FINAL REPORT HYDROGEOLOGICAL IMPACT STUDY.

Establishment of Photo Voltaic facility on the Old Ash Dam, Grootvlei Power station

Prepared for

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Executive Summary

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Executive Summary

SGW has been commissioned by Environmental Impact Management Services (EIMS) (Pty) Limited to conduct a specialist hydrogeological investigation at the ESKOM Grootvlei Power Station around the old defunct ash dam to the south of the property. This site (Alternative 1) was selected after the initial alternative site selection process for the PV facility identified the site as the only feasible alternative. ESKOM is planning to cover Alternative site 1 with Photo Voltaic cells to generate solar power to augment the power of Grootvlei power station. ESKOM is planning to cover the area with Photo Voltaic cells to generate solar power to augment the power grid. The study focused on any possible impacts on the groundwater environment and in turn the receiving surface water environment. The old ash dam has been out of use for approximately 30 years now and has been rehabilitated with vegetation and capped with a soil layer of approximately 30 cm. The ash has solidified over time to the point where collecting a sample for the geochemistry was a very difficult task.

The ESKOM Grootvlei Coal Fired Power Station is situated on the Farm Grootvlei 457 IR approximately 18 km from the town of Balfour in the Mpumalanga Province (Figure 1-1). The investigation was a phased approach to ascertain what the current groundwater scenario is and what the possible impacts of the old ash dam could have on the receiving downstream environment as well as adjacent groundwater users. The project area is approximately 16 Ha with the old ash dam occupying 6 Ha.

The first phase documented in this report focused on the characterisation by non-intrusive methods but also intrusive. A ground geophysical investigation including the magnetic and electromagnetic method was conducted as well as pump out and slug in and out aquifer tests and hydrochemical sampling. The second phase included a numerical model to simulate different impact scenarios associated with the establishment of the Photo Voltaic Cells at the old ash dam.

Conclusions:

The following conclusions were forthcoming from the study:

Field work

- Due to the small diameter of the monitoring piezometers installed in the boreholes only one pump out test could be performed representing the upper weathered aquifer and none from the lower aquifer;
- As the boreholes in general are low yielding the slug-in test were sufficient to acquire information from the lower aquifer;
- The geophysics delineated possible weathered zones during the survey and no other work is necessary;
- The monitoring network for Grootvlei does not address the old ash dam area and new monitoring boreholes needs to be established on the geophysical survey results;

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- Therefore no relevant groundwater quality data for the old ash dam was available and TCLP leach testing results of ash dam material had to be used for the numerical model simulation;
- The TCLP test values could be an over estimation of the migration concentrations and needs to be verified;
- The leach test results indicated that the TDS is well above the norm at 5100 mg/L and EC of 686 mS/m, the chloride, calcium and sodium values are also elevated (Table 2-2);
- The three samples collected at the closest monitoring boreholes BH18 and BH19 can be classified as Class I under SANS:241 guidelines due to chloride and EC concentrations;
- The samples was necessary to verify the current results under the existing monitoring programme and it was found that they correlate very well;

Impact assessment with numerical modelling simulations

Two different scenarios planned for the establishment of PV Solar Cells were assumed around the old ash dam planned project area, using a compacted clay / soil layer which could still allow around 50 % of natural recharge to reach the groundwater or a concrete cell block permanent paved area for constructing and fixing the PV Cells, this will allow approximately 0 % of precipitation to recharge to groundwater in the area. A third no go option was also simulated to ascertain what the impact will be if the current state is left to progress. Two scenarios were simulated using a 3 D numerical model for all phases of the project and the results were as follows:

<u>Pre-operation</u>

Quantity

With recharge reduced by 50 % the highest estimated change in the groundwater level at the control points is 1.005 m after 100 years. The cone of depression after 50 years advances approximately 0.25 m, in a radius of 200 m away from the old ash dam. This is insignificant as the seasonal fluctuations indicated in the report by Vermeulen *et. al.,* 2012, clearly indicates values of around 0.5 m and more.

The water level change if this scenario is selected as an option is therefore seen as slight over a relatively short distance and therefore a low impact over a long period.

Quality

It can be seen that the plume migration is towards the immediate north towards the stream and also towards the east towards the eastern surface water component as the ash dam is situated within the corner of the confluence of two systems. Within two years the plume migrated around 50 m away from the source when recharge occurs as usual. This will be the current situation

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and cannot really be assessed as there are no monitoring boreholes to the north and east of the old ash dam.

Operational Phase

Quantity

Scenario one:

With recharge reduced by 50 % the highest estimated change in the groundwater level at the control points is 1.005 m after 100 years. The cone of depression after 50 years advances approximately 0.25 m, in a radius of 200 m away from the old ash dam. This is insignificant as the seasonal fluctuations indicated in the report by Vermeulen *et. al.,* 2012, clearly indicates values of around 0.5 m and more.

The water level change if this scenario is selected as an option is therefore seen as slight over a relatively short distance and therefore a low impact over a long period.

Scenario two:

With recharge reduced by 100 % the highest change in the groundwater level is 1.165 m after 100 years. The cone of depression after 50 years advances approximately 0.25 m deep, in a radius of 375 m away from the old ash dam. This cone of depression does extend beyond the ESKOM property boundary into adjacent land but no boreholes are influenced. Although the impact compared to scenario one is slightly higher the flow of groundwater is not affected significantly and the impact is therefore still perceived as low over a long duration.

Quality

Scenario one:

The migration plume simulated for 5 years during the operation phase can be seen in Figure 8-9. After 50 years (Figure 8-10) the plume will have developed 375 m to the east at a concentration of around 50 mg/L. Again none of the adjacent boreholes will be affected during this time. The impact is therefore high over a long duration if this scenario is selected and no mitigation is applied.

Scenario two:

The migration plume simulated for 5 years during the operation phase can be seen in Figure 8-11. After 50 years (Figure 8-12) the plume will have also developed 375 m to the east at a concentration of around 50 mg/L. Again none of the adjacent boreholes will be affected during this time. The impact is therefore high over a long duration if this scenario is selected and no mitigation is applied.

Long term post-operational phase (groundwater rebound)

Groundwater quantity

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Scenario one:

The reduction of 50 % recharge will cause the cone of depression to still extend further towards the downstream surface water environment. It can be seen from the graph in Figure 8-1 that the drawdown of groundwater levels after 50 years starts to stabilize and starts to achieve equilibrium conditions. So no major reduction in groundwater levels takes place in the 50 years after the life of the operation even with the reduction in recharge still valid. Figure 8-13 depicts the drawdown cone after 100 years and it can be seen that the effect is very similar to that of year 50. Therefore the impact remains the same as with the operational phase as low impact over a long term.

Scenario two:

The reduction of 100 % recharge will cause the cone of depression to still extend further towards the downstream surface water environment. It can also be seen in this simulation from the graph in Figure 8-2 that the drawdown of groundwater levels after 50 years starts to stabilize and starts to achieve equilibrium conditions. So no major reduction in groundwater levels takes place in the 50 years after the life of the operation even with the reduction in recharge still valid. Figure 8-14 depicts the drawdown cone after 100 years and it can be seen that the effect is very similar to that of year 50. Therefore the impact remains the same as with the operational phase as low impact over a long term.

Groundwater quality

Scenario one:

Figure 8-15 depicts the migration of the contaminant plume away from the project area. It can be seen that the plume extends to around 625 m away towards the east. Borehole B12 could be influenced during this time but at 50 mg/L concentration is well below the water quality standards for drinking water.

Scenario two:

Error! Reference source not found. depicts the migration of the contaminant plume away from the project area. It can be seen that the plume extends to around 650 m away towards the east. Borehole B12 could be influenced during this time but again at 50 mg/L concentration is well below the water quality standards for drinking water.

In closing it can be said that the project have a low long term quantitative possible impact with a medium probability and a high qualitative impact over a long term with a medium probability.

Current Steady State (no go option)

If the old ash dam is left in the current state and no PV Cells established on top of the old ash dam then groundwater flow will not be influenced and no drawdown will be resulting from reduced recharge as per the other two scenarios. However the contaminant migration will continue and a simulation of this indicates that the spread of contaminants will exceed both

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scenario one and two migrations by approximately 50 to 100 m as can be seen from Figure 8-17.

This option is therefore the problematic scenario as no use will be derived but under the regulations will have to be cleaned up which could be a very expensive option.

Simulations therefore indicates this to have a no quantitative impact but a high long term quantitative impact that will have to be corrected before closure could eventually be obtained.

<u>Transmission Lines</u>

The only concern from a groundwater point of view will be the footprint size of the pylons used for construction of the transmission lines. These will cause compaction and slight excavation of the wetland immediate area, which will cause the groundwater flow to be disturbed. However if this footprint can be kept to a small overall extent then the impact will be low but over the long term. The construction of these will be critical as heavy vehicles will have to enter the wetland system which could cause short term or longer term permanent damage to the wetland and in turn the groundwater flow as groundwater levels are normally within 0.5 m below the wetland surface.

It will be important to manage this process very carefully and ensure that an environmental management plan be compiled detailing exactly how this will be achieved and approved by the relevant authorities before work commences and needs to adhere to GN 1199, section 6 (b).

<u>Storm Water Control</u>

The fact that the area will be covered by hard compacted or paved areas means that no extra berms or canals are required only designed drain pipes or canals. An emergency lined storage pond will have to be added though that can handle flood events and reduce weathering to the natural environment. Table 9-1 indicates the volumes that will run off from the hard paved areas in the event of a 100 mm precipitation event. These volumes are substantial and cannot be allowed to run away freely as this could create weathering to natural surfaces as the runoff coefficient is much higher than natural vegetated areas. These figures are for the total area and it is not anticipated that the full extent will be prepared with stable areas, but these are indicative of what can be expected per areal extent.

When the exact areas are available more precise calculations can be performed to ensure that engineering drainage designs can handle the 50 and 100 year flood events.

<u>Mitigation</u>

Mitigation methods can be applied once the PV process is finalised and can be indicated in the future management plan for the project and does not necessarily need to be performed immediately.

However if the planned project does not go ahead then further impacts from the old ash dam will have to be investigated according to Section 21 (h) of the National Water Act of 1998.

Method One:

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New dewatering boreholes can be established up-gradient towards the west of the project area to act as a dewatering curtain to keep groundwater flow away from the old ash dam source concentration. The abstracted water can then be diverted along with the surface water collected from the stabilised areas and discharge if the quality is within limits. This will keep clean water clean and away from the source. Also solar driven submersible pumps can be used to pump the water and gravity fed to the downstream collector basin, which makes it a sustainable long term solution.

Method two:

The other option is to apply pump and treat where boreholes are drilled to abstract water from the aquifer down gradient in line with the plume migration and then pumped to a treatment facility. The water is then treated to a reasonable level ready for discharge to the surface water environment. This option is quite expensive and not the best option in the long term.

A third very expensive option is to remove all material and dispose at a disposal facility designed and regulated to handle such material.

Monitoring

The monitoring at the Grootvlei ESKOM Power Station is currently up to date and needs to be maintained in this fashion. The only area which has not been covered sufficiently is the old ash dam. From the numerical model contaminant transport simulations it can clearly be seen that the area of importance is not adequately monitored. It is therefore suggested that two ne monitoring boreholes be established to the north and east of the area. The geophysical targets summarised in Table 3-1 and specifically target one and two should be used to ensure optimum results during drilling and to be most representative. If possible all three boreholes should be established for completeness.

The boreholes should then be incorporated into the current monitoring network and the same frequencies should be adhered to.

Recommendations:

The following Recommendations were forthcoming as a result of this study:

- As part of future mitigation actions and depending on the scenario selected going forward it is advised that two to three new monitoring boreholes needs to be established around the old ash dam as per targets summarised in Table 3-1, these then need to be sampled to ascertain the current contamination plume derived from the old ash dam;
- Once this is achieved and completed the numerical model should be re-calibrated and final simulations performed;
- A land surveyor should firm up on the positions of all monitoring positions especially the elevation component as this will be crucial for future numerical models;

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- More detailed plans and scenarios needs to be provided to firm up on the results of this study; and
- As a partial mitigation option it is recommended that scenario two which includes a 100 % capping be applied to restore conditions over the long term.

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Section 1 Introduction

1 Introduction

1.1 Background

SGW has been commissioned by Environmental Impact Management Services (EIMS) (Pty) Limited to conduct a specialist hydrogeological investigation at the ESKOM Grootvlei Power Station around the old defunct ash dam to the south of the property. This site (Alternative 1) was selected after the initial alternative site selection process for the PV facility identified the site as the only feasible alternative. ESKOM is planning to cover Alternative site 1 with Photo Voltaic cells to generate solar power to augment the power of Grootvlei power station. ESKOM is planning to cover the area with Photo Voltaic cells to generate solar power to augment the power grid. The study focused on any possible impacts on the groundwater environment and in turn the receiving surface water environment. The old ash dam has been out of use for approximately 30 years now and has been rehabilitated with vegetation and capped with a soil layer of approximately 30 cm. The ash has solidified over time to the point where collecting a sample for the geochemistry was a very difficult task.

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The first phase documented in this report focused on the characterisation by non-intrusive methods but also intrusive. A ground geophysical investigation including the magnetic and electromagnetic method was conducted as well as pump out and slug in and out aquifer tests and hydrochemical sampling. The second phase included a numerical model to simulate different impact scenarios associated with the old ash dam.

Previous work in the area (Vermeulen et al, 2012) comprised a detailed monitoring report of the area.

This document details all the methods utilised as well as findings and recommendations during this first phase hydrogeological specialist investigation. The methodology utilised was performed according to world and local best practise guidelines for hydrogeological technical studies.

1.2 Objectives and Scope of Work

The objective was to conduct a detailed hydrogeological investigation to ascertain what impacts the establishment of PV Cells on top of the old ash dam and surrounding area could have on the groundwater aquifers. This includes the following:

Phase 1

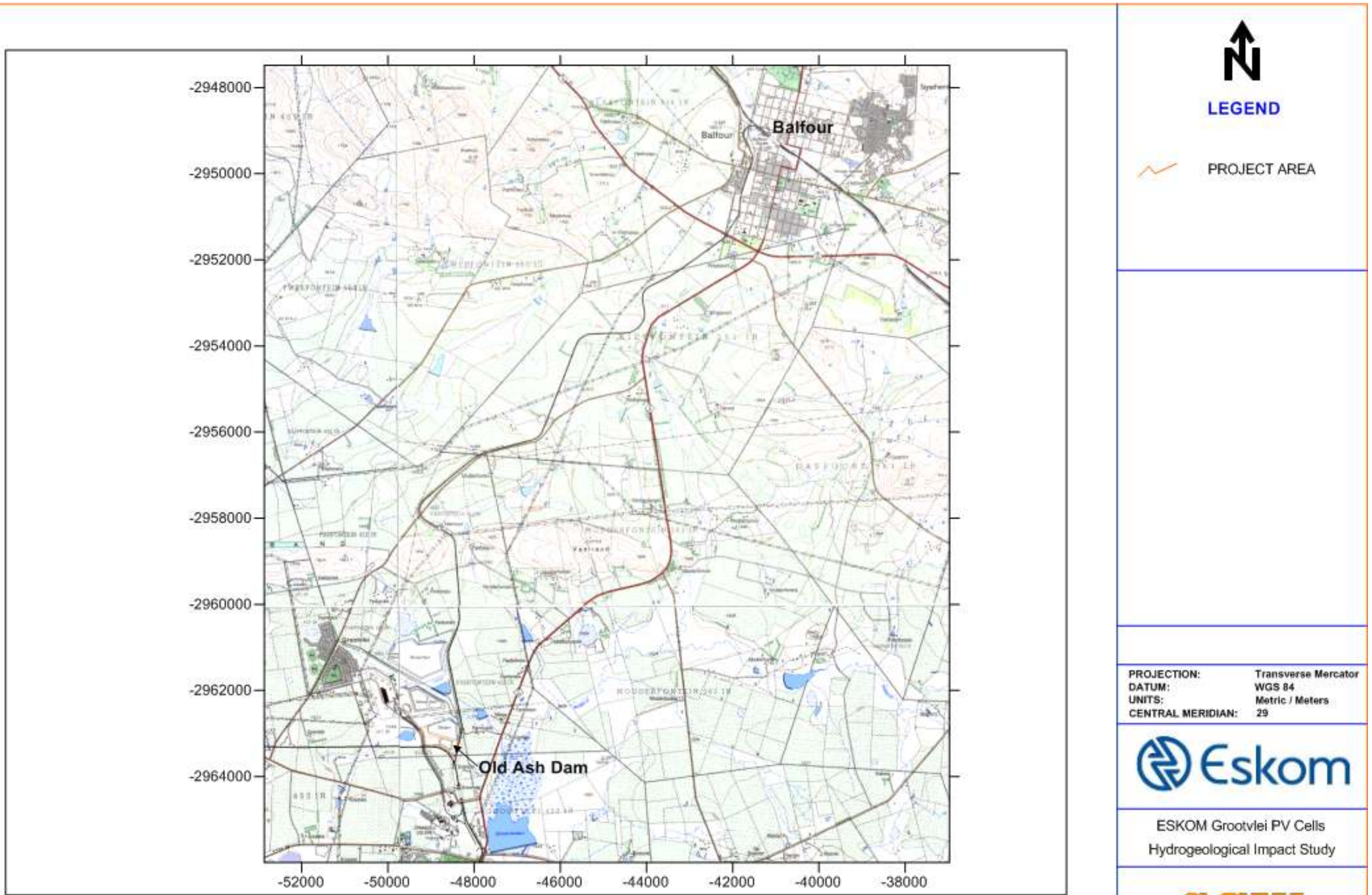
Section 1 Introduction

- Ground geophysical investigation to delineate possible weathered zones and geological structures in the area as well as assist with positioning of possible new monitoring boreholes;
- Aquifer testing and interpretation; and
- Hydrochemical sampling to verify the results from the report previously compiled by Vermeulen *et. al*, 2012.

Phase 2

- Conceptual modelling;
- Numerical modelling and contaminant transport modelling for risk assessment; and
- Technical report and findings.

Section 1 Introduction



LOCALITY MAP

FIGURE 1-1

Section 2 Site Physiographic Setting

2 Site Physiographic Setting

2.1 Location and Landform

The ESKOM Grootvlei Coal Fired Power Station is situated on the Farm Grootvlei 457 IR approximately 18 km from the town of Balfour in the Mpumalanga Province Figure 1-1 and the project layout in Figure 2-1.

The site is typical Highveld grassland with undulating hills. The highest topographical point lies to the south-west of the area at 1551 m amsl and the lowest to the northern drainage line at 1540 m amsl with a total difference in elevation of around 11 m (data derived from the SRTM data set).

The area is bounded by a ridge to the far north and an unnamed non-perennial stream to the immediate north, the Molspruit to the south is a perennial stream bounding the project area. No springs issue in the area and the large wetland system to the north of the Grootvleidam is probably as a result of the dam leaking over time in the near subsurface.

2.2 Precipitation

Rainfall data has been recorded at the Heidelberg weather station. Table 2-1 provides a summary of the average data, based on Bureau of Meteorology records. The average annual rainfall is 671 mm. The average monthly rainfall varies considerably throughout the year due to the influence of wet and dry seasons. Rainfall events are typical summer regime and highest rainfall events occur during October to March.

Table 2-1 Average precipitation data for the Heidelberg Meteorological Station

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
112.8	87.3	71.9	39.4	17.9	7.6	6.3	10.9	28.7	68.7	102.8	116.7	671

2.3 Geology

The project area comprise mainly of sandstone, coal and shale beds (Pv) of the Vryheid Formation of the Ecca Group of the Karoo Sequence. Approximately 3.5 km to the direct south are outcrops of Dolerite intrusive sills (Jd). No other intrusive dykes or sills are evident in the immediate project area. No faulting is indicated in the project area (Figure 2-2).

2.4 Hydrogeology

Two aquifers exists in the area, an upper weathered unconsolidated aquifer and a deeper fractured rock secondary aquifer. The aquifers can be described as follows:

Upper weathered material aquifer:

The upper aquifer forms due to the vertical infiltration of recharging rainfall through the weathered material being retarded by the lower permeability of the underlying competent rock material. Groundwater collecting above the weathered / competent material contact migrates down gradient along the contact to lower lying areas. In places where the contact is near surface the groundwater can daylight on surface as springs. There is a non-perennial stream as well as a wetland area that occurs on as well as off site and receives base flow contributions from shallow groundwater.

It is considered that effectively 1 to 3 % of the mean annual rainfall eventually reaches the groundwater table. Aquifer transmissivities of these types of aquifers are in the order of 0.5 to 10 m^2/day.

Lower fractured rock aquifer:

Although the lower permeable competent rock material will retard vertical infiltration of groundwater some of the water in the upper aquifer will recharge the lower aquifer. The geological map doesn't indicate major faults or fractures in the area; however, it is considered that the competent rock will be subjected to fracturing associated with tectonic movements that created features such as the dolerite sill that overlie the southern area.

Groundwater flows in the lower aquifer is associated with the secondary fracturing in the competent rock and as such will be along discrete pathways associated with the fractures. The general transmissivity of the competent rock material normally is around 0.1 m^2/day but could be as high as several 100 m^2/d where linear geological features exist.

2.5 Geochemistry

It is not anticipated that the ash dam material will be acid generating and therefore no Acid Base Accounting (ABA) leach tests were performed during this study.

A sample of the ash dam material was collected on the 19th of December 2012 of the top of the storage facility as well as the wall. The composite sample was lodged with SGS Laboratories in Randburg for analysis on the 20th of December 2012.

2.5.1 Method

The toxicity characteristic leaching procedure (TCLP) is designed to determine the mobility of both organic and inorganic analytes in liquid, solid, and multiphasic waste under conditions that simulate those found in a waste facility (EPA, 2009). Tests of such short duration cannot be expected to identify long term effects which, if present, are likely to dominate leachate generation behaviour once the waste is disposed. However it gives some indication as to what analytes could be expected to be anomalous in groundwater. This is also seen to be the worst case scenario and only proper monitoring over time in the correct position can verify these results. See Appendix E for the testing procedures and analysis certificate.

2.5.2 Results

The results from the SGS TCLP test is summarised in Table 2-2. This clearly indicates the elevated salts and high Total Dissolved Solids (TDS). Compared to the SANS:241 water quality standards (this is only for comparison sake and cannot strictly be compared directly as this test uses aggressive extraction liquids) the following analytes were elevated:

- TDS;
- Conductivity;
- Chloride;
- Calcium; and
- Sodium.

Table 2-2 TCLP analysis results for the old ash dam sample

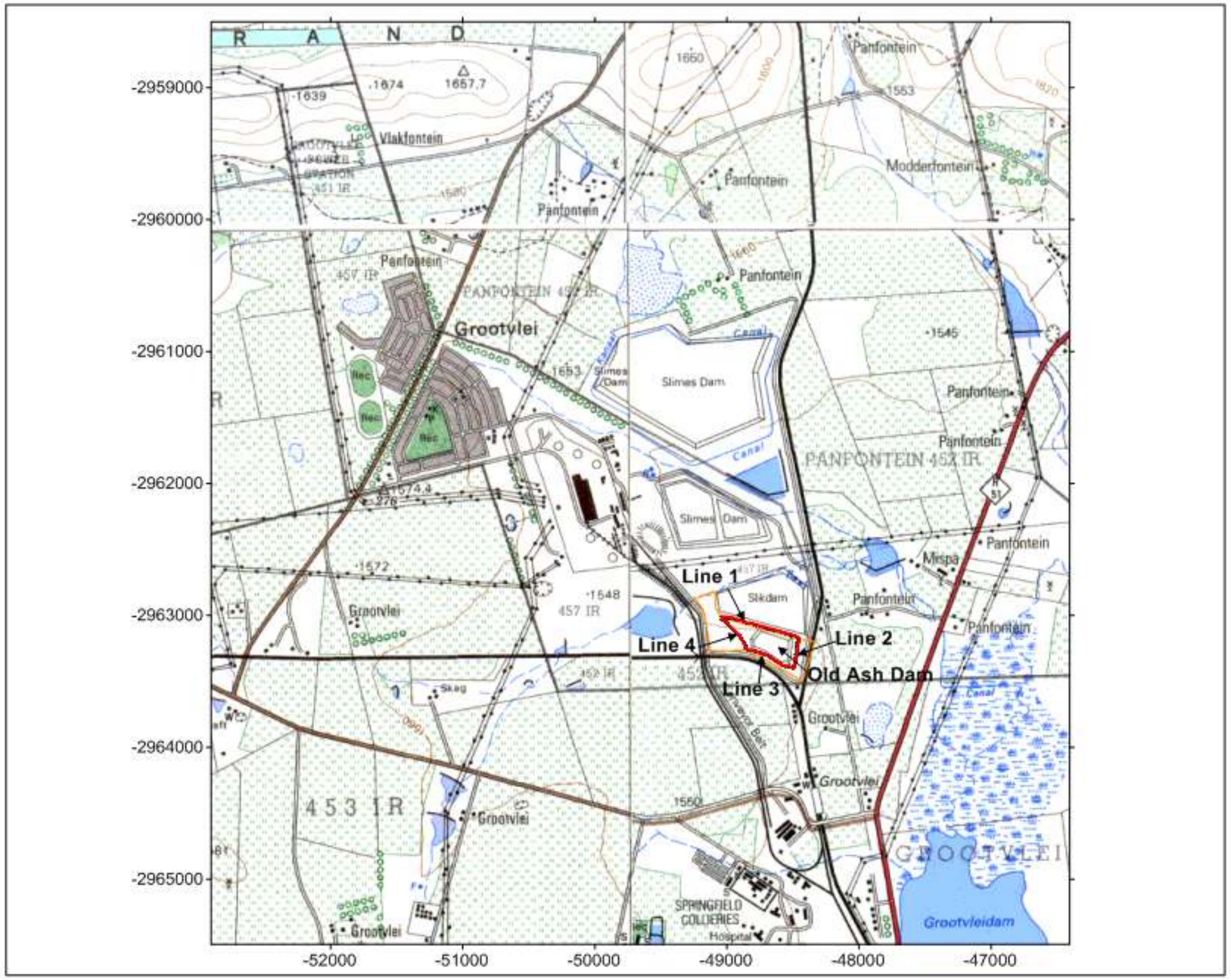
Sample Name	ESADAM01		
Analyte Name	**Units**	**Reporting Limit**	**Result**
Final pH	-	0.1	6.1
Evaluation pH	-	0.1	9.1
TDS (0.7µm) @ 105ºC	mg/l	21	5100
Conductivity	mS/m	2	686
Chloride	mg/l	0.05	596
Sulphate	mg/l	0.05	36
Sodium	mg/l	0.5	1330
Calcium	mg/l	0.5	568
Magnesium	mg/l	0.01	25
Arsenic	mg/l	0.01	0.03
Boron	mg/l	0.005	0.78
Lead	mg/l	0.01	<0.01
Nickel	mg/l	0.005	<0.005
Selenium	mg/l	0.01	0.03
Strontium	mg/l	0.001	7.5
Vanadium	mg/l	0.001	0.038
Zinc	mg/l	0.01	<0.01

The results from the leach testing were used for the contaminant transport as the source and specifically sodium with the highest value of 1330 mg/L. This is a good indication what the ash dam source would be that mixes with groundwater to form a leachate over time.

2.6 Hydrocensus

No hydrocensus was performed during this study as the report by Vermeulen *et. al*, 2012 summarises most of the boreholes in the project area and its associated information. The chemistry on a temporal basis is also available for all these boreholes and was sufficient for this study. New samples were collected on five of the boreholes during the testing phase of the boreholes, however only the three most relevant samples were submitted for testing and analysis, see Section 5..

