GROUNDWATER IMPACT STUDY

FOR

THE PROPOSED OPENCAST COAL MINE ON THE FARM ROODEPOORT 151 IS, MPUMALANGA

GPT Reference Number:	Eco-Cur-13-469
Client Reference Number:	N/A
Version:	Final
Date:	September 2013

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Report Type:	Groundwater Impact Study
Project Title:	Groundwater Impact Study for the Proposed Opencast Coal Mine on the farm Roodepoort 151 IS, Mpumalanga
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GPT Reference:	EcoCur-13-469
Version:	Draft Ver. 1.0
Date:	September 2013
Distribution List (Current Version):	PDF by e-mail to Eco Elementum (Pty) Ltd, Copy at Geo Pollution Technologies

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EXECUTIVE SUMMARY

Geo Pollution Technologies (Pty) Ltd (GPT) was appointed by Eco Curo to conduct a hydrogeological impact study for the opencast coal mine located approximately 2 km north-west of Pullens Hope, on the farm Roodepoort 151 IS, Mpumalanga.

This geohydrological study aimed to contain and relate the following objectives:

- Description of the pre-opencast geohydrological environment.
- Prediction of the environmental impact of the proposed opencast coal mine on the geohydrological regime of the area.
- Forecasting the effect of the open cast on the receiving environment.
- Compilation of all the relevant data and recommendations in a geohydrological report, structured in such a way that it can be incorporated into the final Environmental Management Program document.

Results of the Investigation

The area is characterised by a gentle undulating topography and in the area of the proposed opencast coal mine the slope is more or less in the order of 1:40 (0.025).The direction of the slope on site is towards the east.

There are a few surface water points around the proposed opencast mine, with a stream down gradient to the east of the site. On a larger scale, drainage occurs towards the generalised flow of the Woes-Alleen spruit which confluences with the Klein Olifants River approximately 12 km from the site.

Groundwater levels were measured in six boreholes during a hydrocensus conducted in September 2013 for the proposed opencast coal mine. The depth of the groundwater was found to vary between 2.3m and 8.6m below ground level.

The fractured aquifer was classified as a minor aquifer as it is not a highly productive aquifer. Using the Groundwater Decision Tool it was found that the aquifer has a medium to high vulnerability and as a result it also has a medium level groundwater quality management index. This indicates that a medium level of aquifer protection is required in the area of the proposed opencast.

Based on the data collected in terms of hydrogeology, the following can be concluded.

- Three aquifers are inferred to be present across the site at varying depths.
- The extent and depth of the aquifers is controlled by the sub-surface Karoo formation layering, weathering, geometry and post-Karoo intrusions.
- Flow within the weathered aquifer is thought to be multi-porous and is controlled by weathering, flow within the fractured aquifer is controlled by the fracturing network while the competent host rocks serve as storage.
- Recharge into the weathered aquifer is thought to be directly linked to rainfall while recharge into the fractured aquifer is linked to shallower aquifers.

If collectedthe groundwater samples, are compared to the DWA guidelines for domestic use, only pH is elevated above the tolerable water quality (ROD1). The concentration of Mn in ROD4 and ROD6 is also elevated above the target water quality range but still falls within the tolerable water quality

range. This constituent can be sourced directly from the underlying geology. Mn is a common component in sandstones of the Ecca. Additionally, Na falls within the tolerable water quality range for ROD6.

Identified Hydrogeological Impacts

The following impacts were identified and can be anticipated during the mining of the proposed opencast:

- Base flow of the tributary to the Woes-Alleenspruit situated to the east of the proposed opencast, could be affected due to the cumulative effect of drawdown resulting from the dewatering of the opencast.
- The surrounding wetlands may experience a decrease in water supply due to dewatering of the opencast. However, a qualified hydrologist specialising in wetland delineation should be consulted to determine the connectivity between the wetland and groundwater as well as to identify the sources feeding the wetland, before final comments can be made about the effect of the dewatering of the opencast, on the wetland.
- Transport modelling indicates that pollution from surface sources such as the ROM stockpiles and Discard dumps are likely. However no receptor is deemed to be influenced via the groundwater pathway as pollution from these sources will be contained within the opencast as a result of dewatering. However, surface seepage may impact on the wetland and the tributary to the Woes-Alleenspruit during mining. Assuming removal of these structures post-mining, no post-mining impacts are expected from these areas.

The following impacts were identified and can be anticipated after the mining and rehabilitation of the proposed opencast:

- The sulphate pollution plume emanating from the mining area, after mining has ceased and rebound of groundwater levels, is predicted to reach a tributary of the Woes-Alleenspruit in the east in about 10 years.
- Following this eventual period, seepage of AMD will increase in concentration and could reach high levels in the tributary to the Woes-Alleenspruit, due to evapotranspiration.

Management/Mitigation Measures

Since the drawdown of the groundwater levels during mining could influence the wetland and tributary to the Woes-Alleenspruit, the following measures are recommended:

- The static level of groundwater in all boreholes within a distance of less than one kilometre must be measured regularly to establish a database against which future groundwater levels can be compared.
- Such measurements must be made preferably quarterly, but at least twice annually, following the dry and rainy seasons.
- In the event of unacceptable decrease of the yield of any affected boreholes, alternative water supply should be supplied to the affected parties until such time that the groundwater recovers following closure of the pit.
- As the tributary of the Woes-Alleenspruit and the adjacent wetland could be affected, monitoring of these surface water bodies is essential. Should clean mine water be available, it is suggested that it be released into the tributary of the Woes-Alleenspruit. A surface water specialist should be consulted to ensure correct volumes and timing of the added water.

- Another very important aspect to consider is the layout and order of the opencast cuts. The best possible scenario for minimising impacting is to start the boxcut parallel to the wetland/tributary and at the farthest point from the wetland. In such a mining scenario the impact on the wetland and tributary will be delayed to the latest possible time before closure of the opencast.

- If it is proven that the opencast is impacting on baseflow, various options should be investigated such as if clean discharge is available to be pumped back into the streams.

- As far possible separate water of differing qualities. The runoff from the dirty water areas must be captured, retained and managed within the mine water system.

- Manage effective water collection infrastructure for the various water sources of the mine. Water stored in the pit form seepage or rainfall should be utilised for dust suppression. Excess water could also be pumped to surface to be incorporated into the mine water balance.

- If at all feasible, water effluent facilities such as pollution control dams should be lined.

- Additionally, it is recommended that surface runoff from overburden dumps and the ROM stockpile facilities should be contained using berms and pollution control dams constructed between the opencast and the wetland/ tributary to the Woes-Alleenspruit, at an early stage of mining, with non-acid forming overburden.

To minimise the effect of groundwater pollution on the receiving environment, post-mining, the following measures are suggested:

- All mined areas should be flooded as soon as possible to bar oxygen from reacting with remaining pyrite.

- Mining should remove all coal from the opencast and as little as possible should be left.

- Acid generating material should be disposed of at the base of the pit.

- The final backfilled opencast topography should be engineered such that runoff is directed away from the opencast areas.

- The final layer (just below the topsoil cover) should be as compacted if feasibly possible, to reduce recharge to the opencasts.

- Quarterly groundwater sampling must be done to establish a database of plume movement trends, to aid eventual mine closure.

- Regular sampling and chemical analyses of the groundwater is imperative to establish a sound database:

    - Groundwater in all boreholes within a distance of less than two kilometres must be sampled regularly to establish a database against which future groundwater levels can be compared.
    - Sampling must be preferably quarterly, but at least twice annually, following the dry – and rainy seasons.

- If it is found during such a sampling event that groundwater from any extraction borehole is polluted beyond acceptable standards, alternative water will have to be supplied to the affected party.

Impacts indirectly related to mining, such as hydrocarbon spills, should be mitigated as follows:

- It must be ensured that a credible company removes used oil after vehicle servicing.
- A sufficient supply of absorbent fibre should be kept at the site to contain accidental spills.
- Used absorbent fibre must be land-farmed, using approved methodologies.
- Domestic waste water, especially sewage, must either be treated at site according to accepted principles, or removed by credible contractors.

Solid waste must similarly either be stored at site on an approved waste dump, or removed by credible contractors.

Further work required

The following further work is recommended

- Monitoring boreholes should be constructed around the opencast as mentioned in the report.
- A monitoring network should be dynamic. This means that the network should be extended over time to accommodate the migration of contaminants through the aquifer as well as the expansion of infrastructure and/or addition of possible pollution sources.
- An audit on the monitoring network should be conducted annually.
- The numerical model should be recalibrated during the mining of the proposed opencast. The numerical model should also be recalibrated during the post-mining phase.

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ABBREVIATIONS

Ag	=	Silver
AH	=	Auger hole
Al	=	Aluminium
As	=	Arsenic
B	=	Boron
BDL	=	Below detection limit
BH	=	Borehole
Ca	=	Calcium
Cat/an bal%	=	Cation/anion balancing error
Cd	=	Cadmium
Cl	=	Chloride
Co	=	Cobalt
Cu	=	Copper
DRO	=	Diesel Range Organics
EC	=	Electrical Conductivity
F	=	Fluoride
Fe	=	Iron
GC-MS	=	Gas Chromatography Mass Spectrometer
GPT	=	Geo Pollution Technologies
GRO	=	Gasoline Range Organics
GW	=	Groundwater
HCO_3	=	Bicarbonate
ICP-OES	=	Inductively Coupled Plasma Optical Emission Spectroscopy
K	=	Potassium
ℓ	=	litre
m	=	metres
mamsl	=	metres above mean sea level
mbgl	=	metres below ground level
Mg	=	Magnesium
mg/l	=	milligram per litre
Mn	=	Manganese
n.a.	=	not analysed
Na	=	Sodium
Ni	=	Nickel
NO_3	=	Nitrate
PAH	=	Poly Aromatic Hydrocarbons
Pb	=	Lead
ppm	=	parts per million
RBCA	=	Risk Based Corrective Actions
RBSL	=	Risk Based Screening Levels
Se	=	Selenium
Si	=	Silica
SO_4	=	Sulphate
SSL	=	Soil Screening Level
SWL	=	Static Water Level
TDS	=	Total Dissolved Solids
Zn	=	Zinc

1 INTRODUCTION

Geo Pollution Technologies (Pty) Ltd (GPT) was appointed by Eco Curo to conduct a hydrogeological impact study for the opencast coal mine located approximately 2 km north-west of Pullens Hope, on the farm Roodepoort 151 IS, Mpumalanga.

This report is not intended to be an exhaustive description of the proposed project, but rather as a specialist interim geohydrological study to evaluate the geohydrological impacts the proposed opencast mine will have on the environment. In order to quantify these impacts further work such as intrusive field investigations and recalibration of numerical models should be done.

This geohydrological study aims to contain and relate the following objectives:

- Description of the pre-opencast geohydrological environment.
- Prediction of the environmental impact of the proposed opencast coal mine on the geohydrological regime of the area. This includes the description of possible negative impacts during the life of the opencast coal mine, which is assumed to be 100 years.
- Forecasting the effect of the open cast on the receiving environment.
- Compilation of all the relevant data and recommendations in a geohydrological report, structured in such a way that it can be incorporated into the final Environmental Management Program document.

2 SCOPE OF WORK

The following work program was envisaged in order to adhere to the scope of work:

- A desk study was conducted, i.e. gathering of existing information from topographical maps, ortho-photos, geological maps, hydrological information, meteorological information, discussions with relevant personnel, studying of geological logs etc.
- A borehole/surface water hydrocensus was conducted in the area to assess groundwater occurrence and utilisation by neighbours. An area of one kilometre surrounding the proposed opencast coal mine was covered in detail, while spot checks were done in the 1 to 2 kilometre range. Based on the information, gathered during the hydrocensus, the groundwater potential (quality & quantity) of the area were evaluated. The data gathered during this phase assisted in the development of a groundwater-monitoring program.
- Groundwater flow and transport modelling to predict the long term impacts on the receiving environment. The impacts, associated with the proposed opencast coal mine, can normally be subdivided into two aspects, namely the de-watering of the surrounding aquifer system and the deterioration of the water quality in the receiving aquifer system. Both these aspects were addressed.
- The available data was interpreted and collated for the prediction of the possible environmental impact and the design of rehabilitative measures.
- Recommendation of a groundwater monitoring network was made and standard operational procedures for groundwater monitoring and management supplied.

This report was constructed in such a way that it can easily be incorporated into the final EMP document. In order to adhere to the requirements of the relevant Governmental Departments, the following aspects were addressed:

- Statement of the current situation.
- Prediction of the environmental impacts, with specific reference to the possible impact on the surface- and groundwater regimes. Possible impacts during the mining of the opencast coal mine will be addressed.
- Rehabilitative measure design and implementation. These designs must be based on the physical, hydraulic and hydro-geochemical information as generated during the preceding phases.
- The compilation of a geohydrological report, which will be structured in such a way that in can be incorporated into the final EMP document.

3 METHODOLOGY

The impact of the proposed opencast coal mine was investigated through field investigations, data analyses and the use of numerical models (flow and transport models). The work completed for the purposes of compiling a groundwater impact study comprised the following:

3.1 Desk Study

A desk study was conducted, entailing the gathering of information from the relevant topographical maps (1:50 000-scale 2529DC and 2629BA Topographic Sheets), geological map (1:250 000 sheets 2526 East Rand and 2528 Pretoria) and geohydrological map (Groundwater Resources of South Africa Sheets 1 and 2). The National Groundwater Archive was used in order to obtain borehole positions in the area as well as logs of these boreholes. Previous reports done in the area were also made available.

A conceptual layout of the opencast coal mine was made available at the time of this study, while some borehole logs were obtained from the National Groundwater Archive. Meteorological information was obtained from the Department of Water Affairs (DWA) Hydrological Services. Available monitoring data applicable to this area as well as previous groundwater studies done for the collieries in the area, including previous EMPR(s), were also made available.

3.2 Hydrocensus

A detailed hydrocensus was conducted on and around the site to a distance of about two kilometres so as to obtain a representative population of the boreholes in the area. During the hydrocensus, all available details of boreholes and borehole-owners were collected and included in the hydrocensus forms. Water samples were collected from boreholes as described in the relevant paragraph below. Information was collected on the use of the boreholes in the area, the water levels and yields of boreholes, etc. The information can be used to assess the risk which potential groundwater pollution poses to groundwater users.

3.3 Sampling and Chemical Analysis

Groundwater was sampled according to the GPT Standard Operating Procedure[1] for groundwater samples by bailing. In summary, the procedure is to measure the groundwater level before introducing any equipment in the borehole. Pump samples were collected from boreholes with restricted access by purging the hole for a period to ensure that a representative sample of the aquifer is obtained. The groundwater samples were contained in pre-cleaned one litre plastic bottles. All samples were kept on ice or in a refrigerator until delivered to a laboratory.

A total of 6 hydrocensus boreholes were sampled during the hydrocensus of September 2013. The water samples were sent to UIS analytical laboratory in Pretoria for major ion analysis to determine water quality in the area.

[1] Available on request from giep@gptglobal.com

3.4 Recharge Calculation

The groundwater recharge was estimated using the RECHARGE program[2], which includes using qualified guesses as guided by various schematic maps. The following methods/sources were used to estimate the recharge:

- Soil information
- Geology
- Groundwater Recharge Map (Vegter)
- Acru Recharge Map (Schulze)
- Harvest Potential Map
- Chloride (Cl) method

The above-mentioned programme incorporates all the different methods to calculate recharge. The following assumptions are necessary for successful application of the Cl Method:

- There is no source of chloride in the soil water or groundwater other than that from precipitation
- Chloride is conservative in the system
- Steady-state conditions are maintained with respect to long-term precipitation and chloride concentration in that precipitation, and in the case of the unsaturated zone
- A piston flow regime, which is defined as downward vertical diffuse flow of soil moisture, is assumed.

3.5 Numerical Modelling

The finite difference numerical model was created using the US Department of Defence Groundwater Modelling System (GMS9.1) as Graphical User Interface (GUI) for the well-established Modflow and MT3DMS numerical codes.

MODFLOW is a 3D, cell-centred, finite difference, saturated flow model developed by the United States Geological Survey. MODFLOW can perform both steady state and transient analyses and has a wide variety of boundary conditions and input options. It was developed by McDonald and Harbaugh of the US Geological Survey in 1984 and underwent eight overall updates since. The latest update (Modflow-NWT) incorporates several improvements extending its capabilities considerably, the most important being the introduction of the Newton formulation of Modflow. This dramatically improved the handling of dry cells that has been a problematic issue in Modflow in the past.

MT3DMS is a 3-D model for the simulation of advection, dispersion, and chemical reactions of dissolved constituents in groundwater systems. MT3DMS uses a modular structure similar to the structure utilized by MODFLOW, and is used in conjunction with MODFLOW in a two-step flow and transport simulation. Heads are computed by MODFLOW during the flow simulation and utilized by MT3DMS as the flow field for the transport portion of the simulation.

[2] Gerrit van Tonder, Yongxin Xu: RECHARGE program to Estimate Groundwater Recharge, June 2000. Institute for Groundwater Studies, Bloemfontein RSA.

4 REGIONAL SITE INFORMATION

The site is situated approximately 2 km north-west of Pullens Hope, in Mpumalanga. The locality map is shown in Figure 2 and the topographic map showing the infrastructure of the area is shown in Figure 3.

4.1 Climate

Climatic data was obtained from the DWA weather station Rondebosch for the Middelburg Dam area (Table 1)[3]. The proposed opencast mine is located in the summer rainfall region of Southern Africa with precipitation usually occurring in the form of convectional thunderstorms. The average annual rainfall (measured over a period of 34 years) is approximately 707.23mm, with the high rainfall months between October and March. If the evaporation is compared with the average monthly rainfall (see Figure 1) it is found that evaporation exceeds rainfall in every month of the year. The highest evaporation measurements for the Pullens Hope area are seen from October to January.

Table 1: Climatic Data for the Pullens Hope Area

Month	Average Monthly Rainfall (mm)	Mean Monthly Evaporation
January	123.36	191.56
February	90.15	172.72
March	74.13	158.83
April	31.92	126.85
May	11.06	104.97
June	7.99	86.19
July	10.47	98.42
August	15.89	130.48
September	27.68	171.99
October	75.12	189.10
November	111.22	185.20
December	128.23	194.08
Annual	707.23	1810.39

[3] Department of Water Affairs (DWA): www.dwa.gov.za

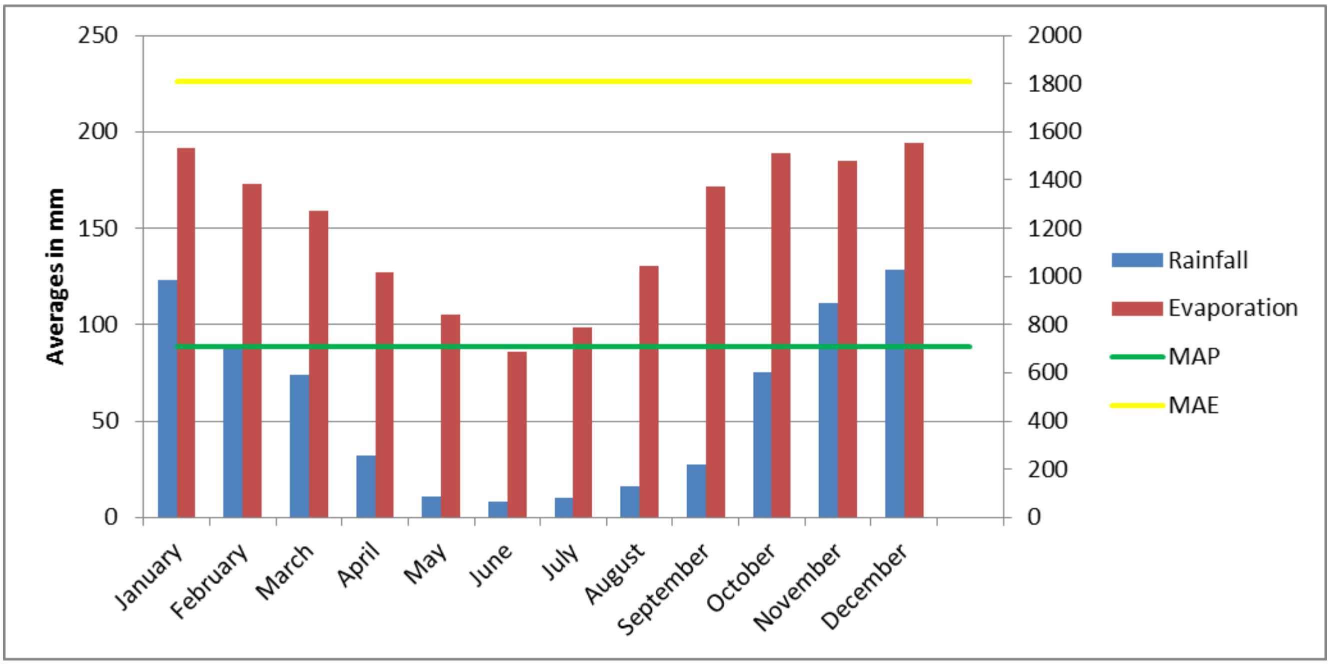

Figure 1 : Average Rainfall/ Evaporation for the Pullens Hope Area

4.2 Topography and Drainage

The topography (Figure 3: Topographical Map) can normally be used as a good first approximation of the hydraulic gradient in an unconfined aquifer. This discussion will focus on the slope and direction of fall of the area under investigation, features that are important from a groundwater point of view.

The area is characterised by a gentle undulating topography and in the area of the proposed opencast coal mine the slope is more or less in the order of 1:40 (0.025).The direction of the slope on site is towards the east.

There are a few surface water points around the proposed opencast mine, with a stream down gradient to the east of the site. On a larger scale, drainage occurs towards the generalised flow of the Woes-Alleen spruit which confluences with the Klein Olifants River approximately 12 km from the site.

