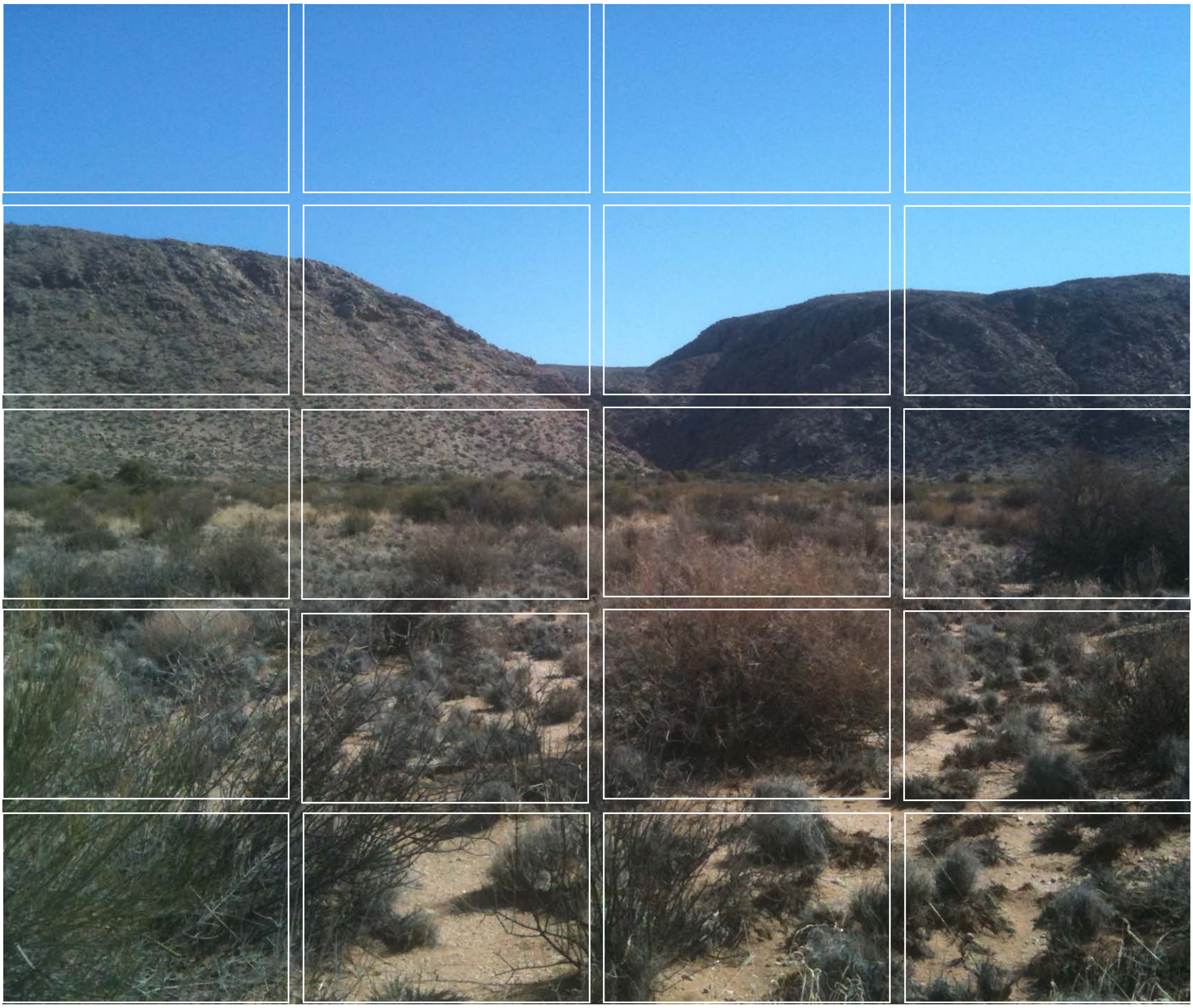
Annex G.2

Geohrydrology Specialist Report



Vedanta – Black Mountain Mining (PTY) LTD

GAMSBERG ZINC PROJECT ESIA

Groundwater Impact Assessment

DRAFT REPORT

April 2013

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Vedanta – Black Mountain Mining (PTY) LTD

GAMSBERG ZINC PROJECT ESIA

Groundwater Impact Assessment

DRAFT REPORT

April 2013

Prepared by: Helen Seyler

For and on behalf of
Environmental Resources Management

Approved by: Stefan Muller

Signed: 

Position: Partner

Date: 17 April 2013

The author of this report, HELEN SEYLER, does hereby declare that she is an independent consultant and has no business, financial, personal or other interest in the activity, application or appeal in respect of which she was appointed other than fair remuneration for work performed in connection with the activity, application or appeal. There are no circumstances that compromise the objectivity of the specialist performing such work. All opinions expressed in this report are her own.

HELEN SEYLER (Professional Reg No. 400042/12)
April 2013

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ABBREVIATIONS

ERM	Environmental Resource Management
ESIA	Environmental and Social Impact Assessment
EMPr	Environmental Management Programme
EC	Electrical Conductivity
K	Hydraulic Conductivity
D	Molecular Diffusion Coefficient
TDS	Total Dissolved Solids
SS	Suspended Solids
SANAS	Aquatico Scientific
QA/QC	Quality Assurance and Quality Control
RMSE	Root Mean Square Error
FEM	Finite Element Method
DEM	Digital Elevation Model
SAWS	South African Weather Service
SANS	South African National Standards
SAWQ	South African Water Quality
DWAF	Department of Water Affairs and Forestry
MAP	Mean Annual Precipitation
WRD	Waste Rock Dumps
TSF	Tailings Storage Facility

1 INTRODUCTION

1.1 BACKGROUND

Black Mountain Mining (Pty) Ltd (the client) tasked Environmental Resources Management Southern Africa (Pty) LTD (ERM) to conduct a Specialist Groundwater Study as part of the Environmental and Social Impact Assessment (ESIA) for the proposed new Gamsberg zinc mine project.

In 1971, zinc deposits were discovered at Gamsberg by O'okiep Copper Company. In 1988 Anglo American Corporation acquired the Gamsberg site and completed subsequent prefeasibility and feasibility investigations in order to explore the viability of mining the zinc deposit. These feasibility investigations included an ESIA, which addressed the open pit mine development and associated infrastructure. The necessary approvals for the mining right and associated Environmental Management Programme (EMPr) were obtained in 2001 and over the years, additional amendments were made. Vedanta Resource Plc. acquired Black Mountain Mining (Pty) Ltd from Anglo American Corporation in 2011. Apart from the abovementioned EMPr right, all other approvals obtained previously by Anglo American have lapsed.

In terms of obtaining the necessary authorisation for the new zinc mine and associated infrastructure, a new ESIA process will be undertaken in order to obtain the necessary authorisation for the new zinc mine and associated infrastructure. This process will provide a detailed assessment of potential impacts as well as suitable mitigation measures. As part of this process ERM has completed a baseline hydrogeology study and groundwater impact assessment, presented in this report.

1.2 TERMS OF REFERENCE

1.2.1 Objectives

The objectives of this groundwater specialist study were as follows:

- Generate groundwater flow and transport numerical model(s), to assess the current groundwater situation (baseline conditions) and quantify potential future impacts of the proposed project and based on long term (closure) scenario(s); and
- Develop groundwater mitigation measure(s) and monitoring plan(s), based on the groundwater impact assessment(s), captured in a report to comply with regulatory requirements for permitting (according to best practise principals).

This report forms a groundwater specialist report based on currently available project description for input into the overall ESIA project. The project description is not finalised and therefore this study includes various assumptions, all listed within this report.

1.2.2 *Scope of Work*

The specialist groundwater study for the Gamsberg Project, consisting of an open pit zinc mine, including waste rock storage and tailings dam, and associated project infrastructure, is divided into the following four tasks:

- Task 1: Numerical Flow and Transport Model(s);
- Task 2: Groundwater Impact Assessment;
- Task 3: Mitigation and management plans; and
- Task 4: Reporting.

1.3 *PROJECT DESCRIPTION*

The new Mine is located between the existing town of Aggeneys and the town of Pofadder, approximately 120 km east of the Springbok, along the N14 (*Figure 3.2 in Section 3.1*). Black Mountain currently operates a zinc, lead, copper and silver mine near the town of Aggeneyes. In addtition to that they are peresently mining 60 000 tpa from underground workings in the Gamsberg inselberg. The ore currently mined at the existing underground operation is transported to the Black Mountain concentrator plant in Aggeneys where it is processed, together with ore from the Black Mountain Deeps Mine.

According to forecasts, the growing global demand for zinc will exceed current global production by approximately 503 KTPA by the year 2015 (Wood Mackenzie, 2012). The proposed mine intends to meet the growing demand, at the time of commencement of operation of the mine (ie 2015). The zinc concentrate generated from the proposed Project would be exported to Europe and Asia for refining and distribution. Gamsberg is also a key project to ensure mining continues in the region.

The zinc deposit present within the Gamsberg inselberg is a defined ore body that ranges from 100 m to 500 m in depth. The ore body has a large lateral extent of 3 500 m (from east to west). The ore body is characterised with high content of sulphide and manganese, resulting in a low grade ore deposit of approximately 6% of zinc.

The feasibility study undertaken during the initial EIA process in 2000 (SRK Consulting) identified open pit mining to be the most suitable mining method applicable for a financially viable and environmentally acceptable extraction.

The Project will include the establishment of a new 10 Million tpa (Mtpa) open pit zinc mine (beneficiation volume) with resultant waste rock dumps; mine machinery fleet and workshops. A concentrator plant with resultant stockpile areas, tailings facility and supporting infrastructure (ie water supply distribution network, laboratories, sewage works and an office complex) will be established to process the mined ore. A port facility is required for shipment and export. Temporary storage facilities for the deposition, storage and handling of ore/waste rock will be required (layout plan *Figure 3.2* in *Section 3.1).*

A process of sequentially excavating push backs will be undertaken to the open pit. The final open pit is expected to cover a total area of 600 hectares, which is expected to be the result of the extraction of some 1.65 billion tons of material. To access the ore, drilling and blasting by means of explosives will take place. An estimated 1.5 billion tons of waste rock will be generated during the life of mine (19 years), resulting in waste rock dumps with a total area of 300 hectares.

ERM was instructed by the client of planned mining activities, on which the modelling study is based. These are described in detail in *Section 95* in terms of how they are represented in the model.

1.4 HEALTH AND SAFETY

As a global leader in environmental, safety and health services, ERM places the highest priority on the health and safety of employees, sub-contractors and the community, whilst maintaining a high level of resilience to work disruption. ERM has implemented a comprehensive programme designed to control and reduce the likelihood of work-related accidents. Driven by strict standards, it emphasizes risk assessment and control, strong communications, training, and self-assessment. It incorporates ISO-based elements, comparable to those programmes implemented by health and safety conscious clients across the globe. Our sub-contractors are required to abide by the ERM standards of health and safety, as described in our policy.

As part of project planning and prior to undertaking any site visit, ERM has prepared a Health and Safety Plan (HASP) including a Travel Risk Assessment (TRA) to determine potential risks associated with travel on the project and how these can best be mitigated. A site specific HASP, including risk assessments for activities associated with the field work, was prepared prior to the ERM field team mobilizing to site. In addition all sub-contractors employed during fieldwork were given a tool box talk by ERM, based on information presented in the HASP, outlining the health and safety requirements for the site. All sub-contractors were required to sign and abide by relevant HASP's and/or TRA's.

2 *METHODOLOGY*

2.1 *INTRODUCTION*

According to the data collation and identification of gaps in the scoping phase, the following methodology was applied for the groundwater specialist study:

1. Field investigations of all available monitoring boreholes, as well as natural springs and privately owned boreholes; to confirm baseline hydrogeological information; and measure groundwater quality
2. Desktop level data analysis, to include new data and available data from previous reports, leading to the development of a conceptual model for the site
3. Site reconnaissance and meetings with Black Mountain and AMEC geologists, by the ERM (Environmental Resource Management) hydrogeological modelling team, to support development of the conceptual model
4. Numerical modelling

2.2 *FIELD INVESTIGATIONS*

2.2.1 *Hydrocensus*

A detailed hydrocensus was conducted within the study area. The aim of the hydrocensus was to compile a complete inventory of springs and available groundwater level monitoring points, groundwater and surface water abstraction points and a comprehensive groundwater level survey of the entire study area.

During the hydrocensus, the following data was recorded:

- Geographic coordinates, recorded using a hand-held GPS;
- Depth to groundwater in boreholes;
- Borehole depths, where possible;
- Field measurements: temperature, pH and electrical conductivity (EC).

2.2.2 *Groundwater Sampling*

Groundwater samples were collected from monitoring boreholes, natural springs and privately owned boreholes and well(s). Samples were obtained from the various sampling points as follows:

Monitoring boreholes: Groundwater samples were collected using a submersible pump.

Privately owned boreholes and wells: Equipped farm boreholes were sampled directly from the tap closest to the pump outlet. Unequipped boreholes and wells were sampled using disposable bailers (grab samples).

Springs: Springs were sampled directly at the discharge points using the sample bottles.

As part of ERM's Standard Operating Procedures, sampling bottles were rinsed three times with water obtained from the sampling point before filling them completely and dedicated disposable bailers were used to obtain water from unequipped boreholes. Parameters pH, electrical conductivity and temperature were measured directly in the field using calibrated equipment.

The analytical schedule for general chemical parameters, major ions and trace elements analysis included the following constituents:

General Chemical Parameters

- pH;
- Electrical Conductivity (EC);
- Total Dissolved Solids (TDS);
- Suspended Solids (SS);
- Turbidity; and
- Total hardness.

Major Ions

- Total Alkalinity (CaCO3);
- Calcium (Ca);
- Magnesium (Mg);
- Sodium (Na);
- Potassium (K);
- Chloride (Cl);
- Sulphate (SO_4);
- Nitrate (NO_3) as N;
- Nitrite (NO2) as N;
- Ammonium (NH_4) as N;
- Orthophosphate (PO_4) as P; and
- Fluoride (F)

Trace Elements

- Aluminum (Al);
- Arsenic (As);
- Barium (Ba);
- Cadmium (Cd);
- Cobalt (Co);

- Copper (Cu);
- Iron (Fe);
- Lead (Pb);
- Manganese (Mn);
- Nickel (Ni);
- Total Chromium (Cr);
- Dissolved Uranium (U); and
- Zinc (Zn).

All samples collected where placed in a cooled container directly after sampling and transported, at 4°C, to Aquatico Scientific Laboratory in Pretoria. Aquatico Scientific is SANAS accredited.

Quality Control – QA/QC

As part of ERM's Quality Assurance and Quality Control protocol (QA/QC) standard operation procedures for sample collection were followed for the collection of each type of sample. Defensible quality control for sampling and decontamination procedures were followed to allow for the collection of representative samples and to minimise the potential for cross-contamination between samples. Duplicate samples were taken and field measurements (pH, temperature and EC) were recorded for each sampling point.

Samples were handled, and stored in accordance with established protocols. Samples were stored in laboratory-prepared sample bottles and placed in coolers containing frozen ice packs.

2.3 DATA ANALYSIS & DESKTOP STUDY

Previous studies in the area have been used as reference material for the desktop study, including:

- Anglo American Technical Services (AATS). Gamsberg Hydrogeological Assessment of the area of the proposed mine as part of the Environmental Impact Assessment (April 2000).
- Golder Associates. Hydrocensus of the Eastern Lobe of the Gamsberg. Technical Report No. 8789/9402/1/G (April 2007).
- SRK Consulting. Preliminary Geohydrology and Groundwater Quality Baseline Report, Gamsberg Pre-Feasibility Project. Report No 396036\Groundwater (January 2010).

In addition, various datasets were received from Black Mountain, and other data sources included South African Weather Service, satellite images, maps and national datasets. These data are referenced within the relevant sections.

2.4 *SITE RECONNAISSANCE*

The ERM hydrogeological modelling team visited site for a reconnaissance in January 2013. The site visit addressed the following:

- geological information was obtained from Black Mountain geologists, including assessment of local scale geological features ;
- sites of potential surface –groundwater interaction were visited to investigate their setting; and
- the ERM hydrocensus was updated with information from mine employees most specifically on the use patterns of various boreholes, and impact of mining on groundwater.

2.5 *NUMERICAL GROUNDWATER MODELLING OVERVIEW*

2.5.1 *Model Objectives*

Using the hydrogeological conceptual model, the current groundwater situation is represented with the use of numerical flow models to simulate the present groundwater flow conditions in the study area.

The calibrated baseline models are flexible tools that are used during the impact assessment, to simulate and quantify potential impacts of the proposed open pit mining activities on the environment, as well as management scenarios.

2.5.2 *Model Approach*

Before considering and implementing mining activities, a 'steady state' groundwater flow model is calibrated based on groundwater levels in the baseline database. Steady-state simulations are independent of time, and the model represents an equilibrium position, ie the long term average of groundwater levels over time at the site. These can be considered as the average of the existing conditions, ie a base-case. Steady state simulations are used to calibrate time independent model parameters such as the hydraulic conductivity, and to refine boundary conditions or conceptual models.

The hydraulic head distribution of the calibrated steady state solution is then used as the initial head distribution for the transient (time-dependent) model. Time dependent parameters such as aquifer storage are usually calibrated by fitting modelled results to observed results for groundwater levels over time, using water level results of pump tests.

There was no transient calibration performed because only four short term constant rate pump tests in individual positions have been conducted, each without observation borehole monitoring. These tests are not useful for calibrating a regional model. Additional tests were not performed by ERM because adding more pump tests even if somewhat longer duration, would not significantly reduce uncertainties when carrying out predictions for 100 years, and at stresses much greater and more regional than that in a short duration pump test (*Section 2.5.5*). Likewise, installation of continuous monitoring at project inception could provide some time series data, however with a heterogeneous fractured environment with erratic rainfall, several years monitoring data is required in order to significantly improve confidence in transient calibration, and thus be a worthwhile exercise and investment at project planning and EIA stages.

The transient flow model is then used to replicate future mining activities and therefore make predictions regarding the impacts from mine activities and infrastructure. The flow model is also converted into a transport model to predict impacts on groundwater quality.

The modelling approach was as follows:

- A regional scale steady state groundwater flow model was set-up taking into consideration hydrogeological flow boundaries to incorporate the project infrastructure;
- This model was calibrated using the baseline water level data;
- The calibrated models were then converted to transient, time-dependent, models and storage parameters sought through curve fitting to pump test data were applied;
- Mining, closure, and post-closure models were set-up and run using the calibrated transient models to run different management scenarios;
- Any changes in the model setup (model discretisation, boundary conditions, hydraulic parameters) were iterated and re-run in steady state and transient, to ensure the final mine model setup also calibrated to observed data; and
- Transport models were set-up in order to simulate different management scenarios.

2.5.3 *Model Calibration*

Model calibration is the process of varying model input data within realistic ranges of values until a satisfactory match between simulated and observed data can be reproduced. The large number of parameters and complex nature of the natural system combined with the simplification assumptions made during the conceptual model process means that the calibrated solution is non-unique. Reducing the non-uniqueness of the parameter combinations that can lead to a seemingly calibrated model can for example be done by reducing the number of degrees of freedom (ie the number of unknown input parameters), by choosing a distinct calibration strategy and by constraining spatially distributed input data via remote-sensing techniques (Brunner, et al., 2007).

In order to avoid an over-fitting of the model, the number of unknown input parameters (ie the degrees of freedom) has to be kept as small as possible. The more the degrees of freedom used for model calibration, the better the measured water levels can be reproduced by the model. However, with an over-fitted or over-parameterised model a good fit between the observed and simulated piezometric heads can always be obtained even if the model does not reflect the structure and the behaviour of the real aquifer. A large number of input parameters are unknown in this modelling problem, and to avoid an over-parameterised model, certain assumptions are made for input parameters such that the degrees of freedom are reduced. The model input data is summarised in *Section 6.1* and only transmissivity is used as the key calibration parameter.

During the model calibration phase, hydraulic conductivities were optimized in order to obtain an acceptable fit of calculated versus observed water levels. A steady state calibration was performed for both recharge scenarios detailed in *Section 6.2.2*. An objective criterion is used for steady state simulations (MSE: mean square error or variance) to compare different calibrations:

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(h_i^m - h_i^c)^2$$ with h_m measured head and h_c calculated head

The model has reached a good or acceptable model calibration, when the root mean square error (RMSE) is $\sqrt{MSE} \leq 10\%$ of the head difference between upstream and downstream measured groundwater heads.

Calibration was performed using both manual and automated methods.
For automated parameter estimation, PEST was applied (Doherty J. L., 1994).

Models should ideally be used in prediction in a manner that is consistent with their calibration. For example, a model that is calibrated in steady state only will likely produce transient predictions of low confidence. Conversely, when a transient calibration is undertaken, the model may be expected to have a high level of confidence when the time frame of the predictive model is of less or similar to that of the calibrated model. Furthermore, when a predictive model includes stresses (ie pumping or dewatering) that are well outside the range of stresses included in the calibration, the reliability of the predictions will be low and the model confidence level also (Barnett, et al., 2012).

2.5.4 *Software Selection*

FEFLOW version 6 was used for the groundwater flow and transport simulations. FEFLOW is a 3D finite element modelling software package for modelling saturated and unsaturated fluid flow and transport of dissolved constituents and/or heat transport processes in porous media. It is developed by DHI-WASY GmbH, the German branch of the DHI group.

The finite element method (FEM) is a good choice for solving partial differential equations over complicated domains, when the domain changes and the desired precision vary over the entire domain. Using the FEM, one can accurately follow complex geometries and material interfaces.

PEST is an inverse code, used for the automated estimation of parameters and sensitivity analysis of parameters including for example transmissivity, hydraulic conductivity or recharge etc (Doherty, Brebber, & Whyte, 1994).

2.5.5 Model Limitations

Numerical models are a powerful tool to solve problems. However, groundwater systems are complicated beyond our capability to practically evaluate them in detail. A model, no matter how sophisticated, will never describe the investigated groundwater system without deviation of model simulations from the actual physical processes that occur in the study area (Spitz & Moreno, 1996).

All numerical modelling simulations require assumptions to be made during the translation of the conceptual model into a numerical model. These assumptions, which reflect data gaps in the conceptual model regarding the aquifer distribution and the aquifer parameters, and reflect the impracticalities of representing the conceptual model exactly, can result in uncertainty in the model output and predictions. Further to these assumptions, the software itself contains intrinsic assumptions in the representation of hydrogeological processes. The model is then limited in its accuracy and ability to predict by these assumptions. As a planning stage model, this model is constructed at a regional scale with spatially averaged parameters. It is not capable therefore of replicating small scale processes dominated by heterogeneous properties; such as flow in an individual fracture system.

Uncertainty over assumptions can be managed with a sensitivity analysis. Sensitivity analysis gives an indication of which assumptions regarding the model input parameters have the greatest effect on the model output. Based on the sensitivity analysis results, areas of concern and parameters that should be studied in more detail can be identified and included in the recommendations.

The transient model is not calibrated to time series data, and is not calibrated to aquifer stresses of a similar order of magnitude to those applied to it. Given the model calibration standard described in *Section 2.5.3*, the model can therefore only be used as an indicative model for future timescales. It is recommended that the model be updated with operational data (dewatering rates, groundwater level responses) as mining commences, such that predictions can be updated and translated into mine management practices (see *Section 9*).

3 PROJECT ENVIRONMENTAL SETTING

3.1 SITE LOCALITY

The Gamsberg is located in the north-eastern region of Namaqualand in the Northern Cape Province of South Africa. The site is located just south of the N14 National Road, with Springbok 115km southwest (124km by road), and Pofadder 43km northeast (58km by road), as shown in *Figure 3.1*.

The closest town, Aggeneys, is located 20km west of the site. Black Mountain currently operates underground mining in the mountain north and northwest of Aggenys.

The study area includes the area on, and around, the Gamsberg inselberg. The site layout plan detailing planned mine infrastructure is shown in *Figure 3.2*.

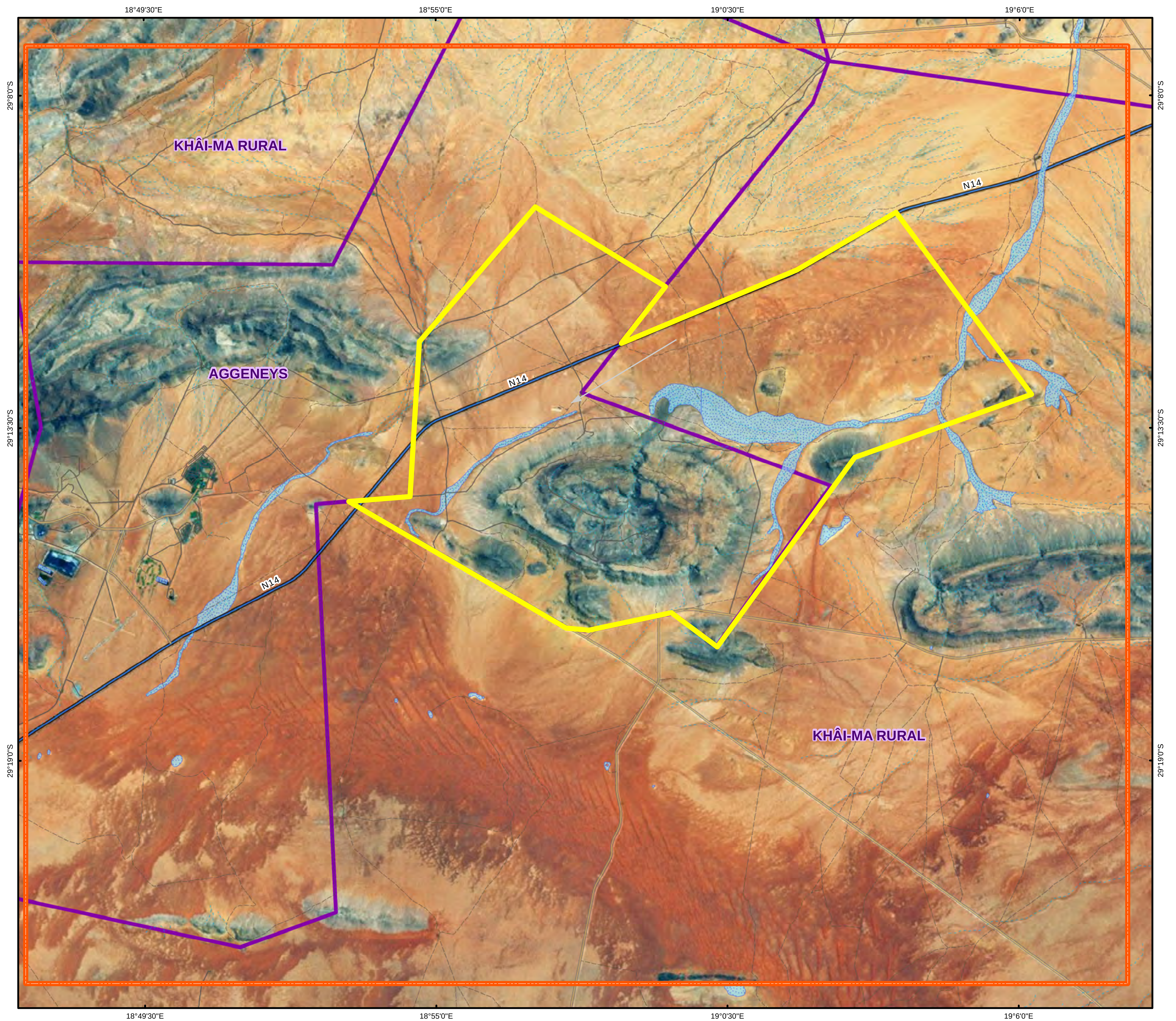
3.2 TOPOGRAPHY AND LAND USE

The Gamsberg inselberg rises 250m above the general ground level of the surrounding relatively flat plains (*Figure 3.3*, showing 20m contours derived from the digital elevation model (DEM)). These maps also show the red boundary, the 'groundwater model domain' for reference, which is the position selected for the numerical model boundaries (see *Section 83*). It is oval shaped in plan with steep slopes on all sides.

The outer rim of the inselberg is formed by resistant quartzite and sits around 60m higher than the centre of the inselberg (AATS, 2000), which has developed as a structurally-controlled kidney shaped drainage basin. One large kloof (gorge) is developed on the northern rim of the inselberg, which has steep sided slopes rising 130m above the base of the kloof at the highest points.

The soil on the plains is predominantly shallow (less than 60cm deep), and stony, overlying dorbank (duripan) or calcrete. Areas of deeper red sandy soils are limited to small dunes and pediment in the south-western portion of the study area (SRK, 2010). Within the inselberg the soils are shallow lithosols, and bare rock on the scarps and crest and shallow gravelly in the Basin.

The relatively flat plains surrounding Gamsberg are populated with large farmsteads with sparse vegetation and low density livestock, supported by groundwater from boreholes equipped with wind pumps. The land that Gamsberg occupies is owned by Black Mountain and is currently used for grazing and some small scale mining operations (see *Section 4.8*).



Legend

- National Route
- Main Road
- Secondary Road
- Other Road
- Track/Footpath
- Ephemeral Rivers
- Mineral Rights Boundary
- Ground Water Model Domain
- Town Boundary
- Flood Plains

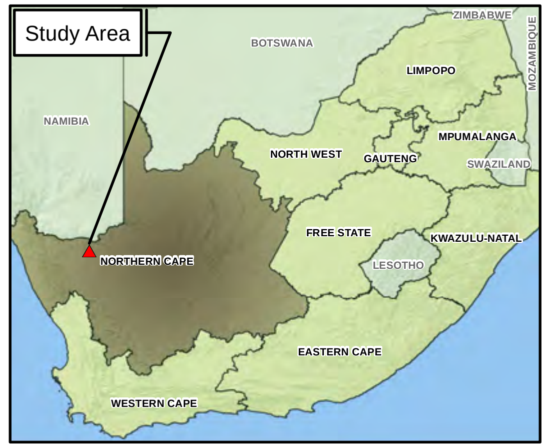


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Figure 3.1: Location of Gamsberg Inselberg

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Fax +27 (0)21 701 7900

ERM

Projection: Transverse Mecator, CM19. Datum : WGS84
Source: Chief Directorate National Geo-Spatial Information. David Morriss, 2012.
Inset Map: Esri Data & Maps

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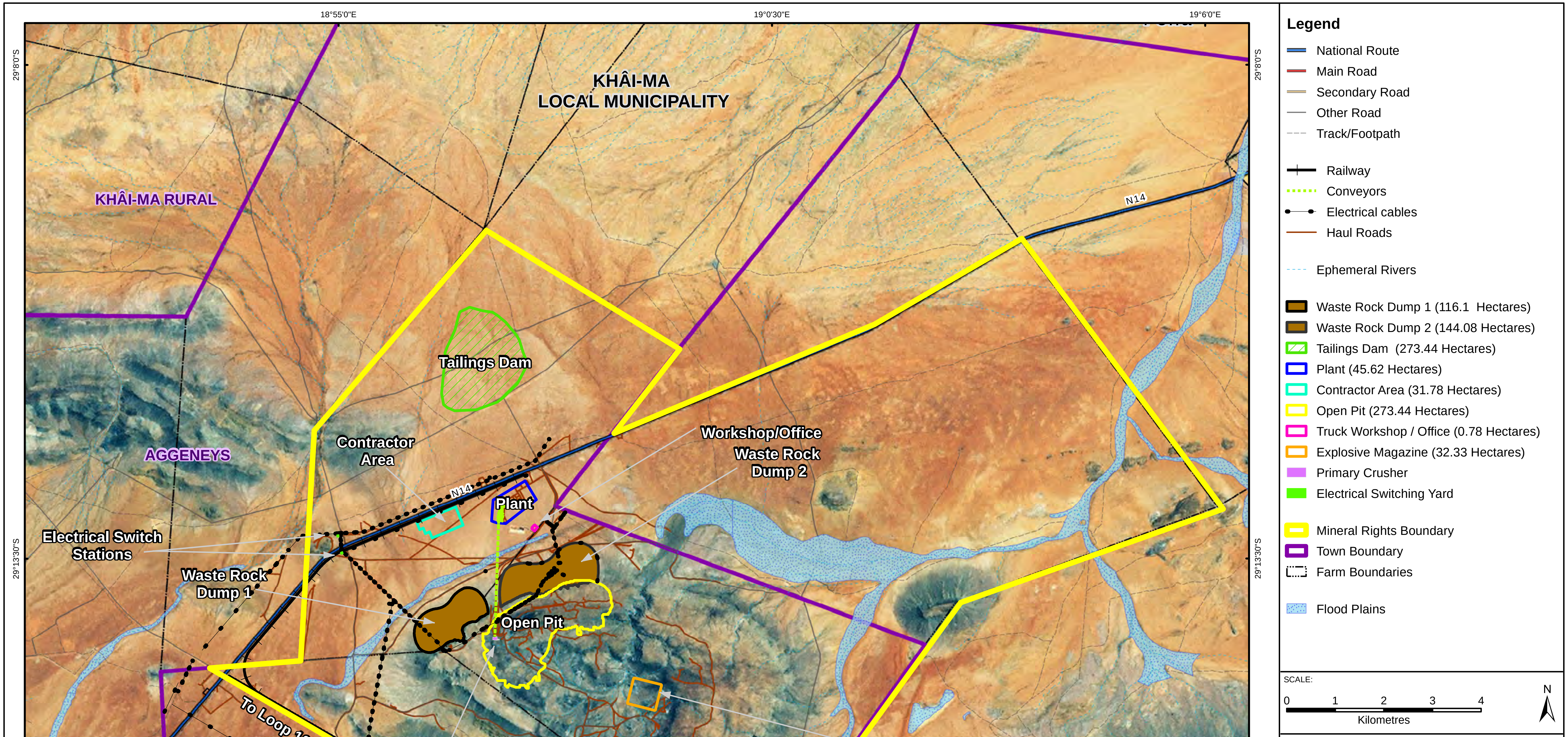

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Figure 3.2: Site Plan showing Mine Infrastructure

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BLACK MOUNTAIN MINING (PTY) LTD

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DRAWING: Site_Plan_of_Gamsberg_Inselberg_Rev2.mxd

REV: 0

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Projection: Transverse Mecator, CM19. Datum : WGS84
Source: Chief Directorate National Geo-Spatial Information. David Morriss, 2012.
Inset Map: Esri Data & Maps

SIZE: A3

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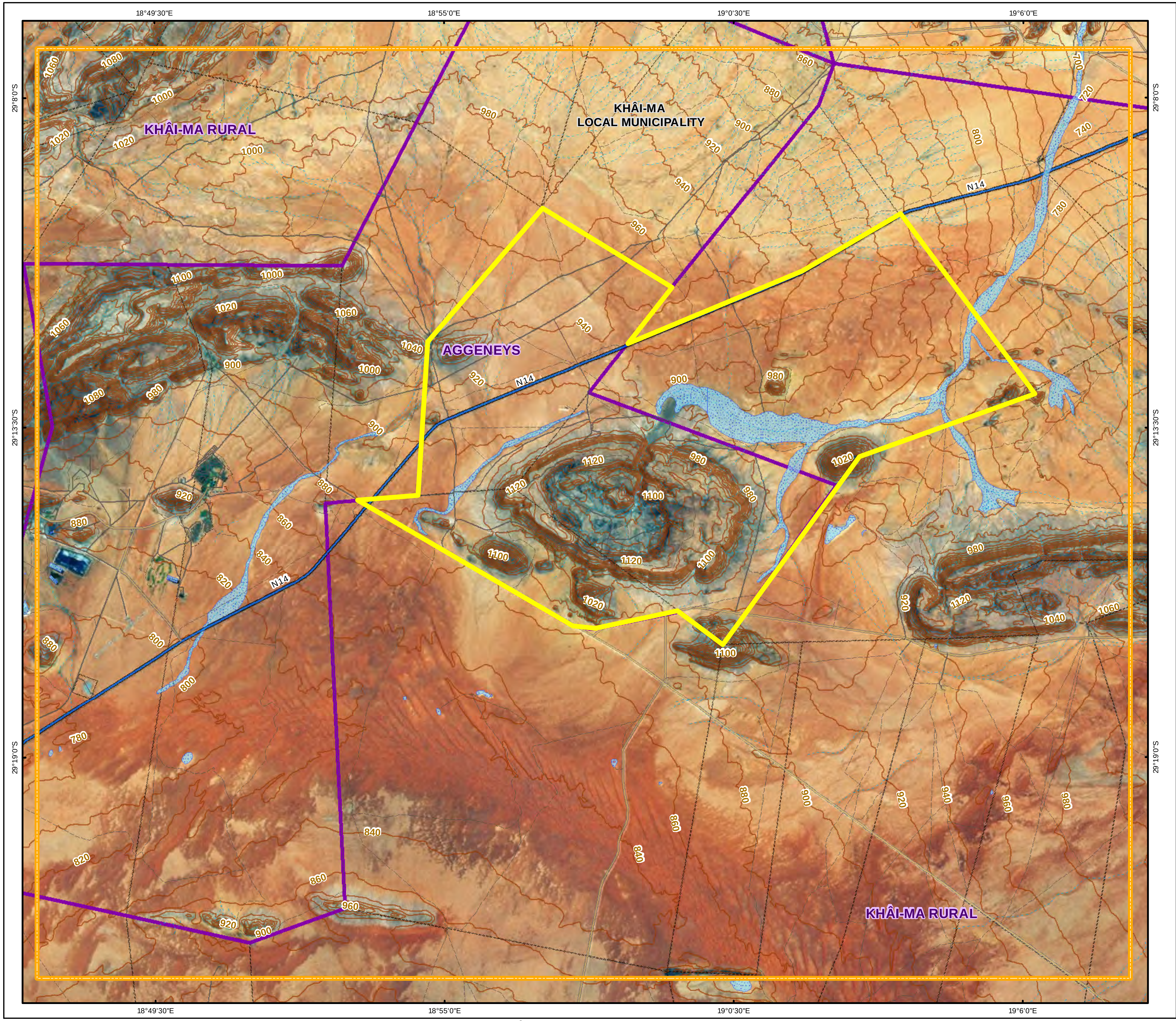

Legend

- National Route
- Main Road
- Secondary Road
- Other Road
- Track/Footpath
- Ephemeral Rivers
- Contours (20m)
- Mineral Rights Boundary
- Groundwater Domain Model
- Town Boundary
- Flood Plains

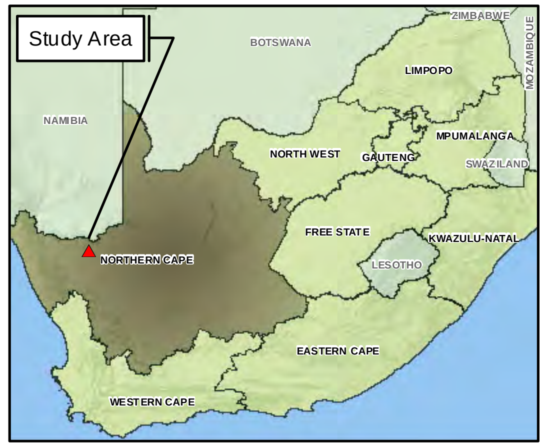

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Figure: 3.3: Topograpghic of Gamsberg Study Area

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DRAWING:	REV:
Topographic_Map_Gamsberg_Rev2.mxd	0

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Projection: Transverse Mecator, CM19. Datum : WGS84 Source: Chief Directorate National Geo-Spatial 2918BD_2003_ED2_GEO.TIF Inset Map: Esri Data & Maps	SIZE: A3

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3.3 *PRECIPITATION AND EVAPORATION*

The conditions in the Gamsberg study area are described as "Hot Desert" (Köppen classification in Peel, Finlayson, & McMahon (2007)), being one of the hottest and driest areas in South Africa, with maximum temperatures exceeding 40°C in summer months (SRK, 2010) and annual rainfall sometimes as low as a few tens of millimetres (*Table 3.1*).

The mean annual evaporation rate is high (3500 mm/a in SRK (2010), 3700 mm/a in AATS (2000) and 2650 mm/a in Midgley & Middelton (1994)) compared to annual rainfall on the plains, hence a permanent water deficit exists in the area. This deficit reaches a peak of 400 mm in November to January and droughts are therefore common in the area (SRK, 2010).

Rainfall data has been recorded at six rainfall stations in the area. The South African Weather Service (SAWS) has been recording daily data at Aggeneys since 1999, in Pella (Station 0247242 W) for 1877-1999, and in Pofadder since 1901. In addition to the SAWS data for Aggenys, a rain gauge is positioned at the Black Mountain offices in the town, and recorded by the Black Mountain Mineral Resources Manager Mr J Potgieter. This data is available since 1986.

Data from two rainfall stations installed by Black Mountain is available, one on the northwest rim of the Gamsberg Inselberg ("Berg"), and a second in an unknown location, named "Plant" (pers comm. Abraham J. Engelbrecht, Project Engineer, Black Mountain). The "plant" station could either be a reported second weather station at the Gamsberg Inselberg (SRK, 2010), or it could reflect data from a weather station installed at the Deeps Shaft at Black Mountain mine, NW of Aggenys (pers comm. Abraham J. Engelbrecht, Project Enginner, Black Mountain). Only one year of incomplete data is available from these stations (May 1999-April 2000, missing August), and their current state of functionality is unknown to Black Mountain.

The average of the annual rainfall (mean annual precipitation, MAP) of these six stations, are listed in *Table 3.1*, for the available data indicated. The MAP varies between 74 mm (Pella) to 110 mm (Aggenys) for stations recording on the plains. Aggenys has a higher MAP than Pella and Pofadder, and it is not possible to determine whether this is due to the longer record at Pella and Pofadder, or whether it is a true difference in rainfall distribution.

There appears to be an orographic control on the rainfall distribution with the mountainous areas receiving higher rainfall, as indicated by the modelled distribution of mean annual precipitation provided by DWA (*Figure 3.4*, from SRK (2010)), which indicates around 110 – 145 mm MAP on the Gamsberg inselberg. The rainfall recorded at Plant and Berg stations are also elevated compared to Aggenys. However, only data for 1999-2000 is available, and the rainfall received at other stations were above average in 1999-2000, hence it cannot be taken as representative. An attempt has been made to estimate a representative MAP for the Berg station, as this is relevant to the estimation of recharge on the inselberg (see *Table 3.2*). The rainfall at Berg in May 1999-April 2000 is compared to the sum for these months at other stations (*Table 3.2*, 1st row). This is compared to the MAP and a factor for the difference in the two values calculated. Applying this factor to the Berg rainfall, provides a guideline of what the representative MAP for the Berg might be; around 90 mm to 170 mm, depending on which stations are used to generate the factor. This of course assumes that the difference between the inselberg and plains is linear and independent of the rainfall magnitude.

The variation in the annual rainfall indicated in the longer records of the Aggenys, Pella and Pofadder stations, is extremely high. For example at Aggenys, the MAP is 110mm, with a minimum MAP of 4mm, and a maximum of 220 mm, representing a range from almost 0% to 200%. Likewise the MAP at Pella and Pofadder is 70-80mm, yet their maximums are 259mm and 262mm respectively. Essentially, given the range in data also highlighted by the high standard deviation in MAP, the concept of a 'mean annual precipitation' actually does not apply in the area.

The monthly distribution in rainfall is show in *Table 3.3* and *Figure 3.5*. Precipitation occurs throughout the year, in summer and winter. The graph (*Figure 3.5*) shows significantly higher rainfall is experienced in summer and February indicated as the wettest month, likely to be dominated by afternoon thunderstorms. However this is skewed as the series for Berg and Plant is based on only one year of data. Assessing the monthly variability for only those stations with significant time series data, the monthly variability is less significant. The graph suggests however that years' of high rainfall are contributed to by significant thunder storms in February, and when these do not occur, annual rainfall is further limited.

Figure 3.4 Map of Mean Annual Precipitation

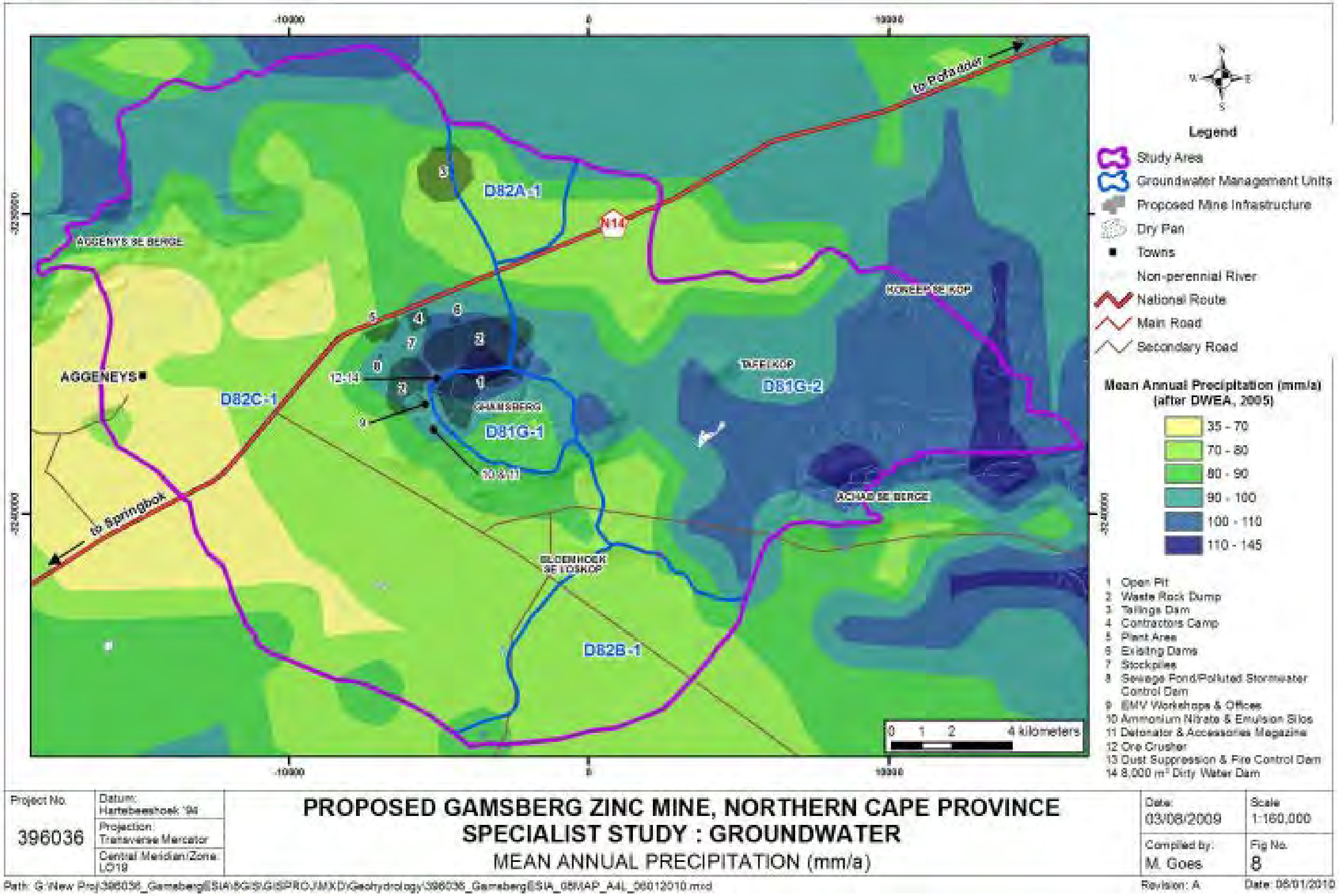


Table 3.1 ***Mean Annual Rainfall for the Aggenys (2), Pella, Pofadder, Plant and Berg Weather Stations for the periods indicated (average of summed rainfall over calendar years)***

Station	Available data	Mean Annual Rainfall	Minimum Annual Rainfall	Maximum Annual Rainfall	Range	Standard Deviation	Source
Aggenys	1999-2012	103	37	196	160	50	SAWS
Aggenys	1986-2012	110	11	220	209	52	Mr J Potgieter Black Mountain
Pella	1877-1999	74	5	259	254	52	SAWS
Pofadder	1901-2012	78	4	266	262	55	SAWS
Plant	May 1999-April 2000	241					AATS 2000
Berg	May 1999-April 2000	329		n/a			AATS 2000

Table 3.2 ***Estimation of a representative Mean Annual Rainfall for the Gamsberg Inselberg***

	Aggenys SAWS	Aggenys BM	Pofadder	Gamsberg
Rainfall May 1999 - April 2000 (mm)	212	208	286	329
MAP (mm)	103	110	78	n/a
Factor	2.06	1.88	3.68	n/a
Average factor, all stations		2.54		n/a
Average factor, Aggenys	1.97		n/a	n/a
Calculated MAP for Berg, using Pofadder (mm)				89
Calculated MAP for Berg, using all stations (mm)				129
Calculated MAP for Berg, using Aggenys (mm)				167

Table 3.3 Average Monthly rainfall for the Aggenys, Pella, Pofadder, Plant and Berg weather stations for the periods indicated

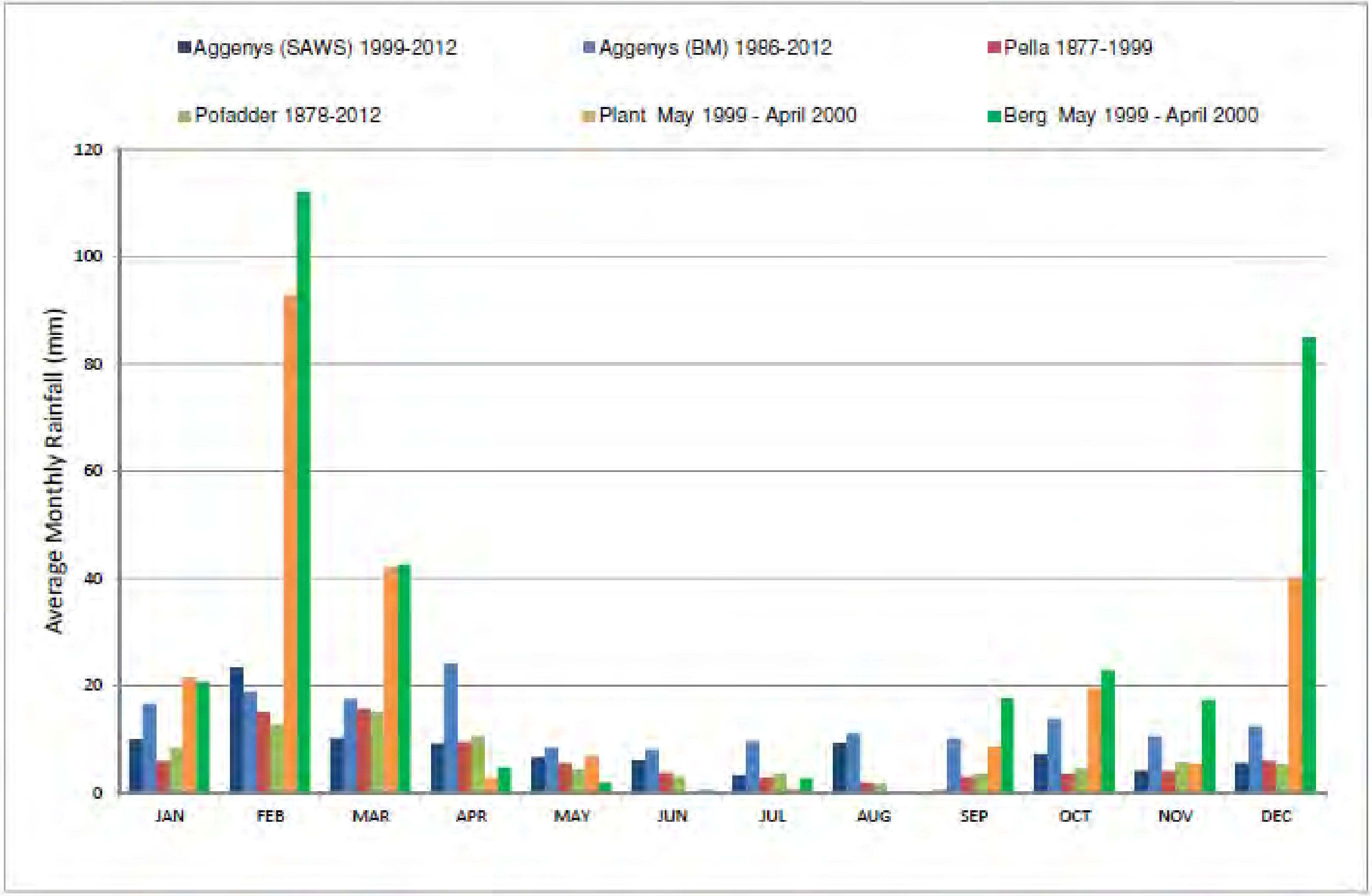
Station	Dates	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Source
Aggenys	1999-2012	10.0	23.4	10.2	9.3	6.7	6.1	3.3	9.4	0.5	7.3	4.3	5.7	SAWS
Aggenys	1986-2012	16.7	18.9	17.5	24.2	8.4	8.1	9.6	11.1	10.2	13.8	10.6	12.4	Mr J Potgieter Black Mountain
Pella	1877-1999	6.0	15.1	15.8	9.5	5.6	3.8	2.9	1.9	3.1	3.6	4.2	6.0	SAWS
Pofadder	1878[3]-2023	8.5	12.8	15.1	10.5	4.4	3.1	3.7	1.7	3.7	4.6	5.8	5.5	SAWS
Plant	May1999-April 2000	21.6	92.8	42	2.8	7	0	0.8	-[1]	8.6	19.6	5.4	40.2	AATS 2000
Berg[2]	May 1999-April 2000	20.8	112	42.6	4.8	2	0.6	2.8	-[1]	17.6	23	17.4	85	AATS 2000

[1]No data

[2]Weather station positioned at high point on north west rim of inselberg (pers comm. Abraham J. Engelbrecht, Project Engineer, Black Mountain)

[3]Pofadder station has incomplete data 1878 to 1901 hence not included in annual rainfall prior to 1901.

Figure 3.5 Average monthly rainfall measured at Aggeneys, Pella, Pofadder and the Gamsberg (Inselberg) weather stations



3.4 *HYDROLOGY AND DRAINAGE*

Situated in the Orange River basin, the study area is located at the watershed between two quaternary catchments, D81G and D82C (*Figure 3.6*). The Gamsberg inselberg itself, excluding the west ridge, is situated within quaternary catchment D81G, which drains in a northerly direction towards the Orange River some 35km from the inselberg. The D82C catchment is endoreic; an interior drainage basin that does not drain to the sea and equilibrates through evaporation (HHO Africa, 2013).

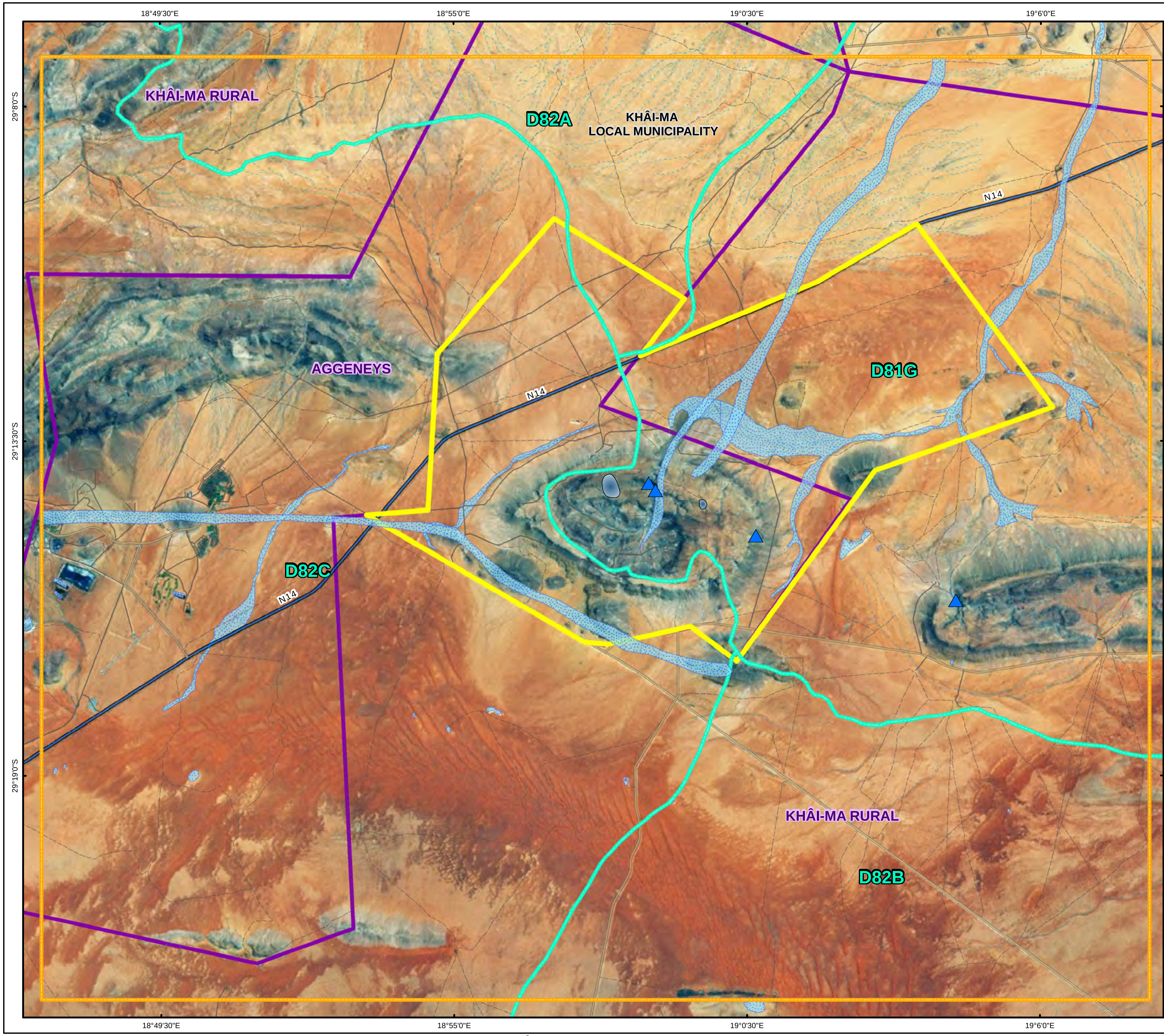
Because of the climate, the drainage features in the region are all ephemeral. All known surface water features are captured and displayed in *Figure 3.6*, and they are summarised as:

- The inselberg itself is drained by an ephemeral drainage course that exits the inselberg via the steep sided kloof in the northern rim (marked as flood plain in *Figure 3.6*). This drainage course, once exits the kloof, flows to the east and connects with other small channels draining from high ground, then trends to the northeast. This drainage channel is considered the main one, and is clearly visible in the landscape from the soils and the vegetation (see *Figure 3.7*). This channel may have developed in the Pleistocene when the climate was wetter, as significantly elevated levels of zinc and other metals are found in the sediments in the channel confirming its origin as runoff water from the inselberg (pers comm Mr J Potgieter Black Mountain Mineral Resources Manager). Local knowledge of the area informs that this channel only flows in response to significant rain events, and when it does, it rarely flows for great distances or durations. This channel is mapped from data stored in the National Surveys and Mapping databases.