Site Physiographic Setting



PROJECT LAYOUT

N

LEGEND

GEOPHYSICS LINES

PROJECT AREA

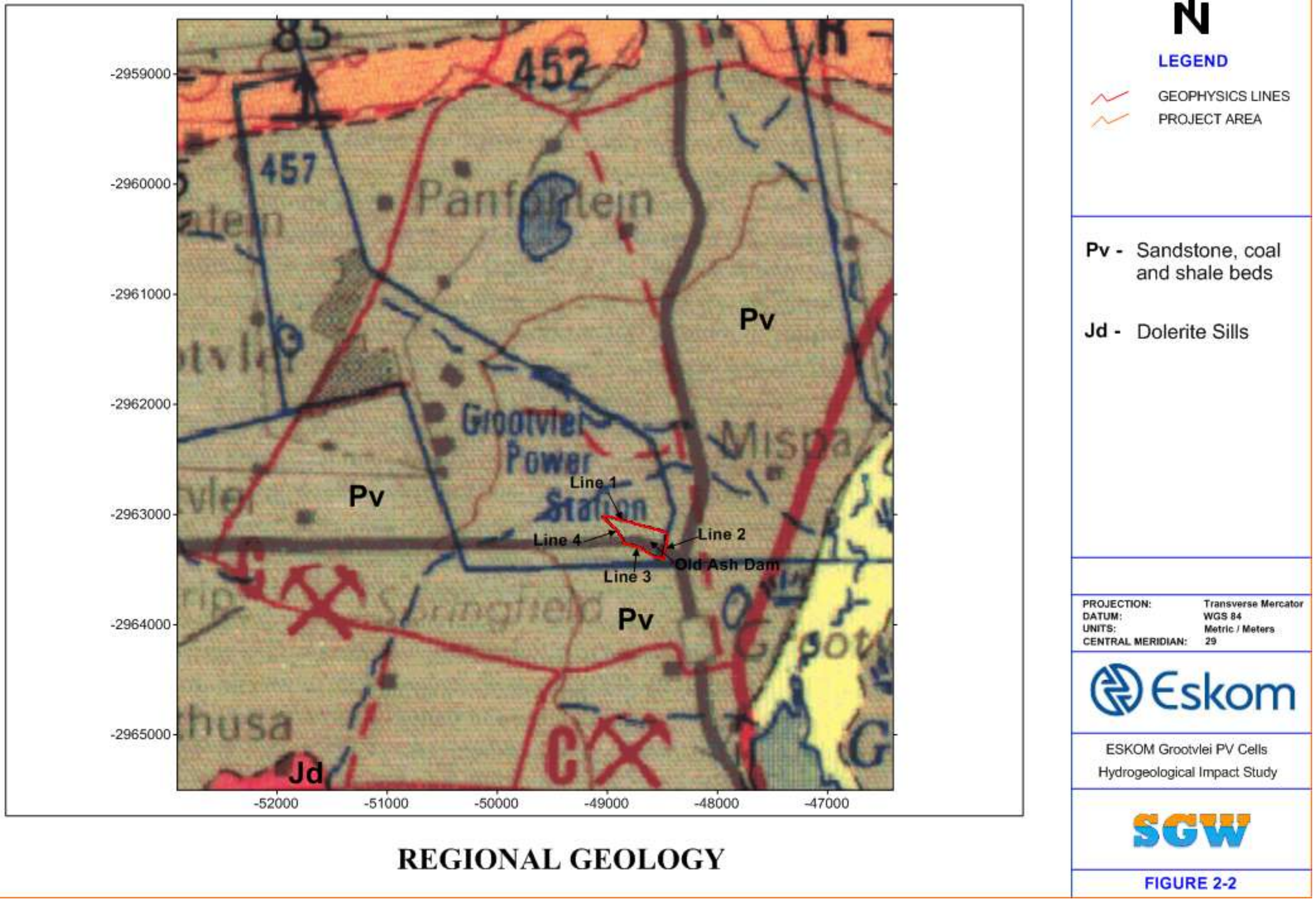
PROJECTION:	Transverse Mercator
DATUM:	WGS 84
UNITS:	Metric / Meters
CENTRAL MERIDIAN:	29

Eskom

ESKOM Grootvlei PV Cells
Hydrogeological Impact Study

SGW

FIGURE 2-1



-2959000
-2960000
-2961000
-2962000
-2963000
-2964000
-2965000
-52000
-51000
-50000
-49000
-48000
-47000
Pv
Jd
Line 1
Line 2
Line 3
Line 4
Old Ash Dam
Grootvlei Power Station
REGIONAL GEOLOGY
LEGEND
GEOPHYSICS LINES
PROJECT AREA
Pv - Sandstone, coal and shale beds
Jd - Dolerite Sills
PROJECTION: Transverse Mercator
DATUM: WGS 84
UNITS: Metric / Meters
CENTRAL MERIDIAN: 29
Eskom
ESKOM Grootvlei PV Cells Hydrogeological Impact Study
SGW

FIGURE 2-2

Section 3 | Ground Geophysical Survey

3 Ground Geophysical Survey

3.1 Methodology

A geophysical ground survey was conducted on 20 December 2012. The project area is mostly covered with alluvium with very little surface outcrops visible, geophysics is a method used to characterise the subsurface physical conditions without the use of extensive intrusive drilling programmes. A magnetic and electromagnetic survey was conducted to delineate vertical to sub-vertical features as well as weathered zones.

The two geophysical methods utilised in the project area included the electromagnetic and magnetic methods. The following is a description of these geophysical methods:

3.1.1 Electromagnetic method

Four lines were surveyed with a station separation of 10 m and positions surveyed using a hand held Global Positioning System (GPS) unit (Cartesian coordinates, WGS 84 datum).

A two man portable EM34-3 (with 20 meter coil separation) instrument was used for the electromagnetic survey. Both the vertical- VMD and the horizontal- HMD dipole modes were applied. These modes measure the out-of- phase component of the induced electromagnetic field, which gives an indication of the subsurface conductivity.

In the frequency domain electromagnetic method, which the EM34-3 instruments is a typical example of, a transmitter coil is energized with an alternating current at audio frequency (6400 Hz-10 m, 1600 Hz-20 m and 400 Hz-40 m). This current generates a primary magnetic field, which in turn induces secondary eddy currents in the subsurface. These currents then generate a secondary magnetic field which is then measured together with the primary magnetic field by the receiver coil. When operating at low induction numbers (i.e. conductivity low enough for a fixed frequency), the ratio of the secondary magnetic field to the primary magnetic field is linearly proportional to the average subsurface conductivity.

Using the VMD mode the maximum response originates from material at depth of approximately 0.4 x coil separation while the surface material has a small contribution. Deeper than x 0.4 coil separation the VMD mode has double the response of the HMD. For the HMD the surface material down to a depth of 0.4 x coil separation contributes to most of the signal (McNeill, 1980).

The out-of-phase component measures the average electrolytic ground conductivity through the moisture-filled pores and passages of the sampled volume. A maximum error of 30 % for the low induction number assumption is assumed, which allows for a maximum measured ground conductivity of 60 mS/m for the EM34-3. Provided the low induction number assumption is applicable, the effective depth of penetration is a function of the coil separation only (geometrically) and not of the skin depth (McNeill, 1980).

In the case where the low induction number assumption is violated by a certain percentage, the measured apparent conductivity is the same percentage lower than the true apparent conductivity (Stoyer, 1989).

The different dipole set-ups have different depths of penetration and different coupling with horizontal and vertical structures. Both the vertical and horizontal dipole set-ups have the same response over a vertical structure. The response of the vertical dipole will however be much larger if the contrast in conductivity remains constant with depth (McNeill, 1983a).

Several basic assumptions are made when empirical topographic corrections (Monier- Williams et al., 1990) are applied. The most important being that the background value (regional) is purely a function of elevation and that the stratigraphy should be horizontal and uniform. Unfortunately such ideal geological conditions are very seldom realized. Thus no elevation corrections applied during this survey.

3.1.2 Magnetic Method

A one-man portable Geotron G5 magnetometer was employed to conduct the survey. The G5 instrument is a Resonance, proton magnetometer and monitors the precession of atomic particles in an ambient magnetic field to provide an absolute measure of the earth's total magnetic field intensity in nanoteslas (nT).

The proton magnetometer has a sensor, which consists of a bottle (casing) containing a proton rich fluid, usually water or kerosene, around which a coil is wound that is connected to the measuring apparatus. Each proton has a magnetic moment M and because it is always in motion, it also possesses an angular momentum G, rather like a spinning top. In an ambient magnetic field like that of the earth's magnetic field (F), the majority of the protons align themselves parallel with this field with the remainder anti-parallel to the field (Figure 3-1 A). Consequently, the volume of proton-rich liquid acquires a net magnetic moment in the direction of the surrounding ambient field (F).

A current is applied to the coil surrounding the liquid and generates a magnetic field roughly 50 to 100 times that of the ambient magnetic field but perpendicular to F. The protons align themselves to the magnetic direction (Figure 3-1 B.). When the applied current is switched of the protons precess around the pre-existing ambient field F (Figure 3-1 C.), at the Larmor precession frequency (fp) which is proportional to the magnetic field strength F.

$$F = 2\pi fp / \phi p$$

where:

ϕ_p is the gyromagnetic ratio of the proton (ratio between magnetic moment and spin angular momentum, see Figure 3-1 D.)

and ϕ_p = **0.26753 Hz/nT and** $2\pi/\phi_p$ **= 23.4859 nT/Hz**

Thus: $\boldsymbol{F = 23.4859 f_p}$

For example, for F = 50 000 nT, f_p = 2128.94 Hz.

Because protons are charged particles they will induce an alternating voltage during precession at the same frequency as f_p into the surrounding coil. Interaction between adjacent protons causes the precession to decay within 2-3 seconds, which is ample time for measuring the precession frequency. The G5 magnetometer gives a direct readout of the field strength in nanoteslas and can be output into a solid state memory for downloading onto a computer (Reynolds, **1997).**

Section 3 Ground Geophysical Survey

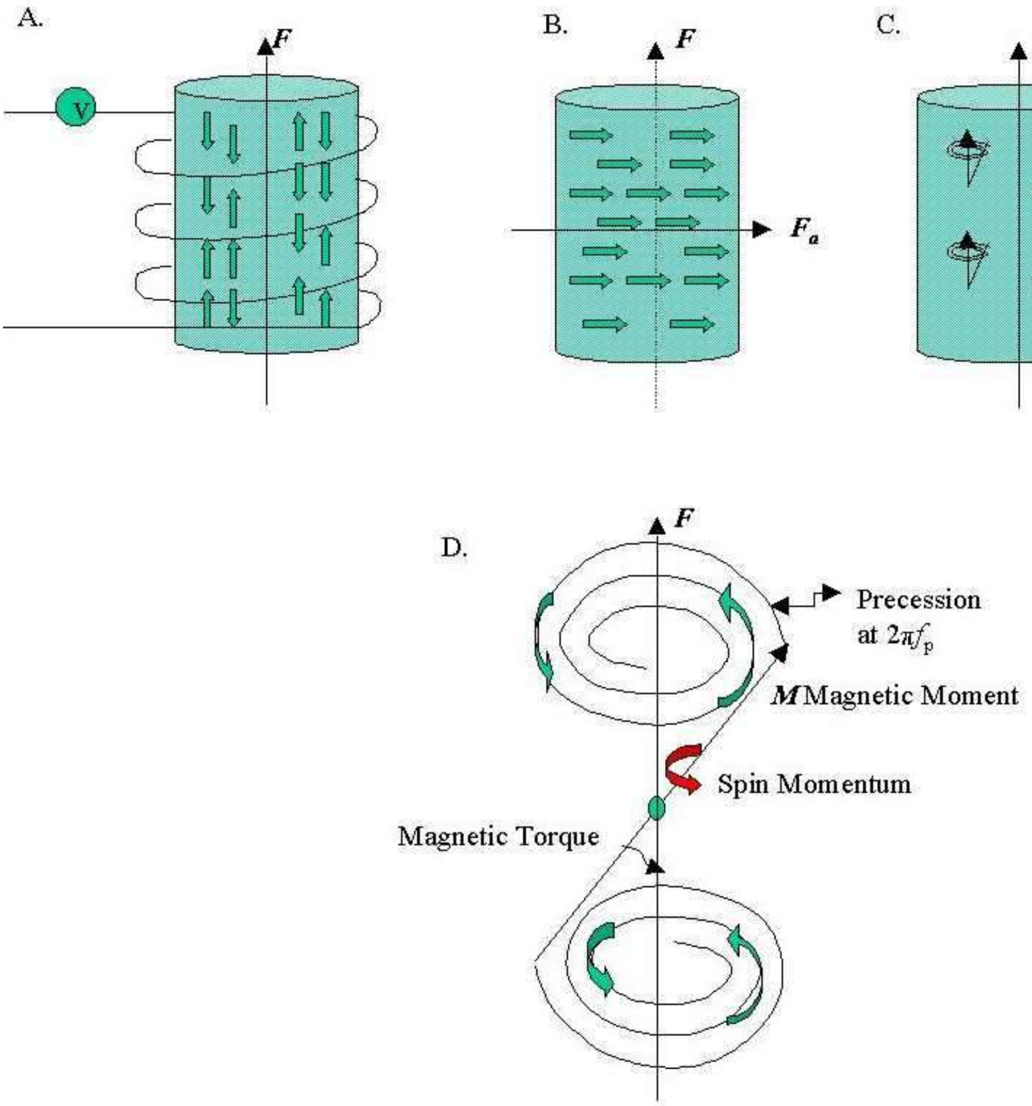


Figure 3-1 Basic operating principles of a proton magnetometer (After Kearey and Brooks, 1991)

3.1.3 Geophysical survey results

The results from the magnetic and electromagnetic survey indicated possible weathered zones along magnetic anomalies. The magnetic data used in the graph has been filtered and the regional magnetic field removed using a third degree polynomial. Due to the scale of the residual field only the raw data is displayed in the graphs as the em data tends to be obscured and not be visible.

Figure 3-2 is an example of em and magnetic raw data along with the magnetic total field residual (calculated data).

Section 3

Ground Geophysical Survey

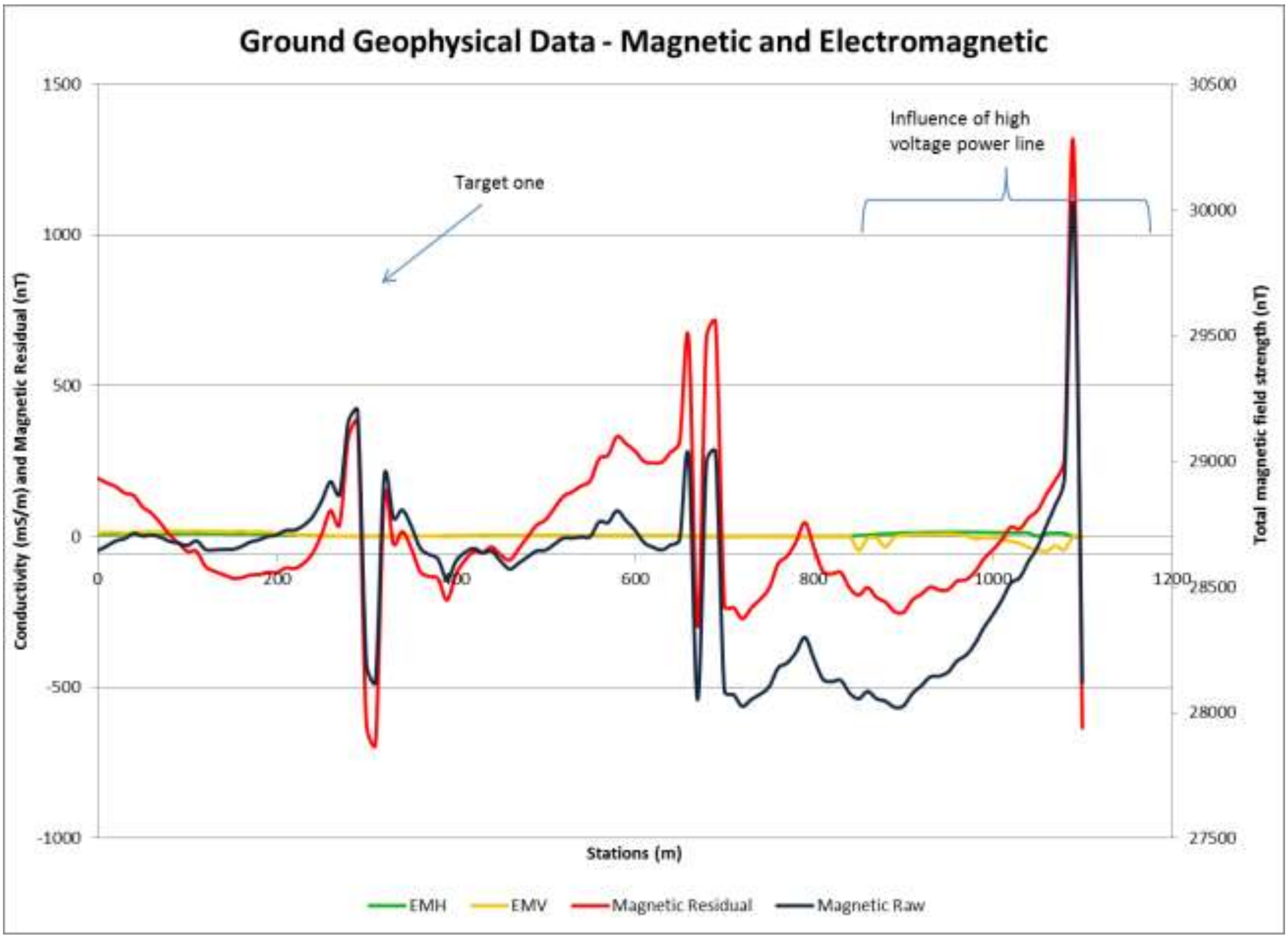


Figure 3-2 Graph indicating an example of the magnetic residual data used for interpretation

3.1.4 Line One

Line one (Figure 3-3) was surveyed from north-east to south-west. The steel pipe at station 370 to 390 m caused the anomaly in the centre of the line. A prominent anomaly can be seen towards the end of the line this is most likely due to a weathered zone and target one was positioned at station 590 m. This has a high associated em vertical anomaly with it indicating possible high conductive zone.

Looking at the overall data set it can be seen from the two dipoles which surveys different depths that the upper horizontal dipole indicates a much higher conductivity. This could be due to a clay layer forming the weathered upper aquifer or seepage that is emanating from the ash dam. As there are no monitoring boreholes next to the ash dam this possibility will have to be investigated by drilling.

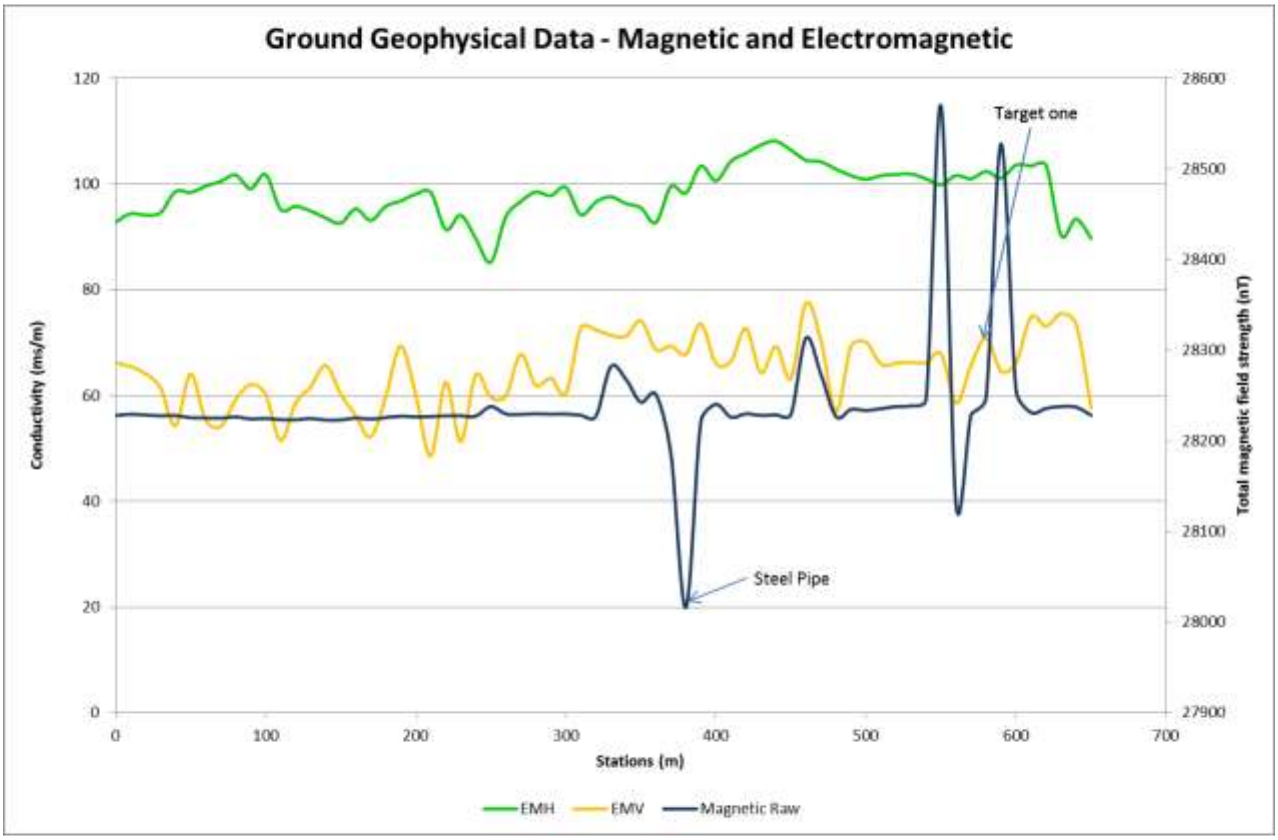


Figure 3-3 Graph indicating em and magnetic raw data surveyed on Line one

3.1.5 Line Two

Line two (Figure 3-4) was surveyed from north to south and no cultural effects were evident on this line. An anomaly between stations 80 and 130 m indicates a possible weathered zone. Target two is therefore positioned at station 100 m.

Section 3 Ground Geophysical Survey

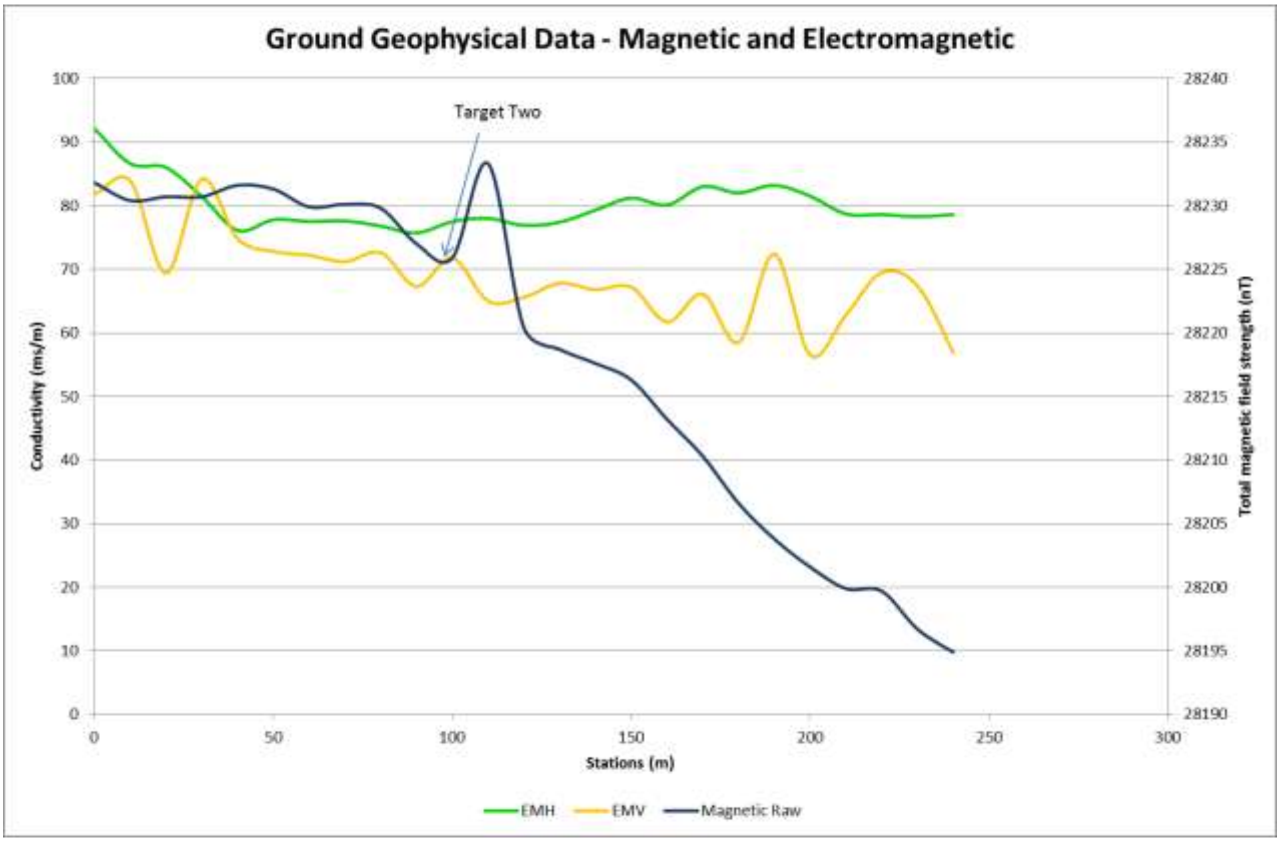


Figure 3-4 Graph indicating em and magnetic raw data surveyed on Line two

3.1.6 Line Three

Line three (Figure 3-5) was surveyed from east to west. The anomaly at the beginning and towards the end of the line was probably caused due to the line going over the ash dam from the bottom to the top and down again and caused by the higher elevation. This was because the fence line of the property was too close to the road and would have caused interference with the instruments. No other significant anomalies were evident on the data.

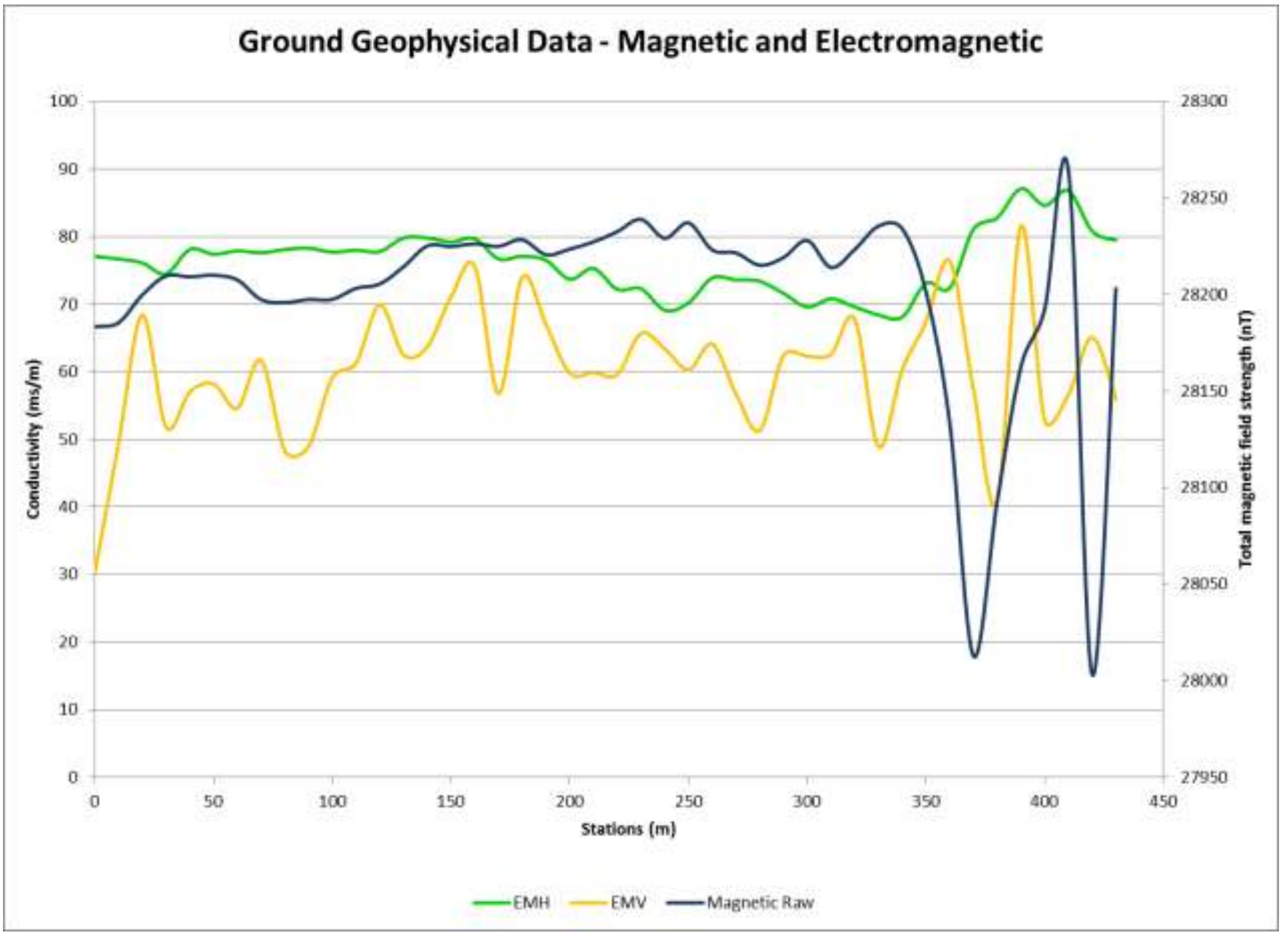


Figure 3-5 Graph indicating em and magnetic raw data surveyed on Line three

3.1.7 Line Four

Line four (Figure 3-6) was surveyed from south-east to north-west. An anomaly between stations 130 and 200 m is possibly caused by a weathered zone with associated higher conductivity values from the vertical dipole. Target three is positioned at station 150 m.

Again the distinct difference in conductivity between the two dipoles indicates two distinct different aquifers.