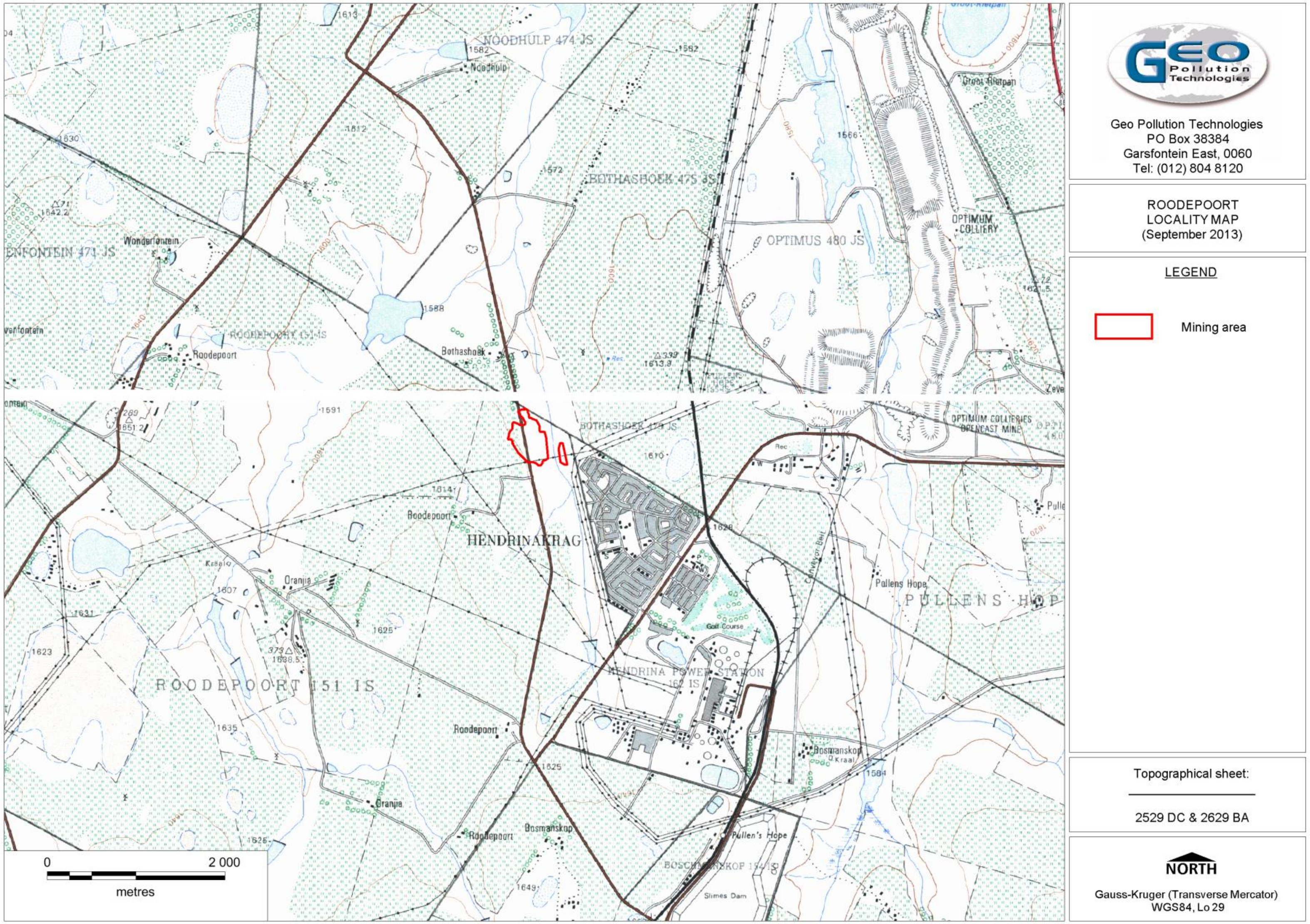

Figure 2: Locality Map

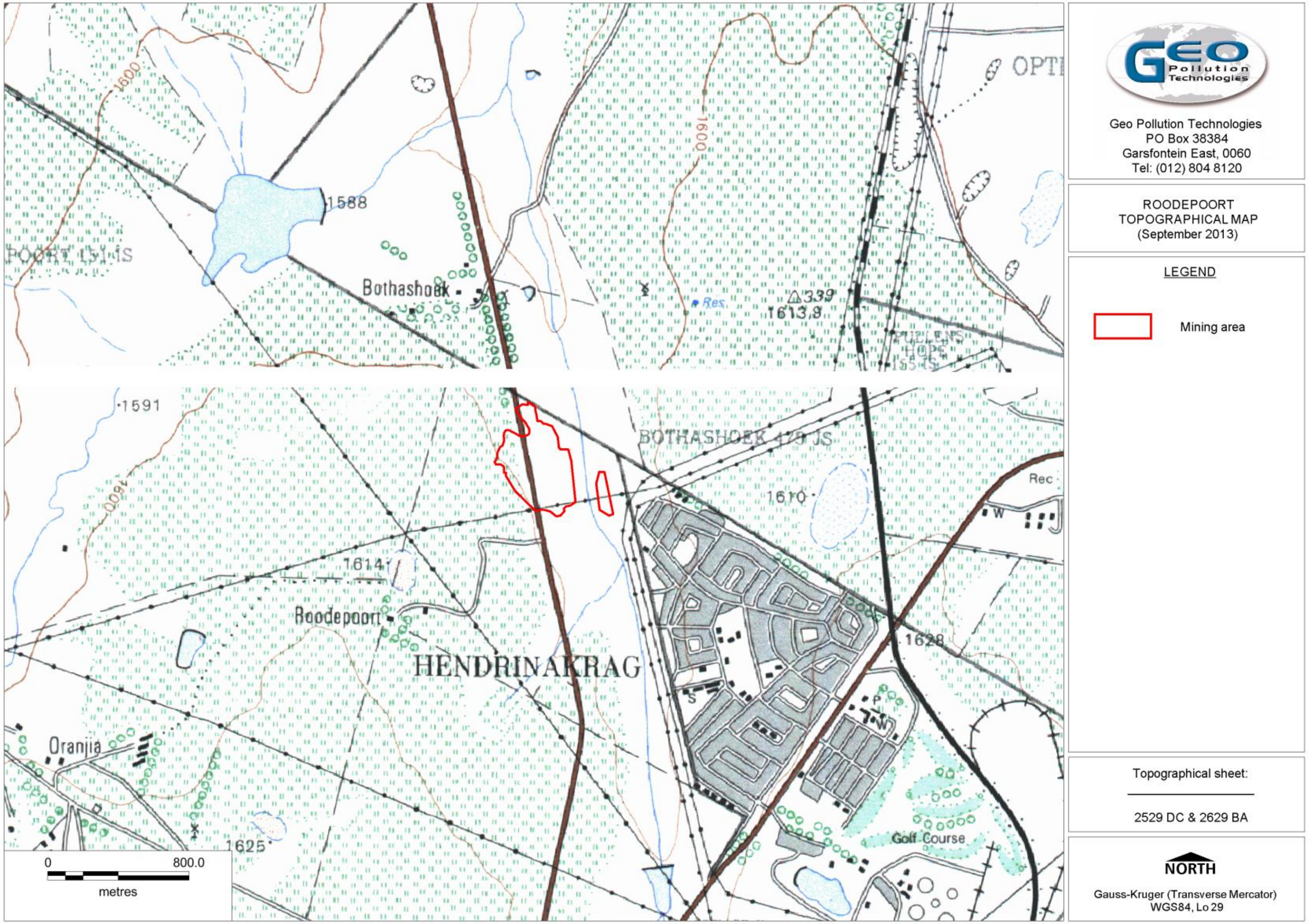

Figure 3: Topographical Map

5 PREVAILING GROUNDWATER CONDITIONS

Most coal mining and mining related activities impact on groundwater quality. Quantification of such impacts on the groundwater regime requires knowledge of the environment existing prior to the establishment of the mine.

The purpose of this section is to describe the pre-opencast environment; thus the current prevailing groundwater conditions. This will serve as a reference baseline for quantifying potential impacts on the existing groundwater regime. In this case, however, the area under investigation cannot be classified as a pristine environment due to current opencast mining activities in the area.

5.1 Geology

5.1.1 Regional Geology

The investigated area falls within the 2528 Pretoria and 2628 East Rand 1:250 000 geology series maps and is situated approximately 2 km north-west of Pullens Hope, Mpumalanga. An extract of this map is shown in Figure 4.

The proposed opencast mining areas falls within the Witbank coalfield, which extends from Belfast in the north-east to Springs in the south-west covering a surface area of approximately 9000 km^2. There are five coal seams present regionally. These coal seams are numbered from 5 (top) to 1 (bottom) and the distribution of these coal seams are affected by the topography of the pre-Karoo basement and the present day erosional surface. The area is characterised by consolidated sedimentary layers of the Karoo Supergroup. It consists mainly of sandstone, shale and coal beds of the Ecca Group (Vryheid Formation) and is underlain by the Dwyka Group. Jurassic dolerite intrusions occur throughout the area in the form of sills and dykes with outcrops found throughout the whole area.

The Ecca Group (Vryheid Formation), which is part of the Karoo Supergroup, comprises of sediments deposited in shallow marine and fluvio-deltaic environments with coal accumulated as peat in swamps and marches associated with these environments. The sandstone and coal layers are normally reasonable aquifers, while the shale serves as aquitards. Several layered aquifers perched on the relative impermeable shale are common in such sequences. The Dwyka Formation comprises consolidated products of glaciation (with high amounts of clay) and is normally considered to be an aquiclude.

The generally horizontally disposed sediments of the Karoo Supergroup are typically undulating. The extent of the coal is largely controlled by the pre-Karoo topography. Steep dips can be experienced where the coal buts against pre-Karoo hills. Displacements, resulting from intrusions of diabase sills, are common. These intrusions comprise sills, which vary from being concordant to transgressive in structure, and feeder dykes. Although these structures serve as aquitards and tend to compartmentalise the groundwater regime, the contact zones with the pre-existing geological formations also serve as groundwater conduits. There are common occurrences of minor slips or faults, particularly in close proximity to the dolerite intrusives. Within the coalfield, these minor slips, displacing the coal seam by a matter of 1 to 2 metres, are likely to be commonplace.

Rocks of the Selons River Formation (Rooiberg Group) and quaternary alluvium are also present regionally. The Selons River Formation consists of porphorytic rhyolite with interbedded sandstone and mudstone.

5.1.2 Local Geology

From the sheet of 2528 Pretoria and the 2628 East Rand geology series map it is evident that the shale, mudstone and coal beds of the Ecca Group as well as the rhyolites of the Rooiberg Group outcrop in the area.

The local geology is best concluded from information obtained from borehole logs from the National Groundwater Archive. A generalised geological stratigraphy (Table 2) was derived from borehole log 2629BA00072, which is the NGA borehole with the closest proximity to the proposed open cast.

Table 2: Generalised Stratigraphic Column of Borehole Log 2629BA00072

AVERAGE DEPTH (MBGL)	AVERAGE THICKNESS (METRES)	DESCRIPTION
0 –5.79	5.8	Shale
5.79 -15.84	10.1	Shale
15.84-24.84	8.2	Coal
24.04 – 28.04	4.0	Shale
28.04 – 34.44	6.4	Sandstone
34.44 – 36.57	2.1	Diabase

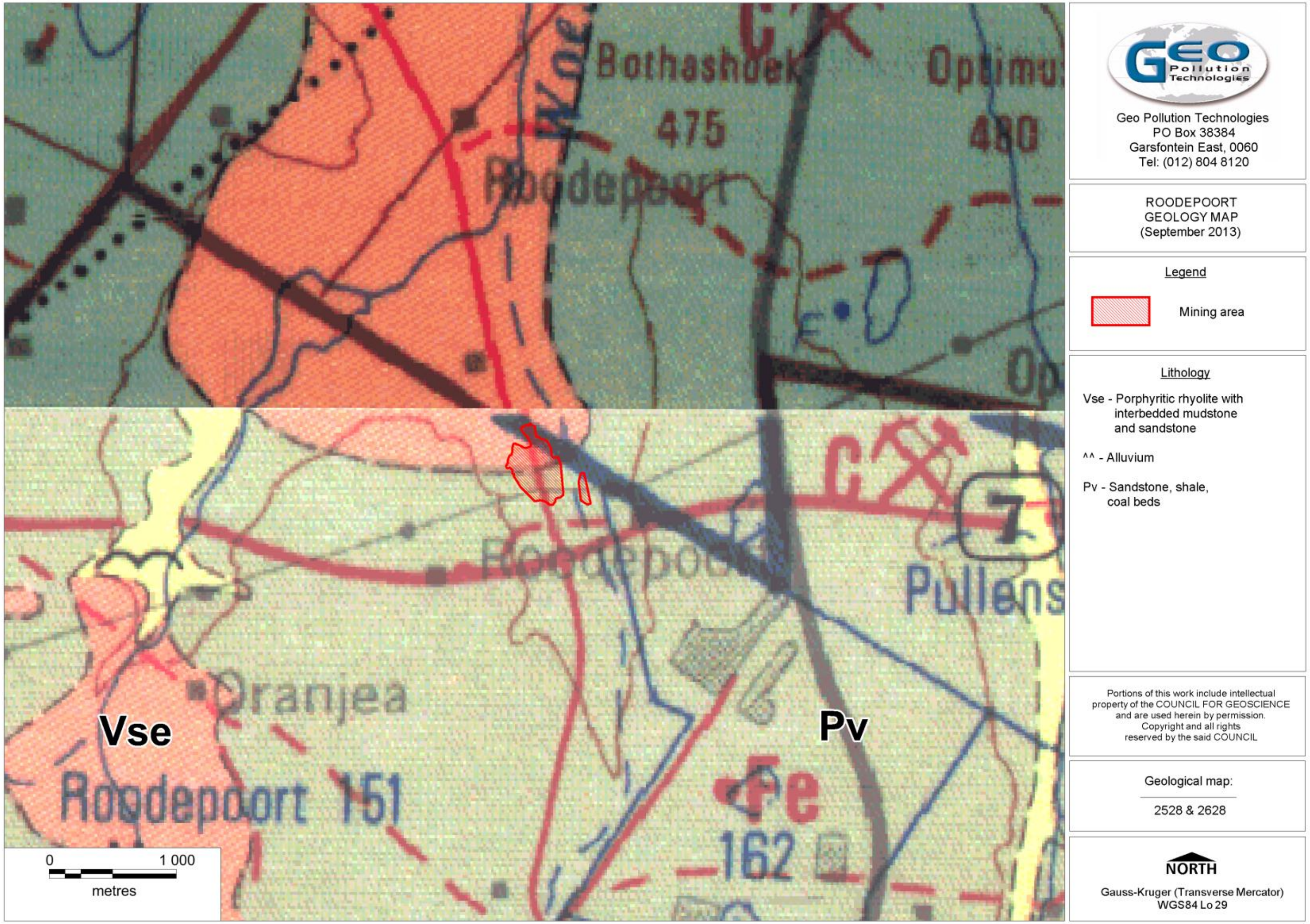

Figure 4: Geology Map

5.2 Hydrogeology

5.2.1 Regional Hydrogeology

The area of concern is situated in the Olifants Water Management area. On regional scale the hydrogeology consist of intergranular and fractured aquifers of the Karoo Supergroup and Rooiberg Group and locally the Karoo Supergroup as well as Jurassic dolerite intrusions, with predominantly arenaceous rocks (sandstone). Blow yields of 0.1 – 0.5 l/s can be expected regionally.

The hydrogeology of the area can be described in terms of the saturated and unsaturated zones:

5.2.1.1 Saturated Zone

In the saturated zone, at least four aquifer types may be inferred from knowledge of the geology of the area:

- A shallow aquifer formed in the weathered zone, perched on the fresh bedrock.
- An intermediate aquifer formed by fracturing of the Karoo sediments.
- Aquifers formed within the more permeable coal seams and sandstone layers.
- Aquifers associated with the contact zones of the dolerite intrusives.

Although these aquifers vary considerably regarding hydrogeological characteristics, they are seldom observed as isolated units. Usually they would be highly interconnected by means of fractures and intrusions. Groundwater will thus flow through the system by means of the path of least resistance in a complicated manner that might include any of these components.

5.2.1.1 Shallow perched aquifer

A near surface weathered zone is comprised of transported alluvium and *in-situ* weathered sediments and is underlain by consolidated sedimentary rocks (sandstone, shale and coal). Groundwater flow patterns usually follow the topography, often coming very close to surface in topographic lows, sometimes even forming natural springs. Experience of Karoo geohydrology indicates that recharge to the perched groundwater aquifer is relatively high, up to 3% of the Mean Annual Precipitation (MAP).

5.2.1.2 Fractured rock aquifers

The host geology of the area consists of consolidated sediments of the Karoo Supergroup and consists mainly of sandstone, shale and coal beds of the Ecca Group (Vryheid Formation). Most of the groundwater flow will be along the fracture zones that occur in the relatively competent host rock. The geology map does not indicate any major fractures zones in this area, but from experience it can be assumed that numerous major and minor fractures do exist in the host rock. These conductive zones effectively interconnect the strata of the Karoo sediments, both vertically and horizontally into a single, but highly heterogeneous and anisotropic unit.

The Selons River Formation forms a secondary aquifer that is composed of porphorytic rhyolite with interbedded sandstone and mudstone. Groundwater in this aquifer is generally found at the boundary between weathered and solid rock and along joint and contact zones. These aquifers have a poor potential yield based on the 86 % of boreholes (from available records) with yields of less than 2l/s. The water level in these aquifers is usually between 10 and 30 mbgl.[4]

5.2.1.3 Aquifers associated with coal seams

The coal seam forms a layered sequence within the hard rock sedimentary units. The margins of coal seams or plastic partings within coal seams are often associated with groundwater. The coal itself tends to act as an aquitard allowing the flow of groundwater at the margins.

5.2.1.4 Aquifers associated with dolerite intrusives

Dolerite intrusions in the form of dykes and sills are common in the Karoo Supergroup, and are often encountered in this area. These intrusions can serve both as aquifers and aquifuges. Thick, unbroken dykes inhibit the flow of water, while the baked and cracked contact zones can be highly conductive. These conductive zones effectively interconnect the strata of the Ecca sediments both vertically and horizontally into a single, but highly heterogeneous and anisotropic unit on the scale of mining. These structures thus tend to dominate the flow of groundwater. Unfortunately, their location and properties are rather unpredictable. Their influence on the flow of groundwater is incorporated by using higher than usual flow parameters for the sedimentary rocks of the aquifer.

5.2.1.5 Unsaturated Zone

Although a detailed characterization of the unsaturated zone is beyond the scope of this study, a brief description thereof is supplied.

The unsaturated zone in the proposed mining area is in the order of between 2.5 and 15.54 metres thick (based on static groundwater levels measured in the existing boreholes as well as the NGA boreholes) and consists of alluvial sediments at the top, underlain by residual sandstone/siltstone/mudstone of the Ecca Group that becomes less weathered with depth.

5.2.2 Local Hydrogeology

Based on borehole logs obtained from the NGA and literature, the following local hydrogeological description (within the aquifer boundary) from top (surface) to bottom can be deduced as follows:

5.2.2.1 Shallow weathered aquifer (unconfined)

This aquifer comprises of weathered arenaceous sandstones and shales. The Ecca sediments are weathered below surface throughout the area. The upper aquifer is associated with this weathered zone and water is found deep below the surface, often deeper than this hydrogeological unit. The hydraulic conductivity value for the aquifer is estimated at $1x10^{-6}$ m/d to 0.10 m/d

The estimated thickness of the aquifer is estimated to have an average thickness of 6 m. Water levels measured in this aquifer ranged from 2.3 to 2.5 meters below ground level.

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[4] Banard, H.C. (2000). An explanation of the 1:500 000 General Hydrogeological Map: Johannesburg 2526. DWAF, Pretoria.

5.2.2.2 Deeper fractured aquifer (confined)

The pores within the Karoo and more specifically the Ecca sediments are too well-cemented to allow any significant flow of water. All groundwater movement therefore occurs along secondary structures, such as fractures and joints in the sediments. These structures are better developed in competent rocks, such as sandstone, hence the better water-yielding properties of the latter rock type.

It should be emphasised, however, that not all secondary structures are water-bearing. Many of these structures are constricted because of compression forces that act within the earth's crust. The chances of intersecting a water-bearing fracture by drilling decrease rapidly with depth. At depths of more than 30 m, water-bearing fractures with significant yield were observed to be spaced at 100 m or greater.

The thickness of the aquifer was estimated at a mean of 18 m. Water levels measured in this aquifer ranged from 8 to 8.6 m below ground level.

Dwyka Tillite occurs at the base of the aquifer. Packer testing of the Dwyka Tillite done by Hodgson (1998) had a permeability distribution as indicated in Table 3. This permeability is very low and therefore can be regarded as a confining layer.

Table 3: Statistics for results on packer hydraulic conductivity testing of the Dwyka Tillite (Hodgson et al., 1998).

Statistics	Dwyka Permeability (m/d)
Mean	0.0034
Median	0.0024
Standard Deviation	0.0034
Minimum	0.0002
Maximum	0.0148

Additionally, the presence of the dense, unfractured rhyolites of the Selonsriver formation may also act as a hydraulic boundary as the conductivities of these igneous rocks are low, with groundwater movement occurring at less than 10^{-5} m/d, based on available data.

5.2.2.3 Lateral extent of aquifers

The lateral extent of the groundwater zone is a severely complex issue. The weathered and fractured Karoo aquifers, barring the occurrence of dolerite intrusions and hydraulic boundaries on the scale of the area of investigation can be taken as infinite. It is obvious however that their lateral extent in the study area is highly dependent on the distribution of dolerite dykes and sills.

Ignoring the effects of geological features, the maximum lateral extent of the aquifers is also limited by hydraulic boundaries as formed by major rivers/streams which act as groundwater discharge boundaries, topographical watersheds which act as no-flow boundaries and surface infiltration sources which usually represent constant head influxes.

5.2.2.4 Recharge

The main source of recharge into the upper aquifer is rainfall that infiltrates the aquifer through the overlying unsaturated zone. Rainfall that manifests as surface run-off and drains to streams may also subsequently enter the shallow aquifer by infiltrating the stream bed (Grobbelaar, 2001). Water impoundments and features such as tailings dams may constitute additional recharge sources in certain areas.

The rainfall ultimately recharging the upper aquifer is estimated at 3–5 %. A higher proportion of infiltration may occur in areas where the natural permeability is increased, such as the increased fracturing associated with high extraction mining. Generally accepted values for recharge in high extraction areas are between 5 % and 7 %.

Recharge of the deep Karoo aquifer occurs from the shallow Karoo aquifer through permeable fracture systems that link the two aquifers. The natural distribution of such fracture systems is highly variable, and the recharge of the deep aquifer is expected to be some orders of magnitude lower than for the shallow aquifer. However, induced fracturing associated with mining can extend from the deep aquifer up to the surface and provides a relatively direct and highly permeable recharge route. The magnitude of recharge by this route depends on the extent of mining and the nature of the induced fracture pattern.

The recharge calculation for the unconfined (water table) aquifer for the study area is calculated below in Table 4.

Table 4: Recharge calculation for the shallow unconfined aquifer

Recharge Estimation			
Method	**mm/a**	**% of rainfall**	**Certainty (Very High=5 ; Low=1)**
Chloride	64.1	9.2	4
Schematic maps			
Soil	42	5.9	3
Geology	34.7	4.9	3
Vegter	32.0	4.5	3
Acru	20.0	2.8	3
Harvest Potential	25.0	3.5	3

5.2.2.5 Summary

Based on the data detailed in the preceding sections the following can be concluded.

- Three aquifers are inferred to be present across the site at varying depths.
- The extent and depth of the aquifers is controlled by the sub-surface Karoo formation layering, weathering, geometry and post-Karoo intrusions.
- Flow within the weathered aquifer is thought to be multi-porous and is controlled by weathering, flow within the fractured aquifer is controlled by the fracturing network while the competent host rocks serve as storage.

- Recharge into the weathered aquifer is thought to be directly linked to rainfall while recharge into the fractured aquifer is linked to shallower aquifers.

5.3 Hydrocensus

A hydrocensus was conducted for the proposed opencast site and in the surrounding area, during September 2013. The position of all the boreholes relative to the proposed opencast mine can be seen in Figure 5. A total of 6 boreholes were identified during this hydrocensus study. The main characteristics of this data are summarized in Table 5 and Figure 6. Some of the boreholes identified were being used for domestic use while others were used for livestock watering. Half of the identified boreholes were not in use. Hydrocensus field forms containing details of the owner and use are attached under Appendix A as separate PDF-files.

5.4 Water Levels

Groundwater levels, varying between 2.3m and 8.6m below ground level, were measured in the surrounding area during the survey. These values were determined from borehole data where the owner was available on site and where it was possible to gain access to the boreholes for precise measuring of water levels.

Usually a good relationship should hold between topography and static groundwater level. This relationship can be used to distinguish between boreholes with water levels at rest, and boreholes with anomalous groundwater levels due to disturbances such as pumping or local geohydrological heterogeneities. The relationship using the boreholes from the hydrocensus is shown in Figure 7 below and a good correlation can indeed be observed. This general relationship is useful to make a quick calculation of expected groundwater levels at selected elevations, or to calculate the depth of to the groundwater level (unsaturated zone):

$$\text{Groundwater level} = \text{Elevation} \times 0.7281$$

$$\text{Depth to the groundwater level} = \text{Elevation} \times (1 - 0.7281)$$

$$= \text{Elevation} \times 0.02719$$

This general relationship is useful to make a quick calculation of expected groundwater levels at selected elevations, or to calculate the depth of the groundwater level (unsaturated zone). However, due to the heterogeneity of the subsurface, these relationships should not be expected to hold everywhere under all circumstances, and deviations could thus be expected. The calibrated static water levels as modelled have been contoured and are displayed as Figure 8. Groundwater flow direction should be perpendicular to these contours and inversely proportional to the distance between contours. Using this relationship, the inferred groundwater flow directions are depicted as Figure 9 below. As can be expected, the groundwater flow is mainly from topographical high to low areas, eventually draining to local streams.

