RESTIGEN PTY LTD

Geohydrological investigation on the farm Droogefontein portions 26, 46, 47

November 2013

SHANGONI AquiScience

A division of Shangoni Management Services Pty Ltd

www.shangoni.co.za

GEOHYDROLOGICAL INVESTIGATION ON THE FARM DROOGEFONTEIN PORTIONS 26, 46, 47

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ON THE FARM DROOGEFONTEIN
PORTIONS 26, 46, 47
November 2013

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PROJECT DETAILS

Project Title:	**Geohydrological Investigation of the farm Droogefontein Portions 26, 46, 47**
Project Number:	**RES-NGU-13-07-24**
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REFERENCES

Aller, L., Bennet, T., Lehr, J.H., Petty, R.J. and Hacket, G. 1987. DRASTIC: A standardized system for evaluating groundwater pollution using hydrological settings. Prepared by the National Water Well Association for the US EPA Office of Research and Development, Ada, USA.

Appelo, C.A.J., and Postma, D., 1999, Geochemistry, groundwater and pollution: A.A. Balkema, Rotterdam, Netherlands, pp. 536.

Barnard, H.C. 2000. An explanation of the 1: 500 000 General hydrogeological map, Johannesburg 2526. Department of Water Affairs and Forestry.

Bean, J.A. 2003. A critical review of recharge estimation methods used in South Africa. PhD dissertation. Bloemfontein: University of the Free State, Department of Geohydrology.

Bouwer, H, and Rice, H.C. 1976. A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells.

Cairncross, B. 2001. An overview of the Permian (Karoo) coal deposits of southern Africa. *Journal of African Earth Sciences*, 33: 529562.

Caruccio, F. T., G. Geidel and M. Pelletier. 1981. Occurrence and Prediction of Acid Drainages. *Journal of the Energy Division*, ASCE 107: 167-178.

Cooper, H.H. and C.E. Jacob 1946. A generalized graphical method for evaluating formation constants and summarizing well field history. Am. Geophys. Union Trans. Vol. 27, pp. 526-534.

Department of Water Affairs and Forestry, 2006. Best Practice Guideline G3. Water Monitoring Systems.

Department of Water Affairs and Forestry, 2008. Best Practice Guideline G4: Impact Prediction.

Hodgson, F.D.I. and Krantz, R.M. 1998. Investigations into Groundwater Quality Deterioration In The Olifants River Catchment Above The Loskop Dam With Specialised Investigation In The Witbank Dam Sub-Catchment. WRC Report No. 291/1/98. Water Research Commission, Pretoria.

Limosella Consulting, 2013. Proposed Coal Mine on the Farm Droogenfontein 241 IR Portions 26, 46 and 47, Delmas, Mpumalanga. Wetland and Riparian Functional Assessment (DRAF report, September 2013).

Lottermoser, B. 2003. Mine wastes: characterisation, treatment and environmental impacts. Springer-verlag Berlin Heidelberg.

Lynch, S.D., Reynders, A.G. and Schulze, R.E., 1997: A DRASTIC approach to groundwater vulnerability mapping in South Africa. SA Jour. Sci., Vol. 93, pp 56 - 60.

Nordstrom, D.K., and Alpers, C.N. 1999. Geochemistry of acid mine waters. IN: Christensen, E.D. 2005. Assessment, water-quality trends, and options for remediation of acidic drainage from abandoned coal mines near Huntsville, Missouri, 2003–2004: U.S. Geological Survey Scientific Investigations Report 2005– 5202, pp. 84.

Parsons, R.P., 1995: A South African aquifer system management classification; WRC Report No. 77/95, Water Research Commission, Pretoria.

Perkins, E.H., Gunter, W.D., Nesbitt, H.W. and St-Arnaud, L.C. 1997. Critical review of classes of geochemical computer models adaptable for prediction of acidic drainage from mine waste rock. Proceedings of the 4th International Conference on Acid Rock Drainage. Vancouver 2: 587-601.

South African Rain Atlas, Index No. 172/170303. http://134.76.173.220/rainfall/index.html

Snyman, C.P. 1998. Coal. *In: Mineral Resources of South Africa* (M.G.C. Wilson and C.R. Anhaeusser, editors). Handbook, Council for Geoscience, 16: 136-205.

South African National Standards, SANS 241: 2011. Physical, aesthetic, operational and chemical determinands for drinking water.

Stumm, W., and Morgan, J.J., 1996. Aquatic chemistry (3d ed.): New York, John Wiley & Sons, pp. 1 022.

Tankard, A.J., Jackson, M.P.A., Eriksson, K.A., Hobday, D.K., Hunter, D.R. and Minter, W.E.L. 1982. Crustal evolution of Southern Africa. 3.8 Billion years of Earth History, Springer-Verlag, New York, 523 pp.

WRC, 1998. Quality of domestic water supplies. Vol. 1: Assessment guide. TT 101/98.

Younger, P.L., Banwart, S.A., Hedin, R.S., 2002. Mine Water – Hydrology, Pollution, Remediation. Kluwer, Dordrecht.

DEFINITIONS

Acid base accounting

Acid-base accounting (ABA) is an analytical procedure that provides values to help assess the acid-producing and acid-neutralizing potential of overburden, waste rock and / or ore stockpiles.

Acid rock drainage

Acid rock drainage (ARD), also known as acid mine drainage (AMD), is the generation of sulphate and acidity as a result of the oxidation of pyrite when exposed to water and oxygen, producing sulphuric acid (H_2SO_4). AMD is a major cause of the contamination of groundwater in areas where coal and gold mining takes place.

Acid Rain leach

This procedure indicates which chemical constituents may be solubilised by an inorganic acid (dilute carbonic acid). This also simulates a “worst case” scenario. This test is a modification of the TCLP procedure, as recommended by the Department of Water Affairs (DWA). The Acid Rain procedure is based on the fact that carbon dioxide dissolves in rain water, to form carbonic acid. The carbonic acid could mobilise organics and/or inorganics in the waste.

Aquifer vulnerability

The tendency or likelihood for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer. Sedimentary rocks composed of or derived from sand or sand-like particles.

Baseflow

Stormflow and baseflow are non-process related terms to signify high amplitude low frequency flow in a river during and immediately after a precipitation event and low amplitude high frequency flow in a river during dry or fair weather periods. Baseflow is not a measure of the volume of groundwater discharged into a river or wetland, but it is recognised that groundwater makes a contribution to the baseflow component of river flow. The term groundwater contribution to baseflow should be used.

Darcy Flux

The Darcy flux (or velocity) is the hydraulic conductivity (K) times the gradient of the water/piezometric level (i.e. q=Ki). Velocity an indication of the rate at which groundwater and groundwater contamination are moving.

Expanded Durov diagram

The Durov diagram defines water in terms of the hydrochemical processes occurring within different hydrogeological systems. The Durov diagram was designed by Durov (1948) and expanded by Lloyd (1965). The Expanded diagram allows for hydrochemical data representation including plausible hydrochemical processes dominating the groundwater chemistry.

Hydraulic conductivity

Measure of the ease with which water will pass through the earth's material; defined as the rate of flow through a cross-section of one square metre under a unit hydraulic gradient at right angles to the direction of flow (m/d).

Hydraulic head

Hydraulic head is the height above a datum plane such as sea level of the column of water that can be supported by the hydraulic pressure at a given point in a groundwater system. Hydraulic heads provide an indication of the direction of groundwater flow and are used to determine hydraulic gradients.

Kriging interpolation

Kriging is a method of interpolation named after a South African mining engineer named D. G. Krige who developed the technique in an attempt to more accurately predict ore reserves. Over the past several decades kriging has become a fundamental tool in the field of geostatistics.

Shale

Shale is a fine-grained sedimentary rock whose original constituents were clay minerals or muds. It is characterized by thin laminae breaking with an irregular curving fracture, often splintery and usually parallel to the often-indistinguishable bedding plane.

Static geochemical testing

Static geochemical tests provide information on bulk geochemical characteristics of materials, for example, the total concentration of carbonate species in a tailings sample. They do not provide information on rates of processes or rates of release of weathering products.

Stiff diagram

A Stiff diagram is an elongate polygon, the precise shape of which is determined by "joining the dots" corresponding to the milli-equivalents per litre (meq/l) concentrations of each major ion on a template.

Storativity

It is a volume of water per volume of aquifer released as a result of a change in head. For a confined aquifer, the storage coefficient is equal to the product of the specific storage and aquifer thickness. It measures the volume of water stored and released in an aquifer and is used to quantify the safe yield of an aquifer system.

Transmissivity

Transmissivity is the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It is expressed as the product of the average hydraulic conductivity (K) and thickness (b) of the saturated portion of an aquifer ($T = Kb$).

Seepage velocity

The seepage velocity is defined as the Darcy flux divided by the effective porosity. This is also referred to as the average linear velocity.

Waste rock characterisation

Characterization of mine waste-rock piles, tailings dams, and naturally exposed alteration areas is important 1) to establish pre-mining background conditions, 2) to characterize and predict stability, weathering, and erosion, 3) to predict acid-rock drainage and other chemical releases, 4) to properly dispose of and manage mine wastes, and 5) to develop mine closure plans.

Zone of influence / cone of depression

The cone-shaped area around a borehole that results from the lowering of the water table or piezometric surface by abstraction.

ABBREVIATIONS

ABA – Acid-base-accounting
AP – Acid potential
A_r – Aquifer media rating
ARD Acid rock drainage
A_w – Aquifer media weight
C_r – Hydraulic conductivity rating
C_w – Hydraulic conductivity weight
Cl_P – Chloride concentration in precipitation
Cl_{GW} – Chloride concentration in groundwater
CMB – Chloride mass balance method
D_r – Depth to water table rating
D_w – Depth to water table weight
D_oH – Department of Health
DWA – Department of Water Affairs
DWAF – Department of Water Affairs and Forestry
EC – Electrical conductivity
EMP – Environmental Management Programme
GRDM – Groundwater Resource Directed Measures
HH – Hydraulic head
ICP-OES – Inductively coupled plasma optical emission spectrometer
Kg/t – Kilograms per ton
I_r – Impact of vadose zone rating
I_w – Impact of vadose zone weight
l/s – Litres per second
mamsl – Meters above mean sea level
mbgl – Meters below ground level
meq/l – Milli-equivalent per litre
mg/l – Milligrams per litre
mm/a – Milli-litres per annum
mmol/l –milli-molar per litre
NGA – National Groundwater Archive
NNP – Net neutralisation potential
NP – Neutralisation potential
NPR – Neutralising Potential Ratio
NWA – National Water Act
R_r – Recharge rating

R_w	– Recharge weight
S_r	– Soil type rating
S_w	– Soil type weight
SaClLm	–Sandy-clay-loam
T_r	– Topography aspect rating
T_w	– Topography aspect weight
T-Alk	–Total alkalinity
TDS	– Total dissolved solids
WISH	– Windows Interpretation System for the Hydrogeologist
WL_m	–Borehole water level in meters
Z_m	– Topography in meters

EXECUTIVE SUMMARY

Shangoni Aquiscience, a division of Shangoni Management Services (Pty) Ltd., was appointed by Restigen (Pty) Ltd. to conduct a geohydrological impact assessment for the proposed open cast coal mining project envisaged on and surrounding the farm Droogefontein portion 26. The aim of the investigation was to define the groundwater regime by means of a desktop study, geo- and hydrochemical investigations and conceptual and numerical models to highlight foreseeable risks towards the receiving surface and groundwater environment. This hydrogeological study was undertaken to fulfil in the requirements of the Environmental Impact Assessment (EIA) which forms part of the mining right application for portions 26, 46 and 47 on the farm Droogefontein, Delmas.

The proposed mining area is situated in a sensitive environmental area from a water drainage perspective. A natural drainage line and C-class seasonal wetland '*Dwars-in-die-wegvlei*'runs through portion 26. This area is underlain by alluvial material followed by a clay layer. The alluvial material may act as sponge which absorbs water rapidly until it reaches the clay layer below it. Such physical attributes are optimal for the establishment of wetlands. Seasonal surface flow occurs in this proposed wetland which drains towards the Aston Lake that in turn feeds the Blesbokspruit. The whole of portion 26 will be exploited through an opencast boxcut to gain access to the seams using a standard truck and shovel configuration. One opencast section is planned for Droogefontein with an estimated life-of-mine (LoM) of 20 years.

All the main aspects required to assess the geohydrological regime in and around the mine lease were investigated as part of the study. The data were combined to construct conceptual and numerical models for the mining area as well as formulating a risk assessment based upon probable risks the mining activities may pose towards the surface and groundwater regime. The main aspects investigated as part of this study included:

- physical properties of the groundwater domain;
- geohydrological features;
- groundwater users and uses around the mining area;
- geology and geochemistry;
- hydrochemical characteristics;
- hydraulic properties of the saturated zones;
- aquifer vulnerability and recharge; and
- groundwater flow velocities.

Portion 26 is located on a gentle eastern facing slope ranging between 1580 mamsl and 1600 mamsl. Drainage will collect in the natural drainage line to the east where it will flow southwest towards the Aston Dam. During the summer and higher rainfall periods when the already shallow groundwater rest levels will be at higher hydraulic head levels, daylighting of groundwater will occur as baseflow. During the winter when groundwater levels are lower, groundwater will still flow towards the stream / wetland and will also follow the stream channel, albeit subsurface.

Droogefontein is directly underlain by rocks of the Vryheid Formation Member belonging to the Ecca Group of the Karoo sequence of rocks. The Vryheid Formation comprises of predominantly sandstone and grit with alternating beds of soft sandy shale and coal which is widely and extensively intruded by dolerite sills and dykes. The stratigraphy throughout the Droogefontein area is typical of the Vischkuil sub-basin. Three seams, namely a top, middle and bottom seam are recognized. The top and middle seams can possibly be correlated with the No. 5 and No. 4 seams and the thicker Bottom seam appears to represent a combination of the No. 1, 2 and 3 seams.

A total of 13 boreholes were surveyed in a 2 km radius around portion 26 where the open pit coal mine is proposed. The survey revealed that groundwater in the immediate vicinity is mainly used for domestic supply, livestock watering and small scale irrigation. The Karoo aquifers do not present major aquifers and typically yield less than 2 l/s. Static water levels ranged between 3.5 m and 18 mbgl. A good Bayesian correlation of 92% exists between the surface topography and groundwater level elevations indicating that groundwater flow paths mimic surface topography.

The geohydrological regime in the study area is made up of three aquifer systems, namely:

I. A shallow unconfined or semi-confined perched aquifer.
   a. This layer is poorly developed and is generally not considered as an aquifer given its inability to sustain reasonable or useful quantities of groundwater.
   b. Yields are less than 0.1 l/s.
   c. The perched unconfined aquifer can be regarded as a **non-aquifer**.

II. A top weathered and deeper intergranulated and fractured semi-confined sandstone aquifer.
   a. The aquifer can be regarded as heterogeneous having a good fracture network formed in the consolidated and mostly impervious matrix as a result of tectonic and depositional stresses.
   b. Movement of groundwater is mostly restricted to fracture and aperture flow although the sandstone/shale matrix may also contribute to the aquifer albeit very little.
   c. The fractured rock aquifer is considered to be a more reliable source of groundwater compared to the perched aquifer with yields ranging between 0.5 l/s and 2 l/s.
   d. ***Due to the fact that the fractured Karoo aquifer is the only source of water for the Droogefontein and Prosperity small holdings landowners, and that no other realistic source are obtainable, this aquifer is regarded as a sole source aquifer.***

III. A confined dolomitic aquifer.

a. Dolomitic groundwater storage mostly occurs in dolomitic compartments and fractures derived from dolomitic dissolution/chemical weathering, which in extreme cases, result in the development of open cavities and caves.
b. Yields are very good and in most cases far in excess of 5 l/s.
c. The dolomitic aquifer can be regarded as a **major aquifer**.

The ABA analyses indicate that the over and underburden consisting of Ecca sandstone and Dwyka tillite is non-acid forming. They contain little or are totally devoid of sulphide minerals with Neutralising Potential Ratios (NPR) ranging between 1.3 and 26.93. The possibility of ARD formation from the sandstone and tillite facies is therefore unlikely. The carbonaceous mudstones did however record relative abundance of sulphur and is classified as being possibly acid forming. The top and bottom seams also recorded high sulphur content and is classified as likely acid-forming while the middle seam is classified as possibly acid-forming. The ICP-OES scan on the leachate of the acid rain leach on the over and underburden revealed the following metals to be present in significant quantities:

- aluminium (Al), boron (B), barium (Ba), calcium (Ca), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), nickel (Ni), lead (Pb), silica (Si), strontium (Sr) and zinc (Zn)

The scan on the coal samples revealed the following metals to be present in significant quantities:

- Al, B, Ba, Ca, Mg, Mn, Ni and Sr

The extent of the dewatering cone was modelled for the period of life of mine and after 50 years post closure. During the operational phase the cone of depression extends approximately 600 m in all directions from the pit perimeter. At mine closure water levels to the south and east of the mine lease will recover sooner and is the direct result of increased recharge to the backfilled opencast pits. Upon mine closure, pumping of water from the mining pit will cease and water levels will recover to pre mining levels over time

The primary receptors of groundwater in this area are irrigation and domestic users. The main risk posed by the mine on the groundwater receptors is the dewatering activities during the operational phase of mining and the cone may extend to include DN21 and DN25 during the operational phase. The model also show that the groundwater levels at the *Dwars-in-die Wegvlei* wetland and drainage region will reach a drawdown of approximately 40 m during mine dewatering. This will definitely impact on the functionality of the wetland as groundwater will not contribute to the baseflow thereof.