Section 3 Ground Geophysical Survey

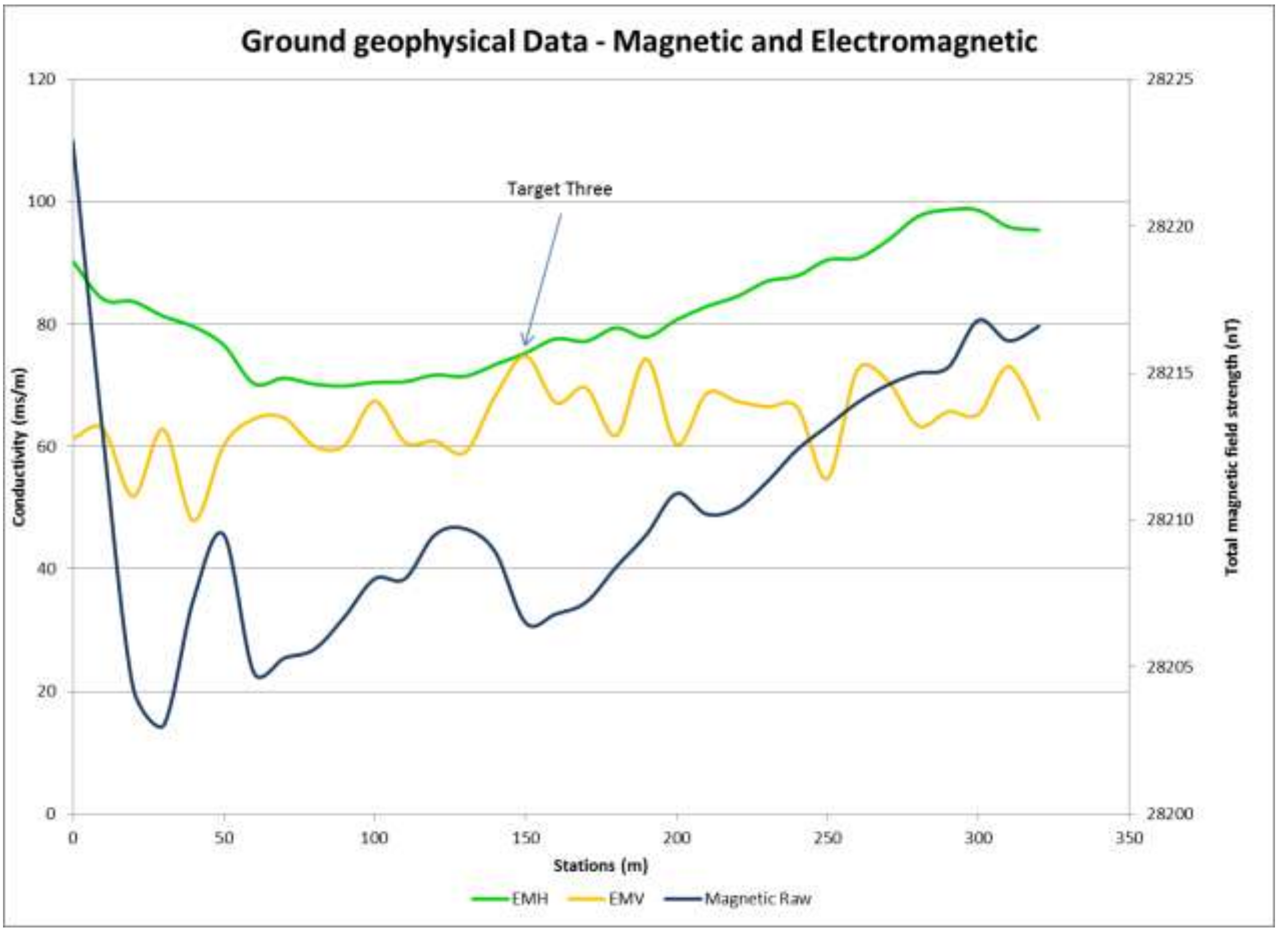


Figure 3-6 Graph indicating em and magnetic raw data surveyed on Line four

3.2 Drilling Targets

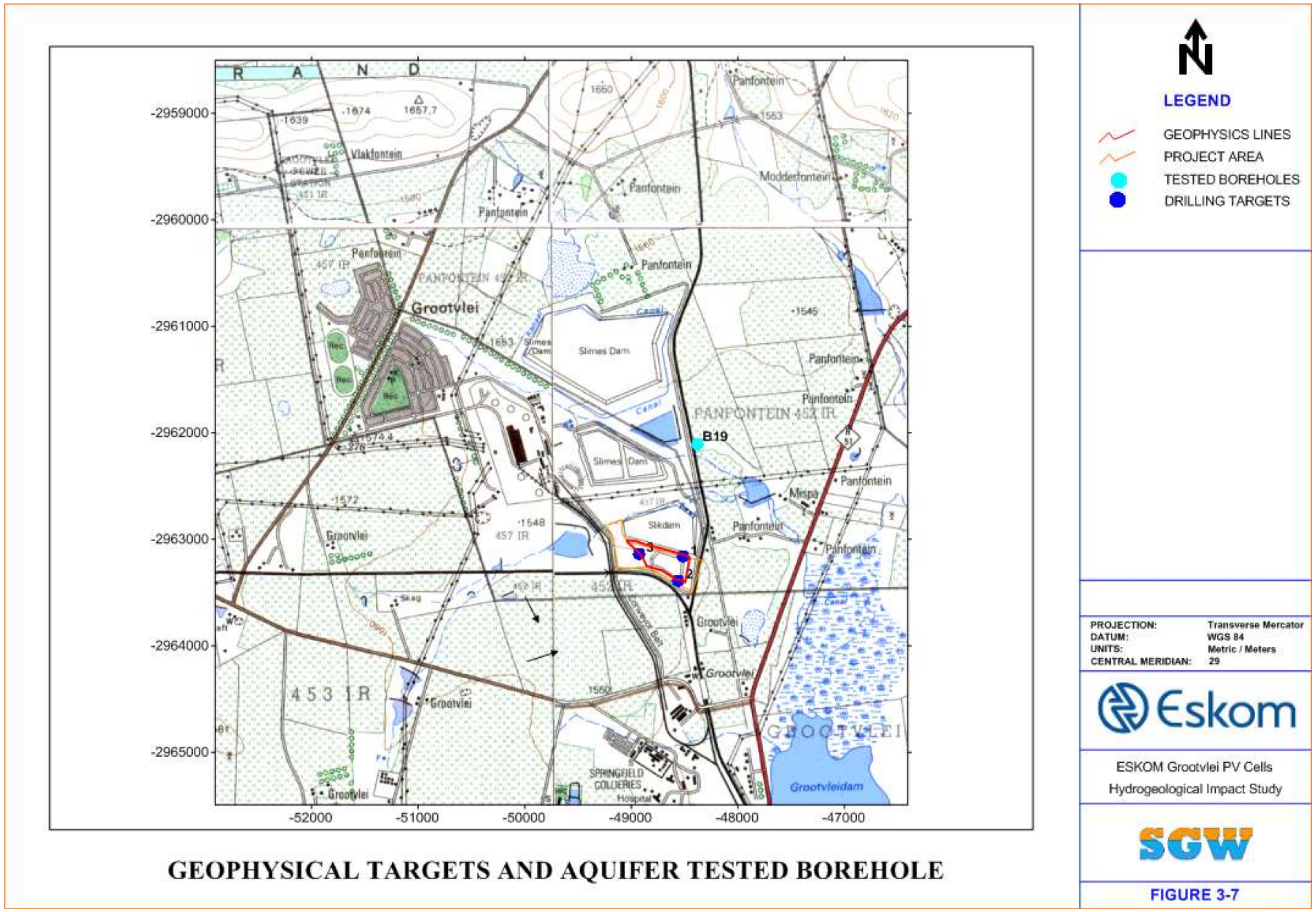
Error! Reference source not found. summarises the possible drilling targets resulting from the interpretation of the geophysical survey conducted around the ash dam. Three targets were derived from four lines (Figure 3-7).

Table 3-1 Drilling targets derived from the geophysical survey data

Line	Station	x	y
1	590	2963158.00	48513.00
2	100	2963384.00	48559.00
4	150	2963132.00	48928.00
Coordinates in Cartesian WGS 84			

Section 3

Ground Geophysical Survey



GEOPHYSICAL TARGETS AND AQUIFER TESTED BOREHOLE

FIGURE 3-7

4 Aquifer Testing

Aquifer testing of one existing borehole was conducted from the 18th to the 20th of December 2012. Due to the small diameter of the monitoring boreholes longer duration pump-out tests could not be performed and a slug test was conducted instead. Only borehole B19 to the north of the project area was tested. A slug test and one short duration pump out test was performed on the borehole. A summary of the derived aquifer parameters and drawdown data obtained during testing is presented in Table 4-1 and Table 4-2. The aquifer test data is appended in Appendix B and the test graphs in Appendix C.

Two types of tests were undertaken:

- Slug tests; and
- Constant-discharge and recovery tests.

4.1 Slug Tests

Slug-in and slug out tests were performed on one borehole of which the diameter was too small to use normal pump out testing. Borehole B19 was tested and represented the deeper fractured sandstone aquifer.

Methodology and analysis

Slug tests can be performed by either introducing or removing a known volume of water or a closed container with known volume. The slug-in test used during this project is performed by introducing a slug into the borehole below the static water level, after which an instantaneous rise in water level will occur. This will then dissipate or fall back to the original level over a period of time, which is carefully recorded by either an electronic dip meter or digital electronic recorder. The data is then graphed as the head ratio against time on a logarithmic / linear scale. The T_0 value is then obtained by connecting the values in a straight line and reading the intercept from the logarithmic axis. The hydraulic conductivity can then be derived by using the Hvorslev method as can be seen in the following formula:

$$K = \frac{r^2 \ln(L/R)}{2LT_0}$$

Where r = radius of the well or piezometer casing

L = length of the saturated portion of the screen or filter pack

R = radius of the screen or screen plus filter pack

T_0 = basic time lag, which is read from the graph

K = hydraulic conductivity of the formation

4.2 Constant Discharge Tests

For the constant-rate discharge test, the borehole was pumped until the water level reached the pump and recovered immediately thereafter. Water levels were monitored in the pumped bore. This was achieved for the upper aquifer penetrated by the steel casing on borehole B19 which had a wide enough casing to allow for testing in the first 12 m of the upper aquifer. The lower aquifer section was constructed using the smaller diameter PVC casing that is only perforated over the deeper fractured section and solid in the first 12 m of the borehole sealing of the upper aquifer.

Methodology and analysis

The constant-discharge test results enable the hydraulic characteristics of the aquifers intersected by each test production bore to be determined. The following methods were used to analyse the constant discharge data acquired:

- Flow Characteristic (FC-method) method (Van Tonder *et all*, 1999), utilising different analytical methods of flow characterization.
- Theis straight line and recovery method for the pumping boreholes (Kruseman and De Ridder, 2000).
- The Cooper-Jacob (“straight-line”) method (Kruseman and De Ridder, 2000) of analysis is a modification of the Theis equation and the data must meet certain requirements in order to validate. The validation requirements are derived using the following equation:

$$u = \frac{r^2 S}{4KDt}$$

Where:

$r =$ Radial distance between the observation bore and the production bore (m)

$S =$ Storativity value obtained from the analysis (-)

$K =$ Hydraulic Conductivity (m/day), [also referred to as permeability in this report]

$D =$ Thickness of the aquifer (m)

$t =$ Time (days)

where, the value of u is generally < 0.01.

Section 4 Aquifer Testing

Table 4-1 Summary of Constant Discharge test and Slug-in test performed at Grootvlei project area

	Constant-Rate Test						
	Pumping Rate (m^3/d)	Available Drawdown (m)	Drawdown (m)	Monitoring Borehole	Distance from pumping well (m)	Drawdown (m)	Sustainable Yield (m^3/d)
B19	0.864	7	4.804	none	-	-	-
B19	Slug-in	-	0.051	none	-	-	-

Table 4-2 Summary of Parameters obtained during Constant Discharge and Recovery test and Slug-in test performed at Grootvlei project area

Bore ID	Constant Test (period hours)	Blow Out Yield, Q (L/s)	Tested Yield, Q (L/s)	Transmissivity (m^2/d)					Storativity (Estimate)
				Logan Method	FC-Method		Theis Recovery Method		
					Early time	Late Time	Early time	Late Time	
B19	0.08	unknown	0.01	0.4	0.12	-	0.6	-	1.00E-06
B19	0.08	unknown	Slug tests	-	1.8	-	-	-	1.00E-06

The data indicates that the upper weathered aquifer has a low hydraulic conductivity in the order of 0.008 m/d and low storage. The deeper fractured rock aquifer has a slightly higher hydraulic conductivity in the order of 0.01 m/d with higher storage.

This would be expected of a clayey upper weathered aquifer and a fractured lower aquifer. The upper unconfined aquifer therefore has the capability of retarding the spread of contaminants away from the project area. The lower aquifer is semi confined and where weathered zones exist the conductivity will be higher and the link with the upper aquifer could be more prominent which could cause the spread of any contaminant at a higher rate. The difference in conductivity values between the two aquifers is not substantial and more or less in the same order. Although only one borehole was tested the data can be compared to a number of publications available dealing with aquifer parameters in Karoo Sequences (Hodgons, Kranz, Van Tonder etc.).

No boreholes exist around the immediate ash dam area and specific data on the aquifer characteristics could therefore not be obtained. Therefore an average estimate of data from other monitoring positions was used. It is recommended that this situation be addressed.

5 Hydro Chemistry

The sampling of groundwater in five existing boreholes was performed using a discrete stainless steel bailer. The samples were collected between the 18th and 20th of December 2012. Only the three most strategic samples were lodged for analysis.

5.1 Methodology

The sample collection of five groundwater samples was conducted at the hand of the following methodology discussed below:

For the three boreholes a sample was collected with a discrete stainless steel bailer pre-treated with Liquinox and rinsed with DI Water before bailing the volume of the borehole and then sampling.

The groundwater sampling was conducted in accordance with the minimum requirements for water quality monitoring at waste management facilities as specified in the Minimum Requirements for Water Monitoring at Waste Management Facilities (DWAF, 2005) as well as SANS:241 and the Groundwater Sampling Comprehensive Guide (WRC, 2007);

Purging was performed to remove stagnant water from the boreholes; and

A handheld instrument was used to measure the pH (The apparatus was calibrated); samples was transferred to a cooler box in the field and kept below five degrees Celsius prior to being submitted for analysis at Clean Stream Laboratory, which is SANAS accredited.

Chemical analysis on the groundwater samples will be analysed for the constituents summarised in the following Table:

Major Inorganic Constituents *(in mg/L unless stated otherwise)*	
Major Ions	
Cations	***Anions***
Sodium	Bicarbonate
Calcium	Chloride
Magnesium	Nitrate as N
Potassium	Sulphate
Minor Ions	

Fluoride
Iron
Ammonia (NH_4)
Sodium Absorption Ratio (SAR)
Trace Elements
Aluminium
Manganese
Physico-Chemical Parameters
Electrical Conductivity (EC) - *L + F
pH - *L + F
Total Alkalinity - *L
Total Dissolved solids - *L
Total Hardness *L
Optional Trace Elements
Total Chromium
Lead
Zinc
Copper
Nickel
***Laboratory measured and Field measured**

5.2 Results

The results from the three groundwater samples were received on the 28th of January 2013 from Aquatico Laboratories in Pretoria. The results are summarised in Table 5-1. Samples were collected from two boreholes and B19-1 represents the upper weathered aquifer and B19-2 the deeper fractured aquifer in borehole B19, the other borehole sample collected was at B18.

The results are compared to the SABS SANS:241 water quality guidelines for domestic use. Both Class 0 and Class II values are specified. Class 0 values represent the ideal range whilst Class II represents the maximum allowable levels. All elements that are expected to exceed the guidelines are highlighted in red. Class I is also highlighted with yellow for convenience although not specified under SANS.

From Table 5-1 it can be seen that the regional groundwater quality in general is good however all samples have elements within Class I with none exceeding this Class. Chloride and sodium are elevated compared to the rest of the elements in this batch, however they are well within the guidelines. This however does indicate along with the more basic nature of the pH that the groundwater could derive leachate from the old ash dam area historically and perhaps this could still be the case.

The negative values in Table 5-1 represents values that are smaller than the numerical value indicated and usually suggests values below detection level.

5.2.1 Chemical character

Trilinear Diagrams were created using the Windows Information System for Hydrogeologists (WISH) program developed at the Institute for Groundwater Studies (IGS) at the University of the Free State. A Piper diagram is utilized to characterise water type in a graphical manner and to distinguish any specific water types in an area.

The Piper diagram (Figure 5-1) is used as a graphical way to simplify this process. The water samples can be grouped into the left, bottom, right and upper quarters. The position of the water sample on the diagram is based on the ratio of the various constituents measured in equivalence and is not an indication of the absolute water quality or the suitability thereof for domestic consumption.

The calcium-magnesium-bicarbonate (left quarter) of the Piper diagram is normally characterised by freshly recharged water. The sodium bicarbonate dominant (bottom quarter) is typical of dynamic groundwater flow within an aquifer, with the sodium replacing calcium and magnesium in solution. The sodium chloride dominant (right quarter) is associated with stagnant or slow moving groundwater with little or no recharge. The sulphate dominant (top quarter) is typical of water impacted by the oxidation of pyrites which is commonly associated with coal and gold mining activities.

The Expanded Durov diagram uses similar ratio techniques as the piper diagram to position the concentrations of the major ions, however six triangular diagrams are used, three for the anions and three for the cations (please refer to

Figure 5-2. The Expanded Durov is divided into 9 areas, each corresponding to a water type; a brief description is given in the legend table below. In each instance the dominant anions and or cations are given. In certain instances there is no dominance by any particular constituents (area 5) or only dominant anions (area 8).

Expanded Durov Legend

1 Calcium Bicarbonate	2 Bicarbonate Magnesium or Calcium Magnesium	3 Bicarbonate Sodium
4 Sulphate and/ or Calcium	5 No dominant anions or cations	6 Sulphate and/or Sodium
7 Chloride and Calcium	8 Chloride	9 Chloride and Sodium

Using the Expanded Durov Diagram

Figure 5-2, it can be seen that in general two water types exists in the area where the study was conducted. Boreholes BH19-1 and BH19-2 can be classed as bicarbonate magnesium or calcium magnesium type. Borehole B18 is a sodium and chloride dominant type water and normally indicates water contaminated by mining and waste disposal activities. However as this area is underlain by Karoo sediments this can also be attributed to the shales and sandstones.

The Piper Diagram indicates the same two water types. BH19-1 and BH19-2 is indicative of more freshly recharged water while BH18 are more indicative of water being enriched in sodium and chloride.

The trace and heavy metals are not existent in any major elemental concentrations. The chemistry results in the report by Vermeulen (2012) correlates well with the latest findings for these two boreholes. Some elevated sulphates were also recorded in their study over time, but is a function of dry seasons as during wet seasons precipitation probably acts as a dilutant and lower concentrations are observed. No anomalies are therefore evident in this area, that said though it must be realised that the ash dam is situated partly over old underground mining areas and this could cause groundwater to flow in a completely different direction, as mining was deeper than 180 m below the surface groundwater surficially at least follows the topography and flows towards the south – east towards the surface drainage. Therefore monitoring boreholes directly adjacent to the old ash dam and in the direction of flow could possibly have a different chemical composition.

Section 5 Hydro Chemistry

Table 5-1 Laboratory Chemical Analysis Results

Element	SABS 241 guideline		B18	B19-1	B19-2
	Class 0	Class II			
pH - at 25° C	6.0 - 9.0	4.0-5.0 or 9.5 to 10	8.64	7.81	8.02
Total Dissolved Solids	>450 - 1000	>1000 - 2400	-	-	-
Conductivity at 25° C	<70	>150 - 370	65.70	89.50	85.80
Sulphate	<200	>400 -600	-0.040	2.070	3.360
Chloride	<100	>200 – 600	155.000	98.600	92.300
Nitrate	<6	>10 – 20	0.060	0.261	0.259
Ammonium	NS	NS	0.086	0.082	0.072
Total Alkalinity	NS	NS	80.500	334.000	297.000
Bi-carbonate	NS	NS	-	-	-
Calcium	<80	>150-300	8.720	89.200	68.600
Magnesium	<30	>70-100	14.700	23.900	20.600
Sodium	<100	>200-400	87.700	65.900	86.200
Potassium	<25	>50-100	7.670	4.860	5.010
Iron	<0.01	>0.2-2	-0.003	-0.003	-0.003
Aluminium	<0.15	>0.3-0.5	-0.003	-0.003	-0.003
Antimony	<0.005	>0.010-0.05	-	-	-
Arsenic	<0.01	>0.05-0.2	-	-	-
Gold	NS	NS	-	-	-
Barium	NS	NS	0.000	0.000	0.000
Beryllium	NS	NS	0.000	0.000	0.000
Bismuth	NS	NS	0.000	0.000	0.000
Cadmium	<0.003	>0.005 – 0.01	-0.001	-0.001	-0.001
Caesium	NS	NS			
Chromium	<0.05	>0.1-0.5	-0.001	-0.001	-0.001
Cobalt	<0.25	>0.5-1	-0.001	-0.001	0.001
Copper	<0.5	>1-2	-0.001	-0.001	-0.001
Indium	NS	NS	-	-	-
Lanthanum	NS	NS	-	-	-
Lead	<0.01	>0.05-0.1	0.000	0.000	0.000
Lithium	NS	NS	0.000	0.000	0.000
Mercury	<0.001	>0.002-0.005	-	-	-
Manganese	<0.05	>0.1-1	-0.001	0.035	0.022
Molybdenum	NS	NS	-0.004	-0.004	-0.004
Nickel	<0.05	>0.15-0.3	-0.001	-0.001	-0.001
Platinum	NS	NS	-	-	-
Rubidium	NS	NS	0.000	0.000	0.000

Selenium	<0.01	>0.02-0.05	-	-	-
Tellurium	NS	NS	0.000	0.000	0.000
Thallium	NS	NS	0.000	0.000	0.000
Tin	NS	NS	-	-	-
Titanium	NS	NS	-	-	-
Tungsten	NS	NS	-	-	-
Vanadium	<0.1	>0.2-0.5	0.000	0.000	0.000
Zinc	<3	>5-10	-0.002	-0.002	-0.002
Uranium	NS	NS	-	-	

Legend:	
Class 0	
Class I	(yellow)
Class II	(orange)
Exceeding Maximum	(red)

Figure 5-1 Piper Trilinear diagram indicating the groundwater character at the proposed project site

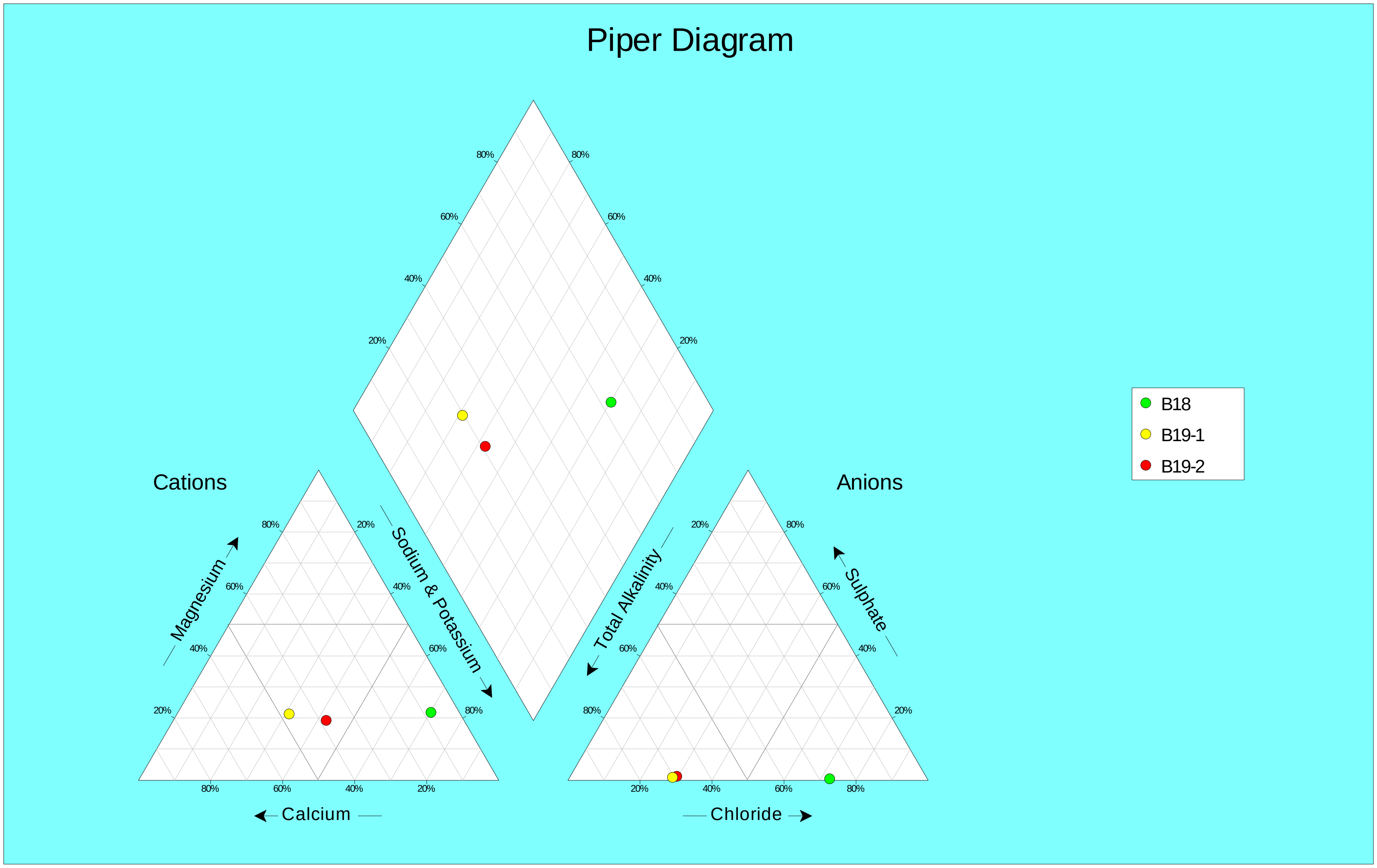
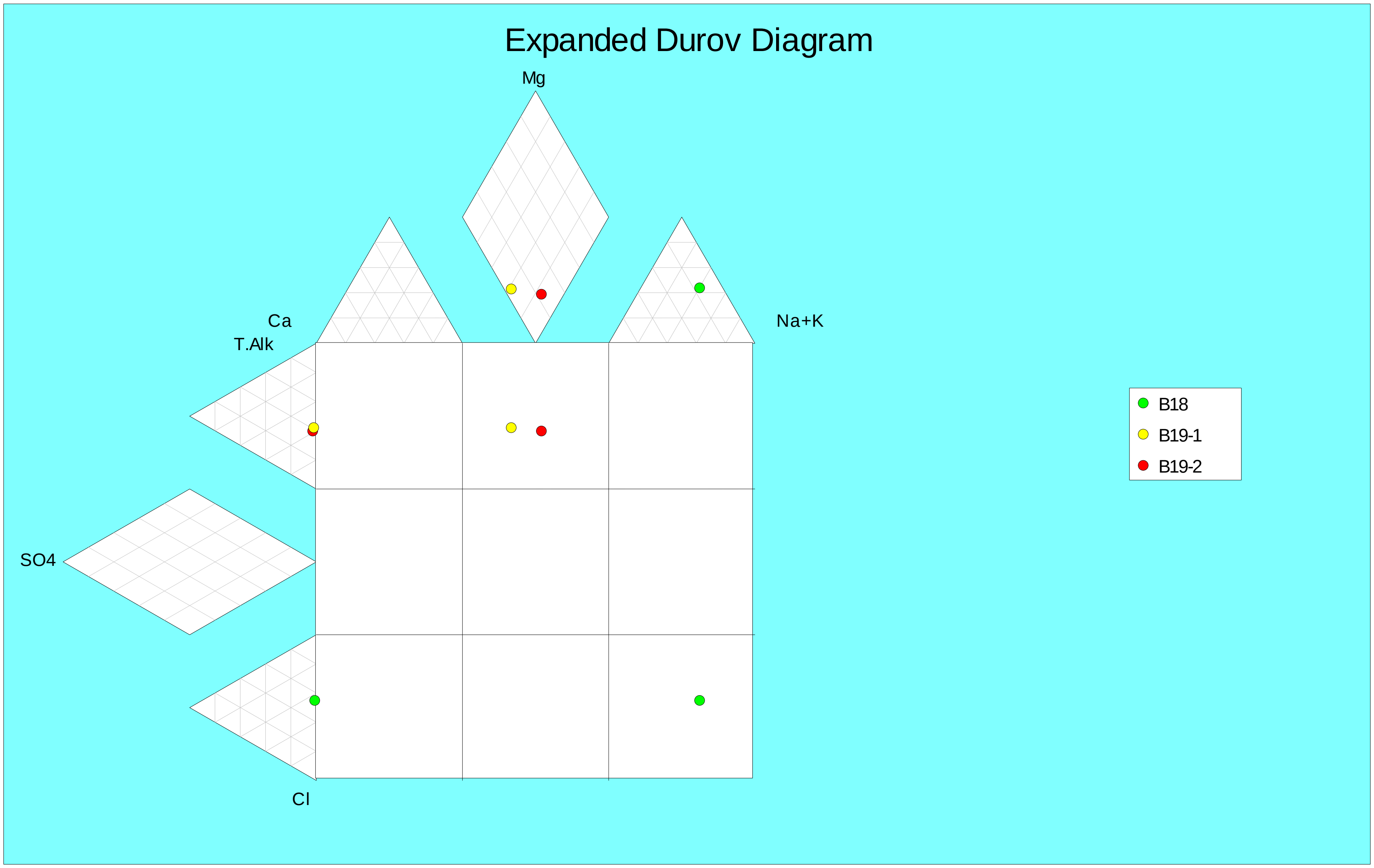


Figure 5-2 Expanded Durov Trilinear diagram indicating the groundwater character at the proposed project site



Section 6 **Conceptual Model**

6 Conceptual Model

The conceptual hydrogeology model was derived from the data obtained from the report by Vermeulen (2012) and aquifer testing as well as the hydrogeological maps of South Africa and also experience of previous work in similar Karoo sediments.