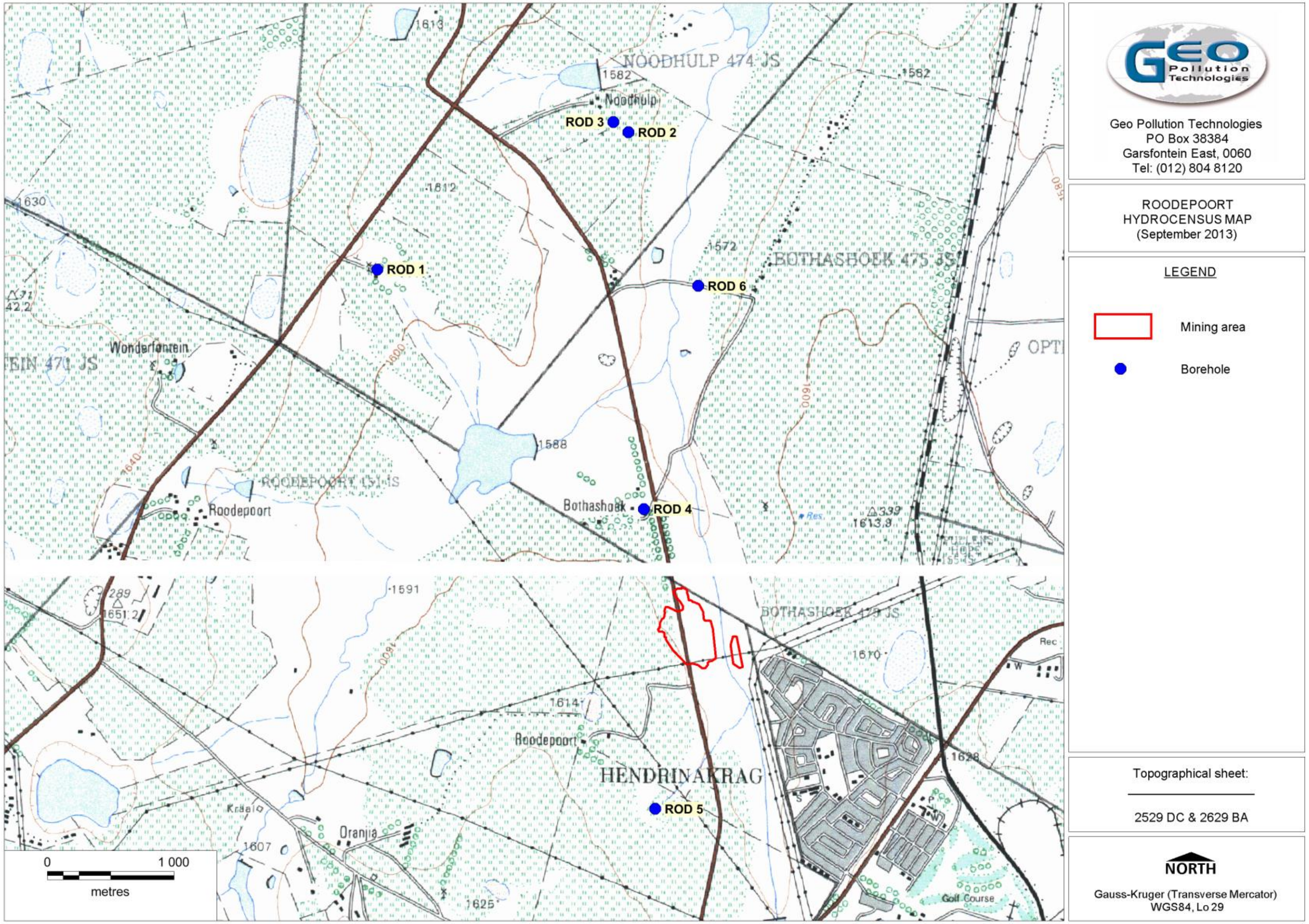
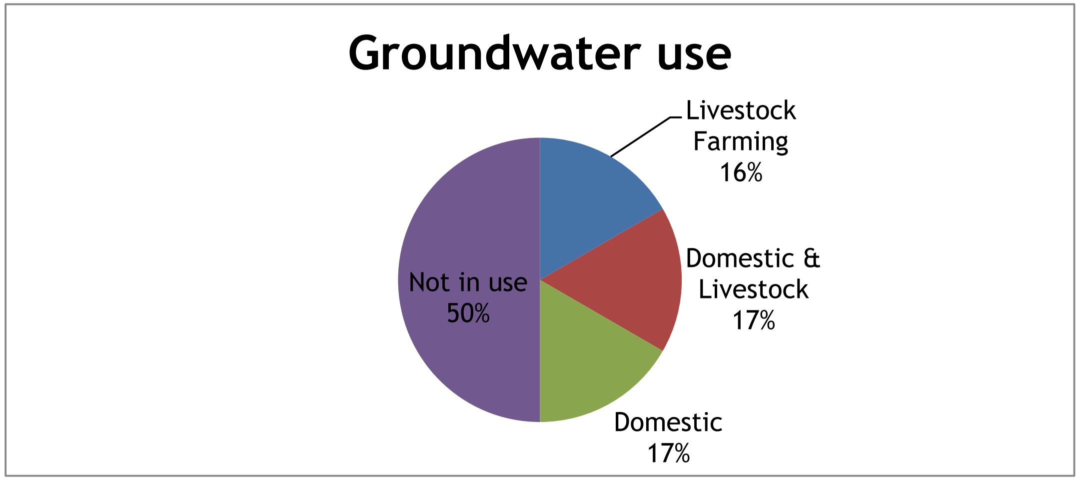


Figure 5: Positions of Hydrocensus Monitored Points

Table 5: Groundwater Hydrocensus and Borehole Information

ID	Latitude	Longitude	Elevation	Owner	Property	Static water level (mbgl)	Collar height (m)	SWL (mamsl)	Sampled	Use	Comments
Groundwater											
ROD 1	-25.97981	29.55531	1754	Christo Schoeman	Noodhulp	-	-	-	Yes	Domestic	Sample taken from overflow dam, tanks were empty
ROD 2	-25.97001	29.57496	1593	Frik Snyman	Noodhulp	8.6	0.15	1584.25	No	None	Owner plans to fit a pump in future
ROD 3	-25.96928	29.57377	1595	Frik Snyman	Noodhulp	-	-	-	Yes	Domestic and crop wetting.	
ROD 4	-25.99672	29.5763	1597	Unknown	Bothashoek	8.03	-	1588.97	Yes	None	
ROD 5	-26.01796	29.57729	1611	CJ van Wyk	Roodepoort	2.5	0.3	1608.2	Yes	Cattle	
ROD 6	-25.98088	29.58049	1581	Unknown	Bothashoek	2.33	0.3	1578.37	Yes	None	

Figure 6: Groundwater use in the vicinity of the proposed opencast area



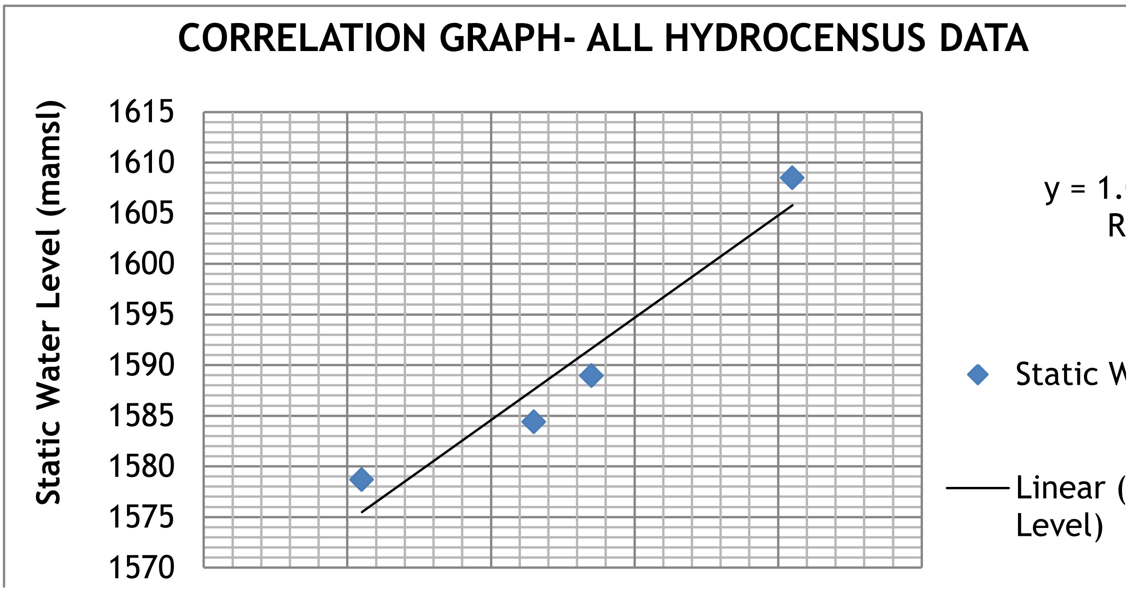


Figure 7: Correlation Graph - Using All Hydrocensus Data

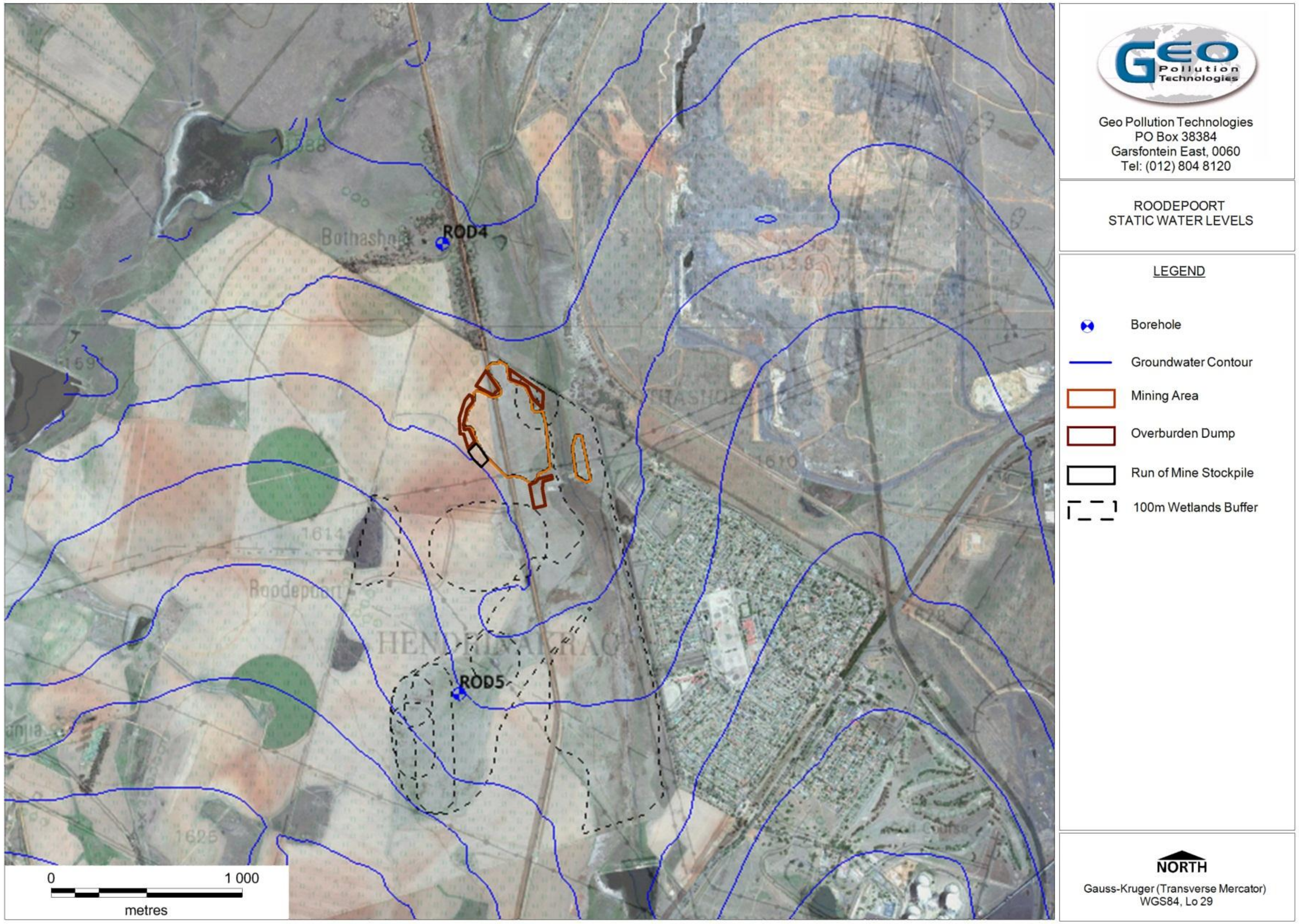


Figure 8: Static Groundwater Levels – Before establishment of the opencast

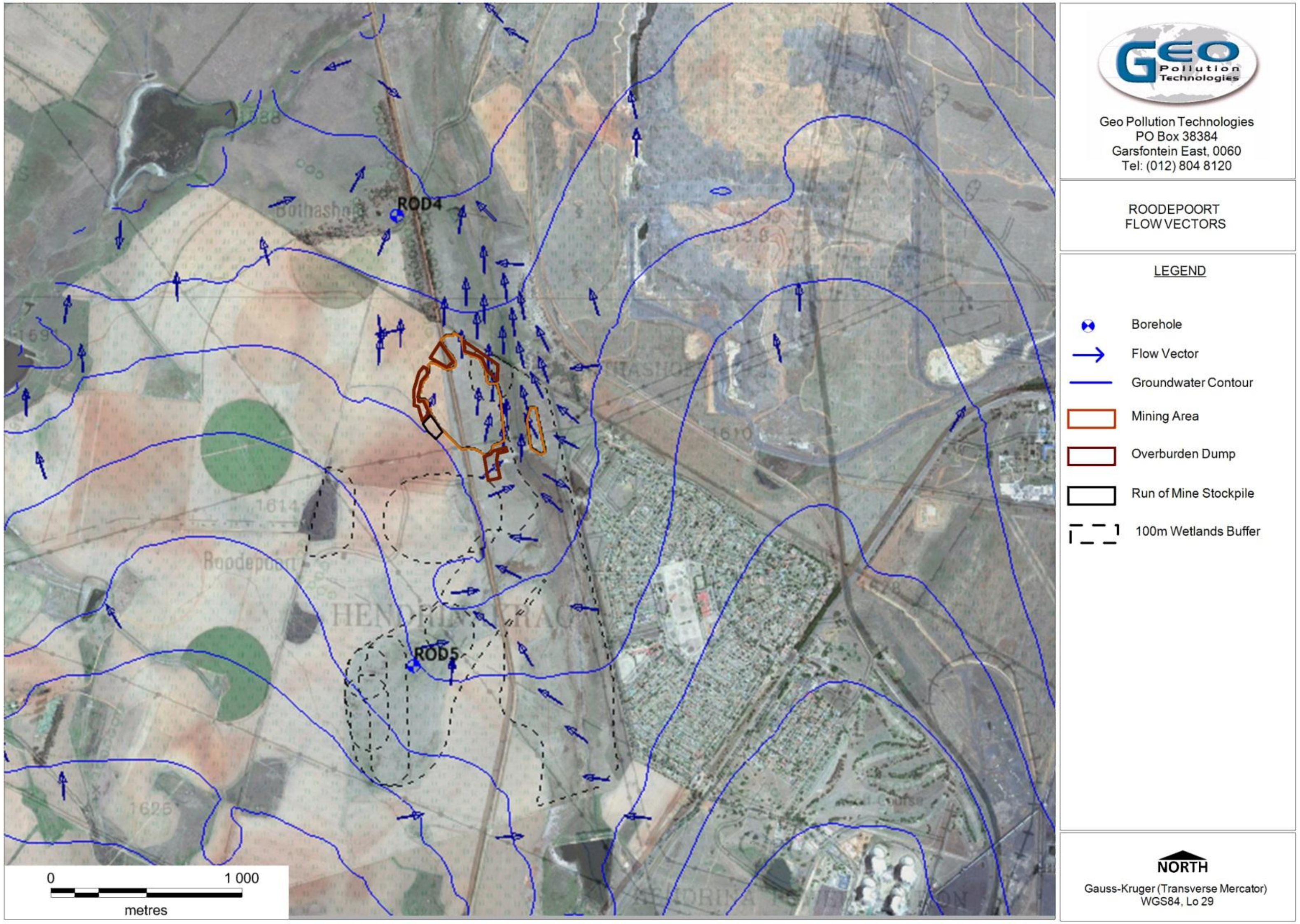


Figure 9: Groundwater Flow Directions - Before establishment of the opencast

5.5 Water Quality

Five water samples were collected from hydrocensus boreholes around the site during the investigation. The samples were submitted for major cation and anion analyses to determine water quality in the area. The groundwater results are compared with the maximum recommended concentrations for domestic use[5] (Table 6) as defined by the DWAF Water Quality Guidelines. The DWAF guidelines are classified as:

- Target water quality range
- Water quality that is tolerable/ acceptable for use
- Water quality that exceeds the target water quality range.

The results from these analyses were plotted as Pie diagrams (circular graphs as in Figure 10), Stiff diagrams (Figure 11) and a piper diagram (Figure 13). The laboratory certificate of analyses and monitoring data can be seen attached as a separate Appendix B.

The pie diagrams show both the individual ions present in a water sample and the total ion concentrations in meq/L or mg/L. The scale for the radius of the circle represents the total ion concentrations, while the subdivisions represent the individual ions. It is very useful in making quick comparisons between waters from different sources and presents the data in a convenient manner for visual inspection.

A Stiff pattern is basically a polygon created from four horizontal axes using the equivalent charge concentrations (meq/L) of cations and anions. The cations are plotted on the left of the vertical zero axis and the anions are plotted on the right. Stiff diagrams are very useful in making quick comparisons between waters from different sources.[6]

On the piper diagram the cation and anion compositions of many samples can be represented on a single graph. Certain trends in the data can be discerned more visually, because the nature of a given sample is not only shown graphically, but also show the relationship to other samples. The relative concentrations of the major ions in mg/L are plotted on cation and anion triangles, and then the locations are projected to a point on a quadrilateral representing both cation and anions.

5.5.1 Groundwater

If the groundwater samples are compared to the DWA guidelines for domestic use only pH is elevated above the tolerable water quality (ROD1). The concentration of Mn in ROD4 and ROD6 is also elevated above the target water quality range but still falls within the tolerable water quality range. This constituent can be sourced directly from the underlying geology. Mn is a common component in sandstones of the Ecca. Additionally, Na falls within the tolerable water quality range for ROD6.

Although all the majority of the sulphate concentrations are below the accepted standards, it forms a high proportion of the water's chemistry in ROD1 as can be seen in Figure 10. It can also be seen from this figure that a general tendency of higher sulphates exists to the east of the proposed

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[5] DWAF 1996, South African water Quality Guidelines,Volume 1, Domestic Use 2nd Ed.

[6] EAS 44600 Groundwater Hydrology, Lecture 14: Water chemistry 1, Dr Pengfei Zhang

opencast near the unnamed tributary of the Woes-Alleenspruit. This could potentially be attributed to existing mining activities in the area. Further to the west of the proposed opencast, the water chemistry is dominated by HCO_3 which may have a natural buffering effect on acidity generated by sulphates. This also indicates an abundance of carbonate in the underlying geology. Some nitrates can also be observed which may be attributed to agricultural activities in the area.

The chemical fingerprints of the boreholes can be seen in stiff diagrams in Figure 11. The boreholes ROD1, ROD3, ROD4 and ROD5 have a Na-Mg/$HC0_3$ signature, while ROD6 has a Na/HCO_3-SO_4 signature. Most groundwater samples around the proposed opencast have a high alkalinity and therefore a high buffer capacity.

Figure 13 illustrates the groundwater type of the boreholes. From this figure ROD5, ROD1 and ROD4 can be seen to have a shallow, fresh groundwater signature while ROD3 was found to have a signature closer to that of deeper, fresh groundwater. This signature may have been influenced by additional ion exchange and Na release from the rhyolites of the Selonsriver formation which is more abundant in the north of the site. ROD6 has a water type of deep, ancient groundwater. This sample was interpreted to have been affected by sulphate from existing mining activities in the area and may have had a signature similar to ROD1. However, the reason why this sample does not plot in the mine water quadrant on the piper diagram is due to its deficiency in Ca due to ion exchange.

From the chemical analysis it can be seen that the groundwater in and around the proposed opencast is suitable for domestic use (with the exception of ROD1). However, from the piper (Figure 13) and pie (Figure 10) diagrams it is found that ROD1 has been negatively affected by mining related contaminants at the time of the investigation.

Table 6: Results of Major Cation and Anion Analyses Compared to the DWA Guidelines for Domestic Use

Water Quality Constituents		ROD1	ROD3	ROD4	ROD5	ROD6	TWQR	Tolerable	Exceeding TWQR
Calcium	Ca [mg/l]	18.00	12.70	8.27	26.60	27.10	0 - 32	32 - 80	> 80
Chloride	Cl [mg/l]	28.30	9.84	13.10	12.00	23.70	0 - 100	100 - 600	> 600
Fluoride	F [mg/l]	0.57	1.80	0.12	0.57	3.06	0 - 1.0	1.0 - 1.5	> 1.5
Iron	Total Fe [mg/l]	0.00	0.00	0.00	0.00	0.00	0 - 0.1	0.1 - 1.0	> 1.0
Magnesium	Mg [mg/l]	14.90	5.14	5.80	13.50	10.30	0 - 30	30 - 70	> 70
Manganese	Mn [mg/l]	0.00	0.00	0.50	0.00	0.17	0 - 0.05	0.05 - 1.0	> 1.0
Nitrate	NO_3 as N [mg/l]	0.00	1.97	2.18	5.01	0.00	0 - 6		> 6
pH	pH units	9.02	8.51	6.21	7.62	7.29	6.0 - 9.0		<6, >9
Potassium	K [mg/l]	8.61	2.65	4.21	6.99	3.70	0 - 50	50 - 100	> 100
Selenium	Se [mg/l]	0.00	0.00	0.00	0.00	0.00	0 - 20	20 - 50	> 50
Sodium	Na [mg/l]	31.80	42.20	9.23	20.30	111.00	0 - 100	100 - 200	> 200
Sulphate	SO_4 [mg/l]	9.22	10.00	10.40	9.76	151.00	0 - 200	200 - 400	> 400
Total Dissolved Solids	TDS [mg/l]	197.00	164.00	83.20	197.00	424.00	0 - 450	450 - 1 000	> 1000
Cation/Anion Balance %		7.99	6.79	5.72	7.22	2.97	*Error should not exceed 5%*		

Notes: A value of zero indicates that the analysis was below the detection limit

TWQR- Target water quality range

Tolerable - Suitable for short-term intake, in some instances health problems can occur during extensive long-term intake in sensitive individuals such as infants

Exceeeding TWQR- Exceedance of target water quality range may lead to adverse affects