During the operational phase, the mine will act as a groundwater sink area and groundwater and associated mass transport will flow radially inwards towards the mined area. Therefore, no pollution movement is possible away from the active mining until the water level has recovered to near pre-mining levels. The time taken to fill the pit post closure to pre-mining levels is difficult to estimate as this is dependable on the effective porosity of the backfilled material and rainfall recharge. A range of between 70y and 100y were calculated which was based upon typically encountered porosity values of between 20% and 30%. Only after recovery to decant level post closure will a pollution plume start to move downstream away from the pits. Water quality which has accumulated in the backfilled voids will be at high risk of acid rock drainage resulting from oxidation and horizontal groundwater seepage. Water quality deterioration in the rehabilitated pits as a result of acid rock drainage will be significant and decant qualities is expected to be poor with TDS in the range of 2500 to 3 000 mg/l and pH from 2.5 to 4.

The source concentrations 50 years after mine closure indicate the movement of a pollution plume in the downstream direction. Pollution plume movement is however slow and restricted due to low transmissivities and gentle gradients. An overall decrease in concentrations was simulated, which is the result of contaminant diffusion and dilution with fresh recharge.

The most significant aspects associated with the mining activities, as discussed and rated according to the risk assessment in Section 9, include:

I. Utilisation of infrastructure
    a. High / moderate impact during construction phase
II. Blasting and development of box cut/ pit (incl. dewatering)
    a. Very high / major during operational phase
III. Concurrent backfilling with overburden
    a. Very high / major after closure

1. INTRODUCTION

Shangoni Aquiscience, a division of Shangoni Management Services, was appointed by Restigen (Pty) Ltd. to conduct a geohydrological impact assessment for the proposed open cast coal mining project envisaged on and surrounding the farm Droogefontein portion 26. Although portions 46 and 47 of Droogefontein are not envisaged to be utilised during the mining project, these portions were also included in the investigation since it forms part of the mining right application. The aim of the investigation was to define the groundwater regime by means of a desktop study, geo- and hydrochemical investigations and conceptual and numerical models to highlight current and foreseeable risks towards the receiving surface and groundwater environments. This hydrogeological study was undertaken to fulfil in the requirements of the Environmental Impact Assessment (EIA) which forms part of the mining right application on portions 26, 46 and 47 of the farm Droogefontein, Delmas.

2. BACKGROUND INFORMATION

The proposed areas for the mining right application are situated on portions 26, 46 and 47 of the farm Droogefontein 242 IR, Delmas. These portions are at present utilised for arable agriculture and chicken rearing practices and/ or residential use. Portions 46 and 47 of the farm Droogefontein 242 IR are situated adjacent to the R555, south of the Sundale agricultural holdings. Portion 26 of the farm Droogefontein 242 IR is situated approximately 2 km to the south of the R555 towards Aston Lake. The proposed mining area is situated in a sensitive environmental area both from a population and water drainage perspective. A drainage line *'Dwars-in-die-wegvlei'*runs through portion 26. A seasonal wetland is also associated within this drainage line. Seasonal surface flow occurs in this wetland which drains towards the Aston Lake which in turn feeds the Blesbokspruit.

The proposed mining operation is planned on portion 26 of the farm Droogefontein, located in the Witbank Coalfield in the Magisterial District of Delmas, Mpumalanga, South Africa. Mining will be conducted by making use of opencast mining techniques. Three minable seams, a top, middle and bottom seam have been identified during exploration and will be exploited. The whole of portion 26 will be exploited through an opencast boxcut to gain access to the seams using a standard truck and shovel configuration. The final void will be backfilled with overburden from the initial boxcut. One opencast section is planned for Droogefontein with an estimated life-of-mine (LoM) of 20 years. The coal is suitable as a feed stock for domestic power generation as well as low volatile pseudo anthracite.

Ngululu Resources submitted a mining right application to the Department of Mineral Resources (DMR) for the mining of coal, and received the acceptance letter from DMR on 17 July 2013.

According to this letter, an environmental scoping report (ESR) in terms of the Minerals and Petroleum Resources Development Act no 28 of 2002 (MPRDA) must be submitted to the department.

Historic mines in the area exploited coal reserves in the late 1800’s and supplied coal to the steam driven hoists on the gold mines. Coal quality was lower than the newly discovered Witbank Coalfield and with the completion of the railway line from Witbank most of these mines closed down. Mining in the Witbank Coalfield started in 1889. The coal seams in the Delmas area were historically exploited at the now defunct Largo Colliery, Vischkuil Colliery and the Welgedacht collieries approximately 25 km southwest of Delmas. Currently a number of Collieries are present in the Delmas area, including Exxaro’s Leeuwpan Mine and Stuart Colliery.

The stratigraphy throughout the area is typical of the Vischkuil sub-basin. In the Springs-Vischkuil block the coal seams are very inconsistently developed, and where present, more closely resemble those of the South Rand Coalfield. The top and middle seams can possibly be correlated with the No. 5 and No. 4 seams and the thicker bottom seam appears to represent a combination of the No. 1, 2 and 3 seams of the main Witbank Coalfield.

The first 3 (three) months will be dedicated to stripping and storing of topsoil and the establishment of stormwater diversion channels to protect topsoil from erosion. Subsoil will be drilled and blasted and stored for later use.

3. SCOPE OF WORK

This report provides methodology and findings of the geohydrological baseline study that will be used as reference for the groundwater impact assessment and management plan.

The full scope of work included the following:

Phase 1 - Fieldwork

- Conduct an initial site visit and hydrocensus to assess ground- and surface water utilisation and baseline qualities on neighbouring properties.
- Determine hydraulic properties of the saturated zone by conducting single well pump and slug testing of abstraction and exploration boreholes.
- Sample the hydrocensus boreholes and discuss and interpret groundwater quality to be used as baseline data.

Phase 2 - Reporting

- Baseline description of geohydrology for the proposed mining area.
- Combine and interpret available topographical and hydrogeological and related information.

- Characterise the coal and waste rock in terms of chemistry and acid base accounting to identify potential environmental risks and potential for acid rock drainage (ARD).
- Calculate groundwater flow velocities to be used in the numerical and conceptual models.
- Estimate groundwater recharge for the area using available information.
- Classify the status of the aquifer/s and estimate the vulnerability of aquifer/s to pollution (DRASTIC).
- Model the groundwater regime conceptually and numerically.
- Identify impacts and rate them in a risk assessment.
- Identify gaps in the monitoring network and recommend a suitable monitoring programme.

4. METHODOLOGY

The project consisted of three phases, namely i) a desktop study, ii) a fieldwork phase and iii) a reporting phase.

The desktop assessment included the gathering of relevant data from the following sources:

- Topographical, geological and hydrogeological maps.
- Exploration drill logs.
- Mine Work Programme.
- Rainfall data.
- Water management attributes for the catchment.

The fieldwork phase consisted of the following aspects:

- Site visit, hydrocensus, borehole logging (GPS) and groundwater sampling.
- Identification of different aquifers and aquifer testing for hydraulic parameters.
- Core sampling of overburden and coal for acid base accounting.

The reporting phase comprised of:

- Hydrogeological baseline description which included a desktop study and conceptual model.
- Literature review on acid rock drainage (ARD) and its potential and risks associated with coal mining and the current project.
- Decant calculations including volume of rock disposed, estimated effective recharge including fill and decant volumes and estimates based upon time to decant following closure.
- Numerical modelling including dewatering (operational) and transport (closure) models.
- Recharge calculation based upon the chloride mass balance (CMB) and literature.
- Aquifer vulnerability.
- Impact identification and risk assessment.
- Proposed groundwater management measures and a monitoring programme.

4.1 Desktop study

The desktop study was compiled with information gathered from topographical, geological and hydrogeological maps including data sourced from the GRDM - a resource database developed by the DWA for South Africa. The objective of GRDM is to facilitate in the proactive protection of the country's water resources within a sustainable framework. Supplementary hydrogeological data was obtained from the NGA. The following information was also gathered as part of this desktop study:

- Topographical map: sheet 2628BA Delmas at a scale of 1: 50 000.
- Geological map: sheet 2628 East Rand at a scale of 1: 250 000.
- Hydrogeological map: sheet 2526 Johannesburg at a scale of 1: 500 000.
- Mean monthly rainfall data from the South African Rain Atlas, Index No. 172/170303.
- Data obtained from the Mining Work Programme related to schedules, proposed infrastructure and exploration borehole logs.
- Quaternary catchment water management attributes.

4.2 Hydrocensus

A detailed hydrocensus was conducted in 2 km radius on and around portions 26, 46 and 47 to obtain representative populations of the boreholes on the lease areas and adjacent land owners' properties.

During the hydrocensus, all available details of boreholes and borehole-owners were collected and recorded. Where possible, information was collected on water use/s, water levels and yields of boreholes, etc. This information was used to assess the risk posed by the mining activities on the groundwater regime and users thereof and to gain baseline data prior to commencement of the mining activities. The following parameters were captured during the hydrocensus:

- XYZ Coordinates
- Existing equipment
- Current use
- Future use
- Yield
- Drill depth
- Static water level
- Water quality
- Photograph

Water quality was interpreted based on the domestic colour coded classification system as summarised in Table 1 (WRC, 1998), including interpretation using the South African Nation Standard for drinking water (SANS 241: 2011) displayed in Table 2.

Table 1: Colour coded classification system (WRC, 1998)

Classification	Risk
Class 0	Ideal drinking water suitable for lifetime use
Class 01	Good drinking water suitable for lifetime use
Class 02	Marginal drinking water which may be used without health effects by the majority of individuals in all age groups but may cause some effects in sensitive individuals.
Class 03	Poor drinking water which poses a risk of chronic health effects, especially in babies, children and the elderly.
Class 04	Unacceptable water quality posing severe acute health effects even with short term use.

Table 2: Relevant physical aesthetic, operational and chemical parameters

Parameter	Risk	Unit	Standard limits [a]
Physical and aesthetic determinands			
Electrical conductivity	Aesthetic	mS/m	≤170
Total dissolved solids	Aesthetic	mg/l	≤1200
Turbidity [b]	Operational	NTU	≤1
	Aesthetic	NTU	≤5
pH [c]	Operational	pH units	≥5 to ≤9.7
Chemical determinands – macro			
Nitrate as N [d]	Acute health	mg/l	≤11
Sulphate as SO_4^{-2}	Acute health	mg/l	≤500
	Aesthetic	mg/l	≤250
Fluoride as F	Chronic health	mg/l	≤1.5
Ammonia as N	Aesthetic	mg/l	≤1.5
Chloride as Cl^-	Aesthetic	mg/l	≤300
Sodium as Na	Aesthetic	mg/l	≤200
Zinc as Zn	Aesthetic	mg/l	≤5
Chemical determinands – micro			
Antimony as Sb	Chronic health	mg/l	≤0.020
Arsenic as As	Chronic health	mg/l	≤0.010
Cadmium as Cd	Chronic health	mg/l	≤0.003
Total chromium as Cr	Chronic health	mg/l	≤0.050
Copper as Cu	Chronic health	mg/l	≤2.0
Iron as Fe	Chronic health	mg/l	≤2.0
	Aesthetic	mg/l	≤0.30
Lead as Pb	Chronic health	mg/l	≤0.010
Manganese as Mn	Chronic health	mg/l	≤0.50

	Aesthetic	mg/l	≤0.10
Mercury as Hg	Chronic health	mg/l	≤0.006
Nickel as Ni	Chronic health	mg/l	≤0.07
Selenium as Se	Chronic health	mg/l	≤0.010
Uranium as U	Chronic health	mg/l	≤0.015
Vanadium as V	Chronic health	mg/l	≤0.2
Aluminium as Al	Operational	mg/l	≤0.3

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

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

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

[d] This is equivalent to nitrate at 50 mg/l NO_3^-/l.

4.3 Geochemistry

4.3.1 Hydrogeochemistry

Knowledge of processes that control natural water composition is required for rational management of water quality. Hydrogeochemistry seeks to determine the origin of the chemical composition of groundwater and the relationship between water and rock chemistry, particularly as they relate to water movement. A basic tool in hydrochemical studies used to summarize and present water quality data are graphical interpretation. A considerable number of methods and procedures exist but the most widely used are diagrams known as **Stiff** and **Durov** diagrams.

A **Stiff** diagram is an elongate polygon, the precise shape of which is determined by "joining the dots", corresponding to the milli-equivalents per litre (meq/l) concentrations of each major ion on a template. This conversion is applicable only to charged species, i.e. ions, as it is essentially a measure of the number of "moles of charge" available for participation in a range of electrochemical reactions. Conversion to meq/l is achieved simply by multiplying the mmol/l concentrations (mmol/l = mg/l divide by relative atomic mass) by the valence (i.e. the charge) of the ion. For instance, if we convert directly from mg/l, the concentration is multiplied by the valence and divided by the molecular atomic mass. Fortunately most major cations and anions do not vary in valence so that constant conversion factors can be established for many dissolved species. The **Durov** diagram defines water in terms of facies used to show the hydrochemical processes occurring within different hydrogeological systems.

The different fields of the Expanded Durov diagram can be viewed in Figure 1 followed by a short description of the water type associated with the fields.

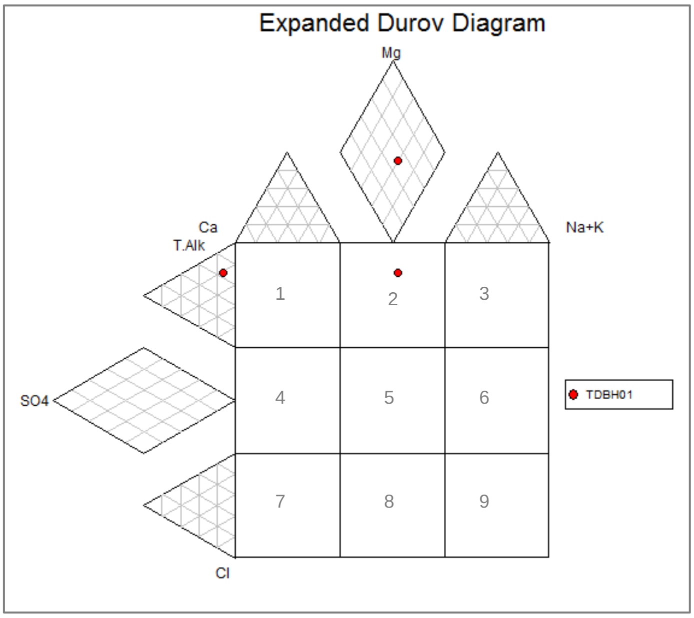

Figure 1: Layout of the Expanded Durov diagram

The fields of the Expanded Durov diagram represent the following:

Field 1

Fresh, very clean, recently recharged groundwater with alkalinity and calcium dominated ions.

Field 2

Fresh, clean, relatively young groundwater that has started to undergo magnesium ion exchange, often found in dolomitic terrain.

Field 3

Fresh, clean, relatively young groundwater that has undergone sodium ion exchange (sometimes in sodium enriched granites or other felsic rocks). The dominance in sodium may also be as a result of sodium enriched pollution.

Field 4

Fresh, recently recharged groundwater that is dominated by calcium cations and sulphate anions. The sulphate enrichment may be as a result of acid mine drainage reactions.

Field 5

Groundwater that is usually a mix of different types – either clean water from fields 1 and 2 that has undergone SO_4 and NaCl mixing/contamination or old stagnant NaCl dominated water that has mixed with clean water.

Field 6

Groundwater from field 5 that has been in contact with a source rich in Na or old stagnant NaCl dominated water that resides in Na rich host rock/material.

Field 7

Water rarely plots in this field that indicates NO_3 or Cl enrichment or dissolution.

Field 8

Groundwater that is usually a mix of different types – either clean water from fields 1 and 2 that has undergone SO_4, but especially Cl mixing/contamination or old stagnant NaCl dominated water that has mixed with water richer in Mg.

Field 9

Old or stagnant water that has reached the end of the geohydrological cycle (deserts, salty pans etc.) or water that has moved a long time and/or distance through the aquifer or on surface and has undergone significant ion exchange because of the long distance or residence time in the aquifer.

4.3.2 Acid base accounting

Coal and many mine wastes contain sulphidic material which may oxidise to produce acid rock drainage (ARD). A number of factors control the generation of ARD, however of primary importance are the relative abundance of acid producing minerals (generally the sulphides) and acid consuming minerals (generally carbonates and silicates), availability of water (moisture) and an oxidising environment (exposure to air). As ARD has the potential to impact significantly on surface and groundwater quality and the leachate characteristics of waste residue deposits, it is necessary to quantify the potential of waste to generate ARD during geochemical characterisation assays.

Geological core samples were selected from the exploration drilling programme at Droogefontein portion 26. The samples were submitted to the Waterlab Pty Ltd, a **SANAS accredited testing laboratory**. Analyses included acid-base-accounting (ABA), major cation and anion distribution and an ICP-OES scan for dissolved metal phases following an acid rain leach procedure. The samples from various boreholes were analysed to determine possible geochemical alterations during mining and post closure phases at Droogefontein portion 26. Geochemical sampling information is included in Table 3.

Table 3: Sampling information for ABA and acid rain leach analyses

Borehole ID	Depth (m)	Lithology	Colour	Prim feature
DN15	9	Sandstone	Cream	Miaceous
	23	Sandstone	Grey	Light
	53	Tillite	Grey	Dark
DN17	9	Sandstone	Cream	Miaceous
	40	Mudstone	Dark	
	42	Mudstone	Dark	with coal
DN16	Top seam	Coal	Black	
DN16	Middle seam	Coal	Black	
DN19	Bottom seam	Coal	Black	

ABA includes a straightforward set of laboratory procedures. The total acid generating potential (AP) is calculated from the analysis of the sulphide content of the rock material. The neutralising potential (NP) of minerals in the material is measured by reacting a finely ground sample of the test material with a measured excess of hydrochloric acid and back-titrating it to a selected pH end-point between 6.0 and 8.3 (to differentiate between the actions of carbonates and silicates). The balance between the potentially acid consuming and potentially acid generating minerals in the sample is expressed as the net neutralising potential (NNP).

4.3.3 Acid rain leach

The acid rain leaching procedure was performed on the geological core and coal samples to assess the potential of harmful substances to be released if the exposed rock comes into contact with acidic solutions such as ARD. The leaching procedure is a modification of the TCLP procedure as recommended by the DWA.

