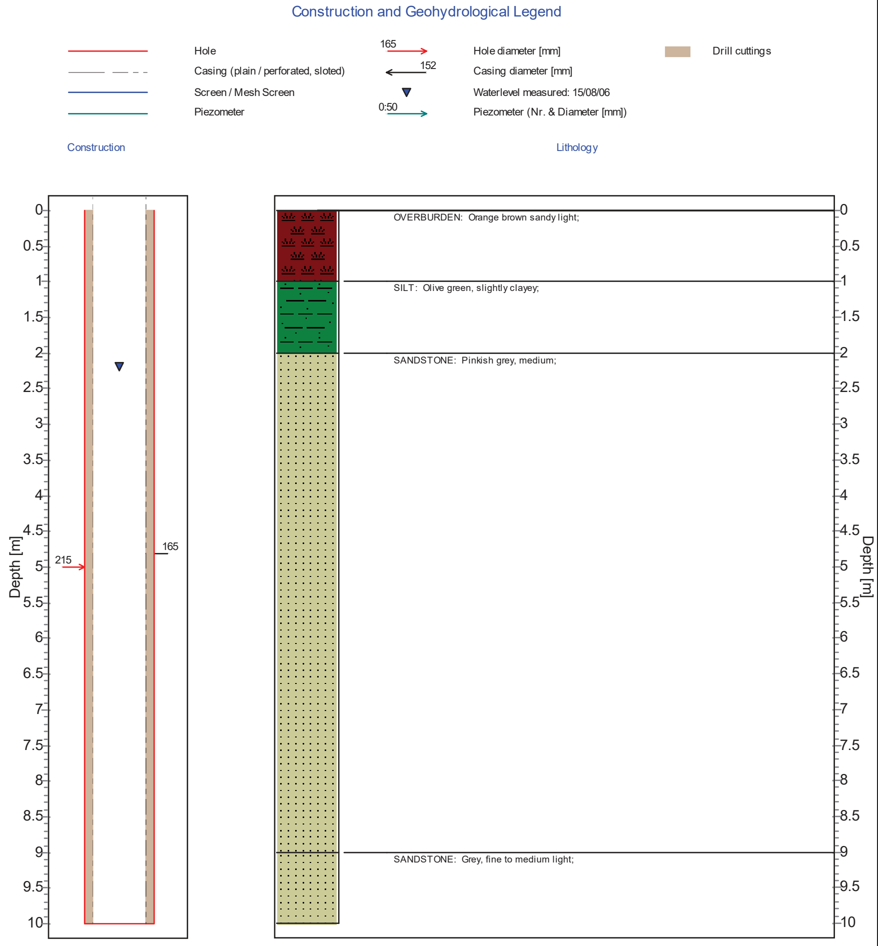
BASIC SITE INFORMATION: ***Site Identifier:*** 2529CD00018 ***Number:*** PB18 ***Site type:*** Borehole

Distr./Farm No.: 336JS ***Site Name/Des.:*** BH NORTH OF SEWAGE PLANT

Region Type: ***Region Descr.:***

Longitude [°]:	-25.958430	***Reg./BB.:***		***Topo-set.:***	At or in waste disposal	***Depth [m]:***	10.00
Latitude [°]:	29.322990	***G-Nr.:***	BH05	***Site status:***	In use	***Col. ht. [m]:***	0.38
Altitude [m]:	1587.50			***Site purp.:***	Observation	***Diam. [mm]:***	165
Coord. acc.:	Accurate to within 1 000 units			***Use applic.:***	Industrial - power generation	***Drain. reg.:***	B11G
Coord. meth.:	Global Positioning System			***Equipment:***	No equipment	***Rep. inst.:***	GHT

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)



COMMENT: User name and adress

Borehole Construction and Geological Log

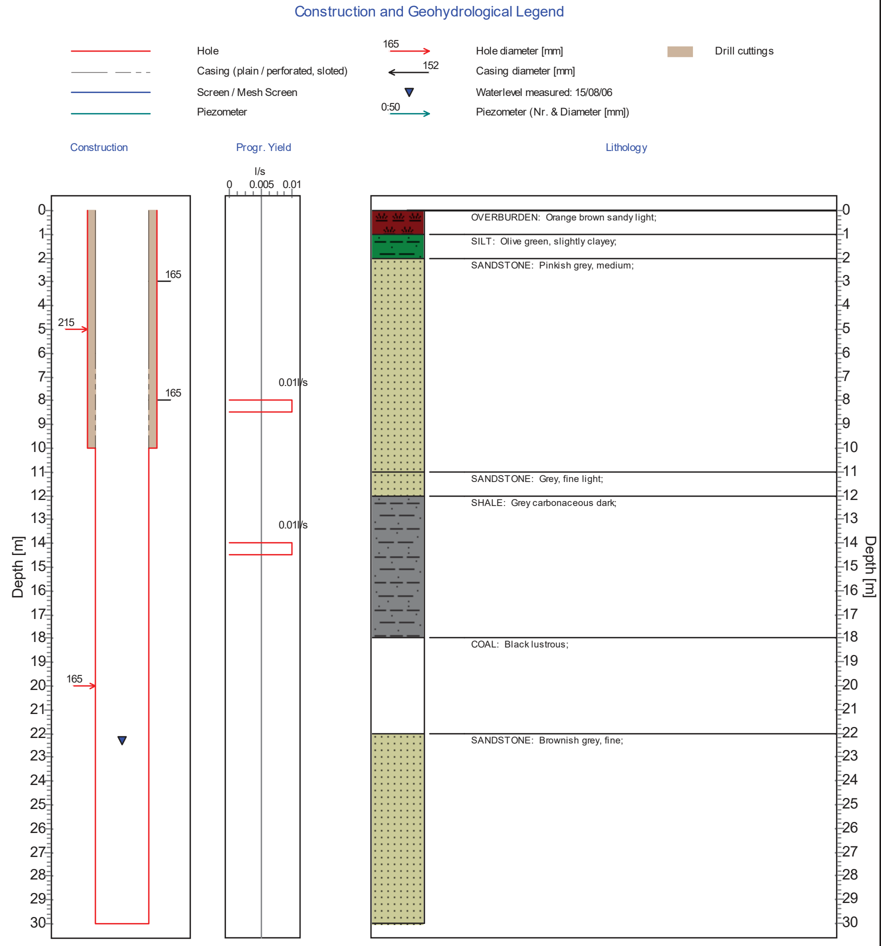
BASIC SITE INFORMATION: ***Site Identifier:*** 2529CD00019 ***Number:*** PB19 ***Site type:*** Borehole

Distr./Farm No.: 336JS ***Site Name/Des.:*** BH SOUTH OF SEWAGE PLANT

Region Type: ***Region Descr.:***

Longitude [°]:	-25.960680	***Reg./BB.:***		***Topo-set.:***	At or in waste disposal	***Depth [m]:***	30.00
Latitude [°]:	29.322780	***G-Nr.:***	BH06	***Site status:***	In use	***Col. ht. [m]:***	0.76
Altitude [m]:	1585.00			***Site purp.:***	Observation	***Diam. [mm]:***	165
Coord. acc.:	Accurate to within 1 000 units			***Use applic.:***	Industrial - power generation	***Drain. reg.:***	B11G
Coord. meth.:	Global Positioning System			***Equipment:***	No equipment	***Rep. inst.:***	GHT

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)



COMMENT: User name and adress

Borehole Construction and Geological Log

BASIC SITE INFORMATION: ***Site Identifier:*** 2529CD00020 ***Number:*** PB20 ***Site type:*** Borehole

Distr./Farm No.: 336JS ***Site Name/Des.:*** BH NORTH OF HLAWRD

Region Type: ***Region Descr.:***

Longitude [°]:	-25.952650	***Reg./BB.:***		***Topo-set.:***	At or in waste disposal	***Depth [m]:***	10.00
Latitude [°]:	29.345140	***G-Nr.:***	BH07	***Site status:***	In use	***Col. ht. [m]:***	0.35
Altitude [m]:	1587.50			***Site purp.:***	Observation	***Diam. [mm]:***	165
Coord. acc.:	Accurate to within 1 000 units			***Use applic.:***	Industrial - power generation	***Drain. reg.:***	B11G
Coord. meth.:	Global Positioning System			***Equipment:***	No equipment	***Rep. inst.:***	GHT

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)

Construction and Geohydrological Legend

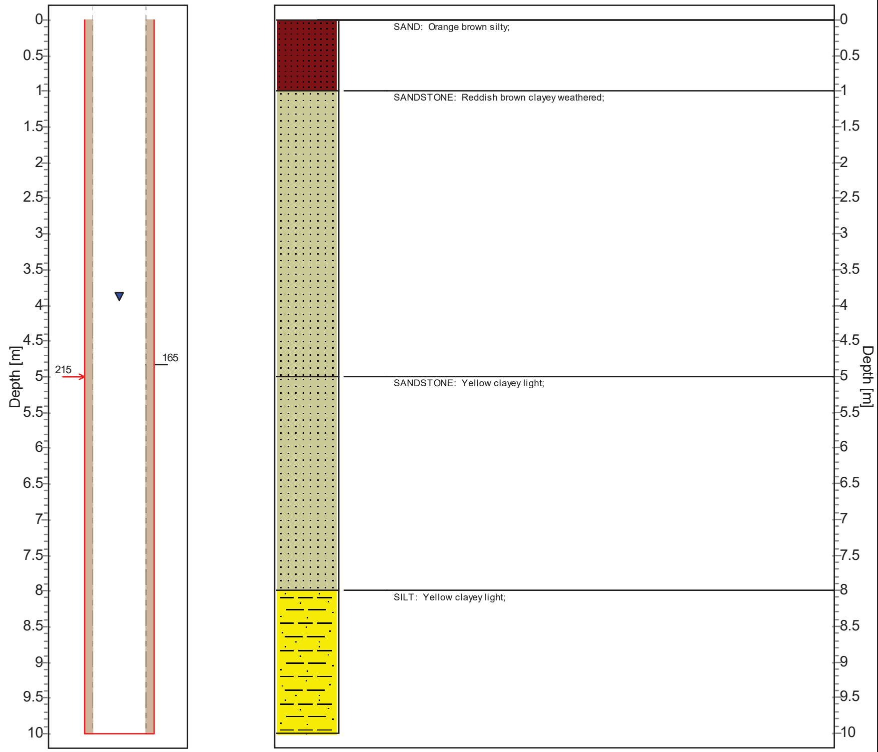
Hole — 165 Hole diameter [mm] — Drill cuttings

Casing (plain / perforated, sloted) — 152 Casing diameter [mm]

Screen / Mesh Screen — Waterlevel measured: 16/08/06

Piezometer — 0:50 Piezometer (Nr. & Diameter [mm])

Construction — Lithology



COMMENT:

User name and adress

Borehole Construction and Geological Log

BASIC SITE INFORMATION: ***Site Identifier:*** 2529CD00021 ***Number:*** PB21 ***Site type:*** Borehole

Distr./Farm No.: 336JS ***Site Name/Des.:*** BH NORTH-EAST OF HLAWRD

Region Type: ***Region Descr.:***

Longitude [°]:	-25.953040	***Reg./BB.:***		***Topo-set.:***	At or in waste disposal	***Depth [m]:***	30.00
Latitude [°]:	29.345440	***G-Nr.:***	BH08	***Site status:***	In use	***Col. ht. [m]:***	0.34
Altitude [m]:	1587.50			***Site purp.:***	Observation	***Diam. [mm]:***	165
Coord. acc.:	Accurate to within 1 000 units			***Use applic.:***	Industrial - power generation	***Drain. reg.:***	B11G
Coord. meth.:	Global Positioning System			***Equipment:***	No equipment	***Rep. inst.:***	GHT

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)

Construction and Geohydrological Legend

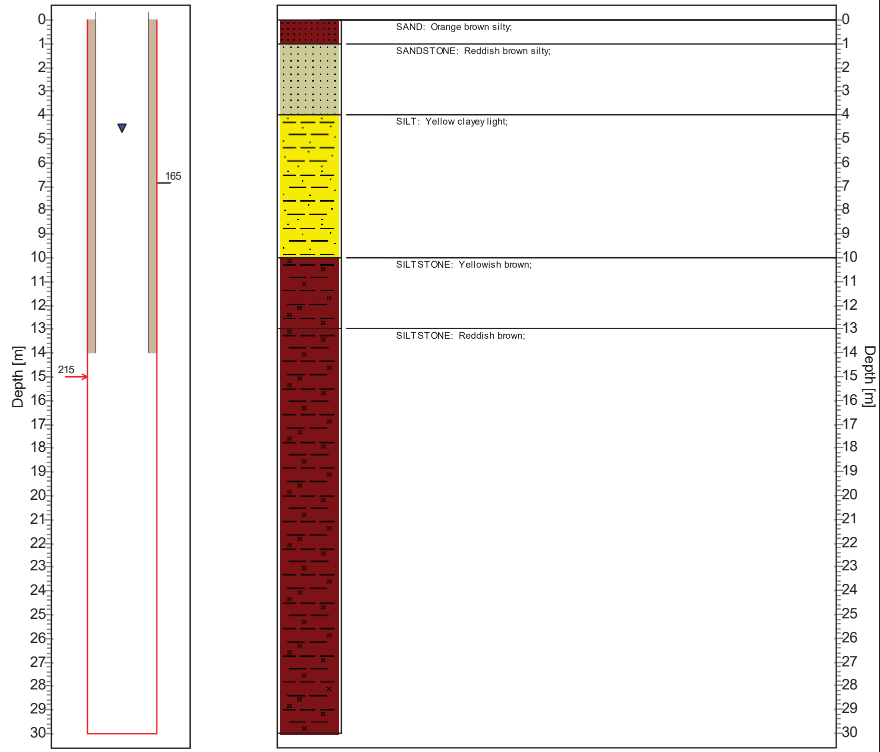
Hole — 165 Hole diameter [mm] — Drill cuttings

Casing (plain / perforated, sloted) — 152 Casing diameter [mm]

Screen / Mesh Screen — Waterlevel measured: 16/08/06

Piezometer — 0:50 Piezometer (Nr. & Diameter [mm])

Construction — Lithology



COMMENT:

User name and adress

Borehole Construction and Geological Log

BASIC SITE INFORMATION: ***Site Identifier:*** 2529CD00022 ***Number:*** PB22 ***Site type:*** Borehole

Distr./Farm No.: 336JS ***Site Name/Des.:*** BH SOUTH-EAST OF HLAWRD

Region Type: ***Region Descr.:***

Longitude [°]: -25.954510	***Reg./BB.:***	***Topo-set.:*** At or in waste disposal	***Depth [m]:*** 10.00
Latitude [°]: 29.346270	***G-Nr.:*** BH09	***Site status:*** In use	***Col. ht. [m]:*** 0.49
Altitude [m]: 1588.75		***Site purp.:*** Observation	***Diam. [mm]:*** 165
Coord. acc.: Accurate to within 1 000 units		***Use applic.:*** Industrial - power generation	***Drain. reg.:*** B11G
Coord. meth.: Global Positioning System		***Equipment:*** No equipment	***Rep. inst.:*** GHT

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)

Construction and Geohydrological Legend

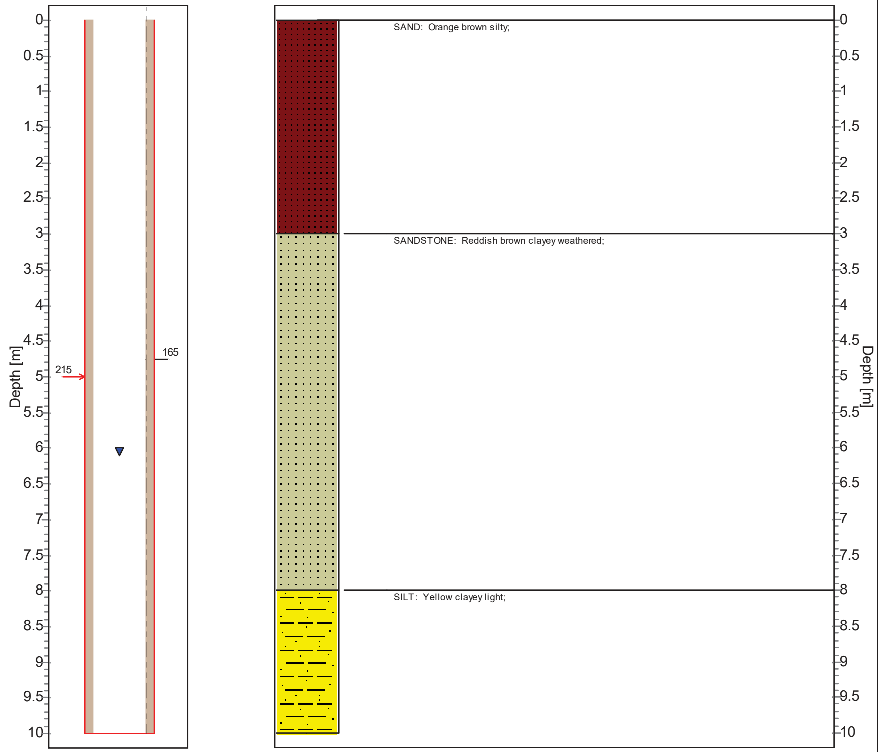
Hole — 165 Hole diameter [mm] — Drill cuttings

Casing (plain / perforated, sloted) — 152 Casing diameter [mm]

Screen / Mesh Screen — Waterlevel measured: 16/08/06

Piezometer — 0:50 Piezometer (Nr. & Diameter [mm])

Construction — Lithology



COMMENT: User name and adress

Borehole Construction and Geological Log

BASIC SITE INFORMATION: ***Site Identifier:*** 2529CD00023 ***Number:*** PB23 ***Site type:*** Borehole

Distr./Farm No.: 336JS ***Site Name/Des.:*** BH NORTH OF EMERGENCY PAN

Region Type: ***Region Descr.:***

Longitude [°]: -25.958770	***Reg./BB.:***	***Topo-set.:*** At or in waste disposal	***Depth [m]:*** 10.00
Latitude [°]: 29.348890	***G-Nr.:*** BH10	***Site status:*** In use	***Col. ht. [m]:*** 0.66
Altitude [m]: 1586.00		***Site purp.:*** Observation	***Diam. [mm]:*** 165
Coord. acc.: Accurate to within 1 000 units		***Use applic.:*** Industrial - power generation	***Drain. reg.:*** B11G
Coord. meth.: Global Positioning System		***Equipment:*** No equipment	***Rep. inst.:*** GHT

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)

Construction and Geohydrological Legend

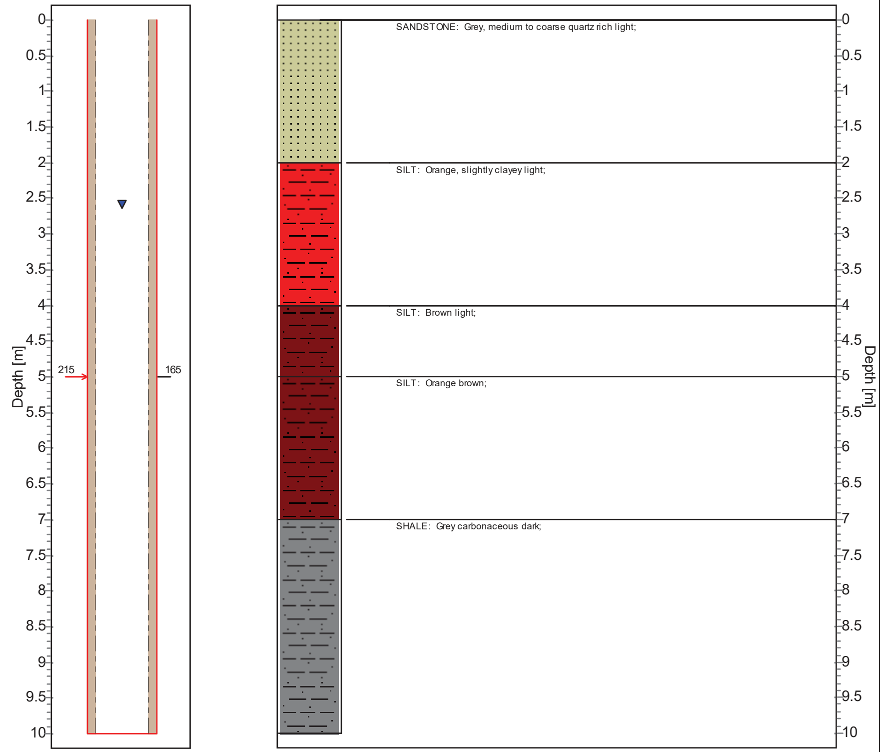
Hole — 165 Hole diameter [mm] — Drill cuttings

Casing (plain / perforated, sloted) — 152 Casing diameter [mm]

Screen / Mesh Screen — Waterlevel measured: 15/08/06

Piezometer — 0:50 Piezometer (Nr. & Diameter [mm])

Construction — Lithology



COMMENT: User name and adress

Borehole Construction and Geological Log

BASIC SITE INFORMATION: ***Site Identifier:*** 2529CD00024 ***Number:*** PB24 ***Site type:*** Borehole

Distr./Farm No.: 336JS ***Site Name/Des.:*** BH NORTH OF EMERGENCY PAN

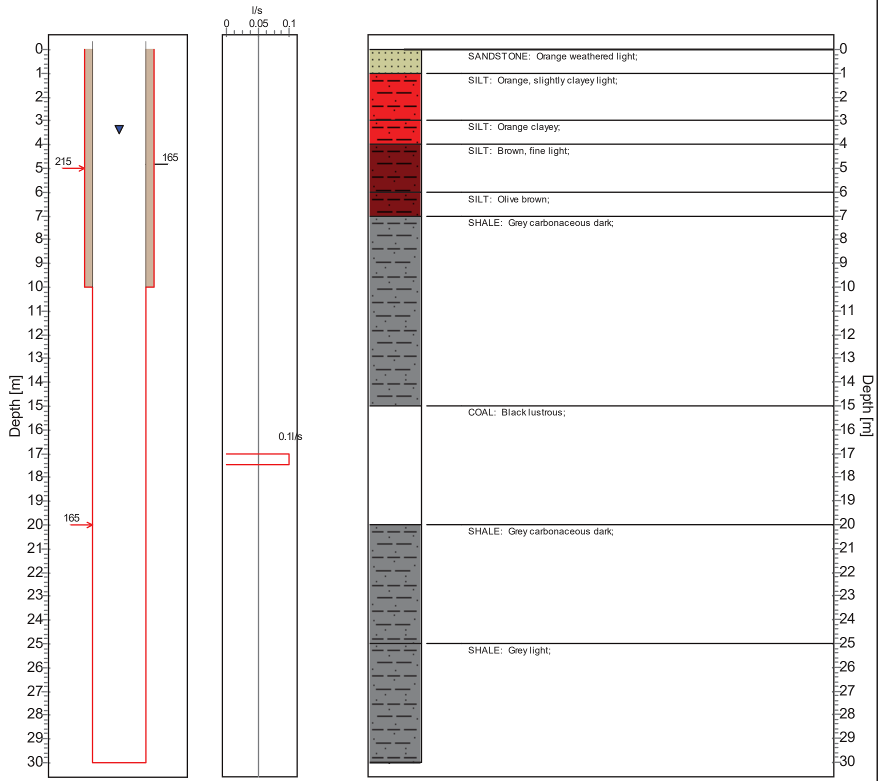
Region Type: ***Region Descr.:***

Longitude [°]:	-25.958850
Latitude [°]:	29.349450
Altitude [m]:	1586.00
Coord. acc.:	Accurate to within 1 000 units
Coord. meth.:	Global Positioning System
Reg./BB.:	
G-Nr.:	BH11
Topo-set.:	At or in waste disposal
Site status:	In use
Site purp.:	Observation
Use applic.:	Industrial - power generation
Equipment:	No equipment
Depth [m]:	30.00
Col. ht. [m]:	0.32
Diam. [mm]:	165
Drain. reg.:	B11G
Rep. inst.:	GHT

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)

Construction and Geohydrological Legend

Hole — 165 Hole diameter [mm] — Drill cuttings
Casing (plain / perforated, sloted) — 152 Casing diameter [mm]
Screen / Mesh Screen — Waterlevel measured: 15/08/06
Piezometer — 0:50 Piezometer (Nr. & Diameter [mm])



COMMENT:

User name and adress

Borehole Construction and Geological Log

BASIC SITE INFORMATION: ***Site Identifier:*** 2529CD00025 ***Number:*** PB25 ***Site type:*** Borehole

Distr./Farm No.: 336JS ***Site Name/Des.:*** BH SOUTH OF EMERGENCY PAN

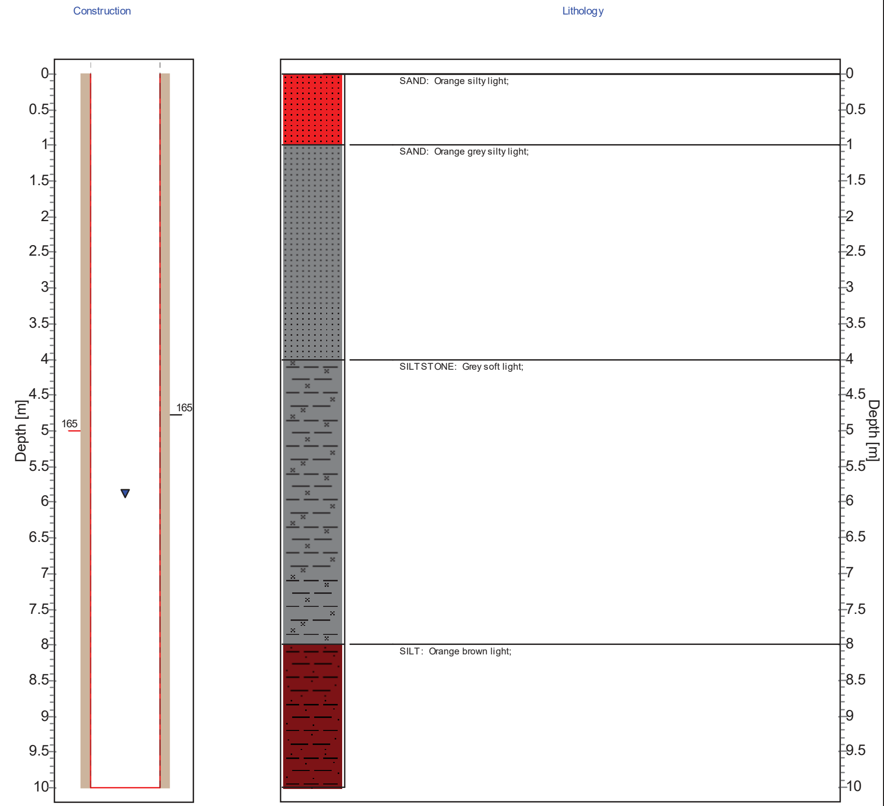
Region Type: ***Region Descr.:***

Longitude [°]:	-25.965380
Latitude [°]:	29.346930
Altitude [m]:	1586.00
Coord. acc.:	Accurate to within 1 000 units
Coord. meth.:	Global Positioning System
Reg./BB.:	
G-Nr.:	BH12
Topo-set.:	At or in waste disposal
Site status:	In use
Site purp.:	Observation
Use applic.:	Industrial - power generation
Equipment:	No equipment
Depth [m]:	10.00
Col. ht. [m]:	0.45
Diam. [mm]:	165
Drain. reg.:	B11G
Rep. inst.:	GHT

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)

Construction and Geohydrological Legend

Hole — 165 Hole diameter [mm] — Drill cuttings
Casing (plain / perforated, sloted) — 152 Casing diameter [mm]
Screen / Mesh Screen — Waterlevel measured: 15/08/06
Piezometer — 0:50 Piezometer (Nr. & Diameter [mm])



COMMENT:

User name and adress

Borehole Construction and Geological Log

BASIC SITE INFORMATION: ***Site Identifier:*** 2529CD00026 ***Number:*** AB26 ***Site type:*** Borehole