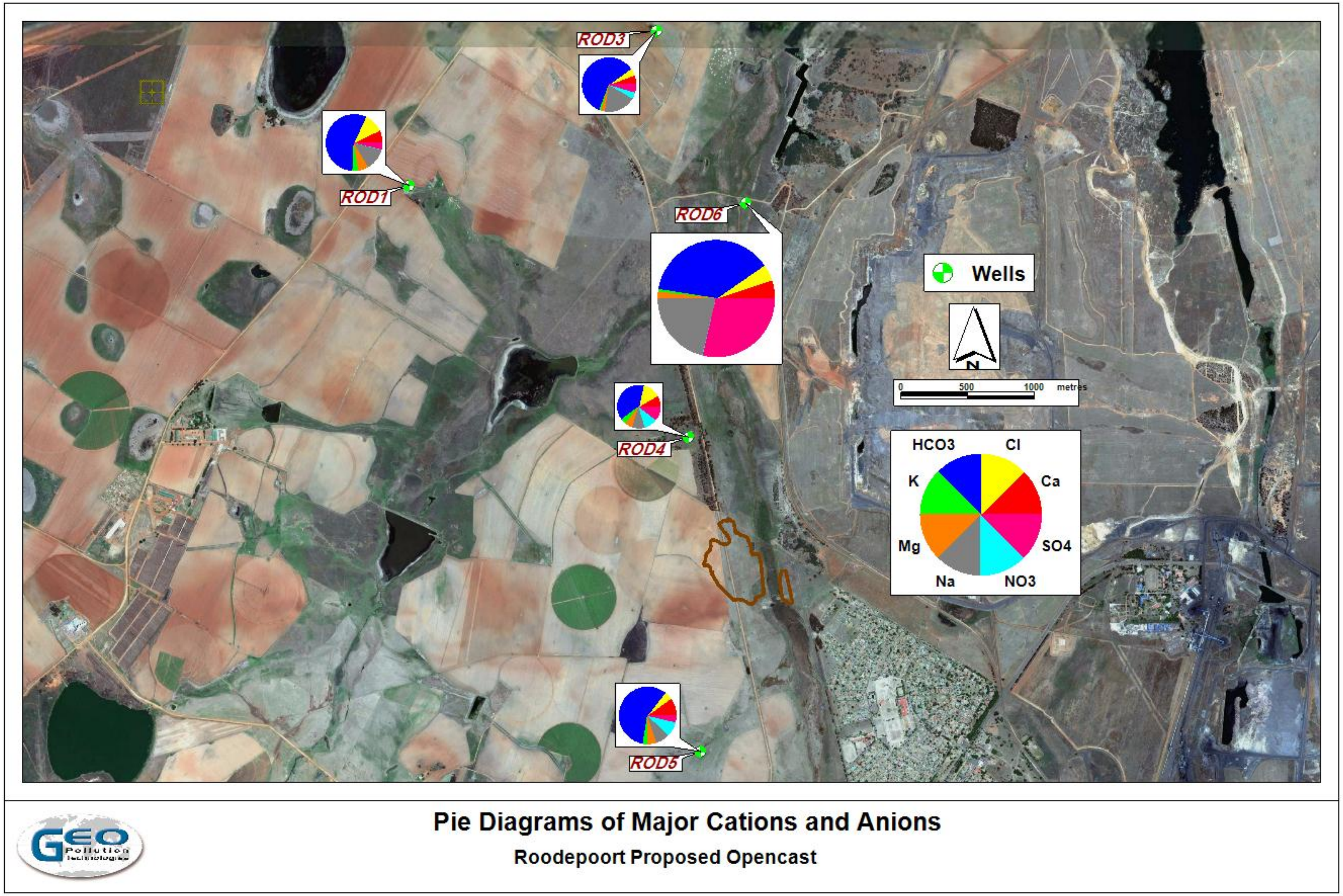

Figure 10: Pie Diagrams (groundwater)

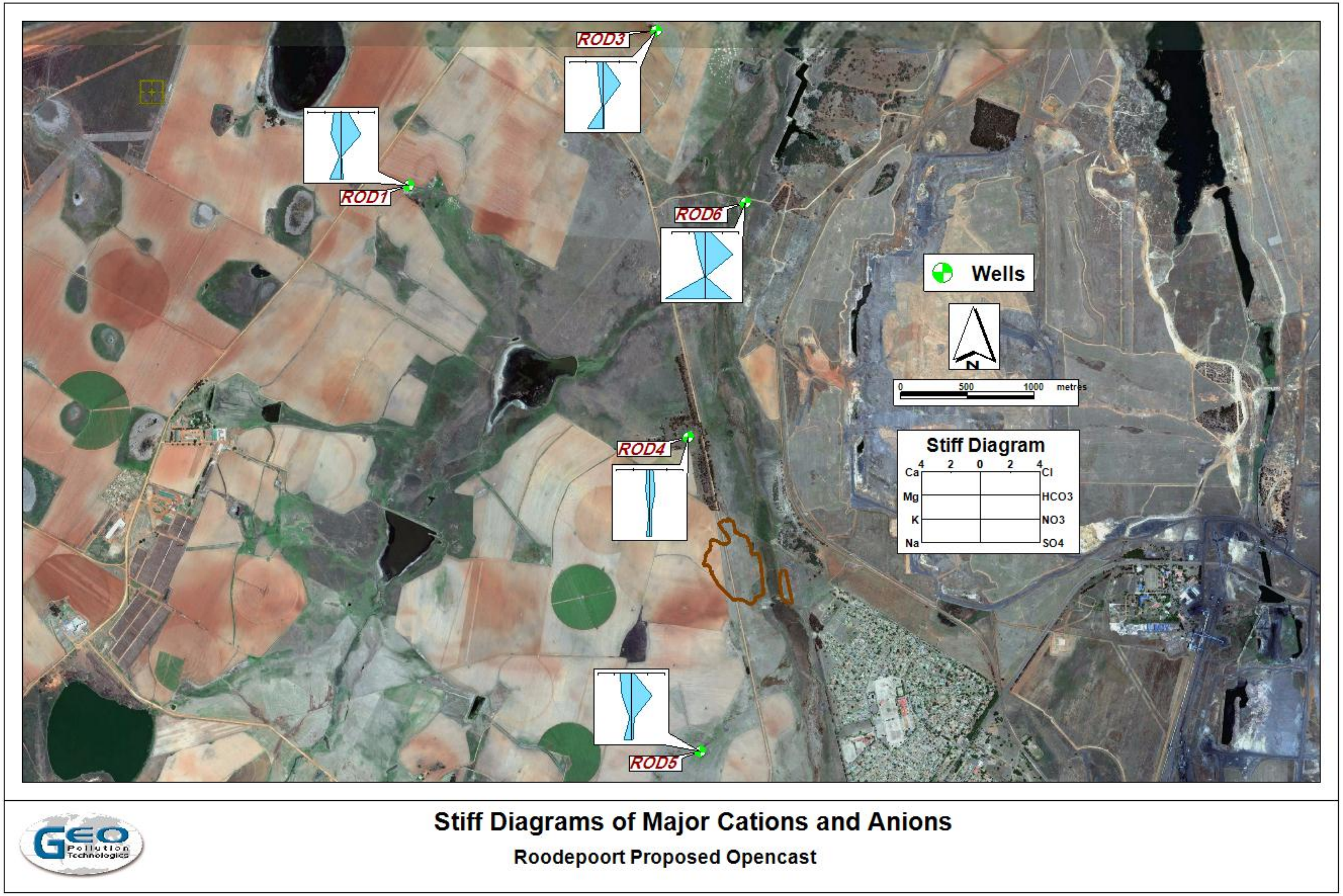

Figure 11: Stiff Diagram (groundwater)

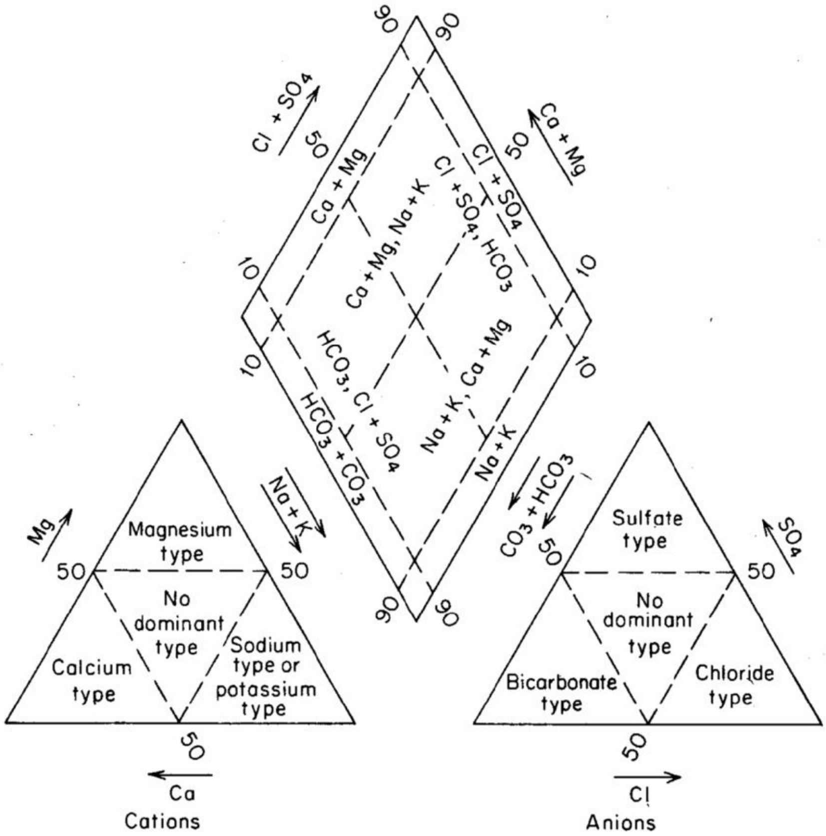

Figure 12: Classification Diagram for Anion and Cation Facies in Terms of Major-ion Percentages.[7]

[7]Freeze, R. Allan, and John A. Cherry. 1979. *Groundwater*. Prentice Hall Inc, New Jersey.

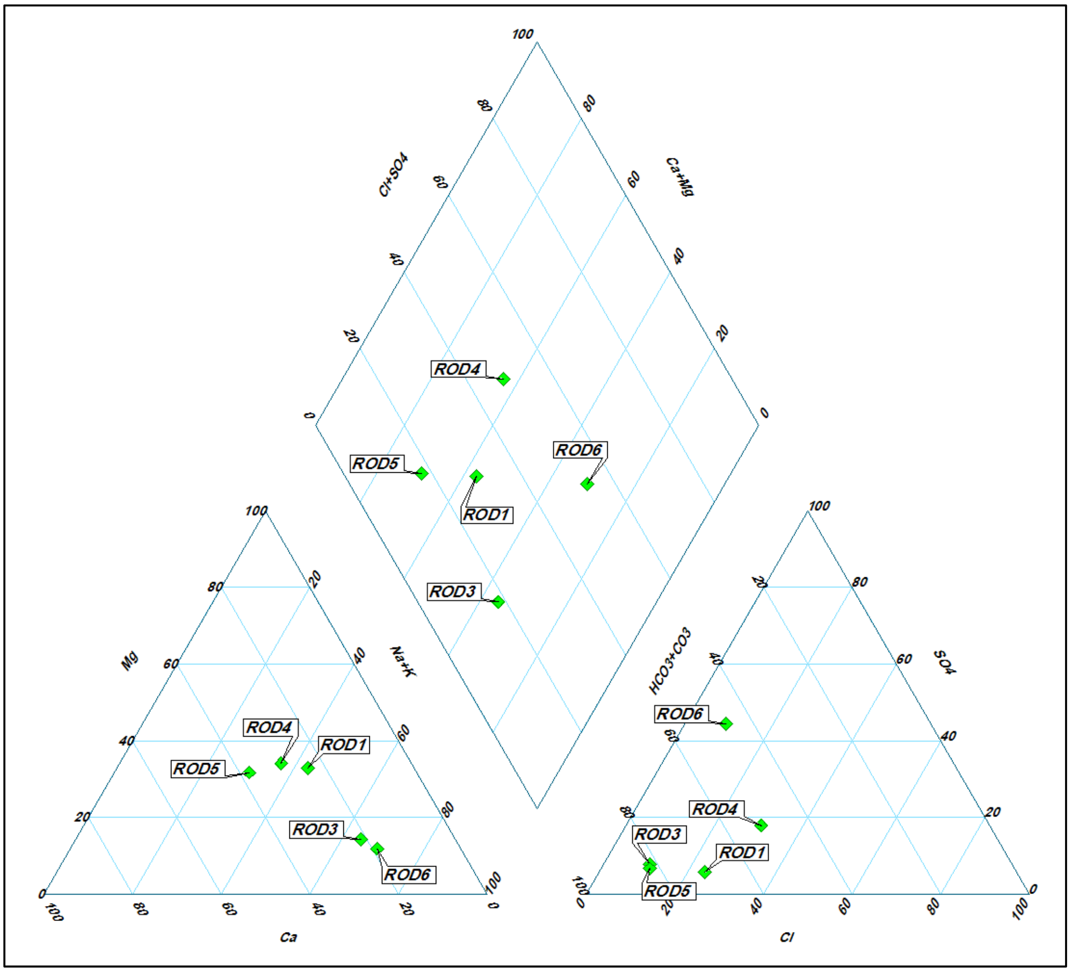

Figure 13: Piper diagram

5.6 Potential Contaminants

The major contaminant sources associated with the activities at the opencast are the overburden dumps, the coal stock pile and the opencast itself.

Workshops and fuel and oil handling facilities are likely sources of hydrocarbon related contaminants within the mining area. Oils, grease and other hydrocarbon products (such as petrol and diesel) handled in these areas may contaminate the environment by spillages and leakages. Oils and greases should be removed and collected in oil traps. Run-off (contaminated with hydrocarbons) which is not collected may enter the storm water system from where it may contaminate surface water bodies and groundwater. Septic tanks and sewage treatment plants potentially contaminate groundwater. Contaminants associated with these plants include coliforms (e.g. E.coli), bacteria viruses, ammonia, phosphate, sulphate and nitrate. Effluent from these systems usually contains elevated concentrations of organic matter which may lead to elevated COD and BOD. Waste disposal areas may source a wide range of contaminants, ranging from metals, organic matter, hydrocarbons, phosphates, etc.

Sulphate is probably the most reliable indicator of pollution emanating from coal mining and related activities. Sulphate concentrations can increase due to mobilisation during the process of activity at the opencast. The chemistry analyses supplied within this report should henceforth serve as baseline water quality throughout the life of the proposed opencast.

Sulphate, as well as Ca, Na, and Cl could, be sourced from leachate produced by the overburden dump and the coal stock pile. Therefore, these constituents should be used as indicators of groundwater contamination. Additionally, Acid Rock Drainage could form in the coal stockpile. The following few paragraphs contain a brief overview of acid rock drainage (ARD) formation.

The reactions of acid and sulphate generation from sulphide minerals are discussed according to the three stage stoichiometric example of pyrite oxidation after James, (1997) and (Ferguson & Erickson, 1988) in which one mole of pyrite oxidized forms two moles of sulphate:

Reaction (2.1) represents the oxidation of pyrite to form dissolved ferrous iron, sulphate and hydrogen. This reaction can occur abiotically or can be bacterially catalysed by *Thiobacillus ferrooxidans*.

$$FeS_2 + 7/2\ O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+ \qquad (2.1)$$

The ferrous iron, (Fe^{2+}) may be oxidised to ferric iron, (Fe^{3+}) if the conditions are sufficiently oxidising, as illustrated by reaction (2.2). Hydrolysis and precipitation of Fe^{3+} may also occur, shown by reaction (2.3). Reactions (2.1), (2.2) and (2.3) predominate at pH > 4.5.

$$e^{2+} + 1/4O_2 + H^+ \rightarrow Fe^{3+} + 1/2H_2O \qquad (2.2)$$

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3\,(s) + 3H^+ \qquad (2.3)$$

Reactions (2.1) to (2.3) are relatively slow and represent the initial stage in the three-stage AMD formation process. Stage 1 will persist as long as the pH surrounding the waste particles is only moderately acidic (pH > 4.5). A transitional stage 2 occurs as the pH decreases and the rate of Fe hydrolyses (reaction 2.3) slows, providing ferric iron oxidant. Stage 3 consists of rapid acid production by the ferric iron oxidant pathway and becomes dominant at low pH, where the Fe^{2+} (ferric iron) are more soluble (reaction 4):

$$FeS_2 + 14\ Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \qquad (2.4)$$

Without the catalytic influence of the bacteria, the rate of ferrous iron oxidation in an acid medium would be too slow to provide significant AMD generation. As such the final stage in the AMD generation process occurs when the catalytic bacteria *Thiobacillus ferrooxidans* have become established. Reactions (2.2) and (2.4) then combine to form the cyclic, rapid oxidation pathway mainly responsible for the high contamination loads observed in coal mining and handling environments.

According to the SANS Guidelines for Drinking Water, high concentrations of sulphate exert predominantly acute health effects. Sulphate also imparts a salty or bitter taste to water. The taste threshold for sulphate falls in the range of 200 – 400mg/L. Above 400mg/L diarrhoea occurs in most individuals and user-adaptation does not occur. It is also important to note that adverse chronic effects may occur in livestock if sulphate levels exceed 1000mg/L, such as diarrhoea and poor productivity.

6 AQUIFER SENSITIVITY

The term aquifer refers to a strata or group of interconnected strata comprising of saturated earth material capable of conducting groundwater and of yielding usable quantities of groundwater to boreholes and /or springs (Vegter, 1994). In the light of South Africa's limited water resources it is important to discuss the aquifer sensitivity in terms of the boundaries of the aquifer, its vulnerability, classification and finally protection classification, as this will help to provide a framework in the groundwater management process.

6.1 Groundwater Vulnerability

According to Lynch et al. aquifer vulnerability is defined as the intrinsic characteristics that determine the aquifer's sensitivity to the adverse effects resulting from the imposed pollutant[8]. The following factors have an effect on groundwater vulnerability:

- Depth to groundwater: Indicates the distance and time required for pollutants to move through the unsaturated zone to the aquifer.
- Recharge: The primary source of groundwater is precipitation, which aids the movement of a pollutant to the aquifer.
- Aquifer media: The rock matrices and fractures which serve as water bearing units.
- Soil media: The soil media (consisting of the upper portion of the vadose zone) affects the rate at which the pollutants migrate to groundwater.
- Topography: Indicates whether pollutants will run off or remain on the surface allowing for infiltration to groundwater to occur.
- Impact of the vadose zone: The part of the geological profile beneath the earth's surface and above the first principal water-bearing aquifer. The vadose zone can retard the progress of the contaminants8.

The Groundwater Decision Tool (GDT) was used to quantify the vulnerability of the aquifer underlying the site. The depth to groundwater below the site was estimated from water levels measured during the hydrocensus inferred to be ~5.3 mbgl. A groundwater recharge of ~32 mm/a, a sandy clay-loam soil and a gradient of 1.3% were assumed and used in the estimation. The GDT calculated a vulnerability value of 56%, which is moderate to high. This implies that the aquifer is reasonably sensitive to contamination and care should be taken with any activities that could generate pollutants.

6.2 Aquifer Classification

The aquifer(s) underlying the subject area were classified in accordance *with "A South African Aquifer System Management Classification, December 1995."*

The main aquifers underlying the area were classified in accordance with the Aquifer System Management Classification document[9]. The aquifers were classified by using the following definitions:

- Sole Aquifer System: An aquifer which is used to supply 50% or more of domestic water for a given area, and for which there is no reasonably available alternative sources should the

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[8] The South African Groundwater Decision Tool (SAGDT), Manual Ver. 1 (Department of Water Affairs and Forestry)

[9] Department of Water Affairs and Forestry & Water Research Commission (1995). A South African Aquifer System Management Classification. WRC Report No. KV77/95.

aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.

- Major Aquifer System: Highly permeable formations, usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (Electrical Conductivity of less than 150 mS/m).
- Minor Aquifer System: These can be fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important for local supplies and in supplying base flow for rivers.
- Non-Aquifer System: These are formations with negligible permeability that are regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer unusable. However, groundwater flow through such rocks, although imperceptible, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.

Based on information collected during the hydrocensus it can be concluded that the aquifer system in the study area can be classified as a “Minor Aquifer System”, based on the fact that the local population is dependent on groundwater. Furthermore the area is characterised some surface water features which can be used if necessary. The aquifer is also important for supplying base flow to the rivers and streams.

In order to achieve the Aquifer System Management and Second Variable Classifications, as well as the Groundwater Quality Management Index, a points scoring system as presented in Table 7 and Table 8 was used.

Table 7: Ratings - Aquifer System Management and Second Variable Classifications

Aquifer System Management Classification		
Class	Points	Study area
Sole Source Aquifer System: Major Aquifer System: Minor Aquifer System: Non-Aquifer System: Special Aquifer System:	6 4 2 0 0 – 6	2
Second Variable Classification (Weathering/Fracturing)		
Class	Points	Study area
High: Medium: Low:	3 2 1	2

Table 8: Ratings - Groundwater Quality Management (GQM) Classification System

Aquifer System Management Classification		
Class	Points	Study area
Sole Source Aquifer System: Major Aquifer System: Minor Aquifer System: Non-Aquifer System: Special Aquifer System:	6 4 2 0 0 - 6	2
Aquifer Vulnerability Classification		
Class	Points	Study area
High: Medium: Low:	3 2 1	2

As part of the aquifer classification, a Groundwater Quality Management (GQM) Index is used to define the level of groundwater protection required. The GQM Index is obtained by multiplying the rating of the aquifer system management and the aquifer vulnerability. The GQM index for the study area is presented in Table 9.

The vulnerability, or the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer, in terms of the above, is classified as **medium** (See section 6.1).

The level of groundwater protection based on the Groundwater Quality Management Classification:

GQM Index = Aquifer System Management x Aquifer Vulnerability

= 2 X 2 = 4

Table 9: GQM Index for the Study Area

GQM Index	Level of Protection	Study Area
<1	Limited	
1 - 3	Low Level	
3 - 6	Medium Level	4
6 - 10	High Level	
>10	Strictly Non-Degradation	

6.3 AQUIFER PROTECTION CLASSIFICATION

A Groundwater Quality Management Index of 4 was estimated for the study area from the ratings for the Aquifer System Management Classification. According to this estimate a **medium level groundwater protection** is required for the fractured aquifer. Reasonable and sound groundwater protection measures are recommended to ensure that no cumulative pollution affects the aquifer, even in the long term.

DWA's water quality management objectives are to protect human health and the environment. Therefore, the significance of this aquifer classification is that if any potential risk exists, measures must be taken to limit the risk to the environment, which in this case is:

- The protection of the underlying aquifer.
- The tributary to the Woes-Alleenspruit which flows in a northern direction.
- The adjacent wetland areas.

7 INITIAL SITE CONCEPTUAL MODEL

Based on the collected information such as operation layouts as well as available data regarding aquifer sensitivity and sensitive receptors in the preceding paragraphs, a source-pathway-receptor conceptual site model (CSM) was constructed. The CSM will be utilised in the numerical mode to make impact predictions and aid in the development of mitigation measures.

To understand the environmental risk as a result of the opencast and its associated infrastructure, it is important to understand the source-pathway-receptor principle. For a groundwater risk to be established a continuous linkage between sources of the pollution, the pathway along which the pollution has migrated towards the receptor, and the actual arrival at the receptor must be demonstrated or proven.

For the CSM we assume that all receptors depend on groundwater usage, the pathways depend on hydrogeology and the source(s) depend(s) on the activities on site that can release contaminants to impact on the groundwater/or that can lower the groundwater table through dewatering of the aquifers. Together these risk factors form the CSM. Thus the CSM is a simplified version of the real situation. A CSM is dynamic and may change with more data becoming available as the activities on site progress.

(Note that a risk can only exist if a source, pathway and receptor are all present).

7.1.1 Sources/Impact Origin

A conceptual layout of the planned infrastructure at the opencast was available during the study. Based on the scope of work for the project, the ROM stockpiles and overburden dumps were used as potential sources, in terms of contamination during mining. As the site changes sources may change and therefore the conceptual model will change and thus needs to be updated on a regular basis. Therefore, the backfilled pits, post-mining, were also considered to be sources after mine closure. The currently identifiable potential sources and their associated impacts are tabulated below in Table 10.

Table 10: Identified Potential Impact Origins, Types and Descriptions

Impact origin	Time Frame	Impact Type	Impact Description
Overburden Dumps (Hards)	During Mining	Groundwater and Surface Water Contamination	Elevated Ca, SO_4, Cl, Na.
Coal Stockpile	During Mining	Groundwater and Surface Water Contamination	Elevated SO_4, Ca and possible metals e.g. Fe
Fuel and Oil Handling Facilities	During Mining	Groundwater Contamination	Hydrocarbon Contaminants
Backfilled Pit	Post-Mining	Groundwater Contamination	Elevated Ca, SO_4, Cl, Na.

7.1.2 Pathways

The following groundwater pathways are inferred to be on site:

- The unsaturated pathway in the proposed project area is in the order of ≈5 metres thick (based on static groundwater levels measured in the existing boreholes). The unsaturated pathway along with the shallow aquifer is the most likely to be impacted by surface point pollution sources.
- An intermediate groundwater pathway formed by fracturing of the Karoo sediments. Groundwater is stored within the pores and fractures of these sediments (matrix) with low flow velocities. Groundwater movement is predominantly along the fractures with much higher flow velocities.
- Groundwater pathways formed within the more permeable fault zones and in coal seams. The coal seam forms a layered sequence within the hard rock sedimentary units. The margins of coal seams or plastic partings within coal seams are often associated with groundwater. The coal itself tends to act as an aquitard allowing the flow of groundwater at the margins. Fault zones may act as preferential pathways for groundwater movement due to high levels of fracturing and subsequent porosity. These zones normally cross cut the horizontally deposited sediments at 30 to 60 degree angles. These zones are often associated with groundwater and targeted for abstraction boreholes.