4.4 Aquifer tests

Three types of aquifers were identified during examination of the exploration boreholes and during compilation of the desktop study. These aquifers were subjected to aquifer tests to gain insight into the aquifer hydraulic characteristics that would govern the fate and movement of groundwater and contaminants through the host material. Two differing types of aquifer tests were employed and included i) slug tests and ii) single well drawdown/pumping tests. Slug and pumping tests were used to determine *in-situ* properties of water-bearing formations and to define the overall hydrogeological regime. Such tests generally determine transmissivity (T), hydraulic conductivity (K), storativity (S), yield, connection between saturated zones, identification of boundary conditions and the cone of influence of a pumping well in a extraction system. However due to the nature and aim of the present study only the T and K values were considered for evaluation and therefore only slug and single well pump tests were considered for estimating the K and T of the formations/aquifer host material.

4.4.1 Slug tests

Slug tests were conducted on three of the exploration boreholes to determine the horizontal hydraulic conductivity (K) of the top unconfined/perched aquifer. A slug test is a quick and easy method that can be used to predict the yield of the borehole and the aquifer characteristics by measuring the rate of recovery of the water level after a sudden change. This test was performed by suddenly raising the static water level in the borehole with the aid of a closed cylinder. The cylinder replaces its own volume of water in the borehole, thus increasing the pressure in the borehole. The equilibrium in the water level is changed and it will recover or stabilise to its initial level. By measuring the rate of recovery or recession of the water level (time taken to recover), the borehole's T- or K-values can be measured. It should be noted that the hydraulic properties determined by slug tests are representative of the material in the immediate vicinity of the well only, which in this case was the unconfined/perched aquifer. The rate of water level change is a function of the K of the formation and the geometry of the well or screened interval. The recovery of the water table was measured over time using a pressure transducer. The data gathered were analysed by means of the Bouwer and Rice method (Bouwer and Rice, 1976) using the software programme FC-Excel as developed by the Institute for Groundwater Studies, University of the Free State.

4.4.2 Single well pump tests

Single well drawdown tests were conducted on two farm boreholes located just adjacent to the northern perimeter of Droogefontein portion 26 and the proposed open pit. The water supply of these 2 boreholes is sourced from the Karoo fractured and Malmani dolomite aquifers with yields of approximately 0.5 l/s and 18 l/s, respectively.

These boreholes were subjected to single well drawdown pumping tests. A single well test involves pumping at a constant or variable rate and measuring changes in water levels in the pumped well during pumping and recovery. Single well pumping tests can be used to determine transmissivity, hydraulic conductivity and yield of a groundwater zone. They are also conducted to determine well loss and optimizing rate and pump setting for a multiple well test. Single well tests generally will not identify impermeable boundaries, recharge boundaries, or interconnection between other ground water and surface water unless these conditions exist in very close proximity to the well being tested.

The transmissivities were calculated by using the Cooper-Jacob (Cooper & Jacob, 1946) equation for drawdown in confined aquifers as given below:

$$T = \frac{2.3Q}{4\pi\Delta s}$$

Eq. 1

Where:

T = Transmissivity (m^2/d)

Q = Flow (m^3/d)

Δs = Drawdown difference of one log cycle

Transmissivity is a function of the hydraulic conductivity (K) and the thickness of the saturated portion of an aquifer (b) and expressed by:

$$T = Kb$$

Eq. 2

The hydraulic conductivity (K) can be calculated by substitution to read:

$$K = \frac{T}{b}$$

Eq. 3

Due to the fact that the dolomitic aquifer thickness is unknown a typical range for hydraulic conductivities in dolomitic aquifers are supplied.

4.5 Groundwater recharge estimation

Groundwater recharge for the area was reported using:

i. The CMB method (Bean, 2003)
ii. Recharge estimation in the GRDM database

The first approach adopted is the CMB approach. This method is based on the principle that chloride behaves as a conservative tracer and is neither absorbed nor lost as it flows from precipitation to groundwater. Thus the method assumes that chloride in recharge water percolating vertically through the unsaturated zone and into the aquifer is derived entirely from precipitation (i.e. no chloride is derived from the soil or unweathered zone) and the chloride concentration of groundwater is controlled by evapotranspiration processes. Thus the proportion of rainfall that occurs as recharge can be quantified as the ratio between the two concentrations. Using the simplified CMB method equation 4 applies (Bean, 2003):

$$R\% = Cl_P / Cl_{GW} \times 100$$

Eq. 4

Where R = recharge and Cl_P and Cl_{GW} represent the Cl-concentration (in mg/l) of precipitation and water percolating through the soil zone (water table), respectively.
The following assumptions are necessary for successful application of the CMB:

- There is no source of chloride in the soil moisture or groundwater other than that from precipitation, i.e. Cl levels suspected to be caused from surface seepage should not be used.
- Chloride is a conservative ion, i.e. it does not readily take part in biological processes nor does it precipitate.
- Steady-state conditions are maintained with respect to long-term precipitation and chloride concentrations.
- A piston flow regime, which is defined as downward vertical diffuse flow of soil moisture, is assumed.

4.6 Aquifer vulnerability

Groundwater plays an important role in supplying water to many regions of Southern Africa due to its low annual average precipitation of 460 mm, which is well below the world average of 860 mm. The quality of groundwater resources in South Africa has therefore received considerable focus and attention on the need for a proactive approach to protect these sources from contamination (Lynch *et. al.*, 1994). Groundwater protection needs to be prioritised based upon the susceptibility of an aquifer towards pollution. This can be done in two ways, namely i) pollution risk assessments and ii) aquifer vulnerability. Pollution risk assessments consider the characteristics of a specific pollutant, including source and loading while aquifer vulnerability considers the characteristics of the aquifer itself or parts of the aquifer in terms of its sensitivity to being adversely affected by a contaminant should it be released.

The DRASTIC model concept developed for the USA (Aller *et. al.*, 1987) is well suited for producing a groundwater vulnerability evaluation for South African aquifers. The DRASTIC evaluates the intrinsic vulnerability (*IV*) of an aquifer by considering factors including **D**epth to water table, natural **R**echarge rates, **A**quifer media, **S**oil media, **T**opographic aspect, **I**mpact of vadose zone media, and hydraulic **C**onductivity. Different ratings are assigned to each factor and then summed together with respective constant weights to obtain a numerical value to quantify the vulnerability:

$$\text{DRASTIC Index } (IV) = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw \quad \text{Eq. 5}$$

Where *D*, *R*, *A*, *S*, *T*, *I*, and *C* are the parameters, *r* is the rating value, and *w* the constant weight assigned to each parameter (Lynch *et al*, 1994). The scores associated with the vulnerability of South African aquifers are shown in Table 4.

Table 4: South African National Groundwater Vulnerability Index to Pollution (Lynch *et al*, 1994)

Score	Vulnerability
50-87	Least susceptible
87 - 109	Moderate susceptible
109 - 226	Most susceptible

The concept of DRASTIC in vulnerability assessments is based on:

- A contaminant is introduced at the surface of the earth
- A contaminant is flushed into the groundwater by precipitation
- A contaminant has the mobility of water
- The area evaluated is 0.4 km^2 or larger

The weighting for each parameter is constant. The minimum value for the DRASTIC index that one can calculate (assuming all seven factors were used in the calculation) is therefore 24 with the maximum value being 226. The higher the DRASTIC index the greater the vulnerability and possibility of the aquifer to become polluted if a pollutant is introduced at the surface or just below it. **Note** that conductivity values for fractured rock aquifers are difficult to estimate and sufficient information on hydraulic conductivity values for Southern Africa is not available at present. In addition, due to the considerable variation over short distances in hard rock aquifers, the use of this parameter was in doubt.

4.7 Formulation of conceptual model

The first step in the modelling study is the development of a conceptual flow model. This is an idealisation of the real world that summarises the current understanding of site conditions and how the groundwater flow system works. It includes all of the important features of the flow system, while incorporating simplifying assumptions. The conceptual model relies heavily on the information gathered during the field investigation phase.

4.8 Numerical groundwater model

Numerical flow and mass transport groundwater models were constructed to simulate current aquifer conditions and impacts and to provide a tool for evaluation of different management options for the future. A risk analysis could also be performed where effects of different flow and concentration parameters as well as the impacts of nearby existing operations and management options could be evaluated.

The modeling package PMWIN Pro (Processing Modflow Professional for Windows) was used for the simulation. The model was run in steady state conditions until representative transmissivity and recharge distributions were obtained with a simulated hydraulic head distribution closely mimicking the average measured conditions. Two model layers were constructed in the model. Layer 1 simulates the upper perched/weathered zone, which has the characteristics of a primary unconfined/semi-confined aquifer. Layer 2 represents the fractured rock, or secondary aquifer. Because the pit will not intersect the dolomitic aquifer, this aquifer was not included in the model.

After the model was run and the steady state solution was used to calibrate simulated water levels with the available measured water level information, a groundwater mass transport model was constructed. Calibration of the flow model was aided largely by existing flow and water level information gathered from various hydrocensus and monitoring boreholes, which are situated within the same geological environment.

4.9 Environmental Impact Assessment

The impact rating process is designed to provide a numerical rating of the various environmental impacts identified for various project activities. The significance rating process follows the established impact/risk assessment facets:

Probability = Likelihood of an impact occurring	**Magnitude** = Duration + Extent + Environment/3

The weight assigned to the various parameters for positive and negative impacts is presented in Table 5.

Table 5: Impact rating

Rating	Probability	Duration	Extent	Environment
1	Never known to have happened, but may happen	Lasting days to a month	Effect limited to the site. (metres);	Limited damage to minimal area of low significance, (e.g. ad hoc spills within plant area). Will have no impact on the environment.
2	Known to happen in industry	Lasting 1 month to 1 year	Effect limited to the activity and its immediate surroundings. (tens of metres)	Minor effects on biological or physical environment. Environmental damage can be rehabilitated internally with / without help of external consultants.
3	<once a year	Lasting 1 – 5 years	Impacts on extended area beyond site boundary (hundreds of metres)	Moderate, short-term effects but not affecting ecosystem functioning. Rehabilitation requires intervention of external specialists and can be done in less than a month.
4	Once per year to up to once per month	Lasting 5 years to Life of Organisation	Impact on local scale / adjacent sites (km's)	Serious medium term environmental effects. Environmental damage can be reversed in less than a year
5	Once a month - Continuous	Beyond life of Organization / Permanent impacts	Extends widely (nationally or globally)	Very serious, long-term environmental impairment of ecosystem function that may take several years to rehabilitate

The significance or severity of the impact is then determined and categorised into one of four categories, as listed in Table 6 and described in Table 7.

Table 6: Severity of the impact

Environmental Impact Rating					
Probability	**Magnitude**				
	1 Minor	**2 Low**	**3 Medium**	**4 High**	**5 Major**
5 Almost Certain	Medium (11)	High (16)	High (20)	Very High (23)	Very High (25)
4 Likely	Low (7)	Medium (12)	High (17)	Very High (21)	Very High (24)
3 Possible	Low (4)	Medium (8)	High (13)	High (18)	Very High (22)
2 Unlikely	Low (2)	Low (5)	Medium (9)	High (14)	High (19)
1 Rare	Low (1)	Low (3)	Medium (6)	Medium (10)	High (15)

Table 7: Description of the impact or severity rating

Score	Description	Rating
1 - 7	An acceptable impact for which mitigation is desirable but not essential. The impact by itself is insufficient even in combination with other low impacts to prevent the development being approved. These impacts will result in either positive or negative short term effects on the social and/or natural environment.	Low / Negligible
8 - 12	An important impact which requires mitigation. The impact is insufficiently itself to prevent the implementation of the project but which in conjunction with other impacts may prevent its implementation. These impacts will usually result in either a positive or negative medium to long term effect on the social and/or natural environment.	Medium / Minor
13 - 18	A serious impact, if not mitigated, may prevent the implementation of the project (if it is a negative impact). These impacts would be considered by society as constituting a major and usually long-term change to the (natural and/or social) environment and result in severe effects or beneficial effects.	High / Moderate
19 - 25	A serious impact, which if negative, may be sufficient by itself to prevent implementation of the project. The impact may result in permanent change. Very often these impacts are immitigable and usually result in very severe effects or very beneficial effects.	High / Major

5. DESKTOP STUDY

5.1 Quaternary catchment and location

Portions 26, 46 and 47 are situated in the C21E quaternary catchment of the Upper Vaal Water Management Area and the South-eastern Highveld groundwater region (Figure 2). The proposed open-cast coal mine is planned on portion 26 of the farm Droogefontein in the Delmas district of Mpumalanga (central coordinates S26.22605 and E28.55864). The major surface water drainage system in the C21E catchment is the Blesbokspruit which flows in a southern direction and is situated approximately 7 km southwest of the mining operations. No envisaged mining activities are planned for portions 46 and 47. Relevant information pertaining to water management for the C21E quaternary is shown in Table 8 (GRDM). The total groundwater usage for the catchment is relatively low which is estimated at approximately 0.3 Mm^3/a of which livestock watering and irrigation are the largest users.

Table 8: Quaternary catchment information (GRDM)

Attribute	C21E
Area	628.2 km^2
Mean annual rainfall	691 mm/a
Mean annual runoff	35 mm/a
Baseflow	6 mm/a
Population (Thaba Chweu, 2001)	133 707 Count
Mean annual evaporation (C2E007)	1600 - 1700 mm/a
Total groundwater use	0.22 Mm^3/a
Present Eco Status Category	D Category
Recharge	~35 mm/a
	~5%
Exploitation potential	10 Mm^3/a
Vegetation type	Moist Cool Highveld Grassland
Ecoregion	Highveld
Land use	Farming
Groundwater General Authorization	75 m^3/ha/a

The Blesbokspruit forms one of the larger wetlands in the Highveld region of southern Africa, lying at an altitude of 1600 m. The wetland is a high conservation priority because it forms an important component of one of the tributaries of the Vaal River, which provides water to the highly industrialized and densely populated Gauteng Province. The value of the system lies in its ability to purify industrial and domestic effluent discharged into the Blesbokspruit from local industries, sewage works and mines, thereby reducing pollutant loads entering the Vaal River. In addition, the Blesbokspruit wetland acts as an important refuge for many waterbird species, particularly in the context of the highly industrialized urban environment of the far East Rand where most of the wetland habitats have been lost.

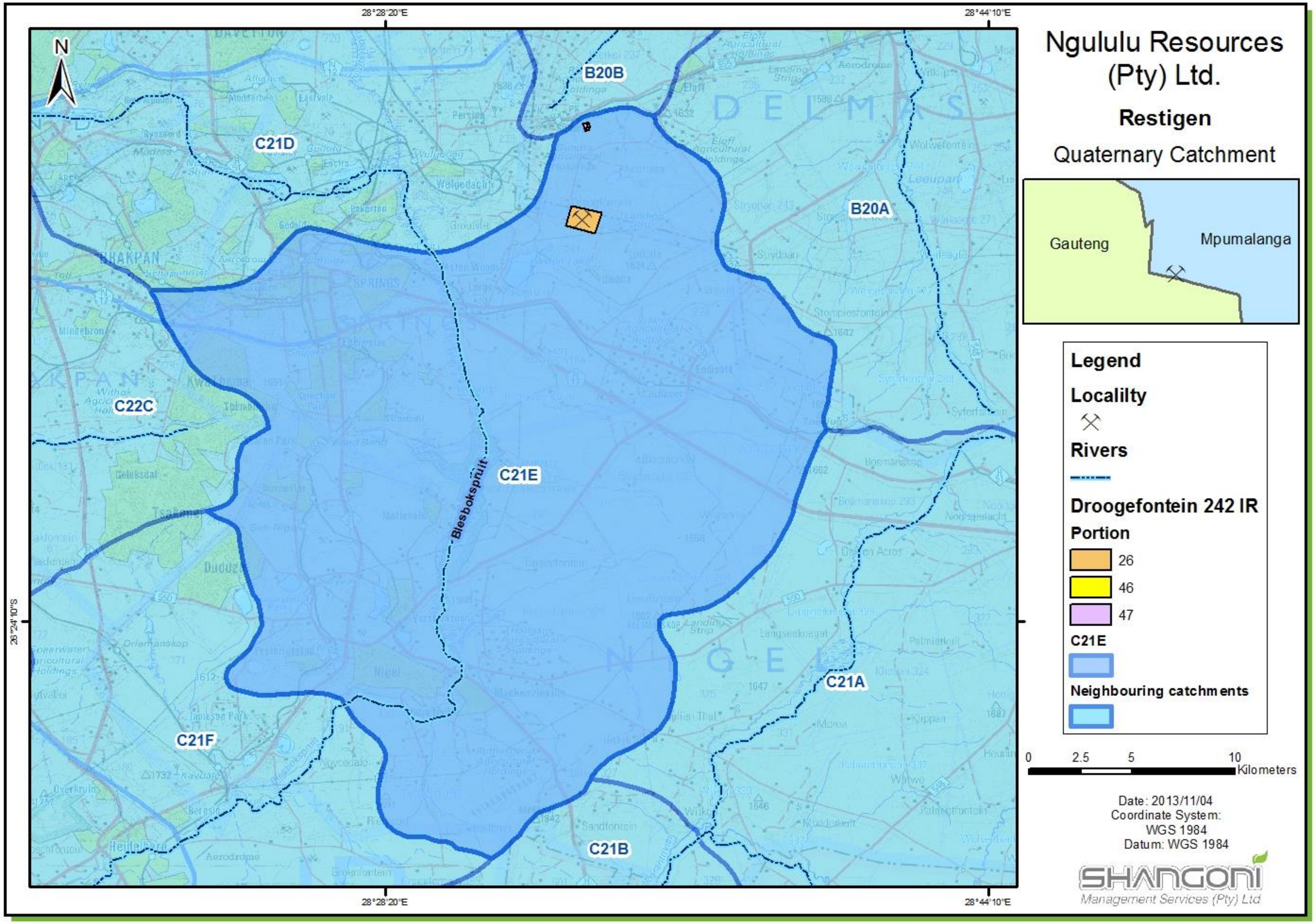

Figure 2: Quaternary catchment map in vicinity of Droogefontein

Although the proposed mining operations may not pose a direct impact on the Blesbokspruit, a natural drainage line and intermittent stream and seasonal wetland, namely '*Dwars-in-die-Wegvlei'*, is located on the eastern perimeter of portion 26 (Figure 3). This intermittent and seasonal stream drains towards the Aston Lake to the southwest which in turn feeds the Blesbokspruit.