Distr./Farm No.: 336JS ***Site Name/Des.:*** BH NORTH OF ASH DAM

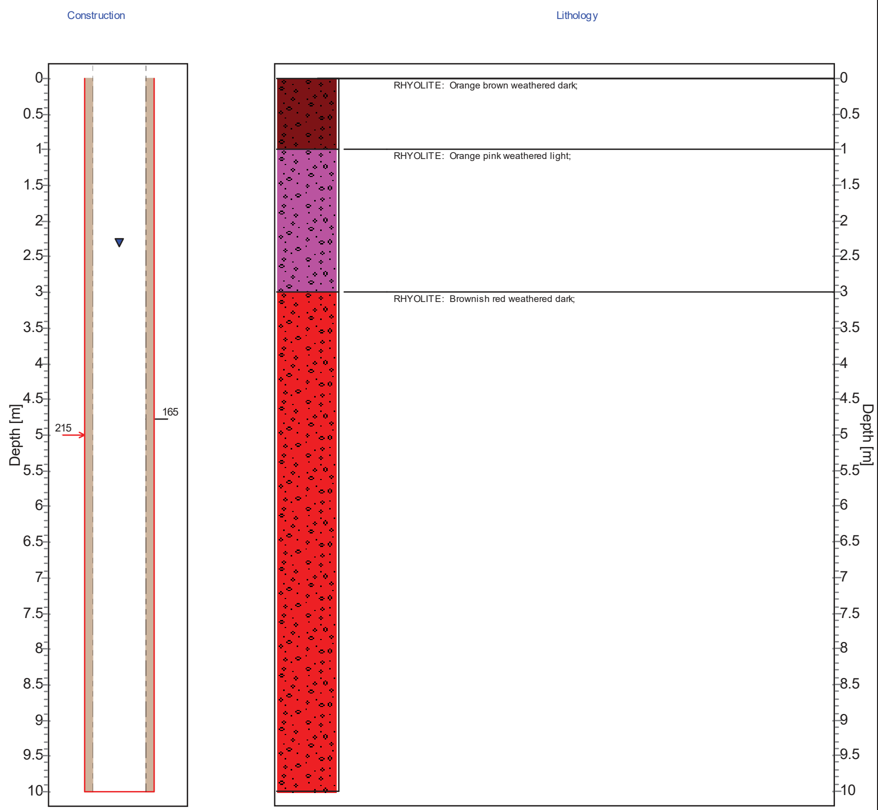
Region Type: ***Region Descr.:***

Longitude [°]: -25.939810	***Reg./BB.:***	***Topo-set.:*** At or in waste disposal	***Depth [m]:*** 10.00
Latitude [°]: 29.322060	***G-Nr.:*** BH13	***Site status:*** In use	***Col. ht. [m]:*** 0.46
Altitude [m]: 1581.00		***Site purp.:*** Observation	***Diam. [mm]:*** 165
Coord. acc.: Accurate to within 1 000 units		***Use applic.:*** Industrial - power generation	***Drain. reg.:*** B11G
Coord. meth.: Global Positioning System		***Equipment:*** No equipment	***Rep. inst.:*** GHT

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)

Construction and Geohydrological Legend

Hole — 165 Hole diameter [mm] — Drill cuttings
Casing (plain / perforated, sloted) — 152 Casing diameter [mm]
Screen / Mesh Screen — Waterlevel measured: 14/08/06
Piezometer — 0:50 Piezometer (Nr. & Diameter [mm])



COMMENT: User name and adress

Borehole Construction and Geological Log

BASIC SITE INFORMATION: ***Site Identifier:*** 2529CD00027 ***Number:*** AB27 ***Site type:*** Borehole

Distr./Farm No.: 336JS ***Site Name/Des.:*** BH NORTH OF ASH DAM

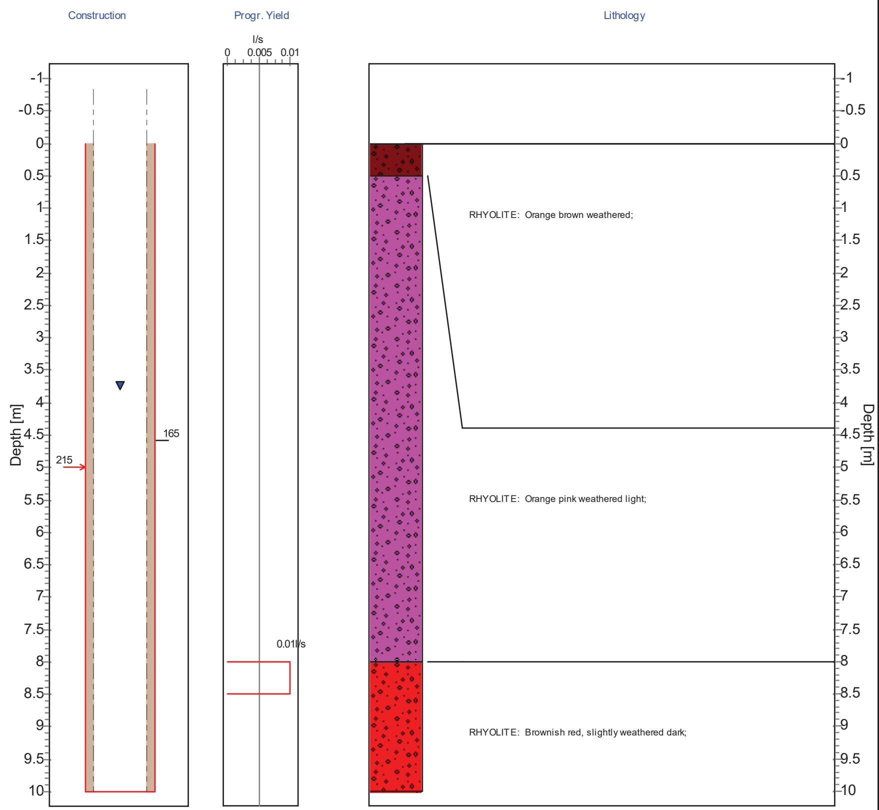
Region Type: ***Region Descr.:***

Longitude [°]: -25.936580	***Reg./BB.:***	***Topo-set.:*** At or in waste disposal	***Depth [m]:*** 10.00
Latitude [°]: 29.327620	***G-Nr.:*** BH14	***Site status:*** In use	***Col. ht. [m]:*** 0.84
Altitude [m]: 1569.00		***Site purp.:*** Observation	***Diam. [mm]:*** 165
Coord. acc.: Accurate to within 1 000 units		***Use applic.:*** Industrial - power generation	***Drain. reg.:*** B11G
Coord. meth.: Global Positioning System		***Equipment:*** No equipment	***Rep. inst.:*** GHT

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)

Construction and Geohydrological Legend

Hole — 165 Hole diameter [mm] — Drill cuttings
Casing (plain / perforated, sloted) — 152 Casing diameter [mm]
Screen / Mesh Screen — Waterlevel measured: 14/08/06
Piezometer — 0:50 Piezometer (Nr. & Diameter [mm])



COMMENT: User name and adress

Borehole Construction and Geological Log

BASIC SITE INFORMATION: ***Site Identifier:*** 2529CD00028 ***Number:*** AB28 ***Site type:*** Borehole

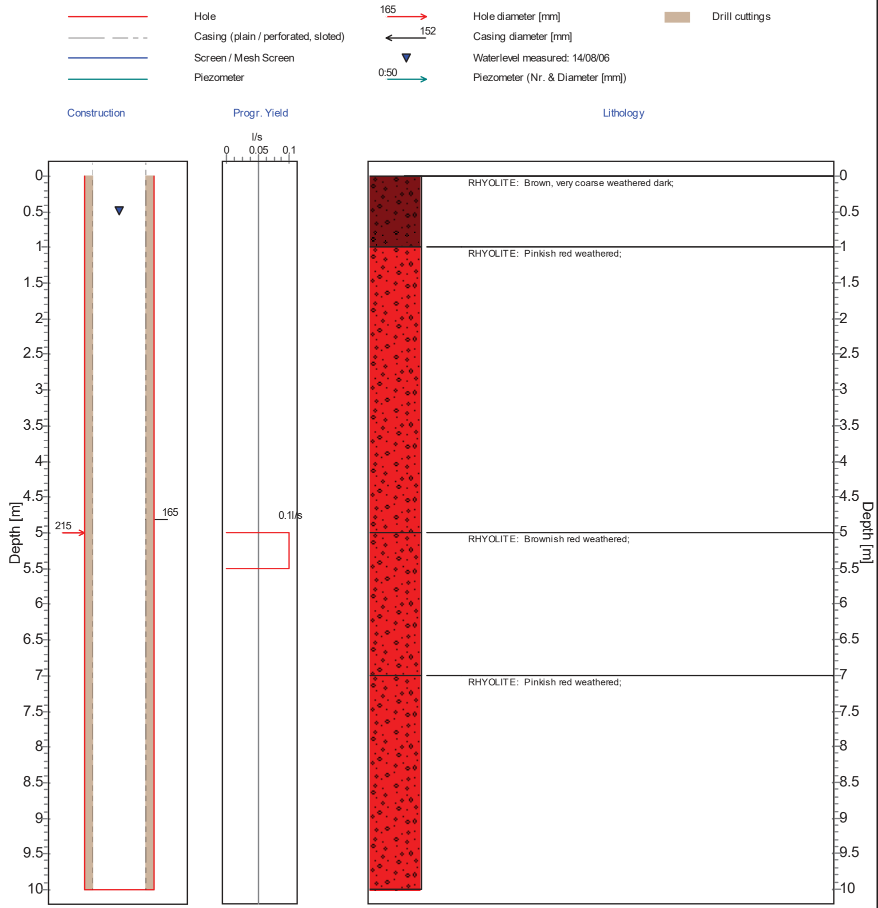
Distr./Farm No.: 336JS ***Site Name/Des.:*** BH NORTH OF ASH DAM

Region Type: ***Region Descr.:***

Longitude [°]:	-25.932770	***Reg./BB.:***		***Topo-set.:***	At or in waste disposal	***Depth [m]:***	10.00
Latitude [°]:	29.334450	***G-Nr.:***	BH15	***Site status:***	In use	***Col. ht. [m]:***	0.38
Altitude [m]:	1559.00			***Site purp.:***	Observation	***Diam. [mm]:***	165
Coord. acc.:	Accurate to within 1 000 units			***Use applic.:***	Industrial - power generation	***Drain. reg.:***	B11G
Coord. meth.:	Global Positioning System			***Equipment:***	No equipment	***Rep. inst.:***	GHT

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)

Construction and Geohydrological Legend



COMMENT:

User name and adress

Borehole Construction and Geological Log

BASIC SITE INFORMATION: ***Site Identifier:*** 2529CD00029 ***Number:*** AB29 ***Site type:*** Borehole

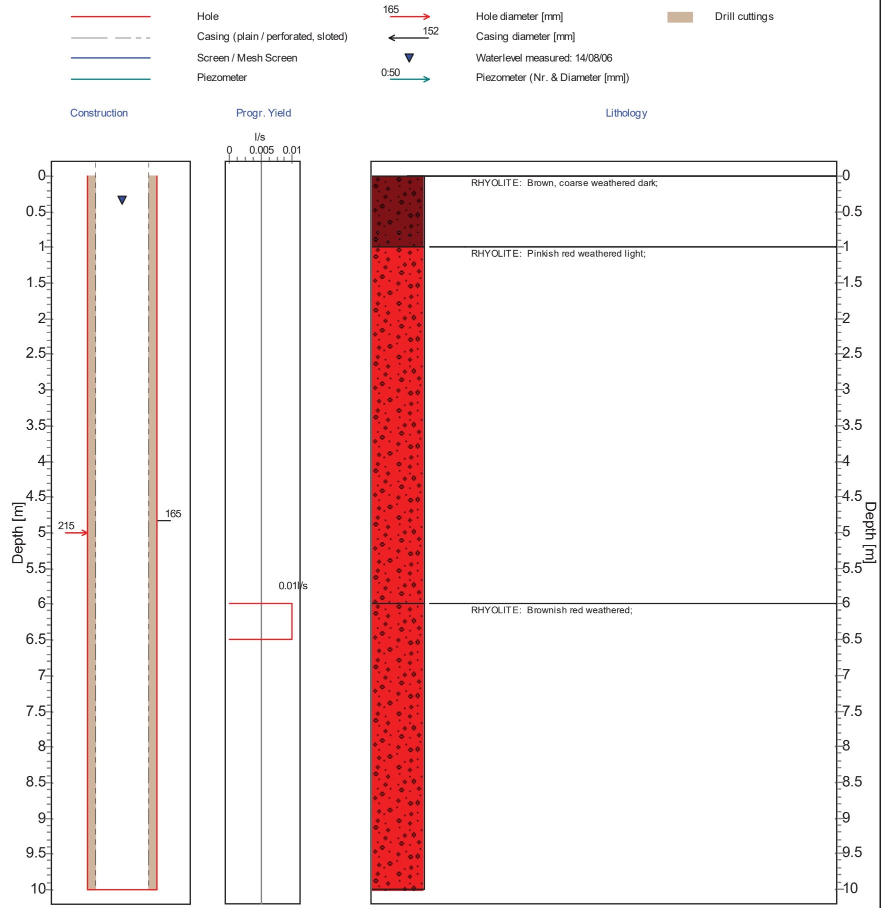
Distr./Farm No.: 336JS ***Site Name/Des.:*** BH NORTH OF ASH DAM

Region Type: ***Region Descr.:***

Longitude [°]:	-25.929810	***Reg./BB.:***		***Topo-set.:***	At or in waste disposal	***Depth [m]:***	10.00
Latitude [°]:	29.339830	***G-Nr.:***	BH16	***Site status:***	In use	***Col. ht. [m]:***	0.34
Altitude [m]:	1548.00			***Site purp.:***	Observation	***Diam. [mm]:***	165
Coord. acc.:	Accurate to within 1 000 units			***Use applic.:***	Industrial - power generation	***Drain. reg.:***	B11G
Coord. meth.:	Global Positioning System			***Equipment:***	No equipment	***Rep. inst.:***	GHT

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)

Construction and Geohydrological Legend



COMMENT:

User name and adress

Borehole Construction and Geological Log

BASIC SITE INFORMATION: ***Site Identifier:*** 2529CD00030 ***Number:*** AB30 ***Site type:*** Borehole