- The springs marked on *Figure 3.6* are based on data from Black Mountain, and field data taken during the hydrocensus. These springs are considered constant groundwater discharge points. At times they only have small standing water pools at them, and do not generate streams, likely due to the evaporation matching the rate of discharge. The springs are described further in *Section 4*.

- Headwater seeps marked in *Figure 3.6* are based on data from Black Mountain. They are assumed to be geologically controlled, where groundwater and surface runoff from the permeable quartzite meets the less permeable ore body formations. The seeps are described further in *Section 4*.

The existing mining operations on the inselberg may have already impacted on groundwater fed spring flows, by reducing the hydraulic head and driving force for discharge (*Section 4.8*).



Legend

- Springs
- National Route
- Main Road
- Secondary Road
- Other Road
- Track/Footpath
- Ephemeral Rivers
- Mineral Rights Boundary
- Groundwater Domain Model
- Town Boundary
- Flood Plains
- Headwater seeps catchments
- Quaternary Catchment

SCALE:

0 1 2 3 4 5 6

Kilometres

N

TITLE:

Figure 3.5 Drainage map

CLIENT:

vedanta

BLACK MOUNTAIN MINING (PTY) LTD

DATE:Jan 2013	CHECKED: MP	PROJECT: 0164903
DRAWN: AT	APPROVED: SHC	SCALE: 1 : 110 000

DRAWING: Drainage_Map_Rev2.mxd

REV: 0

ERM
Block A, Silverwood House
Silverwood Close
Steenberg Office Park, 7945
Cape Town, SOUTH AFRICA
Tel: +27 (0)21 702 9100
Fax +27 (0)21 701 7900
ERM

Projection: Transverse Mecator, CM19. Datum : WGS84
Source: Chief Directorate National Geo-Spatial Information. David Morriss, 2012.
Inset Map: Esri Data & Maps

SIZE: A3

C:\Users\Dell4\Documents\Thurlow Mapping\PRIVATE WORK\ERM\CONTRACT\GIS\0164903_GAMSBERG\MXD\MXD_REV2\Drainage_Map_Rev2.mxd

Figure 3.7 Photograph of drainage channel exiting from Kloof

3.5 GEOLOGY

3.5.1 *Regional Geology*

The study area is situated in the Bushmanland terrane, one of the Northern Cape's tectonically bound terrains. The area consists of hard-rock formations; metasedimentary, metavolcanic and intrusive rock units of the Namaqua Metamorphic Province (Vegter, 2006), or Namaqua-Natal Province (SRK, 2010).

The Bushmanland Terrane is composed of basement granitic rocks (1 700-2 050Ma), supracrustal sequences of sedimentary and volcanic origin (1 200, 1 600 & 1 900Ma) and intrusive charnokite to granitic rocks (950, 1 030-1 060 & 1 200Ma). The rocks here have been subjected to multiple phases of deformation and medium- to high-grade metamorphism during the Namaqua Orogeny at ~1 200-1 000Ma (SRK, 2010).

Legend

- Mineral Rights Boundary
- Ground Water Model Domain
- Kbk - Brulkolk Formation*
- Kga - Gams Member
- Kht - Hoston Formation
- Kkoe - Koeris Formation*
- Kkop - Koeiporrt Gneiss
- Kwr - Wortel Formation*
- Nsm - Swartmodder Gneiss*
- Q-S1 - Quaternary Sedimentary/volcanic Rocks
- Q-S2 - Quaternary Sedimentary/volcanic Rocks

SCALE: 0 1 2 3 4 5 6 Kilometres

N

TITLE:

Figure 3.6: Geological Map

CLIENT:

vedanta

BLACK MOUNTAIN MINING (PTY) LTD

DATE:Jan 2013	CHECKED: MP	PROJECT: 0164903
DRAWN: AT	APPROVED: SHC	SCALE: 1 : 110 000

DRAWING: Geology_Map_of_Gamsberg_Inselberg_rev2.mxd

REV: 0

ERM
Block A, Silverwood House
Silverwood Close
Steenberg Office Park, 7945
Cape Town, SOUTH AFRICA
Tel: +27 (0)21 702 9100
Fax +27 (0)21 701 7900

Projection: Transverse Mecator, CM19. Datum : WGS84
Source:Council of Geoscience Geology Kaarte 2918
Inset Map: Esri Data & Maps

SIZE: A3

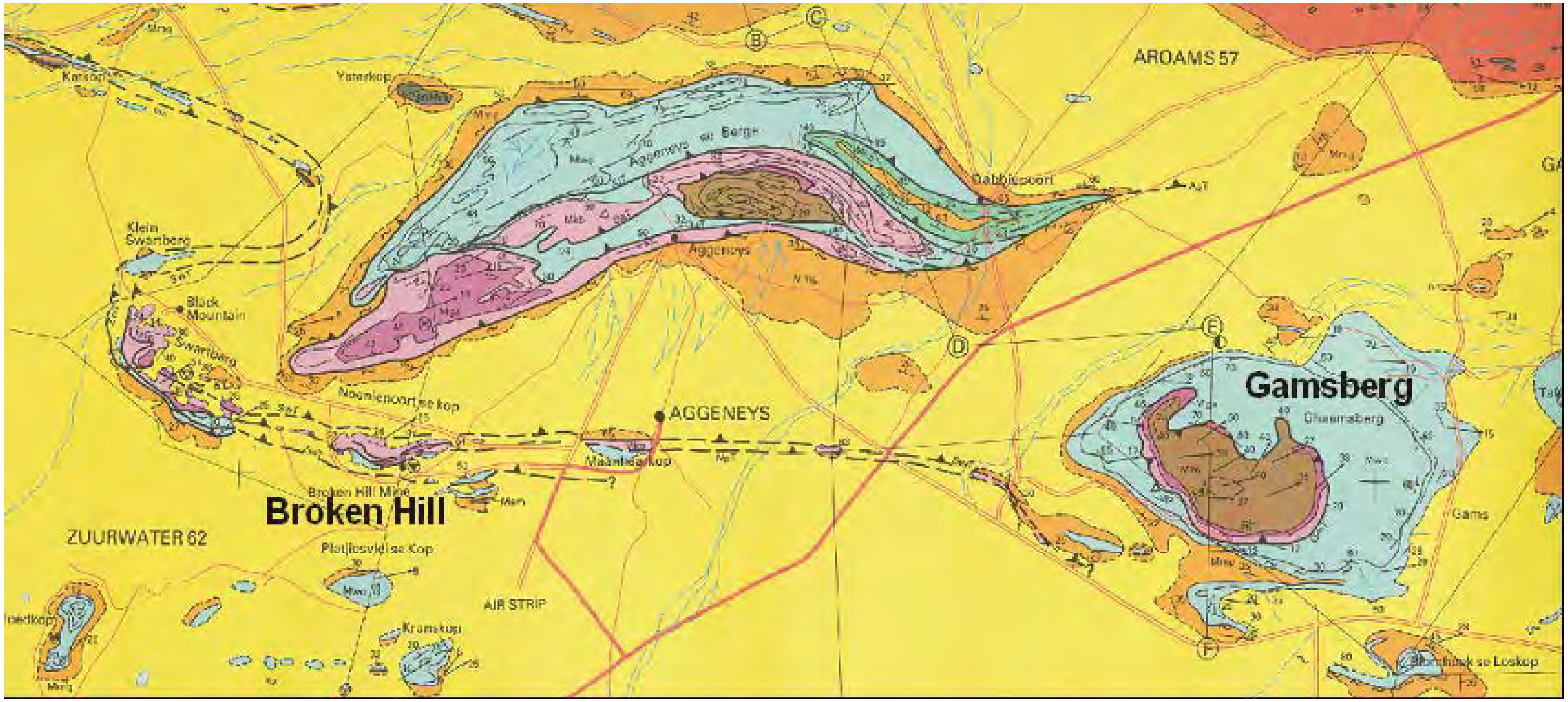
C:\Users\Dell4\Documents\Thurlow Mapping\PRIVATE WORK\ERM\CONTRACTS\GIS\0164903_GAMSBERG\MXD\MXD_REV2\Geology_Map_of_Gamsberg_Inselberg_rev2.mxd

Figure 3.9 Geological Map [1]

Strydom et al, 1987

[1] Geological map available in hard copy only at Black Mountain, and reproduced for this report as a photograph of the original. No key is available

Figure 3.10 Geological Map [2]



Colliston, et al., 1986

[2] Geological map available as a digital image only, provided by Black Mountain. No key is available

3.5.2 *Local Geology*

Three geological maps from various authors are presented in *Figure 3.8* (Council for Geoscience), *Figure 3.9* (Strydom, et al., 1987) and *Figure 3.10* (Colliston, et al., 1986). The stratigraphy is provided in *Figure 3.11* (Black Mountain) and *Table 3.4* (SRK, 2010). A local scale geological map and associated cross section is presented in *Figure 3.12* and *Figure 3.13* respectively, based on geological mapping by Black Mountain, supported by an annotated photograph presented in *Figure 3.14*. Based on different level of detail of geological mapping, and different geological interpretations, these data sets show slightly different distributions of various units, slightly different traces of various faults, and slightly different sub-divisions of the stratigraphy. The important features for this study are summarised as:

- The plains consist of various depths of surficial, relatively thin cover of wind-blown sand, dunes, scree rubble, sandy soil and alluvium (SRK, 2010). Underlying this in the vicinity of the inselberg is the Haramoep Gneiss Member of the Koeipoort (Gneiss) Formation, which is a pink medium to fine grained, biotite-rich, leucogneiss. The gneiss can be considered the basement rocks in the region (*Figure 3.13*).

- The Namies Schist Member of the Wortel (Witputs) Formation overlies the Haramoep Gneiss. It is a pelitic schist around 70 m thick. The schist is clearly visible in the walls of the inselberg (Figure 3.14), and the base of the schist forms a bowl shape (Figure 3.13).

- Overlying the Koeipoort Formation, is the Pella Quartzite Member of the Wortel (Witputs) Formation, reported as a layered sequence of medium to thick bedded quartzite with interbedded sillimanite, lenticular quartzite, biotite gneiss and amphibolite/calc-sillicate gneiss (SRK, 2010). Outcrops of the Pella Quartzite in Gamsberg inselberg suggest the interbedded units are minor, and the massive fractured quartzite dominates (Figure 3.16). The unit reaches a maximum stratigtraphic thickness 375 m.

- The Gamsberg Iron Formation overlies the Pella Quartzite, and is a sequence of schist, quartzite, banded iron formation, and the ore body, which is the target of the proposed mining operations.

- The Koeris Formation (schists and amphibolite) overlies the Gamsberg Iron Formation

Table 3.4 Lithology of Geological Formations present in the Gamsberg Area (from SRK, 2010)

Eon/ Epoch	Group	Sub-group	Formation	Member	Description
Quaternary	Recent				Alluvium Red, wind-blown sand and dunes Sand, scree, rubble and sandy soil
Proterozoic / Mokolian-Keisian	Bushman-land	Aggenys	Koeris		Brown psammitic schist, conglomerate, amphibolite and quartzite
			Hotson	Gams	Sulphide bearing magnetite-grunerite-garnet-pyroxene rocks, cordierite feldspar, sillimanite schist and quartzite
					Rhythmically layered quartzite, quartz-feldspar-biotite gneiss ±sillimanite nodules, quartz-biotite-sillimanite gneiss
			T'hammaberg[1]		Upper units – white quartzite and schist ± graphite
					Lower unit – well embedded dark blue quartzite and muscovite-sillimanite schist ± graphite, minor iron formation lenses
			Skelmpoort[1]		Muscovite-sillimanite schist grading into rhythmically bedded graphite-fuchsite-quartz-garnet schist and graphite-quartzite, biotite-sillimanite schist with interlayered brown quartzite and minor gossans and garnet-quartz rocks
			Wortel (Witputs)	Pella quartzite	Layered sequence of medium to thick bedded quartzite with interbedded sillimanite, lenticular quartzite, biotite gneiss and amphibolite/calc-sillicate gneiss
	Glad-kop		Koeipoort	Namies schist	Pelitic schist
				Haramoep gneiss	Pink medium to fine grained biotite-rich, augen Leucogneiss

[1] Formations do not occur in the Gamsberg area and outcrop further west and north within the other mineralised deposits (SRK, 2010).

Figure 3.11 Stratigraphy (from Black Mountain)

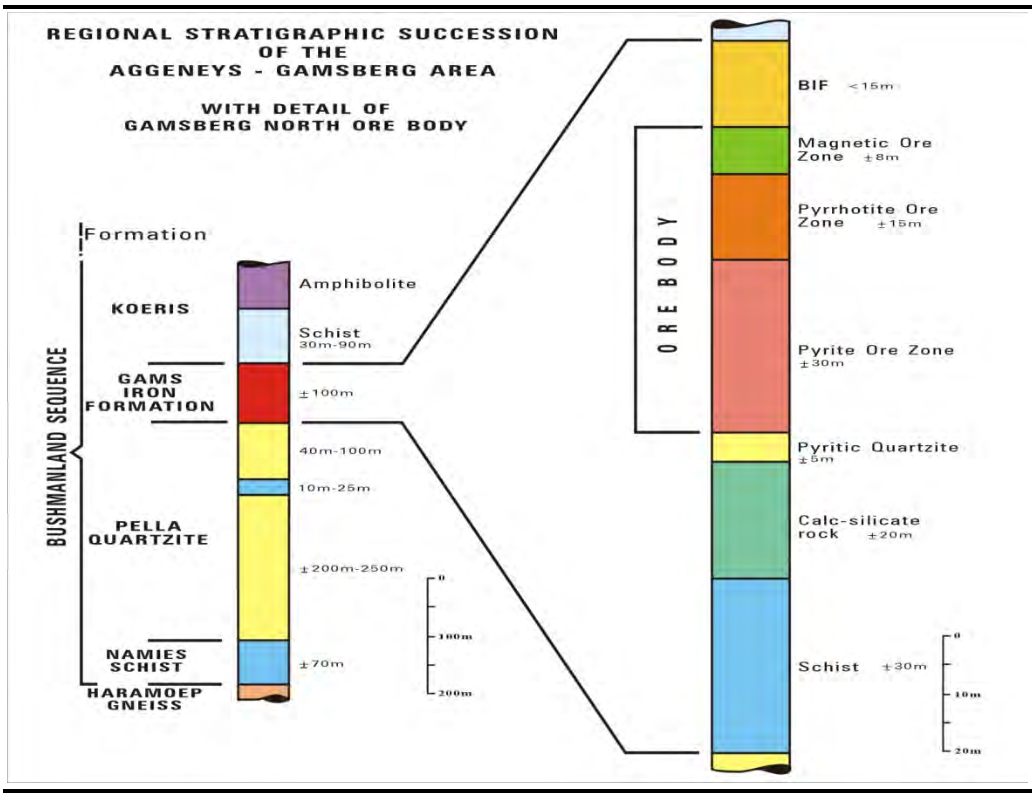


Figure 3.12 Local Geological Map (from Black Moutain)

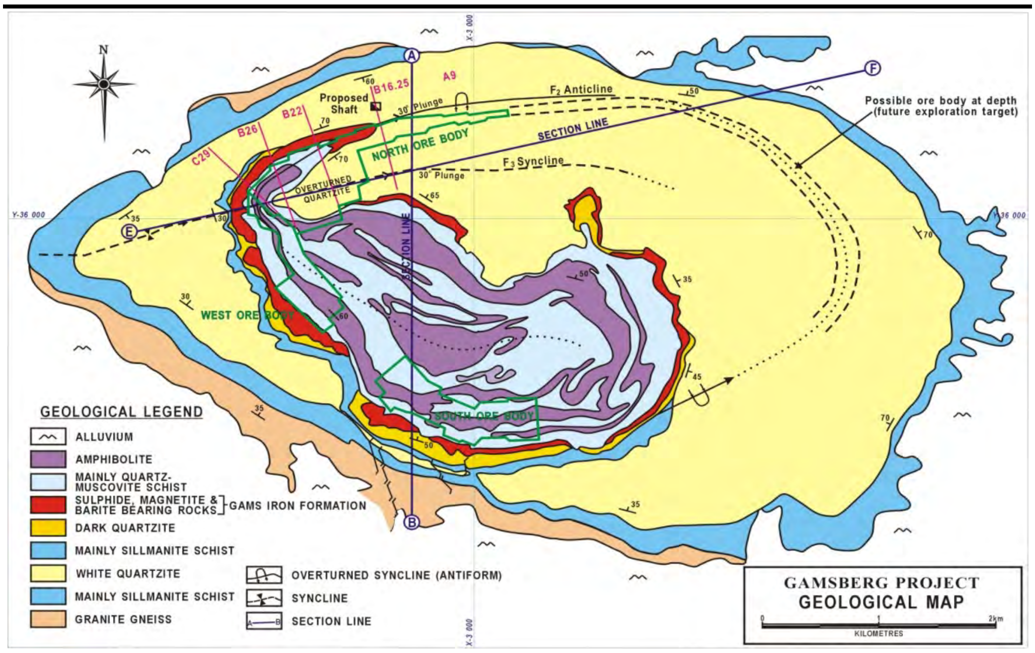


Figure 3.13 Geological Cross Sections over Gamsberg (from Black Mountain)

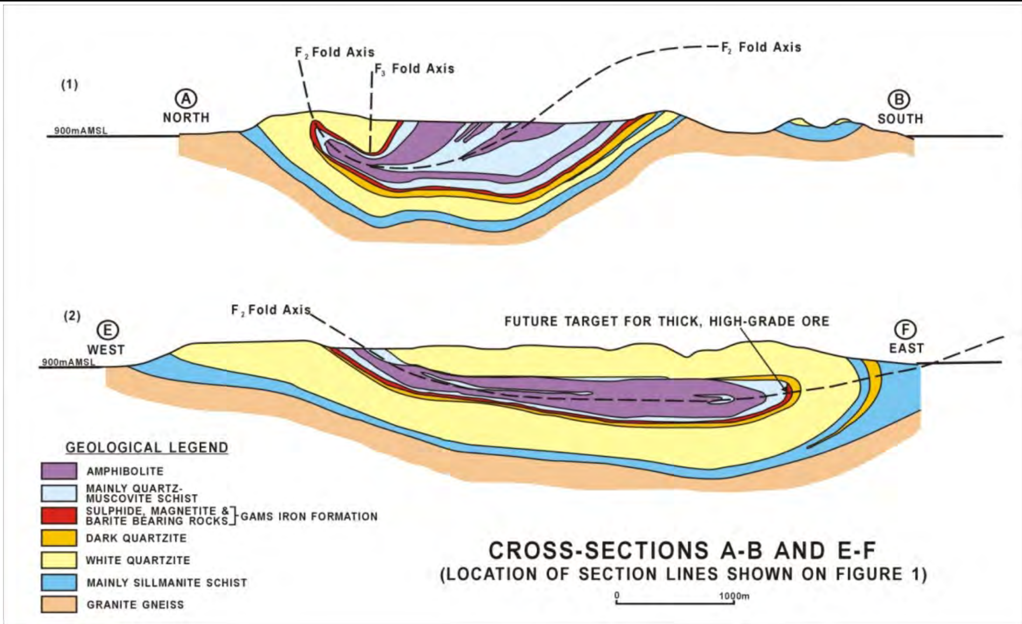
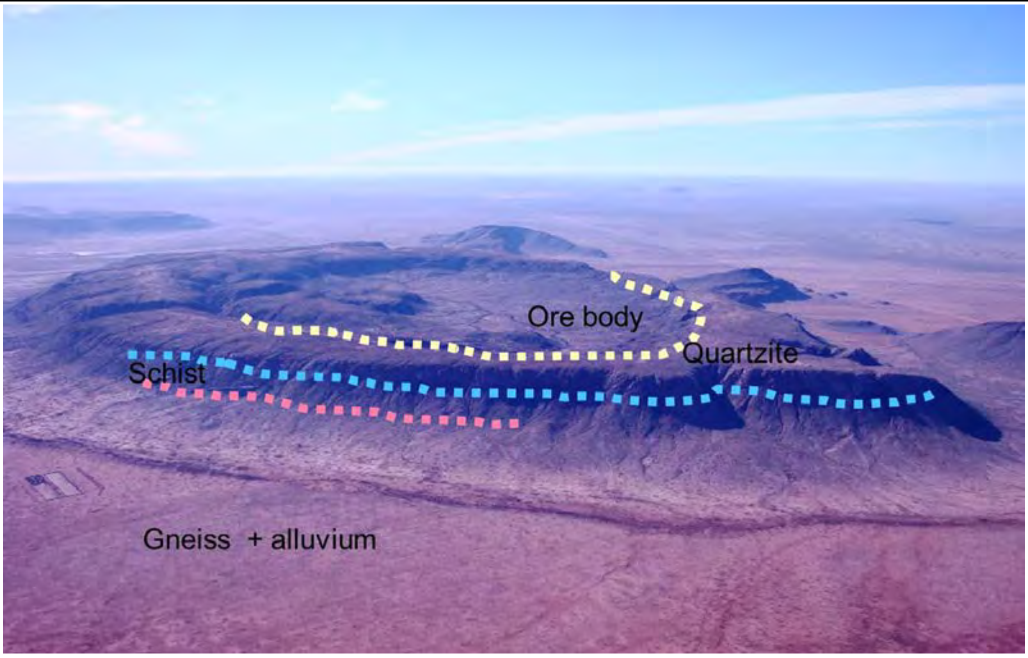


Figure 3.14 Annotated photograph of the North West face of Gamsberg, showing key geological units (photograph from Black Mountain)



3.5.3 Structural Geology

The Bushmansland Terrain shows multi-phase metamorphic and tectonic events, four of which have been identified in the Aggenys – Gamsberg area, and are summarised by SRK (2010). The key structural information relevant to this study can be summarised as:

- The main deformation events resulted in the development of the Gamsberg – a large east trending inclined basin structure with over-folded beds within it, allowing for a doubling up of the thickness of the Pella Quartzite and the Gamsberg Iron Formation (*Figure 3.13*).

- The main deformation events also resulted in the large east- west trending thrust faults at Broken Hill, Aggenys se Berg, and also within Gamsberg (*Figure 3.9* and *Figure 3.10*). The alluvial deposit makes the geological mapping of faults, and their correlation between mountains where they are exposed in outcrops, difficult. Colliston et al (1986), and Strydom et al (1987), extent the Broken Hill trust fault east towards Gamsberg, trending south-east before reaching the inselberg (*Figure 3.9* and *Figure 3.10*). Lineament mapping by SRK (2010), highlights a structure close to the southwest rim of the inselberg. Pump test results from AATS (2000), show one higher yielding borehole also on the southwest of the inselberg (Section 4), which formed the basis for AATS (2000), developing a structurally controlled higher hydraulic conductivity and drainage channel in this location. These two observations could suggest that the Broken Hill thrust extends closer to the Gamsberg inselberg than that mapped by Colliston et al (1986), and Strydom et al (1987).

- Inspection of the outcrops along the south-east of the inselberg (current road access to the inselberg), highlights no major fault within the inselberg wall. The contact from the gneiss to the schist, and from the schist to the quartzite, are deformed by contact thrusts that have generated shear zone material at the contact, and are not considered to be regional water bearing features (pers comm, Mr J Potgieter Black Mountain Mineral Resources Manager, *Figure 3.15*).

- In addition to the larger scale faulting, the multiple phases of deformation have resulted in an extremely folded and fractured environment, evident in the exposed quartzite in the kloof (*Figure 3.16*).

Figure 3.15 Photograph of the thrusted contact between basement gneiss and overlying schist[1], on the southwest wall of Gamsberg inselberg. Pella Quartzite cap rock visible in top right of photograph.

[1]View of schist partly obscured by Pella Quartzite boulders

Figure 3.16 Photograph of fractured white Pella Quartzite in kloof, from top of kloof

4 HYDROGEOLOGY BASELINE

4.1 HYDROCENSUS RESULTS OVERVIEW

The hydrocensus survey was carried out by ERM between 30th August and 8th September 2012.

In total, 42 hydrocensus sites were identified. These included the following:

- 35 boreholes of which 15 were privately owned by farmers and 20 were existing Verdanta-owned monitoring boreholes;
- 3 wells, all privately owned by farmers (well refers to hand dug wells or open holes);
- Four natural springs of which two were located on privately owned land and two springs were located on land owned by Verdanta.

The September 2012 hydrocensus survey results are summarised in *Table 4.1*. This data has been combined with hydrocensus data from all previous studies (AATS (2000), Golders (2007), and SRK (2010)), and with data from Black Mountain, to generate a borehole data inventory, presented in *Table 4.2*, and shown graphically in *Figure 4.1*.

Table 4.1 September 2012 Hydrocensus Survey Results

ID	Latitude	Longitude	Description	Water depth (mbgl)	Depth of hole (mbgl)	Type	Water samples collected
RS1	-29.1537	18.81145	Borehole	NM	NM	Private	Yes
RS2*	-29.14561	18.84222	Borehole	NM	NM	Private	Yes
RS3*	-29.14472	18.84124	Borehole	NM	NM	Private	Yes
RS4	-29.1552	18.88154	Borehole	NM	NM	Private	Yes
RS5	-29.08655	18.91156	Borehole	NM	NM	Private	Yes
RS6	-29.08593	18.9124	Spring	NM	NM	Private	Yes
RS7	-29.11157	18.85755	Borehole	NM	NM	Private	Yes (plus DUP 2)
KGT1	-29.2886	19.06108	Borehole	NM	NM	Private	Yes
KGT2	-29.28803	19.06112	Borehole	NM	NM	Private	Yes
KGT3	-29.29607	19.0735	Borehole	NM	NM	Private	Yes
KGT4	-29.29631	19.07336	Well	NM	NM	Private	Yes
KGT5	-29.3247	19.08273	Borehole	NM	NM	Private	Yes
KGT7	-29.42412	19.02975	Borehole	NM	NM	Private	Yes (plus DUP 1)
KGT8	-29.30538	19.01575	Borehole	NM	NM	Private	Yes
GAMS 2	-29.22713	18.98031	Borehole	NM	NM	Mine	Yes
GAMS 3	-29.25241	18.98299	Borehole	25.65	100+	Mine	Yes (plus DUP 3)
GAMS 4	-29.24893	18.9684	Borehole	15.43	100+	Mine	Yes
GAMS 5	-29.25766	18.9637	Borehole	37.7	100+	Mine	Yes
GAMS 6	-29.25608	18.96474	Borehole	37.09	100+	Mine	Yes
GAMS 7	-29.23132	18.98006	Spring	DRY	-	Mine	No (DRY)
GAMS 8	-29.21529	18.96745	Borehole	44.3	54	Mine	Yes
GAMS 9	-29.25111	19.01113	Spring	-	-	Mine	Yes
GAMS10	-29.23074	19.02155	Borehole	NM	NM	Mine	Yes
AR 1	-29.20106	18.91166	Well	NM	NM	Private	Yes
AR 2	-29.19986	18.91041	Well	4.56	NM	Private	Yes
AR 3	-29.21723	18.90741	Borehole	NM	NM	Private	Yes
AR 4	-29.21636	18.94176	Borehole	42.1	55	Mine	Yes
AR 5	-29.22956	18.92467	Borehole	40.7	53	Mine	Yes
AR 7	-29.19654	18.93952	Borehole	22.3	77	Mine	Yes
AR 8	-29.18588	18.93958	Borehole	20.5	62	Mine	Yes
AR 9	-29.17954	18.95613	Borehole	26.8	62	Mine	Yes

ID	Latitude	Longitude	Description	Water depth (mbgl)	Depth of hole (mbgl)	Type	Water samples collected
AR10	-29.16872	18.95609	Borehole	35.3	61.5	Mine	Yes
AR11	-29.16931	18.94323	Borehole	22.92	61.5	Mine	Yes
AR12	-29.18267	18.95382	Borehole	NM	NM	Mine	Yes
ACH1	-29.26867	19.07354	Spring	-	-	Private	Yes
ACH2	-29.24767	19.04433	Borehole	NM	NM	Private	Yes
BLH1	-29.29483	18.98713	Borehole	NM	NM	Private	Yes
BLH2	-29.27109	18.94107	Borehole	DRY	45	Mine	No (DRY)
BLH3	-29.24851	18.90795	Borehole	52.7	84	Mine	Yes
BLH4	-29.24631	18.92064	Borehole	47.7	53	Mine	Yes (plus DUP4)
AGG1	-29.18801	18.86794	Borehole	NM	NM	Mine	Yes
LUS1	-29.31576	19.01696	Borehole	53.58	100+	Mine	Yes

* Wind pumps RS2 and RS3 pump into the same reservoir. One groundwater sample (RS2+3) collected.

NM Not measured (often due to borehole being capped by pump infrastructure)

mbgl metres below ground level

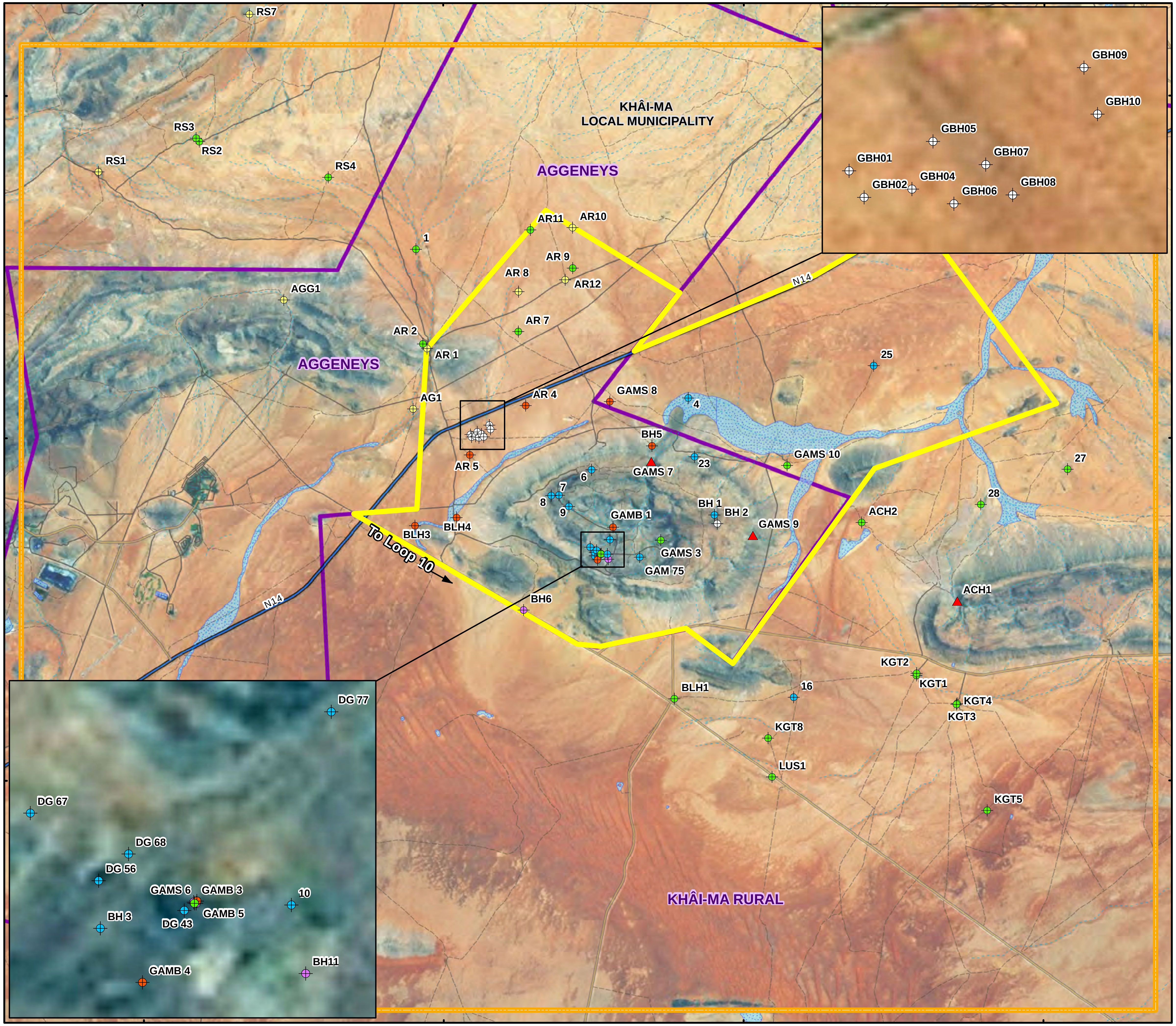
DUP Duplicate sample

Table 4.2 Borehole Data Inventory

ID	Alternate ID	Owner	Farm name	In SRK Hydrocensus	In ERM Hydrocensus	Type	Latitude	Longitude	Altitude	Gamsberg inselberg	Water Level: mbd AATS: Appendix 4	mbgl AATS: G-HMS Table 1,	mbgl AATS: G-HMS Table	mbgl Golder Associates Africa	mbgl SRK pg xi (76)	mbgl SRK - Appendix 2, pg	mbd ERM Hydrocensus	mbd / mgbl RANGE	mbd / mbgl MEAN	mamsl MEAN
ACH1	20	Girrie v/d Heever	Achab	yes	yes	spring	-29.26867	19.07354	921											921.03
ACH2	21	Girrie v/d Heever	Achab	yes	yes	BH	-29.24767	19.04433	901			51.60			51.00			0.60	51.30	849.37
AGG1		Mine			yes	BH	-29.18801	18.86794	934											
AR 1		Tore van Niekerk	Aroam Daddiespoort		yes	Well	-29.20106	18.91166	933											
AR 2	2	Tore van Niekerk	Aroam Daddiespoort		yes	Well	-29.19986	18.91041	928			5.70			3.49		4.00	2.21	4.40	923.64
AG1	3	Tore van Niekerk	Aroam Daddiespoort	yes	yes	BH	-29.21723	18.90741	914											
AR 4	MBH 2	Mine	Ghaamsberg		yes	BH	-29.21636	18.94176	917		50.00	24.01					42.10	25.99	38.70	878.30
AR 5	MBH 3, GBH03	Mine	Ghaamsberg	yes	yes	BH	-29.22956	18.92467	902		43.09	42.97			40.03	40.00	40.70	3.09	41.36	860.64
AR 7	MBH11	Mine			yes	BH	-29.19654	18.93952	939								22.10		22.10	916.90
AR 8	MBH 7	Mine			yes	BH	-29.18588	18.93958	953											
AR 9	MBH 9	Mine			yes	BH	-29.17954	18.95613	953					26.83			26.86	0.03	26.85	926.16
AR10	MBH10	Mine			yes	BH	-29.16872	18.95609	967											
AR11	MBH 8	Mine			yes	BH	-29.16931	18.94323	966								23.92		23.92	942.08
AR12		Mine			yes	BH	-29.18267	18.95382	957											
BH 1		Mine				BH	-29.24563	18.99939	1135	yes				178.70					178.70	956.50
BH 2		Mine				BH	-29.24794	19.00027	1146	yes										
BH 3		Mine				BH	-29.25658	18.96286	1037	yes				34.10					34.10	1003.00
BH5	GAMS2, 5	Mine	Ghaamsberg	yes	yes	BH	-29.22713	18.98031	919		9.44	9.68			8.56			1.12	9.23	909.47
BH6	BLH2, MBH 6	Mine	Loop 10 road	yes	yes	BH	-29.27109	18.94107	868		44.00	dry							44.00	824.05
BH11	11	Mine				BH	-29.25748	18.96696	1045	yes		52.73							52.73	992.27
BLH1	14, 13, (12)	Mine	Blomhoek	yes	yes	BH	-29.29483	18.98713	875			50.18	47.14		41.33	43.00		8.85	45.41	829.92
BLH3	MBH 5	Mine			yes	BH	-29.24851	18.90795	876			54.09		52.62			52.70	1.47	53.14	822.36
BLH4	MBH 4	Mine			yes	BH	-29.24631	18.92064	887		50.48	41.12					47.70	9.36	46.43	840.57
DG 43		Mine				BH	-29.25622	18.96454	1033	yes				26.37					26.37	1006.47
DG 56		Mine				BH	-29.25563	18.96283	1041	yes				34.10					34.10	1007.01
DG 67		Mine				BH	-29.25428	18.96146	1033	yes				31.01					31.01	1002.46
DG 68		Mine				BH	-29.25510	18.96342	1037	yes				31.63					31.63	1005.02
DG 77		Mine				BH	-29.25226	18.96747	1013	yes				21.15					21.15	991.76
GAM 75		Mine				BH	-29.25695	18.97658	1015	yes				26.93					26.93	988.29
GAMB 1	GAMS4	Mine	Gamsberg	yes	yes	BH	-29.24893	18.96840	1002	yes			15.65	14.16	13.79	16.00	15.43	2.21	15.01	987.29
GAMB 2		Mine				BH	-29.25606	18.96472	1032					34.93					34.93	997.12
GAMB 3		Mine				BH	-29.25608	18.96477	1032	yes				33.35					33.35	998.95
GAMB 4	GAMS 5	Mine	Gamsberg	yes	yes	BH	-29.25766	18.96370	1045	yes				37.64	36.85		37.70	0.85	37.40	1007.40
GAMB 5		Mine				BH	-29.25603	18.96479	1033	yes				34.65					34.65	998.25
GAMS 3	K 1	Mine	Gamsberg	yes	yes	BH	-29.25241	18.98299	1015	yes				24.85	25.00		25.65	0.80	25.17	990.08
GAMS 6		Mine	Gamsberg	yes	yes	BH	-29.25608	18.96474	1031	yes				37.32	34.11		37.09	3.21	36.17	994.60
GAMS 7		Mine	Gamsberg	yes	yes	Spring	-29.23132	18.98006	923											922.95
GAMS 8	MBH1	Mine	Gamsberg	yes	yes	BH	-29.21529	18.96745	920			40.19				44.00	44.30	4.11	42.83	877.12
GAMS 9	22	Mine	Gamsberg	yes	yes	Spring	-29.25111	19.01113	912											912.00
GAMS 10	24	Mine				BH	-29.23240	19.02154	868			34.10							34.10	833.90
GBH01		Mine	Gamsberg	yes		BH	-29.22410	18.92492	846											
GBH02		Mine	Gamsberg	yes		BH	-29.22475	18.92529	908											
GBH04		Mine	Gamsberg	yes		BH	-29.22455	18.92646	842											
GBH05		Mine	Gamsberg	yes		BH	-29.22338	18.92698	852											
GBH06		Mine	Gamsberg	yes		BH	-29.22491	18.92749	961											
GBH07		Mine	Gamsberg	yes		BH	-29.22395	18.92827	907											
GBH08		Mine	Gamsberg	yes		BH	-29.22469	18.92893	911											
GBH09		Mine	Gamsberg	yes		BH	-29.22157	18.93068	850											
GBH10		Mine	Gamsberg	yes		BH	-29.22271	18.93101	907											
KGT1		Jan Visser	Kykgat	yes	yes	BH	-29.28860	19.06108	922											
KGT2	17	Jan Visser	Kykgat	yes	yes	BH	-29.28803	19.06112	926			27.52							27.52	898.48
KGT3	18	Jan Visser	Kykgat	yes	yes	BH	-29.29607	19.07350	934			36.99							36.99	896.96
KGT4		Jan Visser	Kykgat	yes	yes	Well	-29.29631	19.07336	934						29.36				29.36	904.31
KGT5	19	Jan Visser	Kykgat	yes	yes	BH	-29.32470	19.08273	943			76.90							76.90	866.15
KGT7		Jan Visser	Kykgat	yes	yes	BH	-29.42412	19.02975	843											
KGT8	15	Jan Visser	Kykgat	yes	yes	BH	-29.30538	19.01575	907			49.28							49.28	857.27
LUS1		Mine	Loop 10 Road	yes	yes	BH	-29.31576	19.01696	905								53.58		53.58	851.42
RS1		Danie Luttig	Rosynebos	yes	yes	BH	-29.15370	18.81145	983											
RS2		Danie Luttig	Rosynebos	yes	yes	BH	-29.14561	18.84222	987						26.59				26.59	960.71
RS3		Danie Luttig	Rosynebos	yes	yes	BH	-29.14472	18.84124	987						42.19				42.19	945.11
RS4		Danie Luttig	Rosynebos	yes	yes	BH	-29.15520	18.88154	971						21.07				21.07	950.23
RS5		Sakkie v Niekerk	Rosynebos	yes	yes	Spring	-29.08655	18.91156	865						0.80					
RS6		Sakkie v Niekerk	Rosynebos	yes	yes	Spring	-29.08593	18.91240	865											
RS7		Sakkie v Niekerk	Rosynebos	yes	yes	BH	-29.11157	18.85755	950											
1		Mine				BH	-29.17451	18.90833	951			22.25							22.25	928.75
4		Mine				BH	-29.21436	18.99143	899			41.40							41.40	857.60
6		Mine				BH	-29.23355	18.96184	1122	yes		123.60							123.60	998.40
7		Mine				BH	-29.24035	18.95191	1041	yes		53.84							53.84	987.16
8		Mine				BH	-29.24045	18.94958	1050	yes		64.15							64.15	985.85
9		Mine				BH	-29.24339	18.95496	1031	yes		44.47							44.47	986.53
10		Mine				BH	-29.25611	18.96668	1032	yes		46.71							46.71	985.29
16		Mine				BH	-29.29446	19.02361	910			45.82							45.82	864.18
23		Mine				BH	-29.23007	18.99330	905			16.50							16.50	888.50
25		Mine				BH	-29.20566	19.04801	889			46.57							46.57	842.43
27		Mine				BH	-29.23337	19.10716	888			55.10							55.10	832.90
28		Mine				BH	-29.24280	19.08072	853			19.60							19.60	833.40
																	MEDIAN		36.17	
																	MAX		178.70	
																	MIN		4.40	

ID	Geology: Geol Log AATS	Depth SRK	Depth ERM	Abstraction Volume (m³/a): SRK - Map, pg 32	SRK - Appendix 1, pg xi	Use type: SRK - Map, pg 32	SRK - Appendix1, pg xi	ERM	Pump tests: AATS Appendix 4	Golder	SRK 04/2009 EC @ 25°C (mS/m)	pH @ 20°C	05/2009 EC @ 25°C (mS/m)	pH @ 20°C	08/2009 EC @ 25°C (mS/m)	pH @ 20°C	17&18/08/2009 EC (mS/m)	pH	Date unknown EC	pH	ERM Hydrocensus Results: EC (mS/m)	Temp FIELD	pH FIELD	MEAN: EC (mS/m)	pH
ACH1				10000-18250	15 768	domestic/livestock	domestic/livestock						30.8	6.4	32.4	6.4	37.3	5.8	29	6.93				32.375	6.4
ACH2		60		500-1000	900	livestock	livestock						30.7	6.3					239	7.54				134.85	6.9
AGG1																									
AR 1				1000-2500	1 800	livestock	livestock						660	8	660	8.4	0.6	8.18	584	7.33				476.15	8.0
AR 2						not used	not used														1776	20.8	7.41		
AG1				1000-2500	1 200	livestock	livestock				129	8.2	114	8.4	150	8.5	147.5	7.53	120	8.45				132.1	8.2
AR 4	yes		55						2												111	23.7	7.62		
AR 5	yes		53			Monitoring			2				208	8	199	7.7	20	7.64			212	24.2	7.59	142.3333	7.8
AR 7	yes																				170	22.3	7.3		
AR 8	yes																				362	24.4	7.46		
AR 9	yes					Monitoring															269	24	7.32		
AR10	yes																				235	24.4	7.16		
AR11	yes																				237	24.9	7.81		
AR12																					356	18.4	8.36		
BH 1																									
BH 2																									
BH 3																									
BH5				1000-2500	18 250	Drilling Water	drilling	No loner used	1				35.6	6.2	26.8	8	34.2	7.51	28	8.28				31.15	7.5
BH6	yes					not used			2																
BH11									5																
BLH1				1000-2500	1 900	livestock	livestock				182	8.3	171	8	185	7.9	192.5	7.53	176	7.36				181.3	7.8
BLH3	yes		84																		130	24.2	7.76		
BLH4	yes		53						2												102	24.2	7.43		
DG 43																									
DG 56																									
DG 67																									
DG 68																									
DG 77																									
GAM 75																									
GAMB 1			100+			not used		Strong borehole previ		yes			114	7.4	114	7.2	123.3	6.85	111	7.16	103	24.1	7.12	115.575	7.2
GAMB 2										yes															
GAMB 3										yes															
GAMB 4			100+			not used				yes									71	6.15	80	23.5	6.94	71	6.2
GAMB 5										yes															
GAMS 3			100+	1000-2500	1 800	Domestic					114	7.6							113	7.5	115	24	7.08	113.5	7.6
GAMS 6			100+	1000-2500	1 200	Drilling Water													93	7.06	82	24.1	6.06	93	7.1
GAMS 7				1000-2500	6 307	Monitoring									16.1	6.6	21	7.14						18.55	6.9
GAMS 8	yes		54			Monitoring			3				145	7.4	124	7.3	144.5	6.63			120	23.6	7.32	137.8333	7.1
GAMS 9					3 154		not used/livest	Damed by boulder dam					105	7.3	104	6.8	116	6.44						108.3333	6.8
GAMS 10																									
GBH01																									
GBH02																									
GBH04																									
GBH05																									
GBH06																									
GBH07																									
GBH08																									
GBH09																									
GBH10						livestock																			
KGT1		31		500-1000	1 900	Domestic	livestock												176	7.18				176	7.2
KGT2				500-1000	900	Domestic	domestic				204	8.0							200	7.44				202	7.7
KGT3					500		domestic, livestock																		
KGT4		29.4		1000-2500	1 200	Domestic/livestock	domestic, livestock												174	7.25				174	7.3
KGT5				1000-2500	1 200	livestock	livestock												265	7.3				265	7.3
KGT7					1 200		livestock												142	7.46				142	7.5
KGT8				1000-2500	1 200	livestock	livestock												1245	7.54				1245	7.5
LUS1			100+			not used															148	22.4	7.67		
RS1				1000-2500	1 200	livestock	livestock												76	8.27				76	8.3
RS2				1000-2500	1 200	Domestic/livestock	domestic,livestock												142	7.4				142	7.4
RS3				1000-2500	900	livestock	livestock				133	7.8							131	7.55				132	7.7
RS4				1000-2500	1 200	livestock	livestock												116	8.4				116	8.4
RS5					3 154		domestic,livestock												93	7.2				93	7.2
RS6					6 307		domestic,livestock												96	7.16				96	7.2
RS7					900		livestock												142	7.35				142	7.4
1																									
4																									
6																									
7																									
8																									
9																									
10																									
16																									
23																									
25																									
27																									
28																									
				SUM	75 240																				
				SUM minus unus	53 836																				

Supporting Notes:
Boreholes 1- 28: from AATS report. Assumed to be mine owned monitoring holes
Altitude: in order of preference altitude uses Golder Survey data, or Golder/ SRK GPS data if survey not avaiable, and DEM data where nothing else available
mbgl = metres below ground level
mbd = metres below datum



Legend

Borehole and Spring Inventory

- Water Level - Borehole
- Chemistry - Borehole
- Water Level, Pump test -- Borehole
- Water Level, Chemistry - Borehole
- Water Level, Chemistry, Pump test - Borehole
- No Data - Borehole
- Water Level, Chemistry -Springs

- National Route
- Main Road
- Secondary Road
- Other Road
- Track/Footpath

- Ephemeral Rivers

- Mineral Rights Boundary
- Groundwater Domain Model
- Town Boundary

- Flood Plains

SCALE:

0 1 2 3 4 5 6

Kilometres

N

TITLE:

Figure: 4.1 Borehole Inventory Map

CLIENT:

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DATE:Jan 2013	CHECKED: MP	PROJECT: 0164903
DRAWN: AT	APPROVED: SHC	SCALE: 1 : 110 000

DRAWING: BH_inventory_Map_Rev2.mxd

REV: 0

ERM
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Silverwood Close
Steenberg Office Park, 7945
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Tel: +27 (0)21 702 9100
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ERM

Projection: Transverse Mecator, CM19. Datum : WGS84
Source: Chief Directorate National Geo-Spatial
Information. ERM 2013
Inset Map: Esri Data & Maps

SIZE: A3

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4.2 *REGIONAL HYDROGEOLGY AND HYDROSTRATIGRAPHY*

Because of the limited thickness of the alluvial cover and the hard rock nature of all other rocks in the area, no regional-scale aquifers transmitting water over large scales have developed in the Namaqualand Metamorphic Complex (Vegter, 2006).

The geological units of hydrogeological interest in the study area are all those in and around Gamsberg: the basement Haramoep gneiss and alluvial cover on the plains, the Namies schist, the Pella Quartzite and the Gamsberg Iron Formation (*Section 3.5.2*).

Some groundwater movement will occur in the primary permeability of the alluvium around Gamsberg. The remaining units – the highly fractured and weathered hard rock terrains, will provide secondary permeability aquifers, albeit with low productivity. Vegter (2006) assessed the properties of 115 boreholes drilled across a larger region including Gamsberg. As drillers logs available did not differentiate between the variety of metamorphic and intrusive rock types present, no attempt was made to differentiate their hydrogeology. However, the results are nonetheless useful for general characteristics of the hard rock formations. The borehole data was analysed for depth, water level, yield, water strikes, and relationships between these parameters. Although the borehole data inventory for Gasmberg has some of this information (*Table 4.2*), there are very few boreholes with each parameter available. Key observations on the data can be summarised as:

- Out of 115 boreholes, the depths ranged from 10 – 152 m. The median depth was 68 m.
- Forty one boreholes (36%) yielded greater than 0.1 l/s, 8 boreholes (7%) yielded greater than 1 l/s, one borehole (<1%) yielded greater than 10 l/s.
- Water levels ranged from 2 to 72 mbgl, with the median depth at 20 mbgl.
- The distribution of water strikes with depth shows a large range from 10 to 113 m, and shows a fairly flat distribution over depth (ie no decrease in water strikes with depth). Boreholes even above 90 m, and boreholes at 110 – 114 m, also encountered water strikes, indicating open water-bearing fractures at depth.

Vegter (2006) summarises that weathering as a primary agent in producing or enhancing secondary porosity is of importance where the water levels are less than around 30 mbgl, and that water can be struck in fractured fresh rock below the weathered zone and not at the transition between weathered zone and fresh rock, as in higher rainfall areas. Although both AATS (2000), and SRK (2010), reference larger scale faults and lineaments, and their degree of connectivity as having a dominant control on water movement, Vegter (2006), suggests the larger regional faults and lineaments are not water bearing as most fault cores in the area consist of impermeable rock. Nevertheless, increased fracturing in the damage zone around fault cores is likely to increase permeability.

The primary control on permeability is taken as depth from surface, controlled by structures and weathering, rather than rock type, with the understanding that un-weathered units at depth can also be water bearing, and that major faults will increase water flow.

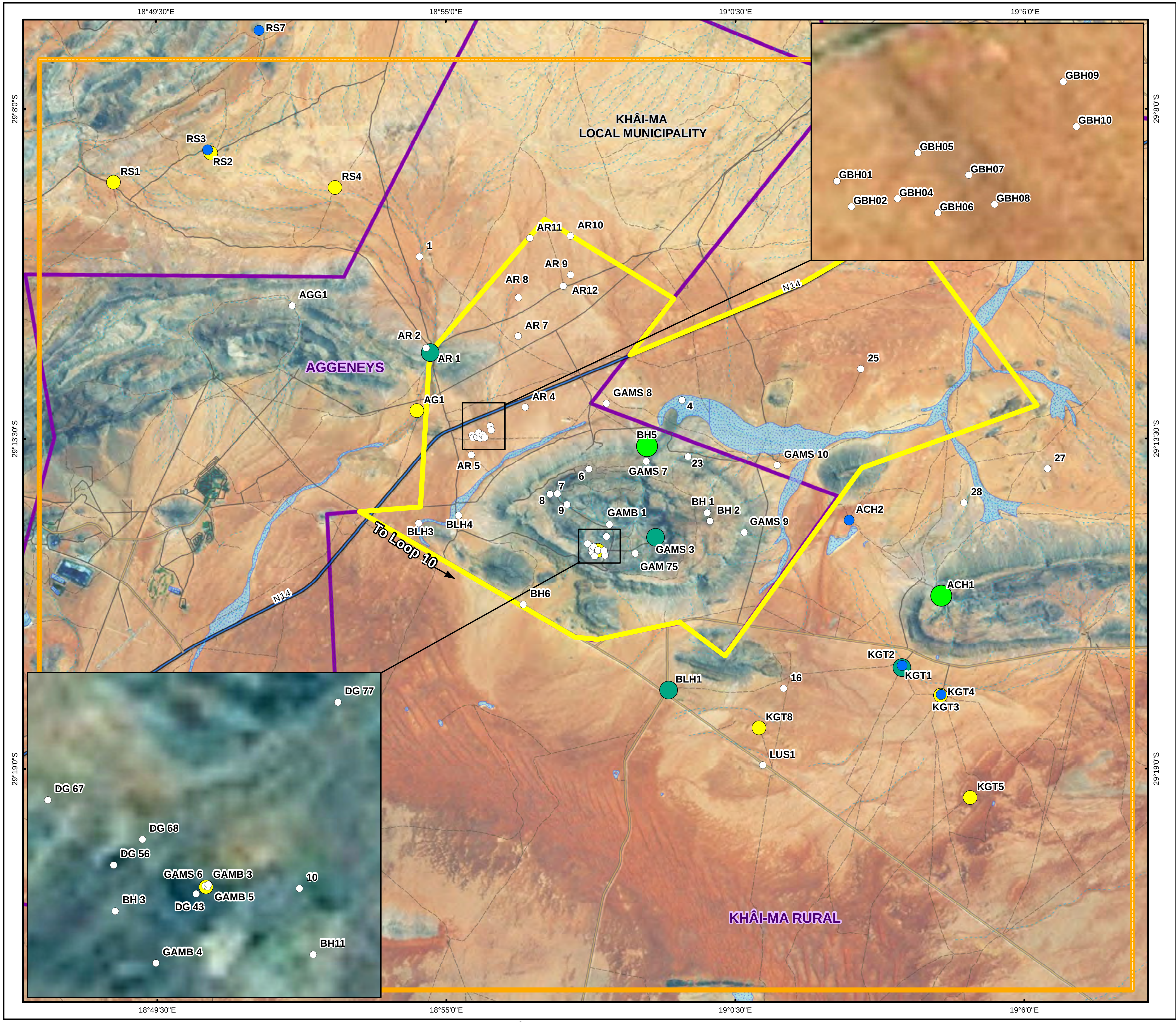
The importance of the weathered zone on rocks that would otherwise be considered impermeable is also highlighted by Kenhardt's municipal water supply (150 km east), which is obtained from alluvium and weathered and fractured gneiss and schist, in the valley of Driekop se Rivier (Vegter, 2006).

4.3 EXISTING GROUNDWATER USE

The extent of local groundwater use in the vicinity of Gamsberg is presented in *Table 4.2* and based on measurements by SRK (2010) (see columns 'abstraction volume' and 'use type'). Private boreholes are used for either domestic or livestock watering, and are equipped with wind pumps. The average borehole abstraction rate is 1 160 m^3/a, or 0.04 l/s. Three springs on private land are recorded as being utilised for abstraction, and their abstraction rates range from 3 154 to 15 768 m^3/a, or 0.1 to 0.5 l/s.

Some mine-owned boreholes have been previously used for drilling water, but are no longer in use (*Table 4.2*). Based on this updated information, the total groundwater abstracted from boreholes and springs in the area is ± 54 000 m^3/a. This however excludes groundwater abstracted in the adits, the volume of which it is not possible to estimate (*Section 4.8*)

The distribution of pumped boreholes is shown in *Figure 4.2*.



Legend

Borehole Abstraction Rates (m³/annum)

- No Data
- < 900.00
- 900.01 - 1200.00
- 1200.01 - 1900.00
- 1900.01 - 18250.00

- National Route
- Main Road
- Secondary Road
- Other Road
- Track/Footpath
- Ephemeral Rivers
- Mineral Rights Boundary
- Groundwater Domain Model
- Town Boundary
- Flood Plains

SCALE:
0 1 2 3 4 5 6
Kilometres
N

TITLE:

Figure: 4.2 Groundwater Abstraction Volumes

CLIENT:

vedanta

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DATE:Jan 2013	CHECKED: MP	PROJECT: 0164903
DRAWN: AT	APPROVED: SHC	SCALE: 1 : 110 000

DRAWING: BH_Abstraction_Map_Rev2.mxd

REV: 0

ERM
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Silverwood Close
Steenberg Office Park, 7945
Cape Town, SOUTH AFRICA
Tel: +27 (0)21 702 9100
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Projection: Transverse Mecator, CM19. Datum : WGS84
Source: Chief Directorate National Geo-Spatial
Information. ERM 2013
Inset Map: Esri Data & Maps

SIZE: A3

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4.4 *GROUNDWATER LEVELS*

The borehole inventory (*Table 4.2*) collates all available data, however often this is incomplete. For example, the date of previous water levels is not known, and whether these were taken in metres below ground level, or more likely as metres below datum (and datum being the borehole collar). At the regional scale of this study, the potential error this would generate in the water levels is insignificant. The water level data have been averaged per borehole, rather than only use one time set of data, to provide a larger dataset as a good distribution of water levels is required. Water levels from one time period are therefore compared to water levels averaged from many times, for example, GAMB1 has 5 measurements ranging from 13.79 mbgl to 16.0 mbgl, compared with GAMB2 which has one measurement only (*Table 4.2*). The boreholes with one measurement may not sit central to the range of those with more than one measurement hence this doesn't compare like with like. The potential error induced in this is also assumed small based on the regional scale of the study based on the range of measurements: 14 boreholes have more than one measurement and 11 of these show a range of water levels less than 4.5 m, two of these show a range 5-10 m, and one outlier (AR4) has a range greater than 25 m. There is also little insight captured into whether a previous measurement was taken whilst or soon after a borehole had pumped.