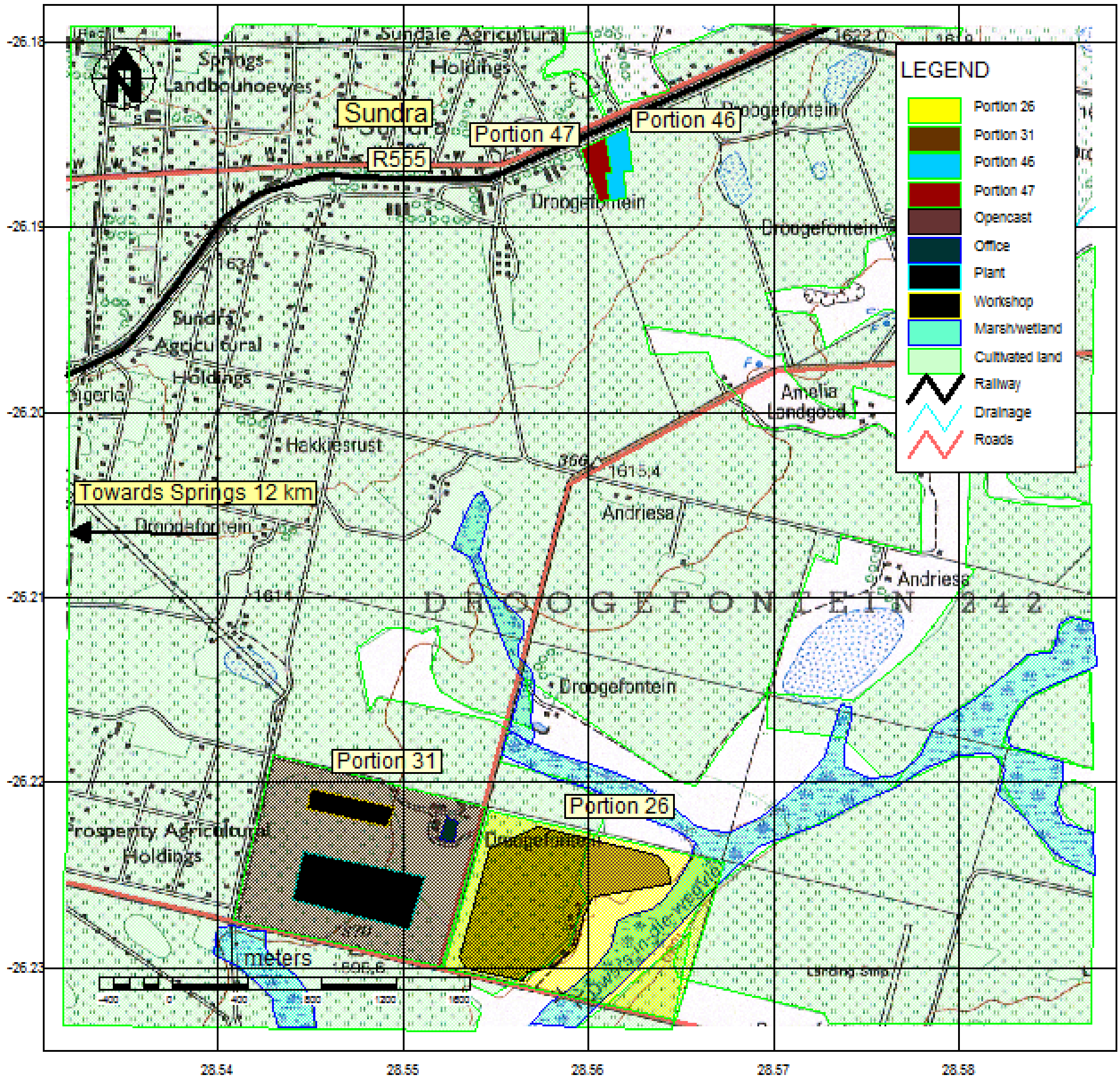

Figure 3: Topographical map showing the locations of portions 26, 46 and 47 of the farm Droogefontein

5.2 Topography, climate and drainage

The climate of the Mpumalanga Province is highly variable as it is defined by its variable topography. The province is subdivided into two distinct regions based on its topography and includes the high-lying grassland savannah of the Highveld escarpment and the subtropical Lowveld plains. The study area falls within the high-lying grassland savannah area, approximately 1 600 meters above mean sea level (mamsl). The climate is mild to hot with hot, wet summers from October to February and cold, dry winters from May to August (Figure 4). Mean annual precipitation for the Highveld area is approximately 650 mm - 700 mm (SA Rain Atlas, Index Nr. 172/170303). The mean summer temperature is 24°C, with temperatures rising to more than 30°C in January. The mean winter temperature is 15°C. Extremely cold weather is the norm during mid-winter (June/July) with average minimum temperatures of 2.7 °C. Heavy frost is also common during these mid-winter months.

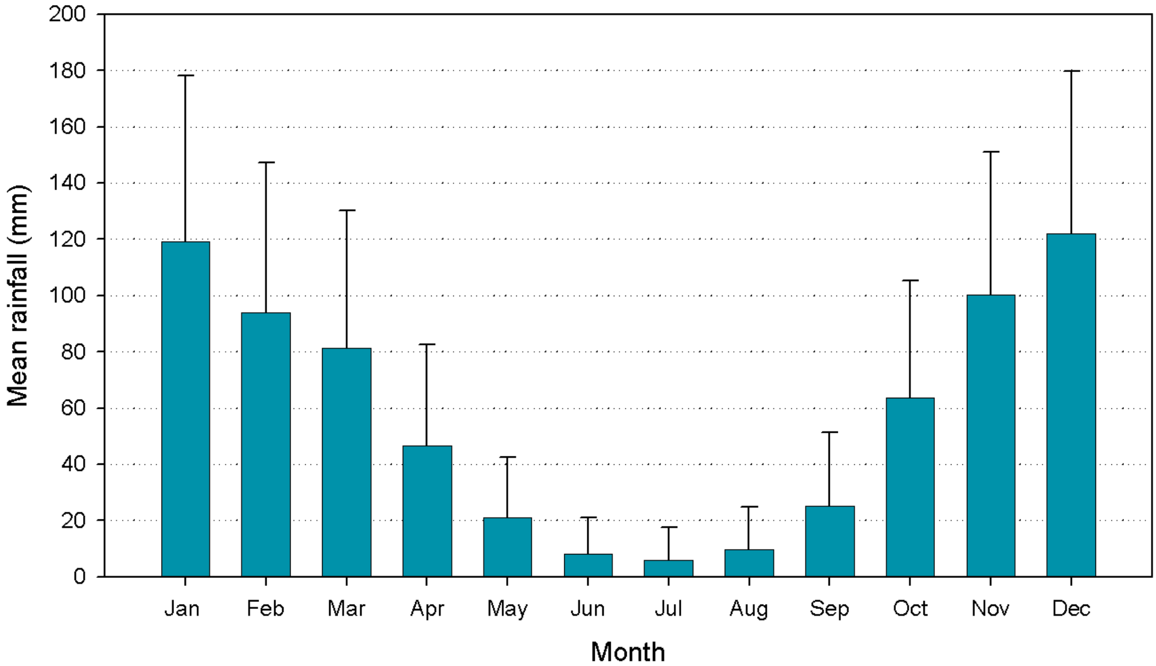

Figure 4: Monthly rainfall (South African Rain Atlas, Index No. 172/170303)

Portion 26 is located on a gentle eastern facing slope ranging between 1580 mamsl and 1600 mamsl. Water (ground and surface) draining this portion will collect in the *'Dwar-in-die-Wegvlei'* natural drainage line to the east (Figure 5) where it will flow southwest towards the Aston Dam. During the summer and higher rainfall periods when the already shallow groundwater rest levels are at their greatest, groundwater will daylight in this region as groundwater contribution to baseflow. During the winter when groundwater levels are lower, groundwater will still flow towards the stream / wetland and will also follow the stream channel, albeit subsurface.

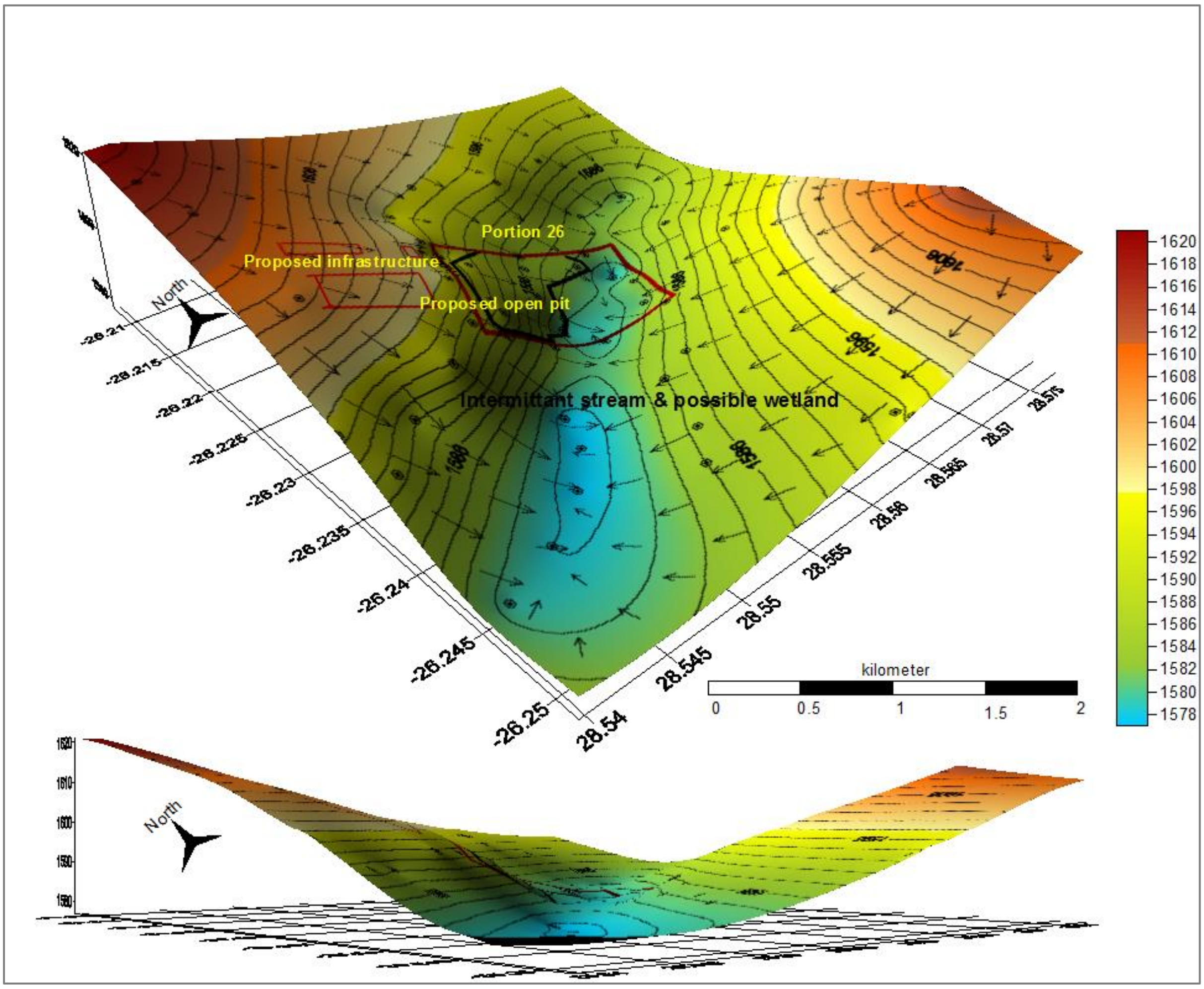

Figure 5: Topography and surface flow maps showing the position of portion 26 and the location of the proposed open pit

5.3 Geology

5.3.1 Regional geology

The 2628 East Rand 1:250 000 geological map indicates that Droogefontein portions 26, 46 and 47 is directly underlain by rocks of the Vryheid Formation Member (Figure 6) belonging to the Ecca Group of the Karoo sequence of rocks believed to be 400 million years old. The Karoo Supergroup comprises mainly a sedimentary succession of sandstone, siltstone, shale, mudstone, coal and tillite. The Karoo Supergroup is lithostratigraphically subdivided into the Dwyka, Ecca and Beaufort groups, succeeded by the Molteno, Elliot and Clarens formations and the Drakensburg Formation. The coals range in age from Early Permian (Ecca Group) through to Late Triassic (Molteno Formation) and are predominantly bituminous to anthracite in rank, which is a classification in terms of metamorphism under the influence of temperature and pressure.

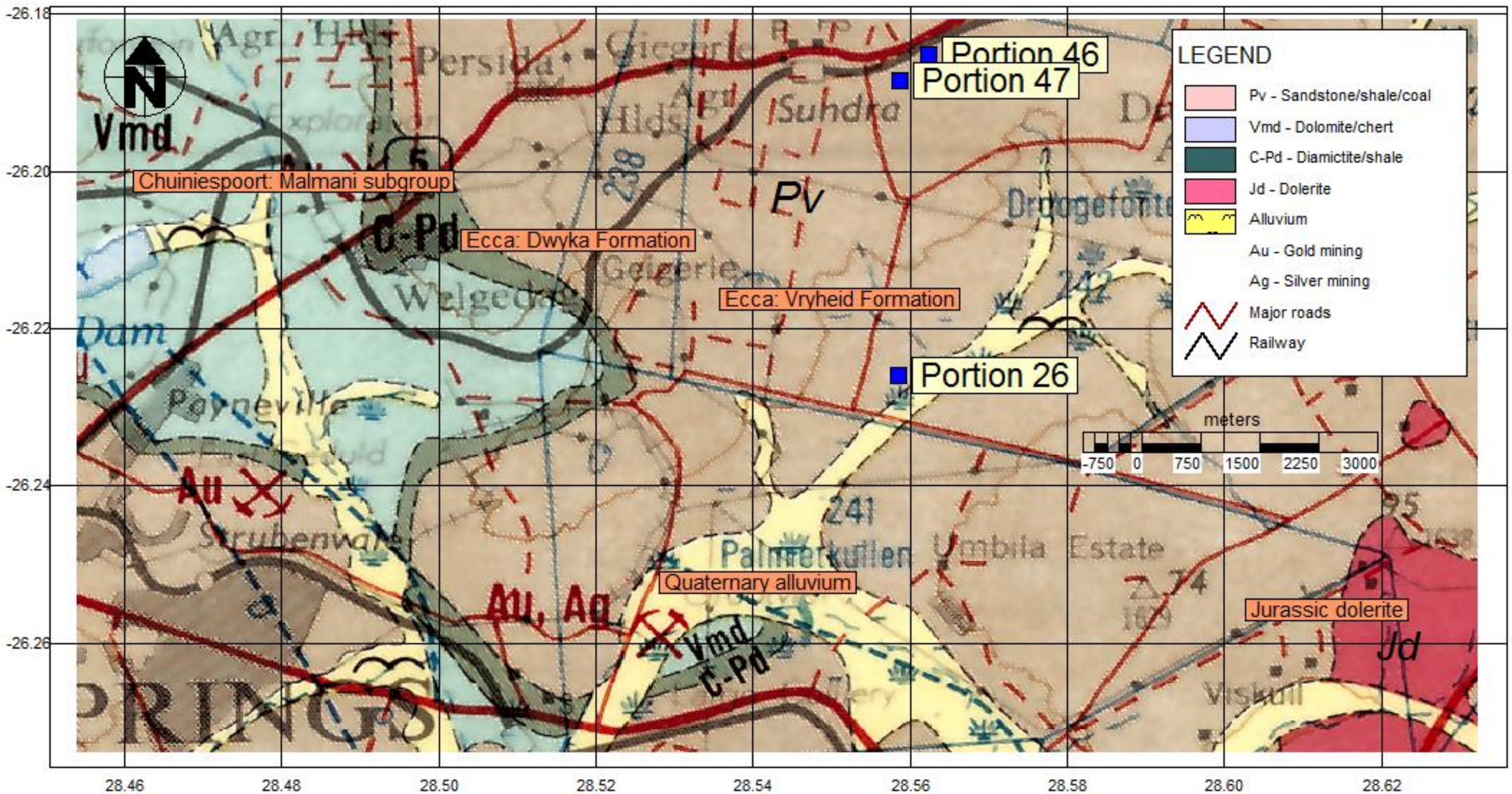

Figure 6: East Rand Geological Map 2628 at a scale of 1:250 000 showing the general underlying geology and locations of Droogefontein portions 26, 46 and 47

The Ecca Group comprises successions of formations which consists of sandstone, shale and coal and were developed within the Karoo basin locally. The thickest portions of the Ecca Group were deposited in the southern Karoo basin in contrast to the relatively thin sequence which is now preserved in the East Rand.

The Vryheid Formation comprises of predominantly thick beds of yellowish to white cross-bedded sandstone and grit with alternating beds of soft sandy shale and coal which is widely and extensively intruded by dolerite sills and dykes. Coal is developed in the Vryheid Formation which forms a clastic wedge in the north and pinches out down-dip and basinwards to the south. The Vryheid sandstones and shales overlie the Dwyka tillites (Tankard *et al*., 1982) which in turn overlie the dolomites of the Malmani subgroup belonging to the Transvaal Supergroup. Several coal seams occur in the Vryheid Formation and these are associated predominantly with the coarser-grained fluvial facies at the top of each sequence. These coal seams can be traced laterally across the entire area of occurrence of the Vryheid Formation.