A conceptual model is a representation of probable geometry of an aquifer system hosted within a defined lithological area. Due to the diversity of the geology more than one aquifer system could exist within a vertical slice of layers. Groundwater flow direction and hydraulic conductivity is important to visualise the movement of groundwater due to gravity and pressure / hydraulic gradients.

The movement of groundwater in the project area is likely to occur as follows: rainfall and moisture precipitates on the higher elevation where geology outcrops directly onto the surface and apart from some direct recharge into preferential flow zones such as fractures and weathering in the rock mass, surface water mostly flows down gradient to where the slope changes in the micro catchment, but also directly into the surface water systems as surface flow. Where the gradient changes and sedimentation accumulated and where the weathering depth increases on top of the more competent sandstone the water will start to infiltrate and move vertically downwards until it reaches the more competent material from where horizontal flow will start to take place and flow towards the wetland under the influence of gravity.

The groundwater that does eventually breech the retarding more competent material layer will recharge the lower consolidated semi confined aquifer and will move downwards as well as laterally in the same directions as the surface slope again towards the wetland / surface water streams.

Two layers can therefore be distinguished with differing hydraulic conductivity or transmissivity values. Storage capacity will also differ from layer to layer with the fractured rock layer having the lowest storativity and the weathered sandy / clayey aquifers the highest value and therefore the highest effective porosity. The transmissivity in the first layer is higher where mostly unconsolidated sediments accumulated just next to the surface streams and water levels here will be atmospheric and should follow topography closely. The second fractured rock more competent layer is an order of magnitude lower.

The sandstone outcrops in the area are fractured with transmissivities ranging between 0.1 to around 1 m^2/d. These outcrops are more towards the higher gradient areas on the ridge to the north and groundwater recharge from precipitation being much lower into these areas compared to the lower gradient weathered material.

Recharge to groundwater will therefore depend on these more competent areas within the model area and will differ from the more weathered areas where recharge will be higher due to lower run off coefficients and much higher effective porosity. The higher evapotranspiration in the wetland areas to the east due to denser vegetation removes water from the aquifer as does the local dams and stream / river systems in the area. As indicated therefore in **Error! Reference source not found.**, groundwater flow will be from the west towards the east towards the wetland and stream area. It can thus be expected that recharge and flow will vary according to seasons. There is currently no temporal data for different seasons to verify the groundwater level change over time and therefore contribution to the wetland and streams but is not expected to exceed 0.5 to 1.5 m between seasons. Recharge lag is also not currently known but according to the groundwater chemistry a fair rate of recharge cycling can be expected.

As no major structural geology is evident in the immediate project area and possibly only localised weathering zones due to intrusive towards the south no major highly conductive zones is expected that could transport contaminants away from the project area.

7 Numerical model set-up and calibration

The numerical model was constructed based on the site specific conditions and takes into account a variety of parameters including both physical parameters of the aquifers, as well as external influences on the groundwater environment such as surface water / groundwater interaction and recharge from rainfall.

7.1 Model construction

The numerical groundwater flow model was constructed using the conceptual model as a basis. The model is intended to reflect the site specific conditions as accurately as possible in order to achieve the highest level of confidence in the simulated impacts. However, it still had to be taken into consideration that this is a regional model spanning an area of 8.2 km (east – west) x 8.4 km (north – south) and therefore some simplifications and assumptions had to be made.

PMWIN, which is a MODFLOW (USGS Designed) based modelling software package, was used as a pre and post processor for the simulations. MODFLOW and PMWIN are internationally recognised modelling packages that have been proven to be capable of simulating these types of groundwater flow and contaminant transport assessments to a high level of accuracy.

7.1.1 Model area and spatial boundaries

The model area and spatial boundaries were defined taking into consideration the position of the proposed project area as well as natural groundwater flow boundaries such as topographical highs and surface water. As stated above the total model area span an area of 8.4 km x 8.2 km. The proposed project area is located approximately in the centre of the model area (Figure 1-1**Error! Reference source not found.**).

Regional natural flow boundaries that were considered to be far enough away from the project area not to influence groundwater flow simulations were selected as the spatial boundaries of the model area Figure 2-1. The general head boundary in the south is based on the fact that there is no water divide in close proximity and that the project area could become too big due to this and flow still needed to be accounted for in and out of this region. The northern, eastern and western boundaries were selected on topographical higher areas which could be assumed to be water dividing areas.

7.1.2 Model grid and layers

PMWIN which is a MODFLOW based software package was used. Therefore, the finite difference method is applicable and the model grid consists of rectangles characterised by right angles at all four corners. The individual cell sizes vary from 25 m x 25 m within the vicinity of the project area to a maximum of 200 m x 200 m in the outer extremes of the model area where less accuracy is required (Figure 7-1)

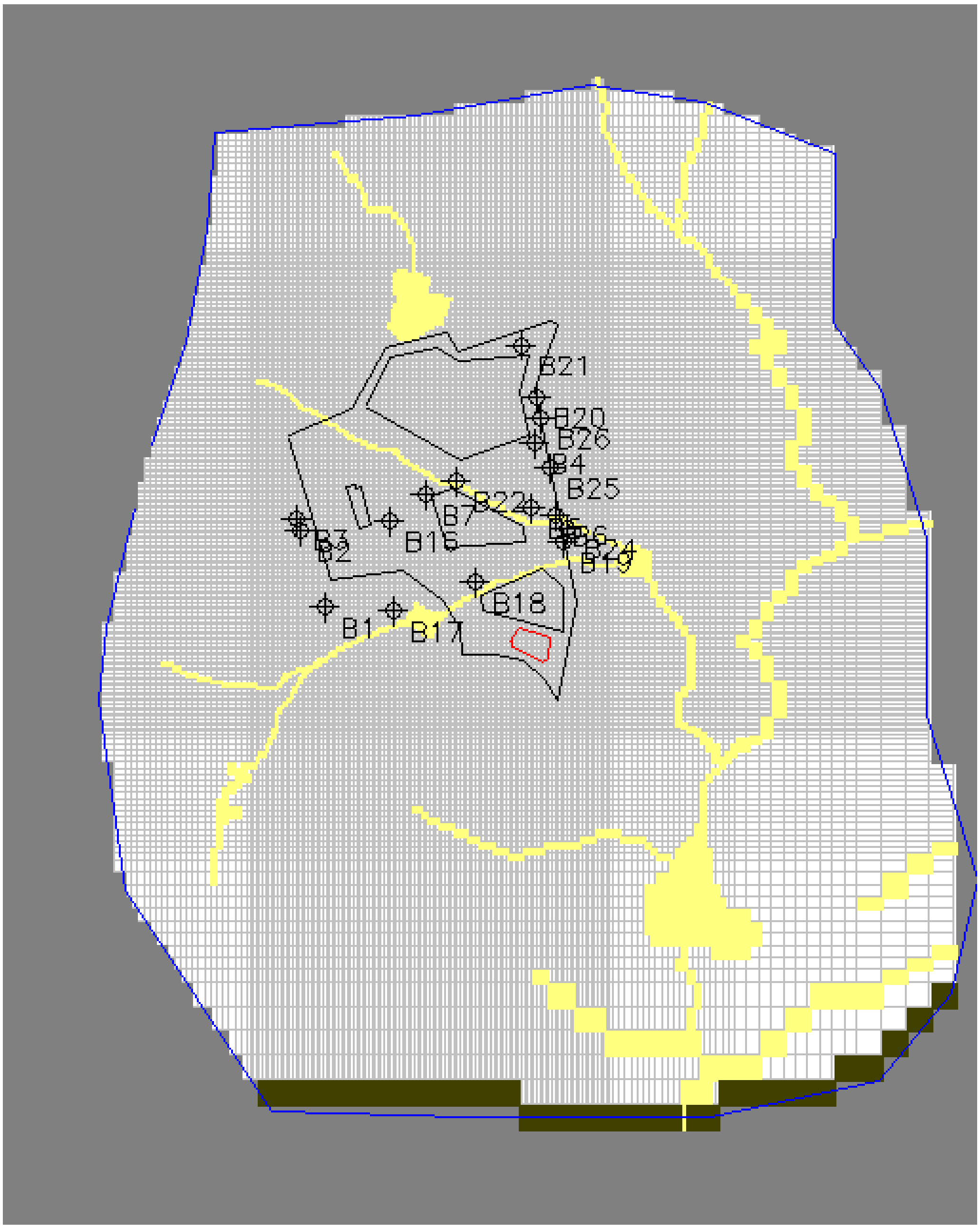


Figure 7-1 Model Domain depicting the boundaries and grid mesh

The numerical model consists of a total of two layers which each represents an individual aquifer or conceptually important lithology:

- Layer 1: Represents the upper unconsolidated weathered material associated aquifer. The aquifer is assumed to extend through the whole of the sub-catchment covered by the model with the exception of the upper outcropping sandstone / quartzitic ridges; and
- Layer 2: Represents the lower transmissivity deeper fractured competent rock aquifer covering the complete area spatially.

The topographical elevations that were used to contour the top of the upper weathered material (in essence ground level) were obtained from the SRTM elevation data.

Data on the regional thickness of the upper aquifer were obtained from borehole logs in Vermeulen *et. al*., 2012. The data indicate that the thickness range between around 1 and 21 m. The boreholes are centred on the project study area and do not cover the whole of the model domain and therefore extrapolation was used to average the thickness for the model area. Caution should be used therefore when interpreting data towards the edges of the model area.

A constant value of 60 m was used as for the second layer or lower fractured rock aquifer. In reality the aquifer could extend deeper, but there is no data available on the extinction depth of this aquifer. It is considered that using the constant value of 60 m is more than sufficient to calculate the impacts derived from the project activities which are all surficial, the old underground mining sections were not simulated as they are not seen as important as there depth extends beyond 150 m bs.

In short the elevations used for the model layers can be summarised:

- Top of layer 1 (unconsolidated material aquifer): SRTM topographical elevation data;
- Top of layer 2 / bottom of layer 1: Use thickness based on results from the drilling program and contoured and extrapolated using Tripol Bayesian correlation; and
- Bottom of layer 2: Apply a constant value of 60 m below the bottom of layer one.

7.2 Temporal set-up

The numerical model was calibrated in the steady state. This means that for parameters that could be seasonally variable (e.g. rainfall) average annual values are specified. The reason for this is that the project activities are not operated on a seasonal basis but rather throughout the year.

7.3 Model characteristics

Initial groundwater levels: The initial groundwater levels were interpolated and assigned based on the results of the data collected during the baseline study program and previous report. Once the model was calibrated the calibrated groundwater levels for each aquifer was assigned as starting conditions for the impact calculation simulations.

Recharge: Regional recharge from rainfall was specified based on the mean annual rainfall and assumed recharge percentages. Available climatic data indicates average rainfall of 671 mm/a at the Heidelberg Meteorological Station. Recharge to groundwater from rainfall can range between 3 and 10 % in the weathered aquifers, values used for the model ranged between 0.9 and 1.2 % of MAP or 1.65E-05 to 2.2 E-05 respectively.

Aquifer transmissivities: Aquifer transmissivities were specified using the “transmissivity” package for horizontal transmissivity, and the “vertical hydraulic conductivity” package for the vertical transmissivity. Table 7-1 summarises the values used in the three layers.

Table 7-1 Summary of hydraulic conductivity values used for initial calibration

Layer	T	VK
1	5	0.022
2	1.2	0.0017

7.3.1 Model Sensitivity

Model sensitivity analyses indicate that the numerical model is sensitive to:

- Transmissivity of both layers (high sensitivity); and
- Recharge (highly sensitive).

Based on this it can be deduced that regional transmissivity of the aquifers and recharge must be derived to a high level of confidence. Accurate derivation of these values will increase the level of confidence in model outputs.

7.3.2 Model Calibration

The model was calibrated using the “trial-and-error” method where aquifer parameters are varied within realistic ranges until the model is able to reproduce the field specific conditions. For this study the model was calibrated in the steady state using the groundwater level elevations measured during the drilling programme.

Since there are a multitude of parameters that influence the model calculations there is no unique single solution to the model where an optimum fit can be obtained. Therefore, it is imperative that realistic values be used and the results evaluated to judge whether the obtained groundwater levels and flow patterns are realistic.

7.3.3 Model groundwater level calibration results

The calculated groundwater levels are compared to the groundwater levels measured in the field as indicated in Figure 7-2. The ranges within which the aquifer parameters were varied were derived from the data collected during the desk study and the baseline study. Aquifer parameter ranges that were used are summarised in Table 7-2.

The maximum residual (difference between calculated and observed groundwater level) is 2.85 m as calculated for borehole B2. The minimum residual is 0.001 m at borehole B5. The mean residual value is calculated to be 0.40 m, meaning that on average the calculated groundwater levels are within 0.4 m of the levels measured in the field. This slight difference will have a very small impact on the calculated groundwater flow simulations.

Final calibration yielded a variance of 1.15 RMSE. It must be noted that the borehole elevations were not surveyed by a surveyor and only derived from the digital terrain model, therefore more accurate levels could have been obtained. However for this simulation where no major elevated elemental concentrations exist at the source this flow simulation are deemed adequate.

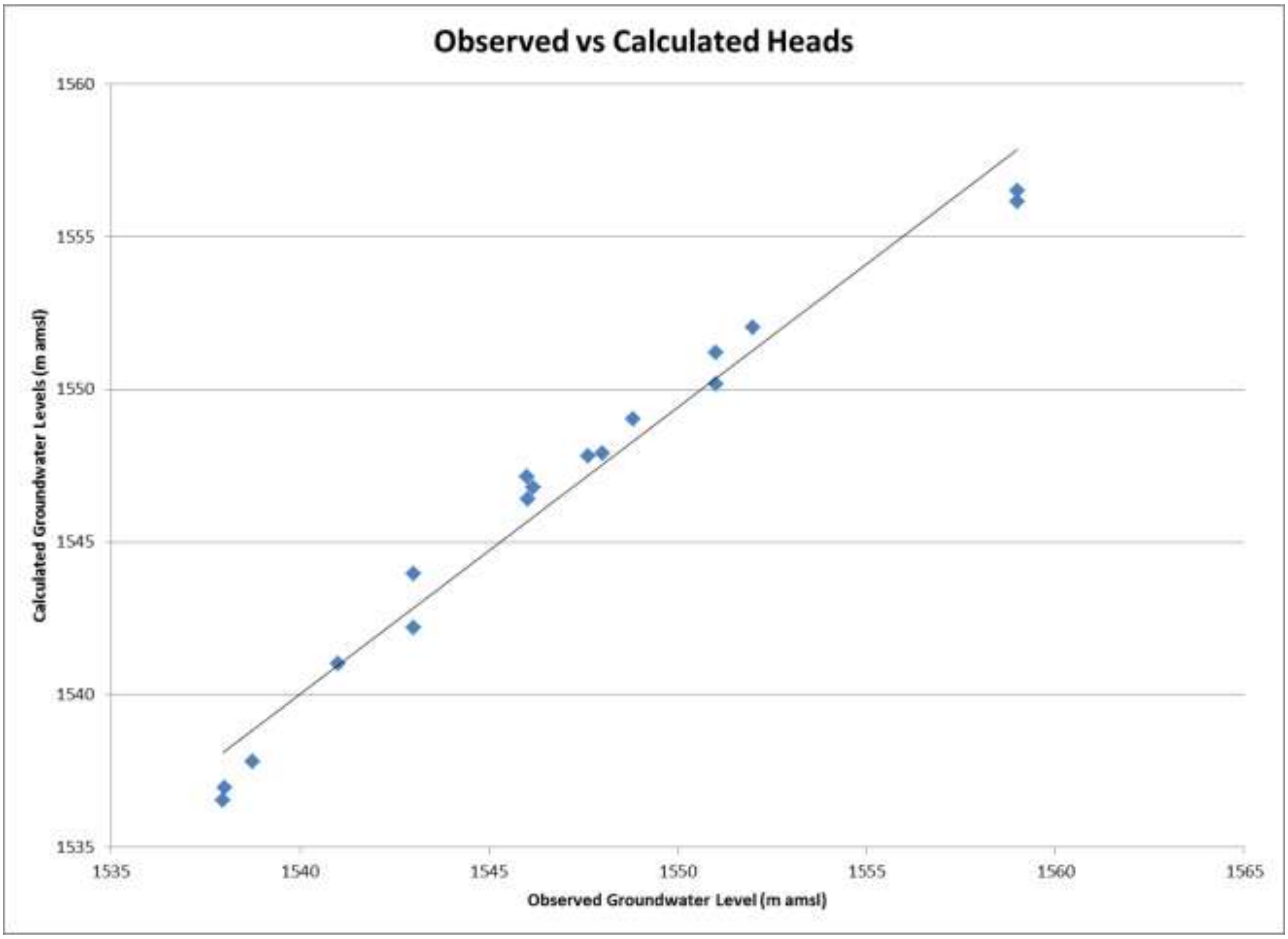


Figure 7-2 Calibration Variance

Table 7-2 Summary of calibrated parameters for the model

Parameter	Unit	Layer	Zone	Range		Source
				Minimum	Maximum	
Transmissivity	m^2/day	1	All	1.2	2.4 around dams and ash dams	Test and literature
		2	All	0.9	-	Test and literature

7.4 Model application

The calibrated model was used to simulate the impacts on the surrounding environment from the proposed project activities. In order to do this the model was adapted:

- The old ash dam receives normal precipitation and recharge and mounding within the ash dam of groundwater will occur due to the elevated nature of the terrace, and
- When the PV panels are installed on concrete cell blocks the recharge will reduce almost 100 % and mounding and flow will seize within the old ash dam and groundwater flow will be less in this area also due to compaction.

No pumping takes place or mining in the area that could cause other long term effects and therefore none was simulated apart from the different recharge scenarios expected and its associated change.

7.5 Contaminant transport model

The groundwater chemistry indicated lower concentrations of sodium, chloride and sulphate. As sulphate was not observed at elevated levels during this sampling phase at the closest boreholes only sodium which had the highest concentration were used for contaminant transport. This included utilising groundwater flow data from both the pre-project phase simulations and the flow during the project when the ash dam is covered completely with no recharge during simulations.

7.5.1 Pre-operational phase

Several parameters were specified:

- Initial concentrations for sodium: A value of 4 mg/L was specified over the whole of the model area, which are typical concentrations of the surrounding farm owner boreholes;

- Advection: There is no information available on the advective characteristics of the rock material. Therefore, default values were assumed and the upstream finite difference methods was applied, with a default Courant number of 0.75;
- Dispersion: There is no site specific information available on the dispersive characteristics of the rock material. Therefore, default values were used. Horizontal and vertical transverse dispersivity of 0.1 was used while the effective molecular diffusion coefficient was assumed to be 0; and
- Surface contamination from the old ash dam area was assigned using the "Time variant specified concentration" package where a constant concentration is specified. A constant concentration value of 1330 mg/L using sodium as the species was assigned for two years under the assumption that continuous deposition will maintain the source concentration.

7.5.2 Long term operational to post operational phase

Long term (up to 50 years after initiation of the PV project and 50 years after cessation of the project) contaminant migration pathways are simulated using the numerical groundwater flow and contaminant transport models to determine the contaminant migration patterns.

The following scenario was simulated to indicate the possible flow paths of any contaminants:

- Years 0 to 100 after installation of the PV Cells and full capping of the old ash dam: A value of 1330 mg/L for sodium is assigned to the pollution source area (old ash dam),

The pollution plume at the end of year two of the pre-project phase is used as the starting point for the long-term plume development.

Section 8 Groundwater Impact Assessment

8 Groundwater Impact Assessment

As mentioned in Section 7 numerical 3D modelling was used to simulate the impacts on the groundwater environment as a consequence of the proposed PV Cell project. The simulations addressed the pre- project phase, project phase, and long-term post operational phases of the proposed life of project. For all purposes and intent the life of the project is assumed to be 50 years and post operational calculations were fixed on 50 years.

The initial planning is to install PV Cells on top of the old ash dam terrace as well as to the east of the old ash dam on the natural topographical landscape obviously with clearance and compaction processes assumed. The issues relating to groundwater is therefore mainly related to the reduced recharge to groundwater over this area and compaction causing groundwater levels to change. There were no dewatering or excavations to include in this study as none were planned. Previously groundwater was pumped from the old underground mine workings (at depths below 150 m bs), but ceased some time ago and it is assumed that the current groundwater conditions are again in some pseudo steady state or at least the surficial aquifer systems.

Therefore only two scenarios were simulated, no capping and only compaction with the solar panels reducing 50 % of the recharge and another when the ash dam is completely covered with impermeable concrete cells and PV panels. A third option included is the no go option where the current steady state conditions were used over time to simulate contaminant transport when no capping is applied. No groundwater drawdown was simulated as none is anticipated due to no external factors such as less recharge being evident over the full 100 years.

8.1 Methodology

8.1.1 Reduced recharge and compaction

The annual recharge on the project area including the old ash dam to the aquifers and the groundwater mounding of the ash dam were simulated using the 3D numerical model as well as general groundwater flow in the area. The model time intervals were specified for two years before operation of the PV Cells and thereafter the two different scenarios were simulated for 100 years both during life of the project and thereafter (which in essence would be the same as the capping would not be removed).

Scenario one: assuming only 50 % recharge to the old ash dam area with only the PV Cells installed and some compaction of clay at the surface for 50 years and another 50 years simulating closure.

Scenario two: assuming only 0 % recharge to the old ash dam area with the PV Cells installed on a full capping created by concrete cell blocks and formal drainage channels leading storm water away from the old ash dam into the surface streams for 50 years and another 50 years simulating closure.

8.1.2 Contaminant migration and impacts

Contaminant migration away from potential source of pollution such as the old ash dam was simulated using MT3DMS. MT3DMS is a transport model for simulating advection, dispersion, and chemical reactions of contaminants in groundwater flow systems. It solves the transport equation after the flow solution has been obtained from the groundwater flow model (MODFLOW).

A starting value of 1330 mg/L chloride was assigned to the ash dam. The resulting plume development therefore represents the element concentration away from the source.

Because of the lack of literature on tested data, the rate at which the pollution source concentrations will reduce due to reduction is not known. Therefore it was assumed that the source concentration for all simulations will remain constant for the duration of the project.

8.2 Impact Assessment Results

8.2.1 Construction phase

The construction phase to erect the PV Cells and associated preparation of the surface is assumed to continue for one year, during which time large machinery and equipment will be on the project site. The following impacts can be expected during this time.

8.2.1.1 Groundwater quantity

The establishment of hard paved areas during infrastructure construction and haul road construction reduces the recharge of aquifers due to increased runoff.

No construction will be allowed to breach the groundwater level and hence no dewatering will be necessary (this is currently the preferred option) around the PV Cells project area. The nature of the project is non-intrusive and no dewatering or related issues are expected thus no groundwater flow reduction or depression cones are anticipated. Only the normal upwelling of groundwater below the old ash dam will continue during this time. The groundwater levels during this phase which is similar to the current steady state is used as the project background values and presents the upwelling which would be typical of a discard facility. No impacts are expected during this time and no cone of depression will be resulting.

8.2.1.2 Groundwater quality

The potential spillage of hydrocarbons from construction machines during the construction of infrastructure, topsoil and overburden stripping, excavation areas construction and road construction has the potential to cause the pollution of groundwater resources especially in primary aquifers where infiltration can be rapid if not immediately removed. Leakage or spillage during normal operation. Included in normal operation is the potential for the incorrect disposal of spill absorbing material. The operation of offices, ablutions and maintenance workshops has the potential for the contamination of groundwater due to incorrect disposal of domestic and hazardous wastes, incorrect handling of workshop effluent spills and leaks.

Handling of all materials needs to be conducted according to well managed and prepared health and safety plans to reduce the risk of these occurring. The movement of contaminants away from the old ash dam simulated in just one year is indicated in Figure 8-4.

It can be seen that the plume migration is towards the immediate north towards the stream and also towards the east towards the eastern surface water component as the ash dam is situated within the corner of the confluence of two systems. Within two years the plume migrated around 50 m away from the source when recharge occurs as usual. This will be the current situation and cannot really be assessed as there are no monitoring boreholes to the north and east of the old ash dam.

8.3 Operational Phase

8.3.1 Groundwater level drawdown

General operational practices will have a slight, but not significant impact on the groundwater quantities.

The establishment of hard stable surfaces at the old ash dam area reduces the recharge of aquifers due to increased runoff and non-permeable surface.

Response of groundwater levels due to the construction of impermeable surfaces can be simulated using two scenarios as discussed in section 7, as follows:

Scenario one:

Installing the PV Cells on a terrace on the old ash dam with only compacted material for stability will decrease the recharge by approximately 50 %. This scenario therefore includes a 50 % reduction in recharge to groundwater over this area during the 50 year life of operation as well as 50 years after operation. Table 8-1 indicates the drawdown over the full 100 years for two existing monitoring observation boreholes, BH18 and BH 19 as well as two extra control observation points used CP1 and CP2 where there are currently no monitoring boreholes adjacent to the old ash dam. Figure 8-1 depicts the drawdown graphically for the full duration and it can be seen that the water levels respond immediately to the decrease in recharge over the ash dam. A cone of depression results and spreads along the flow direction as can be seen in

Figure 8-5 after five years. Figure 8-6 depicts the advance of the cone of depression after 50 years at the end of operations. With recharge reduced by 50 % the highest estimated change in the groundwater level at the control points is 1.005 m after 100 years. The cone of depression after 50 years advances approximately 0.25 m, in a radius of 200 m away from the old ash dam. This is insignificant as the seasonal fluctuations indicated in the report by Vermeulen *et. al.,* 2012, clearly indicates values of around 0.5 m and more.

The water level change if this scenario is selected as an option is therefore seen as slight over a relatively short distance and therefore a low impact over a long period.