The median depth to water, as shown in *Table 4.2*, is 36 m, with a range of 4.4 to a maximum of 178.8 m. The frequency distribution shows that most boreholes have water depth ranging from 20 – 50 m, and up to 60 m deep, which applies to boreholes on the inselberg and those on the plains (*Figure 4.3*). Two outliers with water levels deeper (lower mamsl) than would be expected for their altitude exist on the inselberg. These may be impacted by draining of the highest water levels in the quartzite, by the existing mining activities (see *Section 4.8*).

SRK (2010) presented a graph of water level compared to topography, with an extremely strong correlation coefficient of 0.96. Presenting this graph for all water level data taken to date, the correlation remains strong at an R^2 value of 0.84 (*Figure 4.4*). The two outliers with deep water levels (>120 m), are boreholes 6 and BH1 with altitudes of 1122 m and 1135 m respectively, measured once each by AATS (2000) and Golders (2007) respectively. These are the highest elevation boreholes in the record, within the quartzite rim of the inselberg. Removing the two outliers from this data set adjusts the R^2 value of correlation between topography and water level to 0.93.

Based on this correlation, topography is clearly a dominant control on the water level and therefore groundwater flow direction. A piezometric map generated through automated interpolation is presented in *Figure 4.5*. As this is based on all available data (the averaged water levels at each point), the contours stop at the edge of an area generated by points with water level data.

A clear trend is visible, also presented by SRK (2010) with higher water levels in the inselberg compared to the plains.

The piezometric map has been adjusted manually to reflect conceptual interpretation of the groundwater flow regime, and is presented in *Figure 4.6* (manual adjustments are dashed contours). This shows:

- Groundwater flowing radially outwards from the inselberg towards the plains with the surface drainage controlling groundwater flow towards the northeast;
- groundwater flows with higher hydraulic gradient around the inselberg, and significantly lower gradient in the plains; and
- two flow divides exist to the northwest of gamsberg and to the southeast, due to the influence of the Aggenys Berg and the Achab se Berge respectively.

Further discussion of the groundwater flow regime is given in *Section 5*.

Figure 4.3 ***Graph showing frequency distribution of depth to groundwater in all boreholes with water level data***

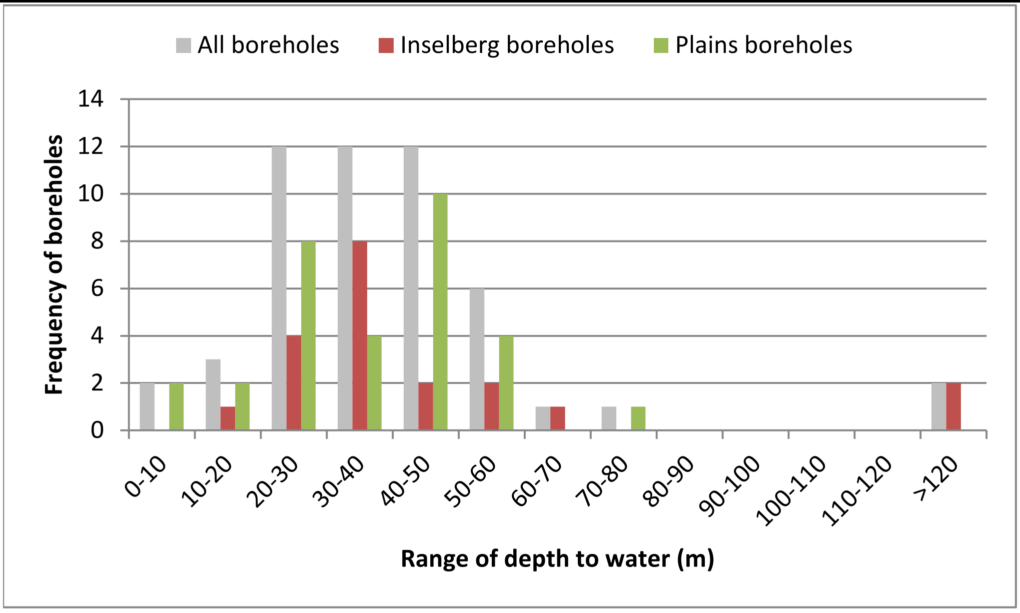
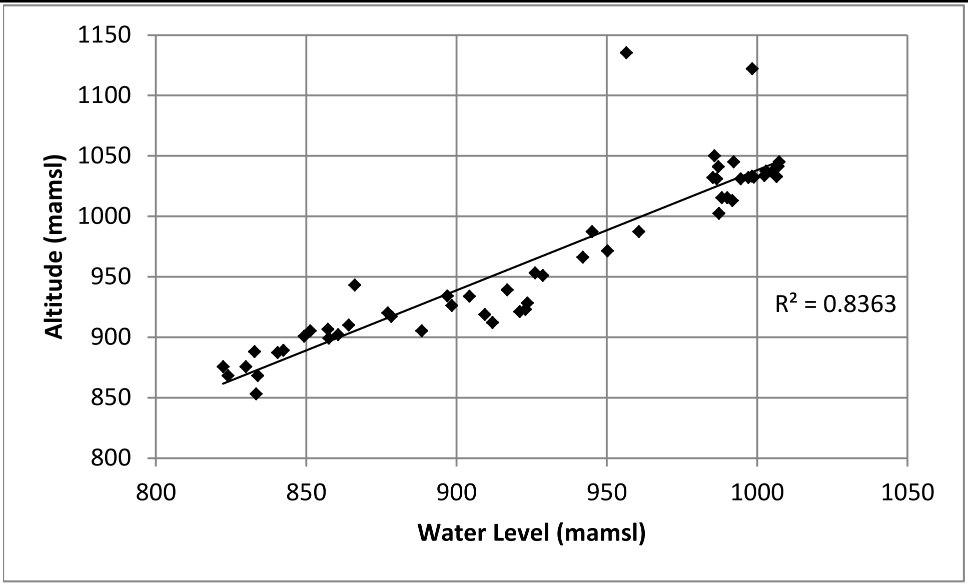
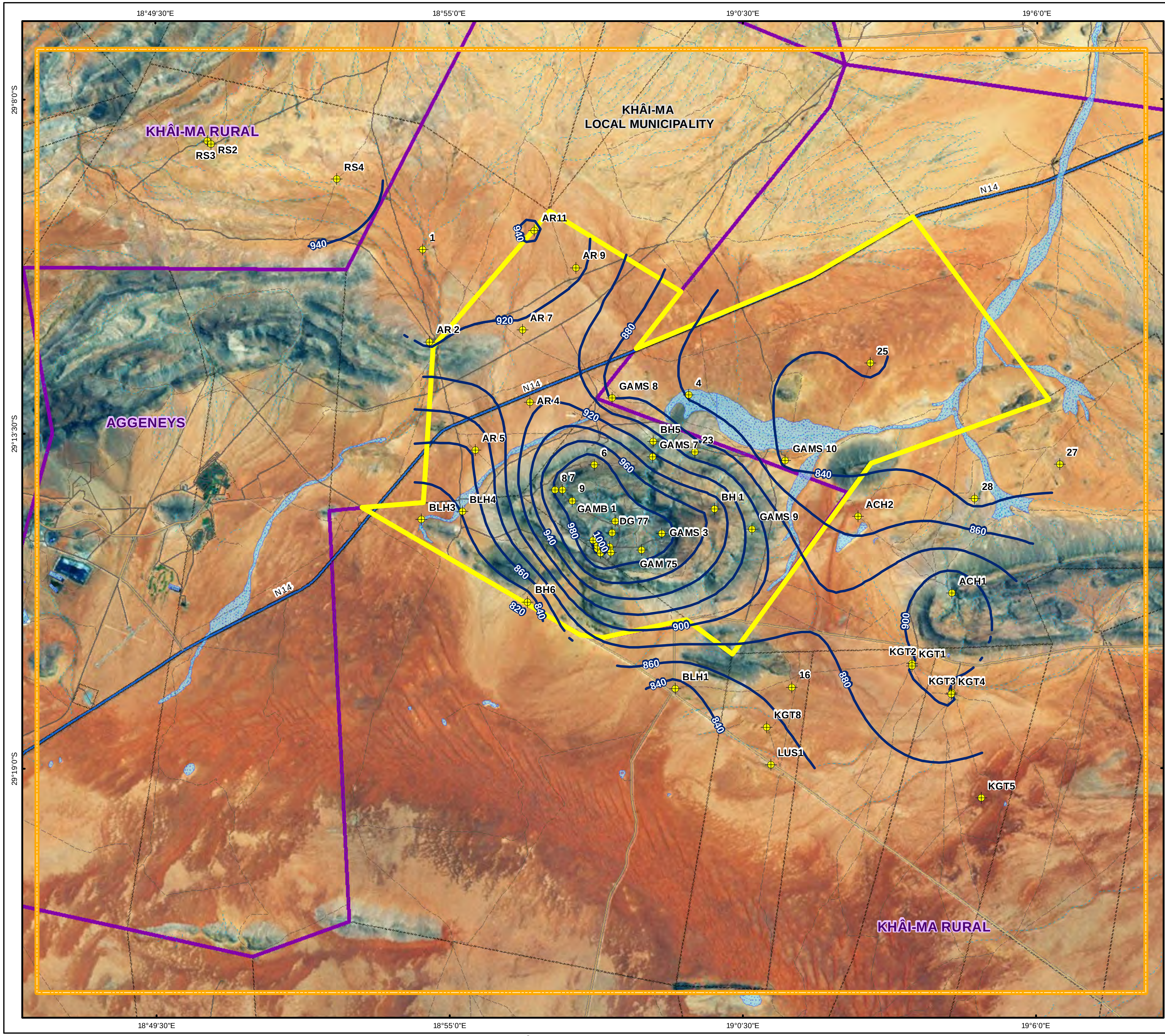


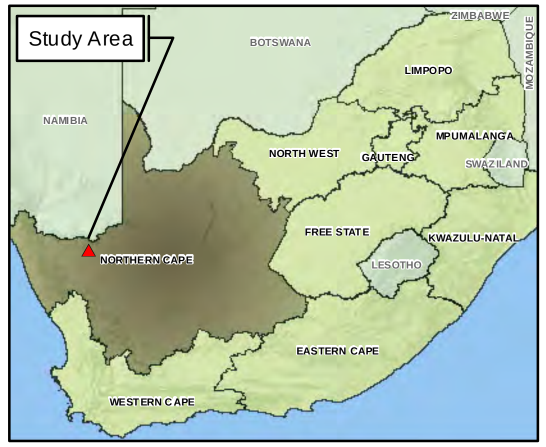
Figure 4.4 Graph of Water Levels Compared to Topography





Legend

- Boreholes (Water Levels)
- Interpolated Groundwater Contours
- National Route
- Main Road
- Secondary Road
- Other Road
- Track/Footpath
- Ephemeral Rivers
- Mineral Rights Boundary
- Groundwater Domain Model
- Town Boundary
- Flood Plains



SCALE:
0 1 2 3 4 5 6
Kilometres
N

TITLE:

Figure: 4.3: Piezometric map - based on all data

CLIENT:

vedanta

BLACK MOUNTAIN MINING (PTY) LTD

DATE:Jan 2013	CHECKED: MP	PROJECT: 0164903
DRAWN: AT	APPROVED: SHC	SCALE: 1 : 80 000

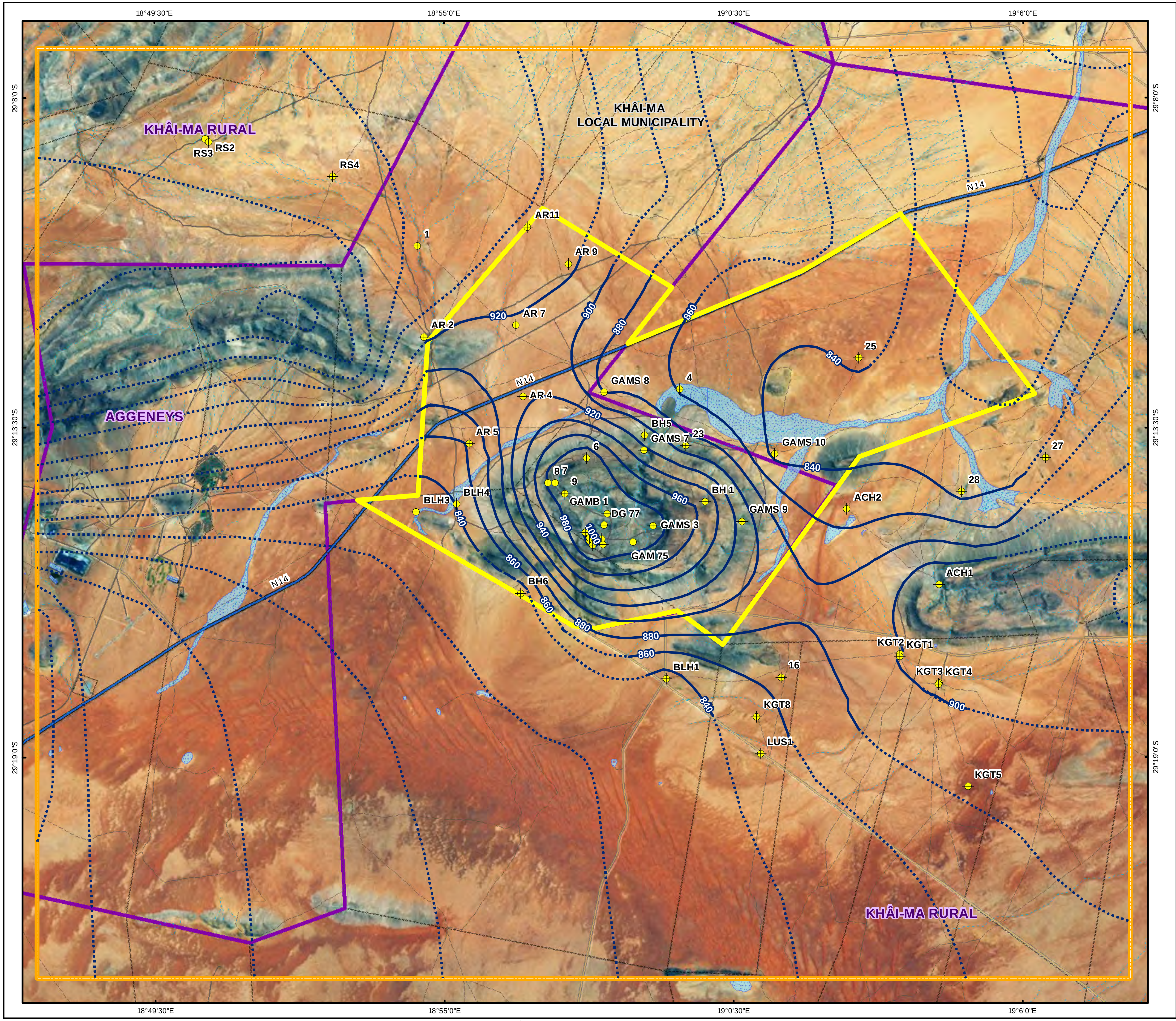
DRAWING:	REV:
Water_Levels_Interpolation_Rev2	0

ERM
Block A, Silverwood House
Silverwood Close
Steenberg Office Park, 7945
Cape Town, SOUTH AFRICA
Tel: +27 (0)21 702 9100
Fax +27 (0)21 701 7900

ERM

Projection: Transverse Mecator, CM19. Datum : WGS84 Source: Chief Directorate National Geo-Spatial 2918BD_2003_ED2_GEO.TIF Inset Map: Esri Data & Maps	SIZE: A3

C:\Users\Dell4\Documents\Thurlow Mapping\PRIVATE WORK\ERM\CONTRACT\GIS\0164903_GAMSBERG\MXD\MXD_REV2\Water_Levels_Interpolation_Rev2



Legend

- Boreholes (Water Levels)
- Intepolated Groundwater Contours
- Conceptual Groundwater Contours
- National Route
- Main Road
- Secondary Road
- Other Road
- Track/Footpath
- Ephemeral Rivers
- Mineral Rights Boundary
- Groundwater Domain Model
- Town Boundary
- Flood Plains

Study Area

SCALE: 0 1 2 3 4 5 6 Kilometres

N

TITLE:

Figure: 4.4: Piezometric map - conceptual

CLIENT:

vedanta

BLACK MOUNTAIN MINING (PTY) LTD

DATE:Jan 2013	CHECKED: MP	PROJECT: 0164903
DRAWN: AT	APPROVED: SHC	SCALE: 1 : 80 000

DRAWING: Water_Levels_Conceptual_Rev2.mxd

REV: 0

ERM
Block A, Silverwood House
Silverwood Close
Steenberg Office Park, 7945
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Tel: +27 (0)21 702 9100
Fax +27 (0)21 701 7900

Projection: Transverse Mecator, CM19. Datum : WGS84
Source: Chief Directorate National Geo-Spatial
2918BD_2003_ED2_GEO.TIF
Inset Map: Esri Data & Maps

SIZE: A3

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4.5 *HYDRAULIC PROPERTIES AND AQUIFER CHARACTERISATION*

All previous hydraulic tests are summarised in *Table 4.3* below. The position of boreholes which underwent hydraulic tests are also marked in *Figure 4.1*, and referenced in *Table 4.2*. A total of 14 boreholes have undergone hydraulic tests and as geological logs are often not available, the geology is assumed to be the surface geology at the borehole. Observations from *Table 4.3* are:

- hydraulic conductivity results in the gneiss range over one order of magnitude; 1E-04 to 4E-03 m/d
- hydraulic conductivity results in the schist range over three orders of magnitude; 4E-03 to 5E+00 m/d
- hydraulic conductivity results in the quartzite range over one order of magnitude; 6E-01 to 6E+00 m/d

The quartzite presents the highest hydraulic conductivity material, closely followed by the schist. However, the number of tests are small, and local structural heterogeneities influence individual tests and may render the test non applicable to the unit across the entire area of interest. For example, boreholes GAMB3 and GAMB4, both presenting in the upper range of measured values, are clustered inside the southern rim of the inselberg, and proposed to be located around southeast-northwest trending structural controls (pers comm Mr J Potgieter Black Mountain Mineral Resources Manager). Also, slug tests and lugeon are tests in which only a small stress is applied to the aquifer, hence they only measure a small radius of aquifer close to the borehole, and it is difficult to take these are representative for the entire area. The constant discharge tests, highlighted in *Table 4.3* below, are considered more representative.

The hydraulic conductivity calibrated in numerical modelling by AATS (2000), is shown in *Figure 4.7*. The hydraulic conductivities are summarised as:

- the inner areas of the inselberg (assumed equivalent to the Gamsberg Iron Formation) has 1E-05 m/d
- the outer areas of the inselberg (assumed equivalent to Pella Quartzite and Schist grouped) has 3E-05 m/d
- the plains (assumed equivalent to alluvium and gneiss grouped) has 1E-03 m/d
- structurally controlled preferential drainage lines are set at 4E-01 m/d and 1E+00 m/d

The AATS modelled values are a similar range of orders of magnitude to the pump tests, however individual units differ greatly. The calibrated conductivity for the quartzite areas for example is 3E-05 m/d compared to the measured range of 6E-01 to 6E+00 m/d. This difference is expected given the reasons above that pump tests measure a small radius close to the borehole. Modelled conductivities are not proposed as those that would be found at an individual site, but those that represent and equivalent hydraulic conductivity over the region it is applied to.

Carrying out additional pump tests in this study, and even for longer duration, was not considered necessary, as this would still yield point data, which would need translation to the entire aquifer, and the stresses that can feasibly be applied in a pump test will still be significantly less than those tested in the model, hence the limitations would not be alleviated. The values from testing and previous modelling can be taken as a guideline and starting point for numerical modelling, and hydraulic parameters remain the key calibration parameter in the modelling.

It is useful to recognise from these pump test readings that the ranges for various units are similar. This supports the interpretation that depth from surface due to weathering, and local (cross cutting) structural controls will be the greatest control on hydraulic parameters, rather than rock type (also in *Section 4.2*).

Fitting characteristic curves to the constant discharge tests shows a broadly confined character for each test (AATS, 2000). This is a usual characteristic for fractured rock environments, even though there is no low permeability layer overlying the aquifers in question, as the fractured rock essentially is self-confining.

Table 4.3 *Summary of previous hydraulic tests performed*

BH No.	Data Source	Geology	Structures	Geology Source	Type of Aquifer Test	Aquifer Thickness[2]	Transmissivity [m2/d]	Hydraulic Conductivity [m/d]
BH5	AATS	Alluvium & Gneiss		Map	CDT[1]		1E+00	
AR 4	AATS	Gneiss		BH log	Slug - In			1E-04
AR 5	AATS	Gneiss		BH log	Slug - In			8E-04
BLH2(BH6)	AATS	Gneiss		BH log	Slug - In			4E-03
BLH4	AATS	Gneiss		BH log	Slug - In			2E-04
MBH1 (GAMS8)	AATS	Gneiss		BH log	Slug - In			1E-04
BLH3 (BH5)	AATS	Quartzite	Thrust Fault?	BH log	Slug - In			6E-01
GAMB 4	Golder	Quartzite	Thrust Fault?	Map	Slug - In&Out			6E+00
BH11	AATS	Schist		Map	CDT	20	7E-02	4E-03
GAMB 1	Golder	Schist		Map	CDT		7E-02	
GAMB 1	Golder	Schist		Map	Slug - In&Out			1E+00
GAMB 2	Golder	Schist	Thrust Fault?	Map	Slug - In&Out			5E+00
GAMB 3	Golder	Schist	Thrust Fault?	Map	CDT		1E+00	
GAMB 5	Golder	Schist	Thrust Fault?	Map	Slug - In&Out			4E+00

[1] CDT = Constant Discharge Test

[2] Aquifer Thickness is that reportedly used in the analysis

Note: AATS (2000) lists an additional 9 boreholes with hydraulic conductivities from slug-in and lugeon tests, and 1 constant rate test, however these borehole names are not referred to elsewhere, are not reflected on any maps, their coordinates and geology is not known, and cannot be recollected by those involved in the AATS (2000) study. They are discarded in this table.

Figure 4.7 Modelled distribution of hydraulic properties

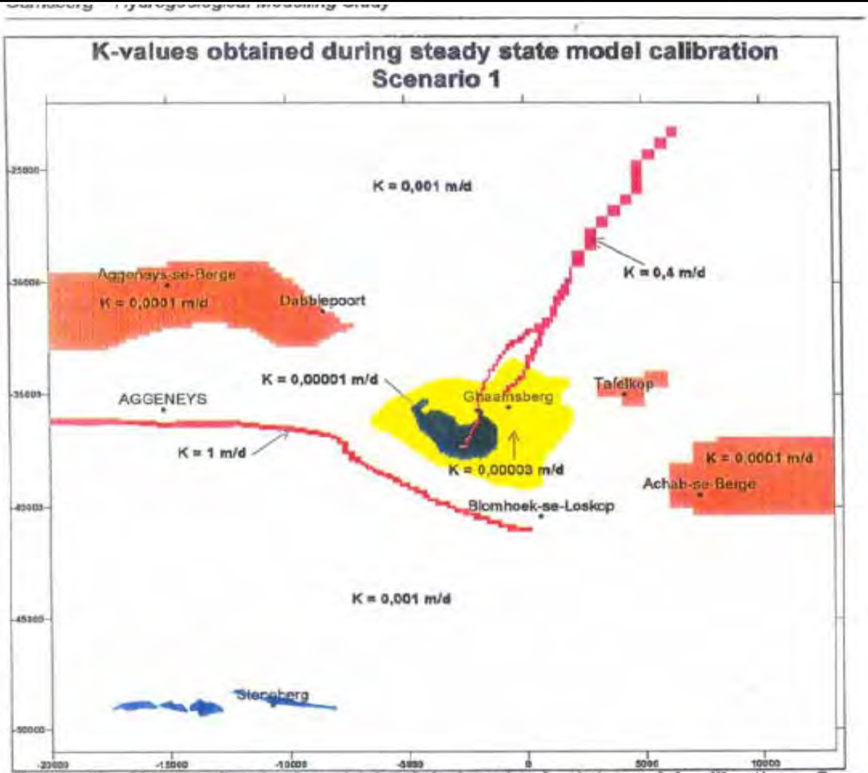


Figure 13 – K-value distribution obtained during steady state model calibration – Scenario 1.

AATS (2000)

4.6 GROUNDWATER RECHARGE

The piezometric contour map, *Figure 4.6*, is taken as indication that there is a driving force for groundwater flow in the area ie there is effective recharge, and that this recharge is higher on the inselberg. The higher recharge on the inselberg is assumed caused by the increased infiltration capacity of the fractured quartzite, with higher permeability and uneven surface reducing the effective evaporation, and due to the potentially higher MAP on the inselberg (*Table 3.1*).

SRK (2010) presented a GIS-based approach to calculation of recharge, adapted from a DWA methodology using various percentages of MAP, with percentages adjusted for geological factors among others (*Figure 4.8*). This shows recharge ranging from <0.5 mm/a in the south west of the area, to >1.3 mm/a broadly correlating with high ground. This study requires better constrained values for recharge on the plains and inselberg.

Given the high evaporation rates, the existence of any effective recharge on the plains is questionable. The poorer quality of groundwater on the plains (*Section 0*) could be taken as indication of the significantly reduced flush of fresh water on the plains, however this will also have some geological control and it is not possible to quantitatively estimate the relative influences. The numerical model prepared by AATS (2000) could not calibrate with inclusion of any recharge in the plains as this generated unrealistically high water levels, and the same was experienced in this modelling study. Hence AATS (2000) applied recharge only to the Gamsberg inselberg and other high ground (their recharge distribution is shown in *Figure 4.9*).

AATS (2000) provided a summary of estimates for recharge on the Gamsberg, which ranged in their literature search for similar environments between 1 mm/a and 2.9 mm/a. Two scenarios for recharge were ran in their models, 1 mm/a and 2 mm/a, over the distribution shown in (*Figure 4.9*). A comparison of 2 mm/a to the MAPs that have been calculated for the inselberg is given in *Table 4.4*, showing that 2 mm/a represents between 1.2 and 2.2% of MAP, which is taken as reasonable (De Vries, Selaolo, & Beekman, 2000).

Figure 4.8 Recharge over project region, based on GIS method, from SRK 2009

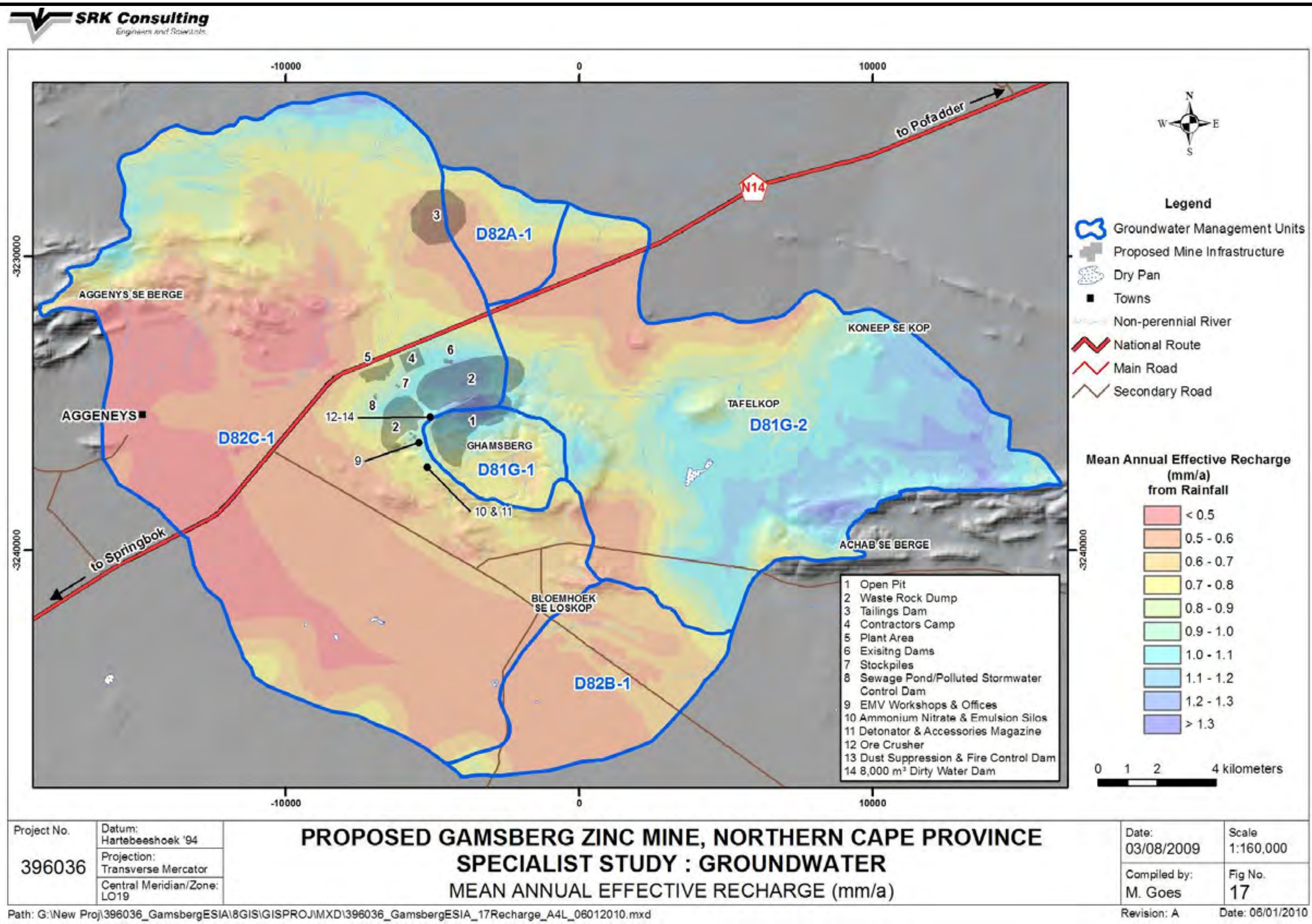
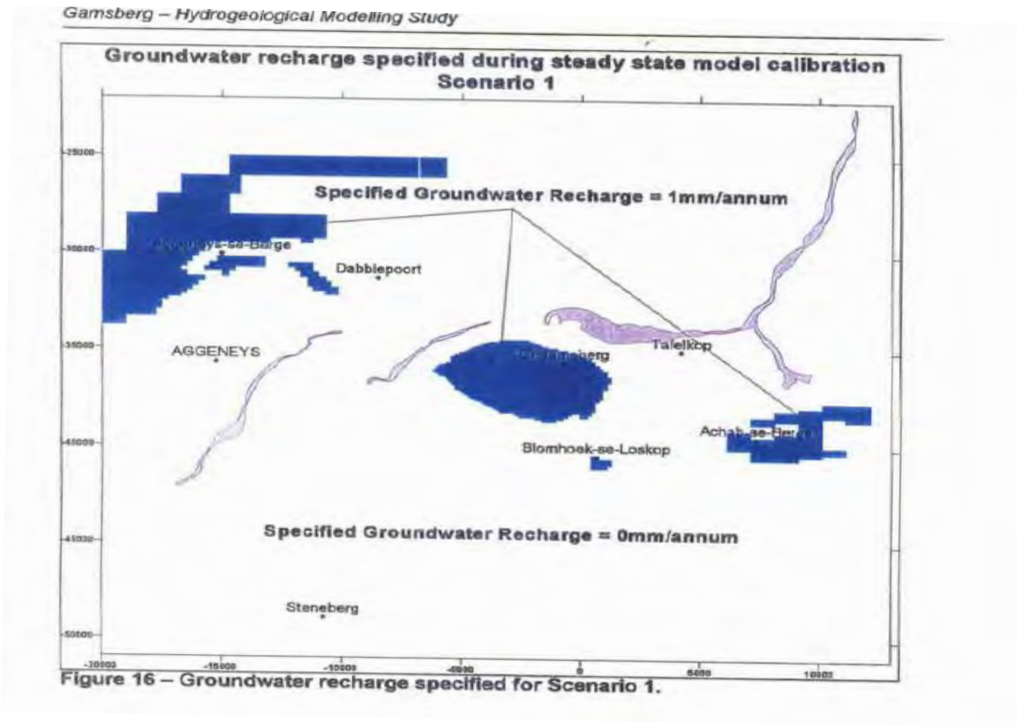


Figure 4.9 Recharge over project region, based on modelling



AATS (2000)

Table 4.4 Calculated recharge for Gamsberg inselberg

	Gamsberg
Calculated MAP for Berg, using Pofadder	89
Calculated MAP for Berg, using all stations	129
Calculated MAP for Berg, using Aggenys	167
2mm/a of recharge as a % of MAP (max)	2.2%
2mm/a of recharge as a % of MAP (min)	1.2%
20% min MAP (mm)	18
20% max MAP (mm)	33

4.7 GROUNDWATER DISCHARGE AND SURFACE WATER – GROUNDWATER INTERACTIONS

The presence of tree lined ephemeral stream beds (*Figure 4.10*) and shallow groundwater levels (BH5, <10 mbgl within drainage channel exiting from kloof), are evidence for groundwater flow and groundwater discharges through evapotranspiration losses; also noted in the area by Vegter (2006). Two such areas are identified: in the kloof, and around 'GAMS9' (see below).

The piezometric map, *Figure 4.6*, is taken as indication that groundwater originating as recharge in Gamsberg, discharges at distances far from the project area, as the piezometric map indicates flow out of the area towards the northeast and southwest.

Two springs are recorded in the Borehole Data Inventory (*Table 4.2*) as GAMS7 and GAMS9. Both of these are considered groundwater fed springs through the following mechanisms:

1) Topographically and structurally controlled spring discharge, GAMS7:

Although only one point is recorded in the inventory, pools of water exist throughout the length of the kloof, and around 8 were noted during a site visit in January 2013. The coordinates of GAMS7 reflect the uppermost spring, locally called the 'waterfall'. In years where there is insignificant rain, these springs / pools do not flow, and they have been reported as not flowing in previous works (AATS (2000) who visited in January 1999). However, the pools are constantly present (pers comm Abraham J. Engelbrecht, Project Engineer, Black Mountain) and they would evaporate, unless there is constant inflow. This leads to the interpretation that the pools are groundwater fed, and should be considered groundwater discharge points, however that the rate of discharge is likely similar to the rate of evaporatoin, generating permament pools. Local scale detailed monitoring (of groundwater levels and climatic factors) would be required to determine the natural groundwater discharge rate at the kloof spring sites.

The mechanism by which groundwater discharges at these kloof springs is likely to be a combination of topographic control, where the groundwater table simple intersects the low topography in the kloof, and also local scale structural control where deep connecting fractures allow groundwater under pressure to seep to surface (refers to confining nature of aquifers, *section 4.5*). Each of the 8 pools visited, were located where two laterally extensive sub-vertical fractures were present, and could be traced all the way up the kloof walls. Given the variability observed in the flow of these springs it is not possible to quantify a groundwater discharge.

2) Geological contact spring discharge, GAMS9:

One spring emanates from the east side of the Gamsberg, likely to be due to groundwater meeting the contact between the gneiss below and the schist above. The discharge from this spring has been estimated at 100 – 200 l/hour in January 1999, and 500-1000 l/hour in October 1999 (AATS, 2000). In January 2013 it was not flowing but formed a large standing pool, dammed by the manmade boulder dam beneath the spring (relics from a previous farm).

Headwater seeps marked on *Figure 3.6* are based on data from Black Mountain. They are assumed to be geologically controlled, where groundwater and surface runoff from the permeable quartzite meets the less permeable Gamsberg Iron Formation.

Figure 4.10 Photograph of trees in ephemeral drainage channel downstream of spring GAMS9

Figure 4.11 Photograph of local structural control on springs in kloof, near GAMS7

4.8 EXISTING MINING ACTIVITIES AND GROUNDWATER IMPACTS

Two adits were constructed in the northern wall of the inselberg in the 1970's, to access the ore body buried beneath the quartzite rim (*Figure 4.12*). There are no historical records of (ground)water volumes pumped to maintain a dry working environment within the adits, however anecdotal evidence from Black Mountain employees states that when constructed the adits flowed freely with water, and they now do not. It is assumed that the groundwater levels within the inselberg have been drained to some degree.

The adits are still cleared of collected water with sump pumps, turned on once a week. It is not possible to determine what of this water may be from internal groundwater seepage however, as it is also removing drilling water sourced from the Pella pipeline and used in the adit. This water from the adit is discharged to the environment on the northern side of Gamsberg (*Figure 4.13*).

Figure 4.12 Photograph of the north face of Gamsberg, showing two mining adits

Figure 4.13 Photograph of pumped water from adits

4.9 GROUNDWATER QUALITY

4.9.1 Groundwater Chemistry Results

Groundwater chemistry results are presented in *Table 4.5* to *Table 4.7.* A full laboratory report is provided in *Annex A*.

Table 4.5 pH and EC for Hydrocensus Boreholes

Hydrocensus ID	Field pH	Field EC	Laboratory pH	Laboratory EC
	pH units	mS/m	pH units	mS/m
GAMS3	7.1	115	8.51	117
GAMS4	7.1	103	7.25	113
GAMS5	6.9	80	5.81	111
GAMS6	6.1	82	7.4	175
GAMS8	7.3	120	7.51	121
AR2	7.4	1776	7.7	1626
AR4	7.6	111	7.54	117
AR5	7.6	212	7.83	239
AR7	7.3	170	7.81	157
AR8	7.5	362	7.74	317
AR9	7.3	269	7.76	241

Hydrocensus ID	Field pH	Field EC	Laboratory pH	Laboratory EC
	pH units	mS/m	pH units	mS/m
AR10	7.2	235	7.49	220
AR11	7.8	237	7.96	217
AR12	8.4	356	7.54	333
BLH3	7.8	130	7.6	101
BLH4	7.4	102	7.65	139
LUS1	7.7	148	7.65	138

Notes:

EC Electrical conductivity

mS/m Milli-Siemens/metre

Table 4.6 Major Ion Chemistry of Hydrocensus Boreholes

Sample	Hardness	Alkalinity	Lab pH	Lab EC	TDS	Cl	SO4	NO3	NO2	NH4	PO4	F	Ca	Mg	Na	K
	mg/L	mg/L as CaCO3	pH units	mS/m	mg/L	mg/L	mg/L	mg/L as N	mg/L as N	mg/L as N	mg/L as P	mg/L	mg/L	mg/L	mg/L	mg/L
DWAF Domestic	NV	NV	6-9	70	450	100	200	6	6	NV	NV	1	32	30	100	50
DWAF Livestock	NV	NV	NV	NV	1000	1500	1000	100	NV	NV	NV	2	1000	500	2000	NV
RS1	201	208.63	8.44	58	324	36	36	1.8	0.12	0.431	<0.025	3.61	49	19.0	50	3.05
RS2+3	448	152.98	8.18	146	853	303	143	14.3	0.12	0.066	<0.025	3.38	111	41.3	141	3.44
RS4	268	187.7	8.67	115	477	118	82	1.6	0.08	0.105	<0.025	2.48	59	29.4	69	2.91
RS5	232	127.27	8.29	56	350	70	65	4.7	0.17	0.095	<0.025	3.02	50	25.8	52	2.57
RS6	266	172.15	7.72	75	435	105	57	0.8	0.04	0.098	<0.025	3.99	68	23.3	71	1.95
RS7	281	174.28	8.5	125	672	217	106	3.9	0.15	0.109	<0.025	4.15	54	35.7	142	4.21
KGT1	714	276.29	7.34	249	1536	603	219	5.9	0.03	0.088	<0.025	3.80	183	62.8	282	11.4
KGT2	805	278.19	7.82	322	1652	741	157	6.9	0.03	0.089	0.061	4.10	203	72.4	291	9.74
KGT3	548	276.9	8.33	177	1019	293	140	32	0.03	0.087	0.047	3.00	141	47.7	189	7.32
KGT4	473	261.12	8.54	150	846	250	115	10.0	<0.005	0.051	0.074	2.98	121	41.5	142	7.08
KGT5	749	229.58	8.58	292	1800	630	378	23.5	<0.005	0.046	0.062	2.76	152	89.7	368	19.0
KGT7	1680	162.24	8.01	1021	6444	3573	352	12.0	0.13	0.057	<0.025	2.09	346	198	1791	72.8
KGT8	351	247.82	8.6	143	810	209	162	5.5	0.13	0.036	<0.025	3.12	86	33.0	159	2.95
GAMS2	78	36.09	7.64	37	190	43	62	0.1	0.03	0.025	<0.025	0.65	14	10.5	33	5.71
GAMS3	361	203.74	8.51	117	679	178	142	0.3	<0.005	<0.015	<0.025	1.03	81	38.6	111	4.81
GAMS4	387	346.61	7.25	113	690	102	136	1.4	<0.005	<0.015	<0.025	0.59	91	38.7	106	6.25
GAMS5	319	<8.26	5.81	111	765	29	599	<0.057	<0.005	0.06	0.057	<0.183	78	30.3	19	9.66
GAMS6	746	131.15	7.4	175	1266	109	673	1.7	<0.005	5.95	0.11	1.10	192	64.7	128	17.9
GAMS8	355	297.01	7.51	121	685	137	105	0.3	<0.005	7.56	0.206	2.02	101	25.0	117	19.7
GAMS9	57	19.91	6.46	24	116	35	22	3.2	<0.005	0.086	0.097	0.25	10	7.7	23	2.59
GAMS10	248	98.82	7.35	94	536	188	103	0.3	<0.005	0.079	0.083	2.00	41	35.2	105	1.89
AR1	1313	282.48	8.03	662	4249	1907	669	2.3	0.06	0.081	0.147	4.04	266	158	1013	60.6
AR2	4139	591.12	7.7	1626	11097	5234	1706	0.4	0.11	0.592	0.128	5.20	878	473	2333	113
AR3	664	280.75	8.01	229	1522	553	277	1.6	0.10	0.119	0.062	2.93	149	71.0	275	24.2
AR4	253	282.51	7.54	117	652	143	94	1.7	0.08	4.79	0.052	2.27	69	19.6	134	18.6
AR5	475	210.35	7.83	239	1392	599	181	0.8	0.02	0.189	0.085	3.04	113	47.0	303	19.6
AR7	423	247.03	7.81	157	961	334	120	6.4	0.01	0.066	0.045	3.06	114	33.7	189	13.4
AR8	701	188.89	7.74	317	1804	625	437	15.8	0.01	0.062	0.044	2.96	188	56.3	349	17.4

Sample	Hardness	Alkalinity	Lab pH	Lab EC	TDS	Cl	SO4	NO3	NO2	NH4	PO4	F	Ca	Mg	Na	K
	mg/L	mg/L as CaCO3	pH units	mS/m	mg/L	mg/L	mg/L	mg/L as N	mg/L as N	mg/L as N	mg/L as P	mg/L	mg/L	mg/L	mg/L	mg/L
AR9	570	276.2	7.76	241	1607	554	314	0.3	0.01	0.153	0.042	2.81	164	38.8	350	16.6
AR10	696	194.57	7.49	220	1404	543	231	15.0	<0.005	0.063	0.06	2.63	201	47.2	235	12.4
AR11	560	154.46	7.96	217	1392	547	259	7.8	0.25	0.063	0.044	2.97	149	45.6	273	15.1
AR12	718	172.98	7.54	333	1450	606	181	9.9	0.13	<0.015	<0.025	2.65	215	43.7	262	25.6
ACH1	83	26.61	6.69	31	172	47	44	3.7	<0.005	0.061	0.052	0.36	16	10.6	32	3.47
ACH2	761	209.59	7.49	414	2295	449	952	18.9	0.13	<0.015	<0.025	4.11	200	63.4	450	32.0
BCH1	394	267.79	7.39	158	916	294	89	7.9	0.02	0.092	0.053	3.29	103	33.3	208	16.8
BCH3	212	243.27	7.6	101	620	108	128	2.8	0.02	0.162	0.047	3.08	53	19.6	146	13.7
BCH4	351	211.38	7.65	139	827	248	128	12.1	0.01	0.069	<0.025	2.73	91	30.0	169	18.6
AGG1	753	123.01	7.04	348	2014	770	440	1.1	0.13	<0.015	<0.025	4.80	155	89.2	463	17.9
LUS1	352	208.74	7.65	138	899	247	202	12.1	0.07	<0.015	<0.025	2.81	92	30.0	170	18.6
MIN	57	19.91	5.81	24	116	28.7	22	<0.057	<0.005	<0.015	<0.025	<0.183	10	7.72	19	1.89
MAX	4139	591	8.67	1626	11097	5234	1706	32	0.25	7.56	0.21	5.20	878	473	2333	113
AVE	589	212	7.74	241	1472	558	264	6.59	0.08	0.66	0.08	2.78	140	58	301	17

Notes:

NV No value

DWAF Department of Water Affairs and Forestry

Highlighted concentrations exceed DWAF water quality guidelines (target values) for domestic use

Concentrations underlined exceed DWAF water quality guidelines (target values) for livestock watering

Table 4.7 Trace Element Chemistry of Hydrocensus Boreholes

Sample	Al mg/L	Fe mg/L	Mn mg/L	Cr mg/L	Cu mg/L	Ni mg/L	Zn mg/L	Co mg/L	Cd mg/L	Pb mg/L	As mg/L	Ba mg/L	U mg/L
DWAF Domestic	0.15	0.1	0.05	0.05*	1	NV	3	NV	0.005	0.01	0.01	NV	0.07
DWAF Livestock	5	10	10	1	0.5	1	20	1	0.01	NV	NV	NV	NV
RS1	<0.006	<0.006	<0.001	<0.002	<0.001	<0.003	0.237	<0.002	<0.001	<0.001	<0.023	0.002	0.01
RS2+3	<0.006	<0.006	<0.001	<0.002	<0.001	<0.003	0.08	<0.002	<0.001	<0.001	<0.023	0.006	0.03
RS4	<0.006	<0.006	<0.001	<0.002	0.003	<0.003	0.13	<0.002	<0.001	<0.001	<0.023	0.011	0.02
RS5	<0.006	<0.006	<0.001	<0.002	<0.001	<0.003	0.012	<0.002	<0.001	0.002	<0.023	0.046	0.02
RS6	<0.006	<0.006	<0.001	<0.002	<0.001	<0.003	<0.004	<0.002	<0.001	<0.001	<0.023	0.03	0.02
RS7	<0.006	<0.006	<0.001	<0.002	<0.001	<0.003	<0.004	<0.002	<0.001	<0.001	<0.023	0.021	0.10
KGT1	<0.006	<0.006	<0.001	<0.002	<0.001	<0.003	0.014	<0.002	<0.001	0.003	<0.023	0.013	0.13
KGT2	<0.006	<0.006	<0.001	<0.002	0.004	<0.003	<0.004	0.003	<0.001	<0.001	<0.023	0.016	0.16
KGT3	<0.006	<0.006	<0.001	<0.002	<0.001	<0.003	0.005	<0.002	<0.001	<0.001	<0.023	0.001	0.12
KGT4	<0.006	0.869	<0.001	<0.002	<0.001	<0.003	0.025	<0.002	<0.001	<0.001	<0.023	0.011	0.08
KGT5	<0.006	<0.006	<0.001	<0.002	<0.001	<0.003	<0.004	0.002	<0.001	<0.001	<0.023	0.027	0.18
KGT7	<0.006	<0.006	<0.001	<0.002	0.047	0.036	<0.004	<0.002	<0.001	<0.001	<0.023	0.043	0.07
KGT8	<0.006	<0.006	<0.001	<0.002	<0.001	<0.003	<0.004	<0.002	<0.001	<0.001	<0.023	0.002	0.03
GAMS2	<0.006	<0.006	1.97	<0.002	<0.001	<0.003	1.147	<0.002	<0.001	<0.001	<0.023	0.017	<0.01
GAMS3	<0.006	<0.006	<0.001	<0.002	<0.001	<0.003	0.031	0.002	<0.001	0.002	<0.023	0.058	0.01
GAMS4	<0.006	<0.006	<0.001	<0.002	<0.001	<0.003	<0.004	<0.002	<0.001	<0.001	<0.023	0.036	0.02
GAMS5	0.138	84.32	69.3	<0.002	0.052	<0.003	11.25	0.006	<0.001	0.028	<0.023	0.017	0.16
GAMS6	<0.006	0.095	3.23	<0.002	<0.001	<0.003	0.027	0.004	<0.001	0.002	<0.023	0.025	<0.01
GAMS8	<0.006	0.009	0.419	<0.002	<0.001	<0.003	<0.004	0.002	<0.001	<0.001	<0.023	0.034	0.05
GAMS9	<0.006	<0.006	<0.001	<0.002	<0.001	<0.003	0.228	<0.002	<0.001	<0.001	<0.023	0.039	<0.01
GAMS10	<0.006	<0.006	0.062	<0.002	<0.001	<0.003	0.229	0.006	<0.001	<0.001	<0.023	0.033	<0.01
AR1	<0.006	<0.006	<0.001	<0.002	0.044	<0.003	<0.004	<0.002	<0.001	<0.001	<0.023	0.08	0.3
AR2	<0.006	<0.006	0.028	<0.002	0.103	<0.003	0.005	<0.002	<0.001	0.017	<0.023	0.231	0.32
AR3	<0.006	<0.006	<0.001	<0.002	0.005	<0.003	0.105	<0.002	<0.001	<0.001	<0.023	0.073	0.16
AR4	<0.006	0.136	0.218	<0.002	<0.001	<0.003	<0.004	<0.002	<0.001	0.006	<0.023	0.027	0.02
AR5	<0.006	<0.006	<0.001	<0.002	<0.001	<0.003	0.018	<0.002	<0.001	<0.001	<0.023	0.047	0.09
AR7	<0.006	<0.006	<0.001	<0.002	<0.001	<0.003	0.01	<0.002	<0.001	<0.001	<0.023	0.026	0.05
AR8	<0.006	<0.006	<0.001	<0.002	0.008	<0.003	0.052	<0.002	<0.001	<0.001	<0.023	0.047	0.09
AR9	<0.006	0.537	0.566	<0.002	<0.001	<0.003	0.006	0.002	<0.001	0.004	<0.023	0.048	0.09
AR10	<0.006	<0.006	<0.001	<0.002	<0.001	<0.003	0.018	<0.002	<0.001	0.003	<0.023	0.034	0.03
AR11	<0.006	<0.006	<0.001	<0.002	<0.001	<0.003	<0.004	<0.002	<0.001	0.001	<0.023	0.033	0.04
AR12	<0.006	<0.006	<0.001	<0.002	0.005	<0.003	<0.004	<0.002	<0.001	0.02	<0.023	0.033	0.05
ACH1	<0.006	<0.006	<0.001	<0.002	0.013	<0.003	0.092	<0.002	<0.001	<0.001	<0.023	0.03	<0.01

Sample	Al mg/L	Fe mg/L	Mn mg/L	Cr mg/L	Cu mg/L	Ni mg/L	Zn mg/L	Co mg/L	Cd mg/L	Pb mg/L	As mg/L	Ba mg/L	U mg/L
ACH2	<0.006	<0.006	<0.001	<0.002	0.014	<0.003	0.031	<0.002	<0.001	0.015	<0.023	0.02	0.16
BCH1	<0.006	<0.006	<0.001	<0.002	<0.001	<0.003	0.639	<0.002	<0.001	<0.001	<0.023	0.008	0.08
BCH3	<0.006	0.024	<0.001	<0.002	<0.001	<0.003	<0.004	<0.002	<0.001	0.002	<0.023	0.019	0.06
BCH4	<0.006	0.424	<0.001	<0.002	<0.001	<0.003	0.006	0.004	<0.001	<0.001	<0.023	0.054	0.13
AGG1	<0.006	<0.006	<0.001	<0.002	0.01	<0.003	0.043	<0.002	<0.001	0.015	<0.023	0.065	0.05
LUS1	<0.006	0.233	<0.001	<0.002	<0.001	<0.003	0.006	<0.002	<0.001	<0.001	<0.023	0.029	0.13
MIN	<0.006	<0.006	<0.001	<0.002	<0.001	<0.003	<0.004	<0.002	<0.001	<0.001	<0.023	0.001	<0.01
MAX	0.138	84.321	69.3	0.002	0.103	0.036	11.25	0.006	<0.001	0.028	<0.023	0.231	0.32
AVE	0.01	2.23	1.94	0.00	0.01	0.00	0.37	0.00	0.00	0.00	-	0.04	0.08

Notes:

NV No value

DWAF Department of Water Affairs and Forestry

Highlighted concentrations exceed DWAF water quality guidelines (target values) for domestic use

Concentrations underlined exceed DWAF water quality guidelines (target values) for livestock watering

* Target value for chromium VI

4.9.2 *Quality Assurance/Quality Control*

Field versus Laboratory Data

The pH and EC were measured in the field during groundwater sampling using calibrated equipment. For quality control purposes, these measurements were repeated in the laboratory.

There is good agreement between field and laboratory data for EC, with a slope of 0.90 and a correlation coefficient of 0.99. A poor correlation exists between field pH measurements and the laboratory recorded pH (correlation coefficient of 0.07). This is due to various factors such as changes in chemistry that occur between sampling and laboratory analysis.

Due to the fact that field pH and EC measurements are only available for a few of the samples, the decision was taken to use the laboratory pH and EC data for the purpose of assessing water quality.

Anion-Cation Balance

The cation charge should equal the anion charge in a water sample. The Anion-Cation Balance (ACB) is the difference between the anion and cation charge and should be between -10% and 10%. Negative ACB values indicate either low cations or high anions in the analysis, and could reflect an analytical error, or an analyte that has not been included in the analysis.

The ACBs calculated for the analysed water samples range between -3.89% and 7.03%. The data are therefore of acceptable quality.

Duplicate Analysis

Four duplicate samples were collected for the hydrocensus samples. The chemical results of both the parent and the duplicate samples are presented in *Table 4.8.*

The blind duplicate samples were submitted to the laboratory in order to measure precision, which is calculated as Relative Percent Difference (%RPD). A calculated RPD (%) range below 30% would be accepted as quality data, whereas data outside of the acceptance criteria would require further discussion and investigation.

The Relative Percent Difference is expressed as:

$$\%RPD = \frac{|D1 - D2|}{(D1 + D2)/2} \cdot 100,$$

Where: D1= parent sample concentration; and
D2=duplicate sample concentration.

Table 4.8 shows that the majority of RPDs calculated for KGT7, RS7 and GAMS3 are below 30%. RPDs for a few duplicate samples are not within acceptable ranges and are discussed below:

- The RPDs for nitrate in RS7, GAMS3 and BLH4 are 165%, 113% and 123%, respectively. This calls into question the confidence that can be placed in nitrate results. Nitrate data should therefore be interpreted with care;
- The RPDs for fluoride in RS7 and GAMS3 are 118% and 41%, respectively. Although the latter represents a concentration difference which is the same order of magnitude as the detection limit, the former is an order of magnitude greater than the detection limit for fluoride. Fluoride concentrations should therefore be interpreted with care.
- The RPDs for calcium in RS7 and BLH4 are 41% and 57.4%, respectively. This calls into question the confidence that can be placed in calcium results.
- RPDs for potassium in GAMS3 and BLH4 are 36% and 30%, respectively. The repeatability of potassium analyses is therefore called into question.
- The RPDs for chloride in GAMS3 and BLH4 are 48% and 77.6%, respectively. This calls into question the confidence that can be placed in chloride results, particularly mid-range concentrations.
- The RPD for alkalinity in GAMS3 is 51%. Alkalinity results are therefore not repeatable within acceptable limits.
- The RPDs for nitrite and magnesium in BLH4 are 159% and 44%, respectively. This calls into question the repeatability of nitrite and magnesium data.
- The RPD for ammonium in BLH4 is 80%. However, this reflects a difference of 0.09 mg/L, which is the same order of magnitude as the detection limit. The repeatability of ammonium analyses is therefore considered to be acceptable;
- The RPDs for barium in KGT7 and BLH4 are 92% and 96%, respectively. Although these values reflect concentration differences of 0.02 mg/L and 0.03 mg/L, respectively, they are an order of magnitude greater than the detection limit for barium. The repeatability of barium analyses is therefore called into question.
- The RPDs for uranium in KGT7 and BLH4 are 55% and 74%, respectively. However, these values reflect differences between the parent and duplicate samples of 0.03 mg/L and 0.07 mg/L, respectively, which are of the same order of magnitude as the detection limit. The repeatability of uranium analyses is therefore considered to be acceptable.
- RPDs for both zinc and cobalt in sample BLH4 are 67%. However, these represent concentration differences of 0.006 mg/L and 0.002 mg/L, respectively, which are of the same orders of magnitude of the

laboratory detection limits. The repeatabilities of zinc and cobalt analyses are therefore considered to be acceptable.

In summary, the repeatability of results for many parameters is poor, notably , nitrate, nitrite, fluoride, calcium, potassium, chloride, alkalinity, magnesium and barium data.