The Ecca Group of rocks in Mpumalanga were deposited in shallow-marine to fluvial environments, which developed after the Dwyka glaciers retreated. In fact, some of the lower coals are interpreted as having formed in cold swampy conditions during glacier retreat (Cairncross, 2001). This is in marked contrast to the northern hemisphere coals which were formed in hot, forested environments (Snyman, 1998). Although there has been some debate about whether the sea was open to the ocean or a semi-closed or closed fresh-water basin, it is now accepted that the younger rocks were deposited under fully marine conditions (Cairncross, 2001). The identification of glauconitic sandstone in the Vryheid Formation supports the marine interpretation because glauconitic sandstone cannot form in fresh water.

5.3.2 Witbank coalfield

The Droogefontein Project area is located on the western edge of the Central Witbank Coalfield in the Vischkuil sub-basin. The Witbank Coalfield is a basin-like feature that extends from Brakpan in the west to Belfast in the east. Five seams are developed in the Witbank Coalfield numbered from No.1 at the base to No.5 at the top with the number 2 seam providing most of the coal mined to date in the Witbank Coalfield.

The **No. 1 seam** is best developed in the northern part of the Witbank Coalfield (in the Pretoria region) where it is 1.5 to 2 m thick and between 90 and 125 m below surface throughout the coalfield.

The **No.2 seam** is estimated to contain about 70% of the coal resources of the coalfield and also contains some of the best quality coal. In the central part of the coalfield it averages about 6.5 m in thickness and comprises up to five zones that differ in coal quality. Ash contents vary from 6.4% to 26.6% averaging around 10 – 15% with calorific values ranging between 25 and 32 MJ/kg.

The **No.4 seam** is approximately 2.5 m thick in the central part of the coalfield, and attains a total thickness of up to 6.5 m towards the margin. It is developed between 65 and 105 m below surface. The coal is overall of bituminous quality and most suitable as feedstock for power stations.

The **No. 5 seam** has been extensively eroded and contributes only about 45% of the resources in the Witbank coalfield. It is found on outcrop and attains a depth of 80 m below surface. The seam varies in thickness from 1.8 to 2 m and comprises mainly bright, banded coal that is used as a blending coke and lower-quality coking coal that can be used for formed coke or as a chemical feedstock.

5.4 Catchment Hydrogeology

The DWA have characterised South African aquifers based on the rock formations in which it occur together with its capacity to transmit water to boreholes drilled into specific formations. The water bearing properties of rock formations in South Africa can be classified into four classes defined as:

1. **Class A - Intergranular**
    - Aquifers associated either with loose and unconsolidated formations such as sands and gravels or with rock that has weathered to only partially consolidated material.
2. **Class B - Fractured**
    - Aquifers associated with hard and compact rock formations in which fractures, fissures and/or joints occur that are capable of both storing and transmitting water in useful quantities.
3. **Class C - Karst**
    - Aquifers associated with carbonate rocks such as limestone and dolomite in which groundwater is predominantly stored in and transmitted through cavities that can develop in these rocks.
4. **Intergranular and fractured**
    - Aquifers that represent a combination of Class A and B aquifer types. This is a common characteristic of South African aquifers. Substantial quantities of water is stored in the intergranular voids of weathered rock but can only be tapped via fractures penetrated by boreholes drilled into the fractured aquifer.

Each of these classes is further subdivided into groups relating to the capacity of an aquifer to transmit water to boreholes, typically measured in l/s. The groups therefore represent various ranges of borehole yields. South African aquifers are classified according to the classification scheme shown in Figure 7.

A segment of the hydrogeological map illustrating the typical groundwater occurrences for the study region (hydrogeological map series 2526 Johannesburg) is shown in Figure 8. The map shows that Droogefontein portion 26, 46 & 47 are located in a **d2 aquifer class** region. The groundwater yield potential is classed as low on the basis that most of the boreholes on record in vicinity of the study area produce between 0.1 and 0.5 l/s. However, higher yields do occur sporadically where groundwater is held in good water yielding fractures. Boreholes drilled deep enough (>100 m) may also intersect the Malmani dolomites which on average yield >5 /s and up to 40 l/s.

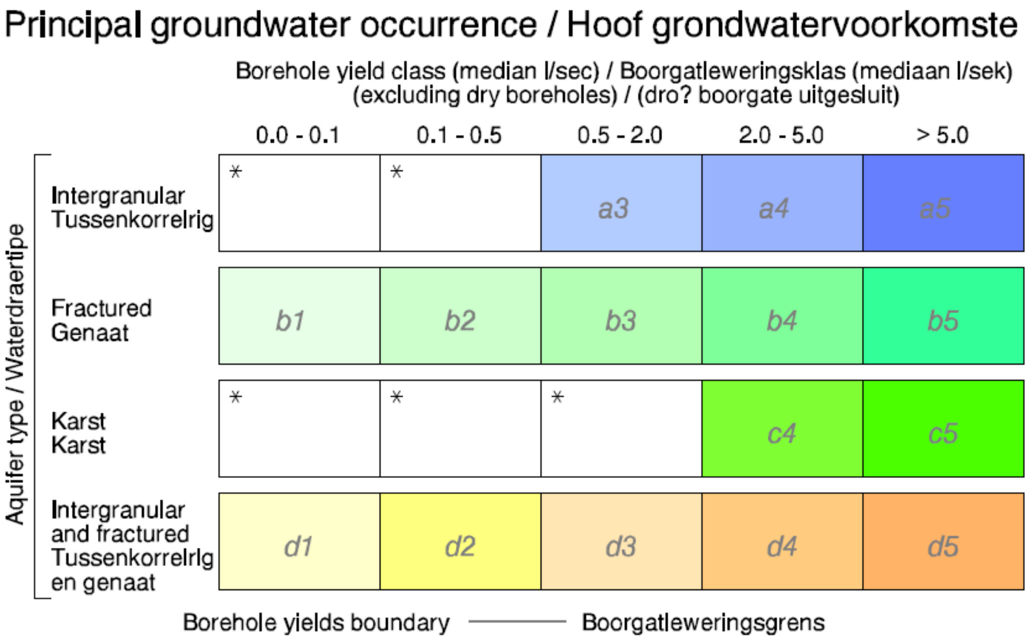

Figure 7: Principal groundwater occurrences in South Africa

The different modes of groundwater occurrences associated with the Vryheid Formation are (Barnard, 2000):

i. weathered and fractured sedimentary rocks not associated with dolerite intrusions;

ii. indurated and jointed sedimentary rocks alongside dykes;

iii. narrow weathered and fractured dolerite dykes;

iv. basins of weathering in dolerite sills and highly jointed sedimentary rocks enclosed by dolerite;

v. weathered and fractured upper contact zones of dolerite sills;

vi. weathered and fractured lower contact zones of dolerite sills; and

vii. minor groundwater occurrences are often encountered in association with coal seams.

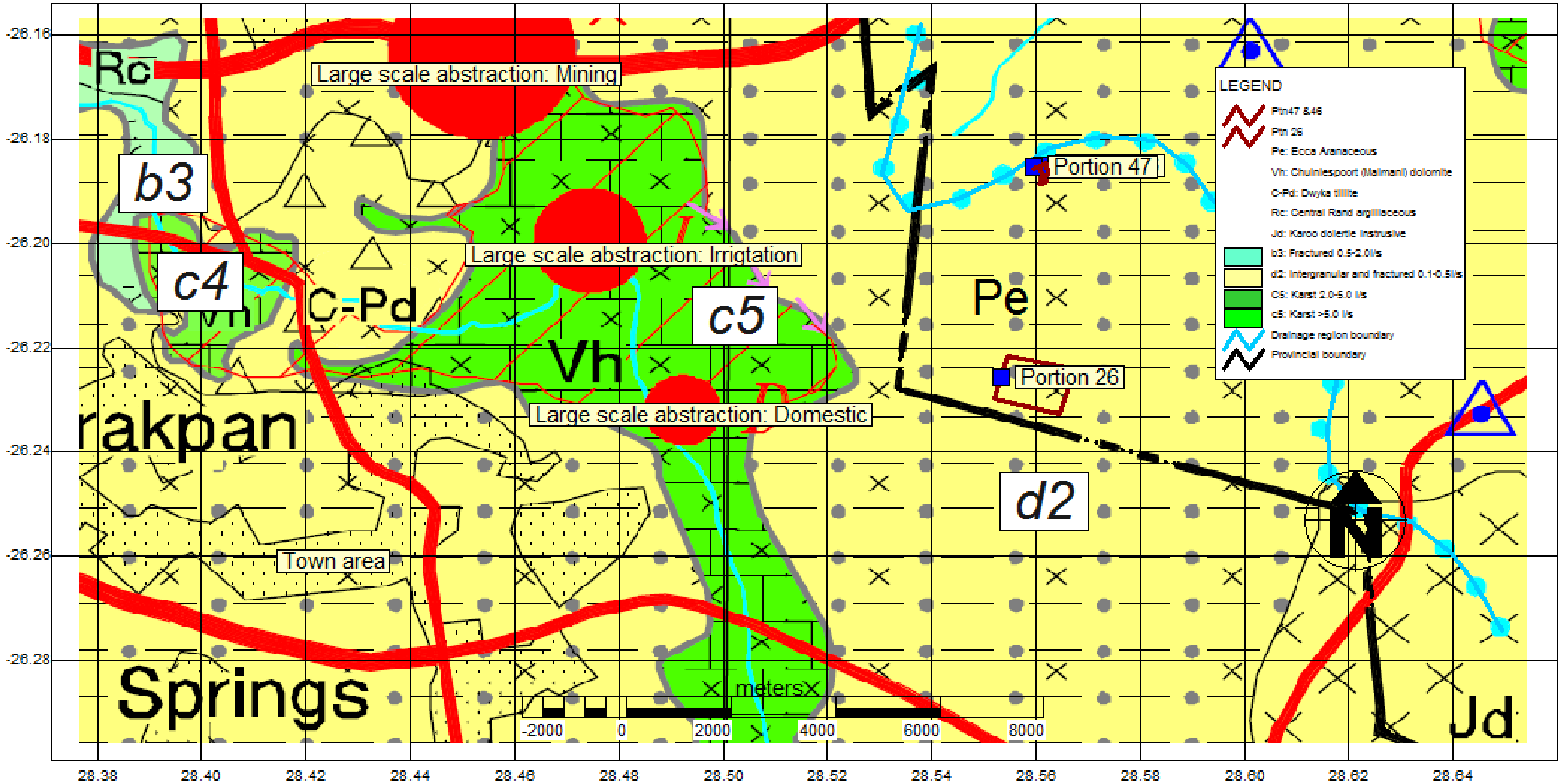

Figure 8: Hydrogeological map illustrating the typical groundwater occurrence for the study region

5.5 Aquifer classification

The aquifer classification system used to classify South African aquifers is the National Aquifer Classification System developed by Parsons (1995). This system has a certain amount of flexibility and can be linked to second classifications such as a vulnerability or usage classification. Parsons suggests that aquifer classification forms a very useful planning tool that can be used to guide the management of groundwater issues. He also suggests that some level of flexibility should be incorporated when using a classification system.

The South African Aquifer System Management Classification is presented by five major classes:

- Sole Source Aquifer System
- Major Aquifer System
- Minor Aquifer System
- Non-Aquifer System
- Special Aquifer System

The definitions in Table 9 are taken from Parsons (1995) and applied as an aquifer classification system:

Table 9: Aquifer classification scheme (Parsons, 1995)

Aquifer system	Defined by Parsons (1995)	Defined by DWA minimum requirements (DWAF, 1998)
Sole source aquifer	An aquifer that is used to supply 50% or more of domestic water for a given area, and for which there are no reasonable alternative sources should the aquifer become depleted or impacted upon. Aquifer yields and natural water quality are immaterial.	An aquifer, which is used to supply 50% or more of urban domestic water for a given area for which there are no reasonably available alternative sources should this aquifer be impacted upon or depleted.
Major aquifer	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.	High yielding aquifer (5-20 L/s) of acceptable water quality.
Minor aquifer	These can be fractured or potentially fractured rocks that do not have a high primary hydraulic conductivity, or other formations of variable	Moderately yielding aquifer (1-5 L/s) of acceptable quality or high yielding aquifer (5-20 L/s) of poor

	hydraulic conductivity. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are both important for local supplies and in supplying base flow for rivers.	quality water.
Non-aquifer	These are formations with negligible hydraulic conductivity that are generally 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 does occur, although imperceptible, and needs to be considered when assessing risk associated with persistent pollutants.	Insignificantly yielding aquifer (< 1 L/s) of good quality water or moderately yielding aquifer (1-5 L/s) of poor quality or aquifer which will never be utilised for water supply and which will not contaminate other aquifers.
Special aquifer	An aquifer designated as such by the Minister of Water Affairs, after due process.	

Droogefontein is directly underlain by rocks of the Vryheid Formation occurring in the Ecca Group of the Karoo Supergroup. The Vryheid Formation consists predominantly of thick beds of yellowish to white cross-bedded sandstone and grit alternating with beds of soft sandy shale. The Vryheid Formation also contains coal seams and is widely intruded by dolerite sills. The Ecca Group overlies the Dwyka Group (tillites) of rocks which in turn overlies the Malmani subgroup (dolomite) of the Transvaal Supergroup.

According to the regional aquifer classification map of South Africa, the dolomite aquifer located at Delmas has been identified as a sole source aquifer system with good groundwater quality (<300 mg/l TDS) with a high vulnerability and high susceptibility to contamination. The surrounding Karoo aquifer has been identified as a minor aquifer also with good groundwater quality (<300 mg/l TDS) with a moderate vulnerability and a medium susceptibility to contamination.

Based on the underlying hydrogeology of the project area, water availability and the corresponding aquifer test results and analyses, the aquifers have been classified according to Parsons and system as follows:

- Shallow Aquifer – Non-aquifer
- **Fractured Karoo Aquifer - Sole Aquifer**
- Dwyka Tillite Aquifer - Non Aquifer
- Basement Karst Aquifer - Major Aquifer

It should be noted that due to the fact that the fractured Karoo aquifer is the only source of water for the Droogefontein and Prosperity small holdings landowners, and that no other realistic source are obtainable, this aquifer is regarded as a sole source aquifer.

5.6 Aquifer vulnerability

Table 10 summarizes the rating and weighting values and the final score for the regional vulnerability of the aquifer/s in vicinity of Droogefontein. The final **DRASTIC score of 120** indicates that the aquifer/s in the region has a medium to high susceptibility to pollution and a **high level of aquifer protection** is therefore required.

Table 10: DRASTIC vulnerability scores

Factor	Range/Type	Weight	Rating	Total
D	0 - 15 m	5	8	40
R	10 - 50 mm	4	6	24
A	Fractured	3	6	18
S	Sandy-clay-loam	2	4	8
T	0-2%	1	10	10
I	Karoo (northern)	5	4	20
C	-	3	-	-
DRASTIC SCORE = 120				

Reasonable and sound groundwater protection measures are recommended to ensure that no cumulative pollution affects the aquifer, during construction, operational and closure. 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
- Protection of the wetland

6. Droogefontein Hydrogeology

6.1 Geology

The stratigraphy throughout the Droogefontein area is typical of the Vischkuil sub-basin. Within the area the Vryheid Formation rests unconformably on Dwyka Group diamictites, which in turn rest on dolomite of the Transvaal Supergroup and Chuniespoort Group (Malmani subgroup). In the Springs-Vischkuil block the coal seams are very inconsistently developed, and where present, more closely resemble those of the South Rand Coalfield. Three seams, namely the top, middle and bottom seams are recognized. The top and middle seams can possibly be correlated with the No. 5 and No. 4 seams and the thicker bottom seam appears to represent a combination of the No. 1, 2 and 3 seams of the main Witbank Coalfield. Logs of the exploration boreholes are illustrated in figures 9 to 11. These logs show that the geology are comprised of a topsoil layer of approximately 5-8 m deep which is followed by a clay layer of approximately 0.35 – 0.40 m in thickness. The bedrock consists of alternating sandstone, mudstone and siltstone of the Ecca Group which overlie tillite of the Dwyka Group of rocks at approximately 40 – 50 mbgl. A dolerite sill/dyke of unknown thickness was intersected in borehole DN17 at 16.04, 34.68 and 40.12 mbgl. The Dwyka tillite overlies dolomite of the Chuniespoort Group (Malmani subgroup). Although not intersected during exploration, logs of boreholes drilled in the Vryheid Formation of similar and nearby environments indicate the presence of dolomite at approximately 60 to 120 mbgl.

The geological map (refer to Figure 6) indicates that the eastern perimeter is underlain by alluvial material. The drill logs indicate that a clay layer is present at between 5 and 6 mbgl. The alluvial material may act as sponge which absorbs water rapidly until it reaches the clay layer below it. Such physical attributes are optimal for the establishment of wetlands (verified by wetland consultant to be a C-class wetland - Limosella Consulting, September 2013).

6.2 Hydrocensus

Hydrocensus surveys of boreholes on and surrounding portions 26, 46 and 47 was conducted during which all groundwater users around the proposed areas were surveyed. During the hydrocensus, all available details of boreholes and borehole-owners were collected. This information was used to assess the risk posed by the mining activities on the groundwater regime and users thereof. The hydrocensus boreholes were sampled for chemical analysis to evaluate the chemical characteristics of the groundwater and to establish baseline data prior to commencement of mining activities.

More information regarding the hydrocensus can be viewed in Appendix C.