7.1.3 Receptors

Any user of a groundwater or surface water resource that is affected by impact from any of the above mentioned sources is defined as a receptor. Furthermore, a borehole or surface water resource may also be a receptor of deterioration in groundwater quantity and quality. The following receptors may be found:

- Groundwater users by means of borehole abstraction
- Possible wetlands in the vicinity of the mining area

The main water use in the vicinity of the proposed opencast is for domestic use (see Table 5). Water is primarily sourced from boreholes in the vicinity of the proposed opencast and its associated infrastructure.

Based on the available information no other groundwater users/receptors apart from those mentioned above are likely to be negatively affected by the proposed opencast.

8 MODELLING

It is the aim of this chapter to assess the likely hydrogeological impact that the proposed Roodepoort opencast and its associated infrastructure might have on the receiving environment through numerical modelling. The typical stages that will be considered in this section are:

- Pre-Mining Phase: Mining activities have been observed in the immediate vicinity of proposed Roodepoort opencast, groundwater conditions in the area are probably not pristine. The pre-mining conditions of the opencast are thus described.
- Operational Phase: This phase will be the groundwater conditions expected during the mining of the proposed Roodepoort opencast.
- Decommissioning Phase: This is the closing of mining operations, site cleanup and rehabilitation of the opencast mining areas.
- Post-mining Phase: This phase relates to the steady-state conditions following closure of the opencast areas. It is assumed for the purpose of this study that the opencasts will be will be backfilled, rehabilitated and allowed to flood.

Numerical groundwater modelling is considered to be the most reliable method of anticipating and quantifying the likely impacts on the groundwater regime. The model construction will be described in detail in the following paragraphs, followed by predicted impacts in terms of groundwater quality and quantity for all the relevant opencast phases.

The finite difference numerical model was created using the US Department of Defence Groundwater Modelling System (GMS9.1) as Graphical User Interface (GUI) for the well-established Modflow and MT3DMS numerical codes.

MODFLOW is a 3D, cell-centred, finite difference, saturated flow model developed by the United States Geological Survey. MODFLOW can perform both steady state and transient analyses and has a wide variety of boundary conditions and input options. It was developed by McDonald and Harbaugh of the US Geological Survey in 1984 and underwent eight overall updates since. The latest update (Modflow-NWT) incorporates several improvements extending its capabilities considerably, the most important being the introduction of the Newton formulation of Modflow. This dramatically improved the handling of dry cells that has been a problematic issue in Modflow in the past.

MT3DMS is a 3-D model for the simulation of advection, dispersion, and chemical reactions of dissolved constituents in groundwater systems. MT3DMS uses a modular structure similar to the structure utilized by MODFLOW, and is used in conjunction with MODFLOW in a two-step flow and transport simulation. Heads are computed by MODFLOW during the flow simulation and utilized by MT3DMS as the flow field for the transport portion of the simulation.

8.1 Flow Model Set-Up

In this paragraph the setup of the flow model will be discussed in terms of the conceptual model as envisaged for the numerical model, elevation data used, boundaries of the numerical model and assumed initial conditions.

8.2 Elevation Data

Elevation data is crucial for developing a credible numerical model, as the groundwater table in its natural state tends to follow topography.

The best currently available elevation data is derived from the STRM (Shuttle Radar Tomography Mission) DEM (Digital Elevation Model) data. The SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000, during which elevation data was obtained on a near-global scale to generate the most complete high-resolution digital topographic database of Earth[10]. Data is available on a grid of 30 metres in the USA and 90 metres in all other areas.

Several studies have been conducted to establish the accuracy of the data, and found that the data is accurate within an absolute error of less than five metres and the random error between 2 and 4 metres for Southern Africa[11]. Over a small area as in this study, the relative error compared to neighbouring point is expected to be less than one metre. This is very good for the purpose of a numerical groundwater model, especially if compared to other uncertainties; and with the wealth of data this results in a much improved model.

[10] http://www2.jpl.nasa.gov/srtm/

[11] Rodriguez, E., et al, 2005. An assessment of the SRTM topographic products. Technical Report JPL D-31639, Jet Propulsion Laboratory, Pasadena, California.

8.3 Conceptual Model

For the purpose of this study, the subsurface was envisaged to consist of the following hydrogeological units.

- The upper few meters below surface consist of completely weathered material. This layer is anticipated to have a reasonably high hydraulic conductivity, but in general unsaturated.
- The next few tens of meters are weathered, highly fractured shale/sandstone bedrock with a low hydraulic conductivity. The permanent groundwater level commonly resides in this unit. The groundwater flow direction in this unit is influenced by regional topography and for the site flow would be in general from high to lower lying areas.
- Below a few tens of meters the fracturing of the aquifer is less frequent with depth and fractures less significant due to increased pressure. This results in an aquifer of lower hydraulic conductivity and very slow groundwater flow velocities.

Fracturing of the bedrock could consist of both major fault structures and/or minor pressure-relieve joints. On a large enough scale (bigger than the Representative Elemental Volume) the effects of lesser structures become less important in a rock matrix. Therefore, parts of the aquifer that did not show major fault zones have been considered as homogeneous in this study. Fracturing of the bedrock could consist of both major fault structures and/or minor pressure-relieve joints. On a large enough scale (bigger than the Representative Elemental Volume) the effect of these structures become less important and has been considered as a homogeneous aquifer in this study.

Groundwater, originating from the vertical infiltration of rainwater through the upper layer(s) up to the groundwater level, will flow mostly horizontally in the directions as discussed above. Water flow volumes and velocities will, on average, decrease gradually with depth.

The following assumptions and simplifications were made in constructing the numerical model:

- The upper completely weathered aquifer is mostly unsaturated, but could be an important part of the hydrogeological system in low lying areas. Although it is very thin in comparison to the fractured bedrock aquifer, it has been modelled as a separate layer to improve model predictions where the groundwater levels are shallow. The permanent groundwater level could be present in this layer in some places.
- The bedrock has been modelled as three layers of decreasing hydraulic conductivity and specific yield. Fractures in bedrock close up at depth, which result in a lowering of the hydraulic conductivity[12].
- It is generally known that only the upper 30 - 50 meters of the Ecca Group contain significant groundwater. Thus, a layer representing the weathered and fractured zone where the permanent groundwater level commonly resides was modelled. This layer was followed by two more layers of 30 metres thickness each. The hydraulic parameters were decreased by an order of magnitude in each successive layer.
- No provision has been made for the lower Pretoria Group as a separate unit, as neither its vertical position nor properties are known with any certainty. However, at depth

[12] Barnes, S. L. et al. Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania. Pennsylvania Department of Environmental Protection

secondary porosity due to bedrock fracturing is more important than the original bedrock properties. It can thus reasonably be assumed that the hydraulic properties are reasonably similar to that of the fractured Ecca rock.

- The local effect of discontinuities, such as faults, fractures and intrusions, has been disregarded. The exact location and characteristics of these structures are unknown and will be difficult and expensive to determine, if at all possible. Besides, on a large enough scale the effect of these structures become less important and can be considered as part of the homogeneous aquifer, as described in paragraph 8.8.

8.4 Fixed Aquifer Parameters

Although the most relevant aquifer parameters are optimised by the calibration of the model (paragraph 8.5), many parameters are calculated and/or judged by conventional means. The following fixed assumptions and input parameters were used for the numerical model of this area:

- Recharge = 36 mm/a ≈ 0.0001 m/d. This value was calculated using the RECHARGE program[13]. This value relates to an average recharge percentage of approximately 5% as indicated by Table 4. Please note that this is not effective recharge, as evapotranspiration was also modelled as discussed below. The result will thus be higher recharge in high topographical areas and lower recharge where the water table is shallow, similar to the conditions in nature.

Maximum Evapotranspiration = 1810 mm/a ≈ 0.005 m/d. This value is based on the S-pan evaporation data for this area[3] as shown in Table 1.

- Note that this rate of evapotranspiration is used by the modelling software only if the groundwater should rise to the surface. For the groundwater level between the surface and the extinction depth, the evapotranspiration is calculated proportionally.
- Evapotranspiration Extinction Depth = 1 m. This depth relates to the expected average root depth of plants in this area.
- The specific storage over the area was taken as 0.000001. This is a typical value for fractured bedrock.
- Horizontal Hydraulic Permeability of Rock Matrix= 0.05 m/d as an initial value, declining with depth by an order of magnitude at the fourth layer due to decreasing weathering of the bedrock and increased pressure that tend to close fractures, as described in paragraph 8.3 (Conceptual Model).
- Horizontal Hydraulic Permeability of Regolith= 1 m/d as a maximum value as described in paragraph 8.3 (Conceptual Model). The upper layer of the model was constructed to represent regolith material which is highly porous and conductive.
- Vertical Hydraulic Anisotropy (KH/KV) of the bedrock = 10. By nature of the pronounced horizontal layering, this value is commonly used in the Karoo sedimentary layers.
- The effective porosity value was taken as 0.3 for the upper regolith with the second highly weathered/fractured layer was assigned a porosity of 0.05, declining gradually to 0.03 at a

[13] Gerrit van Tonder, Yongxin Xu: RECHARGE program to Estimate Groundwater Recharge, June 2000. Institute for Groundwater Studies, Bloemfontein RSA.

depth of 100 - 150 metres. This value could not be determined directly and was taken as typical of the fractured bedrock.

- Longitudinal dispersion was taken as 50 metres, which is about 10% of expected plume dimensions, as recommended in various modelling guidelines.
- Transverse and vertical dispersion was taken as 5 metres and 0.5 metre respectively as recommended in various textbooks, being about 10% of the expected plume dimensions.
- Opencasts were simulated as drains, with a conductance of 0.1 $m^2/day/m^2$. This value was found to be just enough to lower the groundwater level to the coal floor during mining.

8.5 Construction of the Model

Construction of the numerical model consists of selecting natural boundaries for the model, discretisation of this area in finite elements, and calibration against measured groundwater levels and/or flow.

8.5.1 Model Boundaries and Discretisation

Boundaries for the numerical model have to be chosen where the groundwater level and/or groundwater flow is known. The most obvious locations are zero flow conditions at groundwater divides, while groundwater levels are known at prominent perennial dams and rivers connected to the groundwater.

To simulate the groundwater conditions in and around the proposed opencast area, the aquifer as described below, has been modelled. Boundaries were chosen to include the area where the groundwater pollution plume could reasonably be expected to spread and simultaneously be far enough removed from the opencast boundaries not to be affected contaminant movement.

Wherever practical, natural topographical water divides have been used as no-flow boundaries, assuming that the groundwater elevation follows the topography. In this particular area, water divides (topographical highs) served as no-flow boundaries to the south whereas two tributaries of the Woes-Alleenspruit served as boundaries to the north, west and to the east of the proposed mining site.

These boundaries resulted in an area of about 3 to 11 km around the proposed opencast, which is considered far enough for the expected groundwater effects not to be influenced by boundaries.

The modelling area was discretised by a 140 by 259 grid, refined at the mining area as depicted in Figure 15 below, resulting in finite difference elements of about 20 by 20 meters at the mining area and up to 200 meters at the edges of the model. All modelled features, like stockpiles, overburden dumps etc., are sizably larger than these dimensions, and the grid is thus adequate for the purpose. Nevertheless, the total amount of active cells over all layers added up to about 81 200 cells, resulting in a relative large model.

8.5.2 Calibration of the Model

As the depths to water levels in 5 boreholes were measured during a hydrocensus of the area in September 2013, the numerical model could be calibrated using this data. Most hydrocensus data is concentrated around the area of the proposed opencast. Some of the boreholes fall outside of the model boundary and were thus ignored in the calibration. The hydraulic conductivity was estimated by manual adjustment.

A good fit was obtained for the measured groundwater levels, as can be visualised through the vertical bars in Figure 18 (calibration interval = 10 metres, that is less than 10% of the altitude differences over the modelled area). The final optimised parameters were:

- Horizontal hydraulic conductivity of Layer1= 1
- Horizontal hydraulic conductivity of Layer2= 0.05
- Horizontal hydraulic conductivity of Layer3= 0.005
- Horizontal hydraulic conductivity of Layer4= 0.0005

All other parameters were unchanged, with values as listed in the paragraph 8.5 above. The calibration error statistics and graph can be seen in and Figure 19 respectively. The head error was below 4, which falls well within the calibration interval of this model.