Table 4.8 RPDs for detected analytes in hydrocensus duplicate samples

Sample ID	**Units**	**KGT7**	**DUP1 (KGT7)**	**%RPD**	**RS7**	**DUP2 (RS7)**	**%RPD**	**GAMS3**	**DUP3 (GAMS3)**	**%RPD**	**BLH4**	**DUP4 (BLH4)**	**%RPD**
pH		8.01	7.97	0.50	8.50	8.42	0.95	8.51	7.19	16.8	7.65	7.71	-0.8
EC	mS/m	1021	1042	-2.0	125	112	12	117	115	1.4	139	102	**30**
Turbidity	NTU	0.8	0.7	13	1.0	5.0	**-135**	5.3	3.6	**39**	11	12	-8.1
Total Hardness	mg/L	1680	1646	2.0	281	369	-27	361	406	-12	351	205	**53**
SS	mg/L	44	50	-13	10	9	11	9	15	**-50**	197	32	**144**
TDS	mg/L	6444	6371	1.1	672	683	-1.6	679	708	-4.2	827	616	29
Alk	mg/L	162	161	0.8	174	207	-17	204	344	**-51**	211	246	-15
Cl	mg/L	3573	3473	2.8	217	174	22	178	108	**48**	248	110	**78**
SO4	mg/L	352	386	-9.3	106	143	-29	142	141	1.1	128	126	1.6
NO3	mg/L as N	12	12	0.0	3.9	0.4	**165**	0.3	1.2	**-113**	12	2.9	**123**
NO2	mg/L as N	0.1	0.1	0.8	0.2	<0.005	NA	<0.005	<0.005	NA	0.01	0.07	**-159**
NH4	mg/L as N	0.1	0.1	-1.7	0.1	<0.015	NA	<0.015	<0.015	NA	0.07	0.16	**-80**
PO4	mg/L as P	<0.025	<0.025	NA	<0.025	<0.025	NA	<0.025	<0.025	NA	<0.025	0.0	NA
F	mg/L	2.1	2.2	-3.8	4.2	1.1	**118**	1.0	0.7	**41**	2.7	3.1	-12
Ca	mg/L	346	359	-3.7	54	81	**-41**	81	92	-13	91	50	**57**
Mg	mg/L	198	182	8.6	36	40	-12	39	43	-10	30	19	**44**
Na	mg/L	1791	1787	0.2	142	115	21	111	109	1.7	169	144	17
K	mg/L	73	73	-0.8	4.2	4.7	-11	4.8	6.9	**-36**	19	14	**30**
Al	mg/L	<0.006	<0.006	NA	<0.006	<0.006	NA	<0.006	<0.006	NA	<0.006	<0.006	NA
Fe	mg/L	<0.006	<0.006	NA	<0.006	<0.006	NA	<0.006	<0.006	NA	0.4	<0.006	NA
Mn	mg/L	<0.001	<0.001	NA	<0.001	<0.001	NA	<0.001	<0.001	NA	<0.001	<0.001	NA
Cr	mg/L	<0.002	<0.002	NA	<0.002	<0.002	NA	<0.002	<0.002	NA	<0.002	<0.002	NA
Cu	mg/L	0.047	0.042	11	<0.001	0.001	NA	<0.001	<0.001	NA	<0.001	<0.001	NA
Ni	mg/L	0.036	0.034	5.7	<0.003	<0.003	NA	<0.003	<0.003	NA	<0.003	<0.003	NA
Zn	mg/L	<0.004	<0.004	NA	<0.004	<0.004	NA	0.031	<0.004	NA	0.006	0.012	**-67**
Co	mg/L	<0.002	<0.002	NA	<0.002	<0.002	NA	0.002	<0.002	NA	0.004	0.002	**67**
Cd	mg/L	<0.001	<0.001	NA	<0.001	<0.001	NA	<0.001	<0.001	NA	<0.001	<0.001	NA
Pb	mg/L	<0.001	<0.001	NA	<0.001	<0.001	NA	0.002	<0.001	NA	<0.001	0.004	NA
As	mg/L	<0.023	<0.023	NA	<0.023	<0.023	NA	<0.023	<0.023	NA	<0.023	<0.023	NA
Ba	mg/L	0.04	0.02	**92**	0.021	0.024	-13	0.058	0.068	-16	0.05	0.02	**96**
U	mg/L	0.07	0.04	**55**	0.10	0.11	-10	0.01	0.01	0.0	0.13	0.06	**74**

Notes:

DUP Duplicate sample

RPD Relative percent difference

< Value smaller than the laboratory detection limit

NA RPD could not be calculated

4.9.3 *Groundwater Quality Classification*

Water quality in the study area was compared to the South African Water Quality Guidelines for domestic purposes as well as livestock watering (Department of Water Affairs and Foresty , 1996).

- Laboratory pH varies from 5.8 to 8.7. All but one of the pH measurements (pH 5.8 in sample GAMS5) fall within the DWAF target range for domestic water use (pH 6-9).

- Electrical conductivities range from 24 mS/m (GAMS9) to 1626 mS/m (AR2). The majority of the EC values exceed the domestic water target of 70 mS/m. The higher EC concentrations are generally detected in boreholes located in the plains surrounding the Gamsberg inselberg. Salts concentrating in the soil by evaporation of rainfall can be washed through the soil by rainfall. As limited recharge occurs on the plains, the concentration of salts in recharge is likely to be high. An groundwater EC map is presented in *Figure 4.14,* which is based on the average of all EC measurements at each borehole (from *Table 4.2*).

- Chloride concentrations range from 29 mg/L (GAMS5) to 5234 mg/L (AR2). The majority of the groundwater samples exceed the DWAF domestic target value of 100 mg/L for chloride. The target value for livestock watering (1500 mg/L) is exceeded in three samples: KGT7, AR1 and AR2.

- TDS concentrations reflect the EC values: TDS concentrations range from 116 mg/L in GAMS9 to 11097 mg/L in AR2. The majority of the samples exceed the target for domestic use (450 mg/L) and a number of samples also exceed the target for livestock watering (1000 mg/L). Higher TDS concentrations are detected in samples collected from boreholes in the plains surrounding the Gamsberg inselberg.

- Sulphate concentrations range from 22 mg/L (GAMS9) to 1706 mg/L (AR2). A number of samples exceed the domestic water target value of 200 mg/L. The sulphate concentration in sample AR2 (1706 mg/L) exceeds the target for livestock watering (1000 mg/L). Well AR2 is located in the kloof at the eastern end of Aggeneys Berg.

- Groundwater nitrate concentrations range from <0.057 mg/L (GAMS5) to 32 mg/L (KGT3). A number of nitrate concentrations exceed the DWAF target value for domestic water use (6 mg/L). Elevated levels appear to be located on farms surrounding the inselberg and are possibly related to livestock farming.

- Fluoride concentrations range from <0.183 mg/L (GAMS5) to 5.2 mg/L (AR2). The majority of the groundwater samples contain concentrations exceeding both the domestic use and livestock watering target values of 1 mg/L and 2 mg/L, respectively. Naturally occurring, high levels of fluoride in groundwater in the Northern Cape are well documented (Ncube & Schutte, 2005).

- Calcium concentrations in the groundwater samples range from 10 mg/L (GAMS9) to 878 mg/L (AR2). The majority of the samples have concentrations exceeding the DWAF domestic target value of 32 mg/L.

- The concentrations of magnesium in the samples range from 7.72 mg/L (GAMS9) to 473 mg/L (AR2). The majority of the samples have concentrations exceeding the DWAF domestic target value of 30 mg/L.

- Sodium concentrations in the groundwater samples range from 19 mg/L (GAMS5) to 2333 mg/L (AR2). The DWAF target value for domestic use (100 mg/L) is exceeded in most of the samples and the target value for livestock watering (2000 mg/L) is exceeded in one sample (AR2).

- Potassium concentrations range from 1.89 mg/L (GAMS10) to 113 mg/L (AR2). The domestic use target value of 50 mg/L is exceeded in three samples (KGT7, AR1 and AR2).

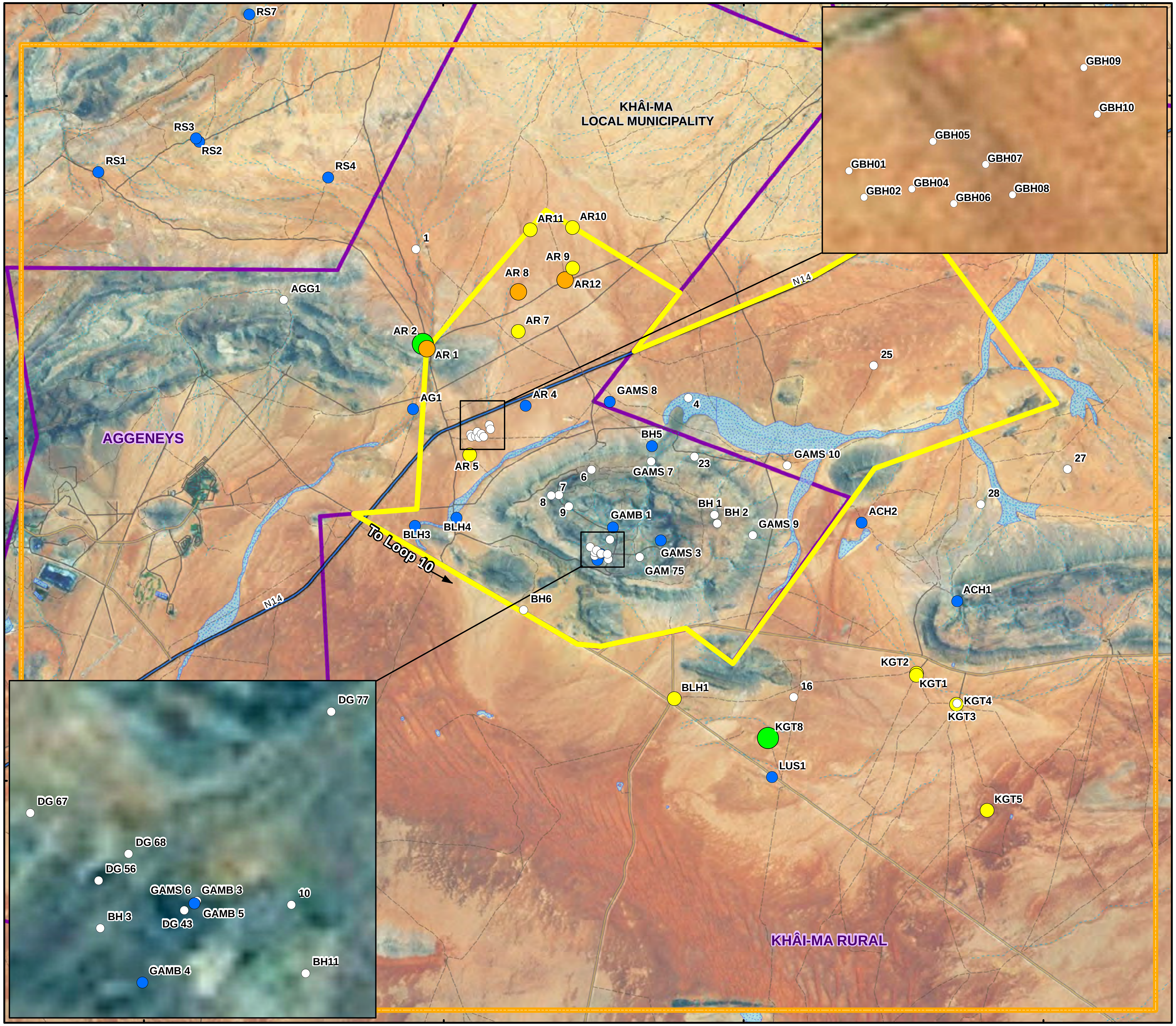
- The domestic use target values for iron (0.1 mg/L), manganese (0.05 mg/L) and lead (0.01 mg/L) are exceeded in several samples. The highest iron (84.32 mg/L), manganese (69.3 mg/L) and lead (0.028 mg/L) concentrations were detected in sample GAMS5, which has the lowest pH of any of the samples. Concentrations of iron and manganese in this sample exceed the target values for livestock watering. GAMS5 was also found to contain the highest concentration of zinc (11.25 mg/L), exceeding the domestic target value of 3 mg/L.

- Almost half of the water samples contain uranium concentrations exceeding the DWAF domestic target value of 0.07 mg/L. Concentrations range from <0.01 to 0.32 mg/L (AR2). Occurrence of elevated uranium in groundwater in the Northern Cape is well documented (Van Wyk & Coetzee, 2008).

- Arsenic concentrations were reported as being below the laboratory limit of detection (0.023 mg/L). This limit of detection, however, is higher than the DWAF target value for domestic use.

The groundwater within the study area is considered to be unsuitable for domestic use as well as livestock watering.

Elevated EC, TDS, chloride, sulphate, calcium, magnesium, sodium and zinc are likely to affect the palatability of the groundwater, while nitrate, fluoride, potassium, iron, manganese, lead and uranium present potential health risks.



Legend

Electrical Conductivity (mS/m)

- No Data
- < 150.00
- 150.01 - 300.00
- 300.01 - 500.00
- 500.01 - 1000.00
- 1000.01 - 1776.00

- National Route
- Main Road
- Secondary Road
- Other Road
- Track/Footpath
- Ephemeral Rivers
- Mineral Rights Boundary
- Groundwater Domain Model
- Town Boundary
- Flood Plains

SCALE:

0 1 2 3 4 5 6

Kilometres

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TITLE:

Figure: 4.10 EC as a measurement of groundwater quality

CLIENT:

vedanta

BLACK MOUNTAIN MINING (PTY) LTD

DATE:Jan 2013	CHECKED: MP	PROJECT: 0164903
DRAWN: AT	APPROVED: SHC	SCALE: 1 : 110 000

DRAWING:	REV:
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ERM

	SIZE:
Projection: Transverse Mecator, CM19. Datum : WGS84 Source: Chief Directorate National Geo-Spatial Information. ERM 2013 Inset Map: Esri Data & Maps	A3

C:\Users\Dell4\Documents\Thurlow Mapping\PRIVATE WORK\ERM\CONTRACT\GIS\0164903_GAMSBERG\MXD\MXD_REV2\BH_Electrical_Conductivity_Map_Rev2.mxd

4.9.4 *Groundwater Characterisation / Fingerprinting*

The hydrocensus groundwater results were plotted on a Piper diagram in order to determine whether there are any groupings or trends within the data (*Figure 4.15*).

Cations are generally more tightly clustered than anions, and indicate a mixture of Na, Ca and Mg, with Na generally being the dominant ion. Anions show a considerably wider spread, with most samples defining a trend from alkalinity to chloride dominated. Samples that are alkalinity dominated generally have lower EC than those that are chloride dominated, indicating an evolution of water from fresher alkalinity dominated water to more saline chloride dominated water. This is clearly illustrated in *Figure 4.16*, where samples become more chloride dominated at higher EC. Salts are likely to concentrate in soils following rainfall. Occasional heavy rainfall will leach the accumulated salts into the groundwater. The lower the recharge, the more salts can concentrate. Minerals will precipitate in soils in order of increasing solubility ie calcite ($CaCO_3$) will precipitate before halite (NaCl), and will also dissolve in order of decreasing solubility ie halite will dissolve before calcite. This results in fractionation of salts with alkalinity remaining in the soil as calcite, and chloride being transported into the groundwater, often at high concentrations due to the accumulation of salts over time in the semi-arid environment. Therefore, samples with higher alkalinity indicate recharge in areas of higher rainfall and higher chloride indicates recharge in areas where there is little rainfall. Alkalinity dominated samples are mostly located close to the inselberg, which has a higher average rainfall than the surrounding plains.

Some samples also indicate a tendency to sulphate dominance. These samples are GAMS2, GAMS5, GAMS6 and ACH2. The GAMS samples are all within the inselberg, and likely to be affected by the sulphide-rich ore deposit. GAMS5 has the highest proportion of sulphate and the lowest pH of water samples collected, and may indicate acid rock drainage.

Radial diagrams illustrating the different geochemical signatures (chloride dominated, alkalinity dominated, sulphate dominated and chloride-alkalinity-sulphate mixture) of the groundwater samples are presented in *Figure 4.13.*

Figure 4.15 Piper Diagram of the Groundwater Data

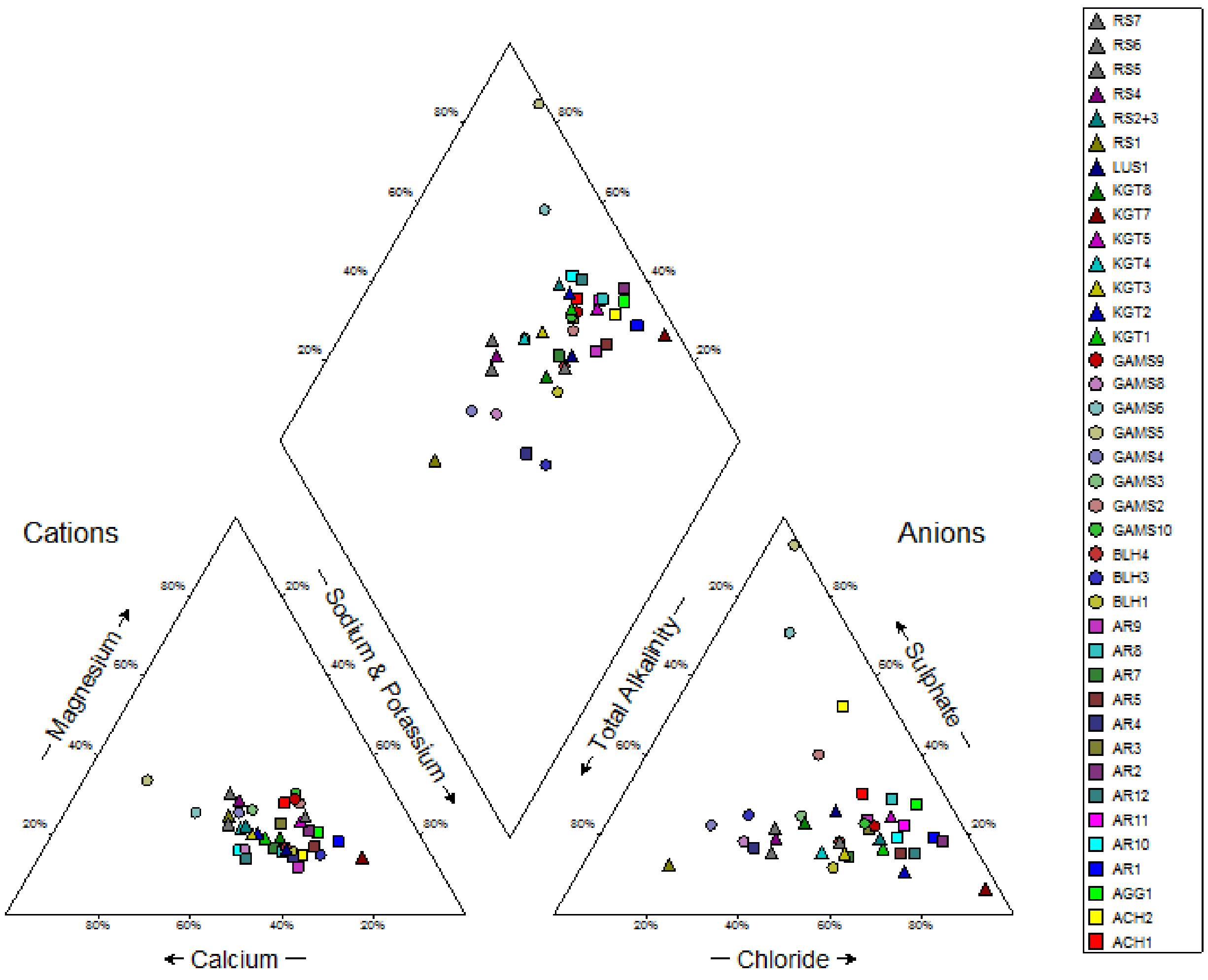


Figure 4.16 Changes in Chloride: Alkalinity Ratio with Increasing Salinity

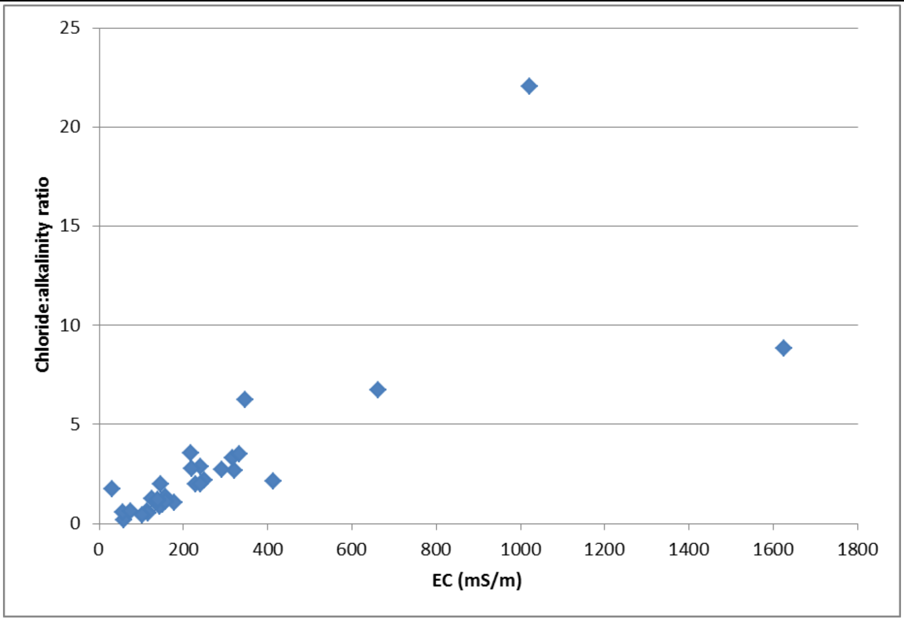
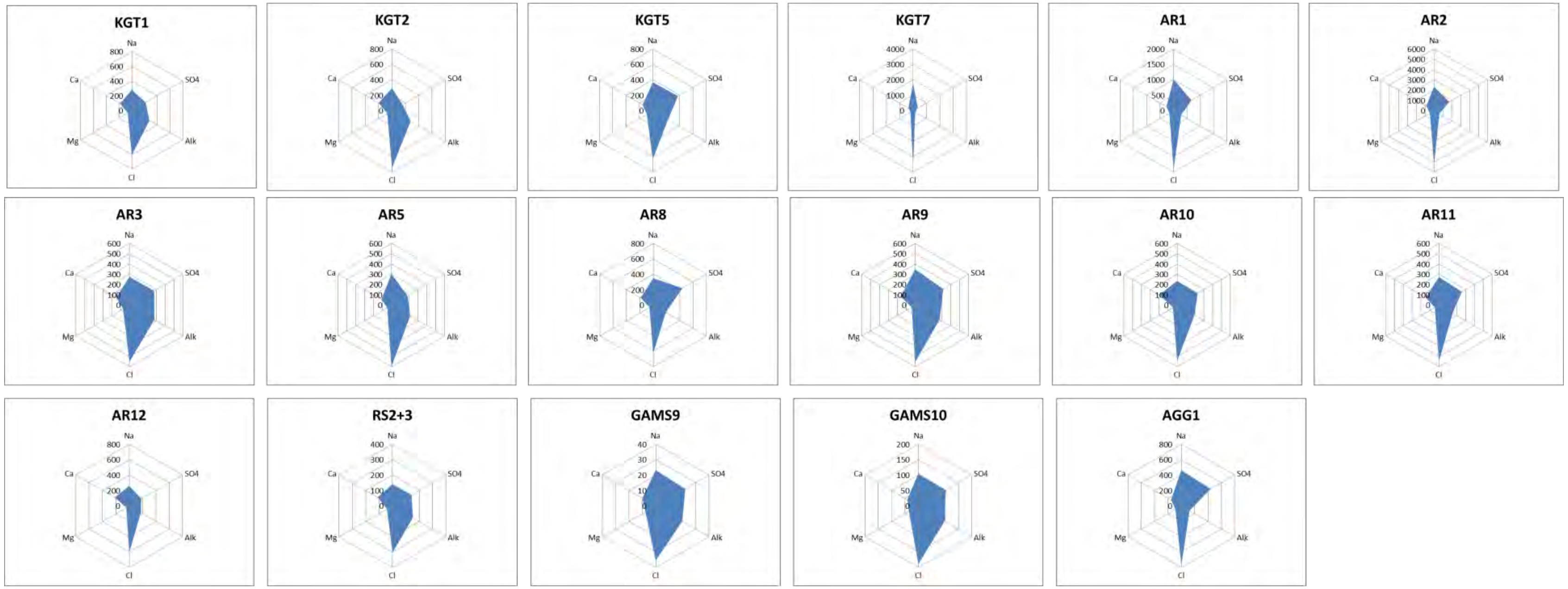


Figure 4.17 Radial Diagrams

Group 1: Chloride dominated



Group 2: Alkalinity dominated

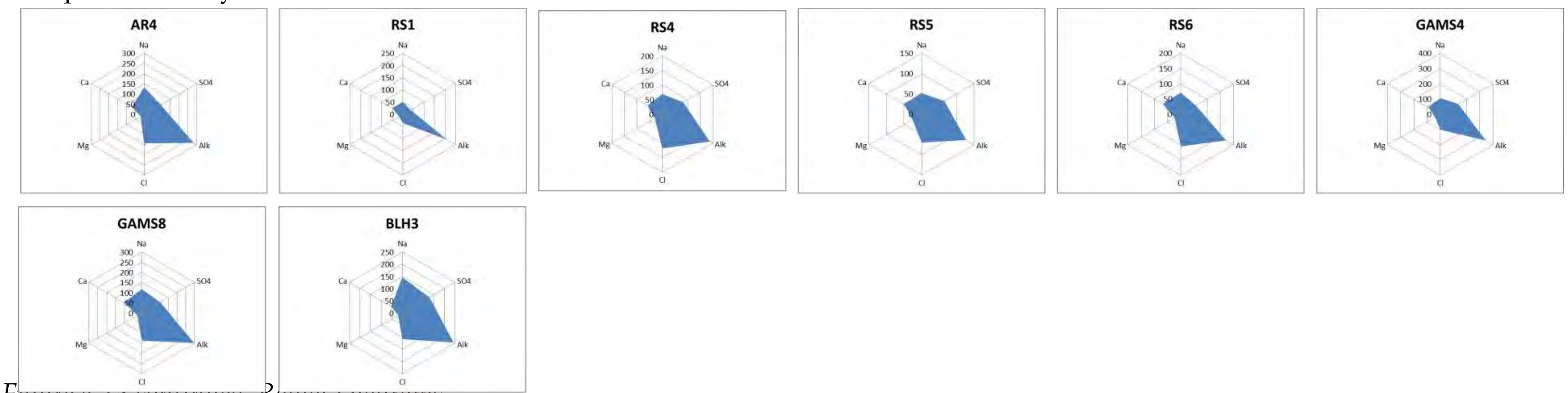
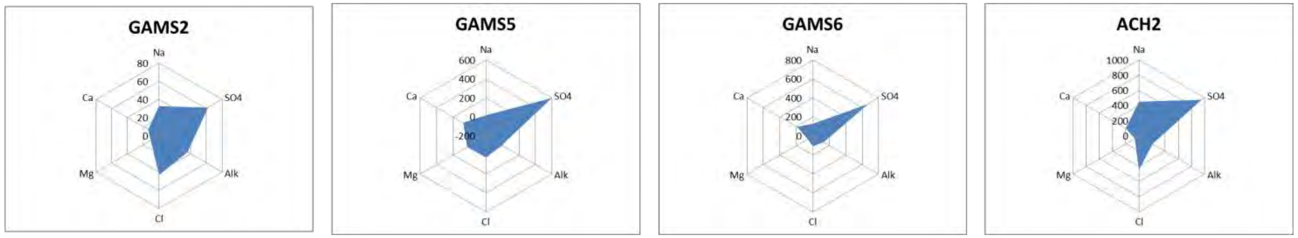
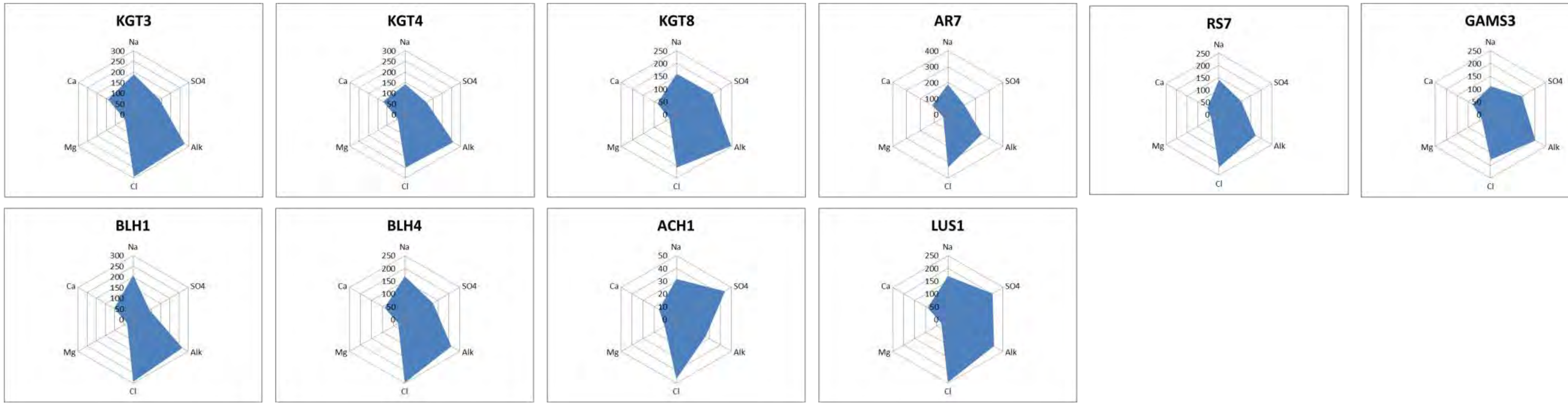


Figure 4.15 continued: Radial Diagrams

Group 3: Sulphate dominated



Group 4: Chloride-alkalinity-sulphate



4.9.5 *Historical Groundwater Chemical Data*

Temporal groundwater pH, EC and sulphate concentrations for selected sampling locations (AG1, KGT2, ACH1, GAMS4, GAMS8 and GAMS10) are presented in *Figure 4.18* to *Figure 4.20*. These data represent sampling events undertaken during 2001, 2009 and the most recent event, September 2012.

Although the data presented do not represent regular sampling intervals during the 2001-2012 period, the graphs suggest the following:

- Relatively little fluctuation in pH and EC concentrations at the sampling locations; and
- The groundwater sulphate concentration at AG1 was an order of magnitude less during the 2001 sampling event than during the most recent sampling event (September 2012).

Figure 4.18 Groundwater pH Measurements for selected sampling Locations (2001 -2012)

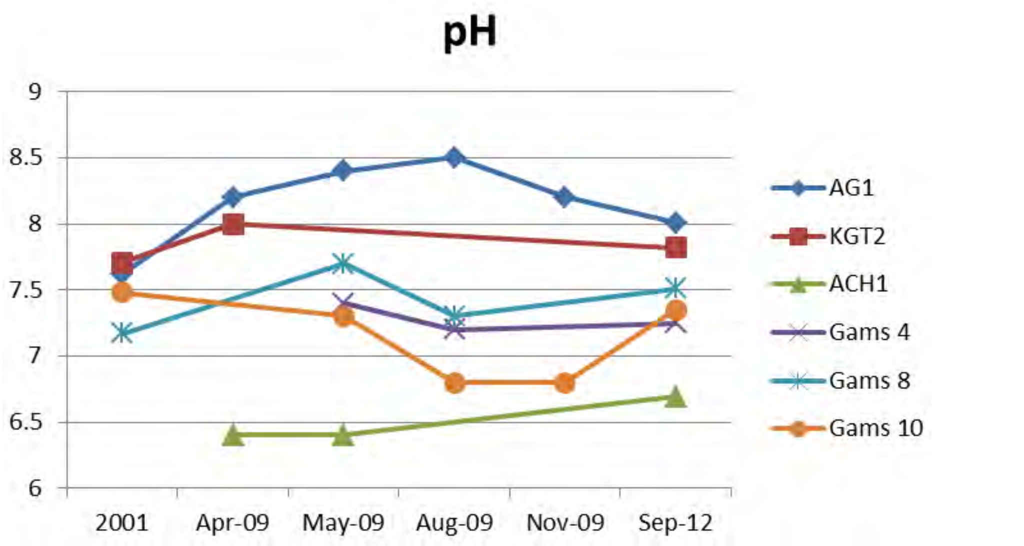


Figure 4.19 Groundwater EC (mS/m) Concentrations for selected sampling Locations (2001 -2012)

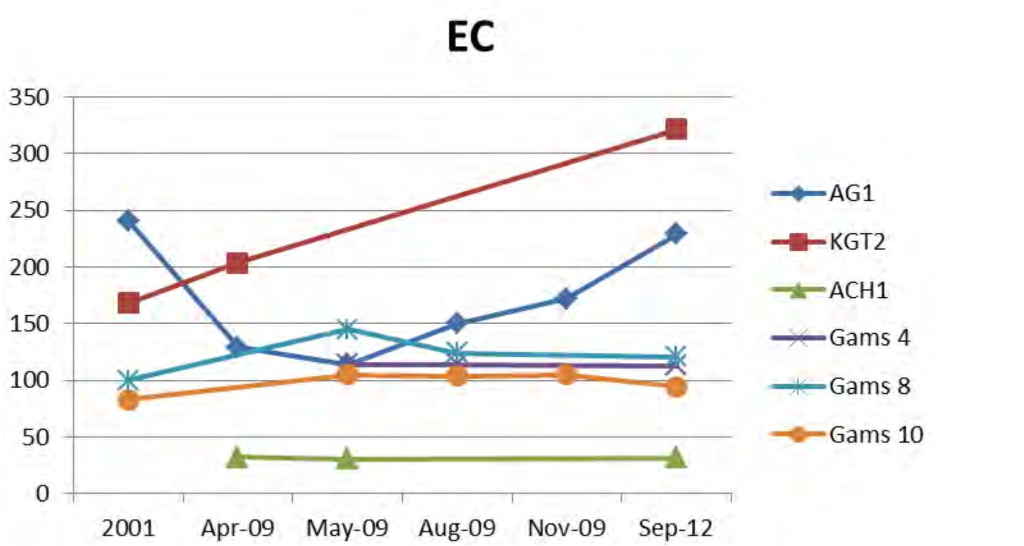
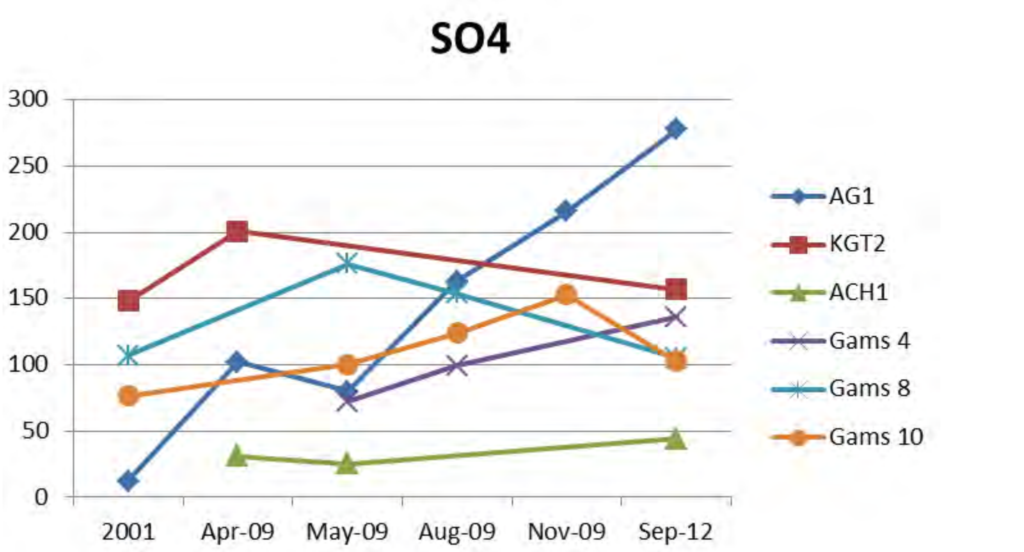


Figure 4.20 Groundwater sulphate (mg/L) Concentrations for selected sampling Locations (2001 -2012)



5 CONCEPTUAL MODEL

5.1 HYDROGEOLOGICAL CONCEPTUAL MODEL

The highly fractured and weathered hard rock terrain of the white quartzite unit, the schist, and the gneiss, are considered to be water-bearing units, or secondary permeability aquifers.

Based on observed groundwater level data on and around the Gamsberg it is assumed that groundwater flow is radially outwards from the berg towards the plains. Available data also indicates a preferential flow in the plains in a north-east direction, mimicking a surface drainage channel which may have structural control, and south-west direction.

Groundwater levels close to the inselberg are higher than the ones in the plains and show a gradual increase in groundwater level closer to the inselberg, very closely mimicking topography. The above indicates that the groundwater flow in the Gamsberg is hydraulically connected to the groundwater in the plains and that there is groundwater flow across the geological units from the quartzite on Gamsberg, through the sillimanite schist, to the gneiss on the plains. This is to be expected given the highly faulted and folded environment, such that a typically low hydraulic conductivity material such as a schist, becomes permeable. Pump test information shows similar ranges of hydraulic conductivities in the gneiss, schist and quartzite, and shows a broadly confined character in the pump test curves.

The primary control on permeability is taken as structures and weathering (related to depth from surface), rather than rock type, appreciating that un-weathered units at depth can also be water bearing, and that fracturing around major faults will increase hydraulic conductivity.

The piezometric contour map, is taken as indication that there is a driving force for groundwater flow in the area ie there is effective recharge, and that this recharge is higher on the inselberg. The higher recharge on the inselberg is assumed caused by the increased infiltration capacity of the fractured quartzite, with higher permeability and uneven surface reducing the effective evaporation, and due to the potentially higher MAP on the inselberg. Due to the high evaporation rates, it is assumed there is zero effective recharge on the plains, which may be supported by the lower EC on the Gamsberg and in boreholes close to the Gamsberg than on the plains.

Groundwater discharge, of water recharged at Gamsberg, is on the form of:

1) springs in the kloof on the northern side of Gamsberg, and on the east of the Gamsberg;

2) through direct evapotranspiration losses in tree lined ephemeral drainage lines and from the water table, where sufficiently shallow; and
3) through lateral flow at great distances from the project area, as the peizometric map indicates groundwater flow out of the area of interest towards the northeast and southwest.

5.2 *SOURCE – PATH – RECEPTOR APPROACH*

In terms of the Environmental Impact Assessment the following potential activities are assessed for their potential impact on groundwater resource availability (drawdown and natural flow regime), and on groundwater quality:

- Mine dewatering and the associated pit lake or sink
- Tailings storage facilities
- Waste rock dumps

The pathway considered in this study is saturated groundwater flow.

The receptors under consideration are:

- Groundwater, as a resource
- Users of groundwater, including
    - Privately owned boreholes
    - The environment, ie groundwater discharge to springs, and plants or trees dependent on shallow groundwater

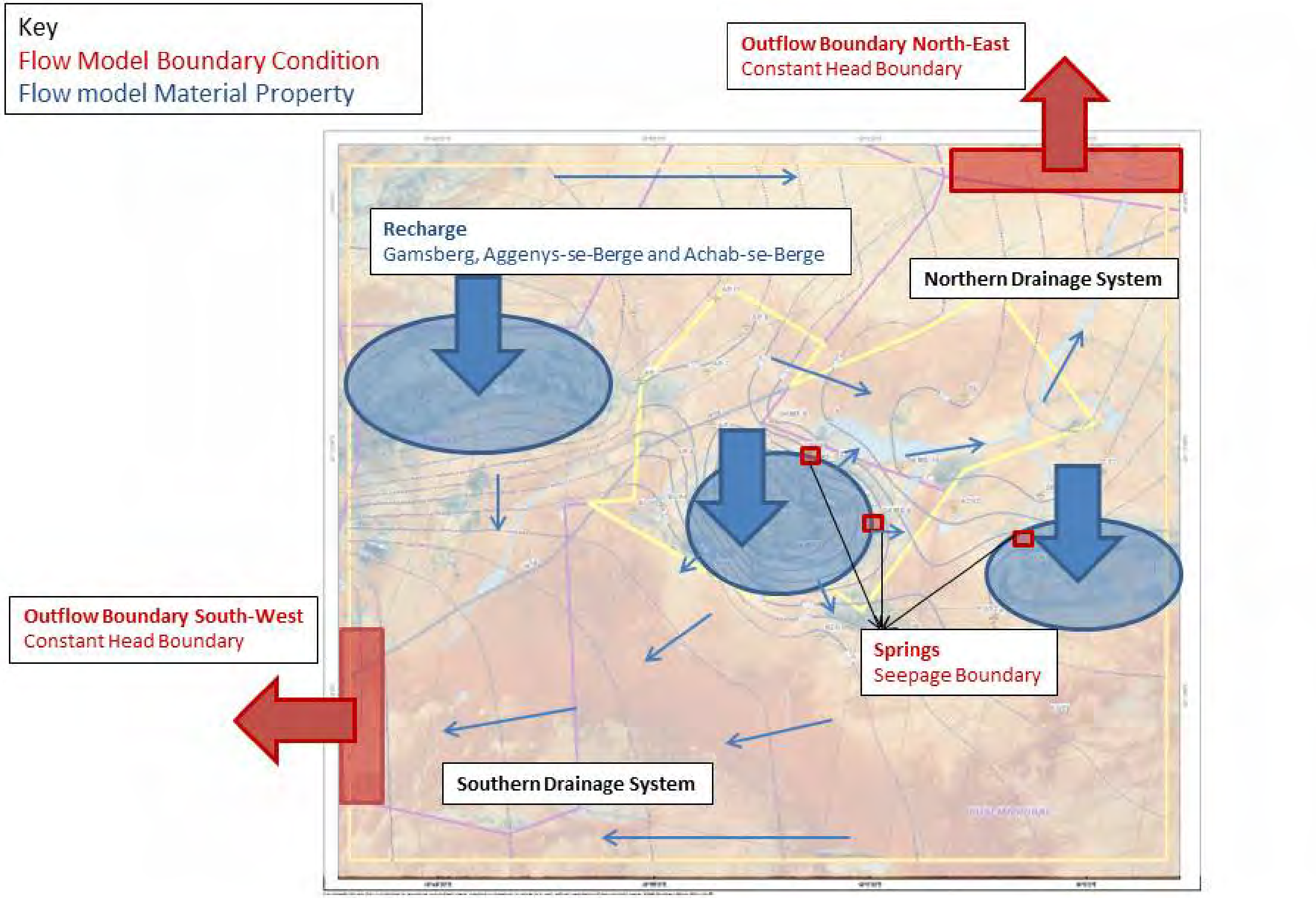
5.3 *TRANSLATION TO NUMERICAL MODEL*

The vertical distribution of hydraulic conductivity (K) in the area is not known. Although weathering will decrease with depth, open water bearing fractures will occur at depth. Without information on the likely decrease in K with depth, a conservative approach is followed assuming constant K values to 550mamsl (final depth of the pit). This assumption could result in an overestimation of pit inflows at depth, however, low inflows are expected and the overestimation is not expected to be significant.

Given the conceptual approach to the vertical distribution of hydraulic conductivity, a two-dimensional (2D) model is applied. AATS (2000) also applied a 2D model. This assumption is valid for aquifers that have a horizontal extent that is much larger than the aquifer thickness, which is the case for the Gamsberg model. Further, the assumption is valid in aquifers where the vertical flow component is negligible (Barnett, et al., 2012).

The conceptual understanding of the groundwater flow regime is shown in below. This figure also includes representation of various features in the numerical model which are described in more detail in *Section 6.1* below.

Figure 5.1 Conceptual Model of groundwater flow regime



5.4 *ALTERNATIVE CONCEPTUAL MODELS*

The conceptual model applied, essentially that there is a hydraulic continuum between the geological units and constant hydraulic conductivity with depth, is a simplification of the natural system, necessary and appropriate for this modelling exercise.

Although this conceptual approach is the same as previous hydrogeological investigations at Gamsberg (AATS (2000), SRK (2010)), it is not a conceptual approach shared by all (pers comm Rod Cameron, AMEC, 2013). Alternative assumptions, not held by the authors of this report, are that the schist acts as a barrier to groundwater flow, thus separating the white quartzite as a perched aquifer system, and the gneiss as a separate aquifer system. If there was a hydraulic separation, any impacts associated with de-watering in the quartzite, would be separated from the gneiss based on the schist as a hydraulic barrier.

Given that the water level data is interpreted to indicate hydraulic continuum, and that a hydraulic continuum allows a more conservative scenario of transmission of impact to be assessed, this is the appropriate approach for an impact assessment modelling exercise. It allows a monitoring plan to be established based on a realistic yet conservative understanding of the natural system. Furthermore, the worth of representing 3D complexity in a model which by definition is low confidence, (due to the long timescale prediction, and the calibration with stresses less than those modelled), is questionable.

It is recommended that the hydraulic continuum conceptual approach be tested with targeted field investigations, and once further information on geological and hydrogeological characteristics are known, the model be updated to a 3D construction.

6 GROUNDWATER FLOW AND TRANSPORT MODELS

6.1 BASE CASE MODEL SETUP

6.1.1 Model Domain

Groundwater level measurements indicate that groundwater flow is similar to surface drainage lines. There are two distinct surface drainage features present in the area around the Gamsberg, being:

1. Northern system comprising drainage from the Gamsberg northerly through the Kloof towards the north-east in the direction of the Orange River; and
2. Southern system draining from the Gamsberg to the south and south-west.

The proposed Gamsberg mine is situated on a surface and groundwater divide and can therefore influence both northern and southern drainage systems. Therefore both catchments have been included in the model domain with the Gamsberg Inselberg at the centre. A rectangular model domain of 34km (west to east) and 29km (north to south) was chosen (shown as a red box in all maps), which is very similar to the Anglo model (AATS, 2000). The area was selected such that the model boundaries are far enough away from the area of interest so as not to negatively impact on results.

6.1.2 Boundary Conditions

Groundwater Flow Boundaries

The following external boundary conditions were implemented in the model:

- Groundwater outflow boundary in the north-east modelled using *hydraulic head(Dirichlet) boundary condition (BC)* with variable head based on topography between 650 and 790mamsl;
- Groundwater outflow boundary in the south-west modelled using *hydraulic head (Dirichlet) BC* with a head of 650mamsl; and
- No-flow boundary condition for the rest of the model boundary.

Recharge

A groundwater recharge rate of 2 mm/a was used over the three inselbergs located within the model domain, Gamsberg, Aggenys-se-Berge and Achab-se-Berge (see Section 4.6).

Groundwater Abstraction

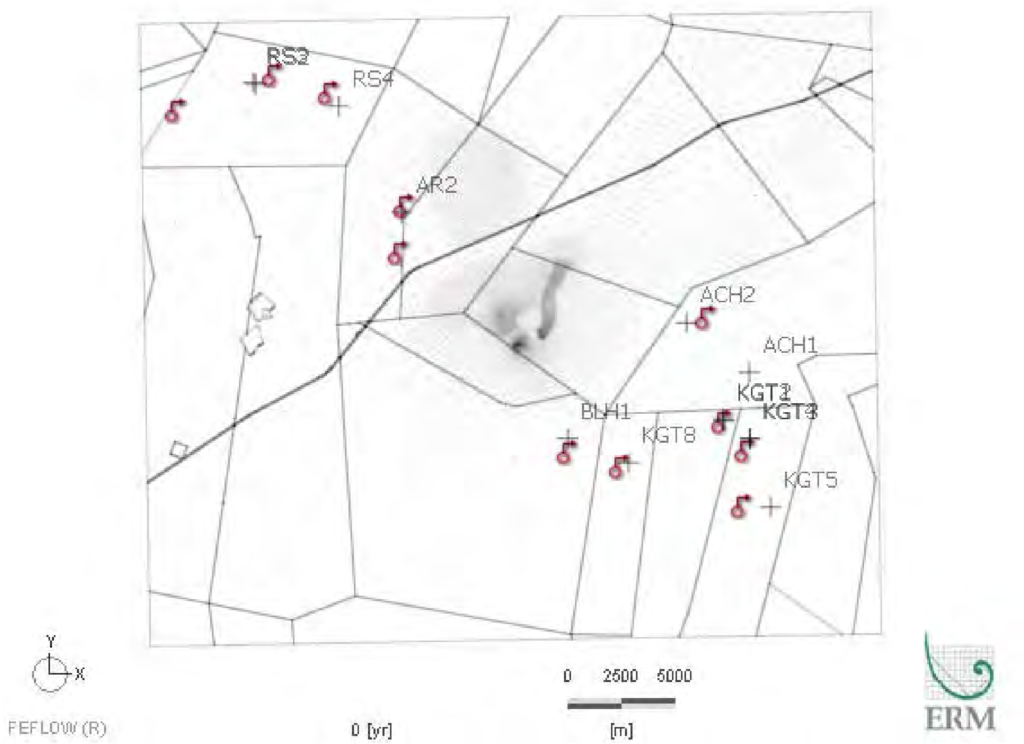
Existing (known) farm abstraction boreholes within the model domain were included in the steady state model. *Table 6.1* details the abstraction rates implemented in the model, which are based on SRK (2010) (and are also reflected in Table 4.2). Mine boreholes on the Gamsberg (BH5, GAMS3 and GAMS6) were not included as they are not actively pumping.

Table 6.1 Abstraction Boreholes

ID	Farm	Owner	X	Y	Abstraction Rate (m3/d)
ACH2	Achab	Girrie v/d Heever	309954	6762989	2.5
AG1	Aggeneys	Abrie van Niekerk	296586	6766133	3.3
AR1	Aroams	Mine	296967	6767933	4.9
BLH1	Blomhoek	Albertus Roux	304484	6757668	5.2
KGT1	Kykgat	Jan Visser	311657	6758480	5.2
KGT2	Kykgat	Jan Visser	311660	6758543	2.5
KGT3	Kykgat	Tertius Visser	312878	6757672	1.4
KGT4	Kykgat	Tertius Visser	312865	6757645	3.3
KGT5	Kykgat	Tertius Visser	313826	6754514	3.3
KGT8	Kykgat	Tertius Visser	307285	6756546	3.3
RS1	Rosynebos	Danie Luttig	287124	6773004	3.3
RS2	Rosynebos	Danie Luttig	290101	6773956	3.3
RS3	Rosynebos	Danie Luttig	290004	6774053	2.5
RS4	Rosynebos	Danie Luttig	293946	6772963	3.3

Abstraction boreholes were implemented using the *Well BC* in the model. Locations of the boreholes are depicted in *Figure 6.1*. In the model, abstraction points were allocated a BC at the closest available node. This resulted in locations slightly different from the surveyed locations. In the event that several boreholes came to lie at the same node due to the proximity of these to each other, abstraction rates were summed (RS2 and RS3; KGT1 and KGT2; KGT3 and KGT4).

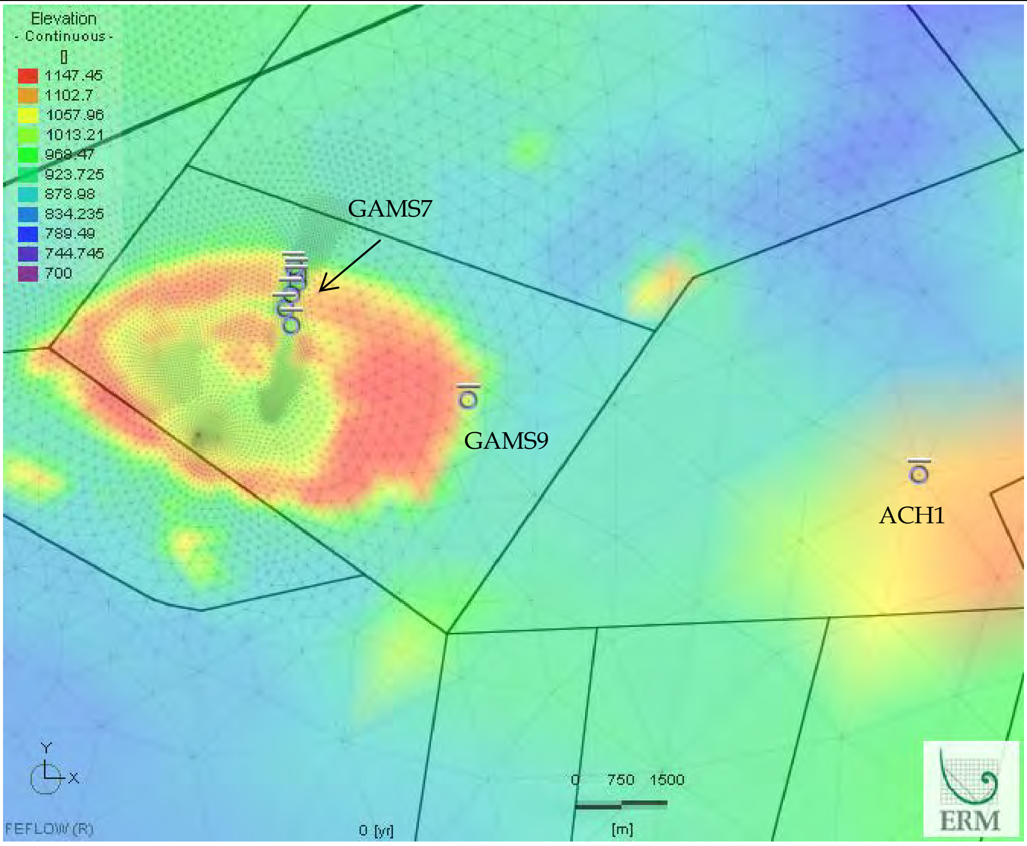
Figure 6.1 Location of Abstraction Boreholes



Springs

Eight springs were implemented in the model using *Seepage Face BCs (Dirichlet* BC with a maximum flow constraint = $0m^3/d$). The spring locations are depicted in *Figure 6.2*. Spring GAMS9 to the east of the Gamsberg and ACH1 on the Achab-se-Berge were included as well as six springs along the Kloof including GAMS7. The locations of springs in the Kloof were based on field observations.

Figure 6.2 Location of Modelled Springs

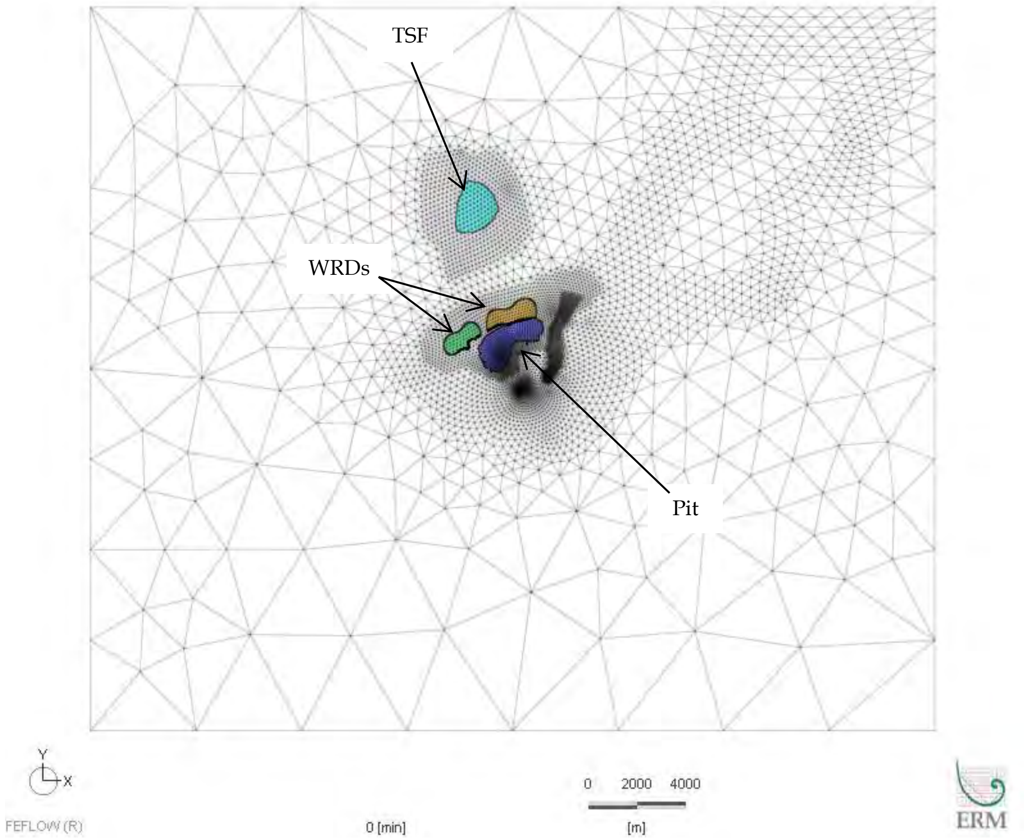


6.1.3 Model Geometry and Discretisation

The numerical simulation of groundwater flow and transport by finite element method as used in FEFLOW requires a spatial discretization of the aquifer parameters across a triangular mesh. The *Triangle Mesh Generator* (Shewchuk, 1996) was used to generate a triangular mesh with local refinement in the project area (x20) and a one kilometre wide buffer zone around the project area (x10). Therefore, element size in the groundwater model grid is variable.

Figure 6.3 depicts the mesh including refinement used for the steady state model, containing 11 887 elements and 5 968 nodes in total. The model was subsequently refined during transient flow and transport modelling (*Section 6.3.1*).

Figure 6.3 Model Mesh



Notes: TSF Tailings Storage Facility
WRDs Waste Rock Dumps

6.1.4 Model Dimension

The model dimension should be chosen based on the dimensions needed to describe the key processes controlling groundwater movement. For this modelling exercise a two-dimensional (2D) areal flow model was constructed (see Section 5.3).

6.1.5 Aquifer Type

Based on the available aquifer test data, the responses observed in the tested boreholes indicate confined behaviour as expected from a fractured aquifer (refer *Section 4.5*). Therefore the aquifer was modelled as a confined aquifer.