Table 8-1 Groundwater level drawdown for scenario one calculated at two observation points used during the simulation (as well as two control points used for the model purpose only)

	Ground water level drawdown (m amsl)			
Year	**B18**	**B19**	**Control 1 (CP1)**	**Control 2 (CP2)**
0	0	0	0	0
2	0	0	0.483	0.305
5	0	0	0.701	0.479
10	0	0	0.837	0.602
30	0.001	0.001	0.966	0.735
50	0.001	0.001	0.991	0.765
70	0.001	0.001	1	0.777
100	0.001	0.001	1.005	0.783

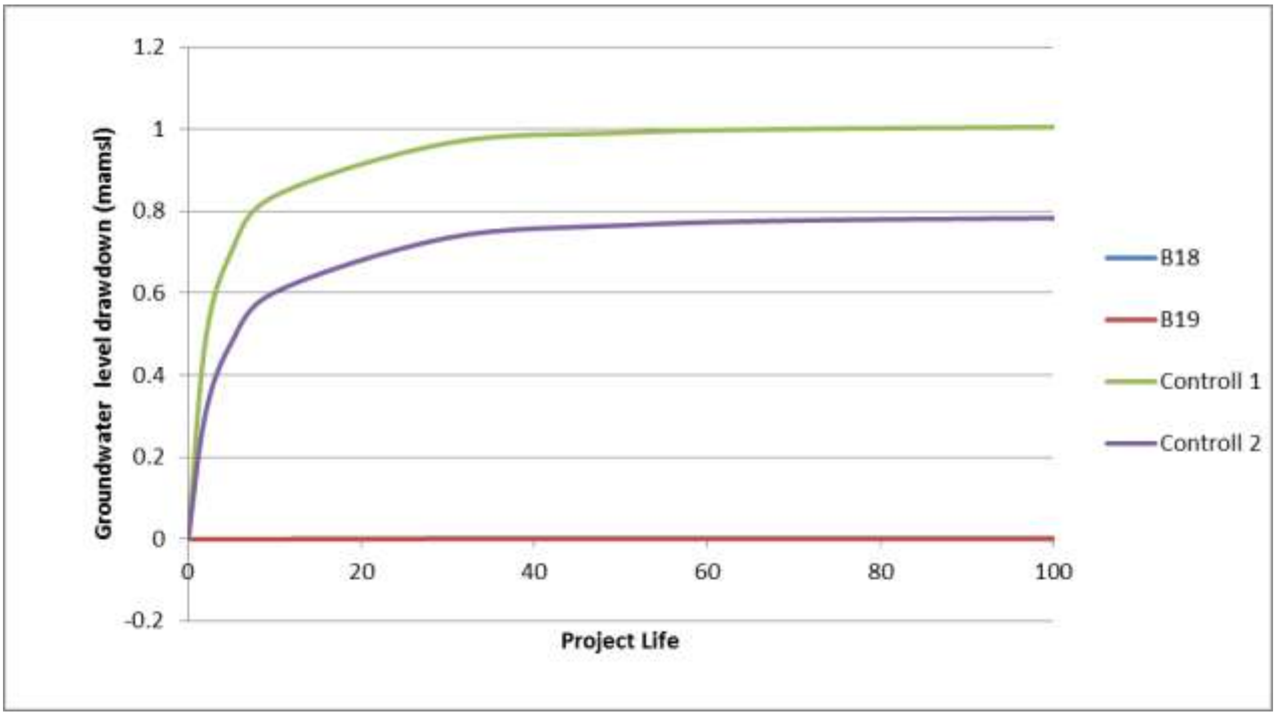


Figure 8-1 Groundwater Level drawdown for scenario one as measured at relevant calculated points for the full 50 years life of operation and 50 years post-project

Table 8-2 Groundwater level drawdown for scenario two calculated at two observation points used during the simulation (as well as two control points used for the model purpose only)

	Ground water level drawdown (m amsl)			
Year	**B18**	**B19**	**Control 1 (CP1)**	**Control 2 (CP2)**
0	0	0	0	0
2	0	0	0.526	0.351
5	0.001	0	0.777	0.558
10	0.002	0.002	0.943	0.711
30	0.003	0.002	1.11	0.888
50	0.003	0.002	1.14	0.929
70	0.003	0.002	1.158	0.946
100	0.003	0.002	1.165	0.954

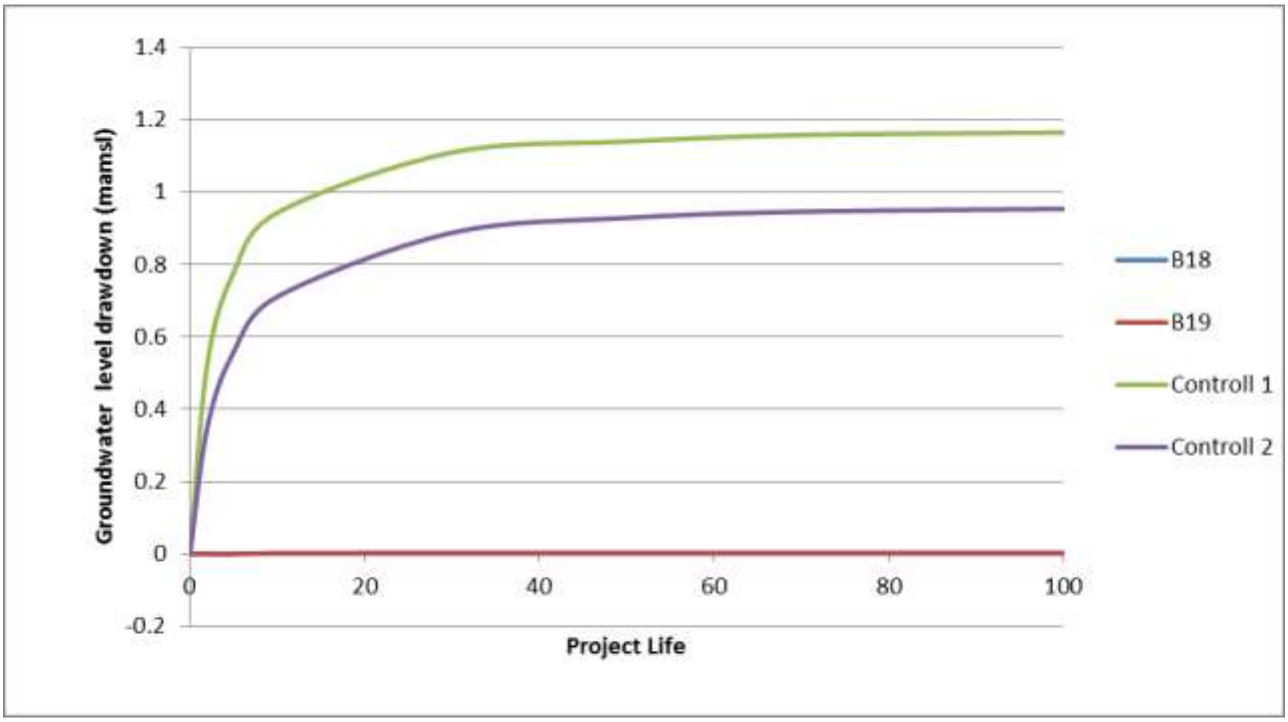


Figure 8-2 Groundwater Level drawdown for scenario two as measured at relevant calculated points for the full 50 years life of operation and 50 years post-project

Scenario two:

Installing the PV Cells on a terrace on the old ash dam with concrete cell blocks for stability will decrease the recharge by approximately 100 %. This scenario therefore includes a 100 % reduction in recharge to groundwater over this area during the 50 year life of operation as well as 50 years after operation. Table 8-2 indicates the drawdown over the full 100 years for two existing monitoring observation boreholes, BH18 and BH 19 as well as two extra control observation points used CP1 and CP2 where there are currently no monitoring boreholes adjacent to the old ash dam. Figure 8-2 depicts the drawdown graphically for the full duration and it can be seen that the water levels respond immediately to the decrease in recharge over the ash dam. A cone of depression results and spreads along the flow direction as can be seen in Figure 8-7 after five years as well as up-gradient. This is similar to the effect created by pumping a borehole at a low rate. Figure 8-8 depicts the advance of the cone of depression after 50 years at the end of operations. With recharge reduced by 100 % the highest change in the groundwater level is 1.165 m after 100 years. The cone of depression after 50 years advances approximately 0.25 m deep, in a radius of 375 m away from the old ash dam. This cone of depression does extend beyond the ESKOM property boundary into adjacent land but no boreholes are influenced. Although the impact compared to scenario one is slightly higher the flow of groundwater is not affected significantly and the impact is therefore still perceived as low over a long duration.

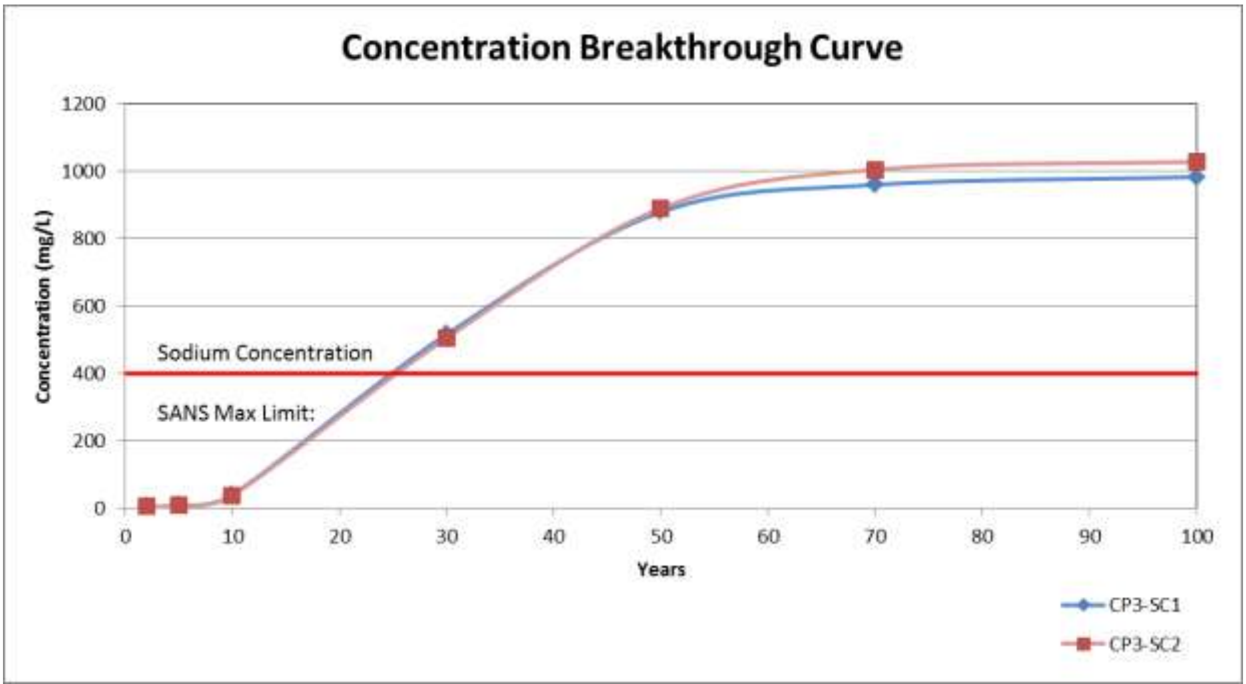


Figure 8-3 Concentration breakthrough curve for both scenarios at CP3 approximately 350 m to the east of the old ash dam

8.3.2 Groundwater quality

There are several potential impacts on the groundwater quality due to general operational procedures. These include:

- Incorrect disposal of spill absorbing material; and
- The potential incorrect disposal of domestic waste at the offices and ablutions may have an impact on groundwater quality.

The ash dam due to its age has already leached into the groundwater system below the footprint. Due to the fact that there is no monitoring boreholes in the migration path way the extent of the current plume cannot be assessed. The simulations performed assumes that the background values still holds of 4 mg/L and contaminant transport only starts pre-operation for two years and continue until the end of the project. Therefore although capping will result in a reduction of recharging water that mixes with the current material and infiltrate groundwater, the existing plume is still significant to be transported with normal groundwater flow below the old ash dam for a long duration. Due to the fact that the reduction in concentration of the plume is not well understood the concentration is assumed to be constant for the full 100 years, this could be an overestimation and these migration results are therefore seen to be the worst case scenario. The reduction in recharge will create a disturbance in groundwater flow, be it slight, but will also reduce the migration rate of contaminants. However that said the normal groundwater flow in the area will still cause the migration to continue outwards.

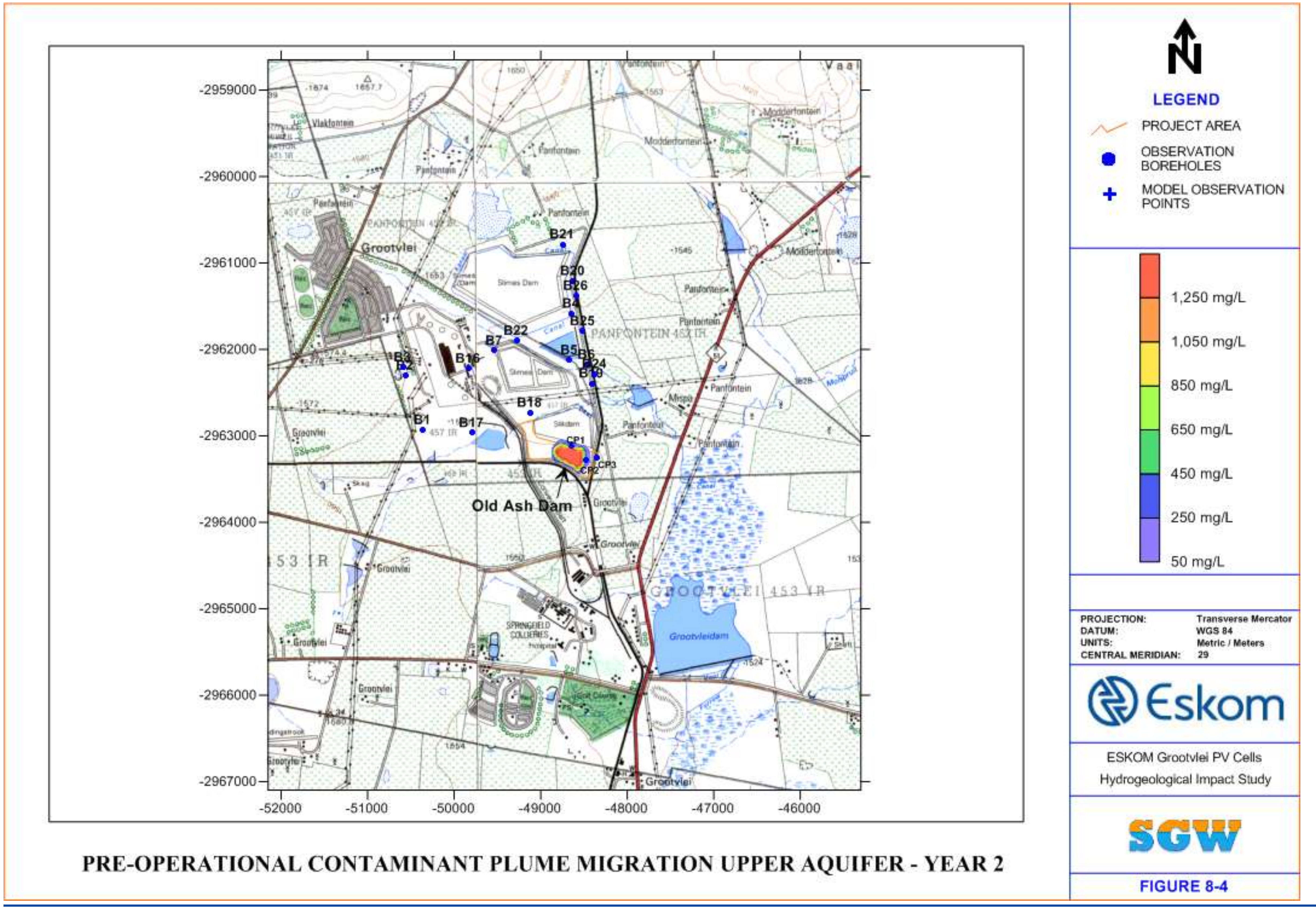
The contaminant transport simulations resulted in the following migration for the two different scenarios:

Scenario one:

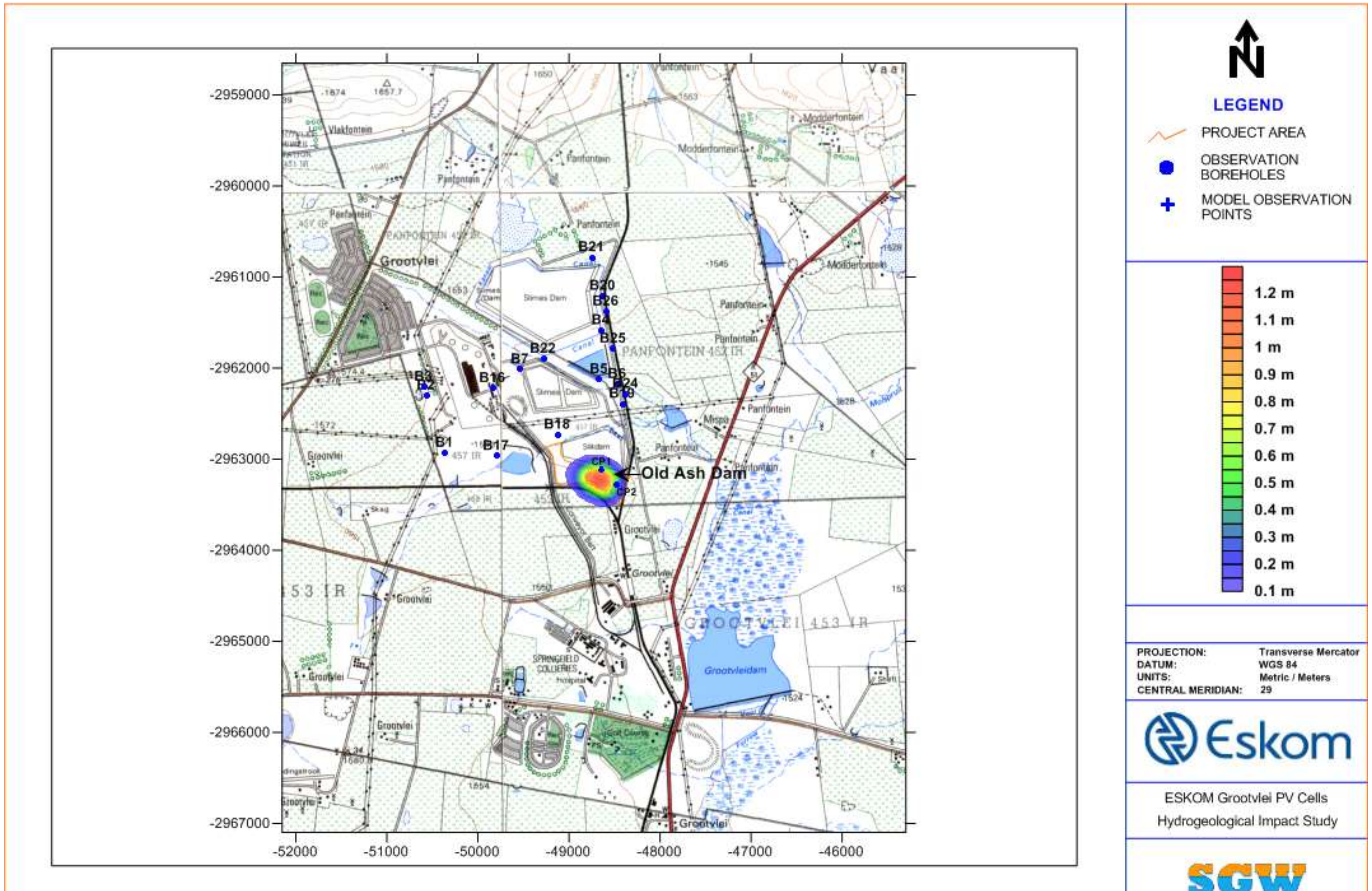
Numerical modelling flow simulations for the 50 % reduction in recharge over the PV Cells area (old ash dam) was used to simulate contaminant transport of sodium. The results indicate that the migration path will be towards the north and east to south-east towards the surface streams. As the maximum drawdown below the old ash dam is only around 1.3 m directly below the dam area after five years there is still sufficient groundwater flow within the upper weathered aquifer to transport contaminants away from the area. The breakthrough curve Figure 8-3 depicts the time when the sodium concentration will be reaching the SANS:241 water quality maximum standard of 400 mg/L. This was for the control point 3 which is a created measuring point in the model domain to calculate and observe the change in chemistry over time. This point is approximately 175 m towards the direct east of the project area and is indicated on the map in Figure 8-4 as CP3. From the graph it can be seen that the breakthrough point is reached in approximately 23 years after operations. The maximum value at CP3 after 100 years is around 983 mg/L, which will be more than double the maximum allowed concentration. The migration plume simulated for 5 years during the operation phase can be seen in Figure 8-9. After 50 years (Figure 8-10) the plume will have developed 375 m to the east at a concentration of around 50 mg/L. Again none of the adjacent boreholes will be affected during this time. The impact is therefore high over a long duration if this scenario is selected and no mitigation is applied.

Scenario two:

Numerical modelling flow simulations for the 100 % reduction in recharge over the PV Cells area (old ash dam) was used to simulate contaminant transport of sodium. The results indicate that the migration path will be towards the north and east to south-east towards the surface streams very similar to scenario one. As the maximum drawdown below the old ash dam is around 1.4 m directly below the dam area after five years there is still sufficient groundwater flow within the upper weathered aquifer to transport contaminants away from the area. The breakthrough curve Figure 8-3 depicts the time when the sodium concentration will be reaching the SANS:241 water quality maximum standard of 400 mg/L. From the graph it can be seen that the breakthrough point is reached in approximately 24 years after operations one year on from scenario one. The maximum value at CP3 after 100 years is around 1028 mg/L, which will be more than 2.5 times the maximum allowed concentration. The migration plume simulated for 5 years during the operation phase can be seen in Figure 8-11. After 50 years (Figure 8-12) the plume will have also developed 375 m to the east at a concentration of around 50 mg/L. Again none of the adjacent boreholes will be affected during this time. The impact is therefore high over a long duration if this scenario is selected and no mitigation is applied.