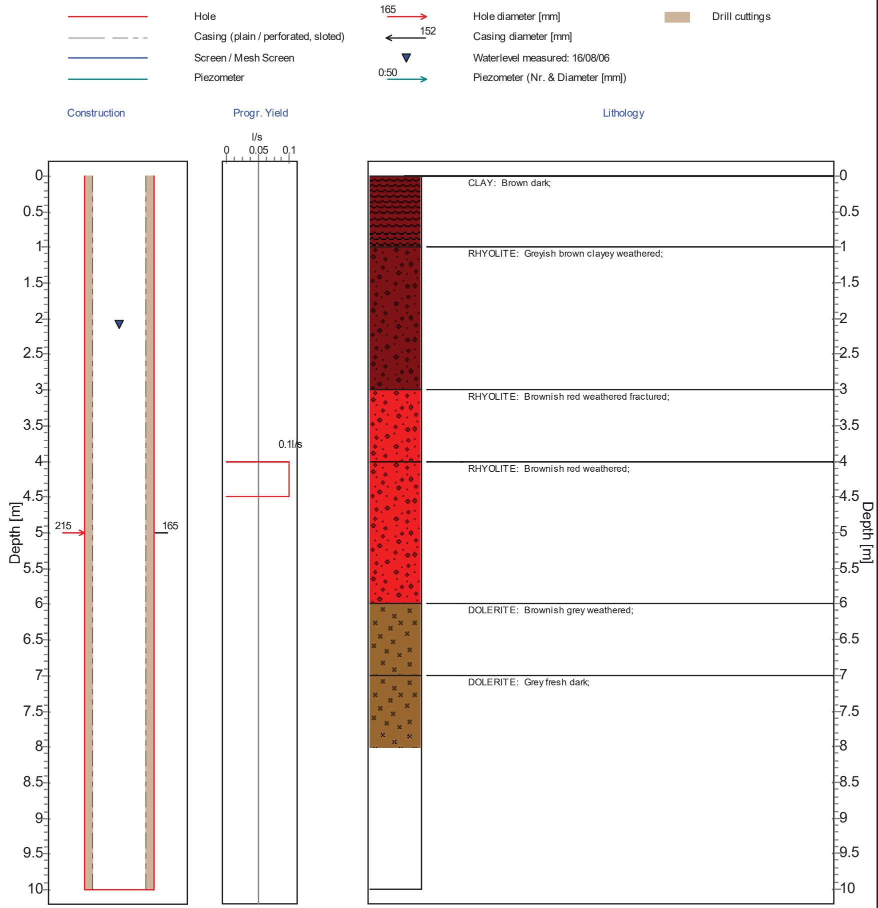
Distr./Farm No.: 318JS ***Site Name/Des.:*** BH NORTH OF LLAWRD

Region Type: ***Region Descr.:***

Longitude [°]:	-25.923150	***Reg./BB.:***		***Topo-set.:***	At or in waste disposal	***Depth [m]:***	10.00
Latitude [°]:	29.344350	***G-Nr.:***	BH17	***Site status:***	In use	***Col. ht. [m]:***	1.13
Altitude [m]:	1528.00			***Site purp.:***	Observation	***Diam. [mm]:***	165
Coord. acc.:	Accurate to within 1 000 units			***Use applic.:***	Industrial - power generation	***Drain. reg.:***	B11G
Coord. meth.:	Global Positioning System			***Equipment:***	No equipment	***Rep. inst.:***	GHT

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)

Construction and Geohydrological Legend



COMMENT: User name and adress

Borehole Construction and Geological Log

BASIC SITE INFORMATION: ***Site Identifier:*** 2529CD00031 ***Number:*** AB31 ***Site type:*** Borehole

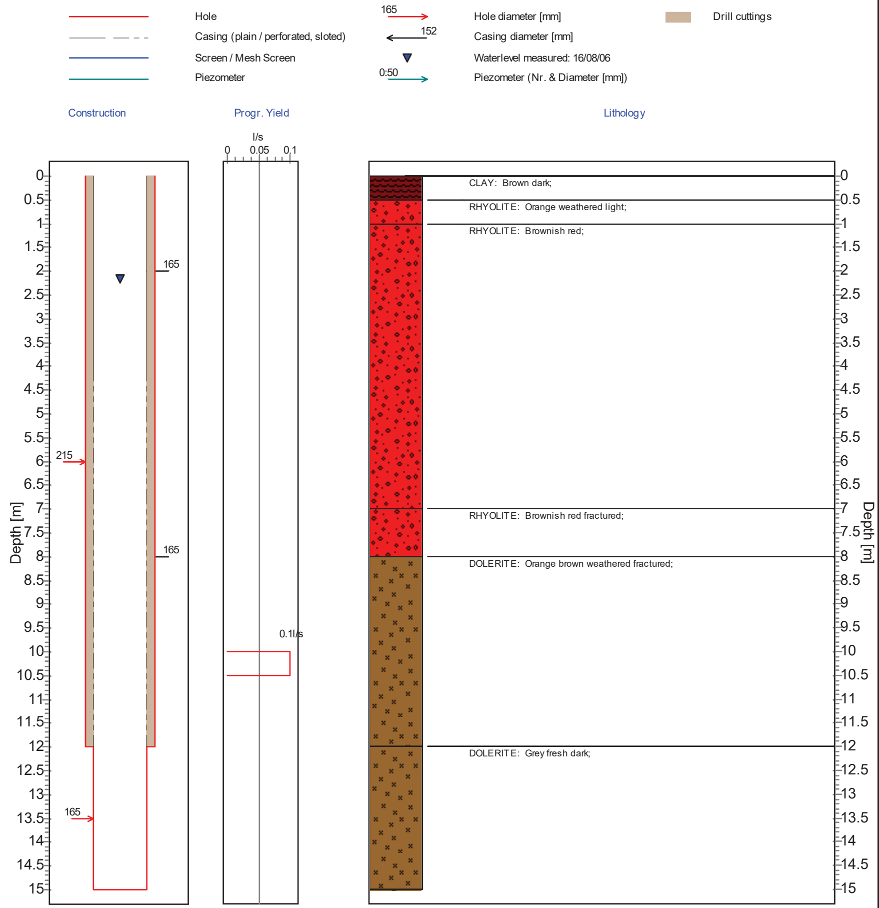
Distr./Farm No.: 318JS ***Site Name/Des.:*** BH NORTH OF LLAWRD

Region Type: ***Region Descr.:***

Longitude [°]:	-25.923070	***Reg./BB.:***		***Topo-set.:***	At or in waste disposal	***Depth [m]:***	15.00
Latitude [°]:	29.344120	***G-Nr.:***	BH18	***Site status:***	In use	***Col. ht. [m]:***	1.15
Altitude [m]:	1528.00			***Site purp.:***	Observation	***Diam. [mm]:***	165
Coord. acc.:	Accurate to within 1 000 units			***Use applic.:***	Industrial - power generation	***Drain. reg.:***	B11G
Coord. meth.:	Global Positioning System			***Equipment:***	No equipment	***Rep. inst.:***	GHT

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)

Construction and Geohydrological Legend



COMMENT: User name and adress

Borehole Construction and Geological Log

BASIC SITE INFORMATION: ***Site Identifier:*** 2529CD00032 ***Number:*** AB32 ***Site type:*** Borehole

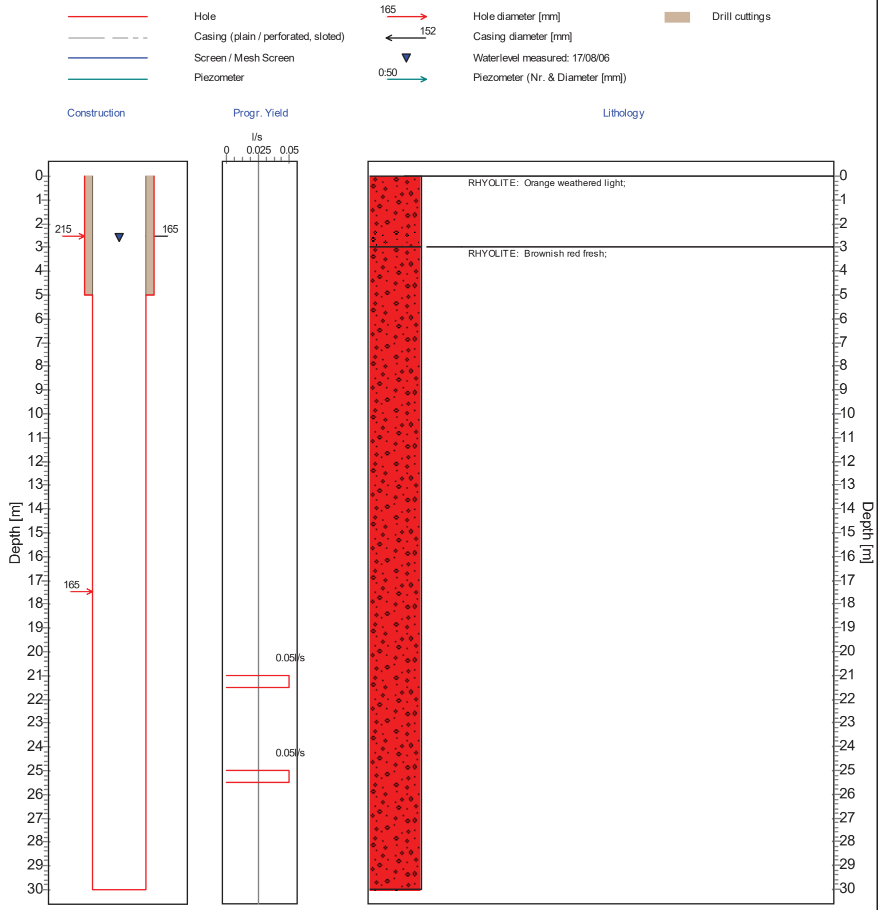
Distr./Farm No.: 336JS ***Site Name/Des.:*** BH NORTH OF ASH DAM

Region Type: ***Region Descr.:***

Longitude [°]:	-25.931283	***Reg./BB.:***		***Topo-set.:***	At or in waste disposal	***Depth [m]:***	30.00
Latitude [°]:	29.333635	***G-Nr.:***	BH19	***Site status:***	In use	***Col. ht. [m]:***	0.80
Altitude [m]:	1560.00			***Site purp.:***	Observation	***Diam. [mm]:***	165
Coord. acc.:	Accurate to within 1 000 units			***Use applic.:***	Industrial - power generation	***Drain. reg.:***	B11G
Coord. meth.:	Global Positioning System			***Equipment:***	No equipment	***Rep. inst.:***	GHT

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)

Construction and Geohydrological Legend



COMMENT: User name and adress

Borehole Construction and Geological Log

BASIC SITE INFORMATION: ***Site Identifier:*** 2529CD00033 ***Number:*** AB33 ***Site type:*** Borehole

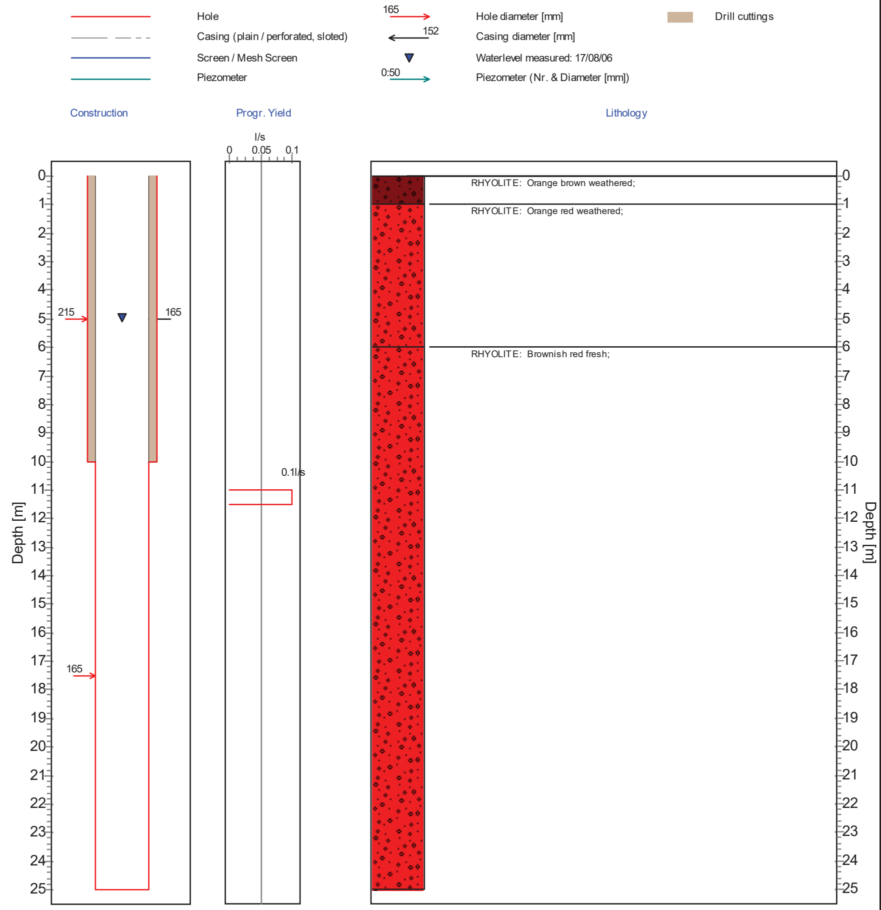
Distr./Farm No.: 318JS ***Site Name/Des.:*** BH NORTH OF ASH DAM

Region Type: ***Region Descr.:***

Longitude [°]:	-25.927810	***Reg./BB.:***		***Topo-set.:***	At or in waste disposal	***Depth [m]:***	25.00
Latitude [°]:	29.338300	***G-Nr.:***	BH20	***Site status:***	In use	***Col. ht. [m]:***	0.79
Altitude [m]:	1545.00			***Site purp.:***	Observation	***Diam. [mm]:***	165
Coord. acc.:	Accurate to within 1 000 units			***Use applic.:***	Industrial - power generation	***Drain. reg.:***	B11G
Coord. meth.:	Global Positioning System			***Equipment:***	No equipment	***Rep. inst.:***	GHT

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)