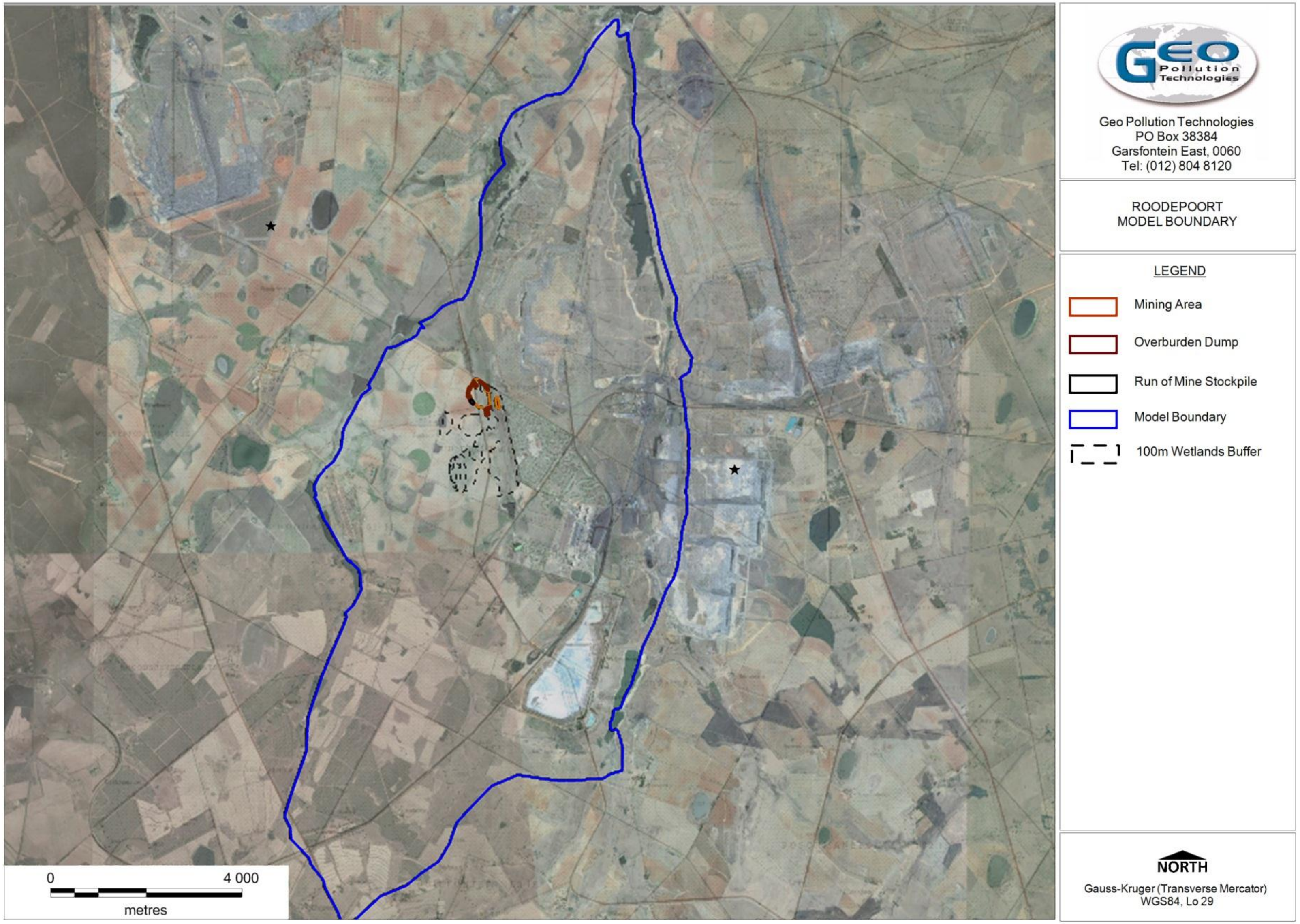

Figure 14: Model Boundaries

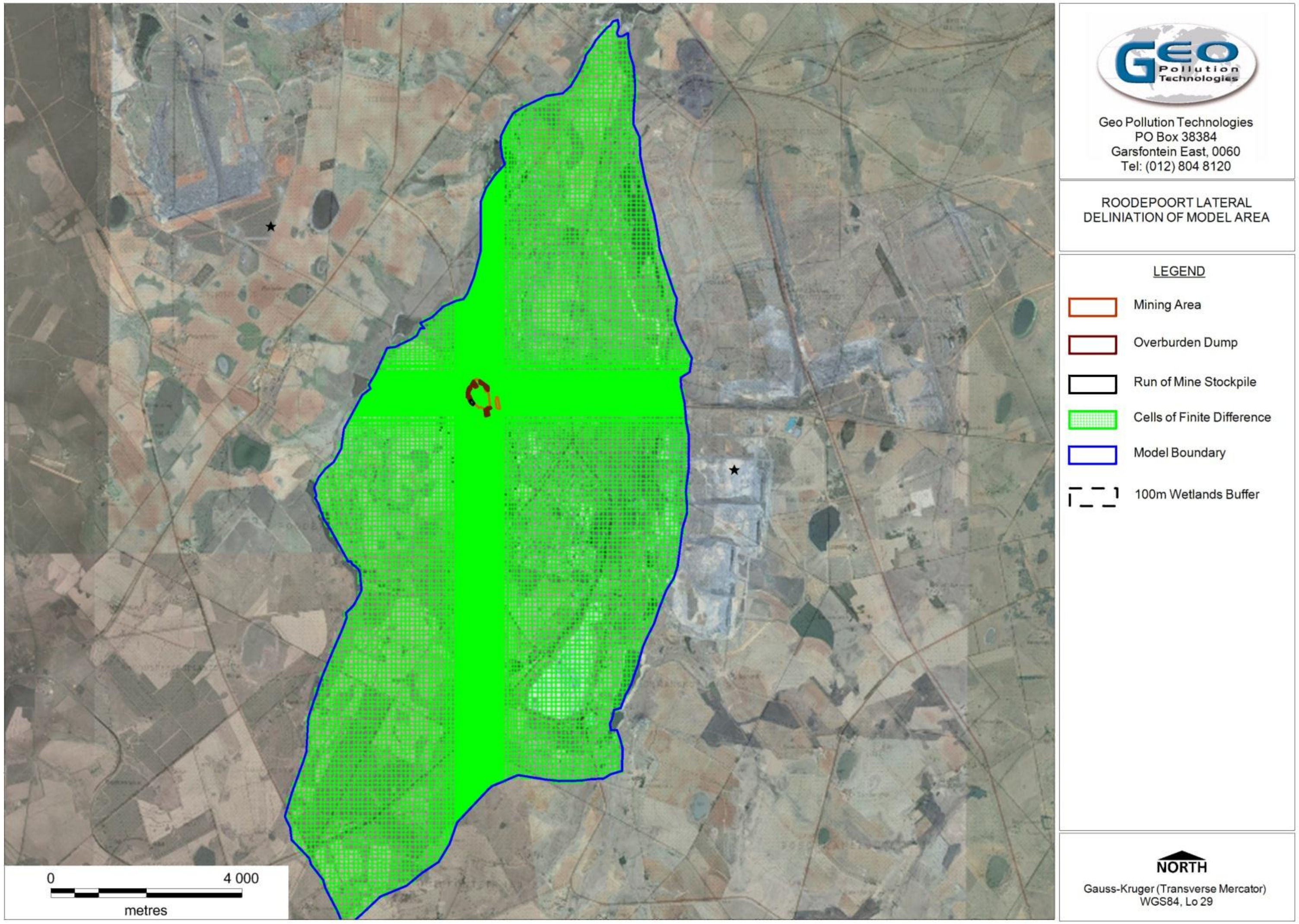

Figure 15: Lateral Delineation of the Regional Model

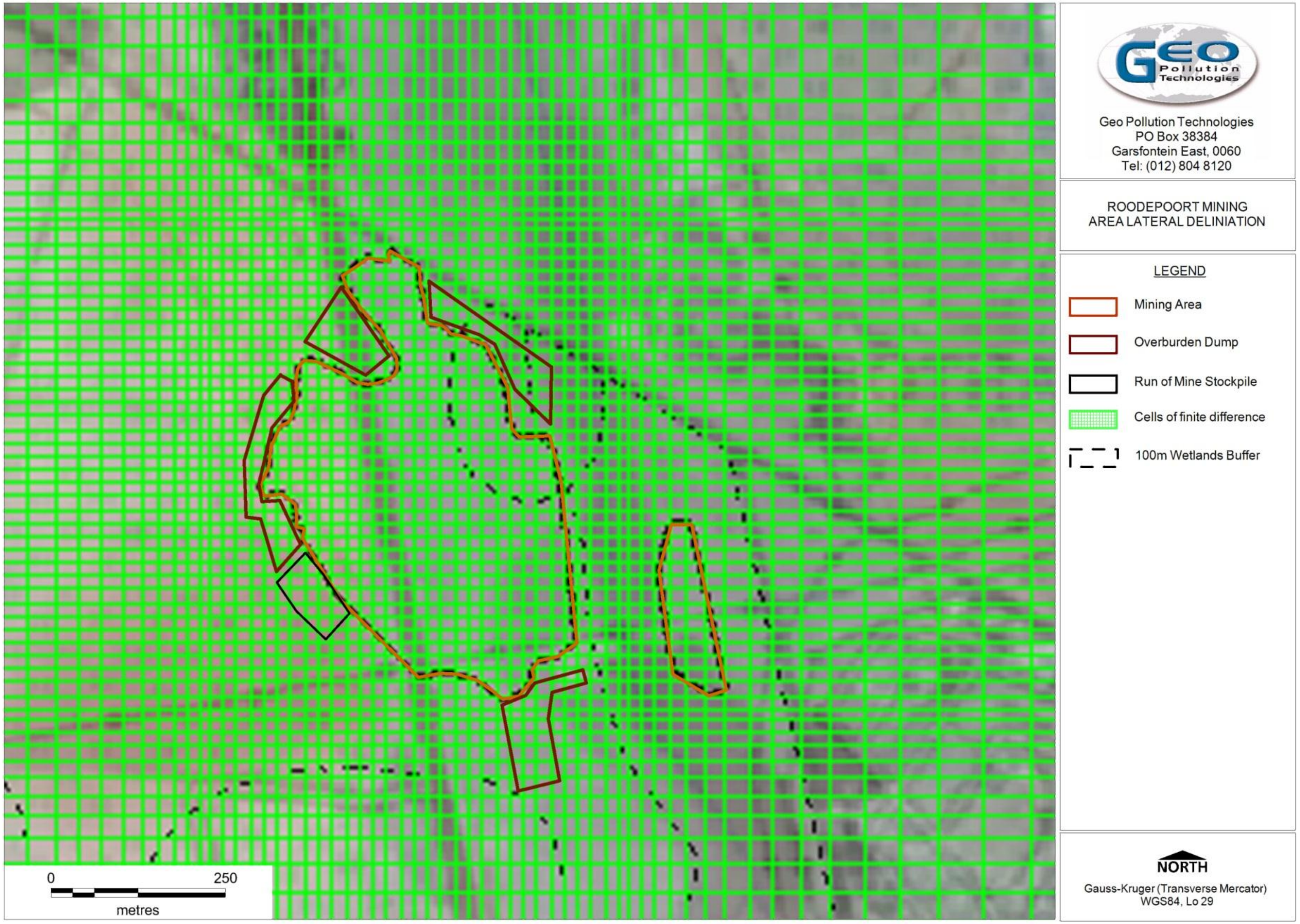

Figure 16: Lateral Delineation in the Mining Area

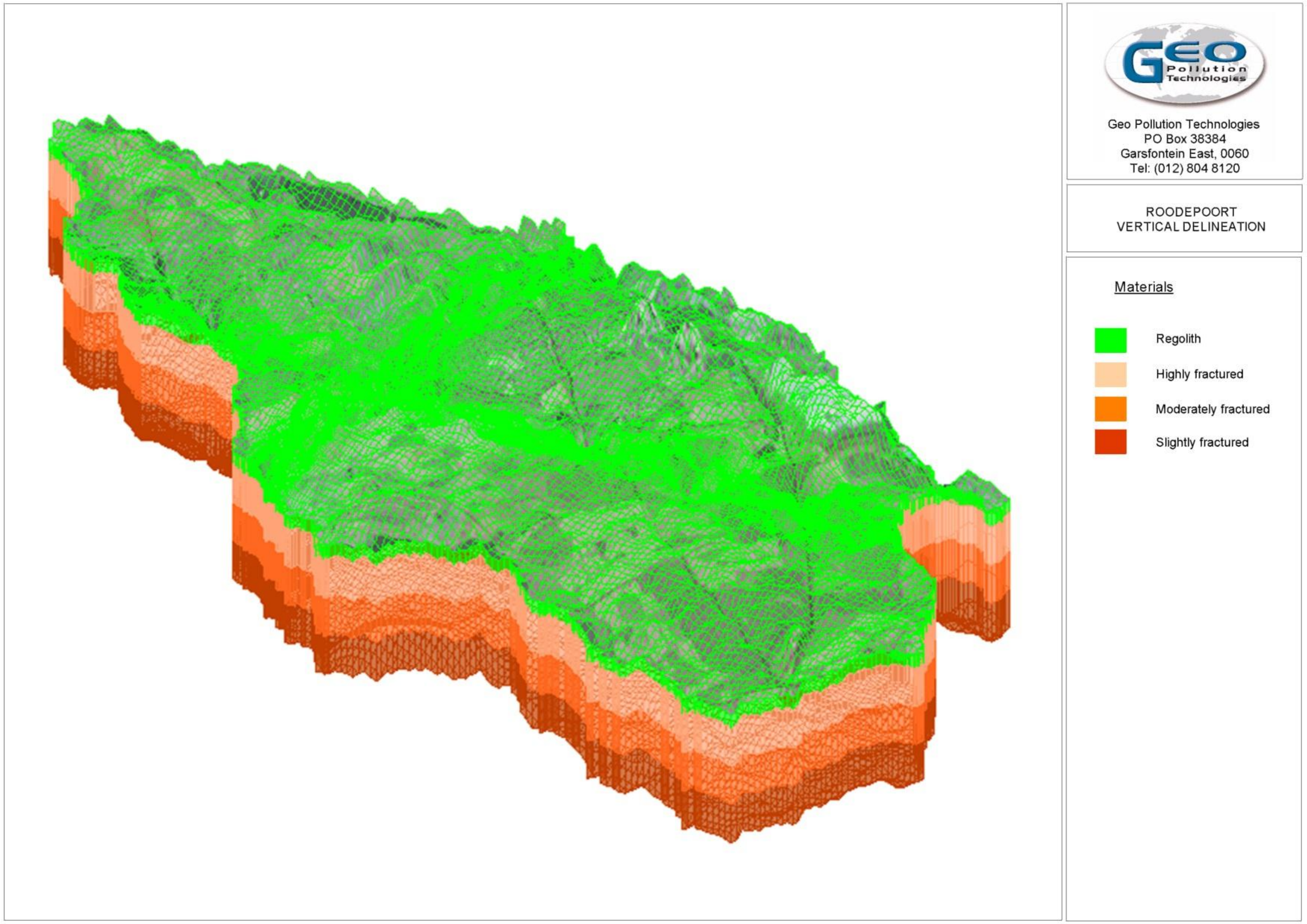

Figure 17: Vertical Delineation of the Modelled Area

[Vertical Exaggeration = 20]

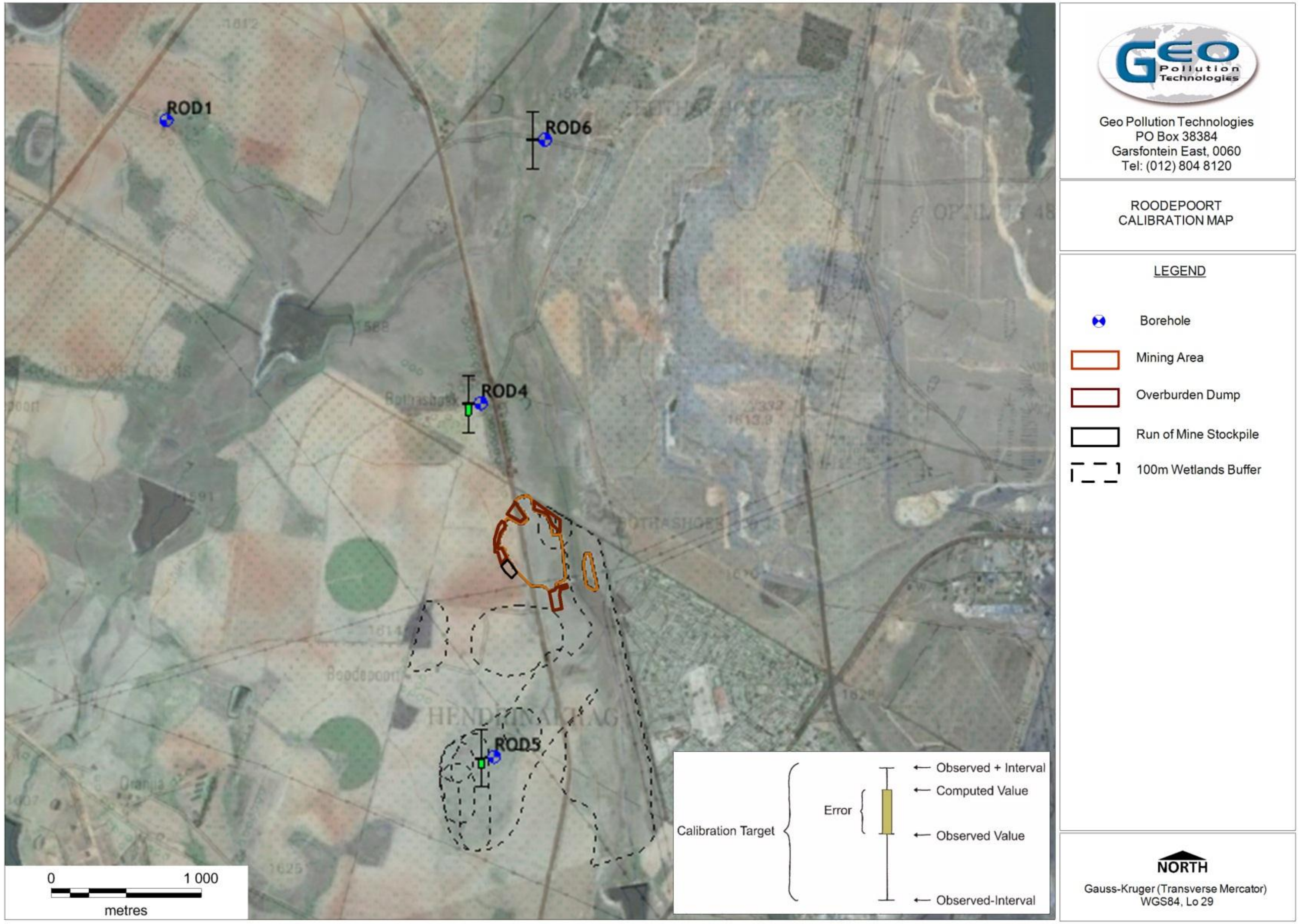

Figure 18: Calibration of the Numerical Model

Table 11: Calibration Statistics

Description	Value
Mean Residual (Head)	3.917
Mean Absolute Residual (Head)	3.917
Root Mean Squared Residual (Head)	4.414

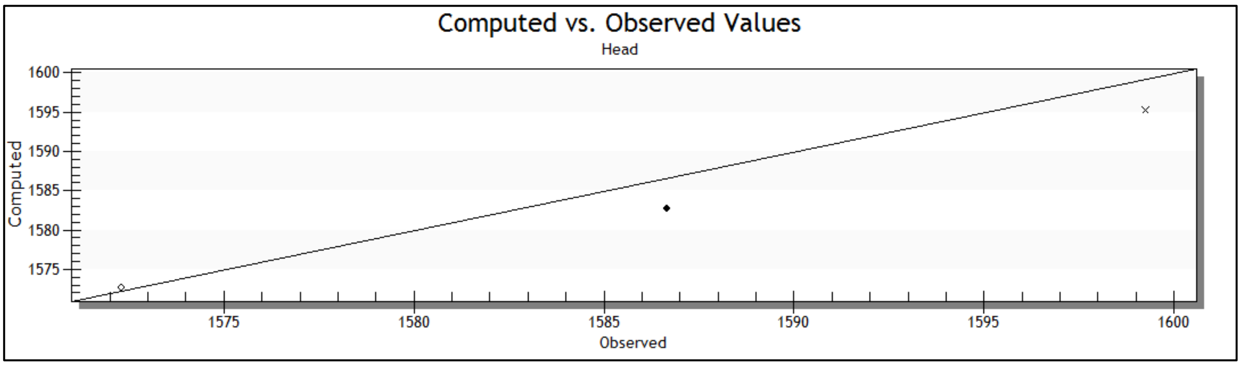

Figure 19: Calibration Graph for the Numerical Model

8.6 Solute Transport Model

The migration rate of a pollution plume was estimated by means of the numerical mass transport model MT3DMS as described in the introduction to this section. Advection and hydrodynamic dispersion are the two main processes that control contaminant transport through a porous medium. Advection is the flow component, while hydrodynamic dispersion refers to mechanical dispersion and molecular diffusion.

The same input parameters as previously stated for the flow modelling were chosen for the numerical model. In addition, the following assumptions were made for the transport modelling:

- The total and effective porosity values of the aquifer was taken as 0.3 (30%), decreasing to 0.02 (2%) at depths of more than 100m. These are estimated reasonable values for the fractured bedrock, decreasing by the square root of the hydraulic conductivity[14].
- Only sulphate was considered for solute transport calculations as it is the main chemical of concern from stockpiles and overburden dumps.
- An initial concentration of 2000 mg/litre was assumed for the sulphate leachate emanating from the overburden dump and stockpile. This is probably an overestimation, and should present a worst case scenario. The same concentration was assumed for the backfilled opencast, post-mining.
- It was assumed that the sulphate will behave as a conservative tracer, that is no decay and no retardation of contaminants occur while the plume is migrating.
- Only advection and hydrodynamic dispersion was therefore modelled, assuming:

[14] Institute for Groundwater Studies, University of the Free State. Class notes

    - Longitudinal dispersion of 50m.
    - Ratio of transverse to dispersion = 0.1.
    - Ratio of vertical to longitudinal dispersion = 0.001.
- It was furthermore assumed that no pollution could migrate to the surrounding aquifer before the post-mining water level has not recovered, as negative water level gradients will prohibit any movement of groundwater from the mining void and contamination would spread towards the opencast during mining.
- The calculated water levels as simulated for the post-mining scenario were used as hydraulic heads in the mass transport model.

This methodology was selected to provide worst-case scenario results within the limitations of the assumptions, which is consistent with the approach followed with the remainder of the report.

8.7 MODEL RUNS

The calibrated model as described above was used to estimate the impact of the proposed opencast on the groundwater quality and quantity. Models ran and assumptions made, were the following:

8.7.1 Construction Phase

This scenario represents the construction of the opencast. It is assumed that additional no groundwater abstraction will take place except for what is currently being used in the area. Therefore, the hydrogeological scenario is assumed to remain in its current status with the exception of lesser hydrocarbon contamination. Therefore, this situation was modelled to represent the current situation.

8.7.2 Operational Phase

This model represents the groundwater situation during mining of the proposed opencast. For the purposes of this model a worst-case scenario was assumed, namely that the whole mine will be dewatered during the mining period. A drain was thus imposed under the mining area at the coal floor elevation.

8.7.3 Post Mining

This models the post-mining scenario, assuming that the most likely recharge over the rehabilitated opencast will be 0.00004 m/d. This amounts to a recharge of about 20% of rainfall, which is probably a realistic, if not worst case scenario[15].

8.8 LIMITATIONS OF THE MODELLING EXERCISE

The modelling was done within the limitations of the scope of work of this study and the amount of monitoring data available. Although all efforts have been made to base the model on sound assumptions and has been calibrated to observed data, the results obtained from this exercise

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[15] Grobbelaar, R et al: Long-Term Impact of Intermine Flow from Collieries in the Mpumalanga Coalfields, Sept 2004. Institute for Groundwater Studies, University of the Free State, Bloemfontein RSA.

should be considered in accordance with the assumptions made. Especially the assumption that a fractured aquifer will behave as a homogeneous porous medium locally, can lead to error. However, on a large enough scale (bigger than the REF, Representative Elemental Volume) this assumption should hold reasonable well.

9 GEOHYDROLOGICAL IMPACTS

It is the aim of this chapter to assess the likely hydrogeological impact that the proposed mining of the planned opencast might have on the receiving environment. The typical mining stages that will be considered in this section are:

- Construction Phase: Start-up of mining operations at the specific site before actual mining operations commences.
- Operational Phase: The conditions expected to prevail during the mining of the new opencast.
- Decommissioning Phase: The closing of mining operations, site cleanup and rehabilitation of the mining area.
- Post-mining Phase: This relates to the steady-state conditions following closure of the opencast. A period will be considered after which it is assumed that impacts will steadily decrease and start returning to normal.

9.1 CONSTRUCTION PHASE

9.1.1 Impacts on Groundwater

It is accepted for the purposes of this document that the construction phase will consist of preparations for the opencast, which is assumed to consist mainly of establishment of infrastructure on site, the mobilisation of earth moving equipment and the opening of the boxcut.

This phase is not expected to influence the groundwater levels. With the exception of lesser oil and diesel spills, there are also no activities expected that could impact on regional groundwater quality. This phase should thus cause very little additional impacts in the groundwater quality. It is expected that the current status quo will be maintained.

9.1.2 Groundwater Management

As only diesel and oil spills have been identified as potential groundwater pollutants during this phase, measures to prevent and contain such spills should be introduced. The following is suggested:

- It must be ensured that a credible company removes used oil after vehicle servicing.
- A sufficient supply of absorbent fibre should be kept at the site to contain accidental spills.
- Used absorbent fibre must be land-farmed, using approved methodologies.

9.2 Operational Phase

The operational phase is interpreted as the active mining of the Roodepoort opencast as well as the operation of the associated stockpile and overburden dumps. It is inevitable that these operations will impact on the groundwater regime. The potential impacts that will be considered are the groundwater quantity and quality.

Conceptual layouts were made available at the time of this study, and conservative assumptions were thus made regarding layout planning. It is recognised that the layout might be simplistic, and it is essential that this model is updated once final information is available.

9.2.1 Impacts on Groundwater Quantity

During the operational phase, it is expected that the main impact on the groundwater environment will be de-watering of the surrounding aquifer. Water entering the mining areas will have to be pumped out to enable mining activities. This will cause a lowering in the groundwater table, in and adjacent to the mine.

The dewatering of the aquifer has been calculated for the opencast using the calibrated numerical model as described above. A worst-case scenario has been modelled, assuming that the entire opencast would be dewatered at once. This will obviously not be the case, and the actual drawdown could thus be less. However, as the recovery of groundwater is expected to be very slow, it could well be that the first boxcut in the opencast would still be in an early stage of recovery upon decommissioning. Thus, the worst case scenario could also be close to the actual scenario.

- The calculated drawdown of the worst case scenario is depicted in Figure 20 below, as contours of drawdown for the opencast. It is evident from this figure that the adjacent wetlands and tributary of the Woes-Alleenspruit to the east of the mining site will potentially be influenced by significant drawdown due to the opencast, based on available data and modelling results.
- There are no privately owned boreholes identified in the potential affected area that might experience a decline in water levels of approximately 5 metres or more.
- A summary of the opencast modelling results can be seen in Table 12.

Despite the modelled predictions, it must again be stressed that structures of preferred groundwater flow have not been modelled. It is known by experience that dolerite will most likely transgress the area, but details are limited and not adequate to model this structure(s). If such a structure is dewatered through mining, any boreholes drilled into the structure might be seriously affected. These effects cannot be predicted with the current knowledge, and can only be established through continuous groundwater level monitoring.

It is also possible to calculate the inflow into the opencast from the numerical model. However, detailed mining plans and schedules have not been finalised at the time of this report, and no detailed inflow per mining cut could thus be calculated. However, the computed inflow to the total opencast, assuming that all areas is dewatered simultaneously, was calculated as shown in Table 12 below.

However, these figures are overestimations and probably reflect worst-case scenarios. The actual inflow will depend on the area being mined at any one moment in time. However, at the last boxcut, the inflow from the backfilled portion of the opencast could be substantial and the above inflows can be approached.

It is important to view these numbers for the water make of the mine in relation to natural evaporation, as listed in the table. Illustrative volumes are included in the table as if the evaporation will take place over the whole opencast, for comparative purposes. As the whole opencast will not be open at any one time, this is obviously an overestimate. Nevertheless, it is illustrative that evaporation can contribute considerably to the removal of groundwater seepage into the opencast.

Furthermore, it should be realised that evaporation is a seasonal effect. It is essential that more realistic volumes be calculated once detailed mining plans are available. Direct recharge from rainfall will in turn add to these volumes. The amount of direct recharge will depend on the season as well as the details of the mining plans and storm water management. It is suggested that this is calculated as part of the surface water study.

It must be cautioned that these calculations have been done using simplified assumptions of homogeneous aquifer conditions. The reality could deviate substantially from this and the model should thus be updated as more information becomes available.

9.2.2 Groundwater Quality

The flow in the aquifer will be directed towards the opencast during this stage of mining, and very little groundwater pollution is thus expected. Any contamination that may take place is likely to be directed towards the opencast.

9.2.3 Cumulative Effects

The cumulative pollution impacts of all current and historic mining operations in addition to the proposed new opencast could not be calculated as any data on surrounding activities is not available. However it is recommended that a regional study be undertaken to quantify impacts on at least a quaternary scale.

9.2.4 Groundwater Management

A substantial drop in groundwater level is expected, but it is confined to no more than 600 metres around the opencast. As a drawdown of 5 metres and more is needed to seriously affect the yield of boreholes, thus no negative quantity impact on any current private groundwater users is predicted as previously discussed. However, the base flow feeding the wetland could be affected, as discussed in the previous paragraph.

It is important to monitor static groundwater levels on a quarterly basis in all boreholes within a zone of two kilometres surrounding the opencast to ensure that any deviation of the groundwater flow from the idealised predictions is detected in time and can be reacted on appropriately. Preferred flow structures (dykes, sills, faults, etc) have not been included in the model due to the unknown hydraulic characteristics, and these structures could alter the actual effects considerably.

If it can be proven that the mining operation is indeed affecting the quantity of groundwater available to certain users, the affected parties should be compensated. This may be done through the installation of additional boreholes for water supply purposes, or an alternative water supply.

Furthermore, if flow in the streams is found to decrease, it will be necessary to mitigate this effect. As this opencast is not situated directly within the path of the tributary to the Woes-Alleenspruit, there are no upstream flow that needs to be routed, and suitable canalisation of rainfall runoff should be able to restore stream flow to very close to undisturbed conditions. However, it will be important to measure stream flow on a regular basis (even well before mining) to quantify the effect on the river. Also, the possible impact on the wetland cannot be mitigated unless the opencast is substantially decreased in size or moved. However, a wetland specialist should be consulted to determine the hydraulic connectivity between the wetland and groundwater environments.

Another very important aspect to consider is the layout and order of the opencast cuts. The best possible scenario for minimising impacting on the wetland/stream is to start the boxcut parallel to the wetland/stream and at the farthest point from the wetland. In such a mining scenario the impact on the wetland will be delayed to the latest possible time before closure of the opencast.

Although little or no groundwater contamination is expected during this stage due to the cone of depression, it is nevertheless also recommended that groundwater quality be monitored on a quarterly basis. This is essential to provide a necessary database for future disputes.

Water samples must be taken from all the monitoring boreholes by using approved sampling techniques and adhering to recognised sampling procedures. Samples should be analysed for both organic as well as inorganic pollutants, as mining activity often lead to hydrocarbon spills in the form of diesel and oil. At least the following water quality parameters should be analysed for:

- Major ions (Ca, K, Mg, Na, SO4, NO3, Cl, F)
- pH
- Electrical Conductivity (EC),
- Total Petroleum Hydrocarbons (TPH)
- Total Alkalinity

These results should be recorded on a data sheet. It is proposed that the data should be entered into an appropriate computer database and reported to the Department of Water Affairs and Forestry.

Table 12: Predicted modelling results and impacts of each individual opencast

Opencast Mining Area	Area (m^2)	Maximum Drawdown (m)	Cone of depression from edge of pit (m)	Estimated Inflow (m3/day)	Evaporation (m3/day)	Potential Impacted Receptor
Roodepoort	164747	40	300	120	757.83	Tributary of the Woes-Alleenspruit and potentially Wetlands

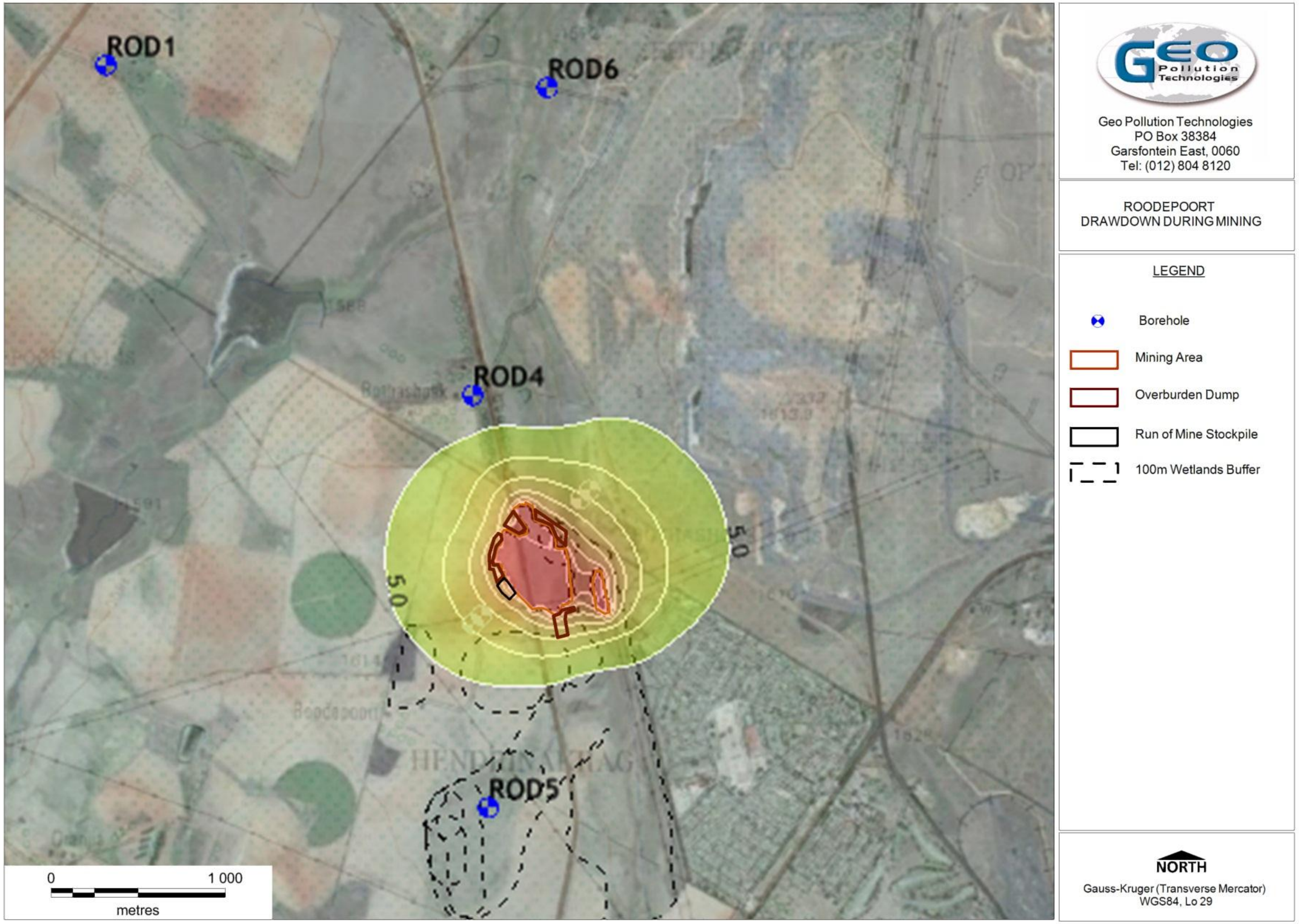

Figure 20: Groundwater Drawdown during Mining

9.3 Decommissioning Phase

During this phase of mining it is assumed that dewatering of the opencast will be ceased, and the surface of the opencast will be rehabilitated. The groundwater regime will return to a state of equilibrium once mining has stopped and the removal of water from the mining void has been discontinued.