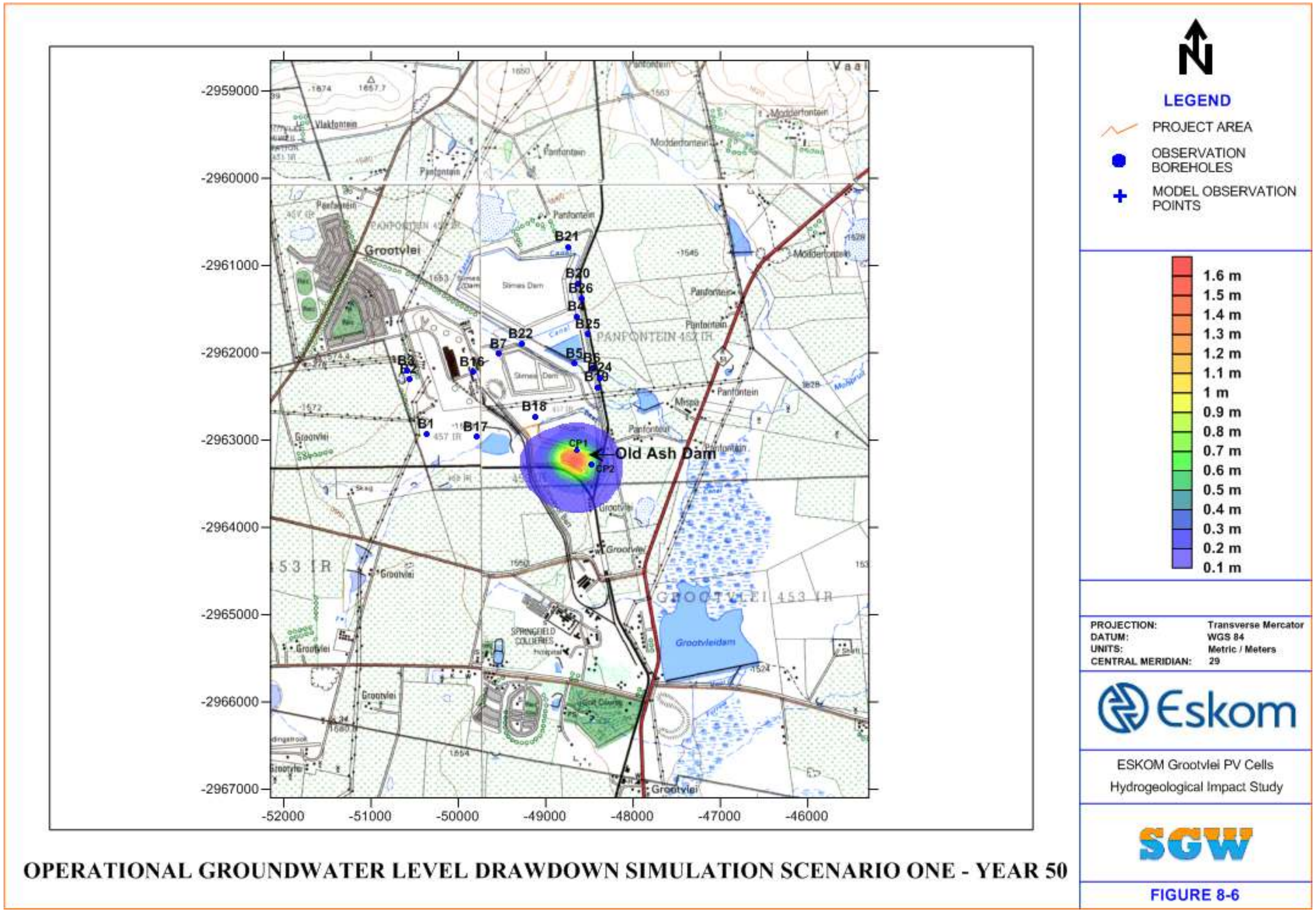


PRE-OPERATIONAL CONTAMINANT PLUME MIGRATION UPPER AQUIFER - YEAR 2



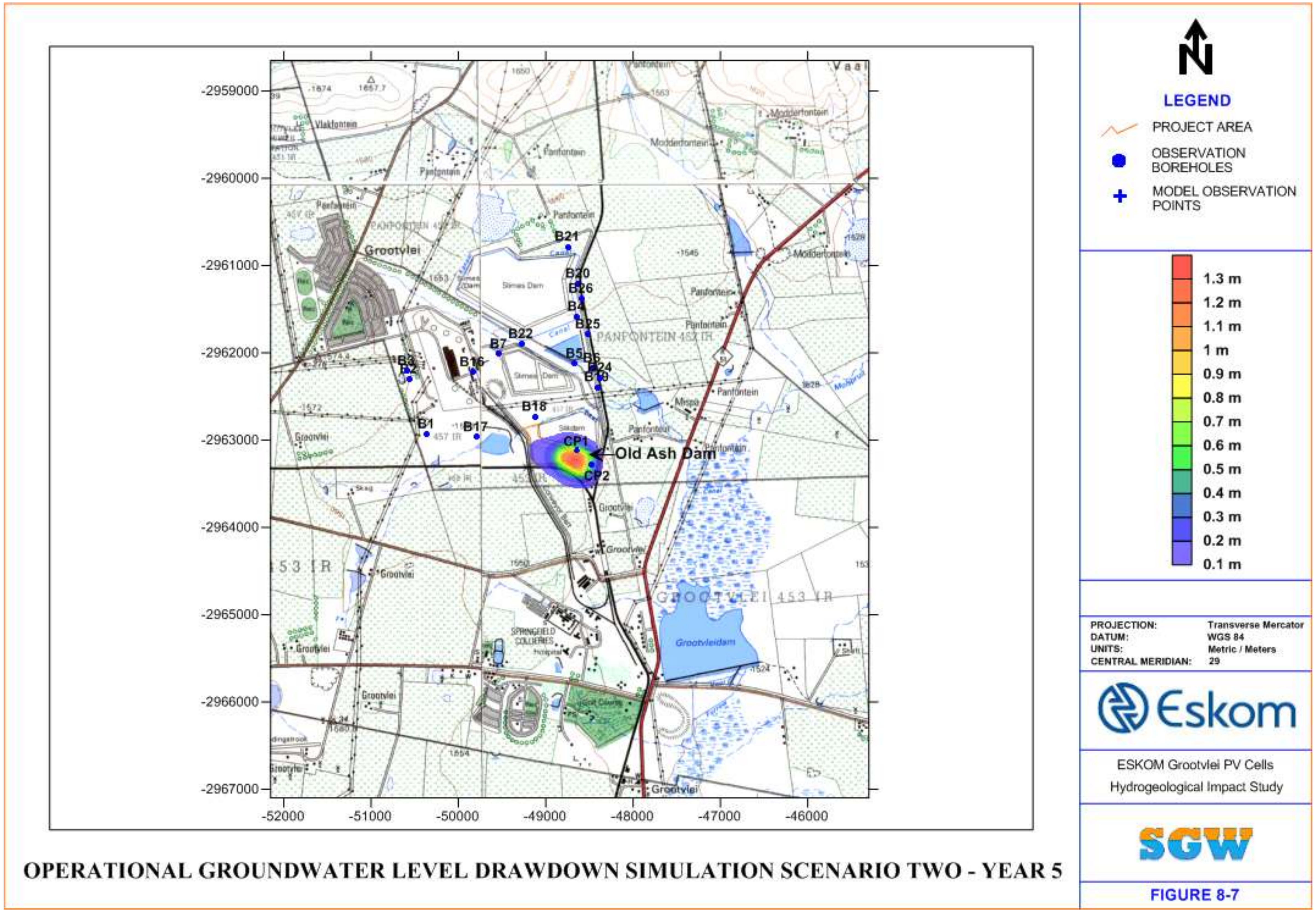
OPERATIONAL GROUNDWATER LEVEL DRAWDOWN SIMULATION SCENARIO ONE - YEAR 5

FIGURE 8-5



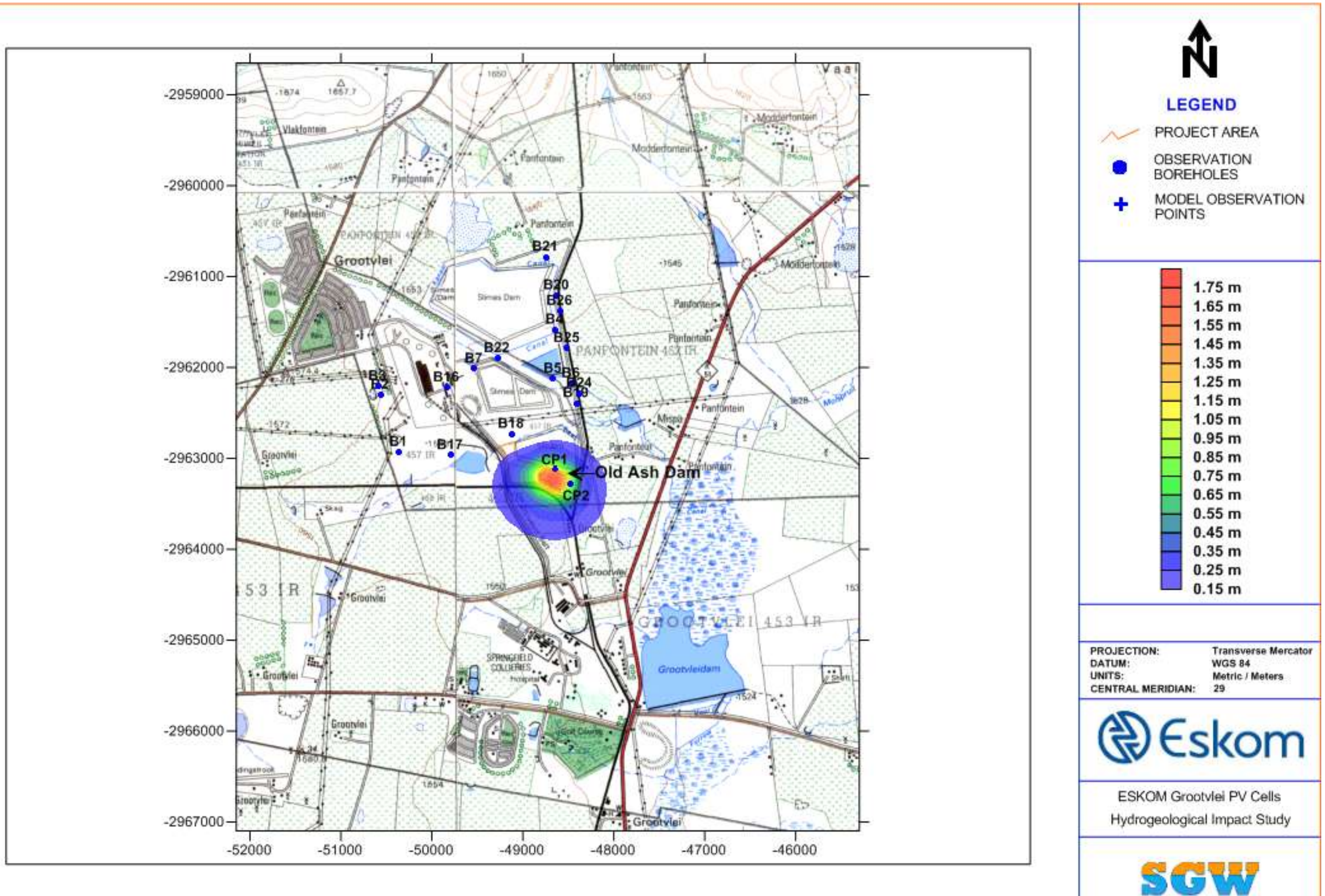
OPERATIONAL GROUNDWATER LEVEL DRAWDOWN SIMULATION SCENARIO ONE - YEAR 50

FIGURE 8-6



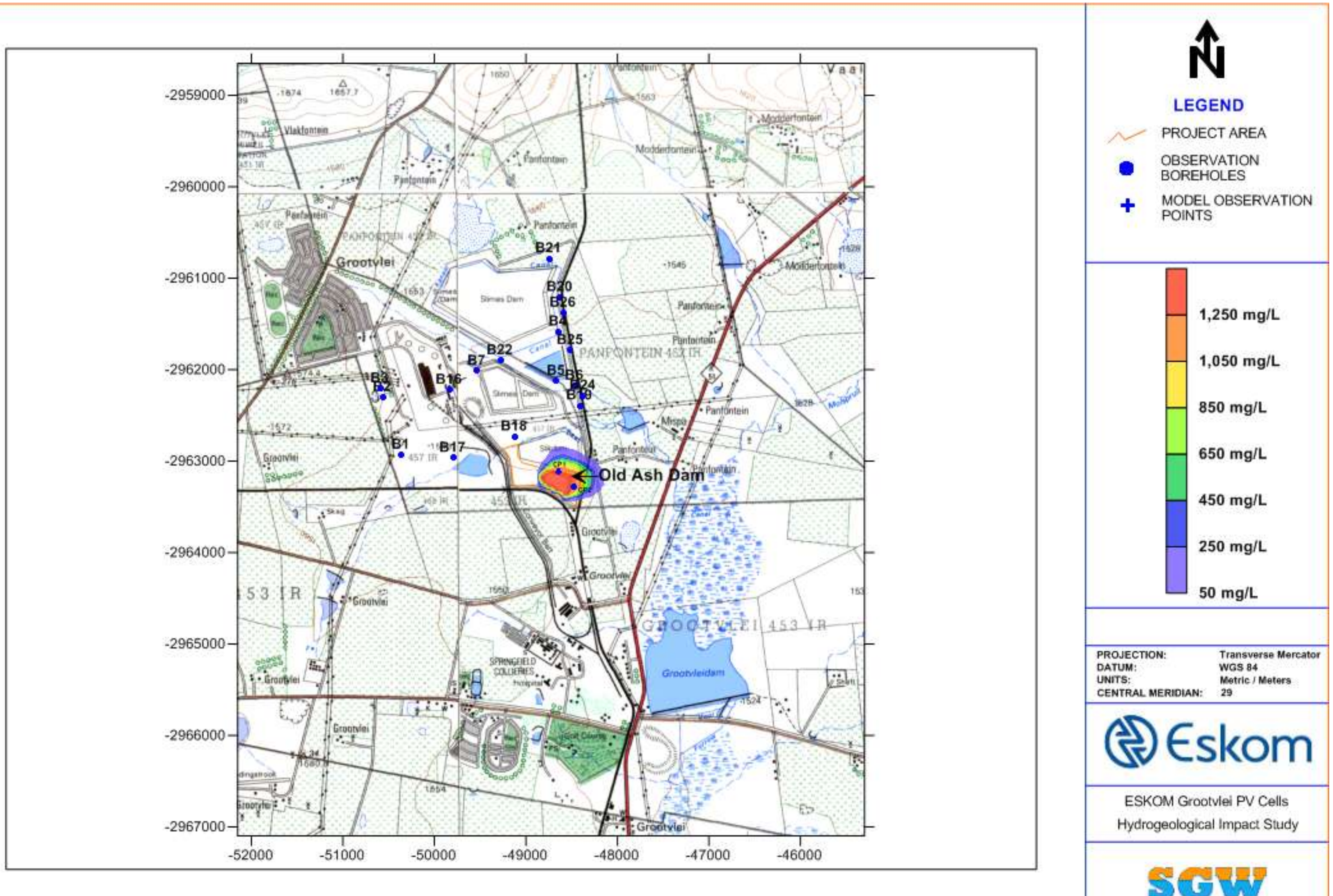
OPERATIONAL GROUNDWATER LEVEL DRAWDOWN SIMULATION SCENARIO TWO - YEAR 5

FIGURE 8-7



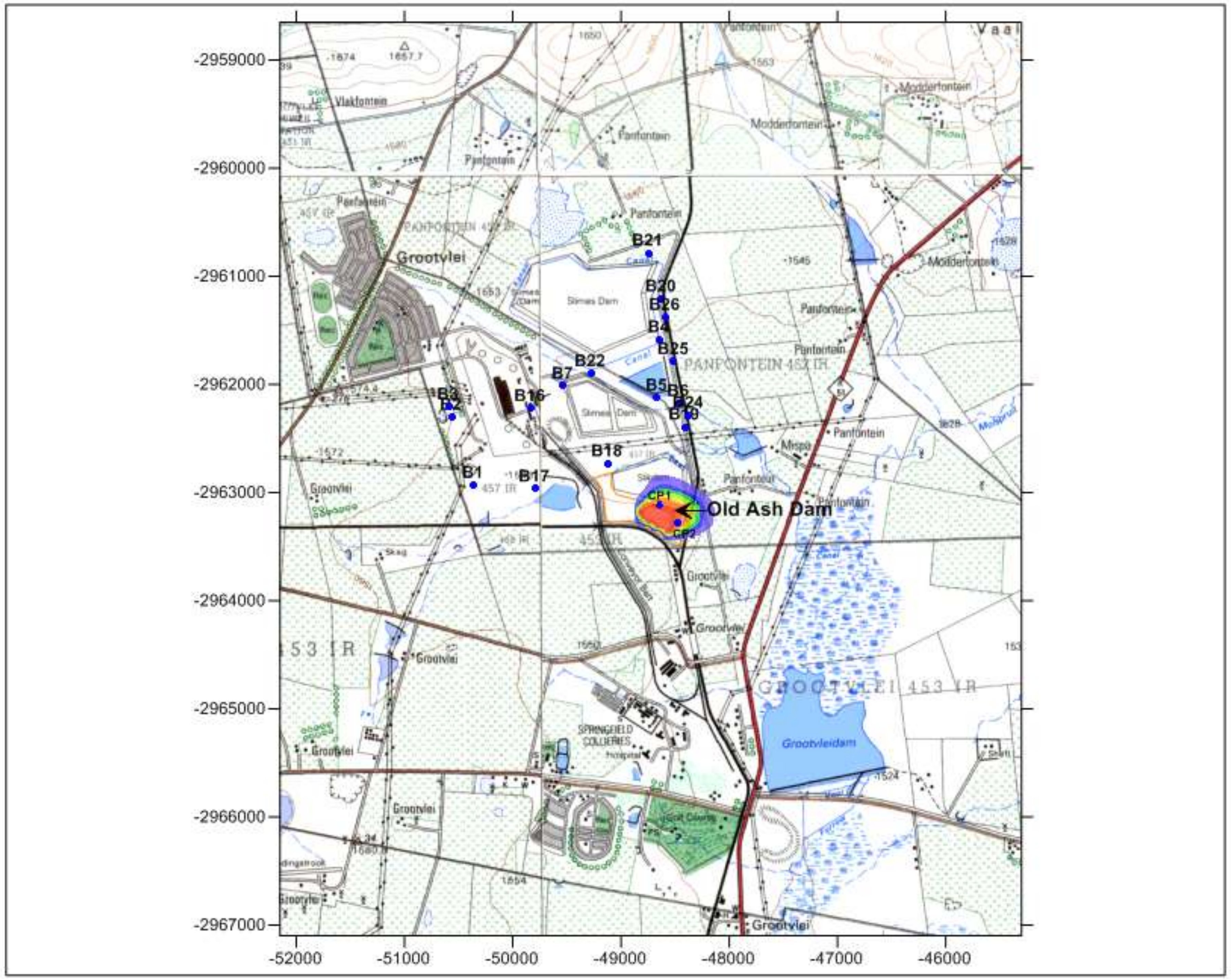
OPERATIONAL GROUNDWATER LEVEL DRAWDOWN SIMULATION SCENARIO TWO - YEAR 50

FIGURE 8-8



OPERATIONAL CONTAMINANT PLUME MIGRATION UPPER AQUIFER - YEAR 10 - SCENARIO 1

FIGURE 8-9



N

LEGEND

- PROJECT AREA
- OBSERVATION BOREHOLES
- MODEL OBSERVATION POINTS

1,250 mg/L
1,050 mg/L
850 mg/L
650 mg/L
450 mg/L
250 mg/L
50 mg/L

PROJECTION:	Transverse Mercator
DATUM:	WGS 84
UNITS:	Metric / Meters
CENTRAL MERIDIAN:	29

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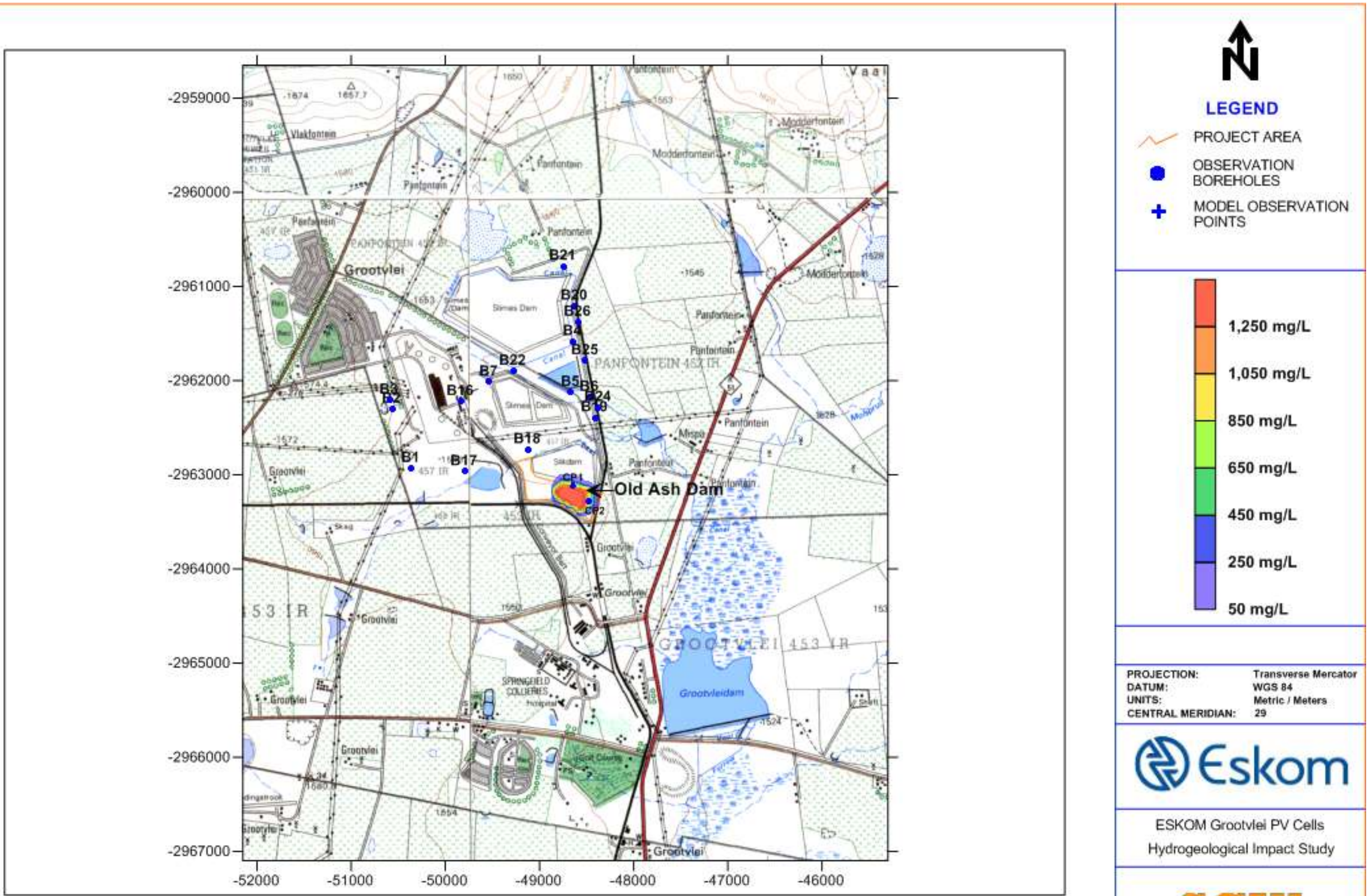
Hydrogeological Impact Study

SGW

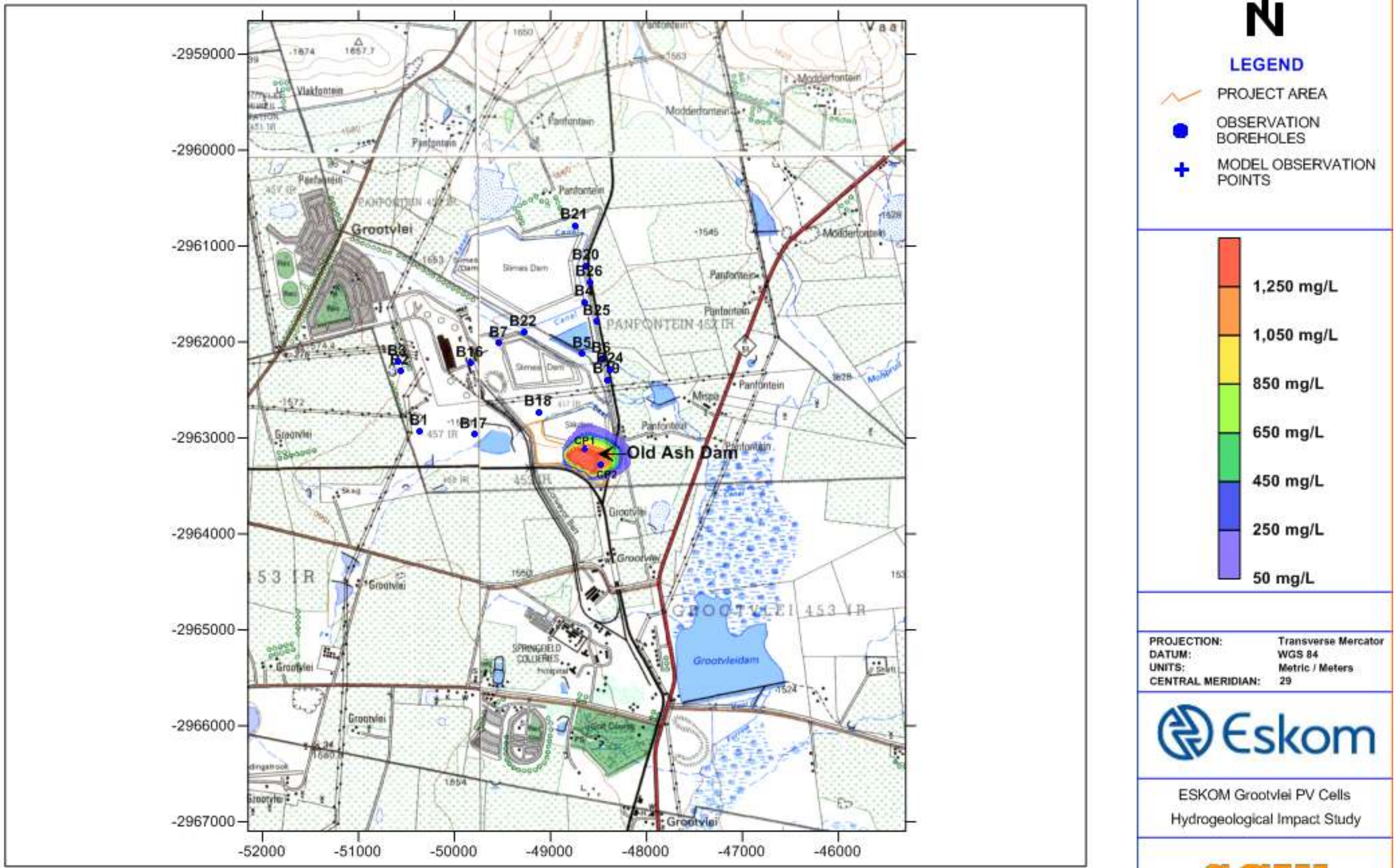
OPERATIONAL CONTAMINANT PLUME MIGRATION UPPER AQUIFER - YEAR 50 - SCENARIO 1

FIGURE 8-10



OPERATIONAL CONTAMINANT PLUME MIGRATION UPPER AQUIFER - YEAR 10 - SCENARIO 2

FIGURE 8-11

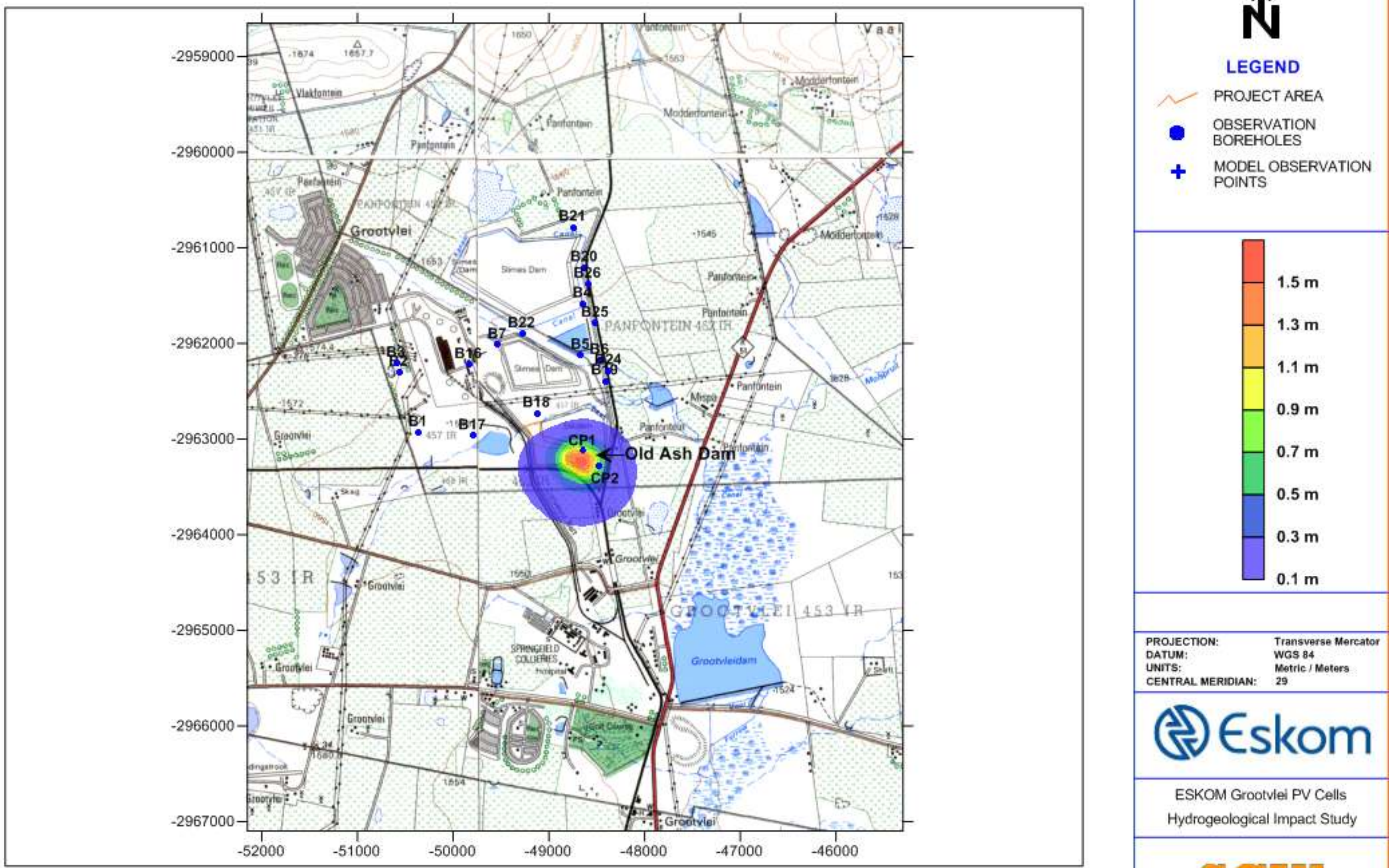


PROJECTION: Transverse Mercator
DATUM: WGS 84
UNITS: Metric / Meters
CENTRAL MERIDIAN: 29