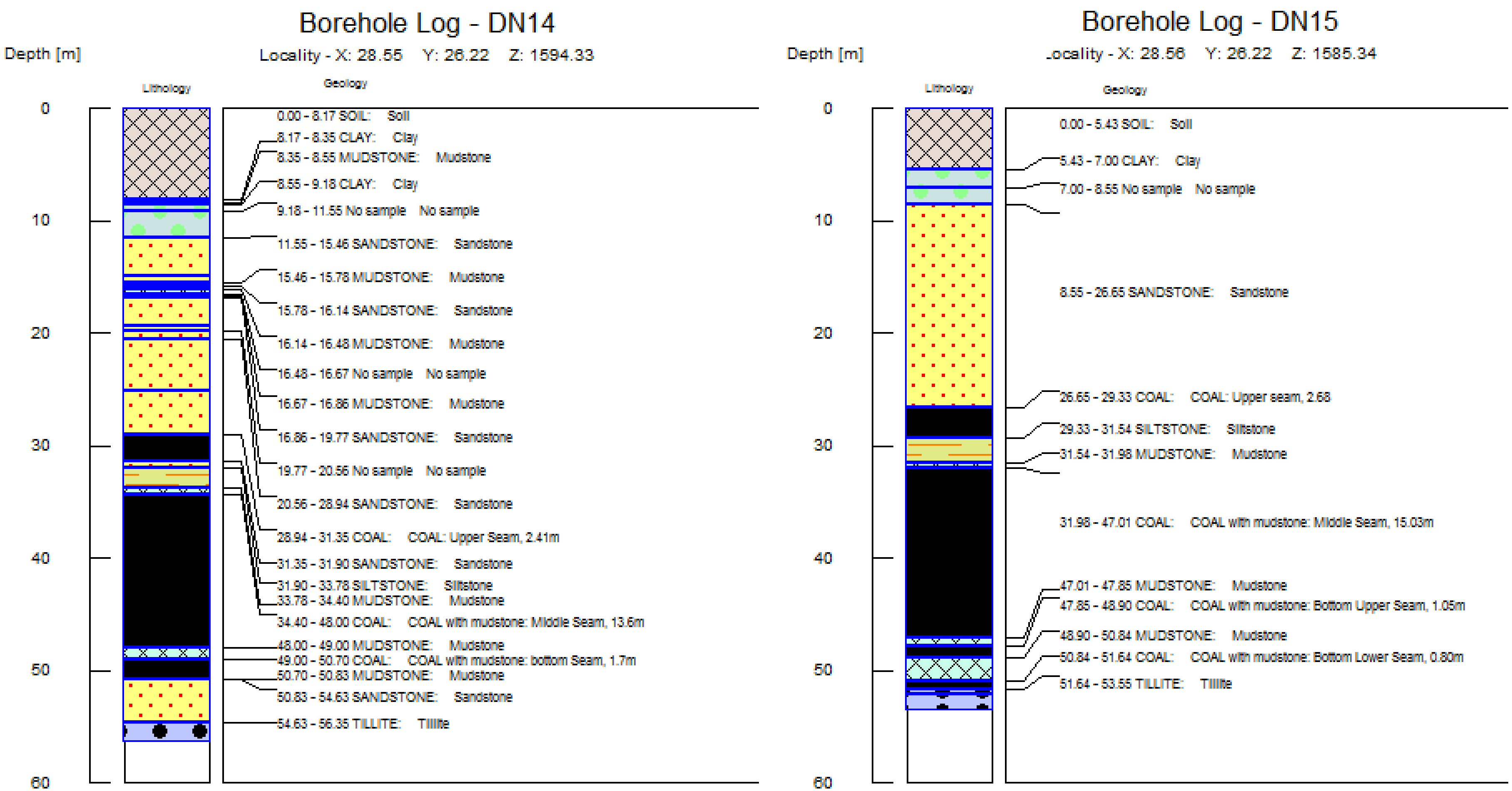

Figure 9: Geology logs of exploration boreholes DN14 and DN15

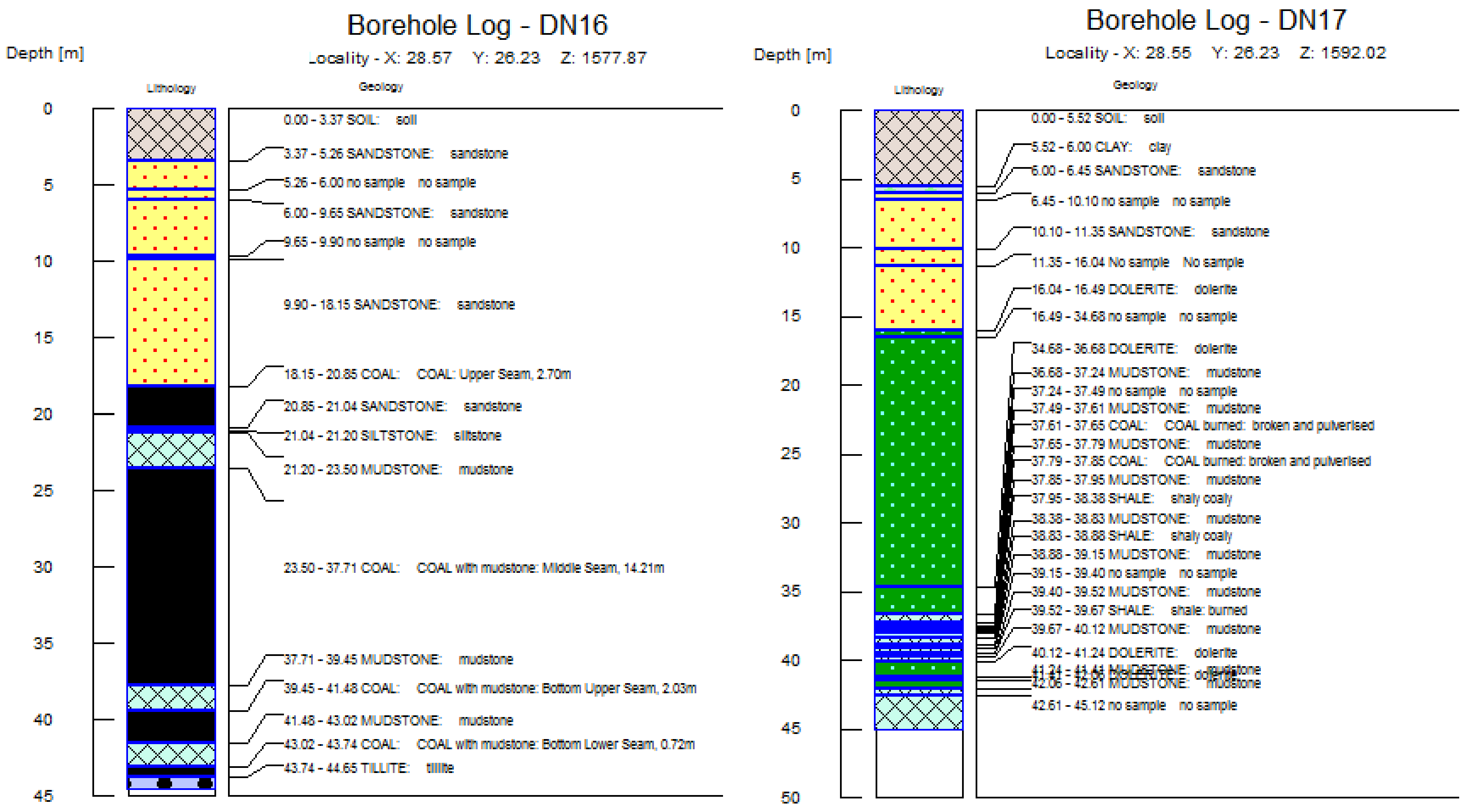

Figure 10: Geology logs of exploration boreholes DN16 and DN17

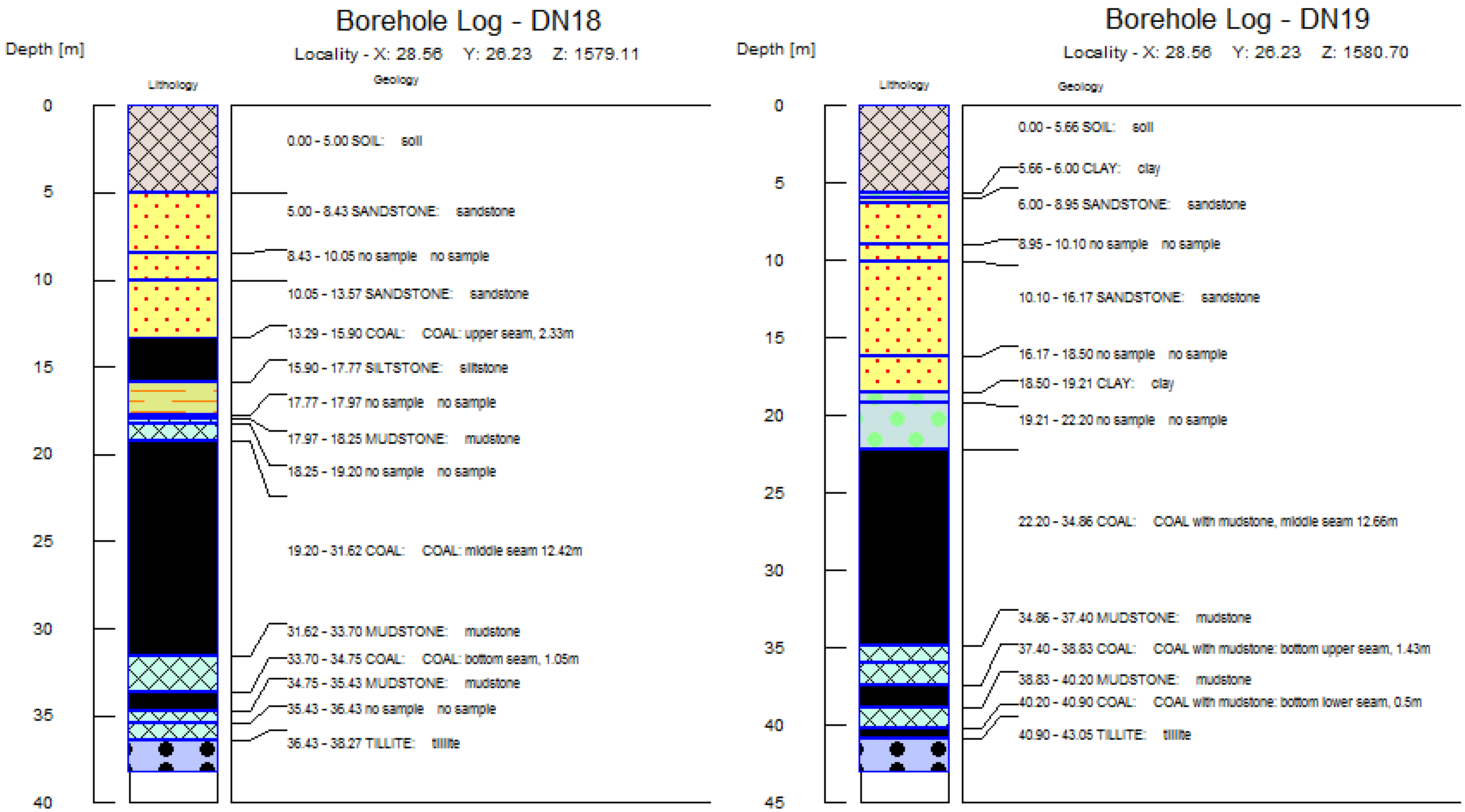

Figure 11: Geology logs of exploration boreholes DN18 and DN19

6.2.1 Portion 26

A detailed hydrocensus was conducted in 2 km radius on and around portion 26 to obtain a representative population of the boreholes and springs on the properties of adjacent land owners. A total of 38 boreholes were surveyed in a 2 km radius around portion 26 where the open pit coal mine is proposed. The results from the hydrocensus are summarized in Table 11 and a map showing their positions relative to the mining infrastructure in Figure 12. The hydrocensus and water user survey revealed that groundwater abstracted from these boreholes is mainly used for domestic supply, livestock watering and watering of gardens at farmsteads. *The landowners included in the Portion 26 hydrocensus rely solely on the groundwater for their water supply since municipal water is not available.* The Karoo aquifers present poor aquifers and typically yield less than 2 l/s. However, deeper boreholes >150 m may intersect the dolomitic aquifer which could yield in excess of 5 l/s.

Water levels could not be obtained from seven (7) boreholes as a result of no access to water levels while 19 of the surveyed boreholes were either pumping or recovering from pumping during the hydrocensus. Static unaffected water levels ranged between 3.55 mbgl and 18.54 mbgl.

Static water level elevations, excluding pumping or recovering boreholes and water levels obtained from the dolomitic aquifer, were plotted against surface elevation/topography and shown in Figure 13. This was done to assess whether a Bayesian correlation exists between the water level and surface topography. A relatively good Bayesian correlation of 83% exists between the surface topography and groundwater level elevation. An assumption that groundwater flow paths will mimic surface topography can therefore be inferred. Due to the sparse availability of static groundwater level data to model a subsurface flow contour map, surface contours was used to estimate flow paths. Figure 14 shows that drainage occurs towards the '*Dwars in die Wegvlei'* wetland from portion 26 to the west of the drainage line and also from the higher lying areas from the east of the wetland/ drainage system.

6.2.1.1 Ground and surface water interaction

During the site visit on the 4th of September 2013, no surface flow was visible in the natural drainage line. It is still however expected that groundwater seepage occurs towards the drainage line during the dryer winter months but will not daylight into this system given the lower hydraulic heads in the dry season. When the hydraulic heads do increase during the summer rainfall months it is expected that groundwater seeping from portion 26 will contribute as groundwater contribution to baseflow and will daylight into this system. Decanting is also expected to occur on the lowest topographical point after closure when the hydraulic heads have returned to baseline levels.

Table 11: Portion 26 hydrocensus results

Borehole ID	Coordinates	Property	Owner	Collar WL (m)	pH	EC (mS/m)	Application	Aquifer	Equipped	Approx yield (l/s)
DN08	S26.23204 E28.55963	Droogefontein 242 Ir/26	SM Boerdery Thinus van Dyk	3.5	8.47	27.6	Exploration	Karoo	No	0.1-0.5
DN09	S26.23282 E28.56392			5.4	7.89	22.2			No	0.1-0.5
DN13	S26.22874 E28.56518			4.88	8.08	44.7			No	0.1-0.5
DN20	S26.21735 E28.55457	Droogefontein 242 Ir/39		NAWL	7.45	51.4	Livestock watering, domestic*	Malmani dolomite	Yes	10
DN21	S26.22248 E28.55331	Droogefontein 242 Ir/31		12.78	7.25	40.2	Irrigation (small scale)	Karoo	Yes	0.1-0.5
DN22	S26.21609 E28.54211	Droogefontein 242 Ir/33		NAWL	7.91	52.3	Livestock watering, domestic*	Malmani dolomite	Yes	5
DN23	S26.20759 E28.54143			10.18	7.4	21.1	Irrigation (small scale), domestic*	Karoo	Yes	0.1-0.5
DN24	S26.21214 E28.54075			20.54	7.5	47.9	Domestic*		Yes	0.1-0.5
DN25	S26.21516 E28.55783	Droogefontein 242 Ir/21	Dan Retief. Schoemans Boerdery	5.79	7.92	33.7	Domestic*		Yes	0.1-0.5
DN26	S26.23536 E28.57491	Droogefontein 242 Ir/25	SM Boerdery Thinus van Dyk	8.28	6.82	28.1	Domestic*, irrigation (small scale)		Yes	0.1-0.5
DN27	S26.25051 E28.56248	Palmietkuilen 241	Dan Retief. Schoemans Boerdery	12.07			None		No	0.5
DN28	S26.25150 E28.56246			11.94	6.52	19.5	None		No	0.1-0.5
DN29	S26.24358 E28.57785			8.55	6.81	36.3	Domestic*, irrigation (small scale		Yes	0.1-0.5

DN43	S26.20796 E28.57349	Droogefontein ptn 25	Steven Victor	31.0	7.42	35.9	Domestic*, livestock	Karoo	Yes	~1.0
DN44	S26.20845 E28.57610			NAWL			None	Karoo	No	-
DN45	S26.20414 E28.56024	Droogefontein ptn 20	JC Du Plessis	25.55	7.05	36.4	Domestic*, irrigation (small scale)	Karoo	Yes	~1.0
DN46	S26.22152 E28.54140	Plot 40 Prosperity	Jan Hattingh	±100	7.7	55.2	Domestic*, irrigation (small scale)	Dolomite/karst	Yes	>5
DN47	S26.22303 E28.53882	Plot 51 Prosperity	Rudi Kocks	34.5	7.28	25.0	Domestic*, irrigation, livestock	Karoo	Yes	~1.0
DN48	S26.22267 E28.53817	Plot 35 Prosperity	Annemarie Bendelberg	34.33	7.01	98.2	Domestic*, irrigation (small scale)	Karoo	Yes	~1.0
DN49	S26.22091 E28.53925	Plot 40 Prosperity	Jan Hattingh	16.55	6.08	34.0	None	Unknown	No	-
DN50	S26.22416 E28.54096	Plot 54 Prosperity	Rodney Craukamp	33.78	7.13	41.4	Domestic*, irrigation	Karoo	Yes	~1.5
DN51	S26.22518 E28.54018	Plot 54;56 Prosperity	FJ Prinsloo	17.32	7.12	37.6	Domestic*, irrigation (small scale)	Karoo	Yes	~1.0
DN53	S26.22529 E28.53105	Plot 12 Prosperity	Neurita Gort	16.6	7.23	49.9	None	Unknown	No	-
DN54	S26.22592 E28.53719	Plot 42 Prosperity	Paul Marnevick	20.40	6.88	36.5	None	Unknown	No	-
DN55	S26.22539 E28.53676			29.03	7.49	31.5	Domestic*	Karoo	Yes	Unknown
DN56	S26.22535 E28.53732			10.2	6.9	51.8	Domestic*	Karoo	Yes	Unknown
DN57	S26.22548 E28.53729			100.52	7.5	51.8	Domestic*	Karoo/Dolomite	No	Unknown
DN58	S26.22188 E28.53834	Plot 33 Prosperity	Nico Venter	-	7.9	78.3	Domestic*	Karoo/Dolomite	Yes	Unknown