6.1.6 Hydraulic Properties

Transmissivity

In a 2D confined model, *transmissivity (T)* is used directly as an input parameter. T relates to *hydraulic conductivity (K)* as follows:

$T = K \cdot D$ where D is aquifer thickness

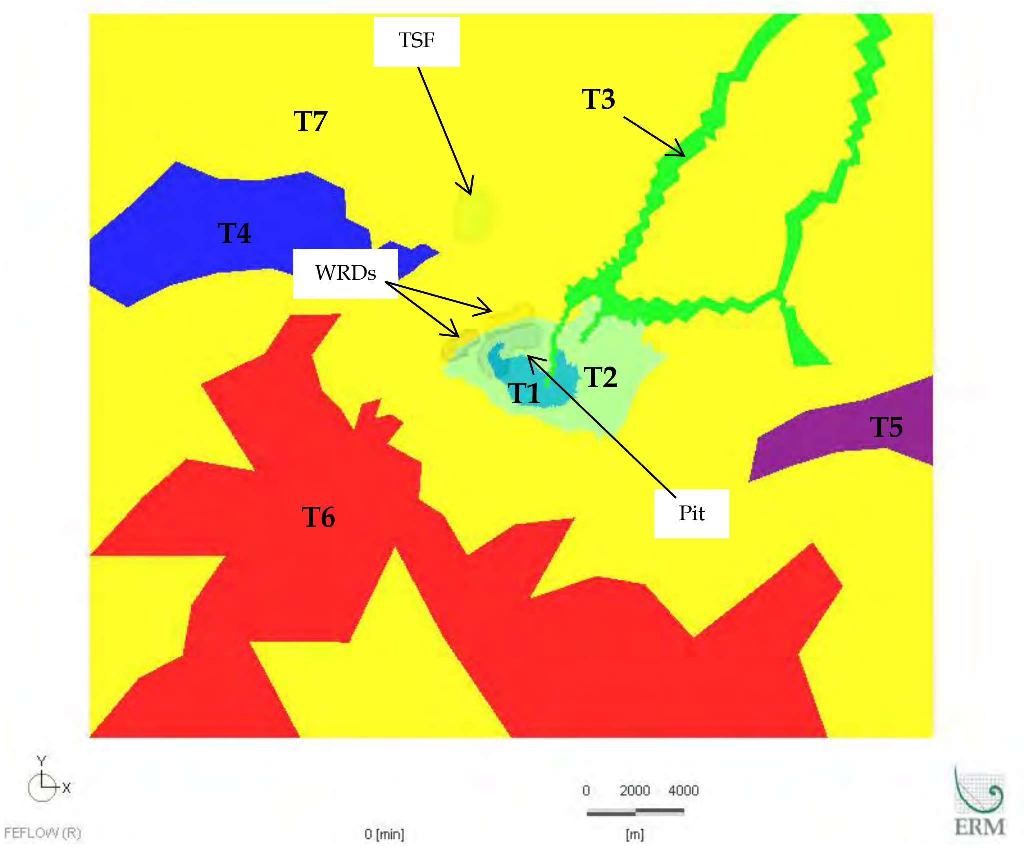
Different T zones were implemented broadly based on surface geology (*Section 3.5.1, Figure 3.10*) and T was calibrated during steady state calibration. T zones are depicted in *Figure 6.4*.

- T1 – Gamsberg inner zone (amphibolite, quartz-muscovite schist, Gams iron formation, dark quartzite and white quartzite at depth);
- T2 – Gamsberg outer zone (mainly white quartzite, sillmanite schist);
- T3 – Drainage lines to north-east (fault-zone);
- T4 – Aggenys-se-Berge;
- T5 – Achab-se-Berge;
- T6 – Sediments; and
- T7 – Plains (granite gneiss).

The fault-zone inferred by AATS (2000) to the south and west of the Gamsberg was not implemented in this model for following reasons:

- Although the western portion of the fault is marked on the 1 : 250 000 geological map (Figure 3.8), the portion close to the Gamsberg was inferred by AATS (2000);
- One borehole (BLH3) had an elevated K value based on slug tests (AATS, 2000) and was interpreted to have intersected a fault;
- AATS (2000) assumed that the intersected fault was an extension of the major fault indicated further west on maps, and included the fault to model a worst case scenario based on the previous position of the tailings storage facility, which was moved to the north; and
- This fault is not expected to have any influence on the results of this modelling exercise due to the location of potential sources and receptors.

Figure 6.4 *Transmissivity Zones*



6.2 STEADY STATE CALIBRATION

During steady state calibration groundwater transmissivity was optimized in order to best fit groundwater elevations observed in the model domain. Surface topography was used as an additional optimisation criterion in areas where no groundwater levels were available, ie model was not allowed to be flooded.

Calibration was performed using both manual and automated methods. For automated parameter estimation methods PEST (Doherty, Brebber, & Whyte, 1994) was used.

6.2.1 Observation points

Available groundwater level data was studied carefully and suitable boreholes were selected as observations for model calibration (*Table 6.2*). Sources included AATS (2000), SRK (2010), Golder (2007) and the recent ERM hydrocensus (*Section 2.2.1 and Table 4.2*). Abstraction boreholes and springs were excluded from calibration.

Table 6.2 Observation Data

BH_ID	X (m)	Y (m)	Groundwater Level (mamsl)
AR_4	299924	6766289	875
AR_5	298288	6764796	861
AR_7	299667	6768481	917
AR_9	301250	6770394	926
AR11	299975	6771506	942
BH_1	305582	6763141	957
BH_3	302053	6761867	1003
BH11	302453	6761774	992
BH5	303692	6765160	909
BLH3	296700	6762667	822
BLH4	297929	6762933	841
DG_67	301912	6762119	1002
DG_68	302104	6762032	1005
DG_77	302492	6762353	992
GAM_75	303387	6761849	988
GAMB_1	302576	6762724	987
GAMB_4	302136	6761748	1008
GAMB_5	302239	6761931	998
GAMS_10	307711	6764644	834
GAMS_3	304001	6762363	990
GAMS_8	302420	6766451	877
LUS1	307422	6755398	851
No1	296591	6770869	929
No10	302423	6761925	985
No16	308028	6757770	864
No23	304961	6764856	889
No25	310235	6767651	842
No27	316036	6764674	833
No28	313482	6763587	833
No4	304749	6766594	858
No6	301909	6764417	998
No8	300731	6763632	986
No9	301259	6763315	987

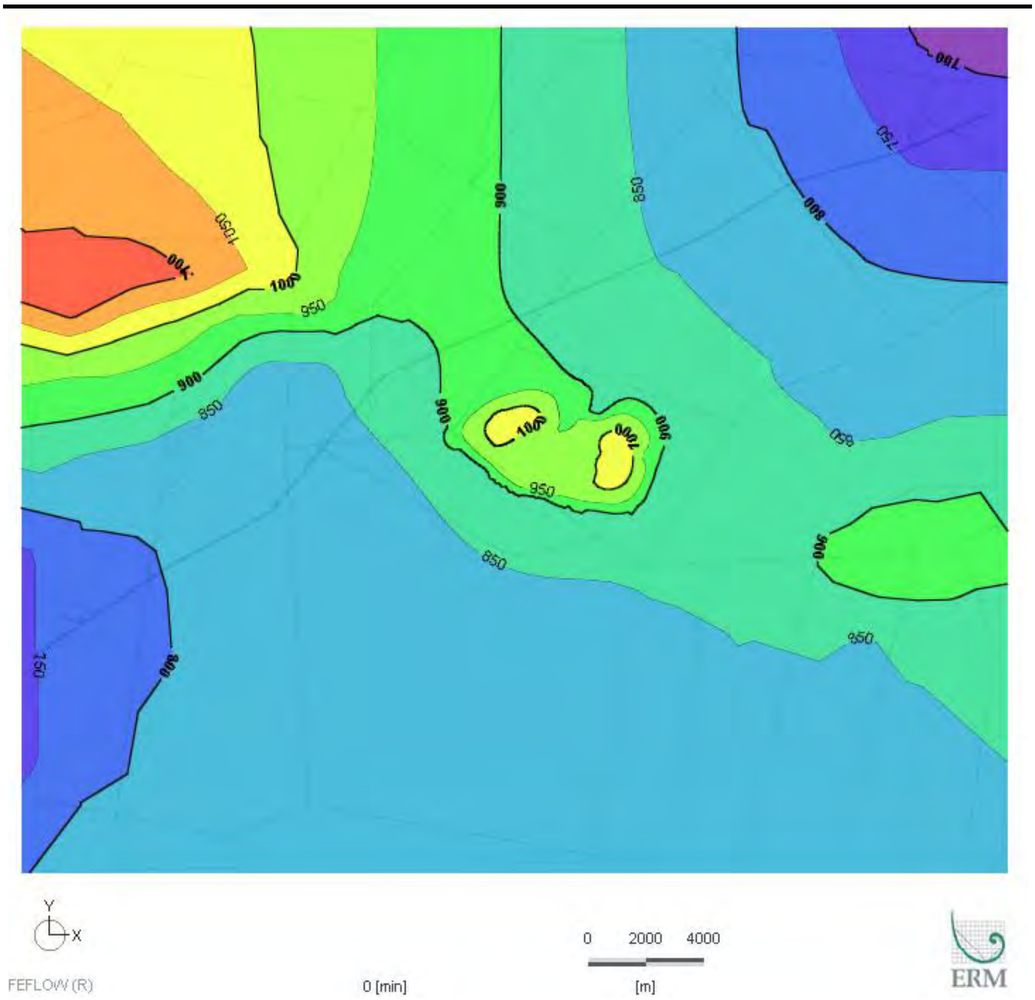
Notes: Co-ordinates in WGS84 – UTM 34S
BH ID Borehole Identification

6.2.2 *Steady State Calibration Results*

Groundwater Levels and Flow Direction

Piezometric heads for the calibrated steady state models range from 650 mamsl in the north-east of the model domain to 1,130 mamsl on the Gamsberg. The main groundwater flow directions are from the Gamsberg in north-easterly and south-westerly direction (*Figure 6.5*).

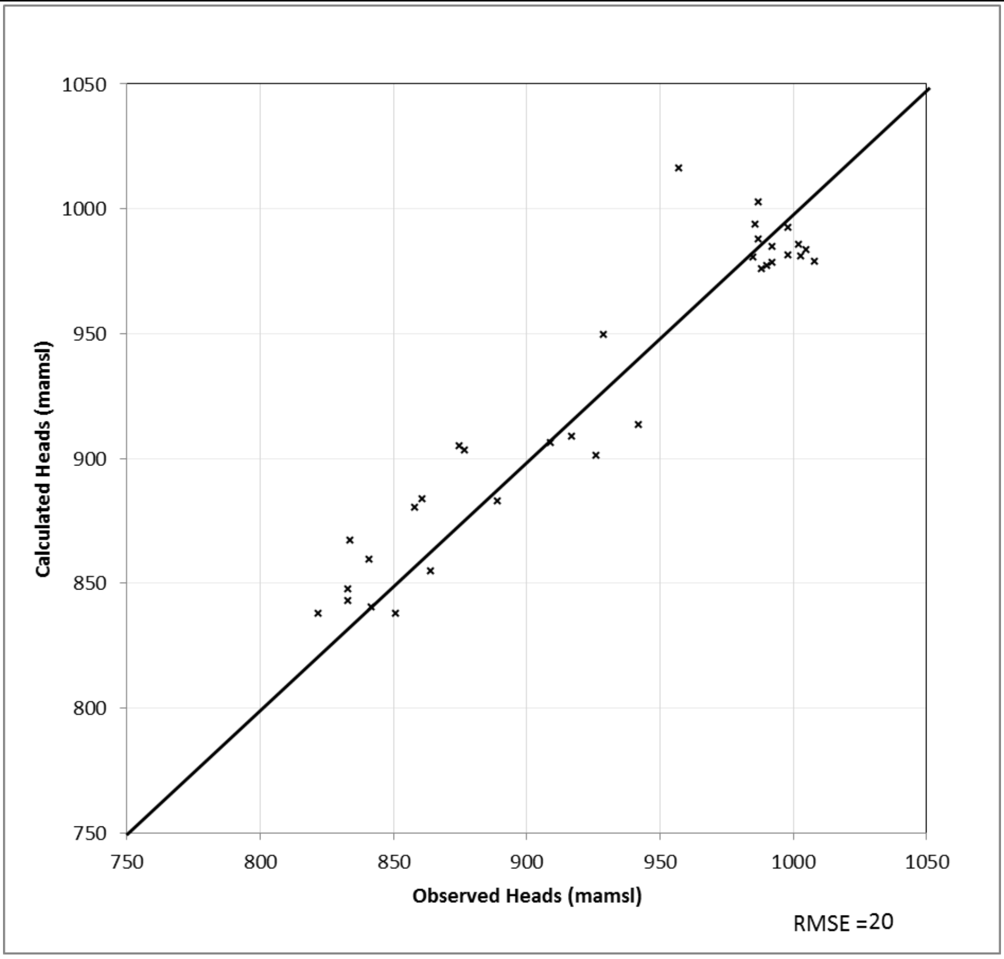
Figure 6.5 Steady State Piezometric Head Distribution



Scatter Diagram

Calculated piezometric heads were compared to observed heads in *Figure 6.6*. The root mean square error (RMSE) of the model calibration is 20 m, which is considered to be sufficiently small, given the model area, limited data and given that the maximum head difference over the model area is 480 m.

Figure 6.6 Scatter Diagram of Calculated vs. Observed Heads



Calibrated Parameters

Optimised transmissivity (T) values are between $5 \cdot 10^{-3}$ and $1 \cdot 10^{1}$ m^2/d (*Table 6.3*). Higher T values were obtained for T3 (drainage lines to north-east) and T6 (quaternary sediments) enabling water drainage in the plains towards the modelled outflow boundaries.

Table 6.3 Optimised Transmissivity (T) Values

T Zone	Description	T (m^2/d)
T1	Gamsberg inner zone (amphibolite, quartz-muscovite schist, Gams iron formation, dark quartzite and white quartzite at depth);	3E-01
T2	Gamsberg outer zone (mainly white quartzite, sillmanite schist)	3E-02
T3	Drainage lines to north-east (fault-zone)	7E+00
T4	Aggenys-se-Berge	1E-01
T5	Achab-se-Berge	5E-03
T6	Quaternary Sediments	1E+01
T7	Plains (granite gneiss)	4E-01

Groundwater Balance

The steady state water budget of the whole model domain is shown in *Table 6.4.* In flux represents water flowing into the groundwater system (aquifer/model) and out flux represents water leaving the system (groundwater discharge).

Water flows into the model domain via recharge on the inselbergs (535 m^3/d) and leaves the model through regional groundwater outflows in the north-east (330 m^3/d) and south-west (150 m^3/d) of the model domain. Further, groundwater is removed from the system by water abstraction from farm boreholes (50 m^3/d) and through springs. Discharging springs includes GAMS7 in the Kloof (1 m^3/d) and GAMS9 to the east of the Gamsberg (4 m^3/d).

It was not possible to re-create the conditions of the Kloof springs (i.e groundwater at surface at discrete points). Only one of the modelled springs in the Kloof actively discharges water under pre-mining conditions (GAMS7). This is an effect of the scale of the model, indicating that small scale features cannot be represented in the regional model. This indicates that the groundwater table may be not so close to surface in places, and local scale structural control allows groundwater to seep to surface at the springs combined with topographical control.

Also, spring ACH1 east of the Gamsberg did not flow in the model. However, there is very limited data available for this region (Achab-se-Berge) and considering the distance of this spring from the planned mining operations, this does not represent a major issue.

In a steady state system total inflow and total outflow fluxes are equal. Total flux into and leaving the model domain equals 535 m^3/d.

Table 6.4 Groundwater Budget Steady-State Calibration

Flow Component	In-Flux (m^3/d)	Out-Flux (m^3/d)
Recharge	535	
Regional Groundwater Outflow		480
Well Abstraction		50
Springs		5
Sums	**535**	**535**

Confidence Levels

PEST provides 95 % confidence limits for estimated parameter values, which are displayed in *Table 6.5*. Confidence limits give an indication of the parameter uncertainty where high confidence limit intervals indicate uncertain parameters.

The most uncertain parameter is T5 (Achab-se-Berge) and T4 (Aggenys-se-Berge), where no observation points were available for calibration. 95 % confidence intervals for other parameters are mostly within one order of magnitude.

Table 6.5 ***95% Confidence Intervals (PEST)***

T Zone	Calibrated Value (m2/d)	95% Lower Limit	95% Upper Limit
T1	3E-01	2E-02	5E+00
T2	3E-02	2E-02	5E-02
T3	7E+00	3E+00	1E+01
T4	1E-01	6E-03	1E+00
T5	5E-03	5E-229	4E+219
T6	1E+01	5E+00	3E+01
T7	4E-01	2E-01	1E+00

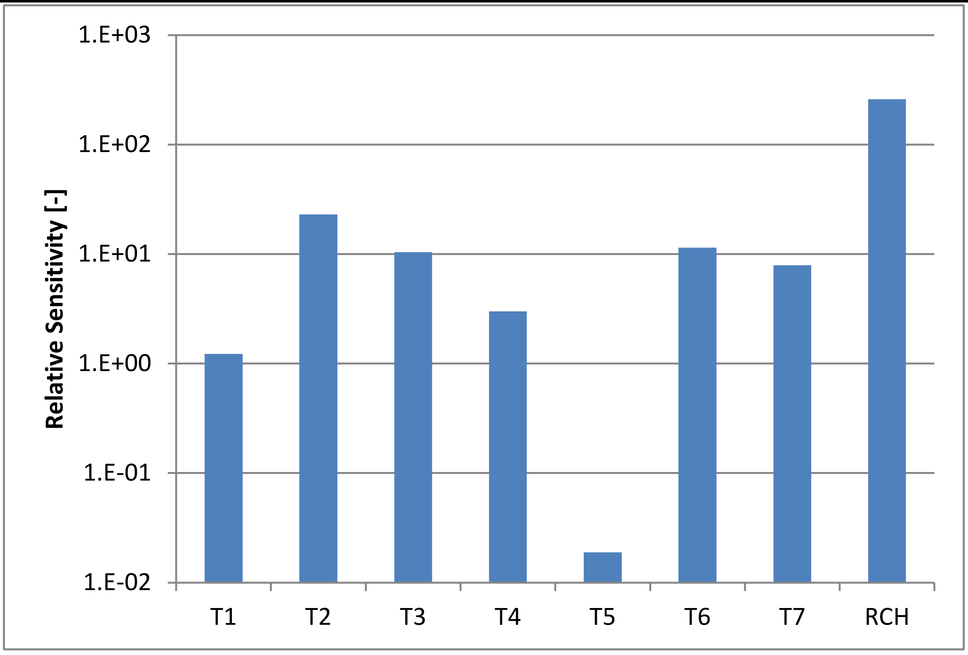
Sensitivity Analysis

Sensitivity analysis was carried out using PEST for transmissivity and recharge. *Figure 6.7* presents the relative sensitivities for the respective parameters. Relative sensitivity of a parameter is a measure of the changes in model outputs that are incurred by a change in the value of the parameter (Doherty, Brebber, & Whyte, 1994).

The most sensitive parameter is recharge (RCH). Sensitivities of transmissivities are generally one to two orders of magnitude lower than of recharge. The most sensitive transmissivity parameter is T2 (Gamsberg outer zone) followed by the T6 (quart. sediments), T3 (drainage lines to north-east) and T7 (plains).

Changes in sensitive parameters (RCH, T2) will have a greater impact on the model output than less sensitive parameters.

Figure 6.7 Sensitivity Analysis Results

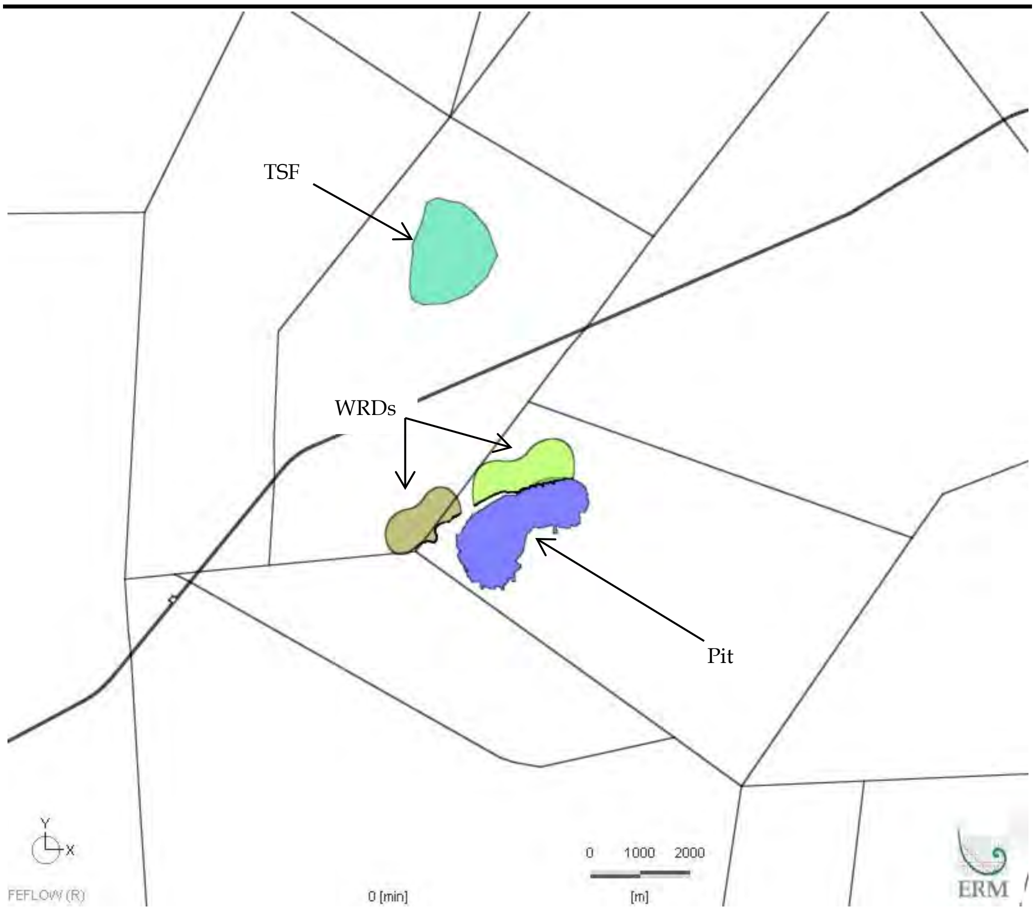


6.3 MINE AND POST CLOSURE MODEL SETUP

During model setup, the steady state groundwater flow model is converted into a transient ("time-dependent") groundwater flow model in order to run a number of simulations and predictive model scenarios.

The planned open pit mine with associated waste rock dumps (WRDs) and a tailings storage facility (TSF) were modelled. The location of these infrastructure components is presented in *Figure 6.8*.

Figure 6.8 Modelled Mine Infrastructure



The geometry of the model domain, boundaries and discretization were taken from the steady state model as well as the optimized time-independent parameters like transmissivities and recharge values. Further, the solution of the calibrated steady state model was used as initial hydraulic head distribution for the transient models.

The model setup for the mining and post-closure models is detailed in the following sections.

6.3.1 Groundwater Flow Model

Open Pit Mining

The open pit mining operation was implemented in the models using yearly time steps according to the mine plan and schedule supplied by the client. Mining progress plans (mining schedule) indicate the stages of the proposed mine on an annual basis over a time period of 19 years. The open pit is partitioned into five *pushbacks*, which are depicted in *Figure 6.9*. The yearly production schedule detailing the pit bottom per year is detailed in *Annex B*.

Open pit groundwater inflows were modelled using *Hydraulic Head (Dirichlet) BCs* with the head value of the BC equal to the pit bottom in the respective pushback at any given time (*Table 6.6*). A maximum flow constraint was implemented to prevent recharge from the pit.

Figure 6.9 Pushbacks

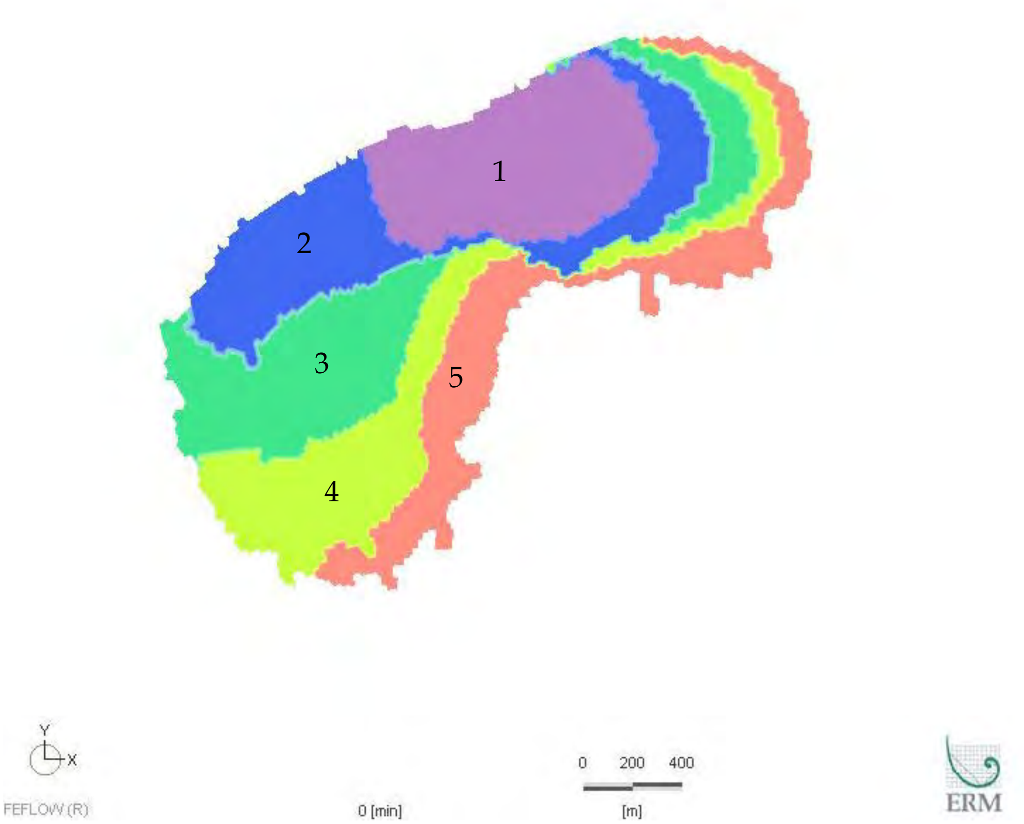


Table 6.6 Time Series Pit Bottom Elevation

Push back 1		Push back 2		Push back 3		Push back 4		Push back 5	
Time [days]	Constant Head Elevation [mamsl]	Time [days]	Constant Head Elevation [mamsl]	Time [days]	Constant Head Elevation [mamsl]	Time [days]	Constant Head Elevation [mamsl]	Time [days]	Constant Head Elevation [mamsl]
365	1100	1095	1100	1095	1100	1095	1100	2920	1100
730	1040	1460	1040	1460	1080	1460	1100	3285	1100
1095	950	1825	970	1825	1060	1825	1100	3650	1100
1460	870	2190	880	2190	1020	2190	1100	4015	1000
1825	800	2555	780	2555	970	2555	1100	4380	1000
2920	730	2920	730	2920	890	2920	1090	4745	960
4380	700	4380	700	3285	840	3285	1010	5110	910
5840	650	5840	650	3650	800	3650	950	5475	840
7300	550	7300	550	4015	740	4015	930	5840	750
				4380	700	4380	850	6205	680
				5840	650	4745	790	6570	640
				7300	550	5110	730	6935	570
						5475	680	7300	550
						5840	650		

Push back 1		Push back 2		Push back 3		Push back 4		Push back 5	
Time [days]	Constant Head Elevation [mamsl]	Time [days]	Constant Head Elevation [mamsl]	Time [days]	Constant Head Elevation [mamsl]	Time [days]	Constant Head Elevation [mamsl]	Time [days]	Constant Head Elevation [mamsl]
						7300	550		

Groundwater recharge over the pit void whilst being mined was set at zero. The groundwater model results therefore calculated the net volume of groundwater inflow into the pit, and do not contain the additional volume of direct rainfall to the open pit. These were, however, added to the pit water balance.

Waste Rock Dumps

A raised water table can be expected under WRDs compared to the pre mining situation, caused by the increase in recharge over the dump. This is in turn caused by the disruption of natural material, increase in hydraulic conductivity and the higher porosity of the dumps reducing the amount of surface runoff and increasing the amount of infiltration. An increase in recharge to 20% MAP (30 mm/a) was incorporated in the model over the footprint of the two WRDs (Vermeulen, 2006).

Due to the expected high porosity and hydraulic conductivity of the waste rock material, it is assumed that no groundwater mounding will happen in the dumps. Therefore, toe seeps were modelled at ground level using *Hydraulic Head (Dirichlet) BCs* with variable head based on topography, including a maximum flow constraint to prevent inflow.

Tailings Storage Facility

Tailings (slurry) deposition will commence in year 2 and continue up until the end of mining in year 19 according to the mine plan provided by the client. For the geochemical assessment a TSF water balance was estimated based on the available data (*Geochemistry Specialist Study*).

Based on information received from Ciaran Molloy (AMEC), the following was assumed:

- A saturated pond will form on the surface of the TSF with an area of 30% of the total surface area of the top;
- The phreatic surface within the TSF was assumed at one third of the embankment height at the respective time during operation; and
- The embankment height will increase linearly with time up to the maximum height of 70 m and initial elevation is assumed at 950 mamsl.

The TSF was modelled using *Fluid-Transfer BC* (3rd kind or Cauchy type) with the head set at the embankment height in the respective year of development.

The time series for the BC head is detailed in *Table 6.7*. The *in-transfer rate* was set to $5 \cdot 10^{-5}$ m/d representing the fine grained (clayey) tailings material (Freeze & Cherry, 1979).

Table 6.7 Time Series TSF Head

Year of Operation	Hydraulic Head [mamsl]
1	920.0
2	950.0
3	954.1
4	958.2
5	962.4
6	966.5
7	970.6
8	974.7
9	978.8
10	982.9
11	987.1
12	991.2
13	995.3
14	999.4
15	1003.5
16	1007.6
17	1011.8
18	1015.9
19	1020.0
20	920.0

Transient Hydrogeological Parameters

Transient simulations require a *storage coefficient* (S) to be defined. In a 2D confined model the storage coefficient relates to *specific storage* (SS) as follows:

$S = SS \cdot D$ where D is aquifer thickness

Specific storage is the amount of water per unit volume of a saturated formation that is stored or expelled from storage owing to compressibility of the mineral skeleton and the pore water per unit change in head.

No field measurements were available for this parameter and therefore a storage coefficient of 10^{-3} was implemented based on AATS (2000). The sensitivity of this parameter was tested.

Simulation Time and Discretisation

Based on the mine schedule provided by the client, a mining period of 19 years was modelled. Following mine closure, a post-closure period of an additional 100 years was modelled.

Time step size was automatically determined in FEFLOW using the *second order accurate (AB/TR[1])* predictor-corrector scheme. An initial time-step length of 10^{-3} d was used and a final simulation time of 43 800 d.

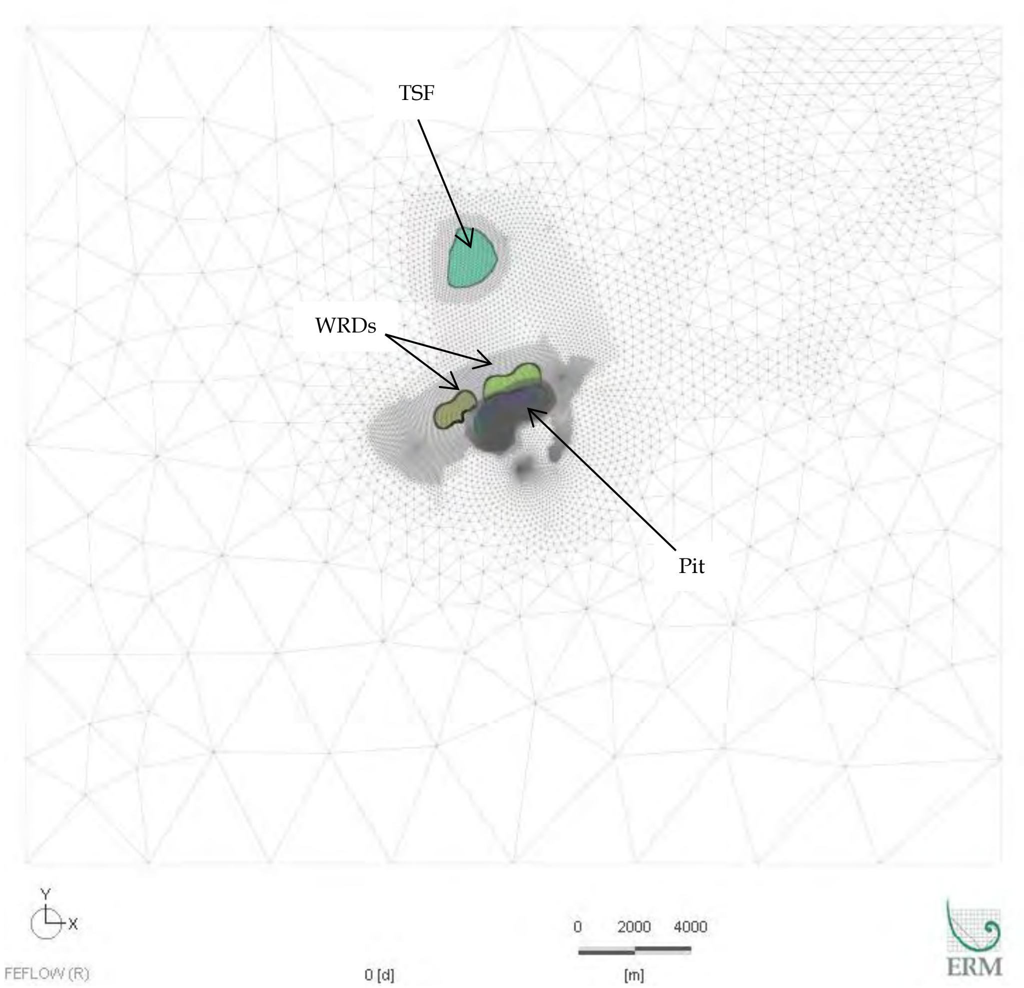
Mesh Refinement

The finite element (FE) mesh was subsequently refined in proximity of the modelled mine infrastructure (pit, WRDs and TSF) to ensure numerical stability. The final FE mesh is presented in *Figure 6.10*.

The total number of elements increased to 44 385 and nodes to 22 217. Element side lengths of approximately 20 m in and around the pit and 80 m in and around the WRDs and TSF were implemented.

[1] **Forward Adams-Bashforth/Backward Trapezoid rule (AB/TR) time integration scheme**

Figure 6.10 Finite Element Mesh used for Mine and Post-Closure Models



6.3.2 *Transport Model*

Groundwater quality impacts of the proposed project were assessed using transient solute transport modelling. Contamination sources identified in the conceptual model were considered for the transport model and included WRDs and TSF.

Sulphate (SO_4) was selected as an indicator of contamination for the transport model. Sulphate is a conservative tracer (transported via advection and dispersion), providing an indication of the maximum potential contaminant extent. The geochemical assessment (*Geochemistry Specialist Study*) identified a number of additional contaminants of concern including Fe, Mn, Zn, Cu, Cd, Pb, As and NO_3. These were, however, not modelled because they are not conservative tracers and therefore their concentration is dependent on chemical reactions, adsorption etc. In order to produce meaningful results detailed input data is required, which was not available.

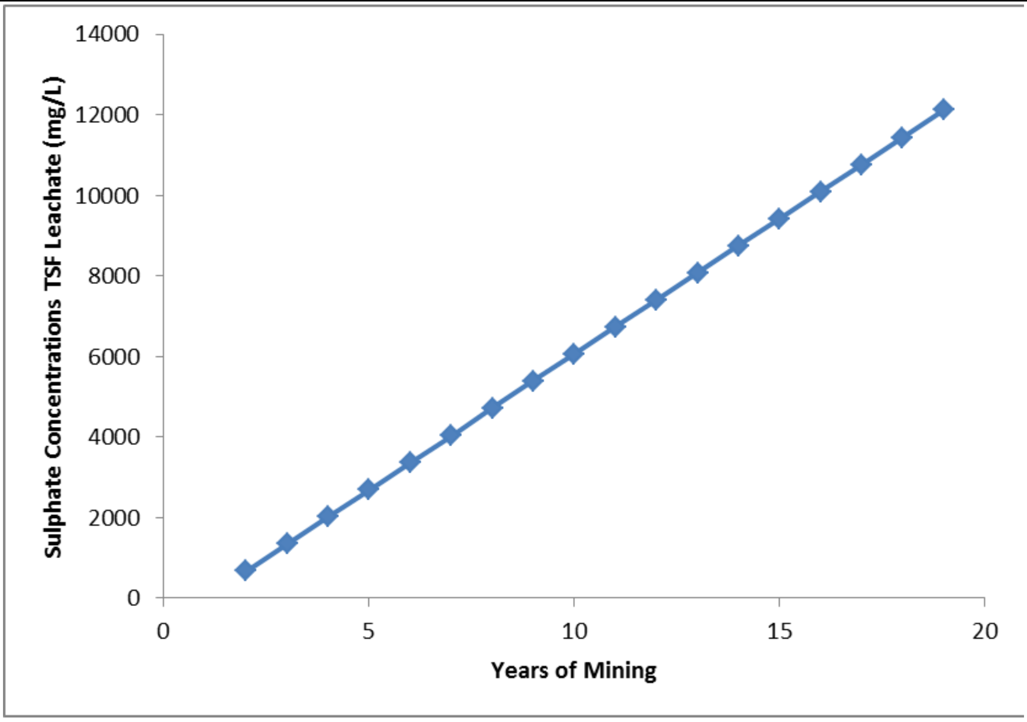
Baseline SO_4 groundwater concentrations were not implemented into the model, in order to assess the impact strictly in relation to additional contamination emerging from mining activities. The actual concentration can be estimated by adding the predicted value from the model to the measured baseline concentration (an average of 257 mg/l, and up to 1706 mg/l).

Source Terms

Sulphate leachate concentrations calculated by geochemical modelling (ERM, 2013) were implemented as *Mass-Sources* to simulate leaching of SO_4 from WRDs and TSF. For the WRDs a constant concentration of 1 770 mg/L was implemented for the entire life-of-mine and post-closure periods. The groundwater recharge was loaded with this concentration resulting in a source value of 0.15 g/m^2/day.

The SO_4 leachate concentrations for the TSF vary with time from 670 mg/L in year 2 to 12 110 mg/L in year 19 (end of mining) (*Figure 6.11*). After mine closure, the tailings disposal will cease and the remaining water body on top of the TSF will be drained. Therefore the *Mass-Source* was switched off after closure. Leachate rates were calculated by the model to between 20 and 80 m^3/d, which were loaded with the respective concentrations resulting in source values of 0.02 to 2 g/m^2/day.

Figure 6.11 Sulphate Leachate Concentration - Tailings Storage Facility



Transport Parameters

The primary mechanisms that control the transport of solutes (contaminants) in porous aquifers are *advection* and *hydrodynamic dispersion*. Advection is the mass transport caused by the bulk movement of flowing groundwater.

Contaminant transport influenced by advection only, will move in the direction of the groundwater flow at the rate of the mean groundwater flow velocity. Hydrodynamic dispersion occurs as a result of mechanical dispersion and molecular diffusion.

Dispersive spreading causes a gradual dilution of the contaminant plume within and transverse to the main flow direction. Solutes that are controlled primarily by advection and dispersion are termed *conservative*. Anions, such as chloride, sulphate or nitrates are conservative tracers and its migration in groundwater is therefore primarily controlled by advective and dispersive flux.

A number of reasonable assumptions for transport parameters had to be made because of the lack of site specific data, which are detailed in this paragraph. A sensitivity analysis was conducted in order to assess the relative sensitivity of the model with respect to a number of input parameters.

No site specific field measurements are available for dispersivity. As a conservative assumption, the horizontal longitudinal dispersivity (α_L) is approximately 0.1 of the advective travel distance of the plume. Therefore a model was run with only advection to determine the relevant plume extent, which is approximately 1 500 m. Therefore an α_L of 150 m was used in the models. Horizontal transversal dispersivity (α_T) was assumed at one tenth of α_L.

No site specific field measurements are available for molecular diffusion either. The molecular diffusion coefficient (D) is generally very small and negligible compared to the mechanical dispersion and is only important when groundwater velocity is very low. For major ions in water, D ranges from $1*10^{-9}$ to $2*10^{-9}$ m^2/s (Fetter, 2001). A conservative, effective diffusion coefficient (D*) of $1*10^{-9}$ m^2/s ($9*10^{-5}$ m^2/d) was used in the models (1).

Porosity of fractured rock is reported to be between 0.00 and 0.05 (Freeze & Cherry, 1979). A conservative value of 0.005 was used for the model. Further, an average aquifer thickness of 100m was used. *Table 6.8* shows a summary of transport parameters used in the model.

Table 6.8 Transport Parameters used in Solute Transport Model

Transport Parameter	**Unit**	**Value**
Porosity	-	0.005
Aquifer Thickness	m	100
Horizontal Longitudinal Dispersivity	m	150
Horizontal Transversal Dispersivity	m	15
Effective Molecular Diffusion Coefficient	m^2/day	9E-05

(1) [1] (Freeze & Cherry, 1979) determined $D^* = \omega D$, with ω ranging from 0.5 to 0.01 for species that are not absorbed onto the mineral surface. A conservative value of 0.5 was therefore assumed for ω.

6.3.3 *Model Setup Summary*

A schematic sketch of the mining processes and their representation in the numerical model is shown in Figure 6.12 for during mining, and Figure 6.13 for post mining, which summarises the input parameters described above.

Figure 6.12 Model representation of mining processes

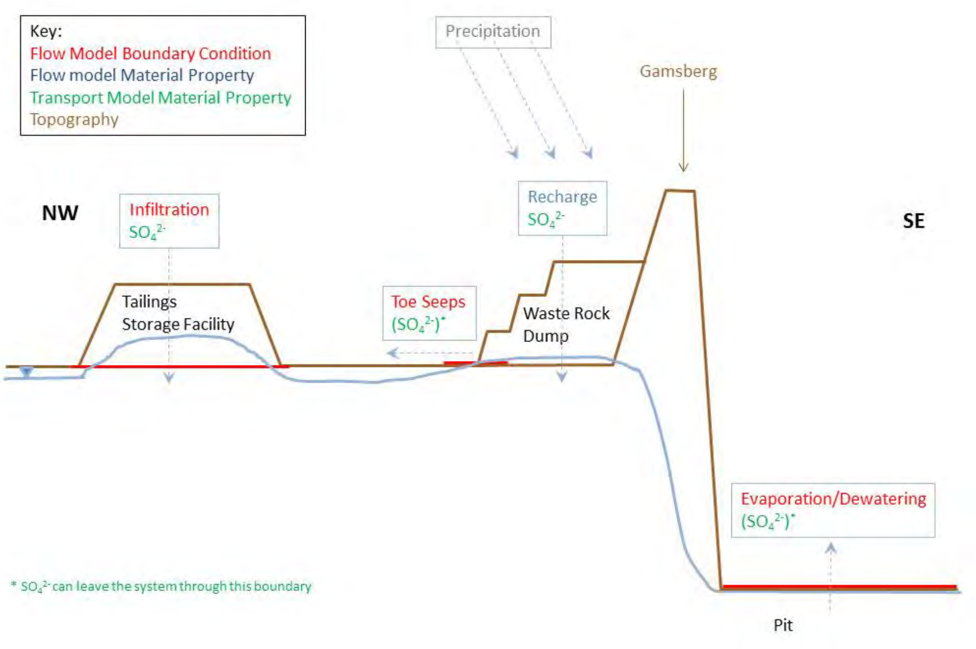
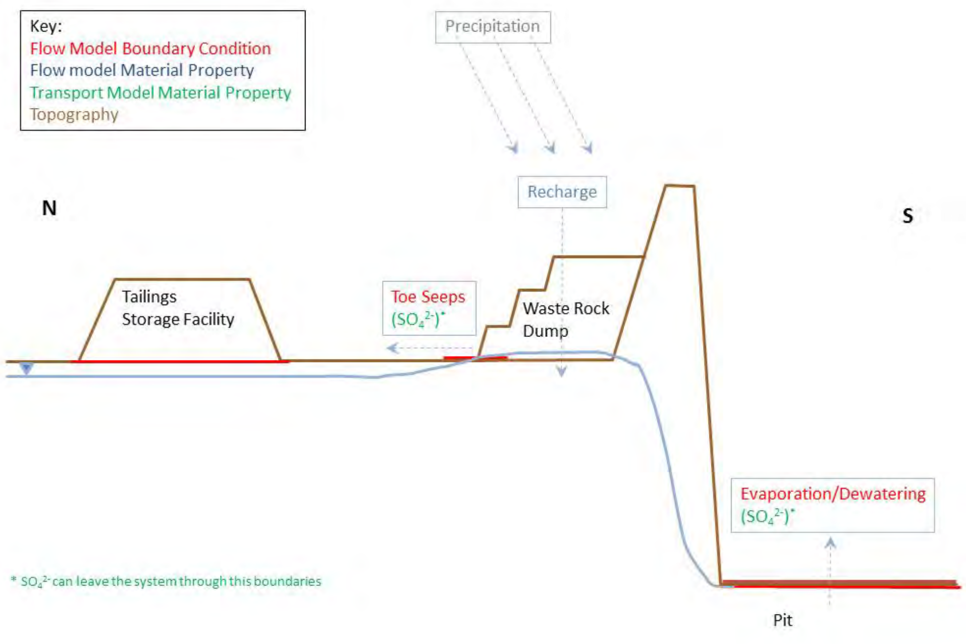


Figure 6.13 Model representation of post operation processes



7 MINE AND POST CLOSURE MODEL RESULTS

7.1 FLOW MODEL RESULTS

7.1.1 *Pit Inflow Rates*

Pit inflow rates were modelled for the life of mine and 100 years post closure. The pit inflow rates averaged for each year are given in *Table 7.1*. Inflow rates increase from 0 L/s in year one to 10 L/s (890 m^3/d) in year 19. AATS (2000) had a result of 8 L/s as the maximum inflow – thus these results are similar. After mine closure the inflow rates steadily decrease to 3 L/s (240 m^3/d) at 100 years post-closure (year 119), because the gradient towards the pit is reduced.

Table 7.1 Yearly Pit Inflow Rates

Year	Pit Inflow Rates in L/s	Pit Inflow Rates in m^3/d
1	0	0
2	0	0
3	1	70
4	3	250
5	3	270
6	3	280
7	5	440
8	5	430
9	4	340
10	3	240
11	5	470
12	4	350
13	5	470
14	5	400
15	6	560
16	7	570
17	6	520
18	9	760
19	10	890
69	3	300
119	3	240

A simplified pit water balance is shown in *Table 7.2*. Water sources in the pit water balance are (i) groundwater inflows (pit inflows), (ii) direct rainfall into the pit and (iii) surface water run-off into the pit; and the only sink is evaporation.

Following a conservative approach, a relatively high annual rainfall of 180 mm/a and a relatively low evaporation rate of 2 650 mm/a was assumed. This simplified water balance does not take into account surface water run-off into the pit. At the time of this assessment, the surface water run-off into the pit was only available for the post-closure period (5 m^3/d). However, compared to the overall deficit this volume is negligible.

The water balance calculation suggests that there is a water deficit in every year due to the high evaporation in the area hence the maximum inflow of 10 L/s during year 19 is unlikely to be visible. Therefore it is currently believed that there will be no need for active pumping on a regular basis. However, due to the nature of rainfall patterns in the area (*Section 3.3*), it is possible that periodical pumping is needed following rain events.

Table 7.2 Yearly Pit Water Balance

	Sources		Sink	Balance
Year	**Groundwater Inflows [m3/d]**	**Direct Rainfall [m3/d]**	**Evaporation [m3/d]**	**[m3/d]**
1	0	280	4 170	-3 890
2	0	280	4 170	-3 890
3	70	280	4 170	-3 820
4	250	280	4 170	-3 640
5	270	580	8 540	-7 690
6	280	580	8 540	-7 690
7	440	580	8 540	-7 520
8	430	910	13 370	-12 030
9	340	910	13 370	-12 120
10	240	910	13 370	-12 220
11	470	910	13 370	-11 990
12	350	1 200	17 620	-16 070
13	470	1 200	17 620	-15 960
14	400	1 200	17 620	-16 030
15	560	1 200	17 620	-15 860
16	570	1 480	21 740	-19 700
17	520	1 480	21 740	-19 750
18	760	1 480	21 740	-19 510
19	890	1 480	21 740	-19 380
69	300	1 480	21 740	-19 970
119	230	1 480	21 740	-20 030

7.1.2 Hydraulic Head Change and Drawdown Cones

The modelled change in hydraulic head across the modelled domain is shown in *Figure 7.1* (north to south) and *Figure 7.2* (west to east) as cross-section graphs of hydraulic head at different times, including (i) pre-mining, (ii) end of mining and (iii) 100 years after mine closure. The location of the different cross-sections is indicated in *Figure 7.3*.

The pre-mining piezometric head mimics topography and is higher under the Gamsberg than on the plains. At the end of mining the head is at the base of the pit, with steep hydraulic gradients around it due to the low hydraulic conductivity of the formation. The maximum drawdown in the pit is approximately 500m.

The water levels continue to decrease after mining and the drawdown cone expands, because the evaporation from the open pit generates a net sink to the aquifers which continues to remove water from the aquifer after mine closure.

Groundwater mounds are visible on the northern and western base of the Gamsberg due to increased recharge under the WRDs. This mound remains after closure on the western side only, whereas the one on the northern side disappears due to the expansion of the drawdown cone.

Figure 7.1 ***North-South Cross-Section detailing Hydraulic Heads at Different Mine Stages***

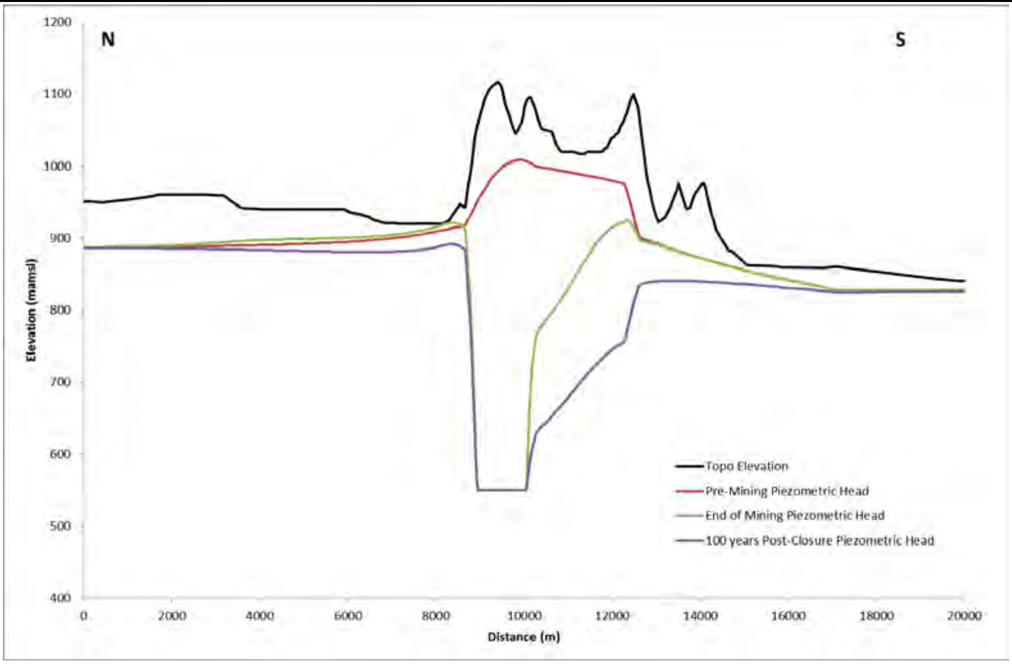


Figure 7.2 West-East Cross-Section detailing Hydraulic Heads at Different Mine Stages

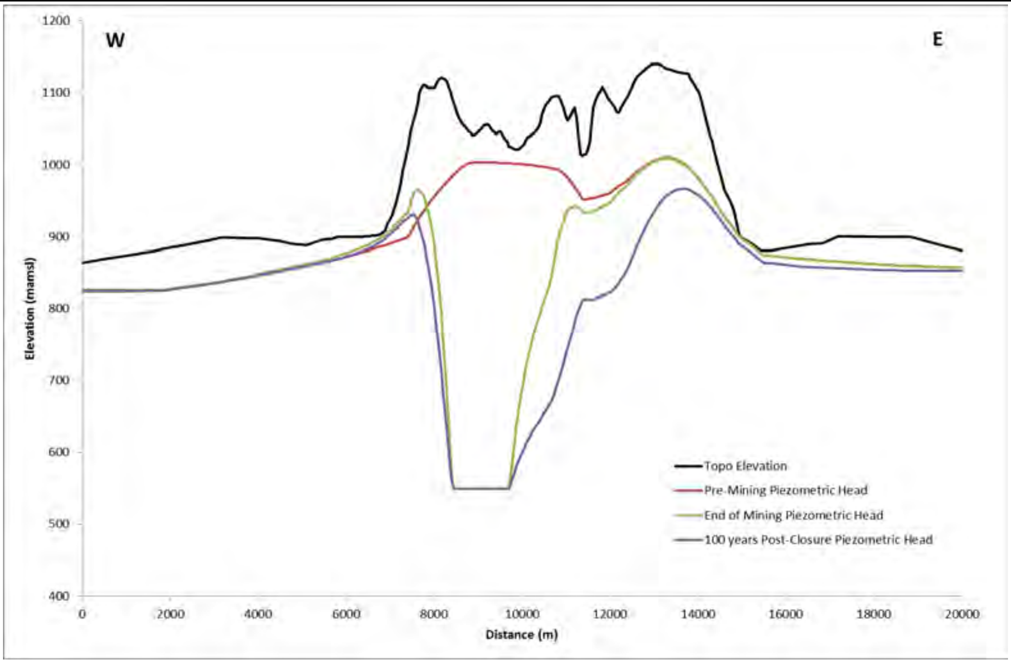
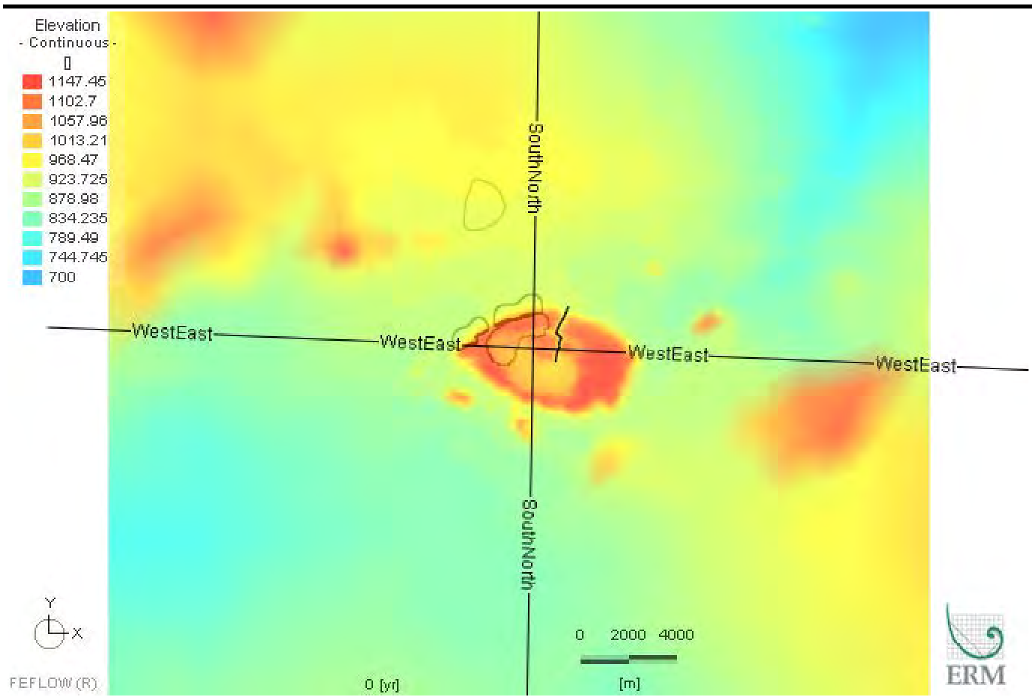


Figure 7.3 Cross-Section Locations



The change in hydraulic head with time is show in *Figure 7.4* for a number of observation points on and around the Gamsberg. The location of the observation points is shown in *Figure 7.5*.

This shows the hydraulic head reduction at points south-east and north-east of the pit (GAMS1, GAMB3, BH5), and a rise in hydraulic head at the waste rock dumps due to the increased recharge. Hydraulic heads are stabilising around 100 years post closure indicating no significant further drawdown is expected in these boreholes.