Construction and Geohydrological Legend



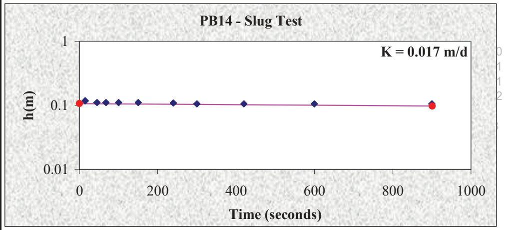
COMMENT: User name and adress

Slug Test PB14

H0 (m)= 0.107152 | r_w(m) = 0.0825 | d(m) = 5.994 | d/rw = 72.655 | C = 3.1555227 | ln(Re/rw)= 3.33224

b (m) = 5.994 | **K (m/d)= 0.0167**

t(s)	h(m)
15	0.118
45	0.111
68	0.111
100	0.111
150	0.111
240	0.109
300	0.106
420	0.106
600	0.106
900	0.106

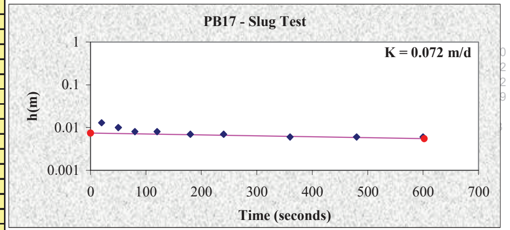


Slug Test PB17

H0 (m)= 0.007413 | r_w(m) = 0.0825 | d(m) = 7.06 | d/rw = 85.576 | C = 3.4738419 | ln(Re/rw)= 3.474418

b (m) = 7.06 | **K (m/d)= 0.072**

t(s)	h(m)
20	0.013
50	0.01
80	0.008
120	0.008
180	0.007
240	0.007
360	0.006
480	0.006
600	0.006

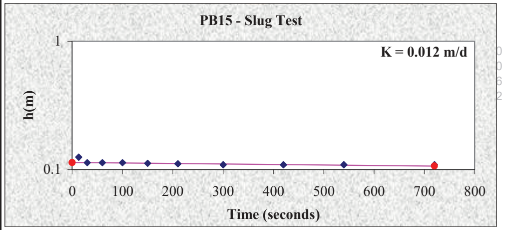


Slug Test PB15

H0 (m)= 0.11324 | r_w(m) = 0.0825 | d(m) = 7.305 | d/rw = 88.545 | C = 3.5460577 | ln(Re/rw)= 3.503964

b (m) = 7.305 | **K (m/d)= 0.0122**

t(s)	h(m)
13	0.125
30	0.113
60	0.113
100	0.113
150	0.112
210	0.111
300	0.109
420	0.109
540	0.109
720	0.109

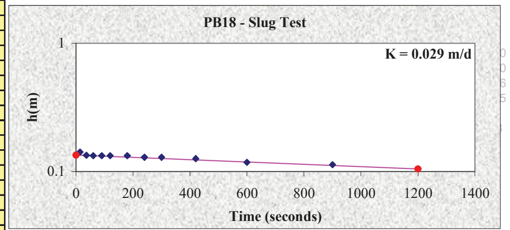


Slug Test PB18

H0 (m)= 0.134276 | r_w(m) = 0.0825 | d(m) = 7.436 | d/rw = 90.133 | C = 3.5845263 | ln(Re/rw)= 3.519348

b (m) = 7.436 | **K (m/d)= 0.0288**

t(s)	h(m)
14	0.142
36	0.134
60	0.133
90	0.133
120	0.133
180	0.133
240	0.129
300	0.129
420	0.126
600	0.118
900	0.113
1200	0.105

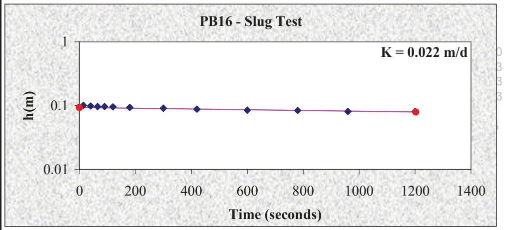


Slug Test PB16

H0 (m)= 0.093325 | r_w(m) = 0.0825 | d(m) = 7.24 | d/rw = 87.758 | C = 3.5269328 | ln(Re/rw)= 3.975542

b (m) = 15.025 | **K (m/d)= 0.0216**

t(s)	h(m)
14	0.101
40	0.099
65	0.097
90	0.097
120	0.096
180	0.094
300	0.091
420	0.088
600	0.085
780	0.084
960	0.081
1200	0.081

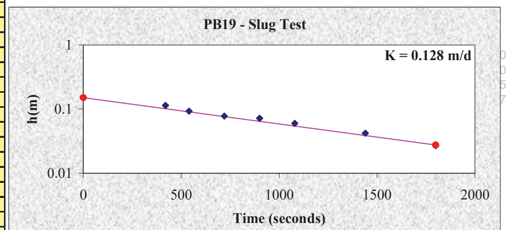


Slug Test PB19

H0 (m)= 0.151356 | r_w(m) = 0.0825 | d(m) = 7.73 | d/rw = 93.697 | C = 3.6704933 | ln(Re/rw)= 3.552886

b (m) = 7.73 | **K (m/d)= 0.1279**

t(s)	h(m)
420	0.114
540	0.093
720	0.078
900	0.072
1080	0.06
1440	0.042
1800	0.027

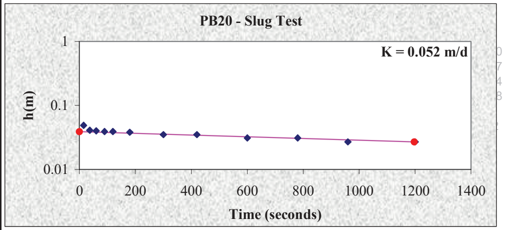


Slug Test — PB20

H0 (m)= 0.038905 | r_w(m) = 0.0825 | d(m) = 5.765 | d/rw = 69.879 | C = 3.0862694 | ln(Re/rw)= 3.298295

b (m) = 5.765 | K (m/d)= 0.0518

t(s)	h(m)
15	0.049
37	0.041
60	0.04
90	0.039
120	0.039
180	0.038
300	0.035
420	0.035
600	0.031
780	0.031
960	0.027
1200	0.027

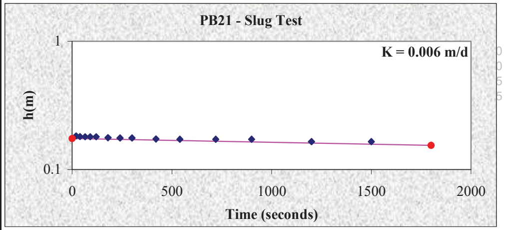


Slug Test — PB21

H0 (m)= 0.174582 | r_w(m) = 0.0825 | d(m) = 16 | d/rw = 193.94 | C = 5.8805654 | ln(Re/rw)= 4.507366

b (m) = 25.74 | K (m/d)= 0.0057

t(s)	h(m)
20	0.183
39	0.181
65	0.18
90	0.18
120	0.18
180	0.177
240	0.176
300	0.176
420	0.173
540	0.172
720	0.172
900	0.172
1200	0.165
1500	0.165
1800	0.155

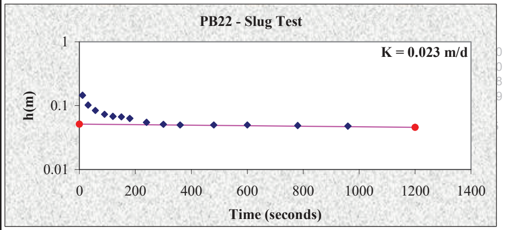


Slug Test — PB22

H0 (m)= 0.051286 | r_w(m) = 0.0825 | d(m) = 3.454 | d/rw = 41.867 | C = 2.370137 | ln(Re/rw)= 2.847679

b (m) = 3.454 | K (m/d)= 0.0233

t(s)	h(m)
11	0.146
31	0.102
57	0.084
90	0.073
120	0.068
150	0.067
180	0.063
240	0.055
300	0.051
360	0.05
480	0.05
600	0.05
780	0.049
960	0.048
1200	0.046

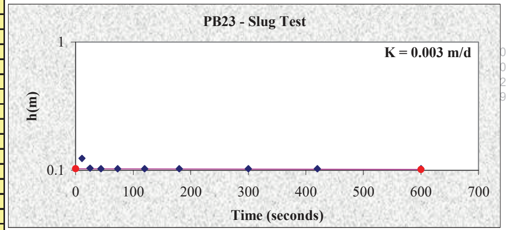


Slug Test — PB23

H0 (m)= 0.103039 | r_w(m) = 0.0825 | d(m) = 6.752 | d/rw = 81.842 | C = 3.3825557 | ln(Re/rw)= 3.435742

b (m) = 6.752 | K (m/d)= 0.0034

t(s)	h(m)
11	0.124
25	0.104
44	0.103
73	0.103
120	0.103
180	0.103
300	0.103
420	0.103
600	0.103

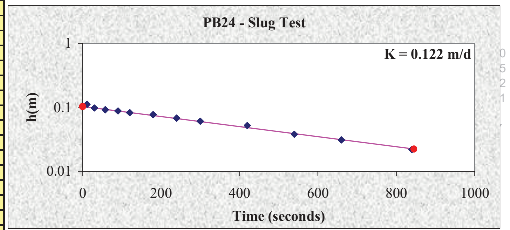


Slug Test — PB24

H0 (m)= 0.103039 | r_w(m) = 0.0825 | d(m) = 20 | d/rw = 242.42 | C = 6.8053037 | ln(Re/rw)= 4.585788

b (m) = 26.97 | K (m/d)= 0.1218

t(s)	h(m)
11	0.112
30	0.098
58	0.092
90	0.088
120	0.083
180	0.077
240	0.068
300	0.061
420	0.052
540	0.038
660	0.031
840	0.022

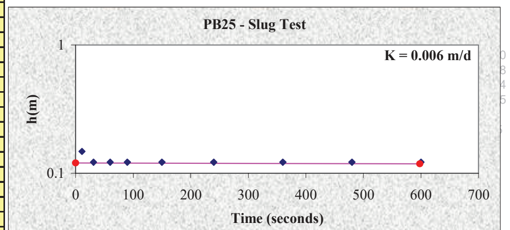


Slug Test — PB25

H0 (m)= 0.120504 | r_w(m) = 0.0825 | d(m) = 3.672 | d/rw = 44.509 | C = 2.4390315 | ln(Re/rw)= 2.90191

b (m) = 3.672 | K (m/d)= 0.0063

t(s)	h(m)
11	0.148
31	0.122
60	0.122
90	0.122
150	0.122
240	0.122
360	0.122
480	0.122
600	0.122

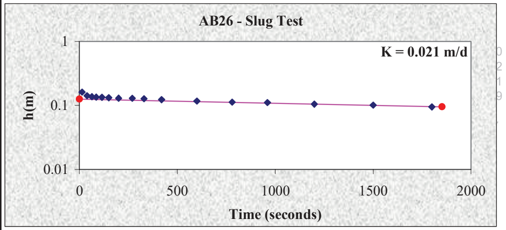


Slug Test — AB26

H0 (m)= 0.125893 | r_w(m) = 0.0825 | d(m) = 7.243 | d/rw = 87.794 | C = 3.527816 | ln(Re/rw)= 3.496584

b (m) = 7.243 | K (m/d)= 0.0212

t(s)	h(m)
13	0.162
39	0.142
64	0.137
86	0.135
115	0.134
150	0.132
200	0.13
270	0.129
330	0.127
420	0.123
600	0.117
780	0.113
960	0.111
1200	0.105
1500	0.101
1800	0.095

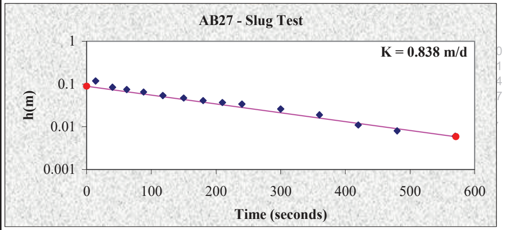


Slug Test — AB27

H0 (m)= 0.089125 | r_w(m) = 0.0825 | d(m) = 5.416 | d/rw = 65.648 | C = 2.9801334 | ln(Re/rw)= 3.243785

b (m) = 5.416 | K (m/d)= 0.838

t(s)	h(m)
14	0.118
40	0.084
62	0.074
88	0.065
118	0.054
150	0.047
180	0.041
210	0.037
240	0.034
300	0.026
360	0.019
420	0.011
480	0.008
570	0.006

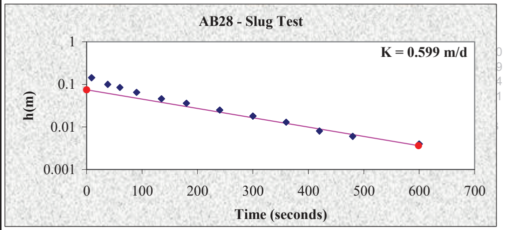


Slug Test — AB28

H0 (m)= 0.074131 | r_w(m) = 0.0825 | d(m) = 9.14 | d/rw = 110.79 | C = 4.0757239 | ln(Re/rw)= 3.697509

b (m) = 9.14 | K (m/d)= 0.599

t(s)	h(m)
9	0.143
38	0.1
60	0.085
90	0.065
135	0.046
180	0.036
240	0.025
300	0.018
360	0.013
420	0.008
480	0.006
600	0.004

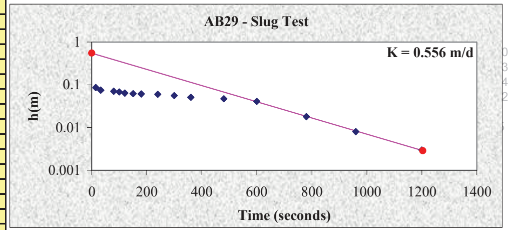


Slug Test — AB29

H0 (m)= 0.549541 | r_w(m) = 0.0825 | d(m) = 8.357 | d/rw = 101.3 | C = 3.8521342 | ln(Re/rw)= 3.620256

b (m) = 8.357 | K (m/d)= 0.5559

t(s)	h(m)
15	0.086
33	0.075
80	0.071
100	0.068
120	0.064
150	0.062
180	0.061
240	0.06
300	0.056
360	0.051
480	0.047
600	0.041
780	0.018
960	0.008
1200	0.003