ESKOM Grootvlei PV Cells Hydrogeological Impact Study

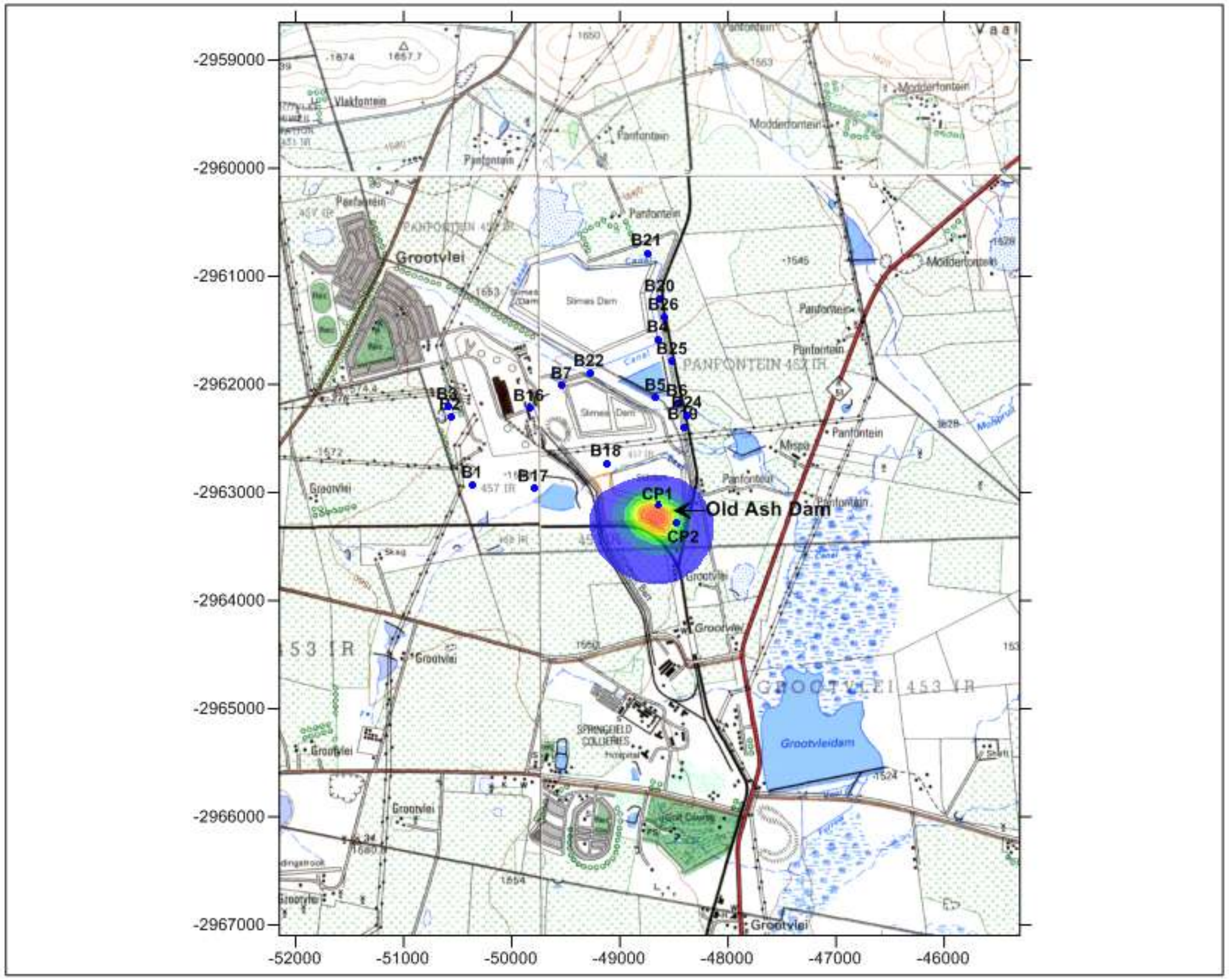
OPERATIONAL CONTAMINANT PLUME MIGRATION UPPER AQUIFER - YEAR 50 - SCENARIO 2

FIGURE 8-12



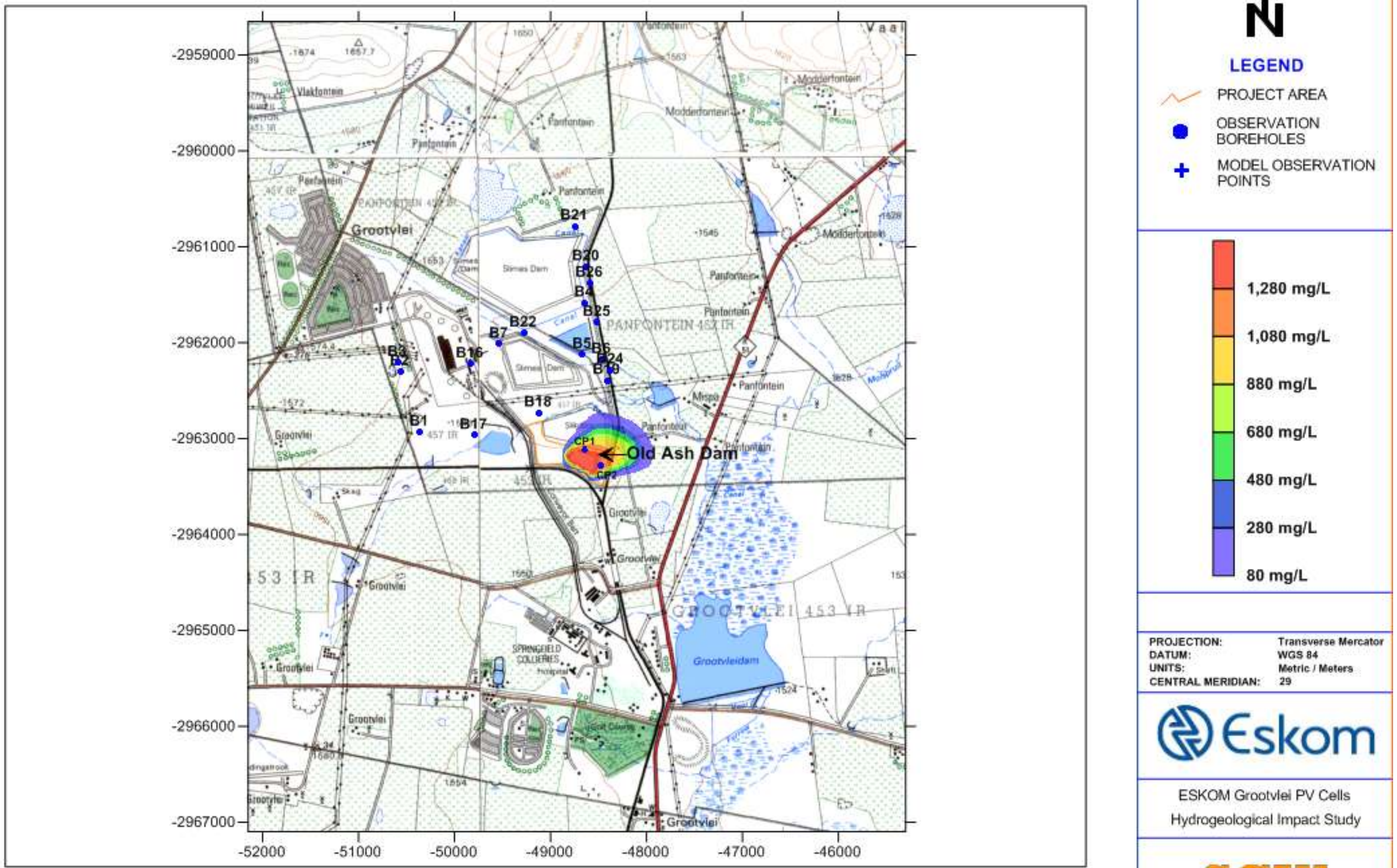
GROUNDWATER LEVEL DRAWDOWN SIMULATION SCENARIO ONE - YEAR 100 - END

FIGURE 8-13



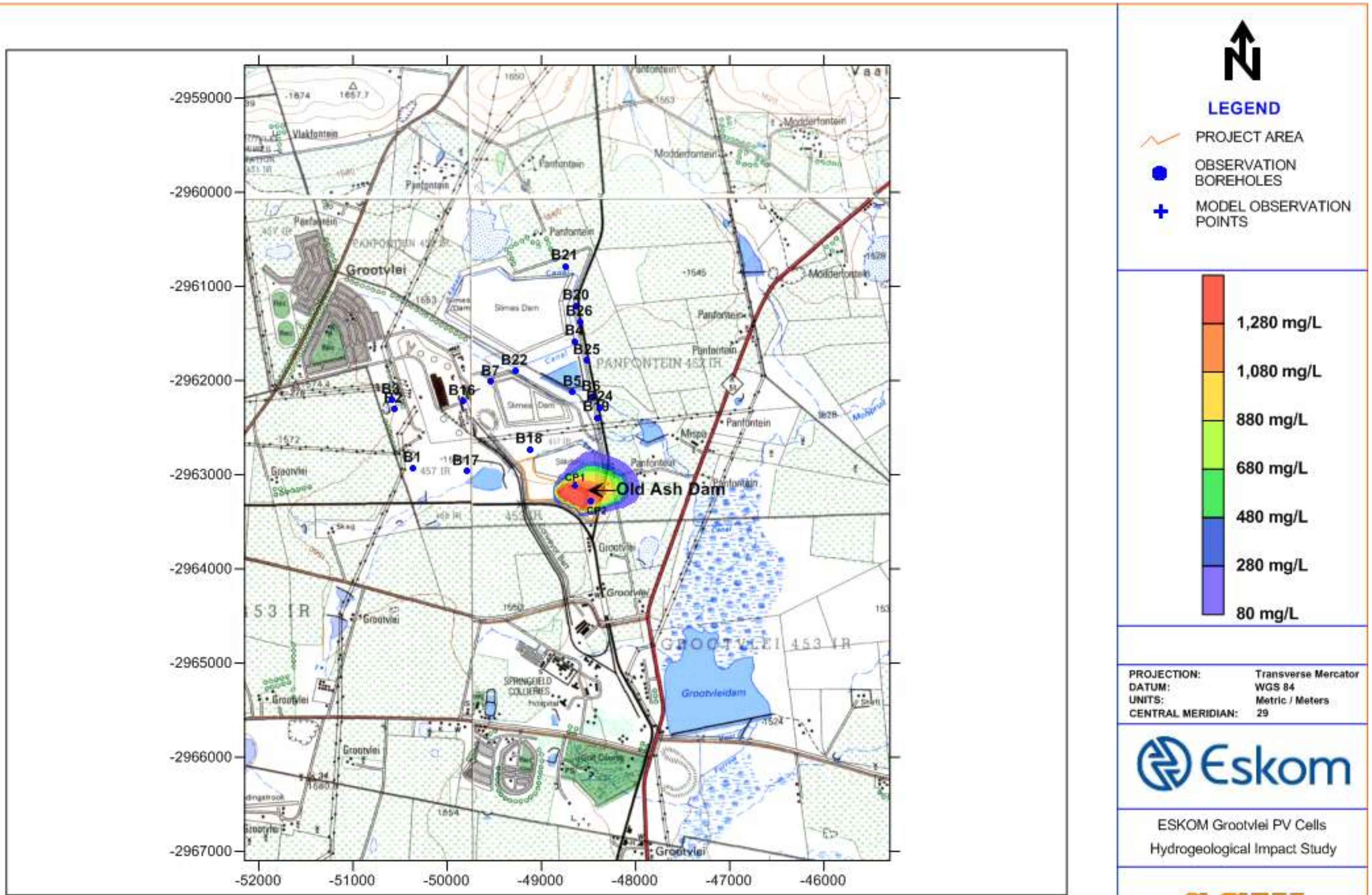
GROUNDWATER LEVEL DRAWDOWN SIMULATION SCENARIO TWO - YEAR 100 - END

FIGURE 8-14



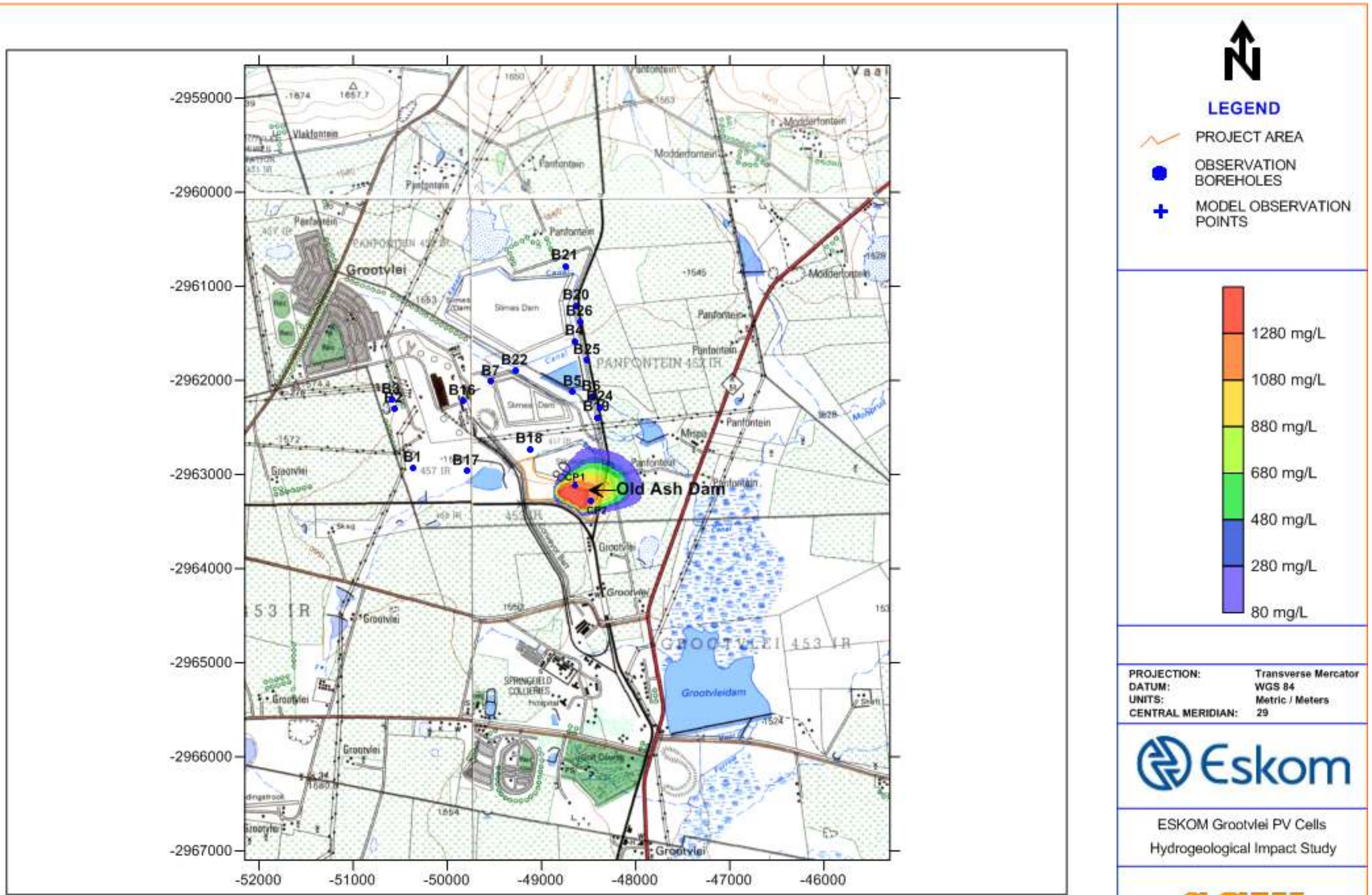
OPERATIONAL CONTAMINANT PLUME MIGRATION UPPER AQUIFER - YEAR 100 - SCENARIO 1

FIGURE 8-15



OPERATIONAL CONTAMINANT PLUME MIGRATION UPPER AQUIFER - YEAR 100 - SCENARIO 2

FIGURE 8-16



ESKOM Grootvlei PV Cells
Hydrogeological Impact Study

OPERATIONAL CONTAMINANT PLUME MIGRATION
UPPER AQUIFER - YEAR 100 - STEADY STATE

FIGURE 8-17

8.3.3 Decommissioning phase

8.3.3.1 Recovery of groundwater levels

No removal of the capping material on the old ash dam and adjacent area is anticipated and therefore the groundwater flow regime will be the same quantity and quality wise.

8.3.4 Long term post-operational phase (groundwater rebound)

8.3.4.1 Groundwater quantity

As mentioned above no changes in the infrastructure will be made and the flow of groundwater will continue as per the operational phase. The following two scenarios were the same as per the operation phase but extended for another 50 years to simulate the impacts they are as follows:

Scenario one:

The reduction of 50 % recharge will cause the cone of depression to still extend further towards the downstream surface water environment. It can be seen from the graph in Figure 8-1 that the drawdown of groundwater levels after 50 years starts to stabilize and starts to achieve equilibrium conditions. So no major reduction in groundwater levels takes place in the 50 years after the life of the operation even with the reduction in recharge still valid. Figure 8-13 depicts the drawdown cone after 100 years and it can be seen that the effect is very similar to that of year 50. Therefore the impact remains the same as with the operational phase as low impact over a long term.

Scenario two:

The reduction of 100 % recharge will cause the cone of depression to still extend further towards the downstream surface water environment. It can also be seen in this simulation from the graph in Figure 8-2 that the drawdown of groundwater levels after 50 years starts to stabilize and starts to achieve equilibrium conditions. So no major reduction in groundwater levels takes place in the 50 years after the life of the operation even with the reduction in recharge still valid. Figure 8-14 depicts the drawdown cone after 100 years and it can be seen that the effect is very similar to that of year 50. Therefore the impact remains the same as with the operational phase as low impact over a long term.

8.3.4.2 Groundwater quality

As there will be no more activities around the area such as offices or ablution facilities the threats associated with this will be removed. The contaminant migration due to flow conditions not changing much will continue to spread away from the project area. For the two scenarios the results are as follows:

Scenario one:

Figure 8-3 indicates the stabilization of the concentration at CP3 and compares well with the stabilization of the groundwater level drawdown after around 58 years, so some lag that can be seen. Figure 8-15 depicts the migration of the contaminant plume away from the project area. It can be seen that the plume extends to around 625 m away towards the east. Borehole B12 could be influenced during this time but at 50 mg/L concentration is well below the water quality standards for drinking water.

Scenario two:

Figure 8-3 indicates the stabilization of the concentration at CP3 and compares well with the stabilization of the groundwater level drawdown but only after around 63 years, so again some lag that can be seen. **Error! Reference source not found.** depicts the migration of the contaminant plume away from the project area. It can be seen that the plume extends to around 650 m away towards the east. Borehole B12 could be influenced during this time but again at 50 mg/L concentration is well below the water quality standards for drinking water.

In closing it can be said that the project have a low long term quantitative possible impact with a medium probability and a high qualitative impact over a long term with a medium probability.

8.3.5 Current Steady State (no go option)

If the old ash dam is left in the current state and no PV Cells established on top of the old ash dam then groundwater flow will not be influenced and no drawdown will be resulting from reduced recharge as per the other two scenarios. However the contaminant migration will continue and a simulation of this indicates that the spread of contaminants will exceed both scenario one and two migrations by approximately 50 to 100 m as can be seen from Figure 8-17.

This option is therefore the problematic scenario as no use will be derived but under the regulations will have to be cleaned up which could be a very expensive option.

Simulations therefore indicates this to have a no quantitative impact but a high long term quantitative impact that will have to be corrected before closure could eventually be obtained.

8.4 Mitigation

Mitigation methods discussed below can be applied once the PV process is finalised and can be indicated in the future management plan for the project. However if the planned project does not go ahead then further impacts from the old ash dam will have to be investigated according to Section 21 (h) of the National Water Act of 1998 as described below.

As the decrease in groundwater levels at the project area will not be creating a significant impact and the fact that the recharge water on the stabilised surfaces will be diverted as clean water towards the surface streams no mitigation is necessary. However a collection sump should be created where monitoring of water quality as per the normal monitoring agreement for Grootvlei should be maintained to ensure that the water discharged complies with DWA requirements.

The contaminant plume migration is a definite impact and needs to be mitigated. First of all the new monitoring boreholes should be established as described in Section 9 and the quality ascertained. If it is found that no major quality changes are evident then this could mean that the old ash dam has either already leached out or stabilised over time or that the solidification of the material caused it to be almost impermeable to recharging water inflow and no leaching activities are taking place. In this case the model can be re-calibrated with the new data. And the impacts reassessed.

If the groundwater after drilling indicates anomalous values and the model simulation holds true then two mitigation actions can be applied to reduce the spread of the plume away from the project area.

Method One:

New dewatering boreholes can be established up-gradient towards the west of the project area to act as a dewatering curtain to keep groundwater flow away from the old ash dam source concentration. The abstracted water can then be diverted along with the surface water collected from the stabilised areas and discharge if the quality is within limits. This will keep clean water clean and away from the source. Also solar driven submersible pumps can be used to pump the water and gravity fed to the downstream collector basin, which makes it a sustainable long term solution.

Method two:

The other option is to apply pump and treat where boreholes are drilled to abstract water from the aquifer down gradient in line with the plume migration and then pumped to a treatment facility. The water is then treated to a reasonable level ready for discharge to the surface water environment. This option is quite expensive and not the best option in the long term.

A third very expensive option is to remove all material and dispose at a disposal facility designed and regulated to handle such material.

Section 8 Groundwater Impact Assessment

8.5 Transmission Lines

The transmission lines necessary to connect the PV Cells to the main power grid will possibly be through some of the existing wetland areas. This is not ideal but if that is the only possibility to enable the use of the old ash dam area then the impacts will be as follows:

The only concern from a groundwater point of view will be the footprint size of the pylons used for construction of the transmission lines. These will cause compaction and slight excavation of the wetland immediate area, which will cause the groundwater flow to be disturbed. However if this footprint can be kept to a small overall extent then the impact will be low but over the long term. The construction of these will be critical as heavy vehicles will have to enter the wetland system which could cause short term or longer term permanent damage to the wetland and in turn the groundwater flow as groundwater levels are normally within 0.5 m below the wetland surface.

It will be important to manage this process very carefully and ensure that an environmental management plan be compiled detailing exactly how this will be achieved and approved by the relevant authorities before work commences and needs to adhere to GN 1199, section 6 (b).

Section 9 **Storm Water Management**

9 Storm Water Management

For both PV installation scenarios, either preparation of the surface area by compaction or installation of concrete paved areas, preparation and levelling will be required. A slight dipping angle should be allowed to facilitate gravity flow towards collector drains leading to a sump at the down gradient side of the project area or at the bottom in case of the old ash dam that is currently elevated. The fact that the area will be covered by hard compacted or paved areas means that no extra berms or canals are required only designed drain pipes or canals. An emergency lined storage pond will have to be added though that can handle flood events and reduce weathering to the natural environment. Table 9-1 indicates the volumes that will run off from the hard paved areas in the event of a 100 mm precipitation event. These volumes are substantial and cannot be allowed to run away freely as this could create weathering to natural surfaces as the runoff coefficient is much higher than natural vegetated areas. These figures are for the total area and it is not anticipated that the full extent will be prepared with stable areas, but these are indicative of what can be expected per areal extent.

When the exact areas are available more precise calculations can be performed to ensure that engineering drainage designs can handle the 50 and 100 year flood events.

Table 9-1 Volumes that needs to be stored in the event of a 100 m precipitation event

Description	Area (m^2)	Precipitation (m)	Volume (m^3)
Total project area	160000	0.1	16000
Old ash dam terrace	34450	0.1	3445

Section 10 Monitoring

10 Monitoring

The main objective of any water monitoring program is to understand the short-, medium- and long-term impacts that an industry of this nature can have on the integrated surface and groundwater regime of the immediate and receiving environment. Groundwater Monitoring forms an integral part in the management thereof. It serves ultimately as a pre-warning system for mitigation actions when anomalous concentrations or water level fluctuations occurs.

The monitoring at the Grootvlei ESKOM Power Station is currently up to date and needs to be maintained in this fashion. The only area which has not been covered sufficiently is the old ash dam. From the numerical model contaminant transport simulations it can clearly be seen that the area of importance is not adequately monitored. It is therefore suggested that two ne monitoring boreholes be established to the north and east of the area. The geophysical targets summarised in Table 3-1 and specifically target one and two should be used to ensure optimum results during drilling and to be most representative. If possible all three boreholes should be established for completeness.

The boreholes should then be incorporated into the current monitoring network and the same frequencies should be adhered to.

Section 11 Conclusions

11 Conclusions

The following conclusions were forthcoming from the field work phase:

11.1 Field work

- Due to the small diameter of the monitoring piezometers installed in the boreholes only one pump out test could be performed representing the upper weathered aquifer and none from the lower aquifer;
- As the boreholes in general are low yielding the slug-in test were sufficient to acquire information from the lower aquifer;
- The geophysics delineated possible weathered zones during the survey and no other work is necessary;
- The monitoring network for Grootvlei does not address the old ash dam area and new monitoring boreholes needs to be established on the geophysical survey results;
- Therefore no relevant groundwater quality data for the old ash dam was available and TCLP leach testing results of ash dam material had to be used for the numerical model simulation;
- The TCLP test values could be an over estimation of the migration concentrations and needs to be verified;
- The leach test results indicated that the TDS is well above the norm at 5100 mg/L and EC of 686 mS/m, the chloride, calcium and sodium values are also elevated (Table 2-2);
- The three samples collected at the closest monitoring boreholes BH18 and BH19 can be classified as Class I under SANS:241 guidelines due to chloride and EC concentrations;
- The samples was necessary to verify the current results under the existing monitoring programme and it was found that they correlate very well;

11.2 Impact assessment with numerical modelling simulations

Two different scenarios planned for the establishment of PV Solar Cells were assumed around the old ash dam planned project area, using a compacted clay / soil layer which could still allow around 50 % of natural recharge to reach the groundwater. Or a concrete cell block permanent paved area for constructing and fixing the PV Cells, this will allow approximately 0 % of precipitation to recharge to groundwater in the area. The no go option is to leave the current steady state scenario as is which would mean the contaminant plume will still spread further than any of the other two scenarios.

The best option as a result of the modelling simulations will be to cap the facility with 100 % impermeable material as this will cause less recharge which will not significantly alter the groundwater flow and therefore have a low impact. But ultimately will also create a smaller contaminant plume which with mitigation can be corrected to an acceptable level. In essence no further contact will be possible from water recharging the aquifers apart from what has seeped through until recently and therefore the source will become less in concentration over time. The scenarios performed assumed constant source throughout the time and all simulations, which will be the worst case conservative approach.

Two scenarios were simulated as well as the current conditions continuing contaminant plume using a 3 D numerical model for all phases of the project and the results were as follows:

11.2.1 Pre-operation

11.2.1.1 Quantity

With recharge reduced by 50 % the highest estimated change in the groundwater level at the control points is 1.005 m after 100 years. The cone of depression after 50 years advances approximately 0.25 m, in a radius of 200 m away from the old ash dam. This is insignificant as the seasonal fluctuations indicated in the report by Vermeulen *et. al.,* 2012, clearly indicates values of around 0.5 m and more.

The water level change if this scenario is selected as an option is therefore seen as slight over a relatively short distance and therefore a low impact over a long period.

11.2.1.2 Quality

It can be seen that the plume migration is towards the immediate north towards the stream and also towards the east towards the eastern surface water component as the ash dam is situated within the corner of the confluence of two systems. Within two years the plume migrated around 50 m away from the source when recharge occurs as usual. This will be the current situation and cannot really be assessed as there are no monitoring boreholes to the north and east of the old ash dam.

11.2.2 Operational Phase

11.2.2.1 Quantity

Scenario one:

With recharge reduced by 50 % the highest estimated change in the groundwater level at the control points is 1.005 m after 100 years. The cone of depression after 50 years advances approximately 0.25 m, in a radius of 200 m away from the old ash dam. This is insignificant as the seasonal fluctuations indicated in the report by Vermeulen *et. al.,* 2012, clearly indicates values of around 0.5 m and more.

The water level change if this scenario is selected as an option is therefore seen as slight over a relatively short distance and therefore a low impact over a long period.

Scenario two:

With recharge reduced by 100 % the highest change in the groundwater level is 1.165 m after 100 years. The cone of depression after 50 years advances approximately 0.25 m deep, in a radius of 375 m away from the old ash dam. This cone of depression does extend beyond the ESKOM property boundary into adjacent land but no boreholes are influenced. Although the impact compared to scenario one is slightly higher the flow of groundwater is not affected significantly and the impact is therefore still perceived as low over a long duration.

11.2.2.2 Quality

Scenario one:

The migration plume simulated for 5 years during the operation phase can be seen in Figure 8-9. After 50 years (Figure 8-10) the plume will have developed 375 m to the east at a concentration of around 50 mg/L. Again none of the adjacent boreholes will be affected during this time. The impact is therefore high over a long duration if this scenario is selected and no mitigation is applied.

Scenario two:

The migration plume simulated for 5 years during the operation phase can be seen in Figure 8-11. After 50 years (Figure 8-12) the plume will have also developed 375 m to the east at a concentration of around 50 mg/L. Again none of the adjacent boreholes will be affected during this time. The impact is therefore high over a long duration if this scenario is selected and no mitigation is applied.

11.2.1 Long term post-operational phase (groundwater rebound)

11.2.1.1 Groundwater quantity

Scenario one:

The reduction of 50 % recharge will cause the cone of depression to still extend further towards the downstream surface water environment. It can be seen from the graph in Figure 8-1 that the drawdown of groundwater levels after 50 years starts to stabilize and starts to achieve equilibrium conditions. So no major reduction in groundwater levels takes place in the 50 years after the life of the operation even with the reduction in recharge still valid. Figure 8-13 depicts the drawdown cone after 100 years and it can be seen that the effect is very similar to that of year 50. Therefore the impact remains the same as with the operational phase as low impact over a long term.

Scenario two:

The reduction of 100 % recharge will cause the cone of depression to still extend further towards the downstream surface water environment. It can also be seen in this simulation from the graph in Figure 8-2 that the drawdown of groundwater levels after 50 years starts to stabilize and starts to achieve equilibrium conditions. So no major reduction in groundwater levels takes place in the 50 years after the life of the operation even with the reduction in recharge still valid. Figure 8-14 depicts the drawdown cone after 100 years and it can be seen that the effect is very similar to that of year 50. Therefore the impact remains the same as with the operational phase as low impact over a long term.

11.2.1.2 Groundwater quality

Scenario one:

Figure 8-15 depicts the migration of the contaminant plume away from the project area. It can be seen that the plume extends to around 625 m away towards the east. Borehole B12 could be influenced during this time but at 50 mg/L concentration is well below the water quality standards for drinking water.

Scenario two:

Error! Reference source not found. depicts the migration of the contaminant plume away from the project area. It can be seen that the plume extends to around 650 m away towards the east. Borehole B12 could be influenced during this time but again at 50 mg/L concentration is well below the water quality standards for drinking water.

In closing it can be said that the project have a low long term quantitative possible impact with a medium probability and a high qualitative impact over a long term with a medium probability.

11.2.1.3 Current Steady State (no go option)

If the old ash dam is left in the current state and no PV Cells established on top of the old ash dam then groundwater flow will not be influenced and no drawdown will be resulting from reduced recharge as per the other two scenarios. However the contaminant migration will continue and a simulation of this indicates that the spread of contaminants will exceed both scenario one and two migrations by approximately 50 to 100 m as can be seen from Figure 8-17.

This option is therefore the problematic scenario as no use will be derived but under the regulations will have to be cleaned up which could be a very expensive option.

Simulations therefore indicates this to have a no quantitative impact but a high long term quantitative impact that will have to be corrected before closure could eventually be obtained.

11.3 Transmission Lines

The only concern from a groundwater point of view will be the footprint size of the pylons used for construction of the transmission lines. These will cause compaction and slight excavation of the wetland immediate area, which will cause the groundwater flow to be disturbed. However if this footprint can be kept to a small overall extent then the impact will be low but over the long term. The construction of these will be critical as heavy vehicles will have to enter the wetland system which could cause short term or longer term permanent damage to the wetland and in turn the groundwater flow as groundwater levels are normally within 0.5 m below the wetland surface.

It will be important to manage this process very carefully and ensure that an environmental management plan be compiled detailing exactly how this will be achieved and approved by the relevant authorities before work commences and needs to adhere to GN 1199, section 6 (b).

11.4 Storm Water Control

The fact that the area will be covered by hard compacted or paved areas means that no extra berms or canals are required only designed drain pipes or canals. An emergency lined storage pond will have to be added though that can handle flood events and reduce weathering to the natural environment. Table 9-1 indicates the volumes that will run off from the hard paved areas in the event of a 100 mm precipitation event. These volumes are substantial and cannot be allowed to run away freely as this could create weathering to natural surfaces as the runoff coefficient is much higher than natural vegetated areas. These figures are for the total area and it is not anticipated that the full extent will be prepared with stable areas, but these are indicative of what can be expected per areal extent.

When the exact areas are available more precise calculations can be performed to ensure that engineering drainage designs can handle the 50 and 100 year flood events.

11.5 Mitigation

Mitigation methods can be applied once the PV process is finalised and can be indicated in the future management plan for the project and does not necessarily need to be performed immediately.

However if the planned project does not go ahead then further impacts from the old ash dam will have to be investigated according to Section 21 (h) of the National Water Act of 1998.

Method One:

New dewatering boreholes can be established up-gradient towards the west of the project area to act as a dewatering curtain to keep groundwater flow away from the old ash dam source concentration. The abstracted water can then be diverted along with the surface water collected from the stabilised areas and discharge if the quality is within limits. This will keep clean water clean and away from the source. Also solar driven submersible pumps can be used to pump the water and gravity fed to the downstream collector basin, which makes it a sustainable long term solution.

Method two:

The other option is to apply pump and treat where boreholes are drilled to abstract water from the aquifer down gradient in line with the plume migration and then pumped to a treatment facility. The water is then treated to a reasonable level ready for discharge to the surface water environment. This option is quite expensive and not the best option in the long term.

Section 11 Conclusions

A third very expensive option is to remove all material and dispose at a disposal facility designed and regulated to handle such material.

11.6 Monitoring

The monitoring at the Grootvlei ESKOM Power Station is currently up to date and needs to be maintained in this fashion. The only area which has not been covered sufficiently is the old ash dam. From the numerical model contaminant transport simulations it can clearly be seen that the area of importance is not adequately monitored. It is therefore suggested that two ne monitoring boreholes be established to the north and east of the area. The geophysical targets summarised in Table 3-1 and specifically target one and two should be used to ensure optimum results during drilling and to be most representative. If possible all three boreholes should be established for completeness.

The boreholes should then be incorporated into the current monitoring network and the same frequencies should be adhered to.

12 Recommendations

The following Recommendations were forthcoming as a result of this study:

The following Recommendations were forthcoming as a result of this study:

- As part of future mitigation actions and depending on the scenario selected going forward it is advised that two to three new monitoring boreholes needs to be established around the old ash dam as per targets summarised in Table 3-1, these then need to be sampled to ascertain the current contamination plume derived from the old ash dam;
- Once this is achieved and completed the numerical model should be re-calibrated and final simulations performed;
- A land surveyor should firm up on the positions of all monitoring positions especially the elevation component as this will be crucial for future numerical models;
- More detailed plans and scenarios needs to be provided to firm up on the results of this study; and
- As a partial mitigation option it is recommended that scenario two which includes a 100 % capping be applied to restore conditions over the long term.