The rise in groundwater level is predicted to be relatively slow and the water levels are expected to recover only in about 10 - 20 years. The slow recovery is ascribed to the low hydraulic conductivity of the surrounding bedrock.

No additional impacts on the groundwater of the study area other than the impacts discussed in paragraph 9.2 are expected during the decommissioning phase of the project.

9.4 Post-mining Phase

This phase of the mining process is the period following the completion of mining and rehabilitation of the proposed opencast. The following possible impacts were identified at this stage:

- Following closure of the opencast, the groundwater level will rise to an equilibrium that will differ from the pre-mining level due to the disturbance of the bedrock and increase in recharge from rainfall.
- Groundwater within the mined areas is expected to deteriorate due to chemical interactions between the geological material and the groundwater. The resulting groundwater pollution plume will commence with downstream movement.

These impacts are discussed separately below and the significance of each impact is discussed.

9.4.1 Groundwater Quantity

After closure, the water table will rise in the rehabilitated opencasts to reinstate equilibrium with the surrounding groundwater systems. However, the mined areas will have a large hydraulic conductivity compared to the pre-mining situation. This will result in a relative flattening of the groundwater table over the extent of mining, in contrast to the gradient that existed previously.

The end result of this will be a permanent lowering of the groundwater level in the higher topographical area and a rise in lower lying areas.

Intuitively, it would be expected that this raise in groundwater could result in decanting of the opencast. However, the predicted groundwater levels indicate that decanting will most probably not occur.

9.4.2 Groundwater Quality

Once the normal groundwater flow conditions have been re-instated, polluted water can migrate away from the rehabilitated areas. As some coal and discards will remain in the mine, this outflow will be contaminated as a result of acid or neutral mine drainage. As sulphate is normally a significant solute in such drainage, it has been modelled as a conservative (non-reacting) indicator of mine drainage pollution. A starting concentration of 2 000 mg/litre has been assumed as a worst case scenario, based on past experience.

The migration of contaminated water from the mining area has been modelled as described, and the results are presented in Figure 21 in terms of the extent of the pollution plume 10, 25, 50 and 100 years after the opencasts has been closed. Experience has shown that the plume stagnates after about 100 years, and no further movement after such time is expected.

As stated previously, the results must be viewed with caution as a homogeneous aquifer has been assumed. Heterogeneities in the aquifer are unknown and the effect of this cannot be predicted. Furthermore, no chemical interaction of the sulphate with the minerals in the surrounding bedrock has been assumed. As there must be some interaction and retardation of the plume, it is hoped that this prediction will represent a worst-case scenario.

Within the limitations of the abovementioned assumptions, it can be estimated from these figures that:

- The sulphate pollution plume emanating from the opencast is predicted to reach the wetland as well as the tributary of the Woes-Alleenspruit about 10 years after mine closure and rebound of the groundwater levels.
- Following this eventual period, seepage of AMD will increase in concentration and could reach very high levels in the wetland and tributary east of the opencast, due to evapotranspiration.
- No identified privately owned boreholes are likely to be affected by the sulphate pollution plume.

9.4.3 Cumulative Effects

The cumulative pollution impacts of all current and historic mining in addition to the proposed new opencasts could not be calculated as any data on surrounding mines is not available. However it is highly recommended that a regional study be undertaken to quantify impacts on at least a quaternary scale.

9.4.4 Groundwater Management

From the modelling results obtained, it seems as if the opencast may not decant. However, in the event that decant is predicted upon refinement of the model or during operation, some mitigation measures can be considered:

- Reducing the extent of the opencast at the decant areas. This will decrease the severity of decanting as well as improving the impact of the plume.
- Mining should remove all coal from the opencast and as little as possible should be left.
- Remaining acid producing material should be placed as low in the pit as possible to ensure fast flooding of the material. All mined areas should be flooded as soon as possible to bar oxygen from reacting with remaining pyrite[15].
- The final backfilled opencast topography should be engineered such that runoff is directed away from the opencast areas.
- The final layer (just below the topsoil cover) should be as clayey as possible and compacted if feasible, to reduce recharge to the opencast.
- Quarterly groundwater sampling must be done to establish a database of plume movement trends, to aid eventual mine closure.

As more groundwater contamination is expected during this stage, it is even more important that groundwater quality be monitored regularly, at least on a quarterly basis. This is essential to provide a reliable database to facilitate eventual closure of the mining operation. The sampling methods and substances to be sampled for are similar to those recommended in the previous paragraph.

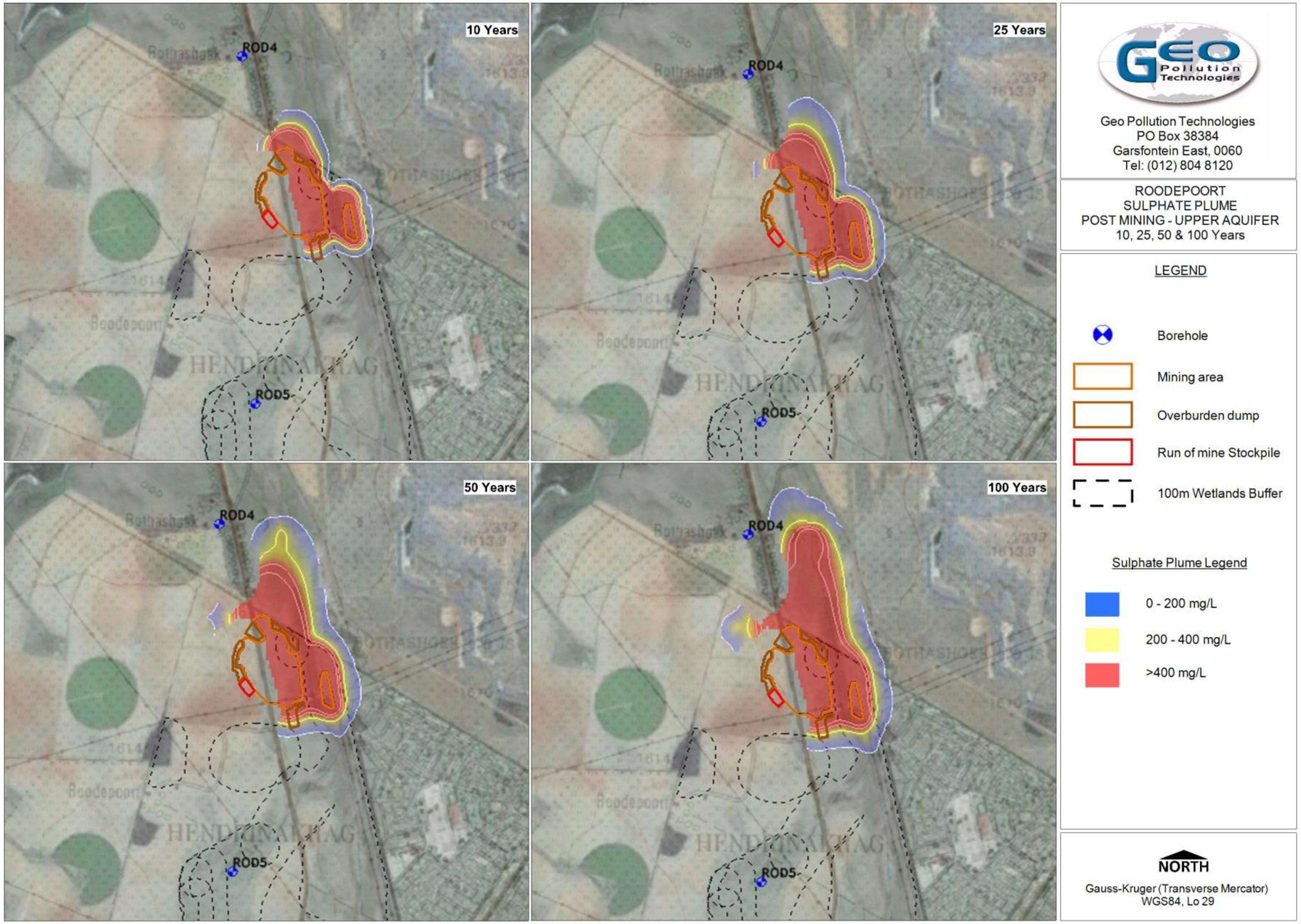

Figure 21: Plume Migration after 10, 25, 50 and 100 years (Upper Aquifer).

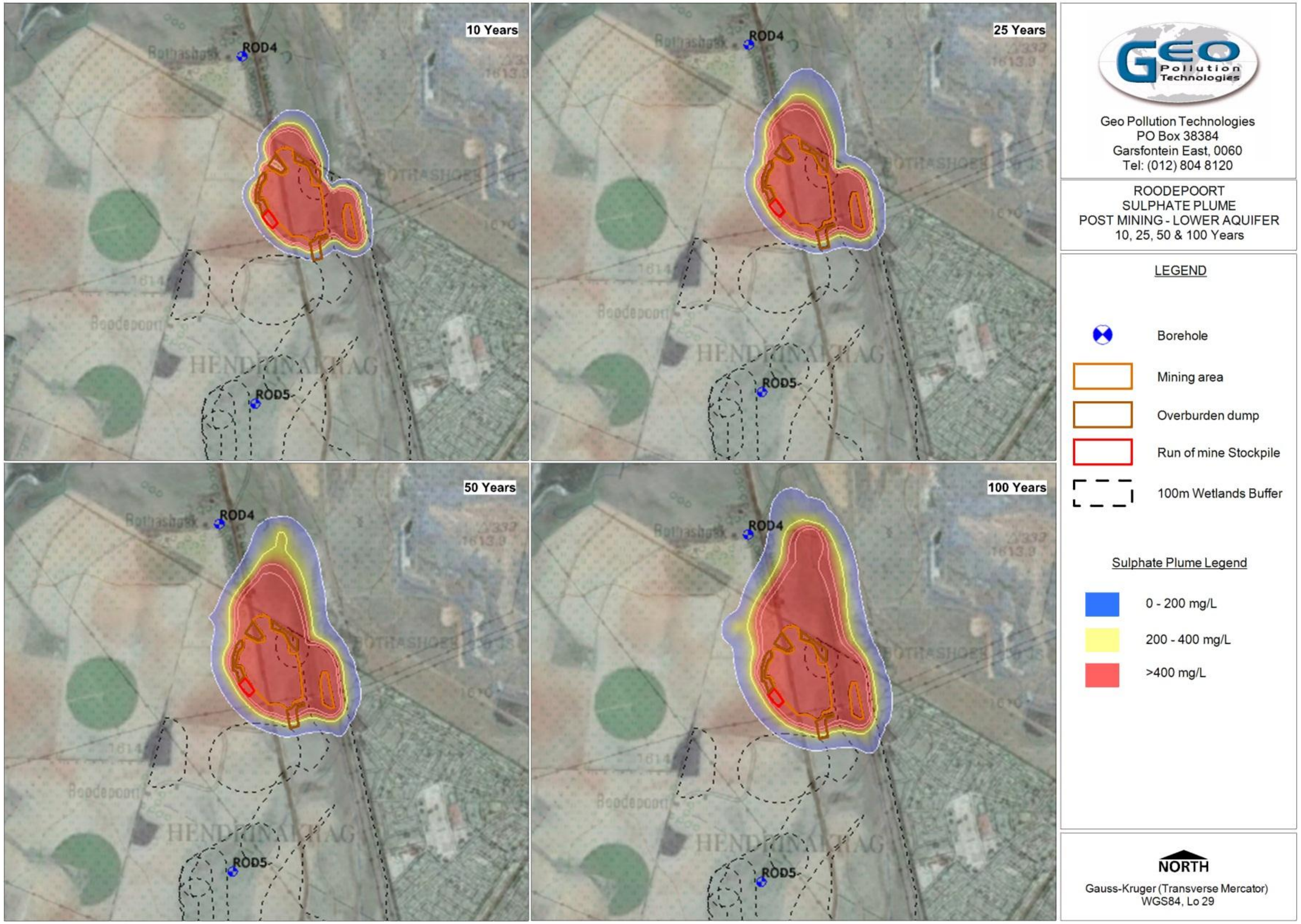

Figure 22: Plume Migration after 10, 25, 50 and 100 years (Lower Aquifer).

10 GROUNDWATER MONITORING SYSTEM

10.1 Groundwater Monitoring Network

A groundwater monitoring system has to adhere to the criteria mentioned below. As a result the system should be developed accordingly.

10.1.1 Source, plume, impact and background monitoring

A groundwater monitoring network should contain monitoring positions which can assess the groundwater status at certain areas. The boreholes can be grouped according to the following purposes:

- **Source monitoring** – monitoring boreholes are placed close to or in the source of contamination to evaluate the impact thereof on the groundwater chemistry.
- **Plume monitoring** – monitoring boreholes are placed in the primary groundwater plume's migration path to evaluate the migration rates and chemical changes along the pathway.
- **Impact monitoring** – monitoring of possible impacts of contaminated groundwater on sensitive ecosystems or other receptors. These monitoring points are also installed as early warning systems for contamination break-through at areas of concern.
- **Background monitoring** – background groundwater quality is essential to evaluate the impact of a specific action/pollution source on the groundwater chemistry.

10.2 System Response Monitoring Network

Groundwater levels – Static water levels are used to determine the flow direction and hydraulic gradient within an aquifer. Where possible all of the above mentioned borehole's water levels need to be recorded during each monitoring event.

10.3 Monitoring frequency

In the operational phase, quarterly monitoring of groundwater quality and groundwater levels is recommended. Quality monitoring should take place before, after and during the wet season, i.e. during September and March. It is important to note that a groundwater-monitoring network should also be dynamic. This means that the network should be extended over time to accommodate the migration of potential contaminants through the aquifer as well as the expansion of infrastructure and/or addition of possible pollution sources.

10.4 Monitoring Parameters

The identification of the monitoring parameters is crucial and depends on the chemistry of possible pollution sources. They comprise a set of physical and/or chemical parameters (e.g. groundwater levels and predetermined organic and inorganic chemical constituents). Once a pollution indicator has been identified it can be used as a substitute a full analysis and therefore save costs. The use of pollution indicators should be validated on a regular basis in the different sample positions. The parameters should be revised after each sampling event; some metals may be added to the analyses during the operational phase, especially if the pH drops.

10.4.1 Abbreviated analysis (pollution indicators)

Physical Parameters:

- Groundwater levels

Chemical Parameters:

- Field measurements:
    - pH, EC
- Laboratory analyses:
    - Major anions and cations (Ca, Na, Cl, SO4)
    - Other parameters (EC)

10.4.2 Full analysis

Physical Parameters:

- Groundwater levels

Chemical Parameters:

- Field measurements:
    - pH, EC
- Laboratory analyses:
    - Anions and cations (Ca, Mg, Na, K, NO3, Cl, SO4, F, Fe, Mn, Al, Cr, Hg & Alkalinity)
    - Other parameters (pH, EC, TDS)
    - Petroleum hydrocarbon contaminants (where applicable, near workshops and petroleum handling facilities)
    - Sewage related contaminants (E.Coli, faecal coliforms) in boreholes in proximity to septic tanks or sewage plants.

10.5 Monitoring Boreholes

There are no source/plume monitoring boreholes that match the criteria as mentioned in the preceding paragraphs. Therefore at least 4 to 6 monitoring holes are recommended to be constructed around each opencast upstream and downstream of the site.

DWAF (1998) states that "A monitoring hole must be such that the section of the groundwater most likely to be polluted first, is suitably penetrated to ensure the most realistic monitoring result."[16] Therefore it is recommended that boreholes be drilled on the positions as mentioned in the paragraph. These boreholes should be drilled as close possible to the opencast and monitored appropriately. Construction of these boreholes should be overseen by a qualified hydrogeologist to monitor the upper weathered as well as lower fractured aquifer.

[16] Department of Water Affairs and Forestry (DWAF). (1998). Minimum Requirments for the Water Monitoring at Waste Managmenet Facilities. CTP Book Printers. Capetown.

A monitoring network should be dynamic. This means that the network should be extended over time to accommodate the migration of contaminants through the aquifer as well as the expansion of infrastructure and/or addition of possible pollution sources. An audit on the monitoring network should be conducted annually.

In Table 13 a monitoring network extension is proposed. These boreholes should be added to boreholes mentioned in Table 5 as part of an extended monitoring network and should be sited using geophysical methods. The monitoring positions are indicated in Figure 23 and show potential drilling positions. However, these positions are purely indications.

Table 13: Proposed monitoring network

Name	X-coord	Y-coord	Monitoring Requirement
RDM01	29.5839211	-26.00813933	Source/Plume Monitoring
RDM02	29.57975849	-26.00823285	Source/Plume Monitoring
RDM03	29.57688704	-26.00306219	Source/Plume Monitoring
RDM04	29.57930092	-26.00155548	Source/Plume Monitoring
RDM05	29.58232399	-26.00300201	Source/Plume Monitoring
RDM06	29.58394288	-26.00395514	Source/Plume Monitoring

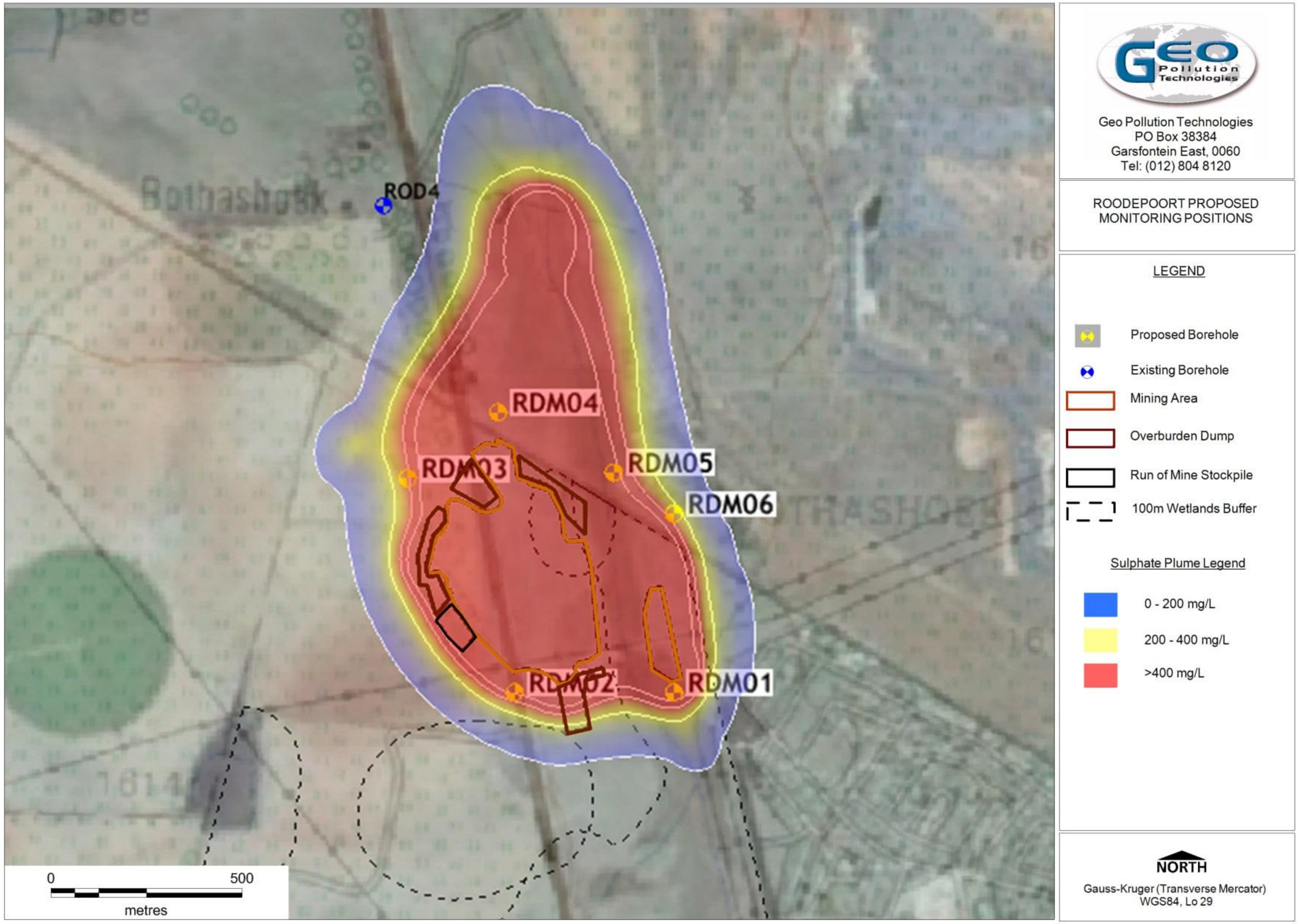

Figure 23: Proposed Monitoring Positions

11 GROUNDWATER IMPACT ASSESSMENT AND ENVIRONMENTAL MANAGEMENT PROGRAMME (EMP)

11.1 Groundwater Impact Assessment Criteria

The criteria for the description and assessment of groundwater impacts were drawn from the EIA Regulations, published by the Department of Environmental Affairs and Tourism (April 1998) in terms of the NEMA[17]. The level of detail as depicted in the EIA regulations was fine-tuned by assigning specific values to each impact. In order to establish a coherent framework within which all impacts could be objectively assessed, it was necessary to establish a rating system, which was applied consistently to all the criteria. For such purposes each aspect was assigned a value, ranging from one (1) to five (5), depending on its definition. This assessment is a relative evaluation within the context of all the activities and the other impacts within the framework of the project. An explanation of the impact assessment criteria is defined below in Table 14 to Table 15.

Table 14: Explanation of the EIA criteria

Severity (Magnitude)	
The severity of the impact is considered by examining whether the impact is destructive or benign, whether it destroys the impacted environment, alters its functioning, or slightly alters the environment itself. The intensity is rated as:	
(I)nsignificant	The impact alters the affected environment in such a way that the natural processes or functions are not affected.
(M)oderate	The affected environment is altered, but functions and processes continue, albeit in a modified way.
(V)ery High	Function or process of the affected environment is disturbed to the extent where it temporarily or permanently ceases.
Duration	
The lifetime of the impact that is measured in relation to the lifetime of the proposed development.	
(T)emporary	The impact will either disappear with mitigation or will be mitigated through a natural process in a period shorter than that of the construction phase.
(S)hort term	The impact will be relevant through to the end of a construction phase (1.5 – 2 years)
(M)edium term	The impact will last up to the end of the development phases, where after it will be entirely negated.
(L)ong term	The impact will continue or last for the entire operational lifetime i.e. exceed 30 years of the development, but will be mitigated by direct human action or by natural processes thereafter.
(P)ermanent	This is the only class of impact, which will be non-transitory. Mitigation either by man or natural process will not occur in such a way or in such a time span that the impact is transient.
Spatial scale	
Classification of the physical and spatial scale of the impact	
(F)ootprint	The impacted area extends only as far as the activity, such as footprint occurring

[17] Guideline document EIA regulations (April 1998): Implementation of sections 21, 22 and 26 of the environment conservation act.

	within the total site area.
(S)ite	The impact could affect the whole, or a significant portion of the site.
(R)egional	The impact could affect the area including the neighbouring farms, the transport routes and the adjoining towns.
(N)ational	The impact could have an effect that expands throughout the country (South Africa).
(I)nternational	Where the impact has international ramifications that extend beyond the boundaries of South Africa.
Probability	
This describes the likelihood of the impacts actually occurring. The impact may occur for any length of time during the life cycle of the activity, and not at any given time. The classes are rated as follows:	
Improbable	The possibility of the impact occurring is none, due either to the circumstances, design or experience. The chance of this impact occurring is zero (0 %).
(P)ossible	The possibility of the impact occurring is very low, due either to the circumstances, design or experience. The chances of this impact occurring is defined as 25 %.
(L)ikely	There is a possibility that the impact will occur to the extent that provisions must therefore be made. The chances of this impact occurring is defined as 50 %.
(H)ighly Likely	It is most likely that the impacts will occur at some stage of the development. Plans must be drawn up before carrying out the activity. The chances of this impact occurring is defined as 75 %.
(D)efinite	The impact will take place regardless of any prevention plans, and only mitigation actions or contingency plans to contain the effect can be relied on. The chance of this impact occurring is defined as 100 %.