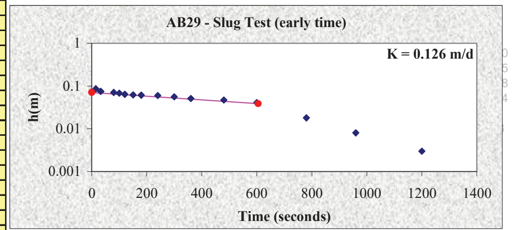


Slug Test — AB29

H0 (m)= 0.070795 | r_w(m) = 0.0825 | d(m) = 8.357 | d/rw = 101.3 | C = 3.8521342 | ln(Re/rw)= 3.620256

b (m) = 8.357 | K (m/d)= 0.126

t(s)	h(m)
15	0.086
33	0.075
80	0.071
100	0.068
120	0.064
150	0.062
180	0.061
240	0.06
300	0.056
360	0.051
480	0.047
600	0.041
780	0.018
960	0.008
1200	0.003

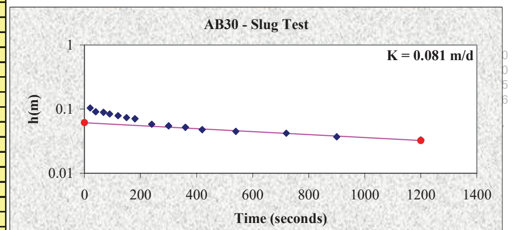


Slug Test — AB30

H0 (m)= 0.06166 | r_w(m) = 0.0825 | d(m) = 6.699 | d/rw = 81.2 | C = 3.3667912 | ln(Re/rw)= 3.428904

b (m) = 6.699 | K (m/d)= 0.0809

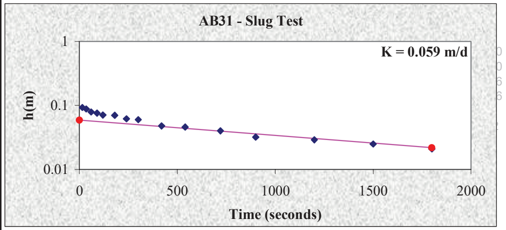
t(s)	h(m)
20	0.104
40	0.091
68	0.089
90	0.084
120	0.079
150	0.074
180	0.071
240	0.058
300	0.055
360	0.052
420	0.048
540	0.045
720	0.042
900	0.037
1200	0.033



Slug Test — AB31

H0 (m)=	0.058884	r_w(m) =	0.0825	d(m) =	11	d/rw =	133.33	C =	4.5924111	ln(Re/rw)=	4.020228
		b (m) =	13.986	K (m/d)=	0.0591						

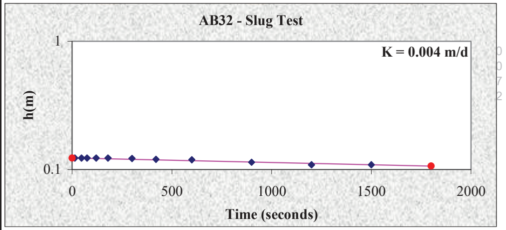
t(s)	h(m)
15	0.093
35	0.088
60	0.079
90	0.076
120	0.071
180	0.07
240	0.062
300	0.06
420	0.048
540	0.046
720	0.04
900	0.032
1200	0.029
1500	0.025
1800	0.021



Slug Test — AB32

H0 (m)=	0.123027	r_w(m) =	0.0825	d(m) =	25	d/rw =	303.03	C =	7.8289951	ln(Re/rw)=	4.661089
		b (m) =	28.056	K (m/d)=	0.0044						

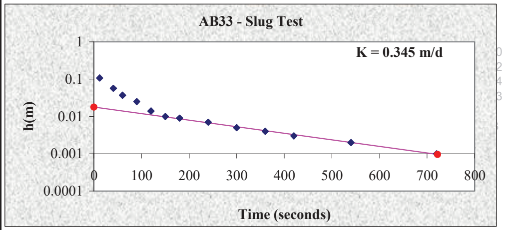
t(s)	h(m)
14	0.123
47	0.123
75	0.123
120	0.123
180	0.123
300	0.122
420	0.12
600	0.119
900	0.114
1200	0.109
1500	0.109
1800	0.106



Slug Test — AB33

H0 (m)=	0.017783	r_w(m) =	0.0825	d(m) =	15	d/rw =	181.82	C =	5.6346884	ln(Re/rw)=	4.347843
		b (m) =	20.748	K (m/d)=	0.3452						

t(s)	h(m)
12	0.107
41	0.057
60	0.037
90	0.025
120	0.014
150	0.01
180	0.009
240	0.007
300	0.005
360	0.004
420	0.003
540	0.002
720	0.001



Surface and groundwater sampling at Duhva Power Station (August 2006)

Sample	Latitude (°S)	Longitude (°E)	Site Description	Date	Time	Water level	Sampled?	Sampling depth
POWER STATION AREA.								
Groundwater Sites								
PB09	25.95560	29.34395	Borehole upstream from HLAWRD	2006-08-16	13:05	6.43	Yes	9.8
PB10	25.95373	29.34246	Borehole downstream from HLAWRD	2006-08-16	13:10	5.30	Yes	9.8
PB11	25.95830	29.34879	Supply borehole on Mr Gouws's farm	2006-08-15	14:30	~	No	~
PB14	25.95350	29.32899	Borehole south-east of Raw Water Dam	2006-08-15	11:03	3.73	Yes	9.0
PB15	25.95040	29.32685	Borehole west of Raw Water Dam	2006-08-15	14:40	2.48	Yes	8.0
PB16	25.95236	29.32678	Borehole south-west of Raw Water Dam	2006-08-15	11:50	5.24	Yes	15.0
PB20	25.95265	29.34514	Borehole north of HLAWRD	2006-08-16	12:15	3.89	Yes	8.0
PB21	25.95304	29.34544	Borehole north-east of HLAWRD	2006-08-16	11:30	4.53	Yes	15.0
PB22	25.95451	29.34627	Borehole south-east of HLAWRD	2006-08-16	10:20	6.06	Yes	8.0
PB23	25.95877	29.34889	Borehole north of Emergency Pan	2006-08-15	09:40	2.59	Yes	9.0
PB24	25.95885	29.34945	Borehole north of Emergency Pan	2006-08-15	09:00	3.35	Yes	20.0
PB25	25.96538	29.34693	Borehole south of Emergency Pan	2006-08-15	10:15	5.88	Yes	9.0
PF01	25.95879	29.34810	Fountain 10m away from Emergency Pan (PP03)	2006-08-03	12:05	Low	Yes	Surface
Surface Water Sites								
PP01	25.96811	29.33340	Station Drain Dams (south)	~	~	~	No	~
PP02	25.96249	29.33341	Duck pond near Conference/Recreation Centre	~	~	~	No	~
PP03	25.96109	29.34756	Emergency Pan (water also used by Mr Gouws)	2006-08-03	12:15	Mod	Yes	Surface
PP04	25.95452	29.34423	HLAWRD	2006-08-15	11:35	Mod	Yes	Surface
PP05	25.95335	29.34769	Station Drain Dams (north)	~	~	~	No	~
PP10	25.92522	29.34438	Raw Water Dam	2006-08-16	08:30	Mod	Yes	Surface
PP12	25.95577	29.35210	Non-perennial pan north-east of Power Station Area	2006-08-15	14:40	Low	Yes	Surface
PC04	25.94897	29.34905	Dirty water canal from northern Station Drain Dams	~	~	~	No	~
PC05	25.95623	29.34777	Emergency canal leaving ESKOM property and running into pan PP03	~	~	~	No	~
PC06	25.96593	29.33309	Dirty water canal running to southern Station Drain Dams	~	~	~	No	~
PC07	25.95287	29.34359	Canal near pump station at HLAWRD	~	~	~	No	~
PC08	25.95428	29.34696	Dirty water canal running to northern Station Drain Dams	~	~	~	No	~
PC09	25.95119	29.34416	Storm water leaving Power Station Area into natural environment	~	~	~	No	~
PC10	25.96695	29.33623	Clean water leaving Power Station Area	~	~	~	No	~
PC11	25.96845	29.34116	(Clean water)? Canal leaving Power Station Area	~	~	~	No	~
PS01	25.95278	29.33835	Possible burst pipe (north-west of power station)	~	~	~	No	~
SEWAGE PLANT AREA								
Groundwater Sites								
PB12 (I)	25.96053	29.32237	Borehole at sewage works - in fenced camp at furthest corner of works	2006-08-16	11:00	1.32	Yes	1.5
PB13 (I)	25.95956	29.32235	Borehole at sewage works - right next to road	2006-08-16	11:05	2.03	Yes	2.5
PB17	25.95921	29.32064	Borehole west of sewage plant	2006-08-15	12:55	2.66	Yes	5.0
PB18	25.95843	29.32299	Borehole north of sewage plant	2006-08-15	13:15	2.18	Yes	9.0
PB19	25.96068	29.32278	Borehole south of sewage plant	2006-08-15	13:40	22.30	Yes	25.0
Surface Water Sites								
PP11	25.96022	29.31819	Dam west of sewage plant	2006-08-15	13:45	Low	Yes	Surface
PP16	25.95904	29.32252	Buffer pond at sewage plant	2006-08-16	11:45	Low	No	~
PP17	25.96037	29.32280	First maturation pond	2006-08-16	11:30	Mod	Yes	Surface
PP18	25.95943	29.32356	Second maturation pond	2006-08-16	11:35	Mod	No	~
PP19	25.95887	29.32313	Third maturation pond	2006-08-16	11:40	Mod	Yes	Surface
PE01	25.95852	29.32326	Final effluent pumped to northern Station Drain Dams	~	~	~	No	~

Surface and groundwater sampling at Duhva Power Station (August 2006)

Sample	Latitude (°S)	Longitude (°E)	Site Description	Date	Time	Water level	Sampled?	Sampling depth
COAL STOCKYARD AREA								
Groundwater Sites								
CB06	25.95814	29.34707	Borehole outside Power Station Area at back of Coal Stockyard	2006-08-03	11:50	4.94	Yes	8.0
CB07	25.96070	29.34594	Borehole outside Power Station Area at back of Coal Stockyard (next to PP03)	2006-08-03	12:30	4.39	Yes	19.0
CB08	25.96413	29.34538	Borehole outside Power Station Area at back of Coal Stockyard (next to PP03)	2006-08-03	12:40	5.87	Yes	13.0
Surface Water Sites								
CC12	25.96051	29.34564	Clean water leaving Coal Stockyard Area	~	~	~	No	~
CC14	25.95574	29.34588	Runoff interception canal around Coal Stockyard	~	~	~	No	~
ASHING AREA.								
Groundwater Sites								
AB01	25.93416	29.32599	Borehole near old farmhouse (Renosterfontein)	2006-08-05	09:48	4.07	Yes	13.0
AB02	25.93181	29.32606	Borehole near AB01 towards Witbank Dam	2006-08-05	09:58	1.13	Yes	13.0
AB03	25.93187	29.32738	Borehole near AB01 and AB02	2006-08-05	09:55	~	No	13.0
AB04	25.92497	29.34515	Borehole at pump station of ash dam	2006-08-03	13:50	1.60	Yes	8.0
AB05	25.93106	29.34893	Borehole north of Ash Dam near lower Ash Water Return Dam	2006-08-03	13:40	1.51	Yes	8.5
AB26	25.93981	29.32206	Borehole north of Ash Dam	2006-08-14	14:30	2.30	Yes	9.0
AB27	25.93658	29.32762	Borehole north of Ash Dam	2006-08-14	15:15	3.74	Yes	9.0
AB28	25.93277	29.33445	Borehole north of Ash Dam	2006-08-14	17:00	0.48	Yes	9.0
AB29	25.92981	29.33983	Borehole north of Ash Dam	2006-08-14	17:30	0.35	Yes	9.0
AB30	25.92315	29.34435	Borehole north of LLAWRD	2006-08-16	16:50	2.07	Yes	5.0
AB31	25.92307	29.34412	Borehole north of LLAWRD	2006-08-16	15:55	2.16	Yes	15.0
AB32	25.93128	29.33364	Borehole north of Ash Dam	2006-08-17	08:20	2.59	Yes	28.0
AB33	25.92781	29.33830	Borehole north of Ash Dam	2006-08-17	10:10	4.95	Yes	22.0
Surface Water Sites								
AP06	25.93459	29.32488	Dam north-west of Ash Dam, collecting drainage from Ash Dam Area	2006-08-05	09:40	Mod	Yes	Surface
AP07	25.92928	29.32590	Dam north-west of Ash Dam	2006-08-05	10:10	Mod	No	~
AP08	25.92933	29.30551	Witbank Dam	~	~	~	No	~
AP09	25.92522	29.34438	LLAWRD	2006-08-03	14:00	Mod	Yes	Surface
AP13	25.92798	29.36492	Dam north-east of Ash Dam (upstream)	~	~	~	No	~
AP14	25.92798	29.36492	Non-perennial pan at south-western toe of Ash Dam	2006-08-05	10:55	Low	Yes	Surface
AP15	25.92585	29.33914	Seepage in pan west of the LLAWRD	2006-08-04	12:22	Low	Yes	Surface
AC01	25.92827	29.34157	Interception canal running into LLAWRD, sample at road	2006-08-05	10:30	Mod	Yes	Surface
AC02	25.94333	29.32117	Storm water canal running into vlei area south-west of Ash Dam	2006-08-05	10:50	Low	Yes	Surface
AC03	25.94897	29.34905	Storm water canal south of Ash Dam	~	~	~	No	~
AC13	25.92757	29.34900	Trench in north-western corner of Ashing Area	~	~	~	No	~
AC15	25.93132	29.33783	Ash Water Return Canal	2006-08-05	10:35	Mod	No	~
AC16	25.94231	29.32091	Clean water canal west of Ash Dam	2006-08-05	10:45	Low	Yes	Surface
AS02	25.93181	29.33305	Seepage in kraal north of Ash Dam	2006-08-04	12:50	Low	Yes	Surface
AS03	25.93319	29.32672	Seepage near AB01, AB02, AB03 in dug pit	2006-08-05	09:20	Mod	Yes	Surface
AS04	25.92355	29.34433	Seepage north of LLAWRD near R03	2006-08-04	11:48	Mod	Yes	Surface
AS05	25.93277	29.33445	Seepage next to borehole AB28	2006-08-05	11:01	Mod	No	~
RIVER/STREAM SITES								
R01	25.92669	29.32570	Stream downstream from dam AP07 (north-west of Ash Dam)	2006-08-05	10:00	Low	Yes	Surface
R02	25.92362	29.33381	Stream north of Ash Dam flowing towards Witbank Dam along fence	2006-08-05	09:10	Low	Yes	Surface
R03	25.92333	29.34469	Stream north of LLAWRDs (Ash Water Drain)	2006-08-04	11:50	Low	Yes	Surface
R04	25.93729	29.36182	Non-perennial stream upstream from Ash Dam	~	~	~	No	Surface
R05	25.95624	29.30105	Non-perennial stream west of Power Station Area	~	~	~	No	Surface