DN59	S26.21802 E28.53913	Plot 27 Prosperity	Roy Atkins	32.05	7.72	57.3	Domestic*, irrigation (small scale)	Karoo	Yes	~1.0
DN60	S26.21832 E28.53650	Plot 11 Prosperity	Sindiso Giqwa	NAWL	7.60	163.6	Domestic*, livestock	Unknown	Yes	Unknown
DN61	S26.22128 E28.53552	Plot 17 Prosperity	Jaco Labuschagne	49.69	7.65	49.5	Domestic*, livestock	Karoo	Yes	~1.0
DN62	S26.22013 E28.53472			22.33	7.71	34.6	None	Karoo	No	Unknown
DN63	S26.22000 E28.53653	Plot 30 Prosperity	Hennie Nagel	56.95	7.28	72.2	Domestic*, irrigation, livestock	Karoo	Yes	~1.0
DN64	S26.22515 E28.53294	Plot 25 Prosperity	Hannes Nagel	18.54	7.88	37.7	Domestic*, irrigation, livestock	Karoo	Yes	~4.0
DN65	S26.22427 E28.53266			19.77	7.88	26.1	Domestic*, irrigation, livestock	Karoo	Yes	~3.0
DN66	S26.22544 E28.53456	Plot 41 Prosperity	Dewald Geldenhuys	48.24	7.97	24.6	Domestic*, irrigation, livestock	Karoo	Yes	~3.0
DN67	S26.22285 E28.53264	Plot 20 Prosperity	Wollie Wolmarans	25.58	6.7	34.6	Domestic*, irrigation, livestock	Karoo	Yes	~1.5
DN68	S26.22116 E28.53293			16.38	-	21.0	Domestic*	Karoo	Yes	~1.0
DN69	S26.21906 E28.53153	Plot 5 Prosperity	Gert Greyvenstein	NAWL	7.39	49.8	Domestic*, livestock	Karoo	Yes	~1.0
DN70	S26.21933 E28.53155			66.35	-	70.2	Domestic*, livestock	Karoo	Yes	~1.0
DN71	S26.21761 E28.53399	Prosperity	Naas Swanepoel	11.60	7.3	40.2	Domestic*	Karoo	Yes	~1.0
DN72	S26.22615 E28.53908	Plot 58 Prosperity	Hannes Van der Westhuizen	28.0	7.38	40.5	Domestic*, irrigation	Karoo	Yes	~1.5

*Sole source of water supply

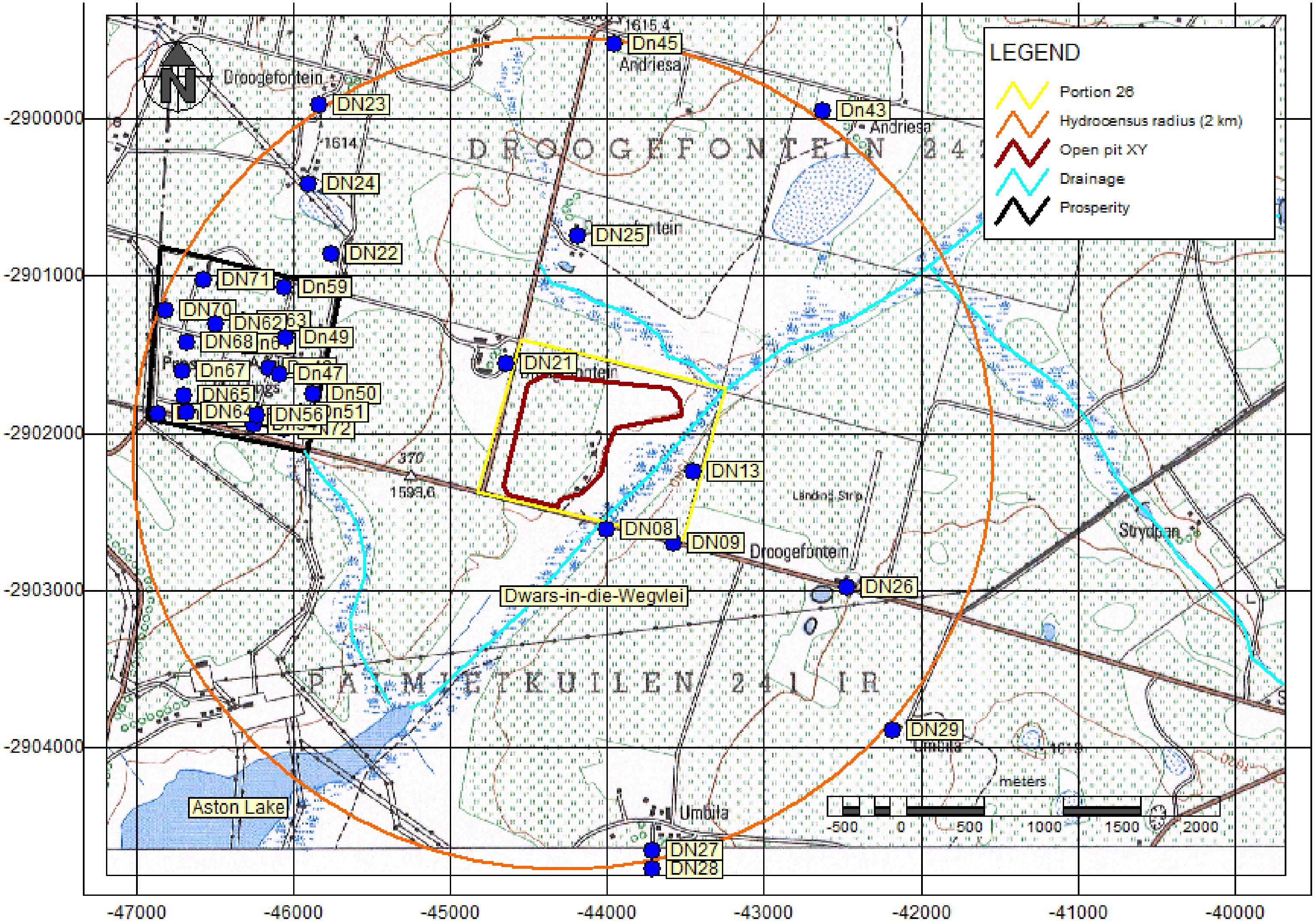

Figure 12: Droogefontein portion 26 hydrocensus map

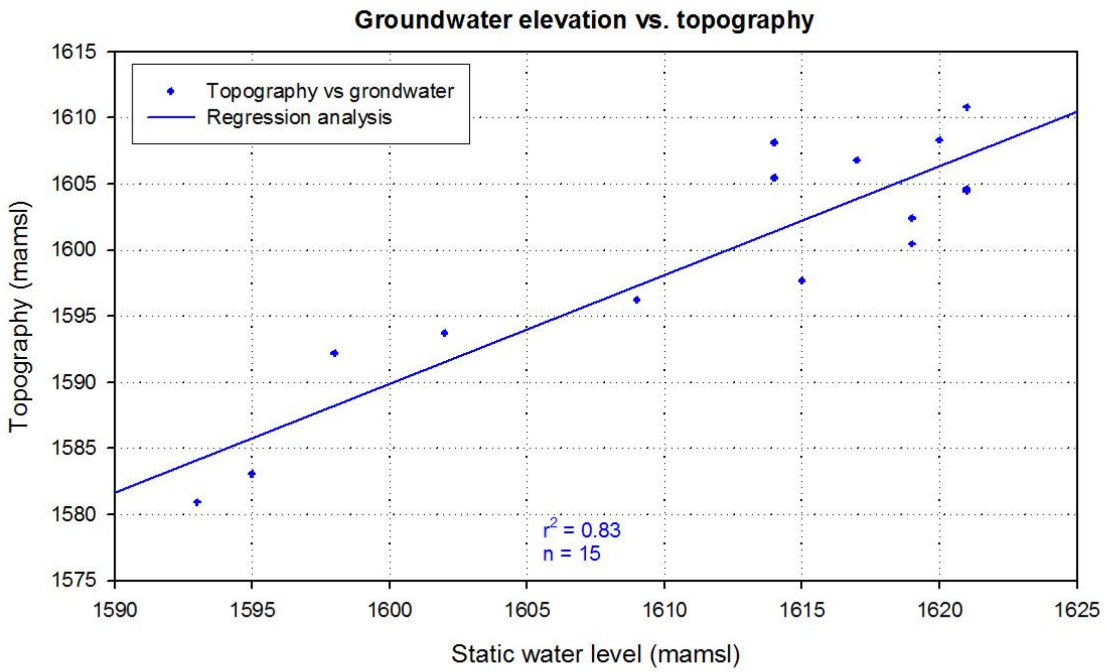

Figure 13: Static groundwater elevations vs. topography

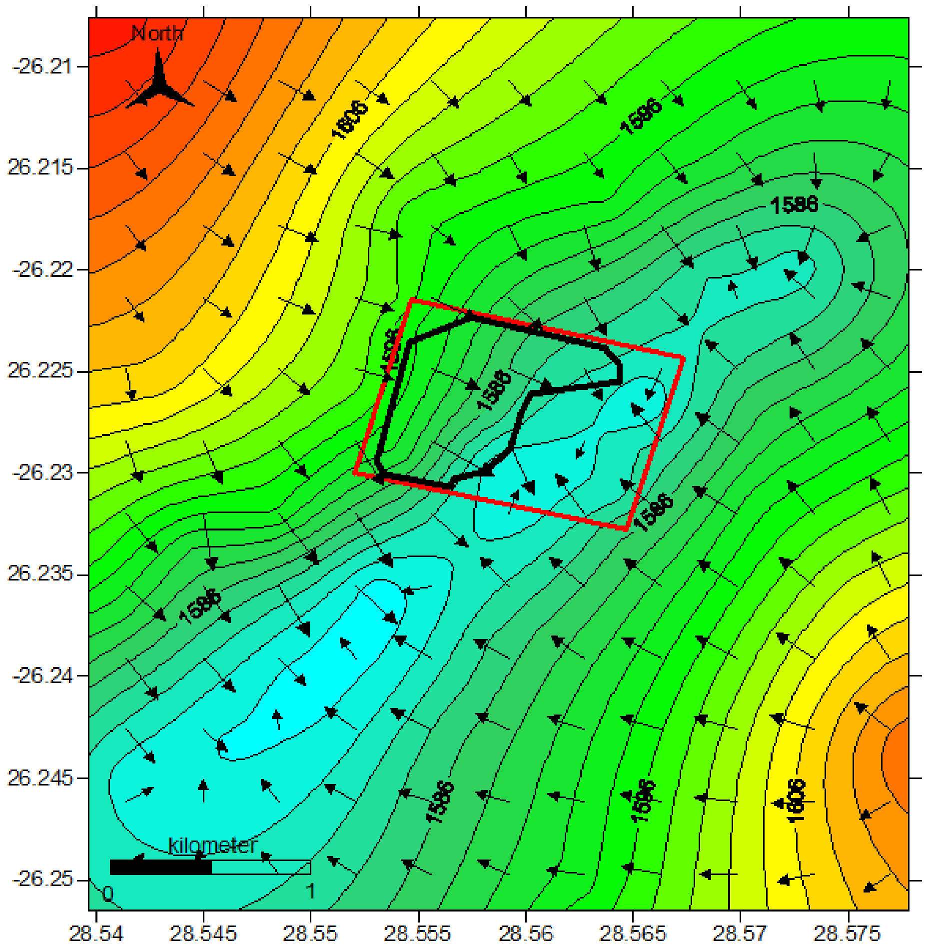

Figure 14: Surface topography contour map

6.2.2 Portion 46 and 47

A detailed hydrocensus was conducted in 2 km radius on and around portions 46 and 47 to obtain a representative population of the boreholes and springs on the properties of adjacent land owners. A total of 13 boreholes were surveyed in a 2 km radius around portions 46 and 47. These portions were included in the hydrocensus due to their inclusion in the mining right application although no activities are planned on these properties. The initial strategy was that the plant and workshops would be erected on portions 46 and 47 but this was later rejected given the distance to portion 26 and the pit.

The results from the hydrocensus are summarized in Table 12 and a map showing their positions relative to the mining infrastructure in Figure 15. The hydrocensus and water user survey revealed that groundwater from these boreholes is used mainly for domestic supply, livestock watering and watering of gardens at farmsteads.

Table 12: Hydrocensus information for portions 46 and 47

Borehole ID	Coordinates	Property	Owner	Collar WL (m)	pH	EC (mS/m)	Application	Aquifer	Equipped	Yield (l/s)
DN30	S26.18661 E28.55896	Droogefontein 242 Ir/3	Danie van Wyk	89.0	7.82	72.2	Irrigation, domestic	Malmani dolomite	Yes	8
DN31	S26.19052 E28.55371	Droogefontein 242 Ir/44	Danie van Wyk	91.0			Irrigation, domestic	Malmani dolomite	Yes	23
DN32	S26.19697 E28.56300	Droogefontein 242 Ir/3	Danie van Wyk	94.6	7.37	70.6	Irrigation	Malmani dolomite	Yes	20
DN33	S26.20565 E28.55396	Droogefontein 242 Ir/29	Danie van Wyk	NAWL	7.73	27.7	Livestock watering	Karoo	Yes	0.5-1.0
DN34	S26.18827 E28.56061	Droogefontein 242 Ir/46	Michael Vereker	40.21	7.54	28.1	Domestic, irrigation (small scale)	-	Yes	-
DN35	S26.18763 E28.56013	Droogefontein 242 Ir/47	Ockie Bezuidenhout	20.12	7.63	22	Livestock watering, domestic	-	Yes	-
DN36	S26.18203 E28.56246	Droogefontein 242 Ir/68	Roy Shearer	77.05	-	-	Domestic	Malmani dolomite	Yes	>5
DN37	S26.18264 E28.56452	Droogefontein 242 Ir/68	Sampie Venter	NAWL	-	-	Boreholes sealed. Possibility of future use	-	No	-
DN38	S26.18444 E28.55955	Droogefontein 242 Ir/38	Debbie Van Den Heever	1.2	-	-	Possible future use: Commercial car wash, domestic	-	No	-
DN39	S26.18347 E28.55722	Droogefontein 242 Ir/38	Gideon Steenberg	21.36	8.02	55.3	Domestic	Karoo	Yes	0.5-1.0
DN40	S26.18317 E28.55673	Droogefontein 242 Ir/38	Frederick Zeelie	20.21	8.01	34.1	Livestock watering: sheep	Karoo	Yes	0.5-1.0
DN41	S26.18628 E28.55533	Droogefontein 242 Ir/38	Pieter Senekal	NAWL-bees	7.38	29.1	None	-	No	-
DN42	S26.18205 E28.55694	Droogefontein 242 Ir/38	Roy Shearer	60.05	7.82	55.4	Domestic, irrigation (small scale)	Malmani dolomite	Yes	>5

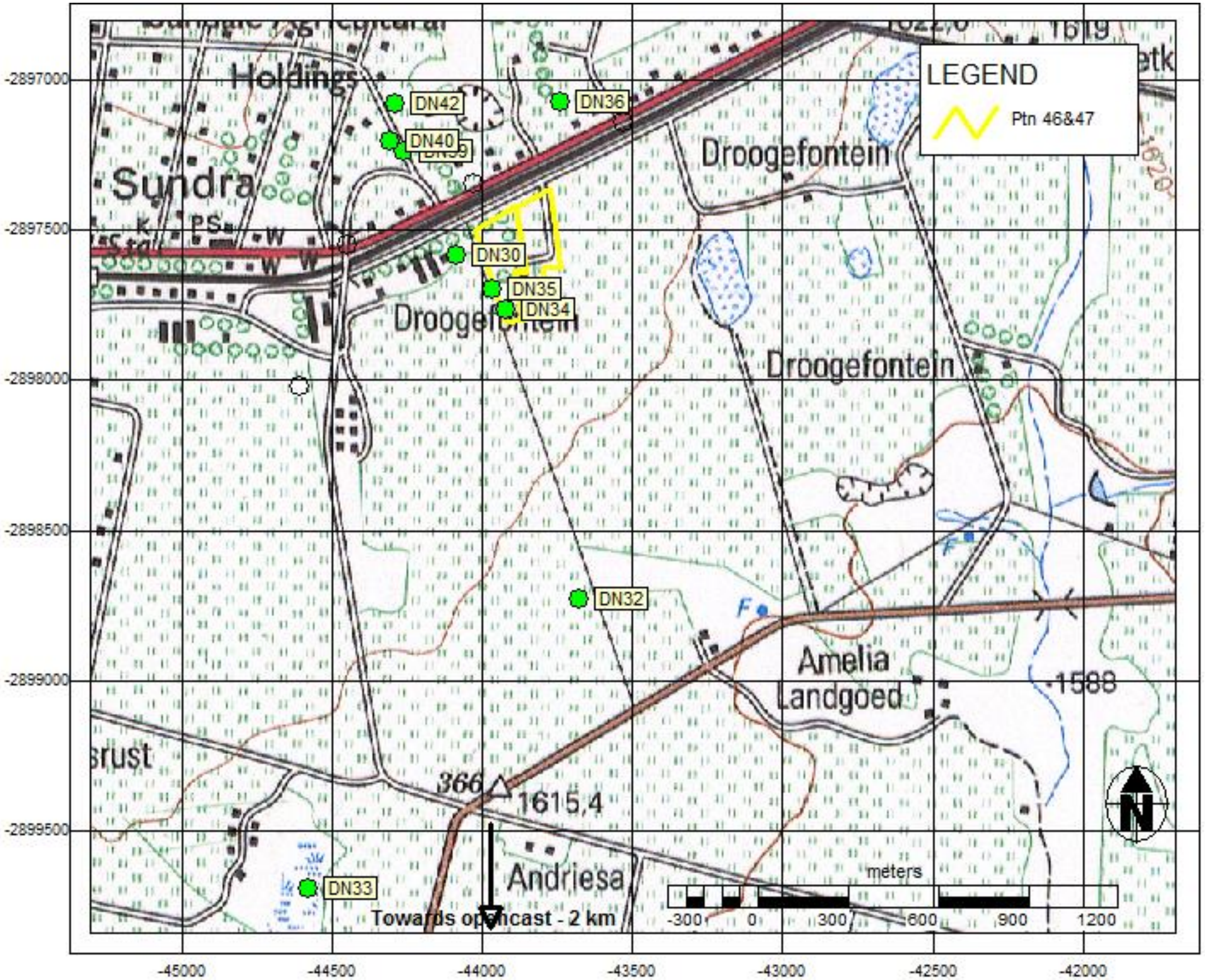

Figure 15: Droogefontein portions 46 and 47 hydrocensus map

6.3 Groundwater quality

Groundwater samples were collected from the hydrocensus boreholes. The samples were submitted to Yanka Laboratories situated in Witbank. Yanka takes part in the SABS inorganic inter-laboratory testing scheme (z-score = 0.73), including in the National Laboratory Association Water Microbiology Proficiency Test Scheme. The laboratory is in the process of achieving SANAS accreditation (ISO/IEC 17025:2005). Water quality was interpreted based on the domestic colour coded classification system (refer to Table 1; WRC, 1998), including the South African Nation Standard for drinking water (SANS 241: 2011; refer to Table 2). Laboratory certificates can be viewed in Appendix A.