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Section 14 Limitations

14 Limitations

SGW has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of EIMS and only those third parties who have been authorised in writing by SGW to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the Proposal dated 14 November 2012.

The methodology adopted and sources of information used by SGW are outlined in this report. SGW has made no independent verification of this information beyond the agreed scope of works and SGW assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to SGW was false.

This report was prepared during January 2013 and is based on the conditions encountered and information reviewed at the time of preparation. SGW disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

Appendix A Ground geophysical survey data

Line 1						
				Coordinates		
Station	Mag	emh	emv	x	y	Comment
0	28228	92.8	66.2	-49040	-2963015	
10	28229.4	94.4	65.5	-49030	-2963013	
20	28228.6	94.1	64.1	-49024	-2963013	
30	28227.7	94.6	61.4	-49015	-2963014	
40	28227.9	98.6	54.3	-49007	-2963016	
50	28225.6	98.4	64.1	-48996	-2963016	
60	28225.3	99.6	55.4	-48986	-2963020	
70	28225.1	100.5	54.1	-48978	-2963019	
80	28226.4	101.7	59.2	-48971	-2963021	
90	28224.3	99.1	62.1	-48964	-2963022	
100	28224.8	101.8	60.2	-48954	-2963024	
110	28223.5	95.2	51.5	-48946	-2963027	
120	28223.3	95.8	58.6	-48933	-2963032	
130	28224.7	94.9	61.6	-48921	-2963035	
140	28223.1	93.6	65.7	-48916	-2963034	
150	28223.1	92.6	60.3	-48904	-2963038	
160	28225.3	95.3	56.2	-48895	-2963038	
170	28224.1	93.1	52.2	-48886	-2963043	
180	28225.7	95.8	59.7	-48876	-2963044	
190	28227.3	96.8	69.4	-48870	-2963047	
200	28226.5	98.1	60.1	-48861	-2963052	
210	28226.9	98.4	48.5	-48857	-2963054	
220	28227.6	91.4	62.5	-48843	-2963054	
230	28227.7	94.1	51.3	-48831	-2963052	
240	28227.4	89.7	63.9	-48823	-2963057	
250	28237.9	85.2	59.7	-48816	-2963060	
260	28229.8	93.8	59.9	-48804	-2963062	
270	28229.3	96.7	67.8	-48790	-2963064	
280	28229.9	98.5	61.9	-48789	-2963067	
290	28229.5	97.8	63.3	-48779	-2963071	
300	28229.6	99.4	60.4	-48772	-2963074	
310	28228.3	94.2	72.8	-48759	-2963077	sump
320	28227	96.6	72.4	-48750	-2963080	
330	28281.8	97.6	71.4	-48742	-2963081	
340	28268.1	96.3	71.2	-48735	-2963082	
350	28242.6	95.5	74.1	-48725	-2963085	
360	28251.3	92.7	68.7	-48718	-2963089	steel casing
370	28186	99.5	69.4	-48708	-2963093	steel casing

Appendix A Ground geophysical survey data

380	28016.1	98.3	67.8	-48699	-2963096	
390	28221.5	103.4	73.6	-48685	-2963097	
400	28240.5	100.6	66.1	-48679	-2963097	
410	28226.2	104.3	66.5	-48671	-2963101	
420	28229.9	105.8	72.7	-48663	-2963104	
430	28228.1	107.4	64.3	-48653	-2963106	
440	28228.8	108.1	69.3	-48651	-2963108	
450	28229.4	106.4	63.2	-48643	-2963111	
460	28313.5	104.5	77.5	-48627	-2963113	
470	28273.2	104.2	70.4	-48619	-2963113	
480	28226.8	102.8	57	-48611	-2963117	
490	28234.7	101.6	69.3	-48597	-2963122	
500	28233.6	100.9	70.1	-48591	-2963123	
510	28235.6	101.6	65.9	-48583	-2963126	
520	28237.8	101.8	66.1	-48573	-2963128	
530	28238.7	101.9	66.3	-48565	-2963132	
540	28245.3	101	66.2	-48555	-2963135	
550	28569.4	99.9	67.9	-48549	-2963133	
560	28130.2	101.6	58.6	-48538	-2963136	
570	28228.9	101	65.7	-48532	-2963140	
580	28247.3	102.4	70.9	-48521	-2963141	
590	28527.7	101.1	64.6	-48513	-2963158	
600	28255.2	103.6	66.2	-48504	-2963147	
610	28231.2	103.4	74.9	-48495	-2963151	
620	28235.9	103.5	73.1	-48486	-2963150	
630	28238	90.3	75.5	-48477	-2963157	
640	28237.2	93.4	73.5	-48471	-2963162	
650	28228.3	89.7	57.6	-48463	-2963170	
Line 2						
				Coordinates		
Station	**Mag**	**emh**	**emv**	**x**	**y**	**Comment**
660	28236	30.2	81.2	-48456	-2963173	
0	28231.8	92.1	81.8	-48459	-2963180	
10	28230.4	86.6	83.9	-48461	-2963191	
20	28230.7	86	69.4	-48462	-2963202	
30	28230.7	81.4	84.2	-48463	-2963209	
40	28231.6	76.1	74.8	-48465	-2963218	
50	28231.3	77.8	72.8	-48463	-2963227	
60	28229.9	77.5	72.2	-48465	-2963235	
70	28230.1	77.6	71.2	-48468	-2963242	
80	28229.8	76.8	72.6	-48469	-2963251	

Appendix A Ground geophysical survey data

90	28227	75.7	67.3	-48470	-2963263	
100	28225.9	77.5	71.8	-48470	-2963273	
110	28233.3	78	65	-48472	-2963280	
120	28220.4	76.9	65.6	-48475	-2963292	
130	28218.7	77.4	67.8	-48477	-2963301	
140	28217.6	79.3	66.8	-48473	-2963311	
150	28216.3	81.2	67.2	-48477	-2963320	
160	28213.2	80.1	61.7	-48480	-2963325	
170	28210.3	83	66.1	-48483	-2963334	
180	28206.6	82	58.5	-48484	-2963340	
190	28203.8	83.2	72.4	-48485	-2963352	
200	28201.6	81.5	56.5	-48484	-2963365	
210	28199.9	78.7	62.8	-48489	-2963377	
220	28199.7	78.6	69.5	-48486	-2963383	
230	28196.7	78.3	67.4	-48488	-2963392	
240	28194.9	78.6	56.9	-48489	-2963404	

Line 3						
				Coordinates		
Station	Mag	emh	emv	x	y	Comment
0	28183.3	77.1	30.2	-48500	-2963398	
10	28185.4	76.7	49.4	-48504	-2963395	
20	28199.8	76.1	68.4	-48510	-2963389	
30	28209.6	74.5	51.8	-48524	-2963386	
40	28209.2	78.1	57	-48530	-2963384	
50	28210	77.4	58.2	-48539	-2963385	
60	28207.6	77.9	54.6	-48549	-2963385	
70	28197.4	77.6	61.7	-48559	-2963384	
80	28195.9	78.1	48.3	-48568	-2963380	
90	28197.4	78.3	48.9	-48567	-2963377	
100	28197.5	77.7	59.1	-48576	-2963377	
110	28203.2	78	61.3	-48584	-2963372	
120	28205.5	77.8	69.9	-48592	-2963365	
130	28214.4	79.8	62.5	-48601	-2963359	
140	28225.2	79.8	63.7	-48606	-2963356	
150	28224.9	79.2	71.1	-48619	-2963351	
160	28226.3	79.7	75.6	-48626	-2963347	
170	28225	76.7	56.8	-48632	-2963344	
180	28228.4	77.1	74	-48638	-2963341	
190	28220.6	76.5	67	-48647	-2963333	
200	28223.6	73.7	59.8	-48656	-2963327	
210	28227.3	75.3	59.9	-48665	-2963321	

Appendix A Ground geophysical survey data

220	28232.6	72.2	59.6	-48672	-2963315	
230	28239	72.3	65.7	-48679	-2963310	
240	28229.2	69.1	63.4	-48686	-2963305	
250	28237.1	70.2	60.3	-48695	-2963301	
260	28223.1	73.9	64.1	-48702	-2963297	
270	28221.6	73.6	56.7	-48714	-2963292	
280	28215.2	73.4	51.3	-48723	-2963291	
290	28219.2	71.6	62.4	-48733	-2963286	
300	28228	69.6	62.3	-48739	-2963284	
310	28214	70.8	62.6	-48753	-2963281	
320	28223.4	69.6	67.8	-48756	-2963279	
330	28235.5	68.4	48.9	-48772	-2963275	
340	28234.1	68.1	60.3	-48778	-2963273	
350	28201.4	73.1	67.4	-48786	-2963269	
360	28133.3	72.4	76.4	-48794	-2963267	
370	28012.7	81.1	57.3	-48800	-2963265	
380	28093.1	82.8	40.8	-48809	-2963267	
390	28162.7	87.1	81.6	-48817	-2963267	
400	28192.6	84.6	52.8	-48825	-2963263	
410	28263.9	86.8	56.6	-48836	-2963259	
420	28003.1	80.8	65.1	-48845	-2963258	
430	28203.1	79.5	55.9	-48853	-2963256	

Line 4						
				Coordinates		
Station	**Mag**	**emh**	**emv**	**x**	**y**	**Comment**
0	28222.9	90.3	61.3	-48857	-2963247	
10	28212.9	84.1	62.9	-48858	-2963238	
20	28204.3	83.7	51.9	-48861	-2963230	
30	28203	81.3	62.8	-48863	-2963222	
40	28207.3	79.6	47.9	-48867	-2963214	
50	28209.5	76.6	60.2	-48870	-2963208	
60	28204.8	70.3	64.5	-48877	-2963197	
70	28205.3	71.2	64.7	-48882	-2963189	
80	28205.6	70.2	60.1	-48888	-2963184	
90	28206.7	69.9	60.2	-48894	-2963175	
100	28208	70.5	67.4	-48897	-2963166	
110	28208	70.6	60.7	-48904	-2963159	
120	28209.5	71.7	60.9	-48908	-2963151	
130	28209.7	71.5	59.1	-48915	-2963143	
140	28208.9	73.4	68.3	-48921	-2963135	
150	28206.5	75.3	74.8	-48928	-2963132	

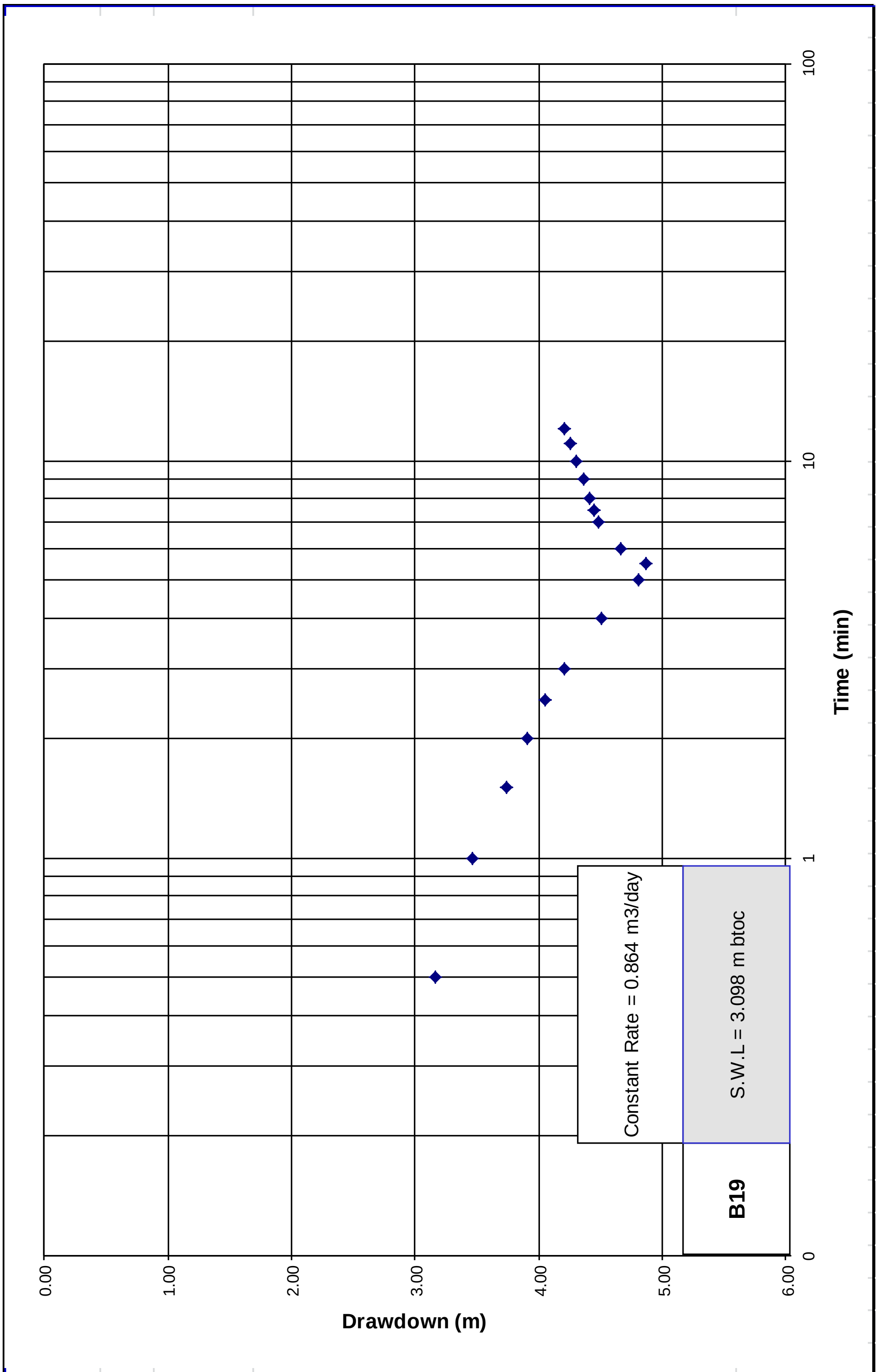
Appendix A Ground geophysical survey data

160	28206.8	77.6	67.2	-48933	-2963123	
170	28207.2	77.2	69.6	-48940	-2963121	
180	28208.4	79.4	61.8	-48948	-2963115	
190	28209.5	77.9	74.3	-48955	-2963106	
200	28210.9	80.7	60.4	-48962	-2963099	
210	28210.2	82.9	68.7	-48969	-2963092	
220	28210.4	84.5	67.4	-48976	-2963087	
230	28211.3	87	66.5	-48983	-2963075	
240	28212.4	87.9	66.4	-48992	-2963068	
250	28213.2	90.5	54.8	-48997	-2963063	
260	28214	90.8	72.6	-49001	-2963057	
270	28214.6	93.7	70.7	-49000	-2963056	
280	28215	97.6	63.4	-49010	-2963048	
290	28215.2	98.7	65.7	-49014	-2963043	
300	28216.8	98.6	65.3	-49022	-2963039	
310	28216.1	95.9	73.1	-49031	-2963033	
320	28216.6	95.4	64.6	-49040	-2963028	

Appendix B Aquifer Testing Data

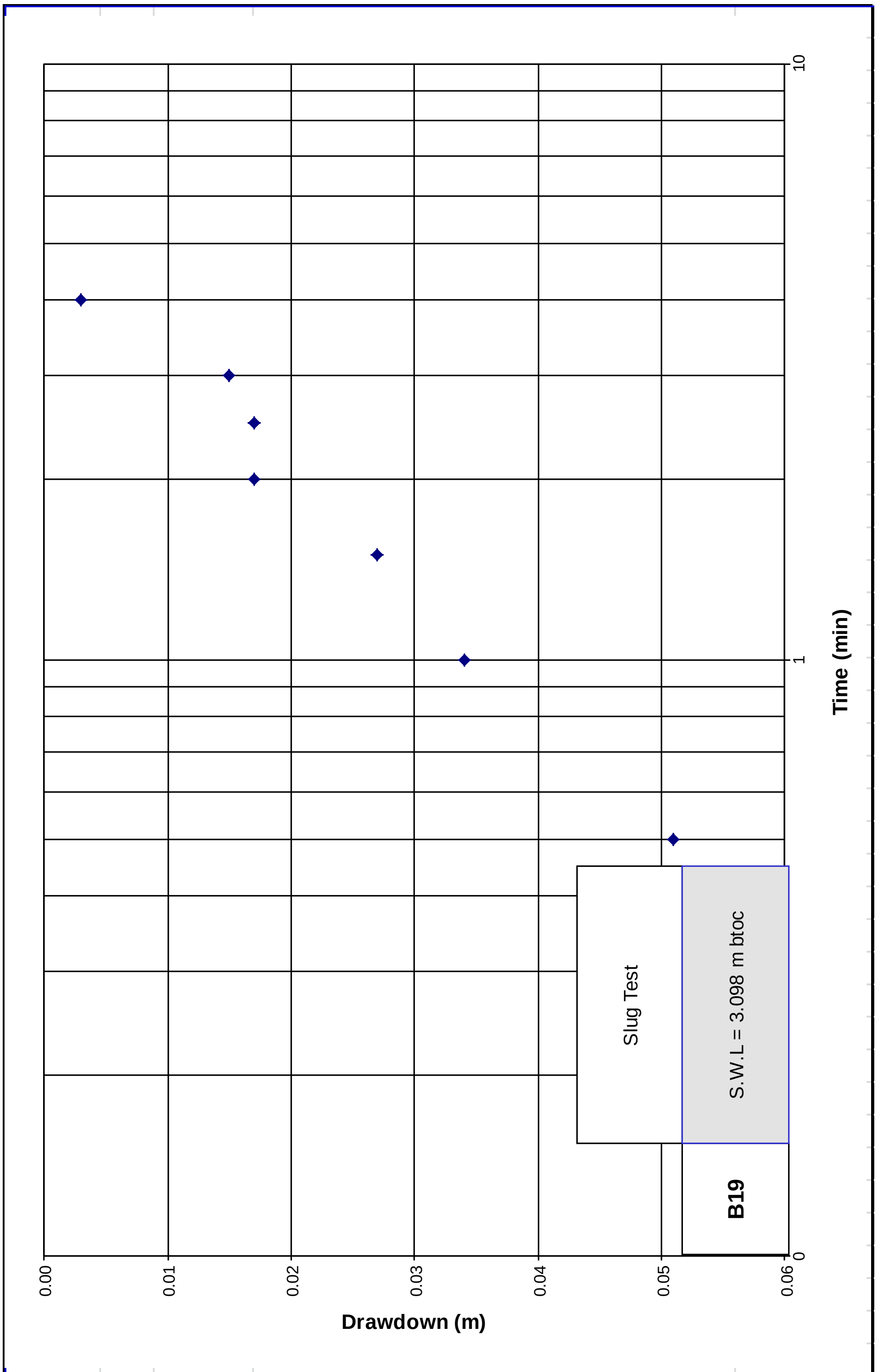
BH ID	B19		
Water level (mbcl)	3.098	Date	18-Dec
Pump depth (m)	9	Time	12:00
Available drawdown (m)	**5.902**	Yield (L/s)	0.03
Borehole Depth (mbgl)	12		
Real Available Drawdown (m)	**8.902**		
Slug-in test		**Recovery Test**	
Time (min)	**Drawdown (m)**	**Time (min)**	**Drawdown (m)**
0.5	3.158	0.5	4.872
1	3.463	1	4.661
1.5	3.741	2	4.482
2	3.908	2.5	4.444
2.5	4.055	3	4.413
3	4.207	4	4.359
4	4.507	5	4.304
5	4.804	6	4.258
		7	4.203
Water level (mbcl)	3.098	Date	18-Dec
Pump depth (m)	Slug	Time	12:00
Available drawdown (m)	**0**	Yield (L/s)	Slug test
Borehole Depth (mbgl)	30		
Real Available Drawdown (m)	**26.902**		
Slug-in test		**Recovery Test**	
Time (min)	**Drawdown (m)**	**Time (min)**	**Drawdown (m)**
0.5	0.051		
1	0.034		
1.5	0.027		
2	0.017		
2.5	0.017		
3	0.015		
4	0.003		

Appendix C Aquifer Testing Graphs



Job No.	09280012		**ESKOM Grootvlei**	
Prep. By	JG	05/01/2013	**Constant Discharge Drawdown Test**	
Chk'd By	JG	05/01/2013	**B19**	
Revision No.		1	**Plate 1**	

Appendix C Aquifer Testing Graphs



Job No.	09280012		ESKOM Grootvlei	
Prep. By	JG	05/01/2013	Slug - in Test	
Chk'd By	JG	05/01/2013	B19	
Revision No.		1	Plate 1	

Appendix D Laboratory Analysis Certificates

aquatico Laboratories (Pty) Ltd.

ilac-MRA sanas T0374

Test Report

Page 1 of 1

Client: SGW
Address: 558 Skukuza Street, Faerie Glen
Report no: 11582
Project: SGW

Date of certificate: 25 January 2013
Date accepted: 21 January 2013
Date completed: 25 January 2013
Revision: 0

Lab no:			117417	117418	117419
Date sampled:			18-Jan-13	18-Jan-13	18-Jan-13
Sample type:			Water	Water	Water
Locality description:			B18	B19-1	B19-2
Analyses	Unit	Method			
A pH	pH	ALM 20	8.64	7.81	8.02
A Electrical conductivity (EC)	mS/m	ALM 20	65.7	89.5	85.8
A Total alkalinity	mg/l	ALM 01	80.5	334	297
A Chloride (Cl)	mg/l	ALM 02	155	98.6	92.3
A Sulphate (SO_4)	mg/l	ALM 03	<0.04	2.07	3.36
A Nitrate (NO_3) as N	mg/l	ALM 06	0.060	0.261	0.259
A Ammonium (NH_4) as N	mg/l	ALM 05	0.086	0.082	0.072
A Ortophosphate (PO_4) as P	mg/l	ALM 04	0.014	0.013	0.013
A Fluoride (F)	mg/l	ALM 08	0.221	0.376	0.410
A Calcium (Ca)	mg/l	ALM 30	8.72	89.2	68.6
A Magnesium (Mg)	mg/l	ALM 30	14.7	23.9	20.6
A Sodium (Na)	mg/l	ALM 30	87.7	65.9	86.2
A Potassium (K)	mg/l	ALM 30	7.67	4.86	5.01
A Aluminium (Al)	mg/l	ALM 31	<0.003	<0.003	<0.003
A Iron (Fe)	mg/l	ALM 31	<0.003	<0.003	<0.003
A Manganese (Mn)	mg/l	ALM 31	<0.001	0.035	0.022
A Total chromium (Cr)	mg/l	ALM 31	<0.001	<0.001	<0.001
A Copper (Cu)	mg/l	ALM 31	<0.001	<0.001	<0.001
A Nickel (Ni)	mg/l	ALM 31	<0.001	<0.001	<0.001
A Zinc (Zn)	mg/l	ALM 31	<0.002	<0.002	<0.002
A Cobalt (Co)	mg/l	ALM 31	<0.001	<0.001	0.001
A Cadmium (Cd)	mg/l	ALM 31	<0.001	<0.001	<0.001
A Lead (Pb)	mg/l	ALM 31	<0.004	<0.004	<0.004
A Total hardness	mg/l	ALM 26	82	321	256

Appendix D Laboratory Analysis Certificates

A = Accredited N= Not accredited O = Outsourced S = Sub-contracted NR = Not requested RTF = Results to follow NATD = Not able to determine
Results marked 'Not SANAS Accredited' in this report are not included in the SANAS Schedule of Accreditation for this laboratory.
This test report shall not be reproduced except in full, without written approval of the laboratory.
Measurement of uncertainty available on request for all methods included in the SANAS Schedule of Accreditation.
Results reported against the limit of detection.

Laboratory Manager: H. Holtzhausen

www.aquatico.co.za 489 Jacqueline Drive, Garsfontein, Pretoria, South Africa Tel: +27 12 348 2813/4 Fax: +27 12 348 8575

Appendix E SGS Laboratory Analysis Certificates

SGS

TEST REPORT

CLIENT DETAILS

Contact	Jacques Groenewald
Client	SGW
Address	P.O Box 36816 Faria Glen 0043 Pretoria 0043
Telephone	012 991 5290 / 079 977 9090
Facsimile	(Not specified)
Email	jgroenewald007@gmail.com
Project	(Not specified)
Order Number	09280012
Samples	1
Sample matrix	SOIL

LABORATORY DETAILS

Laboratory	SGS South Africa (Pty) Limited
Address	259 Kent Avenue Ferndale, 2194
Telephone	+27 (0)11 781 5689
Laboratory Manager	Joanne O'Sullivan
SGS Reference	JB13-03382 R0
Report Number	0000003774
Date Received	2012/12/20 11:36:30AM
Date Reported	2013/02/13 09:45:24AM

COMMENTS

The document is issued in accordance with SANAS's accreditation requirements.
Accredited for compliance with ISO/IEC 17025. SANAS accredited laboratory T0107.

sanas T0107

Sample(s) leached using TCLP solution # 1. Results reported on leachate.

SIGNATORIES

James Dryman
Technical Supervisor/Technical Signatory

Joanne O'Sullivan
Laboratory Manager/Technical Signatory

SGS South Africa (Pty) Limited
Environmental Services
259 Kent Avenue, Ferndale
Randburg, 2194, South Africa
t +27 (0)11 781 5689 www.za.sgs.com
Member of the SGS Group

Appendix E SGS Laboratory Analysis Certificates

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ANALYTICAL REPORT

JB13-03382 R0

Report number 0000003774
Client reference 09280012

Parameter	Units	LOR	Sample Number: JB13-03382.001 Sample Name: ESADAM01
Toxicity Characterization Leaching Procedure (TCLP) Method: ME-AN-022			
Final pH	-	0.1	8.1
TCLP - Leachate Evaluation Method: ME-AN-022			
Evaluation pH	-	0.1	9.1
Total Dissolved Solids (TDS) in leachates Method: ME-AN-011			
TDS (0.7µm) @ 105°C	mg/l	21	5100
Conductivity on leachates Method: ME-AN-007			
Conductivity	mS/m	2	686
Anions on leachates by Ion Chromatography Method: ME-AN-014			
Chloride	mg/l	0.05	596
Sulphate	mg/l	0.05	36
ICP-OES Metals on leachates (Dissolved) Method: ME-AN-027			
Sodium	mg/l	0.5	1330
Calcium	mg/l	0.5	568
Magnesium	mg/l	0.01	25
Arsenic	mg/l	0.01	0.03
Boron	mg/l	0.005	0.78
Lead	mg/l	0.01	<0.01
Nickel	mg/l	0.005	<0.005
Selenium	mg/l	0.01	0.03
Strontium	mg/l	0.001	7.5
Vanadium	mg/l	0.001	0.036
Zinc	mg/l	0.01	<0.01

13-February-2013 Page 2 of 3

Appendix E SGS Laboratory Analysis Certificates

SGS

METHOD SUMMARY

JB13-03382 R0

Report number: 0000003774
Client reference: 09280012

METHOD	METHODOLOGY SUMMARY
ME-AN-007	The conductivity of an aliquot of aqueous sample is measured electrometrically using a standard cell connected to a calibrated meter with automated temperature correction. This method is based on APHA 2510.
ME-AN-011	Total dissolved solids (TDS) is determined gravimetrically on a filtered aliquot of aqueous sample by evaporating the sample to dryness in a pre-weighed container at 105 deg C. The method is based on APHA 2540 C.
ME-AN-014	Inorganic anions (Br, Cl, F, NO3, NO2, SO4) are determined on aqueous samples by ion chromatography. The method is based on EPA 300.1 and APHA 4110 B. Br, Cl, F and NO2 are not determined on TCLP leachates.
ME-AN-022	The appropriate extraction fluid for the TCLP leach is determined based on the inherent alkalinity of the sample by measuring the pH of a portion of the sample mixed with deionised water.
ME-AN-022	Extraction Fluid #1: This fluid is made by combining dilute sodium hydroxide solution and glacial acetic acid with water. The pH of this fluid should be 4.93 +/- 0.05. Extraction Fluid #2: This fluid is made by diluting glacial acetic acid with water. The pH of this fluid should be 2.88 +/- 0.05.
ME-AN-027	Dissolved metals are determined on a filtered and acidified portion of aqueous sample by inductively coupled plasma optical emission spectrometry (ICP-OES). The method is based on EPA 200.7 and APHA 3120.

FOOTNOTES

IS	Insufficient sample for analysis.	QFH	QC result is above the upper tolerance
LNR	Sample listed, but not received.	QFL	QC result is below the lower tolerance
*	This analysis is not covered by the scope of accreditation.	-	The sample was not analysed for this analyte
**	Performed by outside laboratory.		
LOR	Limit of Reporting		
↑↓	Raised or Lowered Limit of Reporting		

Samples analysed as received.
Solid samples expressed on a dry weight basis.

Unless otherwise indicated, samples were received in containers fit for purpose.

sanas

T0107