DUVHA POWER STATION - SEEPAGE INVESTIGATIONS

No.	Date	pH	EC mS/m	TDS mg/L	Na mg/L	Ca mg/L	Mg mg/L	K mg/L	Cl mg/L	SO_4 mg/L	P.Alk mg/L	T.Alk mg/L	F mg/L	NO_2-N mg/L	NO_3-N mg/L	PO_4 mg/L	NH_4-N mg/L	Fe mg/L	Mn mg/L	B mg/L	Ionbal %
AB01	20050221	6.6	33.8	119	35	7	5	5	35	32	0	48	0.16		0.01						17.8
AB01	20050523	6.8	30.6	143	42	8	5	5	32	26	0	61	4.72		4.72						14.1
AB01	20051214	7.0	24.7	75	32	4	3	4	30	0	0	68	0.40		0.01			0.99	0.910		40.4
AB01	20060805	6.7	22.0	96	42	5	2	3	39	4	0	57	0.17	0.01	0.17	0.1		0.06	0.340	0.11	0.3
AB02	20050221	6.5	45.3	121	37	7	6	3	68	0	0	31	0.05		0.01						12.8
AB02	20050523	6.7	44.3	114	94	7	6	3	3	0	0	33	1.86		0.01						93.3
AB02	20050927	6.8	35.6	381	49	5	4	2	71	0	0	37	0.06		54.97			5.70	1.070		34.2
AB02	20051214	6.5	35.9	65	45	5	4	2	6	0	0	25	0.08		0.01			2.17	1.830		88.5
AB02	20060805	6.1	54.2	273	90	7	5	2	165	3	0	18	0.01	0.01	0.29	0.1		0.06	1.107	0.08	0.3
AB03	20050221	7.2	27.2	67	31	22	6	2	3	0	0	137	1.97		0.01						88.2
AB03	20050523	7.2	26.9	180	29	22	5	2	37	84	0	133	0.13		0.01						1.1
AB03	20050927	7.3	26.8	66	27	23	6	2	3	0	0	140	2.04		0.01			2.44	0.440		87.5
AB03	20051214	7.2	26.8	61	26	22	6	2	3	0	0	135	1.87		0.01			0.73	0.490		87.8
AB04	20050221	7.0	77.3	299	62	79	23	4	59	72	0	153	0.07		0.01						46.4
AB04	20050523	7.7	84.9	995	119	110	75	4	3	33	0	161	0.06		147						20.1
AB04	20050927	6.9	83.5	415	67	55	44	5	59	177	0	173	0.04		0.01			7.08	0.880		28.1
AB04	20051214	6.9	83.4	281	68	51	42	4	36	76	0	151	0.05		0.01			4.35	0.070		55.8
AB04	20060803	6.8	77.7	422	75	54	33	4	68	187	0	159	0.01	0.01	0.19	0.1		0.19	0.096	0.09	0.9
AB05	20050221	7.3	29.7	87	35	8	4	4	27	6	0	98	1.93		0.61						38.5
AB05	20050523	7.4	27.7	74	50	6	3	3	3	9	0	88	0.08		0.01						83.0
AB05	20050927	8.0	27.9	84	34	11	3	3	28	2	0	100	2.32		0.01			0.07	0.480		42.3
AB05	20051214	7.7	28.1	80	35	8	3	4	28	1	0	92	2.07		0.01			0.03	0.830		41.9
AB05	20060803	7.0	25.0	102	53	7	2	3	30	5	0	86	1.63	0.01	0.12	0.1		0.13	0.198	0.08	2.1
AB26	20060814	6.4	62.4	360	99	14	9	10	80	146	0	48	0.78	0.01	0.21	0.1		0.12	1.570	0.16	1.8
AB27	20060814	6.4	88.7	525	120	25	22	21	74	259	0	65	0.01	0.01	0.59	0.1		0.06	3.555	0.20	1.3
AB28	20060814	5.9	106	714	106	71	14	26	90	405	0	8	0.01	0.01	0.19	0.1		1.20	4.040	0.24	4.1
AB29	20060814	6.9	66.4	480	112	37	5	25	98	201	0	64	0.11	0.01	0.2	0.1		0.36	2.584	0.24	1.6
AB30	20060816	6.8	68.5	336	31	79	47	2	83	93	0	218	0.16	0.01	0.19	0.1		0.32	2.561	0.04	4.3
AB31	20060816	6.7	43.7	204	15	41	21	3	65	54	0	83	0.05	0.01	1.14	0.1		0.40	0.160	0.04	1.5
AB32	20060817	6.5	29.1	135	42	3	2	16	37	33	0	46	0.75	0.01	0.045	0.1		0.04	0.658	0.05	0.5
AB33	20060817	6.2	24.9	132	35	3	6	8	42	34	0	23	0.04	0.02	0.75	0.1		0.70	0.378	0.04	0.9
AC01	20060805	5.7	95.8	670	125	45	18	26	103	349	0	6	0.03	0.01	0.79	0.1		0.01	2.813	0.30	1.6
AC02	20060805	7.5	19.1	126	21	28	3	8	35	30	0	65	0.26	0.01	0.24	0.08		0.02	0.000	0.07	3.6
AC16	20060805	7.0	116.0	925	95	140	28	16	102	427	0	96	0.48	0.01	0.16	0.1		0.05	0.002	0.05	0.4
AP06	20060805	3.6	104.0	810	181	41	24	27	222	314	0	22	0.36	0.01	0.04	0.59		0.37	2.304	0.10	0.8
AP09	20050103	7.6	507.0	53	22				3	29			0.01	0.01			0.03				7.3
AP09	20060803	12.0	514.0	1445	113	560	0	37	88	638	0	265	1.21	0.05	1.86	0.1		0.00	0.000	0.20	3.9
AP14	20060805	6.3	42.1	259	39	15	6	27	80	56	0	29	0.17	0.01	0.33	0.1		1.19	1.129	0.04	4.6

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No.	Date	pH	EC mS/m	TDS mg/L	Na mg/L	Ca mg/L	Mg mg/L	K mg/L	Cl mg/L	SO_4 mg/L	P.Alk mg/L	T.Alk mg/L	F mg/L	NO_2-N mg/L	NO_3-N mg/L	PO_4 mg/L	NH_4-N mg/L	Fe mg/L	Mn mg/L	B mg/L	Ionbal %
AP15	20060328	7.1	444.0	205	76			5	109	14			0.01	0.01	0.01						1.2
AP15	20060425	4.0	270.0	119	20			8	32	58			0.01	0.01	0.01						33.1
AP15	20060515	6.2	300.0	150	30			9	40	71			0.01	0.01	0.01						26.3
AP15	20060804	3.4	36.4	278	53	12	7	20	80	105	0		0.12	0.01	0.34	0.58		0.44	8.957	0.07	0.9
AS02	20050103	6.3	403.0	322		14		19	5	34			0.01	0.01	56.70						61.4
AS02	20060221	6.2	424.0	177	62			6	88	21			0.01	0.01	0.01						1.2
AS02	20060328	6.5	425.0	180	66			6	97	11			0.01	0.01	0.01						0.8
AS02	20060425	6.4	440.0	188	61			9	108	10			0.01	0.01	0.01						5.8
AS02	20060515	6.4	459.0	199	69			7	110	13			0.01	0.01	0.01						3.3
AS02	20060619	6.6	436.0	107	7			74	14	13			0.04	0.01	0.01						52.7
AS02	20060725	6.4	394.0	204	66			4	123	11			0.04	0.01	0.01						11.1
AS02	20060804	6.2	617.0	4878	1580	124	44	43	1378	1708	0	57	0.36	0.01	0.21	0.1		0.31	4.939	0.14	2.8
AS03	20060221	6.8	211.0	85	13			6	16	51			0.01	0.01	0.01						36.6
AS03	20060328	6.7	242.0	104	19			6	26	53			0.16	0.01	0.01						30.2
AS03	20060425	7.6	502.0	211	75			6	113	16			0.01	0.01	0.01						1.5
AS03	20060619	7.1	534.0	300	115			6	143	36			0.15	0.01	0.01						3.5
AS03	20060725	6.9	520.0	286	98			3	145	41			0.01	0.01	0.01						6.4
AS03	20060805	7.0	115.0	888	183	36	34	18	121	397	0	83	0.18	0.01	0.15	0.1		0.06	0.098	0.07	1.5
AS04	20060804	7.5	73.3	477	28	60	36	5	108	119	0	101	0.10	0.01	0.14	0.1		0.05	0.003	0.03	2.0
CB06	20050221	7.1	7.2	19	2	6	5	3	3	1	0	34	0.26		0.01						78.3
CB06	20050523	7.3	7.7	21	2	6	4	3	3	0	0	36	0.24		0.39						74.9
CB06	20050927	7.1	7.9	22	2	7	5	3	3	0	0	39	0.35		0.01			1.70	0.170		82.4
CB06	20051214	7.0	8.0	19	2	6	5	3	2	0	0	38	0.31		0.01			0.20	0.150		82.6
CB06	20060803	6.7	7.6	23	5	5	3	3	5	2	0	33	0.13	0.01	0.14	0.1		0.25	0.114	0.05	4.0
CB07	20050221	6.9	11.5	34	7	9	6	3	3	7	0	49	0.03		0.01						71.1
CB07	20050523	7.1	12.5	30	7	10	6	3	2	0	0	51	0.24		0.33						84.7
CB07	20050927	7.6	26.1	59	25	16	9	4	2	3	0	83	0.10		0.01			0.63	0.400		90.5
CB07	20051214	7.4	14.6	38	7	13	8	3	2	5	0	72	0.09		0.01			0.01	0.030		81.7
CB07	20060803	7.3	15.7	46	11	14	6	3	4	6	0	78	0.01	0.01	0.14	0.1		0.05	0.020	0.04	0.2
CB08	20050221	5.8	4.1	33	2	2	5	2	3	1	0	12	0.01		4.20						19.9
CB08	20050523	6.6	14.8	29	4	8	8	5	4	0	0	68	0.14		0.01						81.8
CB08	20050927	6.8	13.5	33	3	8	8	5	4	0	0	68	0.16		0.01			4.75	0.460		84.1
CB08	20051214	6.7	10.7	22	3	6	6	4	4	0	0	49	0.12		0.01			0.19	0.440		80.0
CB08	20060803	6.4	9.8	28	5	5	4	3	6	2	0	37	0.06	0.99	0.42	0.1		0.02	0.176	0.04	4.5
PB09	20050221	6.3	45.0	19	5	2	6	1	5	0	0	15	0.01		0.01						70.4
PB09	20050523	6.0	4.1	108	5	52	40	1	5	0	0	11	0.01		1.27						92.5
PB09	20050927	6.6	6.3	21	5	2	2	1	6	0	0	26	0.03		0.01			4.85	0.180		57.4
PB09	20051214	6.5	6.3	20	4	2	2	1	6	0	0	24	0.01		0.01			4.97	0.240		55.9
PB09	20060816	6.0	3.4	18	6	1	1	1	6	2	0	13	0.01	0.05	0.05	0.1		0.03	0.095	0.03	4.0

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PB10	20050927	7.8	12.3	32	3	15	7	3	3	1	0	65	0.15		0.01			0.08	0.130		87.5
PB10	20051214	7.9	12.4	29	3	14	6	3	3	0	0	63	0.14		0.01			0.01	0.110		89.5
PB10	20060816	6.8	9.4	29	5	10	4	3	4	2	0	50	0.03	0.01	0.11	0.1		0.06	0.148	0.04	0.8
PB11	20050927	6.7	5.2	21	2	3	1	3	3	8	0	8	0.48		0.01			0.43	0.030		15.8
PB12	20060816	7.8	20.5	62	15	12	7	4	20	2	0	84	0.31	0.02	0.24	0.1		0.00	0.075	0.03	4.3
PB13	20060816	6.4	18.7	72	22	3	2	4	24	13	0	54	0.01	0.01	0.80	0.1		0.03	0.120	0.03	2.7
PB14	20060815	6.0	6.2	24	8	2	2	2	8	2	0	20	0.01	0.01	0.03	2.01		0.45	0.228	0.06	4.3
PB15	20060815	6.3	9.4	44	11	3	3	8	9	7	0	39	0.05	0.01	0.32	0.1		0.21	0.570	0.06	0.8
PB16	20060815	6.0	5.2	25	8	2	1	1	9	2	0	15	0.01	0.01	0.32	0.1		0.57	0.142	0.06	5.2
PB17	20060815	5.7	9.6	47	13	2	2	2	18	8	0	15	0.01	0.01	0.33	0.1		0.20	0.113	0.05	4.7
PB18	20060815	6.3	9.4	37	10	4	2	5	12	3	0	30	0.01	0.01	0.17	0.1		0.52	0.816	0.05	0.1
PB19	20060815	6.7	15.4	59	11	13	5	5	14	6	0	56	0.11	0.01	1.07	0.1		0.00	0.138	0.05	1.8
PB20	20060816	6.0	82.1	518	116	31	13	5	60	285	0	22	0.04	0.04	0.93	0.1		2.76	1.070	0.05	0.7
PB21	20060816	6.5	76.5	439	124	12	10	8	62	223	0	54	0.04	0.01	0.13	0.1		0.16	0.382	0.05	3.0
PB22	20060816	6.0	37.8	229	72	2	1	1	21	130	0	12	0.01	0.01	0.46	0.1		0.50	0.177	0.05	3.1
PB23	20060815	6.0	18.9	106	18	8	7	4	12	55	0	16	0.01	0.01	0.52	0.1		0.56	0.415	0.05	1.1
PB24	20060815	5.4	27.1	184	33	11	9	4	16	103	0	7	0.01	0.01	2.26	0.1		0.12	0.169	0.05	2.0
PB25	20060815	6.0	5.5	26	7	3	2	1	9	3	0	15	0.01	0.04	0.44	0.1		0.29	0.068	0.05	3.5
PF01	20060803	3.8	64.0	474	36	33	9	14	30	269	0	17	0.01	0.01	0.10	0.91		81.88	0.449	0.18	4.0
PP03	20050103	9.3	1601.0	1987	173	500		107	150	1045			2.75	0.01			0.01				14.3
PP03	20060116	7.9	377.0																		
PP03	20060123	8.4	312.0																		
PP03	20060131	6.9	1093.0																		
PP03	20060208	8.2	1444.0																		
PP03	20060213	7.3	1277.0																		
PP03	20060221	10.4	1608.0	334	142			35	94	63			0.33	0.01	0.01						28.0
PP03	20060307	8.4	1536.0																		
PP03	20060316	7.8	1580.0																		
PP03	20060320	8.2	1536.0																		
PP03	20060328	8.1	1604.0	956	151			37	101	668			0.01	0.01	0.01						38.1
PP03	20060409	7.0	367.0																		
PP03	20060425	6.7	225.0	66	7			2	13	15			0.05	0.01	6.70						50.1
PP03	20060508	6.7	271.0																		
PP03	20060515	6.5	221.0	71	9			3	13	15			0.04	0.01	6.86						42.9
PP03	20060522	7.3	453.0																		
PP03	20060530	6.5	329.0																		
PP03	20060606	6.9	411.0																		
PP03	20060613	7.3	745.0																		
PP03	20060619	7.5	842.0	459	78			21	51	309			0.01	0.01	0.01						33.5
PP03	20060627	6.2	307.0																		