Figure 7.4 Hydraulic Head Time Series on- and surrounding the Gamsberg

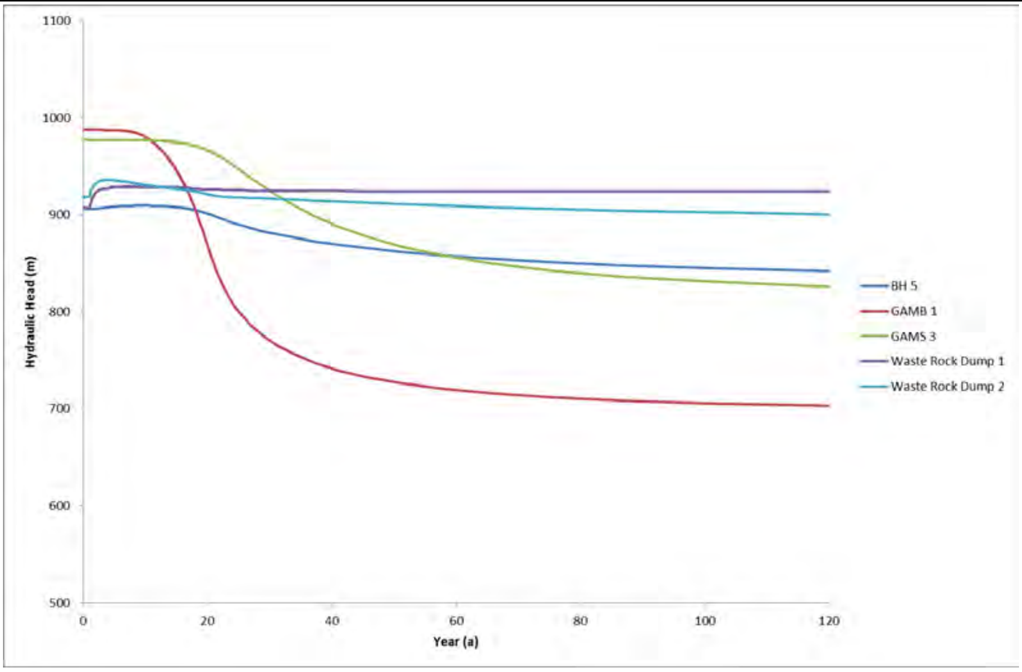
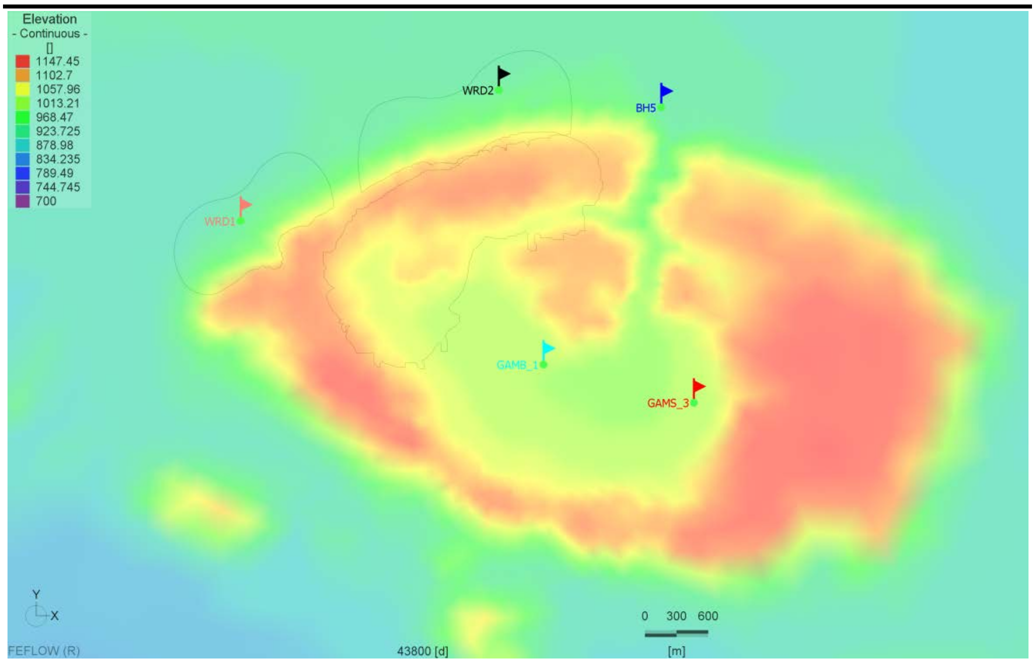


Figure 7.5 Location of Observation Points on- and surrounding the Gamsberg



Drawdown Cones

Figure 7.6, Figure 7.7, and *Figure 7.8* show the change in hydraulic head in plan view (hydraulic head at said time minus initial water level, with negative values being a drop in water level or drawdown and positive being an increase or groundwater mounding). These are presented at the end of mining, 50 years post closure and 100 years post closure. Existing (known) farm-boreholes are indicated with crosses, and labelled with the borehole ID. The drawdown cone induced by the planned mining activities develops from the pit towards the north-east, east, south and south-west. Drawdown is not expected to expand towards the west due to the increased recharge on the WRDs.

Groundwater mounds (increase of hydraulic head) develop under both the TSF and the WRDs due to increased recharge. The tailings storage facility (TSF) is modelled without a liner, and a constantly saturated pond forms on top by the piping of tailings to its surface. The total modelled groundwater mound is of approximately 70 m compared to pre-mining levels.

The modelled water level within the TSF at the end of mining equals 25 metres above initial topographic surface elevation. This represents approximately one third of the height of the dam (70 m), which is in line with the engineering of the TSF.

The pond on the TSF will be drained during mine decommissioning and the groundwater mound will steadily seep away. Modelling results suggest, that 2-3 years after mine closure, the water level will drop below surface level (bottom of the TSF). Groundwater levels are expected to reach pre-mining levels approximately 80 years post-closure. The mound underneath WRDs will remain as infiltration continues indefinitely.

The waste rock dump consists of significantly coarser material than the surrounding country rock, allowing increased infiltration, and hence is modelled with an increased recharge, from 1% MAP to 20% MAP (Vermeulen, 2006). This results in a groundwater mound of maximum 50m compared to pre-mining levels, which however was not allowed to exceed the topography (would be drained at the base of the WRD).

Figure 7.6 Hydraulic Head Change at 19 Years (End of Mining)

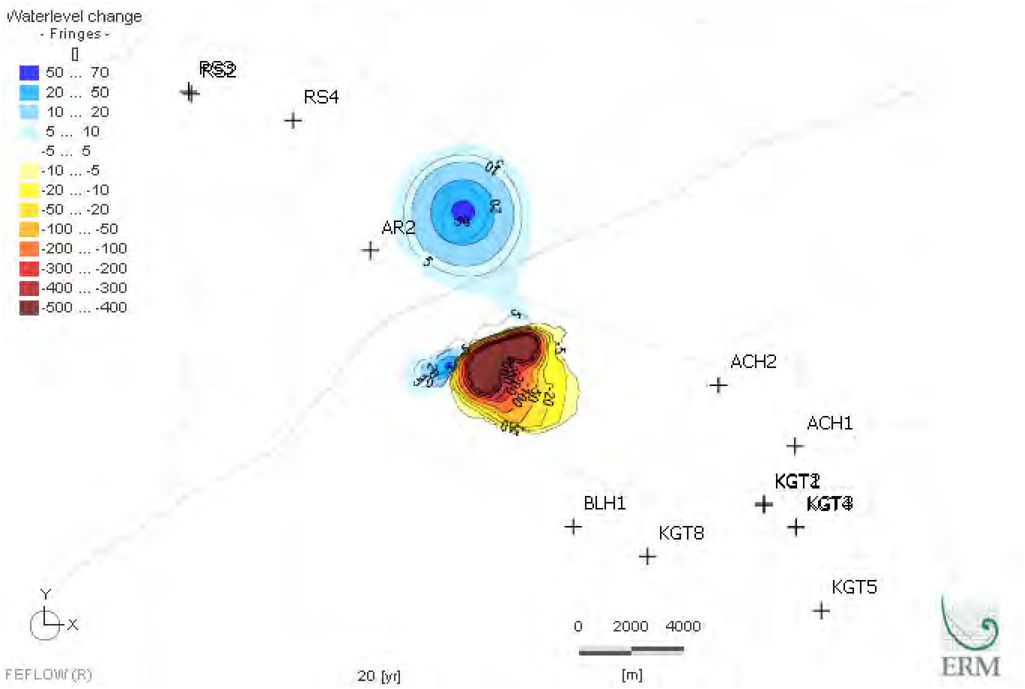


Figure 7.7 Hydraulic Head Change at 69 Years (50 Years after Mine Closure)

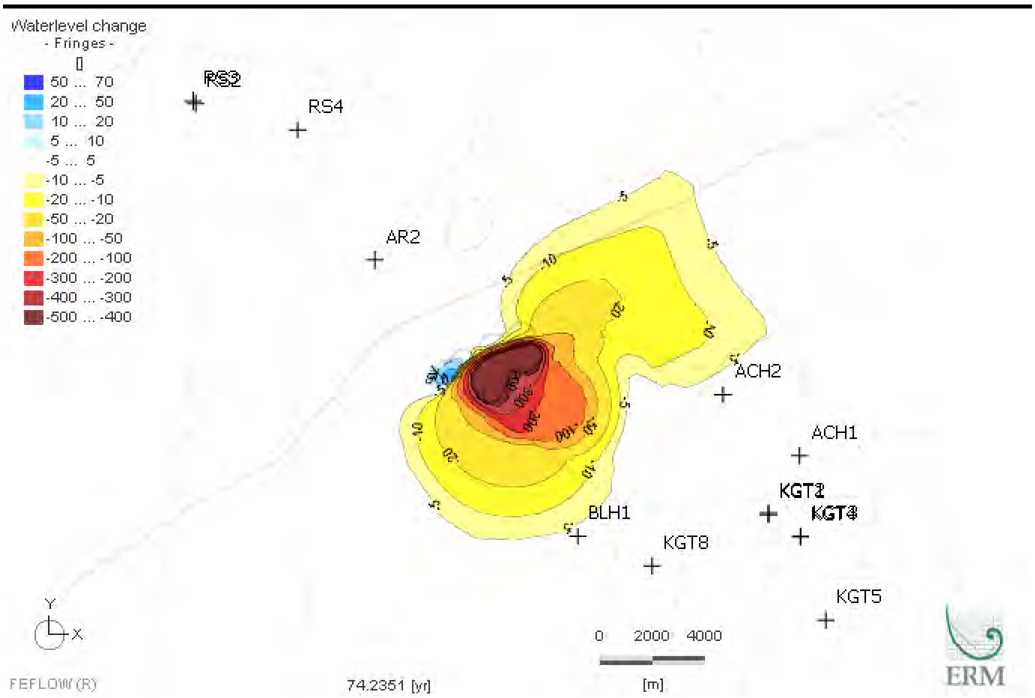
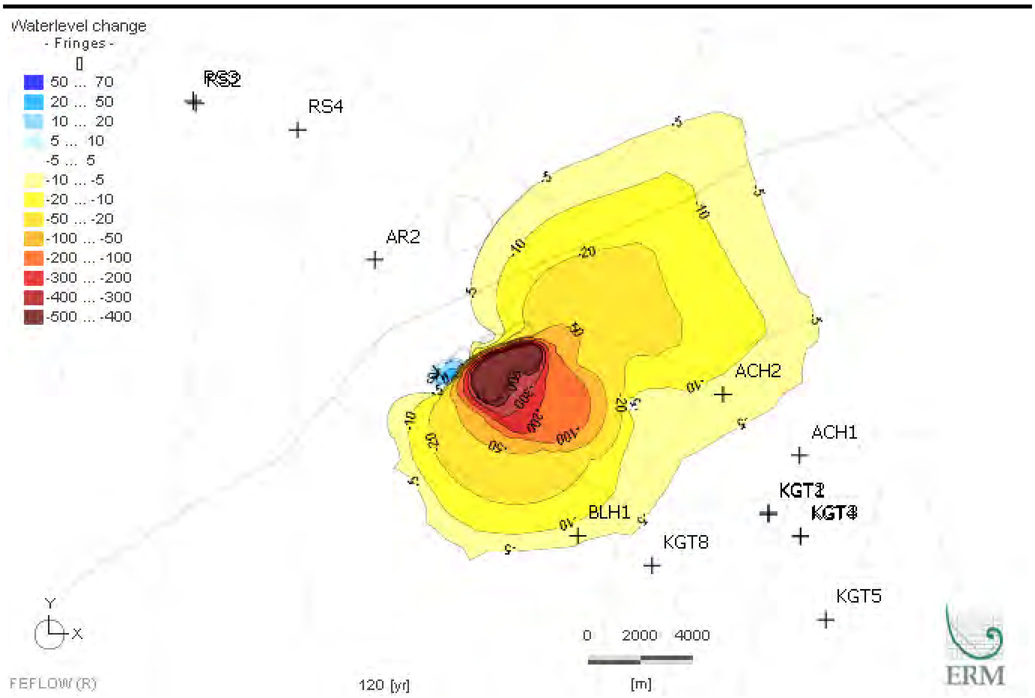


Figure 7.8 ***Hydraulic Head Change at 119 Years (100 Years after Mine Closure)***



Impact on Private Groundwater Users

Groundwater modelling indicates that most existing (known) farm boreholes experience no significant head change during mining and post-closure phases (ie less than 5m), except ACH2 (Achab) and BLH1 (Blomhoek), where model results suggest drawdowns of between 5 and 10 m 100 years after mine closure.

The predicted change in water level for each known farm borehole is given in *Table 7.3*.

Table 7.3 ***Groundwater Level Impacts at Farm-Boreholes***

Farm	Owner	Boreholes	Waterlevel Change at 19 years (end mining) in m	Waterlevel Change at 119 years (100 years post mining) in m
Achab	Girrie v/d Heever	ACH1	No significant impact	No significant impact
Achab	Girrie v/d Heever	ACH2	No significant impact	-10 to -5
Aroams	Tore van Niekerk	AR2	No significant impact	No significant impact
Blomhoek	N/A	BLH1	No significant impact	-10 to -5
Kykgat	Jan Visser	KGT1	No significant impact	No significant impact
Kykgat	Jan Visser	KGT2	No significant impact	No significant impact
Kykgat	Tertius Visser	KGT3	No significant impact	No significant impact
Kykgat	Tertius Visser	KGT4	No significant impact	No significant impact
Kykgat	Tertius Visser	KGT5	No significant impact	No significant impact
Kykgat	Tertius Visser	KGT8	No significant impact	No significant impact
Rosynebos	Danie Luttig	RS2	No significant impact	No significant impact

Farm	Owner	Boreholes	Waterlevel Change at 19 years (end mining) in m	Waterlevel Change at 119 years (100 years post mining) in m
Rosynebos	Danie Luttig	RS3	No significant impact	No significant impact
Rosynebos	Danie Luttig	RS4	No significant impact	No significant impact
Rosynebos	Sakkie v Niekerk	RS5	No significant impact	No significant impact

Impact on Groundwater Levels in the Kloof

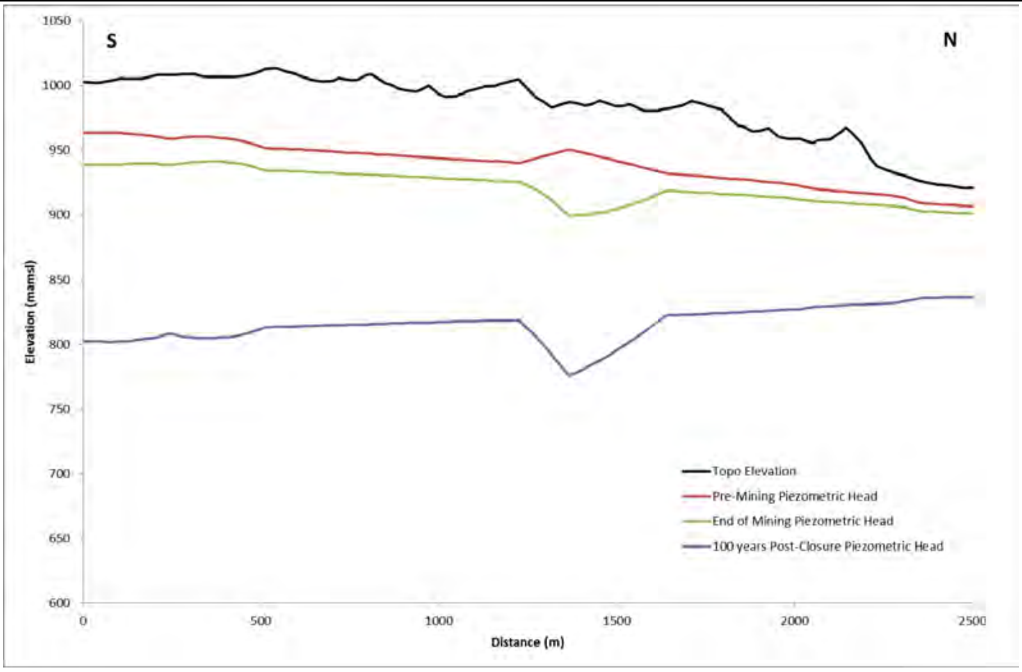
The change in hydraulic head for a cross section along to the Kloof is show in *Figure 7.9*, with different series indicating various times, including (i) pre-mining, (ii) end of mining and (iii) 100 years after mine closure.

The modelled pre-mining water table is within 50 m of topography and it was not possible to re-create the conditions of the Kloof springs (i.e groundwater at surface at discrete points). Only one of the modelled springs in the Kloof actively discharged water ($1m^3/d$) under pre-mining conditions (GAMS7). However, the model can still be used to indicate relative change of hydraulic heads in the Kloof.

The difference between the pre-mining piezometric head (red line) and the end of mining head (green line) gives an indication of the drawdown in groundwater level along the Kloof, which is 15 to 20 m during mining. At the end of mining the piezometric level in the Kloof has reduced, however the groundwater gradient is still towards the plains hence water still flows out along the Kloof at depth.

After mine closure the mine pit continues to act as a sink to groundwater flow because of the elevated evaporation rates and therefore the drawdown extent will also increase. At 100 years post closure groundwater levels in the Kloof are expected to decrease by 100-125m and hence the hydraulic gradient along the Kloof is reversed and water is flowing from the plains towards the Gamsberg (pit).

Figure 7.9 *South-North Cross-Section detailing Hydraulic Heads at Different Mine Stages along the Kloof*



7.1.3 *Impacts on Groundwater Budget (Fluxes)*

The impact of the planned mining activities on groundwater fluxes and budget is presented in *Figure 7.10* and *Table 7.4*. Fluxes at end of mining and 100 years after mine closure are compared to pre-mining fluxes (steady state model).

The pre-mining natural groundwater major inflows and outflows across the modelled area are indicated by the red bars in *Figure 7.10*, where inflows (recharge) equal outflows (boundary outflow and well abstraction).

At the end of mining (green bars) recharge has increased due to the increased recharge over the waste rock dumps. However, not all of this increased recharge is actually reaching groundwater, since 50% of it is drained at the base of the WRDs on average over the 19 operational years. In the figure only net recharge rates are displayed, ie drained portion was subtracted.

Total outflows (pit inflow, boundary outflow and well abstraction) are greater than model inflows (recharge) indicating that a part of the outflows is coming from groundwater storage. Regional groundwater boundary outflows are reduced slightly during mining (-6%) and post-closure (-14%) compared to pre-mining outflows.

Figure 7.10 Groundwater Fluxes

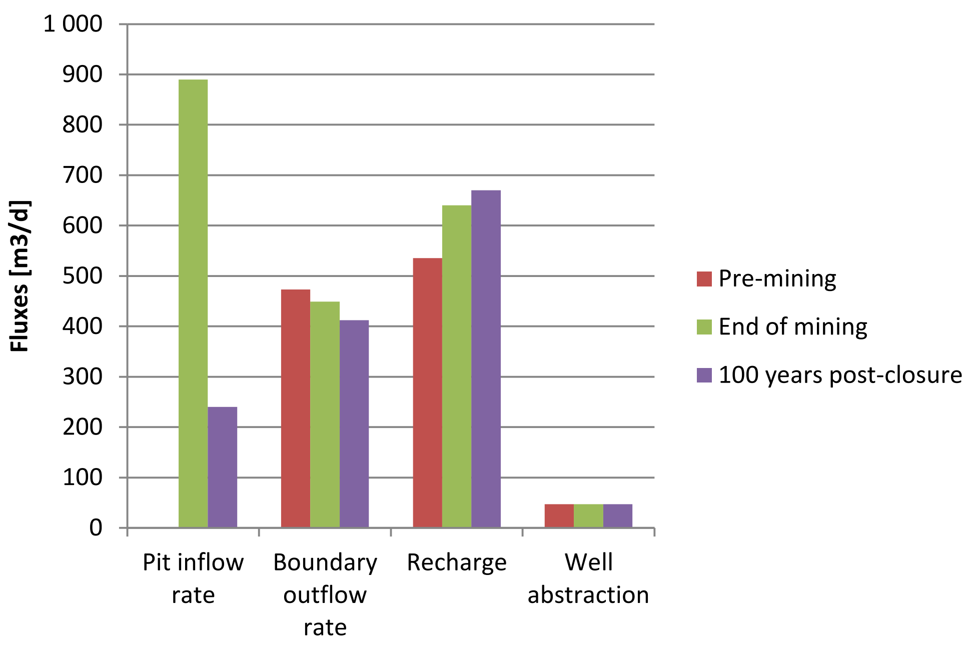


Table 7.4 Groundwater Fluxes Pre-Mining (Baseline), End of Mining and 100 Years Post Closure

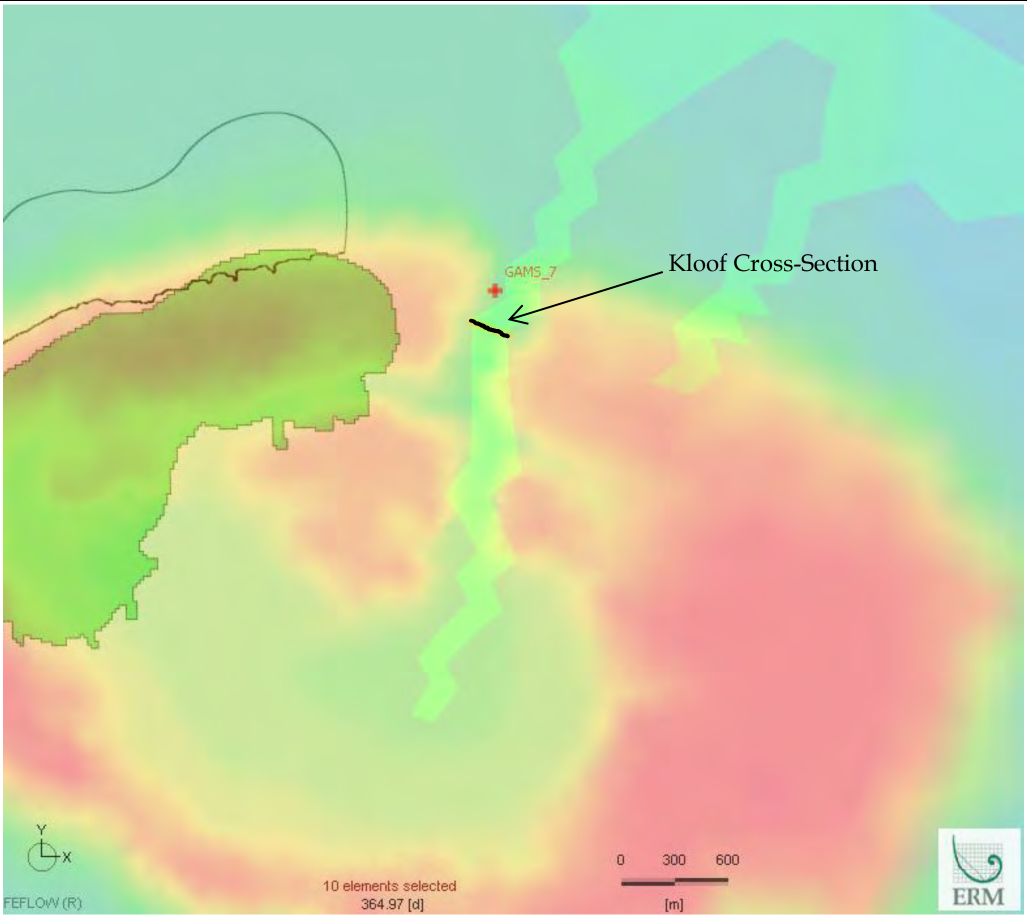
Flux [m³/d]	**Pre-Mining (Baseline)**	**End of Mining (Year 19)**	**100 Years Post Closure (Year 119)**
Pit inflow rates	0	890	240
Boundary outflow rates	480	450	410
Recharge	540	640	670
Well abstraction	50	50	50
Spring Flow (Kloof)	1	0	0
Spring Flow (East)	4	4	3
Model flow across a 50m wide cross section in the Kloof	40	30	-20
Leachate rate WRDs	0	130	170
Leachate rate TSF	0	80	0

As detailed in *Table 7.4* spring flow in the Kloof (GAMS7) decreases from 1m³/d pre-mining to zero at the end of mining. The discharge of the spring in the east of the Gamsberg (GAMS9) remains at 4 m³/d at the end of mining and is reduced to 3 m³/d 100 years after mine closure.

Groundwater flow through the Kloof (across a 250 m cross-section) was quantified using *Darcy Flux (nodal)* approximation in FEFLOW. The cross-section is located in the lower reaches of the Kloof close to the spring GAMS7 (*Figure 7.11*). Groundwater flow through the Kloof is reduced by approximately 25% at the end of mining compared to pre-mining conditions.

At 100 years after mine closure, the flow is reversed and approximately 20 m^3/d is flowing from the plains towards the Gamsberg (pit) across the section.

Figure 7.11 Flow through the Kloof - Cross-Section Location



Leachate rates from the TSF and WRDs are in the order of 80 and 130 m^3/d respectively at the end of mining. Modelling results suggest, that the leachate rate from the WRDs will increase after mine closure to 170 m^3/d in year 119.

7.2 *TRANSPORT MODEL RESULTS*

This section details results of the groundwater solute transport modelling which was used to quantify water quality impacts of the proposed Project. Sulphate (SO_4) was selected as an indicator of contamination for the solute transport model. Sulphate is a conservative tracer, providing an indication of the maximum potential contaminant extent.

7.2.1 *Sulphate Plumes*

Figure 7.12, *Figure 7.13* and *Figure 7.14* show the sulphate plumes emanating from WRDs and TSF for different time stages (end of mining, 50 years post closure and 100 years post closure). The figures show groundwater concentrations above the SANS 241-1:2011 (2011) drinking water limit of 400 mg/L.

The plumes grow over time due to the continued leaching and combined dispersion and diffusion processes. SO_4 concentration of leachate released from the TSF is increasing over time and is higher than the SO_4 concentration of leachate from the WRDs. Therefore, the maximum SO_4 concentration modelled is observed underneath the TSF at 10 500 mg/L, at the end of mining. Thereafter, the SO_4 concentrations in groundwater underneath the TSF will decrease slowly (refer *Table 7.5*) and the plume will start to move eastwards.

Figure 7.12 Sulphate Plume in Year 19 (End of Mining)

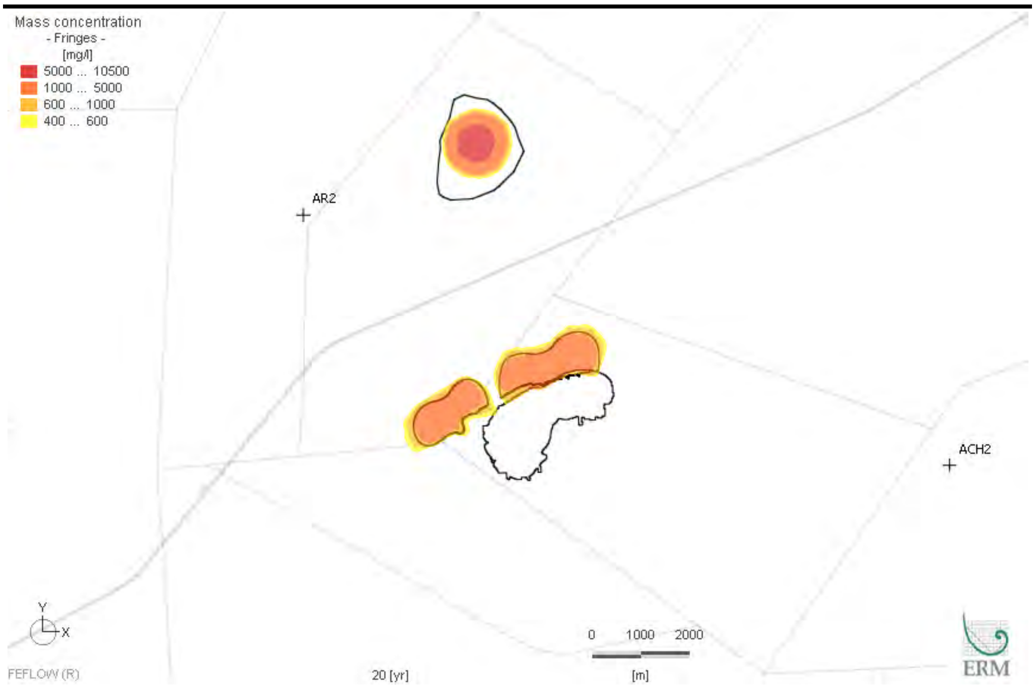


Figure 7.13 Sulphate Plume in Year 69 (50 Years after Mine Closure)

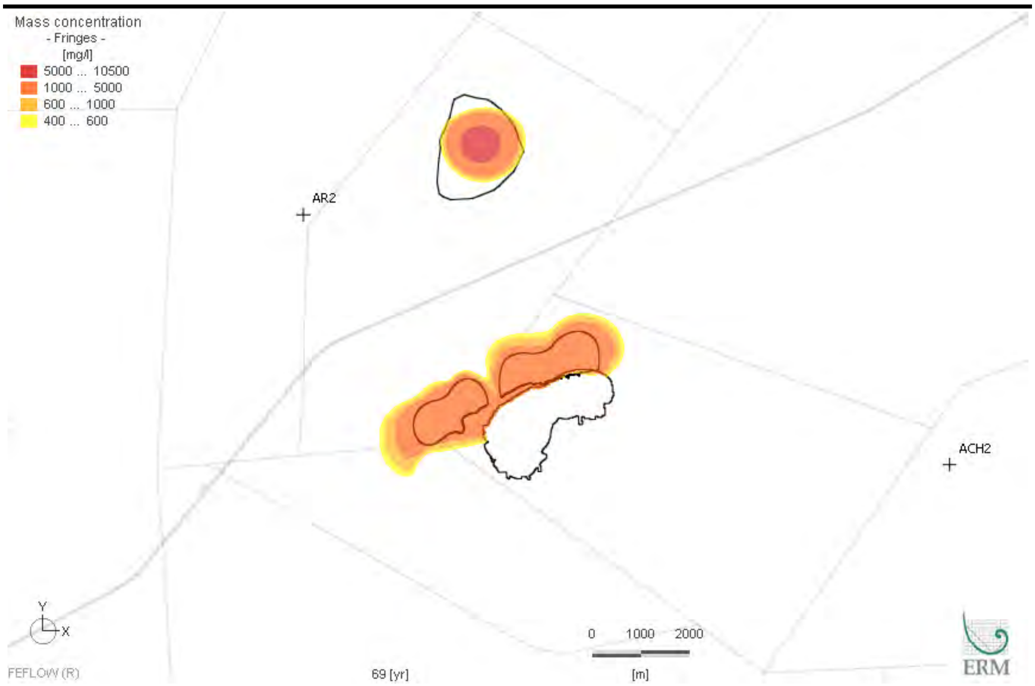


Figure 7.14 Sulphate Plume in Year 119 (100 Years after Mine Closure)

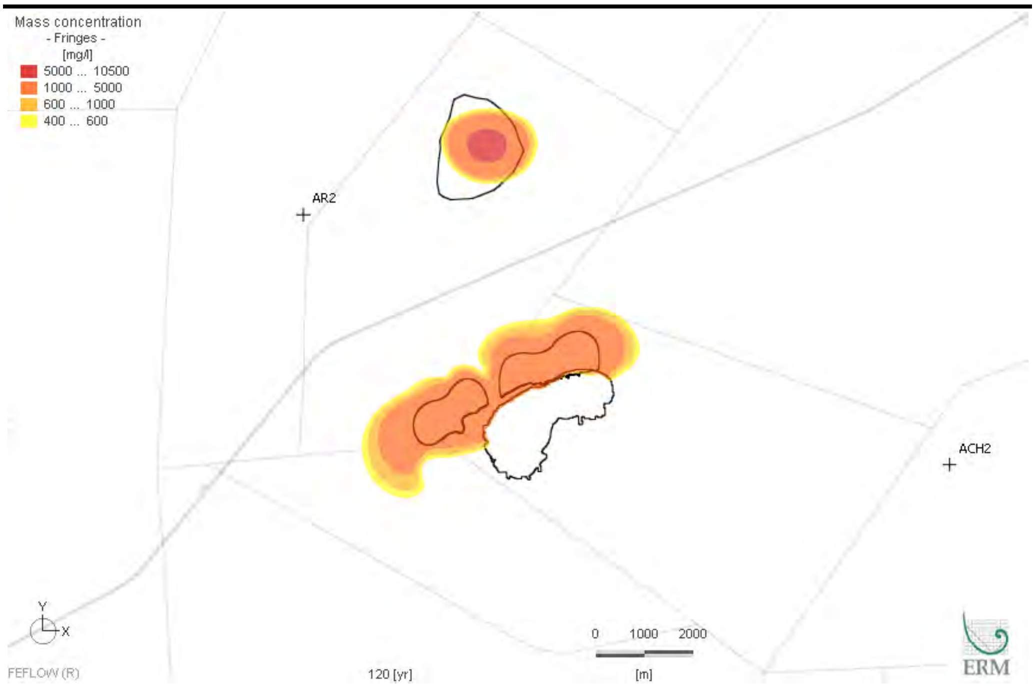


Table 7.5 Characteristic Values Transport Model Plume SO_4^{2-}

		End of Mining	50 years Post Closure	100 years Post Closure
Tailings Storage Facility				
Maximum Concentration	[mg/l]	10 500	9 390	8 190
Plume Size (>400 mg/L)	[km²]	1.6	2.1	2.4

		End of Mining	50 years Post Closure	100 years Post Closure
Maximum Transport Distance	[m]	350	620	900
Waste Rock Dumps				
Plume Size (>400 mg/L)	[km^2]	3.8	6.4	8.8
Maximum Transport Distance	[m]	250	800	1 200

The plumes emanating from the WRDs have larger extent and transport distances, with a maximum of 1 200 m after 100 years post-closure (refer *Table 7.5*). This is mainly due to the larger source area of the WRDs compared to the TSF, greater seepage rates and continued seepage after mine closure. The plumes do not expand across the pit boarder, as all inflow into the pit evaporates. SO_4 mass flux into the pit is discussed in *Section 7.2.2* below.

Impact on Private Groundwater Users

Modelling results further suggest that existing (known) farm boreholes will not be impacted by SO_4 contamination. The borehole located closest to any SO_4 plume is AR2, located on the farm Aroams, which remains 3km south-west of the plume emanating from the TSF. The nearest farm boreholes are indicated with crosses on the figures.

7.2.2 *Sulphate Mass-Fluxes*

SO_4 mass loads flowing into the pit from the WRDs located immediately on the western pit boarder were quantified. Further, the volumes and quality of water seeping out at the base of the WRDs, captured by the toe drains, was equally quantified using the model.

Water seeping out at the base of the TSF is not considered in the groundwater model and therefore quantification was not possible. However, the TSF water balance used for geochemical modelling (*ERM, 2013*) indicates that significant seepage rates of contaminated water can be expected at the base of the TSF.

Sulphate Flux into Open Pit

Modelling results indicate that the SO_4 concentration of pit inflow water from the western pit boundary will increase to 670mg/L at the end of mining and increase further to 1 580mg/L 100 years post-closure (*Table 7.6*). Combined with pit inflow rates of 140 – 180m^3/d, sulphate mass flux of 120kg/day is expected at the end of mining and will increase to 220kg/day 100 years post-closure.

As discussed in *Section 7.1.1*, it is unlikely that water will be visible in the pit except following rain events. These results therefore indicate a potential accumulation of salts and other contaminants in the pit.

Table 7.6 ***Sulphate Mass Flux into the Open Pit***

Year	Seepage Rates into Open Pit [m3/d]	SO_4 Concentration [mg/L]	SO_4 Mass Flux [kg/d]
1	0	0	0
2	10	20	0.1
3	30	60	2
4	40	120	5
5	60	120	7
6	80	120	10
7	90	160	10
8	80	200	20
9	80	250	20
10	90	280	20
11	100	330	30
12	100	390	40
13	100	440	50
14	100	490	50
15	110	530	60
16	130	560	70
17	150	600	90
18	170	630	110
19	180	670	120
69	140	1 230	170
119	140	1 580	220

Waste Rock Dump Toe Seepage Quality

At the base of the WRDs, seepage will occur mainly due to the increased recharge through the coarse material stored in the WRDs. It is anticipated that this will mainly happen following rain events. However, since the groundwater models do not take into account discrete rain events but rather a mean annual precipitation resulting in a mean annual recharge value, average yearly seepage rates were calculated and the water quality determined in terms of SO_4 concentrations.

Average yearly seepage rates during operation are expected to be in the order of 20 – 140 m^3/d (refer *Table 7.7*). However, these could fluctuate due to the erratic rainfall patterns observed in the area.

Seepage SO_4 concentrations are expected to exceed the SANS 241-1:2011 (2011) standard for drinking water of 400 mg/L from year 7 onwards, where after they will increase to 1 000 mg/L in year 18, 1 460 mg/L in year 69 and 1 550 mg/L in year 119 (*Table 7.7*). These concentrations are not expected to vary significantly depending on the rainfall patterns.

Table 7.7 ***Waste Rock Dump Average Yearly Seepage Rates and Quality (Toe Drains)***

Year [yr]	Seepage Rates (Toe Drains) [m3/d]	SO_4 Concentration [mg/L]
1	20	20

Year [yr]	Seepage Rates (Toe Drains) [m3/d]	SO_4 Concentration [mg/L]
2	90	80
3	130	150
4	140	220
5	140	290
6	140	350
7	130	440
8	130	480
9	120	550
10	110	630
11	110	660
12	110	680
13	100	770
14	100	790
15	90	890
16	90	910
17	90	900
18	80	1 000
19	80	970
69	50	1 460
119	50	1 550

7.3 *SENSITIVITY ANALYSIS*

Through sensitivity analysis the uncertainty in the calibrated model caused by uncertainty in the estimates of aquifer parameters, stresses, boundary conditions and transport parameters can be quantified (Anderson & Woessner, 1992).

Sensitivity analyses were conducted and the sensitivity of the model output was quantified with respect to different input parameters, including specific storage, aquifer thickness, porosity, molecular diffusion coefficient and dispersivity.

Each of these parameters was changed by one order of magnitude and the sensitivity quantified by determining their relative effects on drawdown and pit inflows (flow model); and on plume size (transport model). A summary of the sensitivity analysis is provided in this section and the detailed results are appended in *Annex C*.

Flow Model

Additional parameters used for solute transport models parameters including dispersivity, molecular diffusion coefficient, aquifer thickness and porosity will not have any influence on the results of the flow model (drawdowns and pit inflows). Therefore, only the sensitivity of specific storage was quantified.

Additional parameters influencing drawdowns and pit inflows are transmissivity and recharge. Their relative sensitivities were assessed using the steady state model (refer *Section 6.2.2*).

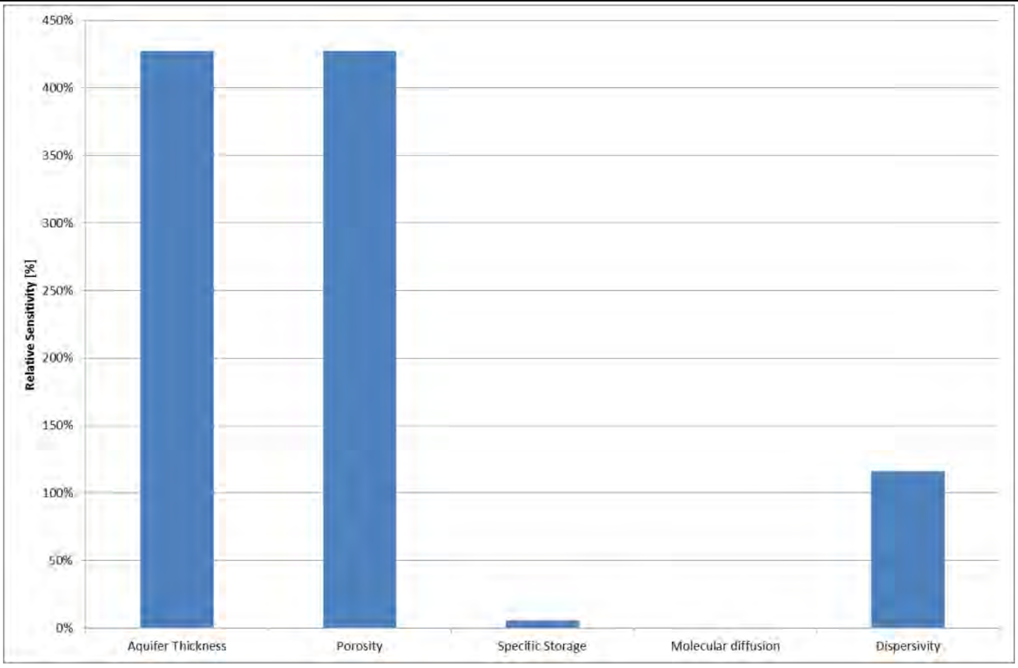
A decrease of specific storage from 10^{-3} to 10^{-4} results in an increase of drawdown extent by 143% based on the 20m drawdown extent. Cumulative pit inflows over the operational phase decrease by 60% and over operational and 100 year post-closure phase by 20%. This indicates that a decreased specific storage "delays" the aquifer response.

Therefore, a change of specific storage has a significant impact on drawdown extent, whereas the impact on pit inflows is less significant.

Transport Model

Figure 7.15 presents the relative sensitivities of the tested parameters on the transport model. The percentage represents the % change in plume size (area) as a result to the one order of magnitude change of the respective input parameter.

Figure 7.15 Sensitivity of Transport Model Parameters



The most sensitive parameters are aquifer thickness and porosity. Both influence the results of the transport model in the same way. As for the transport parameters, the sensitivity of molecular diffusion is not significant, whereas the dispersivity is a sensitive parameter. Specific storage has no significant influence on transport model results.

7.4 DISCUSSION AND CONCLUSIONS OF MODELLING RESULTS

The modelling results from steady state, mine and transport models are discussed in this section. Conclusions are drawn from the discussion with regards to the groundwater impact assessment.

7.4.1 *Steady State Model*

A two-dimensional (2D) areal flow model was constructed, based on the assumption that groundwater flow is predominantly in the horizontal plane. This assumption is valid for aquifers that have a horizontal extent that is much larger than the aquifer thickness, which is the case for the Gamsberg model. This approach assumes that K does not decrease with depth. Lower K with depth would result in decreased pit inflows and decreased drawdown extent with depth. Therefore, modelled impacts represent a conservative scenario.

Rainfall in the area is of erratic nature and it has been reported that 100% of the average annual precipitation can occur during one 24 hour rain event. The groundwater response to rainfall events is currently not well understood as no continuous groundwater level measurements are available. However, it is thought that the natural variations in groundwater levels remain within a few meters and therefore within the model accuracy.

The model time discretisation is set at a yearly increment and an average recharge was assigned based on the long term mean annual precipitation in the area. Discrete rainfall events were not considered in the model but the potential impact of heavy rainfall events on groundwater was assessed qualitatively, highlighting the potential risks associated with this.

Recharge was found to be the most sensitive parameter with regards to the steady state solution followed by the transmissivity zone T2 (Gamsberg outer zone: mainly white quartzite, sillimanite schist). Further data collection and calibration effort should therefore be focussed on improving the certainty/confidence in these parameters since changing them will have the largest effect on model results (*see Section 9*).

7.4.2 *Mining Flow Model*

Model results indicate that pit inflows will be insignificant compared to expected evaporation rates from the pit at different mine stages. Further, a simple pit water budget calculation taking into account inflows from groundwater and rainfall indicated that there will be a constant water deficit of between 4 000 m^3/d in year one to 20 000 m^3/d at the end of mining and during post-closure, which is greater than expected surface water inflows.

Therefore it is concluded that there will be no need for active dewatering. However, due to the nature of rainfall patterns in the area, it is possible that periodical pumping will be necessary following heavy rain events.

Hydraulic gradients in proximity of the pit are very steep due to low hydraulic conductivities, which resulted in drawdown cones with limited horizontal extent. It is therefore not expected that private groundwater users will be affected significantly by the lowering of groundwater levels due to mining activities at the Gamsberg. Modelling results suggest that two boreholes will, however, experience drawdowns in excess of 5 m, which is deemed significant. These drawdowns are only expected to happen between 50 and 100 years after mine closure and should not exceed 10 m.

In terms of the groundwater budget, overall inflows through recharge are expected to increase by 19% due to increased recharge from the waste rock dumps (WRDs). However, these additional inflows are mainly discharged into the open pit due to the proximity of the WRDs to the pit. The overall budget at the end of mining indicates, that outflows exceed inflows and therefore the groundwater system is not balanced, water being taken from storage. A new equilibrium will almost be reached 100 years after mine closure.

Modelling results suggest further, that mining will have a significant impact on the groundwater flow regime in the Kloof. Although the Kloof is a local feature, which cannot be adequately represented in a regional model, it was possible to calculate relative water level changes and draw conclusions from the results.

Groundwater levels in the Kloof are expected to decrease by 15-20 m during mining and by 100-125 m 100 years post closure. This is expected to reverse the groundwater flow gradient in the Kloof resulting in groundwater flowing from the plains towards the Gamsberg (mine pit). It is expected, that groundwater controlled spring flow in the Kloof will essentially be reduced to zero during mining and is not expected to be reinstated after mine closure.

Sensitivity analysis has shown that the parameter specific storage has a significant impact on drawdown extent, whereas the impact on pit inflows is less significant. Further data collection and calibration effort should include this parameter.

7.4.3 Solute Transport Model

The geochemical assessment identified contaminants of concern including SO_4, Fe, Mn, Zn, Cu, Cd, Pb, As and NO_3. Sulphate (SO_4) being a conservative tracer (no adsorption or decay), was selected as an indicator of contamination for the solute transport model, providing an indication of the maximum potential contaminant extent.

At the end of mining modelled SO_4 plumes at concentrations exceeding the SANS 241-1:2011 drinking water standard (400 mg/L) are mainly confined within the immediate footprint (250-350 m) of the contaminant sources including the tailings storage facility and the waste rock dumps. After mine closure, the plumes expand mainly due to the continued seepage of contaminated water from the WRDs. The plume emanating from the TSF is expected to remain in proximity of the footprint of the facility. The plumes are not predicted to intersect private boreholes.

Impact on the groundwater resource is therefore expected to be more significant as a result of seepage from the WRDs, although seepage from the TSF will has higher SO_4 concentrations. The main difference in terms of seepage characteristics of these two sources is that the TSF will be drained at the end of mine and is not expected to continue releasing contaminants assuming that due to the fine texture of the tailings material any rainfall would not result in infiltration but rather surface run-off.

The seepage from WRDs is controlled by increased recharge from rainfall due to the disruption of natural material, increase in hydraulic conductivity and the higher porosity of the dumps reducing the amount of surface runoff and increasing the amount of infiltration. Therefore the seepage from WRDs is not expected to stop after mine closure unless suitable infiltration control measures (ie capping) are implemented.

WRDs are located immediately adjacent to the mine pit and contaminated seepage from the WRDs is expected to partly flow into the pit. It is unlikely that water will be visible in the pit except following rain events. Due to the high evaporation rate, salts and other contaminants are expected to accumulate in the pit and can be dissolved and mobilised during heavy rain events. Pumped water from the pit following heavy rain events could therefore be heavily contaminated and might need to be treated before discharge into the environment.

Further, toe seepage is expected to occur at the base of the WRDs following heavy rain events. This seepage is expected to be contaminated and suitable management measures should be in place to prevent the release of this contaminated water into the environment. These include the collection of seepage water (ie by the means of toe drains) and the treatment of collected water to applicable standards prior to release into the environment.

The most sensitive of the additional parameters needed for solute transport simulations are aquifer thickness and porosity. As for the transport parameters, the sensitivity of molecular diffusion is not significant, whereas the dispersivity is a sensitive parameter. Specific storage has no significant influence on transport model results. Further data collection and calibration effort should include porosity and aquifer thickness.

8 GROUNDWATER IMPACT ASSESSMENT

8.1 ASSESSMENT METHODOLOGY

The adequate assessment and evaluation of the potential impacts and benefits that will be associated with the proposed Project necessitates the development of a methodology that will reduce the subjectivity involved in making such evaluations. A clearly defined methodology is used in order to accurately determine the significance of the predicted impact on, or benefit to, the surrounding natural and/or social environment. For this the Project must be considered in the context of the area and the people that will be affected.

Nonetheless, an impact assessment will always contain a degree of subjectivity, as it is based on the value judgment of various specialists and ESIA practitioners. The evaluation of significance is thus contingent upon values, professional judgment, and dependent upon the environmental and community context. Ultimately, impact significance involves a process of determining the acceptability of a predicted impact to society.

The purpose of impact assessment is to identify and evaluate the likely significance of the potential impacts on identified receptors and resources according to defined assessment criteria, to develop and describe measures that will be taken to avoid, minimize, reduce or compensate for any potential adverse environmental effects, and to report the significance of the residual impacts that remain following mitigation. There are a number of ways that impacts may be described and quantified. An impact is essentially any change to a resource or receptor brought about by the presence of the Project component or by the execution of a Project related activity.

8.1.1 Assessing Impacts

A definition of each impact characteristic is provided to contextualise the requirements. The designations for each of the characteristics are defined below.

Table 8.1 Defining Impact Characteristics

Characteristic	Definition	Designation
Type	A descriptor indicating the relationship of the impact to the Project (in terms of cause and effect).	**Direct -** Impacts that result from a direct interaction between the Project and a resource/receptor (eg, between occupation of a plot of land and the habitats which are affected). **Indirect -** Impacts that follow on from the direct interactions between the Project and its environment as a result of subsequent interactions within

		the environment (eg, viability of a species population resulting from loss of part of a habitat as a result of the Project occupying a plot of land). **Induced -** Impacts that result from other activities (which are not part of the Project) that happen as a consequence of the Project (eg, influx of camp followers resulting from the importation of a large Project workforce).
Duration	The time period over which a resource / receptor is affected.	**Temporary** (negligible/ pre-construction) **Short-term** (period of less than 5 years ie production ramp up period) **Long-term** (period of more than 5 years and less than 19 years ie life of mine) **Permanent** (a period that exceeds the life of mine – ie irreversible.)
Extent	The reach of the impact (ie physical distance an impact will extend to)	**On-site** – impacts that are limited to the project site. **Local** – impacts that are limited to the project site and adjacent properties. **Regional** – impacts that are experienced at a regional scale, eg District or Province. **National** – impacts that are experienced at a national scale. **Trans-boundary/International** – impacts that are experienced at an international scale, eg extinction of species resulting in global loss.
Scale	The size of the impact (eg the size of the area damaged or impacted the fraction of a resource that is lost or affected).	1 - functions and/ or processes remain ***unaltered*** 2 - functions and/ or processes are ***notably altered*** 3 - functions and/ or processes are ***severely altered***
Frequency	Measure of the constancy or periodicity of the impact.	1 - Periodic 2 - **Once off**

The terminology and designations are provided to ensure consistency when these characteristics are described in an Impact Assessment deliverable.

An additional characteristic that pertains only to unplanned events (eg, traffic accident, accidental release of toxic gas, community riot, etc) is likelihood. The likelihood of an unplanned event occurring is designated using a qualitative (or semi-quantitative, where appropriate data are available) scale.

Table 8.2 Definitions of likelihood

Likelihood	Definition
Unlikely	The event is unlikely but may occur at some time during normal operating conditions.
Possible	The event is likely to occur at some time during normal operating conditions.
Likely/ Certain	The event will occur during normal operating conditions (ie, it is essentially inevitable).

Likelihood is estimated on the basis of experience and/or evidence that such an outcome has previously occurred. It is important to note that likelihood is a measure of the degree to which the unplanned event is expected to occur, not the degree to which an impact or effect is expected to occur as a result of the unplanned event. The latter concept is referred to as uncertainty, and this is typically dealt with in a contextual discussion in the Impact Assessment deliverable, rather than in the impact significance assignment process.

Assessing Significance

Once the impact characteristics are understood, these characteristics are used (in a manner specific to the resource/receptor in question) to assign each impact a magnitude. Magnitude is a function of the following impact characteristics:

- Extent (1)
- Duration (2)
- Scale
- Frequency
- Likelihood

Magnitude essentially describes the degree of change that the impact is likely to impart upon the resource/receptor. The magnitude designations are as follows:

- Positive
- Negligible
- Small
- Medium
- Large

The methodology incorporates likelihood into the magnitude designation (ie, in parallel with consideration of the other impact characteristics), so that the

(1) Important in defining 'extent' is the differentiation between the spatial extent of impact (ie the physical distance of the impact in terms of on-site, *local*, *regional, national* or *international*) and the temporal extent/ effect of an impact may have (ie a localised impact on restricted species may lead to its extinction and therefore the impact would have global ramifications).
(2) Duration must consider irreversible impacts (ie permanent).

"likelihood-factored" magnitude can then be considered with the resource/receptor sensitivity/vulnerability/irreplaceability in order to assign impact significance.

The magnitude of impacts takes into account all the various dimensions of a particular impact in order to make a determination as to where the impact falls on the spectrum from negligible to large. Some impacts will result in changes to the environment that may be immeasurable, undetectable or within the range of normal natural variation. Such changes can be regarded as essentially having no impact, and should be characterised as having a negligible magnitude.

In addition to characterising the magnitude of impact, the other principal step necessary to assign significance for a given impact is to define the sensitivity/vulnerability/ irreplaceability of the resource/receptor. There are a range of factors to be taken into account when defining the sensitivity/vulnerability/ irreplaceability of the resource/receptor, which may be physical, biological, cultural or human. Where the resource is *physical* (for example, a water body) its quality, sensitivity to change and importance (on a local, national and international scale) are considered. Where the resource/receptor is *biological or cultural* (for example, the marine environment or a coral reef), its importance (for example, its local, regional, national or international importance) and its sensitivity to the specific type of impact are considered. Where the receptor is *human*, the vulnerability of the individual, community or wider societal group is considered.

As in the case of magnitude, the sensitivity/vulnerability/ irreplaceability designations themselves are universally consistent, but the definitions for these designations will vary on a resource/receptor basis. The universal sensitivity/vulnerability/irreplaceability (1) of resource/receptor is:

- Low
- Medium
- High

Once magnitude of impact and sensitivity/vulnerability/irreplaceability of resource/receptor have been characterised, the significance can be assigned for each impact. The following provides a context for defining significance.

(1) Irreplaceable (SANBI, 2013): "*In terms of biodiversity, irreplaceable areas are those of highest biodiversity value outside the formal protected area network. They support unique biodiversity features, such as endangered species or rare habitat patches that do not occur anywhere else in the province. These features have already been so reduced by loss of natural habitat, that 100% of what remains must be protected to achieve biodiversity targets.*"

Table 8.3 Context for Defining Significance

• An impact of ***negligible*** significance is one where a resource/receptor (including people) will essentially not be affected in any way by a particular activity or the predicted effect is deemed to be 'imperceptible' or is indistinguishable from natural background variations.
• An impact of ***minor*** significance is one where a resource/receptor will experience a noticeable effect, but the impact magnitude is sufficiently small (with or without mitigation) and/or the resource/receptor is of low sensitivity/ vulnerability/ importance. In either case, the magnitude should be well within applicable standards.
• An impact of ***moderate*** significance has an impact magnitude that is within applicable standards, but falls somewhere in the range from a threshold below which the impact is minor, up to a level that might be just short of breaching a legal limit. Clearly, to design an activity so that its effects only just avoid breaking a law and/or cause a major impact is not best practice. The emphasis for moderate impacts is therefore on demonstrating that the impact has been reduced to a level that is as low as reasonably practicable (ALARP). This does not necessarily mean that impacts of moderate significance have to be reduced to minor, but that moderate impacts are being managed effectively and efficiently.
• An impact of ***major*** significance is one where an accepted limit or standard may be exceeded, or large magnitude impacts occur to highly valued/sensitive resource/receptors. An aim of IA is to get to a position where the Project does not have any major residual impacts, certainly not ones that would endure into the long-term or extend over a large area. However, for some aspects there may be major residual impacts remaining even after all practicable mitigation options have been exhausted (ie ALARP has been applied). An example might be the visual impact of a facility. It is then the function of regulators and stakeholders to weigh such negative factors against the positive ones, such as employment, in coming to a decision on the Project.

Based on the context for defining significance, the impact significance rating will be determined, using the matrix below.

Table 8.4 Impact Significance Rating Matrix

		Sensitivity/Vulnerability/Irreplaceability of Resource/Receptor		
		Low	Medium	High
Magnitude of Impact	Negligible	Negligible	Negligible	Negligible
	Small	Negligible	Minor	Moderate
	Medium	Minor	Moderate	Major
	Large	Moderate	Major	Major

Once the significance of the impact has been determined, it is important to qualify the **degree of confidence** in the assessment. Confidence in the prediction is associated with any uncertainties, for example, where information is insufficient to assess the impact. Degree of confidence can be expressed as low, medium or high.

8.1.2 *Mitigation Potential and Residual Impacts*

Once the significance of a given impact has been characterised using the above matrix, the next step is to evaluate what mitigation measures are warranted. In keeping with the Mitigation Hierarchy, the priority in mitigation is to first apply mitigation measures to the source of the impact (ie, to avoid or reduce the magnitude of the impact from the associated Project activity), and then to address the resultant effect to the resource/receptor via abatement or compensatory measures or offsets (ie, to reduce the significance of the effect once all reasonably practicable mitigations have been applied to reduce the impact magnitude). A demonstration of the application of the mitigation hierarchy must be outlined in the specialist reports, for purposes of transparency.

Once mitigation measures are declared, the next step in the Impact Assessment Process is to assign residual impact significance. This is essentially a repeat of the impact assessment steps discussed above, considering the assumed implementation of the additional declared mitigation measures.

The approach taken to defining mitigation measures is based on a typical hierarchy of decisions and measures, as described below.