Table 15: Assessment criteria: Ranking scales

PROBABILITY		MAGNITUDE	
Description / Meaning	Score	Description / Meaning	Score
Definite/don't know	5	Very high/don't know	10
Highly likely	4	High	8
Likely	3	Moderate	6
Possible	2	Low	4
Improbable	1	Insignificant	2
DURATION		**SPATIAL SCALE**	
Description / Meaning	Score	Description / Meaning	Score
Permanent	5	International	5
Long Term	4	National	4
Medium Term	3	Regional	3
Short term	2	Local	2
Temporary	1	Footprint	1/0

11.2 Identifying the Potential Impacts without Mitigation Measures (WOM)

Following the assignment of the necessary weights to the respective aspects, criteria are summed and multiplied by their assigned probabilities, resulting in a value for each impact (prior to the implementation of mitigation measures). Significance without mitigation is rated on the following scale as contemplated in Table 16.

Significance Rating (SR) = (Extent + Intensity + Duration) x Probability

Table 16: Significance Rating without Mitigation

SR < 30	Low (L)	Impacts with little real effect and which should not have an influence on or require modification of the project design or alternative mitigation. No mitigation is required.
30 < SR < 60	Medium (M)	Where it could have an influence on the decision unless it is mitigated. An impact or benefit which is sufficiently important to require management. Of moderate significance - could influence the decisions about the project if left unmanaged.
SR > 60	High (H)	Impact is significant, mitigation is critical to reduce impact or risk. Resulting impact could influence the decision depending on the possible mitigation. An impact which could influence the decision about whether or not to proceed with the project.

11.3 Identifying the Potential Impacts with Mitigation Measures (WM)

In order to gain a comprehensive understanding of the overall significance of the impact, after implementation of the mitigation measures, it will be necessary to re-evaluate the impact. Significance with mitigation is rated on the following scale as contemplated in Table 17 below.

Significance Rating (SR) = (Extent + Intensity + Duration) x Probability

Table 17: Significance Rating Scales with Mitigation

SR < 30	Low (L)	The impact is mitigated to the point where it is of limited importance.
30 < SR < 60	Medium (M)	Notwithstanding the successful implementation of the mitigation measures, to reduce the negative impacts to acceptable levels, the negative impact will remain of significance. However, taken within the overall context of the project, the persistent impact does not constitute a fatal flaw.
SR > 60	High (H)	The impact is of major importance. Mitigation of the impact is not possible on a cost-effective basis. The impact is regarded as high importance and taken within the overall context of the project, is regarded as a fatal flaw. An impact regarded as high significance, after mitigation could render the entire development option or entire project proposal unacceptable.

11.4 Impact Assessment and developed groundwater EMP's

The table summarised all the groundwater related EMP's and should be implemented during the various phases of the opencast's lifetime. The EMP's were developed in accordance with the DWA Best Practice Guideline series.

Table 18: Groundwater Related EMP

Activity/phase	Type of environment	Impacted	Aspect	Impact	Determination of Significance		Actions/Mitigations
					With Mitigation (WM)	Without Mitigation (WOM)	
Construction Phase	Shallow water table	Yes	Deterioration of groundwater quality	Oil, diesel and chemical spills from machinery	14	21	It must be ensured that a credible company removes used oil after vehicle servicing.
	Rapid infiltration and flow	No					A sufficient supply of absorbent fibre should be kept at the site to contain accidental spills
	Groundwater abstraction within 1km of development	Yes					Store all potential sources in secure facilities with appropriate storm water management, ensuring contaminants are not released into the environment.
	Aquifer is particular vulnerable to pollution	No		Contamination potential of mine material exposed during mine construction	22	40	Ensure that the appropriate design facilities (berms, storm water channels etc.) are constructed before constructing the coal handling facilities and boxcuts.
	Abstraction from an aquifer in karstic terrain	No					Implement the EMP's of other environmental related aspects, including pollution prevention and impact minimisation.
	Aquifer occurs in material susceptible to consolidation or subsidence	No					Groundwater monitoring boreholes should be sited with the aid of geophysics at designated positions based on final infrastructure layout, to comply with the design requirements of a groundwater monitoring system, as recommended.
	Aquifer classification requires management to a pristine level	No					Groundwater monitoring boreholes should be installed to comply with the minimum requirements as set by governmental guidelines.
	Groundwater dependant ecosystems occurs within 1km of development	Yes					
	Aquifer has a high exploitation potential	No					
	Development located near coast	No					
	Groundwater is polluted with toxic vapour releasing substances	No					
	Aquifer is the only significant water source	No					

Activity/phase	Type of environment	Impacted	Aspect	Impact	Determination of: With Mitigation (WM)	Determination of: Without Mitigation (WOM)	Actions/Mitigations
Operational Phase	Shallow water table	Yes	Groundwater quantity- lowering of groundwater table	Impact on water supply of groundwater users surrounding mine	22	22	Monitor static groundwater levels on a quarterly basis in all boreholes within a zone of one to two kilometres surrounding the opencast to ensure that any deviation of the groundwater flow from the idealised predictions is detected in time and can be reacted on appropriately.
	Rapi infiltration and flow	No					If it can be proven that the mining operation is indeed affecting the quantity of groundwater available to certain users, the affected parties should be compensated. This may be done through the installation of additional boreholes for water supply purposes, or an alternative water supply.
	Groundwater abstraction within 1km of development	Yes					The numerical model should be updated during mining by using the measured water ingress, water levels, mining and geophysics information to re-calibrate and refine the impact prediction
	Aquifer is particular vulnerable to pollution	No		Potential impact on base flow of streams/wetlands	65	65	If it is proven that the opencast is impacting on baseflow in the tributary and wetland, various options should be investigated such as if clean discharge is available to be pumped back into the surface water bodies.
	Abstraction from an aquifer in karstic terrain	No					Ensure that all fracture or groundwater intersections be thoroughly sealed
	Aquifer occurs in material susceptible to consolidation or subsidence	No					
	Aquifer classification requires management to a pristine level	No					
	Groundwater dependant ecosystems occurs within 1km of development	Yes					
	Aquifer has a high exploitation potential	No					
	Development located near coast	No					
	Groundwater is polluted with toxic vapour releasing substances	No					
	Aquifer is the only significant water source	Yes					

Activity/phase	Type of environment	Impacted	Aspect	Impact	Determination of: With Mitigation (WM)	Determination of: Without Mitigation (WOM)	Actions/Mitigations
Operational Phase	Shallow water table	Yes	Groundwater quality - Contamination of groundwater	Deterioration of groundwater quality down gradient of the mining operations	27	48	Groundwater quality must be monitored on a quarterly basis .
	Rapid infiltration and flow	No					The monitoring results must be interpreted annually by a qualified hydrogeologist and the monitoring network should be audited annually to ensure compliance with regulations.
	Groundwater abstraction within 1km of development	Yes					Numerical groundwater model must be updated by calibrating the model with monitoring data.
	Aquifer is particular vulnerable to pollution	No					Pollution control dams should be lined to prevent ingress of contamination
	Abstraction from an aquifer in karstic terrain	No					Mine sections should be sealed where possible during mining to reduce the contact of water and air with remaining sulphides.
	Aquifer occurs in material susceptible to consolidation or subsidence	No					Install water collection and pumping systems within the mining areas capable of rapidly pumping water out, so minimising contact of water with the geochemically reactive material.
	Aquifer classification requires management to a pristine level	No					Assess the impact of the neighbouring mines on this colliery and vice versa. This is best done by pooling measured groundwater data to update and expand the current numerical model
	Aquifer has a high exploitation potential	No					Kinetic testing of the overburden and discard material should be conducted to aid in the prediction of post mining geochemical conditions.
	Groundwater dependant ecosystems occurs within 1km of development	Yes					Clean and dirty water systems should be separated.
	Groundwater is polluted with toxic vapour releasing substances	No					Construct berms and pollution control dams between the wetland and opencast to ensure that contaminated runoff does not enter the wetland system.
	Aquifer is the only significant water source	No	Groundwater quality - Contamination of groundwater	Oil, diesel and chemical spills/leaks from machinery and storage facilities	14	21	It must be ensured that a credible company removes used oil after vehicle servicing.
							A sufficient supply of absorbent fibre should be kept at the site to contain accidental spills
							Store all potential sources in secure facilities with appropriate storm water management, ensuring contaminants are not released into the environment.
				Sewage related groundwater contamination			Sewage effluent emanating from latrines or ablution blocks should be treated to acceptable levels before discharge into the environment

Activity/phase	Type of environment	Impacted	Aspect	Impact	Determination of With Mitigation (WM)	Determination of Without Mitigation (WOM)	Actions/Mitigations
Decommissioning Phase	Shallow water table	Yes	Groundwater quantity - change in groundwater level	Decant volume	3	3	All sulphate containing waste material should be stored at the base of the pit and flooded as soon as possible to exclude oxygen.
	Rapid infiltration and flow	No					Major underground fractures encountered while mining must be sealed by grouting, both on inflow and outflow areas
	Groundwater abstraction within 1km of development	Yes					
	Aquifer is particular vulnerable to pollution	No	Groundwater quality - Contamination of groundwater	Deterioration of groundwater quality down gradient of the mining operations due to plume movement	26	52	Pollution control dams should be maintained to intercept polluted seepage water. This is necessary even after mine closure to ensure the wetland is not negatively affected by pollution. Regular sampling of the streams and wetland is essential to determine the efficiency of this action.
	Abstraction from an aquifer in karstic terrain	No					Implement as many closure measures during the operational phase, while conducting appropriate monitoring programmes to demonstrate actual performance of the various management actions during the life of mine.
	Aquifer occurs in material susceptible to consolidation or subsidence	No					All mined areas should be flooded as soon as possible to minimise oxygen from reacting with the remaining pyrite.
	Aquifer classification requires management to a pristine level	No					Mining should remove all coal from the opencast and separate acid forming and non-acid forming material. Deposit acid forming material at the base of the pit.
	Groundwater dependant ecosystems occurs within 1km of development	Yes					The final backfilled opencast topography should be engineered such that runoff is directed away from the opencast areas.
	Aquifer has a high exploitation potential	No					The final layer (just below the topsoil cover) should be as clayey as possible and compacted if feasible, to reduce recharge to the opencast.
	Development located near coast	No					Quarterly groundwater sampling must be conducted to establish a database of groundwater quality to assess plume movement trends.
	Groundwater is polluted with toxic vapour releasing substances	No					Audit the monitoring network annually.
	Aquifer is the only significant water source	No	Groundwater quality - Contamination of groundwater	Contaminants emanating from historic Oil, diesel and chemical spills and facilities	24	24	Remove or remediate areas of hydrocarbon contaminated soils by following a risk based approach, take action if a negative risk is found. A risk assessment should be conducted by a qualified hydrogeologist.

Activity/phase	Aspect	Determination of Significance		Actions/Mitigations
		With Mitigation (WM)	Without Mitigation (WOM)	
All phases	Groundwater management	26	52	All the monitoring data needs to be collated and analysed on at least a bi-annual basis and included in management reports. This information will also be required by government departments (Department of Water Affairs, Department of Environmental Affairs) for compliance monitoring.
				After 2 years from start of mining, the monitoring information collated should be used to update the groundwater flow and geochemical models. These models should thereafter be updated so that sufficient mitigation measures can be implemented. Management and mitigation plans should be continuously adapted using the monitoring data.
Closure Phase	Groundwater management	26	52	A detailed mine closure plan should be prepared during the operational phase, including a risk assessment, water resource impact prediction etc. as stipulated in the DWA Best Practice Guidelines.
				The implementation of the mine closure plan, and the application for the closure certificate can be conducted during the decommissioned phase.

12 CONCLUSIONS AND RECOMMENDATIONS

This section will briefly summarise the current groundwater conditions in the area of the proposed opencast, the expected impacts of the mine on the groundwater and the recommendations to minimise these effects.

This report was not intended to be an exhaustive description of the proposed project, but rather as a specialist interim geohydrological study to evaluate the geohydrological impact the proposed project might have on the receiving groundwater environment.

12.1 Current Groundwater Conditions

The area is characterised by a gentle undulating topography and in the area of the proposed opencast coal mine the slope is more or less in the order of 1:40 (0.025).The direction of the slope on site is towards the east.

There are a few surface water points around the proposed opencast mine, with a stream down gradient to the east of the site. On a larger scale, drainage occurs towards the generalised flow of the Woes-Alleen spruit which confluences with the Klein Olifants River approximately 12 km from the site.

Groundwater levels were measured in six boreholes during a hydrocensus conducted in September 2013 for the proposed opencast coal mine. The depth of the groundwater was found to vary between 2.3m and 8.6m below ground level.

The fractured aquifer was classified as a minor aquifer as it is not a highly productive aquifer. Using the Groundwater Decision Tool it was found that the aquifer has a medium to high vulnerability and as a result it also has a medium level groundwater quality management index. This indicates that a medium level of aquifer protection is required in the area of the proposed opencast.

Based on the data collected in terms of hydrogeology, the following can be concluded.

- Three aquifers are inferred to be present across the site at varying depths.
- The extent and depth of the aquifers is controlled by the sub-surface Karoo formation layering, weathering, geometry and post-Karoo intrusions.
- Flow within the weathered aquifer is thought to be multi-porous and is controlled by weathering, flow within the fractured aquifer is controlled by the fracturing network while the competent host rocks serve as storage.
- Recharge into the weathered aquifer is thought to be directly linked to rainfall while recharge into the fractured aquifer is linked to shallower aquifers.

If the groundwater samples collected, are compared to the DWA guidelines for domestic use, only pH is elevated above the tolerable water quality (ROD1). The concentration of Mn in ROD4 and ROD6 is also elevated above the target water quality range but still falls within the tolerable water quality range. This constituent can be sourced directly from the underlying geology. Mn is a common component in sandstones of the Ecca. Additionally, Na falls within the tolerable water quality range for ROD6.

12.2 Predicted Impacts of the Proposed Opencast

The impacts on the groundwater regime normally associated with mining is dewatering of the aquifer during mining and pollution of the groundwater following mine closure. The dewatering is essential to allow access to the mining areas, while the pollution is due to chemical weathering by oxidation of the sulphide containing minerals (mostly pyrite).

During mining, groundwater seeping into the opencast mining areas will have to be pumped out to facilitate access. This will inevitably lead to a lowering of the groundwater table and the development of a local cone of depression. This cone of depression will also contain pollution resulting from mining. Polluted groundwater pumped from the mine should be used for mining purposes.

Post mining, following the closure of the pit and discontinuing of dewatering, the groundwater levels will return to equilibrium. The cone of depression that contained polluted groundwater will cease to exist and movement of a groundwater pollution plume will commence.

Numerical groundwater modelling is considered to be the best method of anticipating and quantifying these likely impacts on the groundwater regime. For this purpose, a numerical model was created using the Department of Defence Groundwater Modelling System (GMS) software as Graphical User Interface (GUI) for the well-established Modflow and MT3DMS numerical codes

Based on the results of the modelling, the following conclusions are made:

12.2.1 Construction Phase:

The construction phase will consist of preparations for the opencast, which is assumed to consist mainly of establishment of infrastructure on site and the mobilisation of earth moving equipment.
This phase is not expected to influence the groundwater levels. With the exception of lesser oil and diesel spills, there are also no activities expected that could impact on regional groundwater quality.

12.2.2 Operational Phase

The operational phase is interpreted as the active mining of the proposed opencast mining areas. It is inevitable that these effects will impact on the groundwater regime. The potential impacts that will be considered are the groundwater quantity and quality.

12.2.2.1 Seepage from waste residue and water storage facilities

Transport modelling indicates that pollution from surface sources such as the ROM stockpiles and Discard dumps are likely. However no receptor is deemed to be influenced via the groundwater pathway as pollution from these sources will be contained within the opencast as a result of dewatering.

However, surface seepage may impact on the wetland and the tributary to the Woes-Alleenspruit. Assuming removal of these structures post-mining, no post-mining impacts are expected from these areas. Therefore, it is recommended that surface runoff from these facilities should be contained using berms and pollution control dams constructed between the opencast and these surface water bodies, at an early stage of mining, with non-acid forming overburden, during the operational phase.

12.2.2.2 Dewatering

During the operational phase, it is expected that the main impact on the groundwater environment will be de-watering of the surrounding aquifer. Water entering the mining areas will have to be pumped out to enable mining activities. This will cause a lowering in the groundwater table, in and adjacent to the mines. The dewatering of the aquifer has been calculated for the opencast area using the calibrated numerical model as described above.
A worst-case scenario has been modelled, assuming that the entire opencast will be dewatered at once. This will obviously not be the case, and the actual drawdown could thus be less. However, as the recovery of groundwater is expected to be very slow, it could well be that the first boxcut in the opencast will still be in an early stage of recovery. Thus, the worst case scenario could also be close to the actual scenario.

- Base flow of the tributary to the Woes-Alleenspruit situated to the east of the proposed opencast, could be affected due to the cumulative effect of drawdown resulting from the dewatering of the opencast.

- The surrounding wetlands may experience a decrease in water supply due to dewatering of the opencast. However, a qualified hydrologist specialising in wetland delineation should be consulted to determine the connectivity between the wetland and groundwater as well as to identify the sources feeding the wetland, before final comments can be made about the effect of the dewatering of the opencast, on the wetland.

12.2.3 Post Mining Phase:

Post mining, after closure, the water table will rise to reinstate equilibrium with the groundwater systems. The mined areas will have a large hydraulic conductivity compared to the pre-mining situation. This will result in a relative flattening of the groundwater table over the extent of mining, in contrast to the gradient that existed previously.

12.2.3.1 Seepage from waste residue and water storage facilities

During the post-mining phase it is expected that waste residue and water storage facilities will be removed or rehabilitated and that their impact have limited affect.

12.2.3.2 Sulphate Pollution & Decant Potential from Mining Areas

Following closure of the colliery, the groundwater level will rise to an equilibrium that will differ from the pre-mining level due to the disturbance of the bedrock and increase in recharge from rainfall. Intuitively, it would be expected that this raise in groundwater could result in decanting. However, decanting of the opencast was not predicted by the groundwater model.

- The sulphate pollution plume emanating from the mining area, after mining has ceased and rebound of groundwater levels, is predicted to reach a tributary of the Woes-Alleenspruit in the east in about 10 years.

- Following this eventual period, seepage of AMD will increase in concentration and could reach high levels in the tributary to the Woes-Alleenspruit, due to evapotranspiration.

It must be kept in mind that the modelling was done within the limitations of the scope of work of this study and the limited amount of monitoring data available. Although all efforts have been made to base the model on sound assumptions and has been calibrated to observed data, the results obtained from this exercise should be considered in accordance with the assumptions made.

12.3 Groundwater Management and Mitigation Measures

Since it is inevitable that a mining operation of this scale will impact on the groundwater regime, measures to manage and reduce these impacts to the absolute minimum must be considered. The identified negative impacts of reduction of the groundwater levels during mining and the spread of groundwater pollution after closure of the opencast will be addressed in the following paragraphs.

12.3.1 Lowering of Groundwater Levels during Mining

Since the drawdown or the groundwater levels during mining could influence the wetland and tributary to the Woes-Alleenspruit, the following measures are recommended:

- The static level of groundwater in all boreholes within a distance of less than one kilometre must be measured regularly to establish a database against which future groundwater levels can be compared.

- Such measurements must be made preferably quarterly, but at least twice annually, following the dry and rainy seasons.

- In the event of unacceptable decrease of the yield of any affected boreholes, alternative water supply should be supplied to the affected parties until such time that the groundwater recovers following closure of the pit.

- As the tributary of the Woes-Alleenspruit and the adjacent wetland could be affected, monitoring of these surface water bodies is essential. Should clean mine water be available, it is suggested that it be released into the tributary of the Woes-Alleenspruit. A surface water specialist should be consulted to ensure correct volumes and timing of the added water.

- Another very important aspect to consider is the layout and order of the opencast cuts. The best possible scenario for minimising impacting is to start the boxcut parallel to the wetland/tributary and at the farthest point from the wetland. In such a mining scenario the impact on the wetland and tributary will be delayed to the latest possible time before closure of the opencast.

- If it is proven that the opencast is impacting on baseflow, various options should be investigated such as if clean discharge is available to be pumped back into the streams.

- As far possible separate water of differing qualities. The runoff from the dirty water areas must be captured, retained and managed within the mine water system.

- Manage effective water collection infrastructure for the various water sources of the mine. Water stored in the pit form seepage or rainfall should be utilised for dust suppression. Excess water could also be pumped to surface to be incorporated into the mine water balance.

- If at all feasible, water effluent facilities such as pollution control dams should be lined.

12.3.2 Spread of Groundwater Pollution Post-mining

Predictions in the previous sections regarding groundwater pollution have been based on the assumption that the rehabilitated mining areas will be a constant source of sulphate pollution of

2000 mg/l, representing a worst-case scenario. With appropriate measures, the oxidation rate of pyrite can be limited, resulting in lower starting concentrations. Furthermore, the migration of the pollution plume from the void can also be limited by surface rehabilitation measures preventing excessive infiltration of groundwater to the mined area. Thus, although it has been predicted that only a limited area of the aquifer might be polluted to such an extent that acceptable standards for domestic water is exceeded, further reduction is achievable.

To minimise the effect of groundwater pollution on the receiving environment, the following measures are suggested:

- All mined areas should be flooded as soon as possible to bar oxygen from reacting with remaining pyrite.
- Mining should remove all coal from the opencast and as little as possible should be left.
- Acid generating material should be disposed of at the base of the pit.
- The final backfilled opencast topography should be engineered such that runoff is directed away from the opencast areas.
- The final layer (just below the topsoil cover) should be as compacted if feasibly possible, to reduce recharge to the opencasts.
- Quarterly groundwater sampling must be done to establish a database of plume movement trends, to aid eventual mine closure.
- Regular sampling and chemical analyses of the groundwater is imperative to establish a sound database:
    - Groundwater in all boreholes within a distance of less than two kilometres must be sampled regularly to establish a database against which future groundwater levels can be compared.
    - Sampling must be preferably quarterly, but at least twice annually, following the dry – and rainy seasons.
- If it is found during such a sampling event that groundwater from any extraction borehole is polluted beyond acceptable standards, alternative water will have to be supplied to the affected party.

12.3.3 Impacts Indirectly Related to Mining

During all phases of mining, vehicles and personnel will be operative in the opencast. Minor spills such as diesel, petrol and oil could results from machinery operations. Also, domestic water and waste disposal could also affect the groundwater quality. The following is thus recommended:

- It must be ensured that a credible company removes used oil after vehicle servicing.
- A sufficient supply of absorbent fibre should be kept at the site to contain accidental spills.
- Used absorbent fibre must be land-farmed, using approved methodologies.
- Domestic waste water, especially sewage, must either be treated at site according to accepted principles, or removed by credible contractors.

- Solid waste must similarly either be stored at site on an approved waste dump, or removed by credible contractors.

12.3.4 Further work

The following further work is recommended

- Monitoring boreholes should be constructed around the opencast as mentioned in the report.
- A monitoring network should be dynamic. This means that the network should be extended over time to accommodate the migration of contaminants through the aquifer as well as the expansion of infrastructure and/or addition of possible pollution sources.
- An audit on the monitoring network should be conducted annually.
- The numerical model should be recalibrated during the mining of the proposed opencast. The numerical model should also be recalibrated during the post-mining phase.