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PP03	20060703	7.4	1635.0																		
PP03	20060711	6.4	433.0																		
PP03	20060725	6.8	6.3	156	91			15	9	33			0.76	0.76	1.74						59.9
PP03	20060803	6.8	180.0	1315	173	212	7	33	131	756	0	58	1.44	0.01	0.29	0.1		0.04	0.003	0.17	2.8
PP03	20060815	11.8	2445.0																		
PP04	20060815	12.0	520.0	1506	106	590	0	35	90	676	0	267	1.19	0.06	1.73	0.1		0.00	0.000	0.15	4.2
PP10	20060103	7.8	332.0	97	12			4	9	72	0	69									47.8
PP10	20060104	7.7	132.0									55									
PP10	20060105	7.7	150.0								0	55									
PP10	20060106	7.9	405.0								0	76									
PP10	20060107	7.4	126.0	19	6			2	3	8	0	52									4.2
PP10	20060109	7.7	134.0									55									
PP10	20060110	7.6	130.0	19	5			2	4	8	0	54									1.7
PP10	20060111	7.7	153.0								0	55									
PP10	20060112	7.7	124.0								0	55									
PP10	20060113	7.6	127.0								0	54									
PP10	20060116	7.6	159.0								0	56									
PP10	20060117	7.7	235.0	68	11			4	9	44	0	53									33.4
PP10	20060118	7.8	237.0								0	61									
PP10	20060119	7.7	281.0								0	64									
PP10	20060120	7.8	231.0								0	59									
PP10	20060123	7.9	319.0								0	66									
PP10	20060124	8.0	289.0	79	10			3	7	59	0	64									48.1
PP10	20060125	7.6	132.0								0	53									
PP10	20060126	7.7	181.0								0	51									
PP10	20060127	7.7	256.0									60									
PP10	20060130	7.6	126.0									52									
PP10	20060131	7.7	200.0	49	8			3	5	32		55									30.9
PP10	20060201	7.8	296.0								0	60									
PP10	20060202	7.7	245.0								0	58									
PP10	20060203	7.5	196.0								0	55									
PP10	20060206	7.5	125.0								0	52									
PP10	20060207	7.4	126.0	19	6			2	3	8	0	52									4.2
PP10	20060208	7.3	153.0								0	47									
PP10	20060209	7.6	124.0									50									
PP10	20060210	7.4	124.0								0	50									
PP10	20060213	7.4	128.0									49									
PP10	20060214	7.5	122.0	18	5			2	3	8	0	49									4.5
PP10	20060215	7.4	127.0								0	50									

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No.	Date	pH	EC mS/m	TDS mg/L	Na mg/L	Ca mg/L	Mg mg/L	K mg/L	Cl mg/L	SO_4 mg/L	P.Alk mg/L	T.Alk mg/L	F mg/L	NO_2-N mg/L	NO_3-N mg/L	PO_4 mg/L	NH_4-N mg/L	Fe mg/L	Mn mg/L	B mg/L	Ionbal %
PP10	20060216	7.3	149.0									47									
PP10	20060217	7.4	126.0									50									
PP10	20060220	7.4	124.0									48									
PP10	20060221	7.5	122.0	18	5			2	3	8		49									4.5
PP10	20060222	7.4	124.0									49									
PP10	20060223	7.4	132.0								0	49									
PP10	20060224	7.4	126.0								0	47									
PP10	20060228	7.4	123.0	18	5			2	3	7		49									6.0
PP10	20060306	7.3	250.0								0	55									
PP10	20060307	7.2	198.0	59	11			5	8	35	0	44									22.5
PP10	20060308	7.2	140.0								0	33									
PP10	20060309	7.1	145.0								0	32									
PP10	20060310	7.1	146.0								0	35									
PP10	20060313	6.8	185.0								0	39									
PP10	20060314	7.3	176.0	53	10			4	7	31	0	44									23.5
PP10	20060315	7.2	141.0								0	35									
PP10	20060316	7.2	138.0								0	35									
PP10	20060317	7.3	139.0									35									
PP10	20060320	7.3	143.0									37									
PP10	20060322	7.2	141.0									36									
PP10	20060323	7.1	141.0	40	8			4	7	21		36									15.7
PP10	20060324	7.4	148.0									38									
PP10	20060327	7.3	159.0								0	39									
PP10	20060328	7.1	150.0	41	8			4	7	21	0	37									17.3
PP10	20060329	7.1	150.0								0	36									
PP10	20060330	7.1	150.0								0	36									
PP10	20060331	7.1	148.0									36									
PP10	20060404	7.1	154.0	49	8			4	8	25		35	0.13		0.61			1.64	0.080		24.1
PP10	20060407	7.3	176.0									38									
PP10	20060410	7.0	142.0									33									
PP10	20060411	7.1	138.0	41	7			3	8	20	0	33	0.12		0.69						26.0
PP10	20060412	7.1	134.0								0	30									
PP10	20060413	7.1	135.0									29									
PP10	20060418	7.2	136.0	37	7			4	8	19		31									21.9
PP10	20060419	7.0	135.0									31									
PP10	20060420	7.0	135.0								0	32									
PP10	20060421	7.1	136.0								0	31									
PP10	20060424	7.1	135.0								0	30									
PP10	20060425	7.2	139.0	40	7			4	8	21	0	33									22.0

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PP10	20060426	7.2	143.0								0	34									
PP10	20060428	7.2	140.0								0	34									
PP10	20060502	7.5	157.0	36	8			4	5	19	0	37									11.3
PP10	20060503	7.1	147.0								0	34									
PP10	20060504	7.3	148.0								0	35									
PP10	20060505	7.3	143.0								0	35									
PP10	20060508	7.3	142.0								0	35									
PP10	20060509	7.4	145.0	42	8			4	8	22	0	35									21.0
PP10	20060510	7.4	151.0								0	35									
PP10	20060511	7.3	142.0								0	35									
PP10	20060512	7.3	145.0								0	35									
PP10	20060515	7.7	150.0									38									
PP10	20060516	7.5	138.0	35	7			3	6	15	0	41	0.08		0.57			0.75	0.070		16.0
PP10	20060519	7.6	137.0									40									
PP10	20060522	7.5	140.0									40									
PP10	20060523	7.6	133.0	29	7			2	6	14		40									14.1
PP10	20060524	7.5	141.0																		
PP10	20060525	7.7	138.0								0	42									
PP10	20060526	7.6	131.0								0	40									
PP10	20060529	7.6	131.0								0	41									
PP10	20060530	7.7	133.0	32	7			3	6	16	0	41									14.4
PP10	20060601	7.6	134.0								0	40									
PP10	20060602	7.7	134.0								0	41									
PP10	20060605	7.7	130.0								0	45									
PP10	20060606	7.6	139.0	34	7			3	7	17		41									19.1
PP10	20060607	7.6	138.0									40									
PP10	20060608	7.6	140.0									41									
PP10	20060609	7.5	138.0								0	40									
PP10	20060612	7.6	137.0								0	41									
PP10	20060613	7.7	141.0	33	7			3	7	16	0	41									15.9
PP10	20060614	7.6	139.0								0	40									
PP10	20060615	7.6	127.0									41									
PP10	20060619	7.7	114.0									45									
PP10	20060620	7.6	111.0	21	5			2	4	10		44									8.4
PP10	20060621	7.6	113.0									41									
PP10	20060622	7.7	275.0									62									
PP10	20060623	7.5	244.0									57									
PP10	20060626	7.7	109.0									44									
PP10	20060627	7.7	329.0	125	17			5	9	94		69									44.8

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No.	Date	pH	EC mS/m	TDS mg/L	Na mg/L	Ca mg/L	Mg mg/L	K mg/L	Cl mg/L	SO_4 mg/L	P.Alk mg/L	T.Alk mg/L	F mg/L	NO_2-N mg/L	NO_3-N mg/L	PO_4 mg/L	NH_4-N mg/L	Fe mg/L	Mn mg/L	B mg/L	Ionbal %
PP10	20060628	7.7	213.0									52									
PP10	20060629	7.7	108.0									43									
PP10	20060630	7.6	110.0									43									
PP10	20060703	7.6	221.0									48									
PP10	20060704	7.6	214.0	63	9			3	7	44		56									40.7
PP10	20060705	7.6	322.0									68									
PP10	20060706	7.7	163.0								0	47									
PP10	20060707	7.7	151.0									44									
PP10	20060710	7.7	110.0									44									
PP10	20060711	7.6	154.0	43	8			2	6	27		47									26.3
PP10	20060712	7.7	188.0									49									
PP10	20060713	7.6	110.0								0	41									
PP10	20060714	7.6	144.0									45									
PP10	20060717	7.6	111.0									43									
PP10	20060718	7.6	114.0	24	6			2	5	12		44									6.8
PP10	20060719	7.8	251.0									56									
PP10	20060720	7.8	253.0									56									
PP10	20060724	7.6	291.0								0	68									
PP10	20060725	7.5	97.0	20	5			2	4	9		43									4.3
PP10	20060726	7.6	178.0									55									
PP10	20060727	7.6	240.0									61									
PP10	20060728	7.7	233.0									60									
PP10	20060731	7.5	230.0								0	61									
PP10	20060801	7.6	308.0	116	18			6	10	82	0	69	0.24		0.01						35.6
PP10	20060802	7.6	102.0								0	47									
PP10	20060803	7.6	102.0								0	47									
PP10	20060804	7.7	97.0								0	41									
PP10	20060807	7.6	310.0								0	68									
PP10	20060808	7.7	292.0	109	17			5	9	78	0	69									36.8
PP10	20060810	7.6	109.0								0	46									
PP10	20060811	7.6	99.0								0	43									
PP10	20060814	7.6	149.0								0	52									
PP10	20060815	7.6	116.0	29	6			2	4	16	0	45									17.4
PP10	20060816	8.0	43.3	223	21	34	20	5	15	128	0	78	0.28	0.01	0.05	0.72		0.03	0.003	0.05	3.5
PP10	20060816	7.6	101.0								0	42									
PP11	20060815	5.7	10.9	58	10	4	2	4	20	17	0	4	0.28	0.01	0.13	0.1		0.04	0.135	0.04	2.3
PP12	20060815	5.7	20.4	91	19	3	2	5	35	17	0	9	0.06	0.01	0.12	0.1		9.72	0.066	0.05	2.4
PP17	20060816	6.9	38.5	231	33	18	8	14	28	7	0	101	0.05	2.57	0.04	0.1		0.68	0.378	0.06	6.1
PP19	20060816	7.2	29.2	182	29	13	6	8	30	27	0	50	0.07	0.28	2.15	6.48		0.01	0.001	0.04	1.7

DUVHA POWER STATION - SEEPAGE INVESTIGATIONS

No.	Date	pH	EC mS/m	TDS mg/L	Na mg/L	Ca mg/L	Mg mg/L	K mg/L	Cl mg/L	SO_4 mg/L	P.Alk mg/L	T.Alk mg/L	F mg/L	NO_2-N mg/L	NO_3-N mg/L	PO_4 mg/L	NH_4-N mg/L	Fe mg/L	Mn mg/L	B mg/L	Ionbal %
R01	20060805	5.8	47.1	264	80	6	4	7	141	16	0	12	0.01	0.01	0.35	0.1		8.89	0.735	0.05	0.2
R02	20060805	6.3	35.7	338	47	10	7	8	60	35	0	107	0.16	0.01	0.64	0.1		41.37	0.373	0.13	2.0
R03	20060804	6.8	50.9	215	21	40	22	6	66	59	0	99	0.12	0.01	0.18	0.1		0.05	0.064	0.03	1.9

Quality of Domestic Water Supplies, DWA&F, Second Edition 1998

Class 0	**- Ideal water quality** - Suitable for lifetime use.
Class 1	**- Good water quality** - Suitable for use, rare instances of negative effects.
Class 2	**- Marginal water quality** - Conditionally acceptable. Negative effects may occur in some sensitive groups
Class 3	**- Poor water quality** - Unsuitable for use without treatment. Chronic effects may occur.
Class 4	**- Dangerous water quality** - Totally unsuitable for use. Acute effects may occur.

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.