Table 8.5 *Mitigation hierarchy*

• **Avoid at Source; Reduce at Source:** avoiding or reducing at source through the design of the Project (e.g., avoiding by siting or re-routing activity away from sensitive areas or reducing by restricting the working area or changing the time of the activity).
• **Abate on Site:** add something to the design to abate the impact (e.g., pollution control equipment, traffic controls, perimeter screening and landscaping).
• **Abate at Receptor:** if an impact cannot be abated on-site then control measures can be implemented off-site (e.g., noise barriers to reduce noise impact at a nearby residence or fencing to prevent animals straying onto the site).
• **Repair or Remedy***:* some impacts involve unavoidable damage to a resource (e.g. agricultural land and forestry due to creating access, work camps or materials storage areas) and these impacts can be addressed through repair, restoration or reinstatement measures.
• **Compensate in Kind; Compensate Through Other Means:** where other mitigation approaches are not possible or fully effective, then compensation for loss, damage and disturbance might be appropriate (e.g., planting to replace damaged vegetation, financial compensation for damaged crops or providing community facilities for loss of fisheries access, recreation and amenity space).

8.1.3 *Cumulative Impacts*

Cumulative impacts and effects are those that arise as a result of an impact and effect from the Project interacting with those from another activity to create an additional impact and effect. These are termed cumulative impacts and effects.

The ESIA Report will predict any cumulative impacts/effects to which the Project may contribute. The approach for assessing cumulative impacts and effects resulting from the Project and another activity affecting the same resource/receptor is based on a consideration of the approval/existence status of the 'other' activity and the nature of information available to aid in predicting the magnitude of impact from the other activity.

8.2 *IMPACT OF GROUNDWATER LEVEL CHANGES ON THE GROUNDWATER RESOURCE*

The impact of groundwater level changes on the groundwater resource is considered in this section while the impact of these groundwater level changes on groundwater users is considered in *Section 8.3*, below.

8.2.1 *Impact Description and Assessment*

Table 8.6 Impact Characteristics: Groundwater Levels

Summary	Construction	Operation	Post-Closure
Project Aspect/Activity	Groundwater may be used for construction however this is not anticipated to result in significant changes in groundwater levels.	Open pit mining will dewater the aquifer and a drawdown cone will develop. Groundwater levels will rise (mounding) underneath tailings storage facility (TSF) and waste rock dumps (WRDs).	Abandoned pit will remain a groundwater sink and drawdown cone will continue to expand. Groundwater mounds underneath TSF will seep away, but will remain underneath the WRDs.
Impact Type	Direct	Direct	Direct
Stakeholders/ Receptors Affected	Groundwater Resource	Groundwater Resource	Groundwater Resource

Construction Phase Impacts

It is anticipated that groundwater will be used during the construction phase which may result in localised groundwater level drawdown. This is, however, not expected to have noticeable impact on the groundwater resource. The significance rating is therefore **NEGLIGIBLE**.

Operational Phase Impacts

The planned open pit mining operation will dewater the aquifer on and around the Gamsberg and a drawdown cone will develop predominantly towards the north-east, east, south and south-west. Increased recharge from the WRDs will prevent the drawdown cone propagation towards the west and north-west.

Groundwater modelling suggests that at the end of mining drawdowns in excess of 5m can be expected to reach approximately 1km to the north-east and south-west of the pit and between 2-3km to the east and south-east. The maximum drawdown in close proximity of the pit is approximately 500m.

Groundwater levels will rise (mounding) underneath tailings storage facility (TSF) to approximately 25 metres above surface (mas) and underneath waste rock dumps (WRDs) to surface level.

Groundwater is used in the area and represents the sole source of water for a number of farmers despite groundwater quality in the study area being considered unsuitable for domestic use or livestock watering when compared to South African Water Quality Guidelines (Department of Water Affairs and Foresty , 1996). Farm boreholes closest to the planned Project are located in between 5.5 and 7km away from the planned open pit and remain unaffected during operation as the drawdown cone will be confined to the Project site. The Sensitivity/Vulnerability/Importance of the groundwater resource was rated as **Medium** since the groundwater resource is an important water supply in the area. The planned activity will not result in the loss of irreplaceable resource with regards to the groundwater resource.

Hydraulic head change is expected to be limited to the Project site and adjacent properties belonging to the client, and is on site and **local** in extent. Groundwater levels are not expected to recover after mine closure, since the pit will continue to act as a sink to groundwater based on the elevated evaporation rate, which results in a **permanent** impact. Lowering of the hydraulic head due to the proposed mining activities will result in drawdowns of up to 500m in the vicinity of the pit reducing to levels in line with natural fluctuations within 1 to 2km from the pit. The frequency is classified as **continuous** due to the nature of the project and the likelihood is **certain**.

The impact magnitude is therefore rated as **Medium** and the impact significance (pre-mitigation) is **MODERATE**. The groundwater model is currently based on a number of conservative assumptions and is not calibrated to aquifer stresses of a similar order of magnitude to those applied to it. This implies that reliability of the model predictions is relatively low. However, the model confidence is deemed sufficient to assess conservative impacts and make appropriate mitigation recommendations at the EIA stage of the project. The degree of confidence in this assessment is **medium**.

Box 8.1 Summary of Operational Impact: Groundwater Level Changes on Groundwater Resource

Nature: Operational activities would result in a **negative direct** impact the groundwater resource in the Project Area.

Sensitivity/Vulnerability/Importance of Resource/Receptor – Medium
Irreplaceability: The activity will **not** result in the loss of **irreplaceable** resources

Impact Magnitude – Medium

- Extent: The extent of the impact is **local**
- Duration: The expected impact will be **permanent (ie irreversible)**
- Scale: The impact will **severely alter** the resource
- Frequency: The frequency of the impact will be **continuous**
- Likelihood: The likelihood of the impact is **certain**

IMPACT SIGNIFICANCE (PRE-MITIGATION) – MODERATE

Degree of Confidence: The degree of confidence is **medium**.

Operational Phase Mitigation

Groundwater level change (drawdown) cannot be mitigated. It is therefore recommended that groundwater levels in the vicinity of the pit, in radially increasing distance, as well as in each of the known farm boreholes, are monitored on a regular basis throughout the operational phase. The monitoring data should be stored in an appropriate data management tool/database (see *Section 9*).

Targeted monitoring, to provide data on key areas of uncertainty, allows the assumptions in predictive models to be reduced and thus the reliance of such models improves. Groundwater models should therefore be validated and updated using the monitoring data such that drawdown predictions can be updated. This will lead to models with a higher confidence level that can be used as management tools throughout the operational phase (ie update predicted impacts in order to be proactive etc) and for planning of the post-closure phase of the Project to ensure appropriate provisions are made.

Post-Closure Phase Impacts

Groundwater levels are not expected to recover after mine closure because the pit will continue to act as a groundwater sink due to the high evaporation rates, which will result in the expansion of the drawdown cone. The maximum drawdown in close proximity of the pit remains at approximately 500m.

Two farm boreholes located between 6 and 7km away from the planned open pit are expected to experience drawdowns of between 5 to 10m approximately

100 years after mine closure. These groundwater level changes match natural fluctuations currently experienced. The Sensitivity / Vulnerability / Importance of the groundwater resource remains **Medium** as the resource is an important water supply and is currently used. The planned activity will not result in the loss of irreplaceable resource with regards to the groundwater resource.

Groundwater level change is expected to be limited to the Project site and adjacent properties, and remains **local** in extent. Groundwater levels are not expected to recover after mine closure, since the pit will continue to act as a sink to groundwater based on the elevated evaporation rate, which results in a **permanent** impact. The frequency is classified as **continuous** due to the nature of the project and the likelihood is **certain**.

The impact magnitude is therefore rated as **Medium** and the impact significance (pre-mitigation) is **MODERATE**. The degree of confidence in this assessment is **medium**.

Box 8.2 *Summary of Post-Closure Impact: Groundwater Level Changes on Groundwater Resource*

Nature: Operational activities would result in a **negative direct** impact the groundwater resource in the Project Area.

Sensitivity/Vulnerability/Importance of Resource/Receptor – Medium
Irreplaceability: The activity will **not** result in the loss of **irreplaceable** resources

Impact Magnitude – Medium

- Extent: The extent of the impact is **local**
- Duration: The expected impact will be **permanent (ie irreversible)**
- Scale: The impact will **severely alter** the resource
- Frequency: The frequency of the impact will be **continuous**
- Likelihood: The likelihood of the impact is **certain**

IMPACT SIGNIFICANCE (PRE-MITIGATION) – MODERATE

Degree of Confidence: The degree of confidence is **medium**.

Post Closure Phase Mitigation

Higher confidence groundwater models (developed/updated using monitoring data collected throughout the operational phase) should be used for post-closure planning and to determine the extent and frequency of post-closure groundwater level monitoring (see *Section 9*).

8.2.2 *Residual Impact*

The impact cannot be mitigated and therefore the impact significance for operational and post-closure phases remain unchanged. The pre- and post-mitigation impacts are compared in *Table 8.7* below.

Table 8.7 ***Pre- and Post- Mitigation Significance: Groundwater Level Changes***

Phase	Significance (Pre-mitigation)	Residual Significance (Post-mitigation)
Construction	**NEGLIGIBLE (-ve)**	**NEGLIGIBLE (-ve)**
Operation	**MODERATE (-ve)**	**MODERATE (-ve)**
Post Closure	**MODERATE (-ve)**	**MODERATE (-ve)**

8.3 IMPACT OF GROUNDWATER LEVEL CHANGES ON PRIVATE GROUNDWATER USERS

8.3.1 *Impact Description and Assessment*

The impact of groundwater level changes on groundwater users is considered below.

Table 8.8 ***Impact Characteristics: Impact of Drawdown on Groundwater Users***

Summary	Construction	Operation	Post Closure
Project Aspect/Activity	None	Open pit mining will dewater the aquifer and a drawdown cone will develop. Groundwater levels will rise (mounding) underneath tailings storage facility (TSF) and waste rock dumps (WRDs).	Abandoned pit will remain a groundwater sink and drawdown cone will continue to expand. Groundwater mounds underneath TSF will seep away, but stay underneath the WRDs.
Impact Type	N/A	Indirect	Indirect
Stakeholders/ Receptors Affected	N/A	Private Groundwater Users	Private Groundwater Users

Construction Phase Impacts

The Construction Phase of the Project is not expected to negatively impact on groundwater users in the Project Area and its significance is **NEGLIGIBLE**.

Operational Phase Impacts

Construction Phase Impacts

The Construction Phase of the Project is not expected to negatively impact on groundwater users in the Project Area and its significance is **NEGLIGIBLE**.

Operational Phase Impacts

Private groundwater users are not expected to be impacted during mining as the drawdown cone remains at a distance of more than 4km from the closest existing (known) farm boreholes being BLH1 and ACH2 and remains on site.

Groundwater is used in the area and represents the sole source of water for a number of farmers. Private groundwater users are not expected to be significantly impacted during mining as the drawdown cone remains at a distance of more than 4km from the closest receptors being BLH1 and ACH2.

Therefore, the Sensitivity/Vulnerability/Importance of the groundwater resource was rated as **Medium**. The planned activity will not result in the loss of an irreplaceable resource with regards to private groundwater users.

Drawdown cone is expected to be limited to the Project site and is therefore on-site and **local** in extent. Groundwater levels are not expected to recover after mine closure, since the pit will continue to act as a sink to groundwater based on the elevated evaporation rate, which results in a **permanent** impact. Lowering of the groundwater level due to the proposed mining activities will not extend off site and therefore groundwater users are not anticipated to be impacted. The frequency is classified as **continuous** due to the nature of the project and the likelihood is **likely**. The impact magnitude is therefore rated as **Negligible** and the impact significance (pre-mitigation) is **NEGLIGIBLE**. The degree of confidence in this assessment is **medium**.

Box 8.3 Summary of Operational Impact: Drawdown on Groundwater Users

Nature: Operational activities would result in a **negative direct** impact the groundwater resource in the Project Area.

Sensitivity/Vulnerability/Importance of Resource/Receptor – Medium
Irreplaceability: The activity will **not** result in the loss of **irreplaceable** resources

Impact Magnitude – Negligible

- Extent: The extent of the impact is on-site and **local**
- Duration: The expected ground level change will be **permanent (ie irreversible)**
- Scale: The drawdown cone is not anticipated to impact groundwater users off-site.
- Frequency: The frequency of the impact will be **continuous**
- Likelihood: Groundwater drawdown is **likely**

IMPACT SIGNIFICANCE (PRE-MITIGATION) – NEGLIGIBLE

Degree of Confidence: The degree of confidence is **medium**.

Operational Phase Mitigation

Groundwater level change (drawdown) cannot be mitigated. However, it is further recommended that groundwater levels in each of the known farm boreholes are monitored on a regular basis throughout the construction and operation phases.

Should monitoring confirm that any of the private boreholes are affected by lowering the groundwater table, rendering boreholes unusable (ie loss of water supply source), the client will compensate affected famers for their loss, replacing the lost water supply source. This can be achieved for example by drilling new boreholes for the affected farmers outside of the drawdown cone, by increasing the depth of the existing boreholes or by providing an alternative good quality water source.

Post-Closure Phase Impacts

Modelling results suggest that two private boreholes located to the south-east of the Gamsberg (BLH1 and ACH2) will experience drawdowns of between 5 and 10m approximately 100 years post closure. Other existing (known) private boreholes will not experience any significant drawdowns (ie less than 5m). However, since the drawdown cone extends to additional farms located adjacent to the Project, this may impact future groundwater users.

The Sensitivity / Vulnerability / Importance of the groundwater resource remains **Medium**. The planned activity is not expected to result in the loss of irreplaceable resource with regards to private groundwater users.

Hydraulic head change is expected to extend off site but remains **local** in extent. Groundwater levels are not expected to recover after mine closure, since the pit will continue to act as a sink to groundwater based on the elevated evaporation rate, which results in a **permanent** impact. Lowering of the hydraulic head due to the proposed mining activities is likely to extend to groundwater users in the vicinity of the site. The frequency is classified as **continuous** due to the nature of the project and the likelihood is **likely**. The impact magnitude is therefore rated as **Medium** and the impact significance (pre-mitigation) is **MODERATE**. The degree of confidence in this assessment is **medium**.

Box 8.4 *Summary of Post-Closure Impact: Drawdown on Groundwater Users*

Nature: Operational activities would result in a **negative direct** impact on groundwater users in the vicinity of the Project, post-closure.

Sensitivity/Vulnerability/Importance of Resource/Receptor – Medium
Irreplaceability: The activity will **not** result in the loss of **irreplaceable** resources

Impact Magnitude – Medium

- Extent: The extent of the impact is **local**
- Duration: The expected ground level change will be **permanent (ie irreversible)**
- Scale: The drawdown cone is anticipated to impact two groundwater users off-site.
- Frequency: The frequency of the impact will be **continuous**
- Likelihood: Groundwater drawdown is **likely**

IMPACT SIGNIFICANCE (PRE-MITIGATION) – MODERATE

Degree of Confidence: The degree of confidence is **medium**.

Post-Closure Phase Mitigation

Higher confidence groundwater models (developed/updated using monitoring data collected throughout the operational phase) should be used for post-closure planning and to determine the extent and frequency of post-closure groundwater level monitoring.

Should monitoring confirm that any private boreholes are affected by lowering the groundwater table, rendering boreholes unusable (ie loss of water supply source), the client will compensate affected famers for their loss, replacing the lost water supply source. This can be achieved for example by drilling new boreholes for the affected farmers outside of the drawdown cone, by increasing the depth of the existing boreholes or by providing an alternative good quality drinking water source.

8.3.2 Residual Impact

Compensation of impacted farmers, where impact is confirmed through monitoring data, would result in the operation and post-closure impacts of **NEGLIGIBLE** and may even change the **negative** impact to a **positive** impact (ie if the quality of the alternative water source provided by the project exceeds the existing one which does not meet drinking water).

The pre- and post-mitigation impacts are compared in *Table 8.9* below.

Table 8.9 *Pre- and Post- Mitigation Significance: Private Groundwater Users*

Phase	Significance (Pre-mitigation)	Residual Significance (Post-mitigation)
Construction	NEGLIGIBLE (-ve)	NEGLIGIBLE (-ve)
Operation	NEGLIGIBLE (-ve)	NEGLIGIBLE (-ve)
Post Closure	MODERATE (-ve)	NEGLIGIBLE (-ve)

8.4 *IMPACT OF GROUNDWATER LEVEL CHANGES ON BASE FLOW AND BASE FLOW DEPENDANT ECOSYSTEMS IN THE KLOOF*

8.4.1 Impact Description and Assessment

Table 8.10 Impact Characteristics: Groundwater Level Impacts on Base Flow and Base Flow Dependant Ecosystems in the Kloof

Summary	Construction	Operation	Post Closure
Project Aspect/Activity	None	Open pit mining will dewater the aquifer and a drawdown cone will develop. Groundwater levels will rise (mounding) underneath tailings storage facility (TSF) and waste rock dumps (WRDs).	Abandoned pit will remain a groundwater sink and drawdown cone will continue to expand. Groundwater mounds underneath TSF will seep away, but stay underneath the WRDs.
Impact Type	N/A	Indirect	Indirect
Stakeholders/ Receptors Affected	N/A	Ecosystems in the Kloof which are dependent on the base flow provided by groundwater	Ecosystems in the Kloof which are dependent on the base flow provided by groundwater

Construction Phase Impacts

The Construction Phase of the Project is not expected to negatively impact on groundwater users in the Project Area and its significance is **NEGLIGIBLE**.

Operational Phase Impacts

Groundwater levels in the Kloof will be lowered by 15-20m during mining. At the end of mining the groundwater level in the Kloof is reduced, however the groundwater gradient is still towards the plains hence water still flows out along the Kloof at depth. Groundwater flows through the Kloof will be reduced by approximately 25% at the end of mining. Further, model results indicate that spring flow in the Kloof might be effectively cut off.

The ecosystems (vegetation and habitat) in the Kloof are dependent on the groundwater fed springs. Therefore, the Sensitivity / Vulnerability / Importance of the groundwater resource is **High**. The planned activity will result in the loss of irreplaceable resource.

Hydraulic head change is expected to be limited to the Project site and adjacent properties belonging to the client, and is **local** in extent. Groundwater levels are not expected to recover after mine closure and therefore the impact is **permanent**. Lowering of the hydraulic head due to the proposed mining activities will severely alter the base flow levels. The frequency is classified as **continuous** due to the nature of the project and the impact is **likely**. The impact magnitude is therefore rated as **Large** and the impact significance (pre-mitigation) is **MAJOR**. The degree of confidence in this assessment is **high** based on the proximity of the Kloof to the planned open pit and the planned final depth of the pit.

Box 8.5 ***Summary of Operational Impact: Impacts on Base Flow and Base Flow Dependant Ecosystems in the Kloof***

Nature: Operational activities would result in a **negative** in**direct** impact on ecosystems (vegetation and habitat) in the Kloof.

Sensitivity/Vulnerability/Importance of Resource/Receptor – High
Irreplaceability: The activity will result in the loss of **irreplaceable** resources

Impact Magnitude – Large

- Extent: The extent of the impact is **local**
- Duration: The expected impact will be **permanent (ie irreversible)**
- Scale: The impact will **severely alter** the resource
- Frequency: The frequency of the impact will be **once off**
- Likelihood: Vegetation and habitat will **certainly** be lost

IMPACT SIGNIFICANCE (PRE-MITIGATION) – MAJOR

Degree of Confidence: The degree of confidence is **high**.

Operational Phase Mitigation

Groundwater level change (drawdown) in the Kloof cannot be mitigated.

Post Closure Phase Impacts

As the cone of depression continues expand after mine closure, groundwater levels in the Kloof continue to decrease. At 100 years post closure, groundwater levels in the Kloof are expected to have decreased by 100-125m compared to pre-mining levels.

Hence the hydraulic gradient along the Kloof will be reversed and water will flow from the plains towards the Gamsberg (pit). It is not expected that spring flow will recover post mine closure.

The impact characteristics and magnitude ratings remain unchanged for post-closure impacts with regards to operational impacts. Significance remains **MAJOR**.

Box 8.6 ***Summary of Post-Closure Impact: Impacts on Base Flow and Base Flow Dependant Ecosystems in the Kloof***

Nature: Operational activities would result in a **negative** in**direct** impact on ecosystems (vegetation and habitat) in the Kloof.

Sensitivity/Vulnerability/Importance of Resource/Receptor – High
Irreplaceability: The activity will result in the loss of **irreplaceable** resources

Impact Magnitude – Large

- Extent: The extent of the impact is **local**
- Duration: The expected impact will be **permanent (ie irreversible)**
- Scale: The impact will **severely alter** the resource
- Frequency: The frequency of the impact will be **once off**
- Likelihood: Vegetation and habitat will **certainly** be lost

IMPACT SIGNIFICANCE (PRE-MITIGATION) – MAJOR

Degree of Confidence: The degree of confidence is **high**.

Post Closure Phase Mitigation

Groundwater level change (drawdown) in the Kloof cannot be mitigated.

8.4.2 Residual Impact

The impact cannot be mitigated and therefore the impact significance for operational and post-closure phase remains unchanged. The pre- and post-mitigation impacts are compared in *Table 8.11* below.

Table 8.11 ***Pre- and Post- Mitigation Significance: Base Flow and Base Flow Dependant Ecosystems in the Kloof***

Phase	Significance (Pre-mitigation)	Residual Significance (Post–mitigation)
Construction	INSIGNIFICANT (-ve)	INSIGNIFICANT (-ve)
Operation	MAJOR (-ve)	MAJOR (-ve)
Post Closure	MAJOR (-ve)	MAJOR (-ve)

8.5 *GROUNDWATER QUALITY IMPACT ON THE GROUNDWATER RESOURCE*

The impact on groundwater quality in this section is considered with respect to the groundwater resource while the impact this will have on groundwater users is considered in *Section 8.6*, below.

8.5.1 *Impact DescriptIon and Assessment*

Table 8.12 Impact Characteristics: Groundwater Quality

Summary	**Construction**	**Operation**	**Post Closure**
Project Aspect/Activity	Accidental spillage from construction equipment and chemicals storage areas.	Contaminated leachate from tailings storage facility (TSF) and waste rock dumps (WRDs). Spillage from mining equipment. Contamination through residuals of explosives used in the mining process.	Contaminated leachate from tailings storage facility (TSF) and waste rock dumps (WRDs).
Impact Type	Direct	Direct	Direct
Stakeholders/ Receptors Affected	Groundwater Resource	Groundwater Resource	Groundwater Resource

Construction Phase Impacts

Accidental spillage of hydrocarbons or other chemical substances used and stored during the Construction Phase can potentially contaminate groundwater locally.

The sensitivity and vulnerability of the groundwater resource to contamination is rated **Medium**.

It is anticipated that large volumes of chemicals, that have a potential to contaminate groundwater, will be stored/used on site during the construction phase however the impact magnitude is **Small** and it is not anticipated that the activity will result in the loss of an irreplaceable source. The impact significance (pre-mitigation) is **MINOR** and the degree of confidence is **Medium**.

Box 8.7 Summary of Construction Impact: Groundwater Quality

Nature: Construction activities could have a **negative direct** impact on groundwater quality.

Sensitivity/Vulnerability/Importance of Resource/Receptor – Medium
Irreplaceability: The activity will **not** result in the loss of **irreplaceable** resources

Impact Magnitude – Small
- Extent: The extent of the impact is **on-site**
- Duration: The expected impact will be **permanent**
- Scale: The resource/ receptor will remain **unaltered**
- Frequency: The frequency of the impact will be **once off**
- Likelihood: Likelihood for accidental spillages is **possible**

IMPACT SIGNIFICANCE (PRE-MITIGATION) – MINOR

Degree of Confidence: The degree of confidence is **medium**

Construction Phase Mitigation

A construction environmental management plan (EMP) needs to be in place including, but not limited to:

- Adhere to best practice principles;
- Construction equipment should be up to standards and serviced regularly to prevent oil spills;
- A spill response plan should be in place and construction workers should be trained accordingly; and
- On-site storage areas for hydrocarbons and other chemicals should be constructed in a way that potential tank failures can be contained including bunds and surface hardstanding.

Operational Phase Impacts

Contaminants of Concern (CoCs) related to the mining operation were identified during the geochemical assessment and include sulphate (SO_4), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), cadmium (Cd), lead (Pb), arsenic (As) and nitrate (NO_3). Further, due to blasting activities it is expected that large amounts of NO_3 will be released and possibly diesel depending on the explosives used.

SO_4 leachate concentrations for tailings storage facility (TSF) and waste rock dumps (WRDs) were quantified using geochemical modelling for input into the groundwater model. SO_4 groundwater contamination emanating from TSF and WRDs was quantified using numerical solute transport modelling. SO_4 is a conservative tracer, providing an indication of conservative contaminant extent.

At the end of mining modelled SO_4 plumes at concentrations exceeding the SANS 241-1:2011 drinking water standard of 400mg/L are mainly confined to within the immediate footprint (250m) of the contaminant sources. The plumes are expected to impact areas of 1.6km^2 (TSF) to 3.8km^2 (WRDs) and not extend off-site.

WRDs are located immediately adjacent to the mine pit and contaminated seepage from the WRDs is expected to partly flow into the pit. It is unlikely that water will be visible in the pit except following heavy rain events. Due to the high evaporation rate, salts and other contaminants are expected to accumulate in the pit and can be dissolved and mobilised during rain events. Pumped water from the pit following rain events could therefore be heavily contaminated. Further, toe seepage is expected to occur at the base of the WRDs following rain events and continuously at the base of the TSF. This seepage is expected to be contaminated.

The Sensitivity/Vulnerability/Importance of the groundwater resource was rated as **Medium** since the groundwater is an important resource even though groundwater quality does not meet drinking water or stock watering standards. The planned activity will not result in the loss of irreplaceable resource with regards to the groundwater resource.

Sulphate leaching from the TSF is predicted to steadily increase in concentration to a maximum of about 12 000 mg/L on closure. This is significantly higher than sulphate concentrations measured in groundwater sampled from hydrocensus boreholes during the current study which range from 22 mg/L to 1706 mg/L. However, water quality impacts are expected to be limited in extent to the footprints of the TSF and WRDs and are therefore on-site and **local** in extent. Groundwater quality is not expected to improve after mine closure, hence it will be a **permanent** impact. Leaching of contaminated water from TSF and WRDs will severely alter the groundwater quality within the footprint of these facilities. The frequency is classified as **continuous** due to the nature of the project and the impact on groundwater quality is considered to be **likely**. The impact magnitude is rated as **Medium** and the impact significance (pre-mitigation) is **MODERATE**. The degree of confidence in this assessment is **medium**.

Box 8.8 Summary of Operational Impact: Groundwater Quality

Nature: Operational activities would result in a **negative direct** impact the groundwater resource in the Project area.

Sensitivity/Vulnerability/Importance of Resource/Receptor – Medium
Irreplaceability: The activity will **not** result in the loss of **irreplaceable** resources

Impact Magnitude – Medium

- Extent: The extent of the impact is confined to the footprint of the TSF and the WRDs and is therefore on-site and **local.**
- Duration: The expected impact will be **permanent (ie irreversible)**
- Scale:The impact will **severely alter** the groundwater quality within the footprint of the TSF and WRDs.
- Frequency: The frequency of the impact will be **once off**
- Likelihood: The likelihood of the impact is **certain**

IMPACT SIGNIFICANCE (PRE-MITIGATION) – MODERATE

Degree of Confidence: The degree of confidence is **medium**.

Operational Phase Mitigation

In keeping with the mitigation hierarchy, the priority in mitigation is to apply mitigation measures to the source of the impact, main sources being the TSF and WRDs.

Modelling results indicate that the TSF and WRDs will produce acid rock drainage (ARD) which is expected to seep into groundwater. This will result in a moderate significance rating based on the assumptions made during modelling. Detailed geotechnical and geophysical investigations will be undertaken prior to construction to refine and confirm assumptions made in respect to the current studies around the integrity of the subsurface beneath the TSF. Mitigation measures required to reduce the impact on groundwater quality include the following:

- Prior to construction of WRDs and TSF, the ground of the facility's footprint should be prepared to reduce the hydraulic conductivity of the material, ie through means of compaction, so that seepage water is forced out of the facility at ground level rather than infiltrating into groundwater.

- Toe drains (interception trenches) along the base of both TSF and WRDs to intercept drainage and convey to a return water dam. Toe seepage from these facilities is expected to be contaminated and suitable management measures should be in place to prevent the release of this contaminated water into the environment. It is recommended to recycle as much water as possible and re-use it.

Management options specifically for the TSF include the following:

- Short deposition cycles should be followed by regularly covering fresh tailings soon after deposition to prevent them drying out and oxidising on placement. Cladding the TSF side slopes with inert waste rock, concurrently with deposition, to minimise both oxygen ingress and side-slope erosion.

- Further addition of additives such as lime or slaked lime could help to increase the alkalinity of the Gamsberg tailings prior to deposition. The WMB (2000) results suggest, however, that the liming requirement to offset the acid potential of the tailings would be high. Note also that neutralising materials introduced during tailings amendment may dissolve and be flushed from the TSF system prior to reacting with acidity generated by the oxidation of sulphides in the tailings.

To decrease quality impact on the groundwater resource in the vicinity of the TSF, a mineral liner system as specified by the design engineers is required to be installed beneath the TSF (see details included in *Annex D*). The detailed specifications of the TSF liner system requirements will be agreed upon by the Department of Water Affairs and be in line with the conditions of the IWULA.

The present numerical groundwater flow and transport model is based on a number of conservative assumptions and should be updated/validated as additional information becomes available (ie SEEP/W model results, geophysics results and hydraulic conductivity of tailings material) prior to construction to ensure assumptions made during the development of the model remain valid.

Pumped water from the pit following heavy rain events is expected to be contaminated and will need to be contained, or treated to applicable standards if it is to be released into the environment, in accordance with the water use licence requirements.

It is further recommended that these mitigation measures be complemented with groundwater quality monitoring in the vicinity of contamination sources and in radially increasing distance from them. Monitoring should be carried out on a regular basis throughout the construction and operational phases. The monitoring data should be stored in an appropriate data management tool/database.

Targeted monitoring, to provide data on key areas of unknown, allows the assumptions in predictive models to be reduced and thus the reliance of such models improves. Groundwater models should therefore be validated and updated using the monitoring data such that transport model predictions can be updated (ie plume extent, modelled concentrations). This will lead to models with a higher confidence level that can be used as management tools throughout the operational phase (ie update predicted impacts in order to be proactive etc) and for planning of the post-closure phase of the Project to ensure appropriate provisions are made.

Post Closure Phase Impacts

The seepage from WRDs is controlled by increased recharge from rainfall due to the disruption of natural material, increase in hydraulic conductivity and the higher porosity of the dumps reducing the amount of surface runoff and increasing the amount of infiltration. Therefore the seepage from WRDs is not expected to stop after mine closure and is therefore expected to expand further.

The TSF will be drained at the end of mine and is not expected to continue releasing contaminants, assuming that due to the fine texture of the tailings material any rainfall would not result in infiltration but rather surface run-off. The plume emanating from the TSF is expected to remain in proximity of the footprint of the facility.

Impact on the groundwater resource is therefore expected to be more significant as a result of seepage from the WRDs, although seepage from the TSF has higher SO_4 concentrations. Modelled areal extent of SO_4 plumes 100 years after mine closure are 2.4km^2 for the TSF and 8.8km^2 for the WRDs which represents increases of 50% and 140% respectively. The maximum travel distance of 1.2km is observed from the WRDs in south-westerly direction.

The Sensitivity/Vulnerability/Importance of the groundwater resource was rated as **Medium**. The planned activity will not result in the loss of irreplaceable resource with regards to the groundwater resource.

Water quality impacts are expected to be limited to the footprints of the TSF and WRDs, and are on-site and **local** in extent. Groundwater quality is not expected to improve after mine closure, hence it will be a **permanent** impact. Leaching of contaminated water from TSF and WRDs will severely alter the groundwater quality within the footprint of these facilities. The frequency is classified as **continuous** due to the nature of the project and the likelihood is **certain**. The impact magnitude is rated as **Medium** since the SO_4 concentrations are high however the extent of the plume is confined to the mine lease area. The impact significance (pre-mitigation) is **MODERATE**. The degree of confidence in this assessment is **medium**.

Box 8.9 ***Summary of Post-Closure Impact: Groundwater Quality***

Nature: Operational activities would result in a **negative direct** impact the groundwater resource in the Project Area.

Sensitivity/Vulnerability/Importance of Resource/Receptor – Medium
Irreplaceability: The activity will **not** result in the loss of **irreplaceable** resources

Impact Magnitude – Medium

- Extent: The extent of the impact is on-site and **local**
- Duration: The expected impact will be **permanent (ie irreversible)**
- Scale: The impact will **severely alter** the resource
- Frequency: The frequency of the impact will be **continuous**
- Likelihood: The likelihood of the impact is **certain**

IMPACT SIGNIFICANCE (PRE-MITIGATION) – MODERATE

Degree of Confidence: The degree of confidence is **medium**.

Decommissioning and Post Closure Phase Mitigation

Operational mitigation measures have to be maintained post closure. Further, final profiling of the TSF and WRDs should be aimed at reducing erosion and minimising further water infiltration.

Higher confidence groundwater models (developed/updated using monitoring data collected throughout the construction and operational phases) should be used for post-closure planning and to determine the extent and frequency of post-closure groundwater level monitoring.

8.5.2 Residual Impact

The implementation of the mitigation measures outlined above would reduce the construction impacts from **Minor** significance to **Negligible** and the operation impacts from **Moderate** to **Moderate-Minor**. The implementation of the decommissioning phase mitigation measures would not reduce the significance rating, and thus remain **Moderate**. The pre- and post-mitigation impacts are compared in *Table 8.13* below.

Table 8.13 ***Pre- and Post- Mitigation Significance: Groundwater Quality***

Phase	Significance (Pre-mitigation)	Residual Significance (Post-mitigation)
Construction	MINOR (-ve)	NEGLIGIBLE (-ve)
Operation	MODERATE(-ve)	MODERATE-MINOR(-ve)
Decommissioning and Post Closure	MODERATE (-ve)	MODERATE-MINOR (-ve)

8.6 *GROUNDWATER QUALITY IMPACT ON PRIVATE GROUNDWATER USERS*

This section considers the potential impact of water quality on groundwater users.

8.6.1 *Impact Description and Assessment*

Table 8.14 Impact Characteristics: Groundwater Users

Summary	Construction	Operation	Post Closure
Project Aspect/Activity	N/A	Contaminated leachate from tailings storage facility (TSF) and waste rock dumps (WRDs). Spillage from mining equipment. Contamination through residuals of explosives used in the mining process.	Contaminated leachate from tailings storage facility (TSF) and waste rock dumps (WRDs).
Impact Type	N/A	Indirect	Indirect
Stakeholders/ Receptors Affected	N/A	Private Groundwater Users	Private Groundwater Users

Construction Phase Impacts

The Construction Phase of the Project is not expected to negatively impact on groundwater users in the Project Area and its significance is therefore **NEGLIGIBLE**.

Operational Phase Impacts

SO_4 groundwater contamination emanating from TSF and WRDs was quantified using numerical solute transport modelling. SO_4 is a conservative tracer, providing an indication of conservative contaminant extent.

At the end of mining modelled SO_4 plumes at concentrations exceeding the SANS 241-1:2011 drinking water standard of 400mg/L are mainly confined within the immediate footprint (250m) of the contaminant sources and are not expected to affect any private groundwater users (farm boreholes).

The Sensitivity/Vulnerability/Importance of the groundwater resource was rated as **Medium**. The planned activity will not result in the loss of irreplaceable resource with regards to the groundwater resource.

Water quality impacts are expected to be limited to the footprints of the TSF and WRDs, and are **on-site** in extent. Groundwater quality is not expected to improve after mine closure, hence it will be a **permanent** impact. Leaching of contaminated water from TSF and WRDs will remain **unaltered** the groundwater quality outside of the footprint of these facilities. The frequency is classified as **continuous** due to the nature of the project and the likelihood is **certain**.

The impact magnitude is therefore rated as **Negligible** and the impact significance (pre-mitigation) is **NEGLIGIBLE**. The degree of confidence in this assessment is **medium**.

Box 8.10 Summary of Operational Impact: Groundwater Users

Nature: Operational activities would result in a **negative direct** impact the groundwater resource in the Project Area.

Sensitivity/Vulnerability/Importance of Resource/Receptor – Medium
Irreplaceability: The activity will **not** result in the loss of **irreplaceable** resources

Impact Magnitude – Negligible

- Extent: The extent of the impact is confined to the site and is **local**
- Duration: The expected impact will be **permanent (ie irreversible)**
- Scale: The groundwater resource is expected to remain **unaltered** outside of the footprint of TSF and WRDs
- Frequency: The frequency of the impact will be **continuous**
- Likelihood: The likelihood of the impact is **certain**

IMPACT SIGNIFICANCE (PRE-MITIGATION) – NEGLIGIBLE

Degree of Confidence: The degree of confidence is **medium**.

Operational Phase Mitigation

Groundwater quality should be monitored at the existing (known) private boreholes in regular intervals to confirm modelling results. Should monitoring data confirm impact on private users, the client will compensate affected famers for their loss, replacing the lost water supply source.

Post Closure Phase Impacts

The seepage from WRDs is not expected to stop after mine closure and will therefore continue to expand post-closure. The plume emanating from the TSF is expected to remain in proximity of the footprint of the facility.

Modelled areal extent of SO_4 plumes 100 years after mine closure are 2.4km^2 for the TSF and 8.8km^2 for the WRDs which represents increases of 50% and 140% respectively. The maximum travel distance of 1.2km is observed from the WRDs in south-westerly direction. Private groundwater users are not expected to be impacted by groundwater contamination as plumes remain within farms owned by the client.

The Sensitivity/Vulnerability/Importance of the groundwater resource was rated as **Medium**. The planned activity will not result in the loss of irreplaceable resource with regards to the groundwater resource.

Water quality impacts are expected to be limited to the footprints of the TSF and WRDs, and remain on site and **local** in extent. Groundwater quality is not expected to improve after mine closure, hence it will be a **permanent** impact. Leaching of contaminated water from TSF and WRDs will remain **unaltered** the groundwater quality outside of the footprint of these facilities. The frequency is classified as **continuous** due to the nature of the project and the likelihood is **certain**.

The impact magnitude is therefore rated as **Negligible** and the impact significance (pre-mitigation) is **NEGLIGIBLE**. The degree of confidence in this assessment is **medium**.

Box 8.11 Summary of Operational Impact: Groundwater Users

Nature: Operational activities would result in a **negative direct** impact the groundwater resource in the Project Area.

Sensitivity/Vulnerability/Importance of Resource/Receptor – Medium
Irreplaceability: The activity will **not** result in the loss of **irreplaceable** resources

Impact Magnitude – Negligible
- Extent: The extent of the impact is confined to the site and is **local**
- Duration: The expected impact will be **permanent (ie irreversible)**
- Scale: The groundwater resource is expected to remain **unaltered** outside of the footprint of TSF and WRDs
- Frequency: The frequency of the impact will be **continuous**
- Likelihood: The likelihood of the impact is **certain**

IMPACT SIGNIFICANCE (PRE-MITIGATION) – NEGLIGIBLE

Degree of Confidence: The degree of confidence is **medium**.

Operational Phase Mitigation

Groundwater quality should be monitored at the existing (known) private boreholes in regular intervals starting prior to or during construction to confirm modelling results (see the groundwater management plan in *Section 10*) Should monitoring data confirm impact on private users, the client will compensate affected famers for their loss, replacing the lost water supply source.

The present numerical groundwater flow and transport model will be updated at regular intervals starting prior to construction as additional information becomes available to ensure assumptions made during the development of the model remain valid and that model predictions remain current.

8.6.2 *Residual Impact*

Pre-mitigation impacts were rated **NEGLIGIBLE** for construction, operational and post-closure phases of the project, maybe change the **negative** impact to a **positive** impact (ie if the quality of the alternative water source provided by the project exceeds the existing one). The pre- and post-mitigation impacts are compared in *Table 8.15* below.

Table 8.15 Pre- and Post- Mitigation Significance: Private Groundwater Users

Phase	**Significance (Pre-mitigation)**	**Residual Significance (Post-mitigation)**
Construction	**NEGLIGIBLE (-ve)**	**NEGLIGIBLE (-ve)**
Operation	**NEGLIGIBLE (-ve)**	**NEGLIGIBLE (-ve)**
Post Closure	**NEGLIGIBLE (-ve)**	**NEGLIGIBLE (-ve)**

8.7 IMPLICATIONS OF SUGGESTED CHANGES TO LAYOUT

Based on recent discussions with the Applicant and design engineers, the following changes to the project layout have been suggested after the completion of this study. The changes are as follows:

- Relocation of the explosives magazine area from the top of the inselberg to an area located between the N14 and inselberg. Due to the impacts to three watercourses on the inselberg, this relocation was requested by the Specialist Team; and
- Increase in size of the waste rock dump from to 270 hectares to 490 hectares. In order to reduce the slope angle of the waste rock dump (i.e. from 450 – 350 degree slope), the footprint of the waste rock dump has increased. This design refinement was in response to DMR requirements for a waste rock dump.

Based on professional judgement, ERM is of the opinion that the suggested changes with regards to the explosives magazine will not have any implications on the outcomes of this study.

Suggested changes to the waste rock dump, however, will likely increase the footprint of the modelled sulphate plumes as detailed in *Section 7.2*, but the sulphate and metal concentrations of the leachate might decrease. ERM is of the opinion that this will, however, not change the impact ratings or proposed mitigation measures.

9 GROUNDWATER MANAGEMENT PLAN

9.1 GROUNDWATER MANAGEMENT ACTIONS

Management actions during mine operation and closure aim to:

- Minimise seepage of contaminants to groundwater through various means including the capture and treatment surface water to minimise seepage to groundwater.

- Reduce the volumes of water in the mine environment.

- Reduce the business risk to the mine of legacy groundwater contamination, and the risk of spiralling closure costs through predictive management of groundwater impacts, using routinely updated numerical groundwater modelling.

Based on these aims, the following groundwater management actions are recommended during operation and closure phases.

- As per the recommendations provided in the surface water impact assessment (HHO, 2013), surface water should be captured in the mining environment to minimise infiltration of potentially contaminated water to groundwater

- Any water obtained from dewatering or sump pumping in the pit or mining environment, will require treatment to applicable standards, if it is to be released into environment, in accordance with legislative requirements. Where possible this water should be considered for re-use in the mining operations.

- The pit should be maintained such that it remains a water sink even during exceptionally heavy rains, through ensuring that the final surface water catchment is minimised such that evaporation exceeds rainfall and runoff, and groundwater recovery

- The numerical groundwater model developed for this study must routinely be updated to support adaptive groundwater management measures. The model developed here is low confidence due to the limitations presented (Section 2.5.5). If the model is updated with operational data, predictions of impact can be updated and translated into mine management practices, supporting risk management and post-closure planning.

- Integrated with update of numerical models, the monitoring plan presented below must be regarded as the starting point for a living document, to be updated based on interpretation of the monitoring results, and results of modelling. In addition, strategies detailing what extra mitigation measures or management actions are initiated based on certain possible results, should be developed.

- Survey all monitoring boreholes to provide elevation of borehole in mamsl.

- Establish a Groundwater Monitoring Committee, for the presentation and sharing of all groundwater monitoring data, as a risk management measure to the mine. The Committee is to be attended by management of the mine, regulatory bodies (DWA, DEA, catchment management agency if established), local groundwater users, and any other Interested and Affected Parties. It is recommended that the Committee meet at least quarterly initially, which could be relaxed to 6-monthly depending on monitoring results.

9.2 PRELIMINARY GROUNDWATER MONITORING PLAN

9.2.1 Purpose of Preliminary Groundwater Monitoring Plan

The monitoring plan has been developed taking into account the best practice guidelines for water monitoring in the South African mining industry (DWA 2007). The measurement of water levels and taking of groundwater samples discussed below should proceed according the best practice for monitoring methods as outlined by Weaver (2007).

Monitoring is required for the following purposes:

1. To detect the actual impact on groundwater quantity and quality timeously,

2. To assess whether the mitigation measures given in *Section 8* are effective, supporting the update of mitigation measures where necessary;

3. To support adaptive management in which the numerical model can be updated based on new information, and used to predict groundwater impacts. With updated high confidence predictions the mine can act in a pre-emptive manner, thus reducing risks, rather than acting in hindsight when monitoring data reveals a problem; and

4. To interrogate unknowns listed in this report, in which various field investigations can be carried out to test and improve the hydrogeological conceptual understanding of the aquifer system.

9.2.2 *Groundwater Monitoring Plan*

The monitoring plan presented in *Table 9.1* below addresses the recommended monitoring required to address items 1, 2 and 3 above. As listed in *Section 9.1* above, this is not a standalone monitoring plan, yet needs to be updated as monitoring data and modelling results are generated, hence it should be considered a preliminary monitoring plan. Details in support of *Table 9.1* are listed as follows:

- Each borehole was selected with reference to mining infrastructure that it is there to monitor – and this is reflected as the 'primary reason'. This is listed as *primary* reason because the borehole may have two purposes, for example borehole '4' is within the plan as it is within the projected drawdown cone and can reflect the change in water level within the kloof drainage channel, yet secondly it can also act as a farfield monitoring borehole for the waste rock dumps.

- "Boundary" boreholes are located at the boundary of the mine infrastructure and are within the projected (drawdown or quality) impact zone. Farfield boreholes are mostly beyond the projected impact zone. Nearfield boreholes sit between these two and are designed to act as early warning boreholes to potential impact reaching the farfield boreholes.

- Existing mine owned boreholes (*Figure 4.1* and *Table 4.2*) have been selected for monitoring, and where there are no boreholes available, yet monitoring in a certain position is required, a Recommended Monitoring Borehole is listed (RMBH1 to RMBH10). The approximate location of these boreholes is shown in *Figure 9.1*.

- Boundary monitoring boreholes are required for the pit, but are not individually listed or positioned in *Figure 9.1* (listed as RMBHx). Wire-line vibrating piezometers should be installed for monitoring pore pressure and wall stability.

- In addition to the existing boreholes and the recommended new boreholes, it is suggested that Black Mountain undertakes the monitoring of all private boreholes, as a risk management measure in order to ensure a reliable and complete dataset of water levels and water chemistry exists for these holes.

- The frequency of water level measurement is divided between monthly (manually with a water level or 'dip' meter), and continual (automatically on 1-hour readings, with pressure loggers installed in the borehole). Certain boreholes are selected for continual measurement for building the conceptual understanding of aquifer behaviour (Table 9.2).

- Boundary and nearfield boreholes are to be sampled for water quality quarterly and Farfield boreholes can be sampled 6-monthly. Samples should be submitted to a SANAS accredited laboratory and the sampling protocol for that chemistry adhered to. Due to the natural poor quality of the groundwater, future water quality results should be compared to the baseline groundwater characteristics presented here rather than DWA guidelines or SANS drinking water standards. The list of chemical constituents to be sampled for should be routinely updated based on prior results. Parameters to be tested include, but are not limited to:

    - Major metals: Al, Cd, Cu, Fe (Ferric & Ferrous iron), Mn, Pb, Sb, Zn, U
    - Majors constituents pH, EC, TDS, Cl, SO4, NO3, F, Ca, Mg, Na and K
    - It is recommended that the metals are assessed via inductively coupled plasma – mass spectrometry

- The weather station established on the northwest rim of the inselberg must be reinstated, maintained and downloaded routinely. This is key to interpretation of water level signatures and can contribute to quantification of recharge

- All monitoring records should be stored in a database which is routinely updated, maintained, and includes all metadata associated with the monitoring activities.

Figure 9.1 Recommended new monitoring boreholes

Table 9.1 Recommended Monitoring Plan

	ID	Alternate ID	Proposed Monitoring Protocol			
			Primary Reason	Category	Water Level frequency	Water quality frequency
Existing boreholes	AR 4	MBH 2	WRD	Nearfield		Quarterly
	AR 5	MBH 3, GBH03	WRD	Nearfield		Quarterly
	AR 7	MBH11	TSF	Boundar y		Quarterly
	AR 8	MBH 7	TSF	Boundar y		Quarterly
	AR 9	MBH 9	TSF	Nearfield		Quarterly
	AR10	MBH10	TSF	Nearfield		Quarterly
	AR11	MBH 8	TSF	Nearfield		Quarterly
	AR12		TSF	Boundar y		Quarterly
	BH5	GAMS2, 5	Pit	Nearfield		Quarterly
	BH6	BLH2, MBH 6	WRD	Farfield		6-monthly
	BLH1	14, 13, (12)	Pit	Farfield		6-monthly
	BLH3	MBH 5	WRD	Nearfield		Quarterly
	BLH4	MBH 4	WRD	Nearfield		Quarterly
	GAMB 1	GAMS4	Pit	Nearfield		Quarterly
	GAMB 3		Pit	Nearfield		Quarterly
	GAMB 4	GAMS 5	Pit	Nearfield		Quarterly
	GAMB 5		Pit	Nearfield		Quarterly
	GAMS 3	K 1	Pit	Nearfield		Quarterly
	GAMS 8	MBH1	WRD	Nearfield		Quarterly
	LUS1		Pit	Farfield		6-monthly
	4		Pit	Farfield		6-monthly
	25		Pit	Farfield		6-monthly
Recommended new boreholes	RMBH1		TSF	Farfield		6-monthly
	RMBH2		TSF	Farfield		6-monthly
	RMBH3		TSF	Farfield		6-monthly
	RMBH4		WRD	Farfield		6-monthly
	RMBH5		WRD	Farield		6-monthly
	RMBH6		Pit	Nearfield		Quarterly
	RMBH7		Pit	Farfield		6-monthly
	RMBH8		WRD	Boundar y		Quarterly
	RMBH9		WRD	Boundar y		Quarterly
	RMBH1 0		WRD	Boundar y		Quarterly
	RMBHx		Pit	Boundar y		Quarterly

Private boreholes	All	n/a	Risk Management	n/a	Monthly	6-monthly

The actions listed in *Table 9.2* address the recommended monitoring actions for item 4 above.

Table 9.2 Recommended Field investigations

Item	Investigation	Implementation Strategy
Groundwater Recharge	The predictions provided in the numerical groundwater model are highly sensitive to the recharge value applied, yet this is a parameter with little data. Recharge to the inselberg and plains should be investigated via various methods, including: • Comparison of continuously monitored water levels to rainfall events, to identify which rain events contribute to groundwater recharge • Quantification of recharge via the chloride method which compares chloride concentration of rainfall and groundwater	Recommend the appointment of a hydrogeological support consultant to manage this investigation. It can be carried out cost effectively to the mine by linking with national research programmes such as carrying out aspects of the investigation under the Water Research Commission.
Hydraulic continuum approach	Test the conceptual understanding of a hydraulic continuum through • Pump tests, detailed below • Comparison of continuously monitored water levels, detailed above	
Aquifer hydraulic properties	The predictions provided in the numerical groundwater model are sensitive to the storage parameters and porosity applied, yet these are uncertain parameters. These can be investigated via: • Extended pump tests conducted in each major lithology, with monitoring of observation holes • Tracer tests to assess porosity	
Structural Heterogeneity	The model is based on a homogeneous medium assumption and the omission of as yet unknown dominant structural features could impact results. Geophysics is recommended in the vicinity of contaminant sources to detect major faults which could act as preferential pathways.	
Aquifer hydraulic properties with depth	The variation of hydraulic properties with depth is uncertain. Deep drilling on the inselberg is planned by Black Mountain and should include: • Drilling should proceed through the base of the ore body to the base of the Pella Quartzite to establish the 3D surface of the base of the Pella Quartizte, such that the numerical model can be translated to a 3D model • Logging of fracture frequency with depth, if possible • Packer testing over various depths to test water bearing strata at depth	

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Annex A

Laboratory Report

aquatico Laboratories (Pty). Ltd.

ilac-MRA | sanas Testing Laboratory T0374

Client: ERM
Address: Building 23, The Woodlands Office Park, Woodlands Drive, Woodmead, Sand
Report no: 9675
Project: ERM

Date of certificate: 20 September 2012
Date accepted: 11 September 2012
Date completed: 19 September 2012
Revision: 0

Lab no:				101161	101162	101163	101164	101165	101166	101167
Date sampled:				03-Sep-12	03-Sep-12	03-Sep-12	03-Sep-12	03-Sep-12	03-Sep-12	01-Sep-12
Sample type:				Water	Water	Water	Water	Water	Water	Water
Locality description:				RS1	RS2+3	RS4	RS5	RS6	RS7	KGT1
	Analyses	**Unit**	**Method**							
A	pH	pH	CSM 20	8.44	8.18	8.67	8.29	7.72	8.50	7.34
A	Electrical conductivity (EC)	mS/m	CSM 20	58.30	145.80	114.50	56.30	74.90	125.30	249.30
A	Total dissolved solids (TDS)	mg/l	CSM 26	324	853	477	350	435	672	1536
A	Total alkalinity	mg/l	CSM 01	208.63	152.98	187.70	127.27	172.15	174.28	276.29
A	Chloride (Cl)	mg/l	CSM 02	36.00	302.86	117.85	69.85	105.47	217.44	602.83
A	Sulphate (SO_4)	mg/l	CSM 03	36.21	143.29	82.46	64.81	57.15	106.06	218.73
A	Nitrate (NO3) as N	mg/l	CSM 06	1.79	14.3	1.61	4.67	0.762	3.92	5.90
A	Nitrite (NO2) as N	mg/l	CSM 07	0.119	0.120	0.081	0.166	0.036	0.151	0.032
A	Ammonium (NH4) as N	mg/l	CSM 05	0.431	0.066	0.105	0.095	0.098	0.109	0.088
A	Orthophosphate (PO4) as P	mg/l	CSM 04	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
A	Fluoride (F)	mg/l	CSM 08	3.605	3.377	2.480	3.022	3.989	4.151	3.802
A	Calcium (Ca)	mg/l	CSM 30	49.13	111.23	59.01	50.27	68.22	53.60	182.58
A	Magnesium (Mg)	mg/l	CSM 30	18.98	41.33	29.38	25.84	23.33	35.70	62.77
A	Sodium (Na)	mg/l	CSM 30	50.42	141.24	69.01	52.20	70.94	142.19	281.97
A	Potassium (K)	mg/l	CSM 30	3.05	3.44	2.91	2.57	1.95	4.21	11.37
A	Aluminium (Al)	mg/l	CSM 31	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
A	Iron (Fe)	mg/l	CSM 31	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
A	Manganese (Mn)	mg/l	CSM 31	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
A	Total chromium (Cr)	mg/l	CSM 31	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
A	Copper (Cu)	mg/l	CSM 31	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001
A	Nickel (Ni)	mg/l	CSM 31	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
A	Zinc (Zn)	mg/l	CSM 31	0.237	0.080	0.130	0.012	<0.004	<0.004	0.014
A	Cobalt (Co)	mg/l	CSM 31	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
A	Cadmium (Cd)	mg/l	CSM 31	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
A	Lead (Pb)	mg/l	CSM 31	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	0.003
A	Turbidity	NTU	CSM 21	1.99	1.96	1.86	3.36	2.12	0.96	0.85
A	Total hardness	mg/l	CSM 26	201	448	268	232	266	281	714
N	Suspended solids (SS)	mg/l	CSM 25	15.0	7.00	5.00	21.0	30.0	10.00	11.0
A	Arsenic (As)	mg/l	CSM 34	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023

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Results reported against the limit of quantification.

HHausen

Laboratory Manager: H. Holtzhausen

aquatico Laboratories (Pty). Ltd.

ilac-MRA sanas Testing Laboratory T0374

Client: ERM
Address: Building 23, The Woodlands Office Park, Woodlands Drive, Woodmead, Sand
Report no: 9675
Project: ERM

Date of certificate: 20 September 2012
Date accepted: 11 September 2012
Date completed: 19 September 2012
Revision: 0

Lab no:				101161	101162	101163	101164	101165	101166	101167
Date sampled:				03-Sep-12	03-Sep-12	03-Sep-12	03-Sep-12	03-Sep-12	03-Sep-12	01-Sep-12
Sample type:				Water	Water	Water	Water	Water	Water	Water
Locality description:				RS1	RS2+3	RS4	RS5	RS6	RS7	KGT1
	Analyses	**Unit**	**Method**							
N	Barium (Ba)	mg/l	CSM 32	0.002	0.006	0.011	0.046	0.030	0.021	0.013
N	Dissolved Uranium (U)	mg/l	CSM 37	0.01	0.03	0.02	0.02	0.02	0.10	0.13

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Laboratory Manager: H. Holtzhausen

aquatico Laboratories (Pty). Ltd.

ilac-MRA sanas Testing Laboratory T0374

Client: ERM
Address: Building 23, The Woodlands Office Park, Woodlands Drive, Woodmead, Sand
Report no: 9675
Project: ERM

Date of certificate: 20 September 2012
Date accepted: 11 September 2012
Date completed: 19 September 2012
Revision: 0

Lab no:				101168	101169	101170	101171	101172	101173	101174
Date sampled:				01-Sep-12	01-Sep-12	01-Sep-12	01-Sep-12	01-Sep-12	01-Sep-12	01-Sep-12
Sample type:				Water	Water	Water	Water	Water	Water	Water
Locality description:				KGT2	KGT3	KGT4	KGT5	KGT7	KGT8	GAMS2
	Analyses	**Unit**	**Method**							
A	pH	pH	CSM 20	7.82	8.33	8.54	8.58	8.01	8.60	7.64
A	Electrical conductivity (EC)	mS/m	CSM 20	321.50	177.20	149.90	291.80	1021.00	142.70	37.40
A	Total dissolved solids (TDS)	mg/l	CSM 26	1652	1019	846	1800	6444	810	190
A	Total alkalinity	mg/l	CSM 01	278.19	276.90	261.12	229.58	162.24	247.82	36.09
A	Chloride (Cl)	mg/l	CSM 02	741.41	293.41	249.78	629.80	3573.18	208.58	43.09
A	Sulphate (SO_4)	mg/l	CSM 03	156.84	139.75	114.95	377.79	351.55	162.19	62.19
A	Nitrate (NO3) as N	mg/l	CSM 06	6.91	31.8	9.99	23.5	12.0	5.48	0.112
A	Nitrite (NO2) as N	mg/l	CSM 07	0.031	0.026	<0.005	<0.005	0.130	0.130	0.028
A	Ammonium (NH4) as N	mg/l	CSM 05	0.089	0.087	0.051	0.046	0.057	0.036	0.025
A	Orthophosphate (PO4) as P	mg/l	CSM 04	0.061	0.047	0.074	0.062	<0.025	<0.025	<0.025
A	Fluoride (F)	mg/l	CSM 08	4.104	3.000	2.975	2.759	2.093	3.115	0.649
A	Calcium (Ca)	mg/l	CSM 30	203.19	140.98	121.05	151.87	346.33	86.37	13.76
A	Magnesium (Mg)	mg/l	CSM 30	72.39	47.69	41.46	89.71	198.01	32.96	10.49
A	Sodium (Na)	mg/l	CSM 30	290.89	188.65	142.29	367.91	1790.71	159.45	32.63
A	Potassium (K)	mg/l	CSM 30	9.74	7.32	7.08	19.03	72.75	2.95	5.71
A	Aluminium (Al)	mg/l	CSM 31	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
A	Iron (Fe)	mg/l	CSM 31	<0.006	<0.006	0.869	<0.006	<0.006	<0.006	<0.006
A	Manganese (Mn)	mg/l	CSM 31	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1.97
A	Total chromium (Cr)	mg/l	CSM 31	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
A	Copper (Cu)	mg/l	CSM 31	0.004	<0.001	<0.001	<0.001	0.047	<0.001	<0.001
A	Nickel (Ni)	mg/l	CSM 31	<0.003	<0.003	<0.003	<0.003	0.036	<0.003	<0.003
A	Zinc (Zn)	mg/l	CSM 31	<0.004	0.005	0.025	<0.004	<0.004	<0.004	1.147
A	Cobalt (Co)	mg/l	CSM 31	0.003	<0.002	<0.002	0.002	<0.002	<0.002	<0.002
A	Cadmium (Cd)	mg/l	CSM 31	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
A	Lead (Pb)	mg/l	CSM 31	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
A	Turbidity	NTU	CSM 21	0.25	0.43	13.40	7.26	0.80	0.69	42.10
A	Total hardness	mg/l	CSM 26	805	548	473	749	1680	351	78
N	Suspended solids (SS)	mg/l	CSM 25	16.0	9.00	16.0	36.0	44.0	7.00	31.0
A	Arsenic (As)	mg/l	CSM 34	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023

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HHausen

Laboratory Manager: H. Holtzhausen

Client: ERM
Address: Building 23, The Woodlands Office Park, Woodlands Drive, Woodmead, Sand
Report no: 9675
Project: ERM

Date of certificate: 20 September 2012
Date accepted: 11 September 2012
Date completed: 19 September 2012
Revision: 0

Lab no:				101168	101169	101170	101171	101172	101173	101174
Date sampled:				01-Sep-12	01-Sep-12	01-Sep-12	01-Sep-12	01-Sep-12	01-Sep-12	01-Sep-12
Sample type:				Water	Water	Water	Water	Water	Water	Water
Locality description:				KGT2	KGT3	KGT4	KGT5	KGT7	KGT8	GAMS2
	Analyses	**Unit**	**Method**							
N	Barium (Ba)	mg/l	CSM 32	0.016	0.001	0.011	0.027	0.043	0.002	0.017
N	Dissolved Uranium (U)	mg/l	CSM 37	0.16	0.12	0.08	0.18	0.07	0.03	<0.01

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Laboratory Manager: H. Holtzhausen

Test Report

Client: ERM
Address: Building 23, The Woodlands Office Park, Woodlands Drive, Woodmead, Sand
Report no: 9675
Project: ERM

Date of certificate: 20 September 2012
Date accepted: 11 September 2012
Date completed: 19 September 2012
Revision: 0

Lab no:				101175	101176	101177	101178	101179	101180	101181
Date sampled:				01-Sep-12	01-Sep-12	01-Sep-12	01-Sep-12	01-Sep-12	01-Sep-12	01-Sep-12
Sample type:				Water	Water	Water	Water	Water	Water	Water
Locality description:				GAMS3	GAMS4	GAMS5	GAMS6	GAMS8	GAMS9	GAMS10
	Analyses	**Unit**	**Method**							
A	pH	pH	CSM 20	8.51	7.25	5.81	7.40	7.51	6.46	7.35
A	Electrical conductivity (EC)	mS/m	CSM 20	116.90	112.80	111.20	175.30	120.90	23.77	94.40
A	Total dissolved solids (TDS)	mg/l	CSM 26	679	690	765	1266	685	116	536
A	Total alkalinity	mg/l	CSM 01	203.74	346.61	<8.26	131.15	297.01	19.91	98.82
A	Chloride (Cl)	mg/l	CSM 02	177.57	101.66	28.68	108.92	137.13	35.49	188.35
A	Sulphate (SO_4)	mg/l	CSM 03	142.43	135.83	598.63	672.97	104.82	22.09	102.71
A	Nitrate (NO3) as N	mg/l	CSM 06	0.329	1.35	<0.057	1.65	0.270	3.21	0.336
A	Nitrite (NO2) as N	mg/l	CSM 07	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
A	Ammonium (NH4) as N	mg/l	CSM 05	<0.015	<0.015	0.060	5.95	7.56	0.086	0.079
A	Orthophosphate (PO4) as P	mg/l	CSM 04	<0.025	<0.025	0.057	0.110	0.206	0.097	0.083
A	Fluoride (F)	mg/l	CSM 08	1.029	0.591	<0.183	1.096	2.022	0.254	1.997
A	Calcium (Ca)	mg/l	CSM 30	80.71	91.27	77.85	192.11	100.96	9.99	41.42
A	Magnesium (Mg)	mg/l	CSM 30	38.61	38.69	30.27	64.72	25.03	7.72	35.22
A	Sodium (Na)	mg/l	CSM 30	110.91	106.13	18.58	128.12	116.91	23.19	104.81
A	Potassium (K)	mg/l	CSM 30	4.81	6.25	9.66	17.94	19.66	2.59	1.89
A	Aluminium (Al)	mg/l	CSM 31	<0.006	<0.006	0.138	<0.006	<0.006	<0.006	<0.006
A	Iron (Fe)	mg/l	CSM 31	<0.006	<0.006	84.321	0.095	0.009	<0.006	<0.006
A	Manganese (Mn)	mg/l	CSM 31	<0.001	<0.001	69.3	3.23	0.419	<0.001	0.062
A	Total chromium (Cr)	mg/l	CSM 31	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
A	Copper (Cu)	mg/l	CSM 31	<0.001	<0.001	0.052	<0.001	<0.001	<0.001	<0.001
A	Nickel (Ni)	mg/l	CSM 31	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
A	Zinc (Zn)	mg/l	CSM 31	0.031	<0.004	11.25	0.027	<0.004	0.228	0.229
A	Cobalt (Co)	mg/l	CSM 31	0.002	<0.002	0.006	0.004	0.002	<0.002	0.006
A	Cadmium (Cd)	mg/l	CSM 31	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
A	Lead (Pb)	mg/l	CSM 31	0.002	<0.001	0.028	0.002	<0.001	<0.001	<0.001
A	Turbidity	NTU	CSM 21	5.26	4.08	28.40	22.40	6.25	0.27	3.78
A	Total hardness	mg/l	CSM 26	361	387	319	746	355	57	248
N	Suspended solids (SS)	mg/l	CSM 25	9.00	21.0	24.0	16.0	15.0	3.00	1.00
A	Arsenic (As)	mg/l	CSM 34	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023

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HHausen

Laboratory Manager: H. Holtzhausen

Client: ERM
Address: Building 23, The Woodlands Office Park, Woodlands Drive, Woodmead, Sand
Report no: 9675
Project: ERM

Date of certificate: 20 September 2012
Date accepted: 11 September 2012
Date completed: 19 September 2012
Revision: 0

Lab no:				101175	101176	101177	101178	101179	101180	101181
Date sampled:				01-Sep-12	01-Sep-12	01-Sep-12	01-Sep-12	01-Sep-12	01-Sep-12	01-Sep-12
Sample type:				Water	Water	Water	Water	Water	Water	Water
Locality description:				GAMS3	GAMS4	GAMS5	GAMS6	GAMS8	GAMS9	GAMS10
	Analyses	Unit	Method							
N	Barium (Ba)	mg/l	CSM 32	0.058	0.036	0.017	0.025	0.034	0.039	0.033
N	Dissolved Uranium (U)	mg/l	CSM 37	0.01	0.02	0.16	<0.01	0.05	<0.01	<0.01

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Report no: 9675
Project: ERM

Date of certificate: 20 September 2012
Date accepted: 11 September 2012
Date completed: 19 September 2012
Revision: 0

Lab no:				101182	101183	101184	101185	101186	101187	101188
Date sampled:				07-Sep-12	07-Sep-12	07-Sep-12	07-Sep-12	07-Sep-12	07-Sep-12	07-Sep-12
Sample type:				Water	Water	Water	Water	Water	Water	Water
Locality description:				AR1	AR2	AR3	AR4	AR5	AR7	AR8
	Analyses	**Unit**	**Method**							
A	pH	pH	CSM 20	8.03	7.70	8.01	7.54	7.83	7.81	7.74
A	Electrical conductivity (EC)	mS/m	CSM 20	662.00	1626.00	229.40	117.10	239.40	157.40	316.70
A	Total dissolved solids (TDS)	mg/l	CSM 26	4249	11097	1522	652	1392	961	1804
A	Total alkalinity	mg/l	CSM 01	282.48	591.12	280.75	282.51	210.35	247.03	188.89
A	Chloride (Cl)	mg/l	CSM 02	1907.11	5234.24	552.65	143.41	599.34	334.32	624.72
A	Sulphate (SO_4)	mg/l	CSM 03	668.72	1706.01	277.47	94.16	180.57	119.52	436.79
A	Nitrate (NO3) as N	mg/l	CSM 06	2.30	0.371	1.58	1.68	0.834	6.43	15.8
A	Nitrite (NO2) as N	mg/l	CSM 07	0.063	0.109	0.099	0.083	0.024	0.006	0.008
A	Ammonium (NH4) as N	mg/l	CSM 05	0.081	0.592	0.119	4.79	0.189	0.066	0.062
A	Orthophosphate (PO4) as P	mg/l	CSM 04	0.147	0.128	0.062	0.052	0.085	0.045	0.044
A	Fluoride (F)	mg/l	CSM 08	4.038	5.195	2.928	2.273	3.042	3.063	2.964
A	Calcium (Ca)	mg/l	CSM 30	266.12	877.64	148.84	68.96	112.60	113.84	188.02
A	Magnesium (Mg)	mg/l	CSM 30	157.55	472.83	70.98	19.62	47.01	33.71	56.26
A	Sodium (Na)	mg/l	CSM 30	1013.31	2332.88	275.09	133.83	302.69	188.65	349.01
A	Potassium (K)	mg/l	CSM 30	60.63	112.70	24.18	18.63	19.58	13.37	17.36
A	Aluminium (Al)	mg/l	CSM 31	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
A	Iron (Fe)	mg/l	CSM 31	<0.006	<0.006	<0.006	0.136	<0.006	<0.006	<0.006
A	Manganese (Mn)	mg/l	CSM 31	<0.001	0.028	<0.001	0.218	<0.001	<0.001	<0.001
A	Total chromium (Cr)	mg/l	CSM 31	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
A	Copper (Cu)	mg/l	CSM 31	0.044	0.103	0.005	<0.001	<0.001	<0.001	0.008
A	Nickel (Ni)	mg/l	CSM 31	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
A	Zinc (Zn)	mg/l	CSM 31	<0.004	0.005	0.105	<0.004	0.018	0.010	0.052
A	Cobalt (Co)	mg/l	CSM 31	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
A	Cadmium (Cd)	mg/l	CSM 31	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
A	Lead (Pb)	mg/l	CSM 31	<0.001	0.017	<0.001	0.006	<0.001	<0.001	<0.001
A	Turbidity	NTU	CSM 21	0.32	1.16	29.50	4.57	5.81	1.23	1.23
A	Total hardness	mg/l	CSM 26	1313	4139	664	253	475	423	701
N	Suspended solids (SS)	mg/l	CSM 25	13.0	106	9.00	88.0	50.0	24.0	23.0
A	Arsenic (As)	mg/l	CSM 34	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023

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Results reported against the limit of quantification.

HHausen

Laboratory Manager: H. Holtzhausen

Client: ERM
Address: Building 23, The Woodlands Office Park, Woodlands Drive, Woodmead, Sand
Report no: 9675
Project: ERM

Date of certificate: 20 September 2012
Date accepted: 11 September 2012
Date completed: 19 September 2012
Revision: 0

Lab no:				101182	101183	101184	101185	101186	101187	101188
Date sampled:				07-Sep-12	07-Sep-12	07-Sep-12	07-Sep-12	07-Sep-12	07-Sep-12	07-Sep-12
Sample type:				Water	Water	Water	Water	Water	Water	Water
Locality description:				AR1	AR2	AR3	AR4	AR5	AR7	AR8
	Analyses	**Unit**	**Method**							
N	Barium (Ba)	mg/l	CSM 32	0.080	0.231	0.073	0.027	0.047	0.026	0.047
N	Dissolved Uranium (U)	mg/l	CSM 37	0.30	0.32	0.16	0.02	0.09	0.05	0.09

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Laboratory Manager: H. Holtzhausen

Client:	ERM	**Date of certificate:**	20 September 2012
Address:	Building 23, The Woodlands Office Park, Woodlands Drive, Woodmead, Sand	**Date accepted:**	11 September 2012
Report no:	9675	**Date completed:**	19 September 2012
Project:	ERM	**Revision:**	0

Lab no:				101189	101190	101191	101192	101193	101194	101195
Date sampled:				07-Sep-12	07-Sep-12	07-Sep-12	07-Sep-12	03-Sep-12	03-Sep-12	06-Sep-12
Sample type:				Water	Water	Water	Water	Water	Water	Water
Locality description:				AR9	AR10	AR11	AR12	ACH1	ACH2	BCH1
	Analyses	**Unit**	**Method**							
A	pH	pH	CSM 20	7.76	7.49	7.96	7.54	6.69	7.49	7.39
A	Electrical conductivity (EC)	mS/m	CSM 20	241.10	220.00	217.30	332.70	31.40	414.00	157.60
A	Total dissolved solids (TDS)	mg/l	CSM 26	1607	1404	1392	1450	172	2295	916
A	Total alkalinity	mg/l	CSM 01	276.20	194.57	154.46	172.98	26.61	209.59	267.79
A	Chloride (Cl)	mg/l	CSM 02	554.40	543.10	547.17	606.13	46.66	448.79	293.55
A	Sulphate (SO_4)	mg/l	CSM 03	314.23	230.51	258.64	181.09	44.09	951.97	89.05
A	Nitrate (NO3) as N	mg/l	CSM 06	0.288	15.0	7.82	9.93	3.74	18.9	7.89
A	Nitrite (NO2) as N	mg/l	CSM 07	0.007	<0.005	0.246	0.130	<0.005	0.126	0.019
A	Ammonium (NH4) as N	mg/l	CSM 05	0.153	0.063	0.063	<0.015	0.061	<0.015	0.092
A	Orthophosphate (PO4) as P	mg/l	CSM 04	0.042	0.060	0.044	<0.025	0.052	<0.025	0.053
A	Fluoride (F)	mg/l	CSM 08	2.811	2.625	2.965	2.646	0.355	4.109	3.294
A	Calcium (Ca)	mg/l	CSM 30	164.45	200.93	149.29	215.43	15.73	200.13	103.12
A	Magnesium (Mg)	mg/l	CSM 30	38.76	47.18	45.57	43.65	10.59	63.35	33.26
A	Sodium (Na)	mg/l	CSM 30	349.51	235.31	272.98	261.85	31.73	450.19	208.06
A	Potassium (K)	mg/l	CSM 30	16.59	12.40	15.11	25.55	3.47	31.96	16.79
A	Aluminium (Al)	mg/l	CSM 31	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
A	Iron (Fe)	mg/l	CSM 31	0.537	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
A	Manganese (Mn)	mg/l	CSM 31	0.566	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
A	Total chromium (Cr)	mg/l	CSM 31	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
A	Copper (Cu)	mg/l	CSM 31	<0.001	<0.001	<0.001	0.005	0.013	0.014	<0.001
A	Nickel (Ni)	mg/l	CSM 31	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
A	Zinc (Zn)	mg/l	CSM 31	0.006	0.018	<0.004	<0.004	0.092	0.031	0.639
A	Cobalt (Co)	mg/l	CSM 31	0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
A	Cadmium (Cd)	mg/l	CSM 31	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
A	Lead (Pb)	mg/l	CSM 31	0.004	0.003	0.001	0.020	<0.001	0.015	<0.001
A	Turbidity	NTU	CSM 21	4.53	1.06	0.72	3.20	0.26	0.79	7.30
A	Total hardness	mg/l	CSM 26	570	696	560	718	83	761	394
N	Suspended solids (SS)	mg/l	CSM 25	11.0	13.0	6.00	18.0	<1.00	12.0	7.00
A	Arsenic (As)	mg/l	CSM 34	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023

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Laboratory Manager: H. Holtzhausen

aquatico Laboratories (Pty). Ltd.

Client: ERM
Address: Building 23, The Woodlands Office Park, Woodlands Drive, Woodmead, Sand
Report no: 9675
Project: ERM

Date of certificate: 20 September 2012
Date accepted: 11 September 2012
Date completed: 19 September 2012
Revision: 0

Lab no:				101189	101190	101191	101192	101193	101194	101195
Date sampled:				07-Sep-12	07-Sep-12	07-Sep-12	07-Sep-12	03-Sep-12	03-Sep-12	06-Sep-12
Sample type:				Water	Water	Water	Water	Water	Water	Water
Locality description:				AR9	AR10	AR11	AR12	ACH1	ACH2	BCH1
	Analyses	**Unit**	**Method**							
N	Barium (Ba)	mg/l	CSM 32	0.048	0.034	0.033	0.033	0.030	0.020	0.008
N	Dissolved Uranium (U)	mg/l	CSM 37	0.09	0.03	0.04	0.05	<0.01	0.16	0.08

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Laboratory Manager: H. Holtzhausen

Test Report

Client: ERM
Address: Building 23, The Woodlands Office Park, Woodlands Drive, Woodmead, Sand
Report no: 9675
Project: ERM

Date of certificate: 20 September 2012
Date accepted: 11 September 2012
Date completed: 19 September 2012
Revision: 0

	Analyses	Unit	Method	101196	101197	101198	101199	101200	101201	101202
Lab no:				101196	101197	101198	101199	101200	101201	101202
Date sampled:				06-Sep-12	06-Sep-12	04-Sep-12	06-Sep-12	01-Sep-12	01-Sep-12	01-Sep-12
Sample type:				Water	Water	Water	Water	Water	Water	Water
Locality description:				BCH3	BCH4	AGG1	LUS1	DUP1	DUP2	DUP3
A	pH	pH	CSM 20	7.60	7.65	7.04	7.65	7.97	8.42	7.19
A	Electrical conductivity (EC)	mS/m	CSM 20	101.20	138.50	347.50	138.40	1042.00	111.60	115.30
A	Total dissolved solids (TDS)	mg/l	CSM 26	620	827	2014	899	6371	683	708
A	Total alkalinity	mg/l	CSM 01	243.27	211.38	123.01	208.74	160.90	207.31	343.80
A	Chloride (Cl)	mg/l	CSM 02	108.22	248.46	769.82	246.81	3472.79	173.66	108.33
A	Sulphate (SO_4)	mg/l	CSM 03	128.48	128.05	439.51	202.31	386.00	142.52	140.84
A	Nitrate (NO3) as N	mg/l	CSM 06	2.77	12.1	1.12	12.1	12.0	0.374	1.18
A	Nitrite (NO2) as N	mg/l	CSM 07	0.018	0.008	0.129	0.069	0.129	<0.005	<0.005
A	Ammonium (NH4) as N	mg/l	CSM 05	0.162	0.069	<0.015	<0.015	0.058	<0.015	<0.015
A	Orthophosphate (PO4) as P	mg/l	CSM 04	0.047	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
A	Fluoride (F)	mg/l	CSM 08	3.077	2.726	4.799	2.807	2.174	1.066	0.680
A	Calcium (Ca)	mg/l	CSM 30	52.68	91.08	154.68	91.55	359.49	81.47	92.31
A	Magnesium (Mg)	mg/l	CSM 30	19.59	30.00	89.16	30.01	181.74	40.29	42.67
A	Sodium (Na)	mg/l	CSM 30	145.90	169.47	463.13	170.01	1787.38	114.69	108.99
A	Potassium (K)	mg/l	CSM 30	13.73	18.59	17.88	18.58	73.37	4.72	6.91
A	Aluminium (Al)	mg/l	CSM 31	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
A	Iron (Fe)	mg/l	CSM 31	0.024	0.424	<0.006	0.233	<0.006	<0.006	<0.006
A	Manganese (Mn)	mg/l	CSM 31	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
A	Total chromium (Cr)	mg/l	CSM 31	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
A	Copper (Cu)	mg/l	CSM 31	<0.001	<0.001	0.010	<0.001	0.042	0.001	<0.001
A	Nickel (Ni)	mg/l	CSM 31	<0.003	<0.003	<0.003	<0.003	0.034	<0.003	<0.003
A	Zinc (Zn)	mg/l	CSM 31	<0.004	0.006	0.043	0.006	<0.004	<0.004	<0.004
A	Cobalt (Co)	mg/l	CSM 31	<0.002	0.004	<0.002	<0.002	<0.002	<0.002	<0.002
A	Cadmium (Cd)	mg/l	CSM 31	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
A	Lead (Pb)	mg/l	CSM 31	0.002	<0.001	0.015	<0.001	<0.001	<0.001	<0.001
A	Turbidity	NTU	CSM 21	12.70	10.60	2.79	5.30	0.70	4.99	3.56
A	Total hardness	mg/l	CSM 26	212	351	753	352	1646	369	406
N	Suspended solids (SS)	mg/l	CSM 25	38.0	197	22.0	164	50.0	9.00	15.0
A	Arsenic (As)	mg/l	CSM 34	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023

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HHausen

Laboratory Manager: **H. Holtzhausen**

Client: ERM
Address: Building 23, The Woodlands Office Park, Woodlands Drive, Woodmead, Sand
Report no: 9675
Project: ERM

Date of certificate: 20 September 2012
Date accepted: 11 September 2012
Date completed: 19 September 2012
Revision: 0

Lab no:				101196	101197	101198	101199	101200	101201	101202
Date sampled:				06-Sep-12	06-Sep-12	04-Sep-12	06-Sep-12	01-Sep-12	01-Sep-12	01-Sep-12
Sample type:				Water	Water	Water	Water	Water	Water	Water
Locality description:				BCH3	BCH4	AGG1	LUS1	DUP1	DUP2	DUP3
	Analyses	**Unit**	**Method**							
N	Barium (Ba)	mg/l	CSM 32	0.019	0.054	0.065	0.029	0.016	0.024	0.068
N	Dissolved Uranium (U)	mg/l	CSM 37	0.06	0.13	0.05	0.13	0.04	0.11	0.01

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HHausen

Laboratory Manager: H. Holtzhausen

Client:	ERM	**Date of certificate:**	20 September 2012
Address:	Building 23, The Woodlands Office Park, Woodlands Drive, Woodmead, Sand	**Date accepted:**	11 September 2012
Report no:	9675	**Date completed:**	19 September 2012
Project:	ERM	**Revision:**	0

Lab no:				101203
Date sampled:				01-Sep-12
Sample type:				Water
Locality description:				DUP4
	Analyses	**Unit**	**Method**	
A	pH	pH	CSM 20	7.71
A	Electrical conductivity (EC)	mS/m	CSM 20	101.50
A	Total dissolved solids (TDS)	mg/l	CSM 26	616
A	Total alkalinity	mg/l	CSM 01	245.55
A	Chloride (Cl)	mg/l	CSM 02	109.58
A	Sulphate (SO_4)	mg/l	CSM 03	126.06
A	Nitrate (NO3) as N	mg/l	CSM 06	2.87
A	Nitrite (NO2) as N	mg/l	CSM 07	0.070
A	Ammonium (NH4) as N	mg/l	CSM 05	0.160
A	Orthophosphate (PO4) as P	mg/l	CSM 04	0.045
A	Fluoride (F)	mg/l	CSM 08	3.082
A	Calcium (Ca)	mg/l	CSM 30	50.46
A	Magnesium (Mg)	mg/l	CSM 30	19.26
A	Sodium (Na)	mg/l	CSM 30	143.50
A	Potassium (K)	mg/l	CSM 30	13.72
A	Aluminium (Al)	mg/l	CSM 31	<0.006
A	Iron (Fe)	mg/l	CSM 31	<0.006
A	Manganese (Mn)	mg/l	CSM 31	<0.001
A	Total chromium (Cr)	mg/l	CSM 31	<0.002
A	Copper (Cu)	mg/l	CSM 31	<0.001
A	Nickel (Ni)	mg/l	CSM 31	<0.003
A	Zinc (Zn)	mg/l	CSM 31	0.012
A	Cobalt (Co)	mg/l	CSM 31	0.002
A	Cadmium (Cd)	mg/l	CSM 31	<0.001
A	Lead (Pb)	mg/l	CSM 31	0.004
A	Turbidity	NTU	CSM 21	11.50
A	Total hardness	mg/l	CSM 26	205
N	Suspended solids (SS)	mg/l	CSM 25	32.0
A	Arsenic (As)	mg/l	CSM 34	<0.023

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Laboratory Manager: H. Holtzhausen

aquatico Laboratories (Pty). Ltd.

ilac-MRA sanas Testing Laboratory T0374

Client:	ERM	**Date of certificate:**	20 September 2012
Address:	Building 23, The Woodlands Office Park, Woodlands Drive, Woodmead, Sand	**Date accepted:**	11 September 2012
Report no:	9675	**Date completed:**	19 September 2012
Project:	ERM	**Revision:**	0

Lab no:				101203
Date sampled:				01-Sep-12
Sample type:				Water
Locality description:				DUP4
	Analyses	**Unit**	**Method**	
N	Barium (Ba)	mg/l	CSM 32	0.019
N	Dissolved Uranium (U)	mg/l	CSM 37	0.06

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HHausen

Laboratory Manager: H. Holtzhausen

Annex B

Mine Schedule

GAMSBERG NORTH OPEN PIT, Based on Pitshell from Whittle Optimization Run Case 1
Yearly Production Schedule

	PUSHBACK 1					PUSHBACK 2				
PERIOD Year	Mill Feed tonnes	Waste tonnes	Total tonnes	Top Elevation	Bottom Elevation	Mill Feed tonnes	Waste tonnes	Total tonnes	Top Elevation	Bottom Elevation
1	-	124 000 000	124 000 000	1120	1040	-	-	-		
2	7 140 767	116 859 233	124 000 000	1040	950	-	-	-		
3	9 882 907	34 204 527	44 087 434	950	870	-	71 999 828	71 999 828	1120	1040
4	3 436 545	5 993 465	9 430 010	870	800	6 482 372	98 471 135	104 953 507	1040	970
5	-	-	-			9 834 780	52 697 043	62 531 823	970	880
6	-	-	-			6 972 361	20 303 806	27 276 167	880	780
7	-	-	-			1 353 950	1 600 715	2 954 665	780	730
8	-	-	-			-	-	-		
9	-	-	-			-	-	-		
10	-	-	-			-	-	-		
11	-	-	-			-	-	-		
12	-	-	-			-	-	-		
13	-	-	-			-	-	-		
14	-	-	-			-	-	-		
15	-	-	-			-	-	-		
16	-	-	-			-	-	-		
17	-	-	-			-	-	-		
18	-	-	-			-	-	-		
19	-	-	-			-	-	-		
TOTAL	20 460 219	281 057 225	301 517 444			24 643 463	245 072 527	269 715 990		

	PUSHBACK 3					PUSHBACK 4				
PERIOD Year	Mill Feed tonnes	Waste tonnes	Total tonnes	Top Elevation	Bottom Elevation	Mill Feed tonnes	Waste tonnes	Total tonnes	Top Elevation	Bottom Elevation
1	-	-	-			-	-	-		
2	-	-	-			-	-	-		
3	-	7 761 190	7 761 190	1110	1080	-	151 548	151 548	1110	1100
4	-	9 616 483	9 616 483	1080	1060	-	-	-	1100	1100
5	-	61 468 177	61 468 177	1060	1020	-	-	-	1100	1100
6	2 731 417	99 992 416	102 723 833	1020	970	-	-	-	1100	1100
7	8 333 031	117 326 121	125 659 151	970	890	-	1 386 183	1 386 183	1100	1090
8	9 612 948	41 780 489	51 393 437	890	840	-	78 346 995	78 346 995	1090	1010
9	9 459 193	22 484 241	31 943 434	840	800	291 489	97 765 076	98 056 566	1010	950
10	8 991 128	11 307 381	20 298 509	800	740	989 711	39 124 195	40 113 907	950	930
11	2 829 779	1 567 468	4 397 247	740	700	7 008 587	113 046 624	120 055 210	930	850
12	-	-	-			9 807 575	62 936 507	72 744 082	850	790
13	-	-	-			9 776 424	34 600 271	44 376 695	790	730
14	-	-	-			9 425 840	11 201 339	20 627 179	730	680
15	-	-	-			2 129 869	1 324 705	3 454 574	680	650
16	-	-	-			-	-	-		
17	-	-	-			-	-	-		
18	-	-	-			-	-	-		
19	-	-	-			-	-	-		
TOTAL	41 957 496	373 303 966	415 261 461			39 429 495	439 883 443	479 312 939		

	PUSHBACK 5				
PERIOD Year	Mill Feed tonnes	Waste tonnes	Total tonnes	Top Elevation	Bottom Elevation
1	-	-	-		
2	-	-	-		
3	-	-	-		
4	-	-	-		
5	-	-	-		
6	-	-	-		
7	-	-	-		
8	-	259 568	259 568	1100	1100
9	-	-	-	1100	1100
10	-	69 587 585	69 587 585	1100	1000
11	-	5 547 543	5 547 543	1000	1000
12	-	57 255 919	57 255 919	1000	960
13	-	85 623 305	85 623 305	960	910
14	455 917	108 916 904	109 372 821	910	840
15	7 553 134	118 992 292	126 545 426	840	750
16	9 999 995	71 199 295	81 199 290	750	680
17	9 999 995	24 179 601	34 179 596	680	640
18	10 000 000	13 076 287	23 076 287	640	570
19	1 721 297	956 553	2 677 849	570	550
TOTAL	39 730 338	555 594 852	595 325 189		

	Mill Feed tonnes	Waste tonnes	Total tonnes	Strip Ratio	Top Elevation	Bottom Elevation
PB1	20 460 219	281 057 225	301 517 444	13.74	1120	800
PB2	24 643 463	245 072 527	269 715 990	9.94	1120	730
PB3	41 957 496	373 303 966	415 261 461	8.90	1110	700
PB4	39 429 495	439 883 443	479 312 939	11.16	1110	650
PB5	39 730 338	555 594 852	595 325 189	13.98	1100	550
TOTAL	166 221 011	1 894 912 013	2 061 133 023	11.40		

Annex C

Sensitivity Analysis

Table 1 ***Sensitivity Analysis Overview, Input Parameters and Results for 100 years Post Closure***

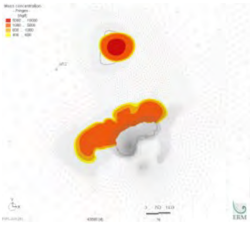
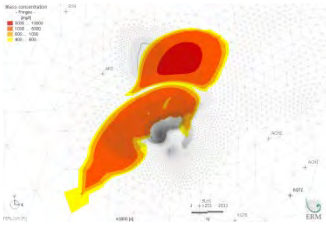
		Reference	Aquifer Thickness	Porosity
Aquifer Thickness	[m]	100	10	
Porosity	[]	0.005		0.0005
Plume				
Plume size	[km²]	12.91	68.15	68.15
TSF	[km²]	3.334		
WRD	[km²]	9.583		
Maximum transport distance WRD	[m]	1400	6500	6500
Drawdown difference	[m]	0	0	0

Table 2 ***Sensitivity Analysis Overview, Input Parameters and Results for 100 years Post Closure***

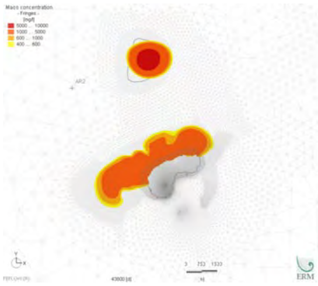
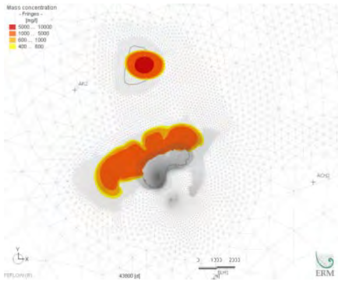
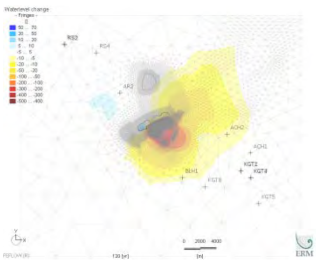
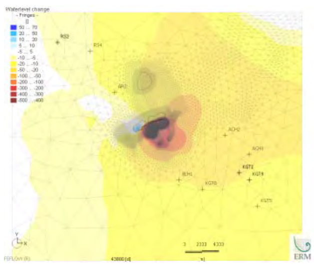
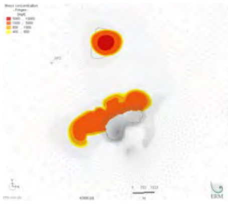
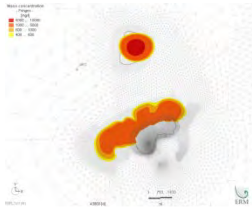
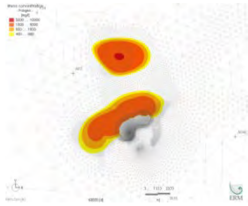
		Reference	Specific Storage
Specific Storage	[]	0.001	0.0001
Plume			
Plume size	[km2]	12.91	13.632
TSF	[km2]	3.334	2.948
WRD	[km2]	9.583	10.684
Maximum transport distance WRD	[m]	1400	1400
Drawdown			
Drawdown difference	[m]	0	36

Table 3 ***Sensitivity Analysis Overview, Input Parameters and Results for 100 years Post Closure***

	Reference	Molecular Diffusion	Dispersivity

		Reference	Molecular Diffusion	Dispersivity
Molecular diffusion	[m2/s]	1.00E-09	1.00E-10	
Dispersivity longitudinal	[m]	150		1500
Dispersivity transversal	[m]	15		150
Plume				
Plume size	[km2]	12.91	12.966	27.935
TSF	[km2]	3.334	3.367	16.65
WRD	[km2]	9.583	9.599	11.285
Maximum transport distance WRD	[m]	1400	1400	2000
Drawdown difference	[m]	0	0	0

Annex D

Details of Mineral Liner as Proposed by AMEC

Gamsberg Tailings Storage Facility Details (For discussion)

HDPE Liner Design Option

Figure 1 Underliner System Drainage Plan (Pre-deposition Stage)

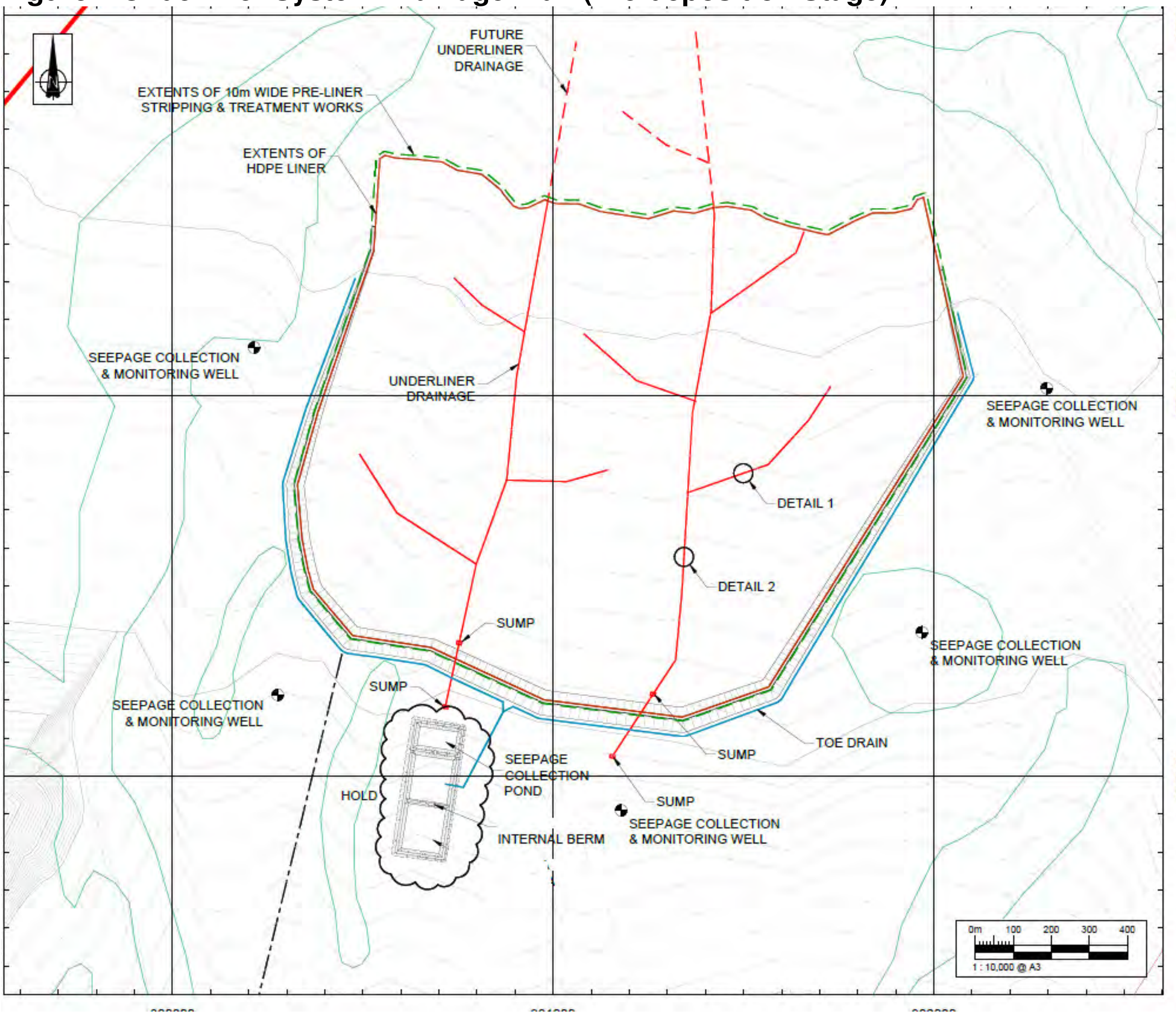


Figure 2 Underliner System Drainage Details – Sand Drains

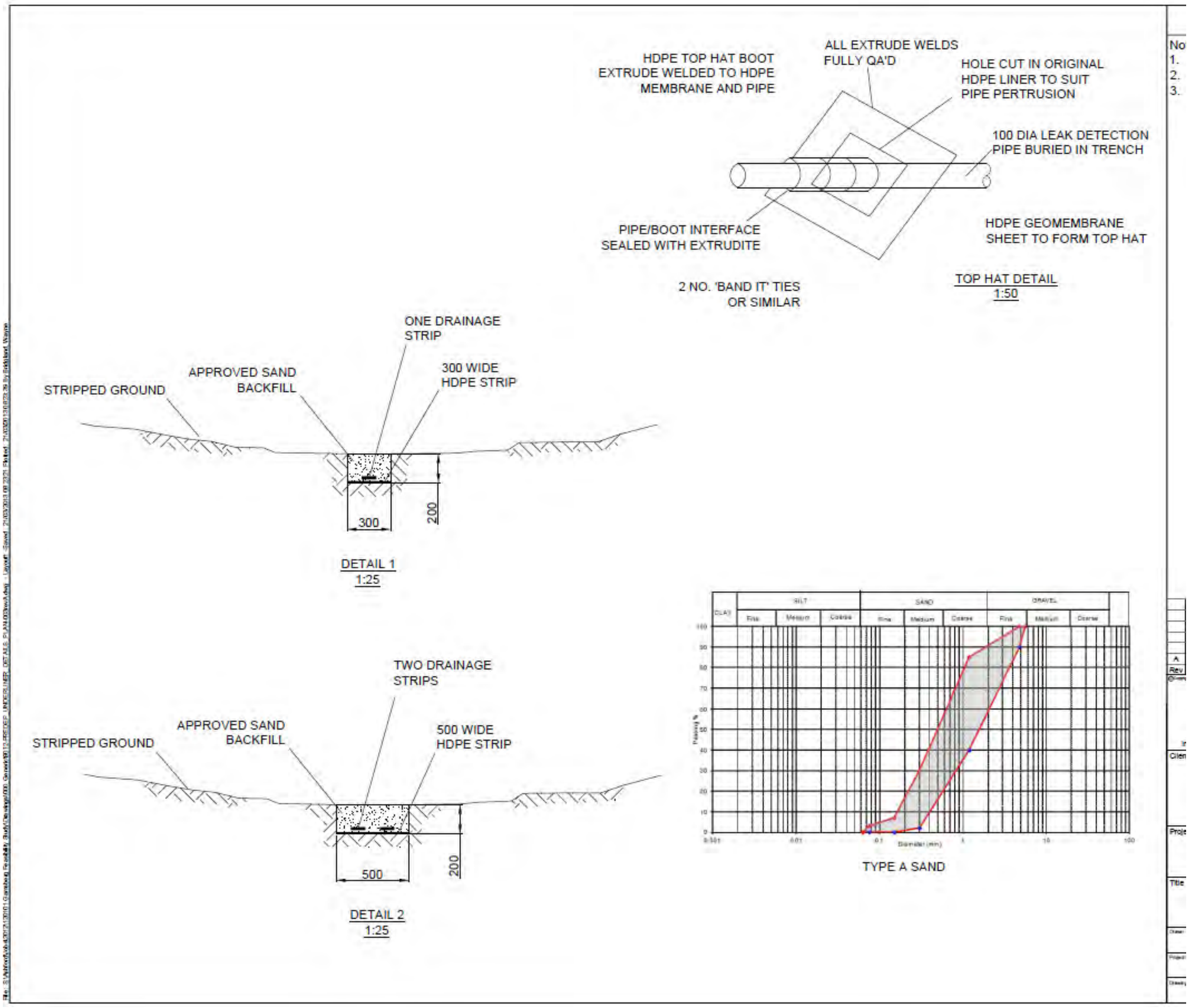


Figure 3 Underliner System Drainage Details – Upstream Sump

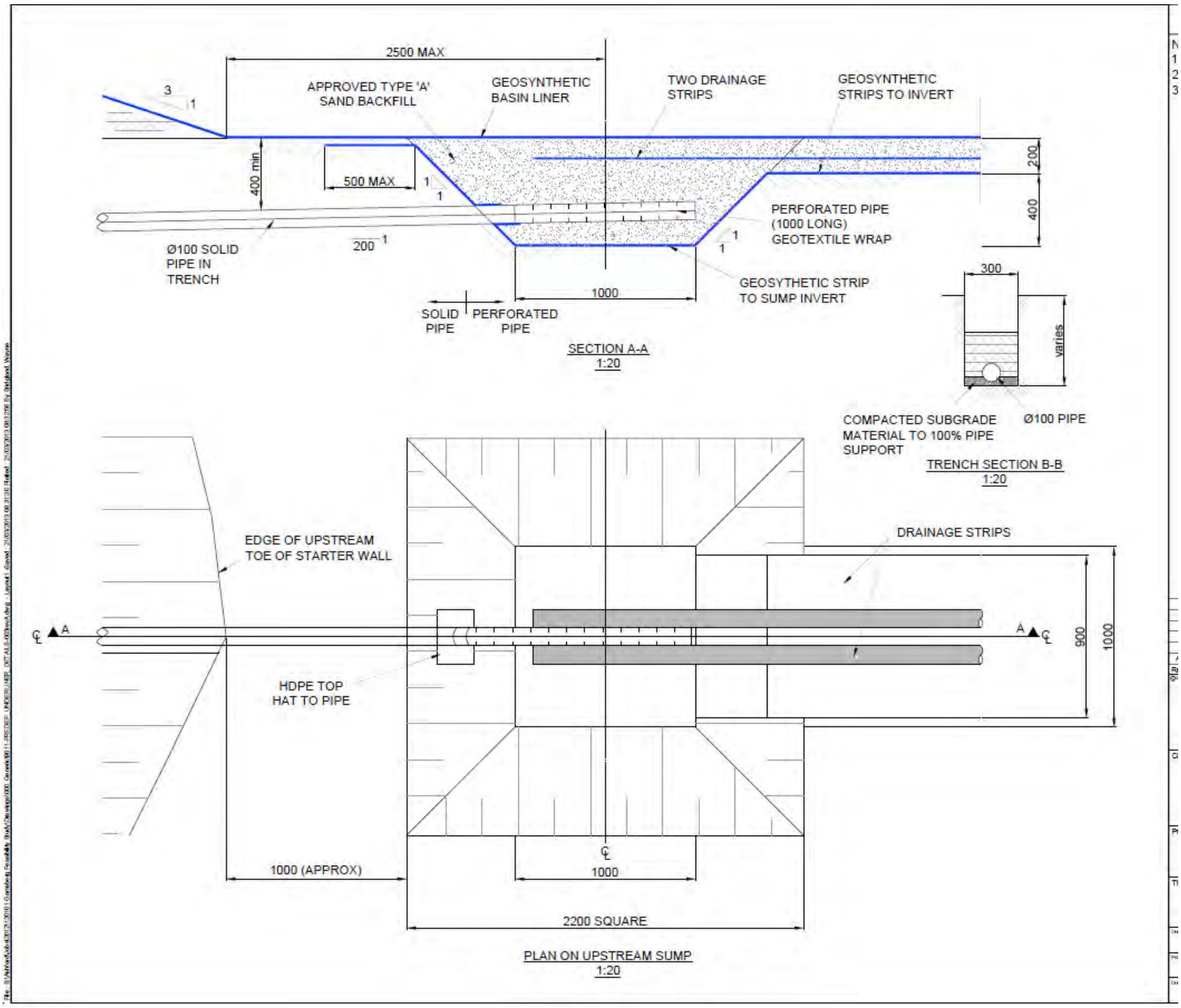


Figure 4 Overliner System Drainage Plan (Pre-deposition Stage)

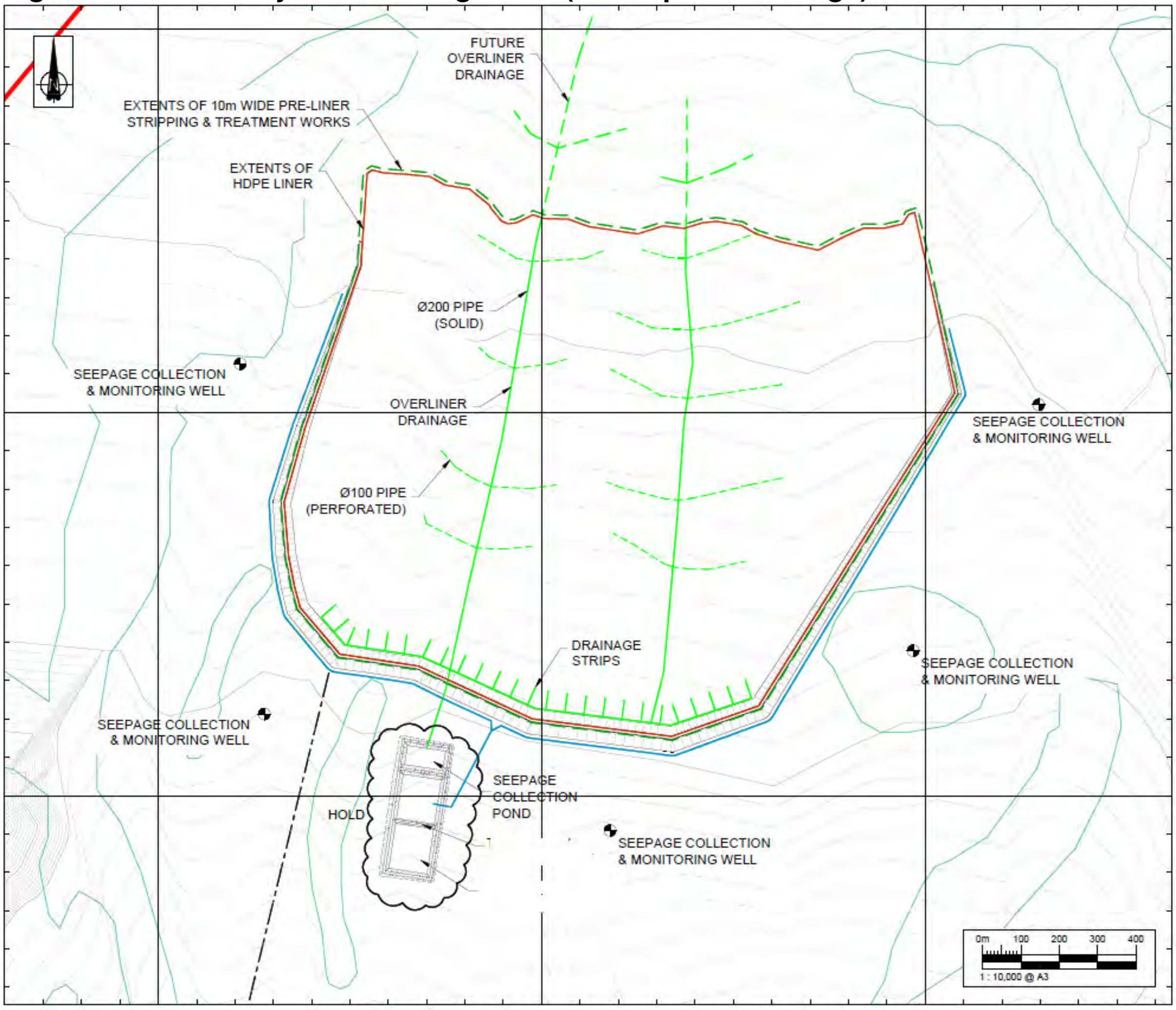
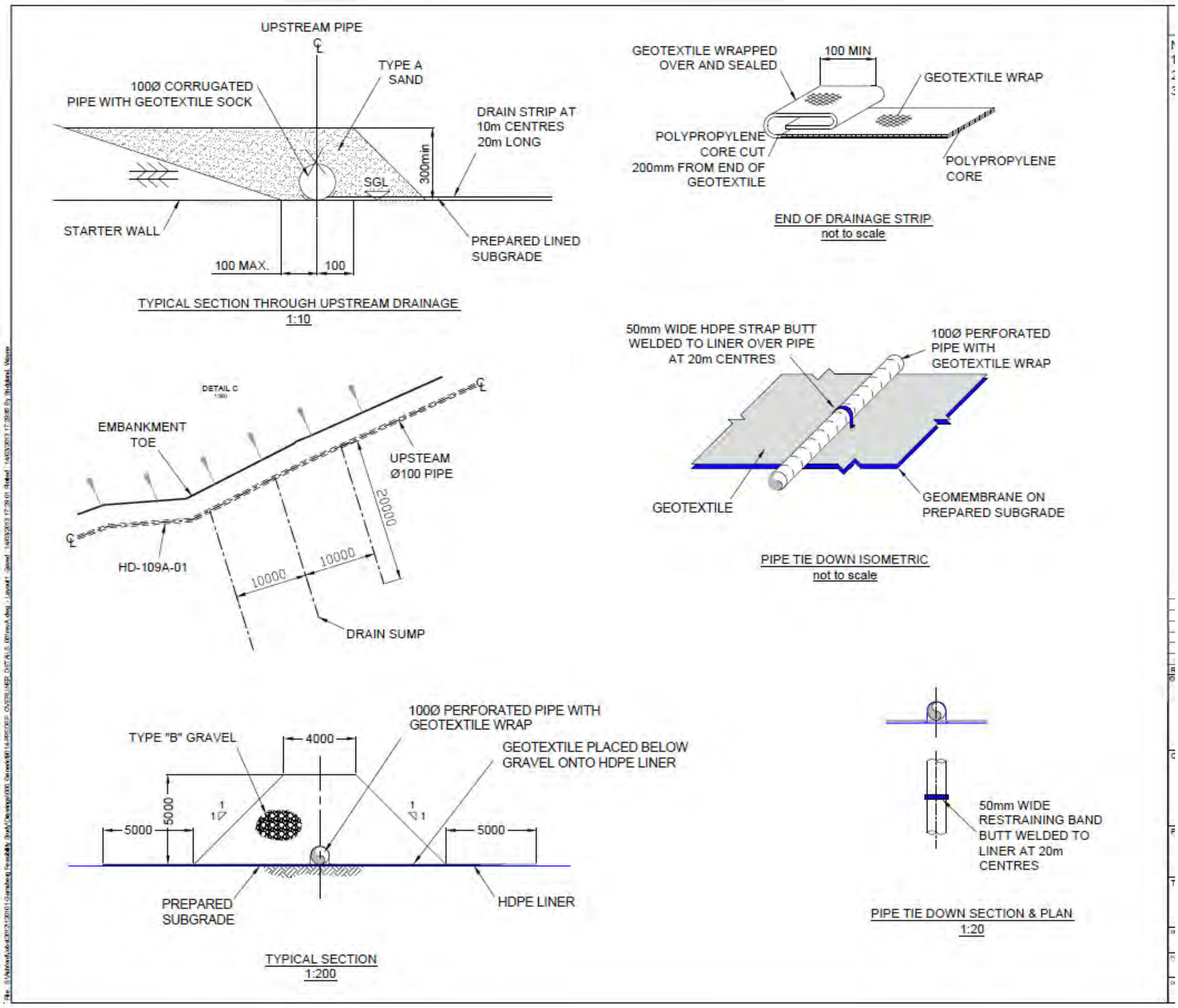


Figure 5 Overliner System Drainage Details



Mineral Liner Design Option (no HDPE liner)

Figure 6 Under-drainage System Drainage Details

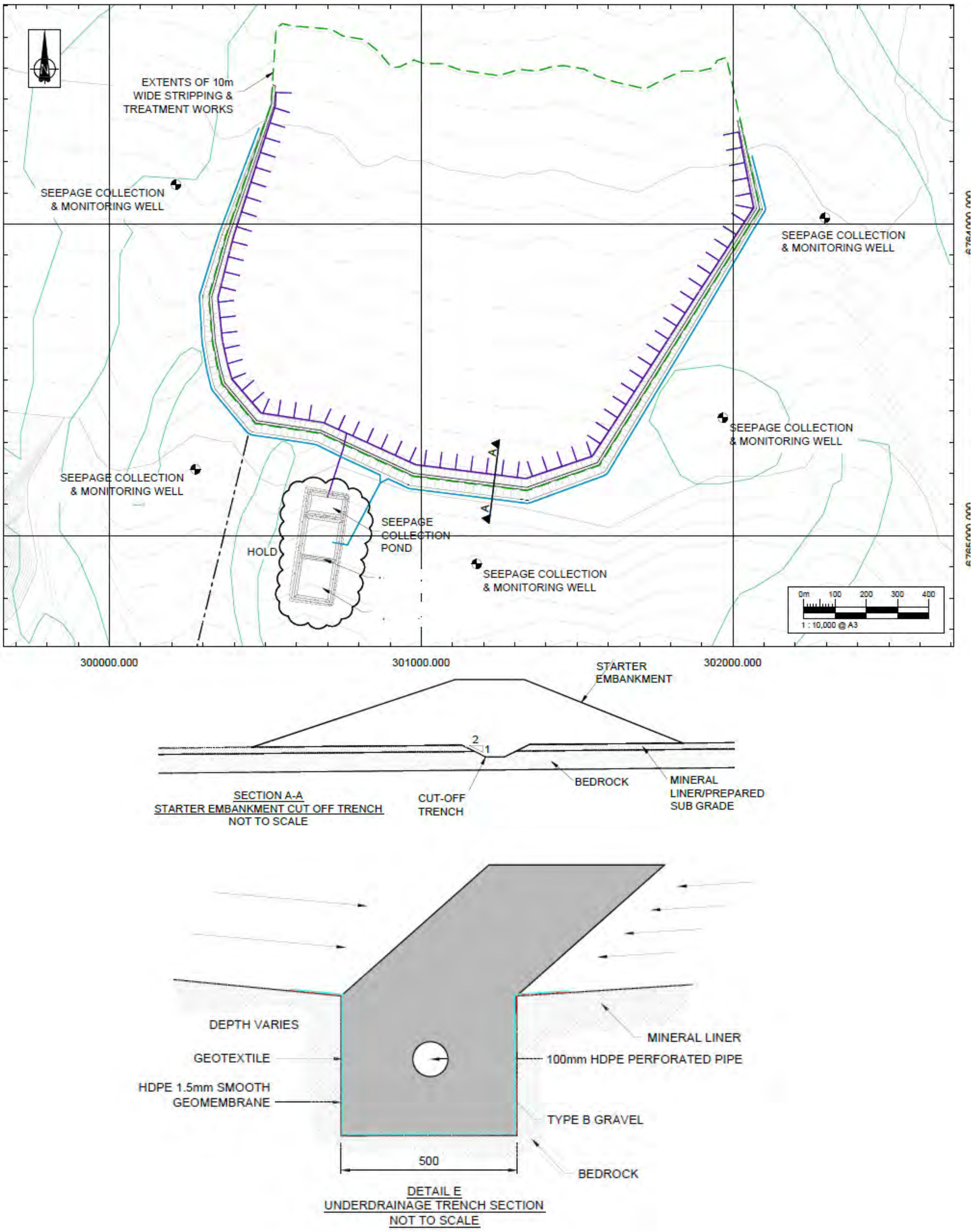


Figure 7 Seepage Collection Pond Detail