6.3.1 Portion 26

Selected hydrochemical data for portion 26 hydrocensus boreholes are shown in Table 13. The results indicate that most parameters recorded well within the SANS: 241 guidelines and can be classified as *Ideal (class 0)* with neutral, non-saline and soft to very hard water. However, groundwater sampled from DN08, DN09, DN13 and D22 recorded high to very high levels of inorganic N – DN08, DN09 and DN13 as NH_4 and DN22 as NO_3, consequently exceeding the SANS: 241 guidelines. DN23 recorded a Fe concentration of 2.42 mg/l exceeding SANS 241 guidelines with a classification of *Marginal* (class 02). In terms of domestic classification, DN08 can be classified as *Marginal (class 02)*, DN09 as *Poor* (*class 03*), DN13 as *Good (class 01*) and DN22 as *Marginal (class 02)*.

The chemistry analyses supplied in Table 13 should serve as baseline water quality throughout the life of the proposed mining operations.

Stiff diagrams displayed in Figure 16 and the Expanded Durov diagram in Figure 17 display mostly Ca-HCO_3^- water types while the boreholes DN08, DN09 and DN13 display Na-HCO_3-(Cl) water types. The Expanded Durov diagram indicate mostly unpolluted fresh and recently recharged water plotting in fields 1 and 2 of the Durov; only DN08 plotted in Field 3 indicating possible Na-Cl enrichment. The Durov diagram also indicates that boreholes DN09 and DN13 are grouped separately from the remaining boreholes in Field 2 which may also indicate a level of Na-Cl enrichment. The above-mentioned boreholes with Na-HCO_3^-(Cl facies) are all exploration boreholes located in a maize field and the enrichment may be due irrigation activities and evapo-transpiration processes.

Table 13: Hydrochemical results for selected portion 26 hydrocensus boreholes

SAMPLE ID	DN08	DN09	DN13	DN20	DN21	DN22	DN23	DN24	DN25	DN26	DN28	DN29
Parameter												
pH	8.47	7.89	8.08	7.45	7.25	7.91	7.40	7.50	7.92	6.82	6.52	6.81
EC (mS/m)	27.6	22.2	44.7	51.4	40.2	52.3	21.1	47.9	33.7	28.1	19.5	36.3
TDS (mg/l)	145	148	216	260	203	288	106	252	170	146	96.8	184
Ca (mg/l)	8.57	11.4	14.8	52.1	38.1	52.0	19.7	48.7	34.2	26.1	19.7	30.8
Mg (mg/l)	4.08	5.09	14.9	22.6	13.2	19.4	6.59	15.0	13.0	10.4	4.42	12.7
Na (mg/l)	27.7	17.1	39.9	17.0	20.4	18.8	7.92	28.3	11.8	11.5	8.81	14.7
K (mg/l)	11.2	3.78	7.43	4.73	4.06	4.61	2.74	5.64	2.91	8.14	3.04	10.5
Cl (mg/l)	35.2	20.5	46.1	23.2	19.3	21.8	11.5	16.0	9.40	7.53	4.96	20.4
SO_4 (mg/l)	0.10	6.10	12.9	9.17	8.09	25.2	11.4	7.57	2.25	3.97	2.95	11.7
Talk (mg/l)	85.4	64.6	129	216	154	158	71.8	216	140	129	87.0	123
Hardness (mg $CaCO_3$/l)	38.2	49.4	98.3	223	149	210	76.3	183	139	108	67.4	129
NO_3 (mg N/l)	0.010	7.16	0.010	0.010	1.51	**11.4**	0.010	0.010	2.72	0.080	0.010	2.06
Total ammonia (mg/ Nl)	**5.00**	**10.1**	**1.64**	0.18	0.09	0.38	0.39	0.13	0.03	0.07	0.29	0.14
PO_4 (mg P/l)	<0.01	0.090	0.010	0.020	0.030	<0.01	0.050	<0.01	<0.01	0.030	0.010	<0.01
F (mg/l)	0.38	0.14	0.31	0.43	0.21	0.09	0.16	0.39	0.10	0.17	0.16	0.18
Si (mg/l)	0.700	2.37	1.82	12.7	26.3	20.6	6.96	14.2	20.9	27.1	15.6	26.3
Al (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Sb (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
As (mg/l)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005

Ba (mg/l)	<0.01	0.05	0.05	0.24	0.15	0.16	0.13	0.15	0.06	0.48	0.33	0.39
B (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cd (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cr (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cr^{6+} (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cu (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fe (mg/l)	<0.01	<0.01	0.070	0.180	<0.01	<0.01	**2.42**	0.230	<0.01	<0.01	<0.01	<0.01
Pb (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mn (mg/l)	<0.01	<0.01	<0.01	0.180	<0.01	<0.01	0.260	0.040	<0.01	<0.01	0.090	<0.01
Hg (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ni (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Se (mg/l)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
U (mg/)l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
V mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zn (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
COD (mg/)l	39.2	33.6	66.3	9.40	6.60	13.8	21.9	10.2	19.3	10.4	22.2	5.90
SAR	1.94	1.05	1.74	0.49	0.72	0.56	0.39	0.91	0.43	0.48	0.47	0.56
DWA classification	Class 02	Class 03	Class 01	Class 0	Class 0	Class 02	Class 02	Class 0	Class 0	Class 0	Class 0	Class 0
Worst parameter	Ammonia	Ammonia	Ammonia	-	-	NO3	Fe	-	-	-	-	-

Values denoted in red font exceeds SANS 241: 2011 drinking water quality guidelines

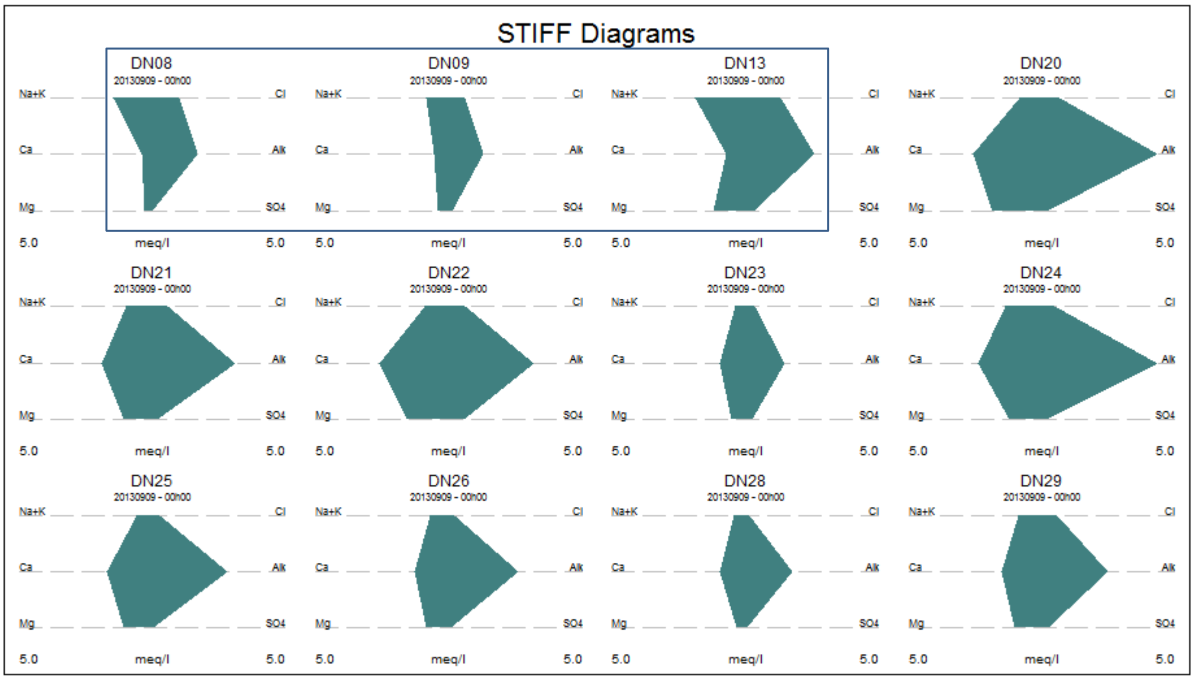

Figure 16: Stiff diagrams displaying major cation and anion distributions in meq/l for portion 26 hydrocensus boreholes

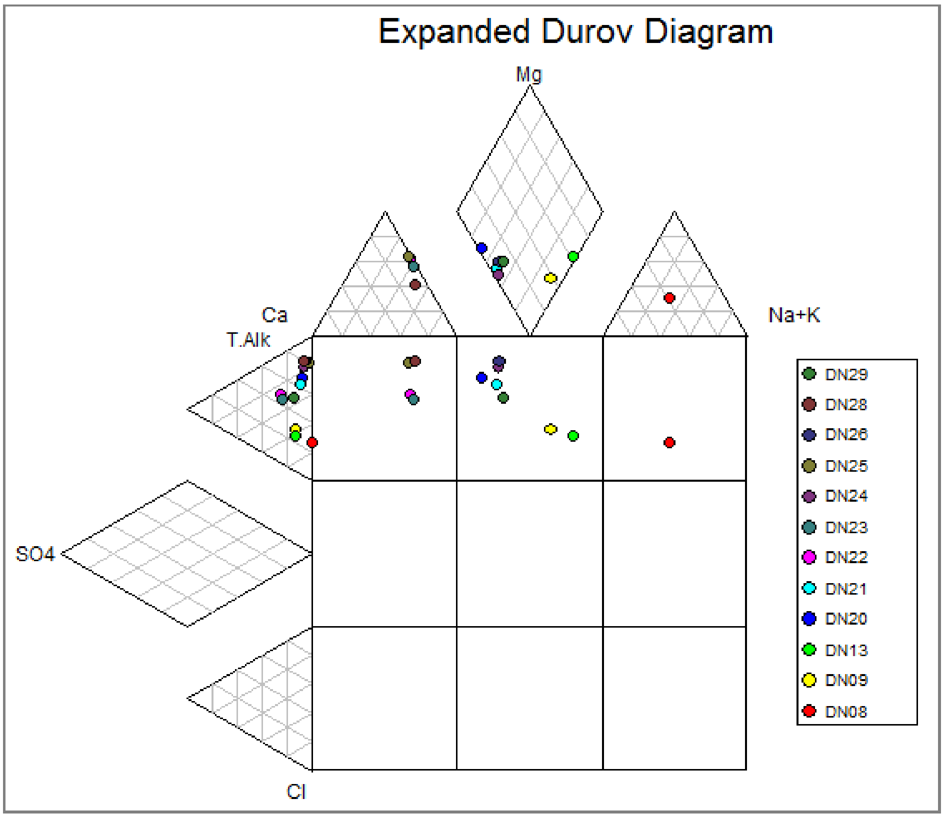

Figure 17: Expanded Durov diagram displaying ratios of major cations and anions in meq/l for portion 26 hydrocensus boreholes

6.3.2 Portion 46 and 47

The hydrochemical data evaluated according to the relevant standards are shown in Table 14. The results indicate that most parameters recorded well within the SANS: 241 standards and can be classified as *Ideal (class 0)* with neutral, non-saline and hard to very hard water typical of dolomitic aquifers. The majority of the hydrocensus boreholes drilled are in excess of 100 m which is the depth at which the Malmani dolomites are expected. Groundwater from a few boreholes recorded fluoride (F) in excess of the *Class 0* and *Class 01* standards (DWAF, 1998) and can be classified as *Marginal* (*Class 02*) as a result thereof. DN30, DN32 and DN36 recorded F of 1.37 mg/l, 1.36 mg/l and 1.38 mg/l, respectively. Slightly raised F was also recorded for DN33 and DN42 with 0.72 mg/l and 0.69 mg/l, respectively. The DWA (DWAF, 1998) proposes that F levels between 1.0 mg/l and 1.5 mg/l may pose increasing health based effects in sensitive groups and may result in tooth staining. Sensitive users as defined by DWA include:

- Children up to the age of 3 years.
- Individuals with HIV infection.
- Individuals with suboptimal dietary calcium.
- Individuals with liver of kidney disease.
- Individuals with malnutrition, particularly those with zinc deficiency.
- Individuals with a high daily water intake.
- Individuals with renal dialysis.

It should be noted that the upper limit for the SANS 241: 2011 health based guidelines for F intake is 1.5 mg/l (based upon consumption of 2 L of water per day by a person of a mass of 60 kg over a period of 70 years) – no sample exceeded this limit.

The chemistry analyses supplied in Table 14 should serve as baseline water quality for future planned activities on portions 46 and 47 (none planned currently). Stiff diagrams in Figure 18 displays water quality with dominantly Ca-HCO_3^- type facies. Samples from DN30, DN32 and DN36 display Na and HCO_3^- domination. The Expanded Durov diagram (Figure 19) displays water of three different types – these can be described as follows (see also Section 4.4.1 and Figure 1):

- Field 2: DN33-DN35; DN39, N40, DN42
    - Fresh, clean, relatively young groundwater that has started to undergo magnesium ion exchange, often found in dolomitic terrain.
- Field 3: DN32 and DN36
    - Fresh, clean, relatively young groundwater that has undergone sodium ion exchange (sometimes in sodium enriched granites or other felsic rocks). The dominance in sodium may also be as a result of sodium enriched pollution.
- Field 6: DN30
    - Groundwater from field 5 that has been in contact with a source rich in Na or old stagnant NaCl dominated water that resides in Na rich host rock/material.

Table 14: Hydrochemical results for the Droogefontein portion 46 and 47 hydrocensus boreholes

SAMPLE ID	DN30	DN32	DN33	DN34	DN35	DN36	DN39	DN40	DN42
pH	7.82	7.37	7.73	7.54	7.63	8.02	8.01	7.38	7.82
EC mS/m	72.2	70.6	27.7	28.1	22.0	55.3	34.1	29.1	55.4
TDS mg/l	421	383	148	145	115	299	184	150	301
Ca mg/l	20.80	20.4	22.4	24.6	22.5	17.8	37.8	22.1	45.0
Mg mg/l	10.40	10.60	8.7	9.8	7.0	7.6	14.98	9.8	22.1
Na mg/l	120.0	118.0	17.9	12.5	11.0	90.7	11.70	13.2	46.4
K mg/l	1.2	1.68	6.70	6.36	4.23	2.55	7.19	5.83	5.27
Cl mg/l	88.8	90.2	13.9	17.8	3.8	34.9	3.5	31.6	22.80
SO_4 mg/l	71.70	38.00	10.2	5.78	1.07	27.8	8.3	<0.01	9.59
Talk mg/l	176.0	169.0	110	85	97	193	166.0	95	246
Hardness mg $CaCO_3$/l	95	95	92	102	85	76	156	96	203
NO_3 mg N/l	0.220	0.14	<0.01	3.88	1.40	0.09	0.150	<0.01	0.18
Total ammonia mg N/l	0.25	0.4	0.95	0.05	0.03	<0.01	<0.01	0.05	0.17
PO_4 mg P/l	<0.01	<0.01	<0.01	<0.01	0.030	<0.01	<0.01	<0.01	<0.01
F mg/l	**1.37**	**1.36**	0.72	0.13	0.31	**1.38**	0.23	**1.36**	**0.69**
Si mg/l	7.280	6.91	1.05	24.4	28.0	9.7	28.50	22.7	11.5
Al mg/l	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	<0.01
Sb mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
As mg/l	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ba mg/l	0.12	0.11	0.10	0.06	0.10	0.09	0.04	0.04	0.03
B mg/l	0.50	0.49	<0.01	<0.01	<0.01	0.53	<0.01	<0.01	0.35
Cd mg/l	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Cr mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cu mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fe mg/l	<0.01	<0.01	0.250	<0.01	<0.01	<0.01	0.02	0.600	<0.01
Pb mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mn mg/l	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	0.34	<0.01
Hg mg/l	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ni mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Se mg/l	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sr mg/l	0.34	0.33	0.15	0.15	0.09	0.30	0.15	0.14	0.84
U mg/l	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
V mg/l	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zn mg/l	<0.01	<0.01	0.18	<0.01	<0.01	<0.01	<0.01	7.92	<0.01
COD mg/l	4.0	1.0	44.0	3.00	8.00	<1.00	1.0	1.0	3.0
SAR	5.34	5.26	0.81	0.54	0.52	4.51	0.41	0.59	1.41
DWA classification	class 02	class 02	class 01	class 0	class 0	class 02	class 0	class 0	class 0
Worst parameter	F	F	F	-	-	F	-	-	-

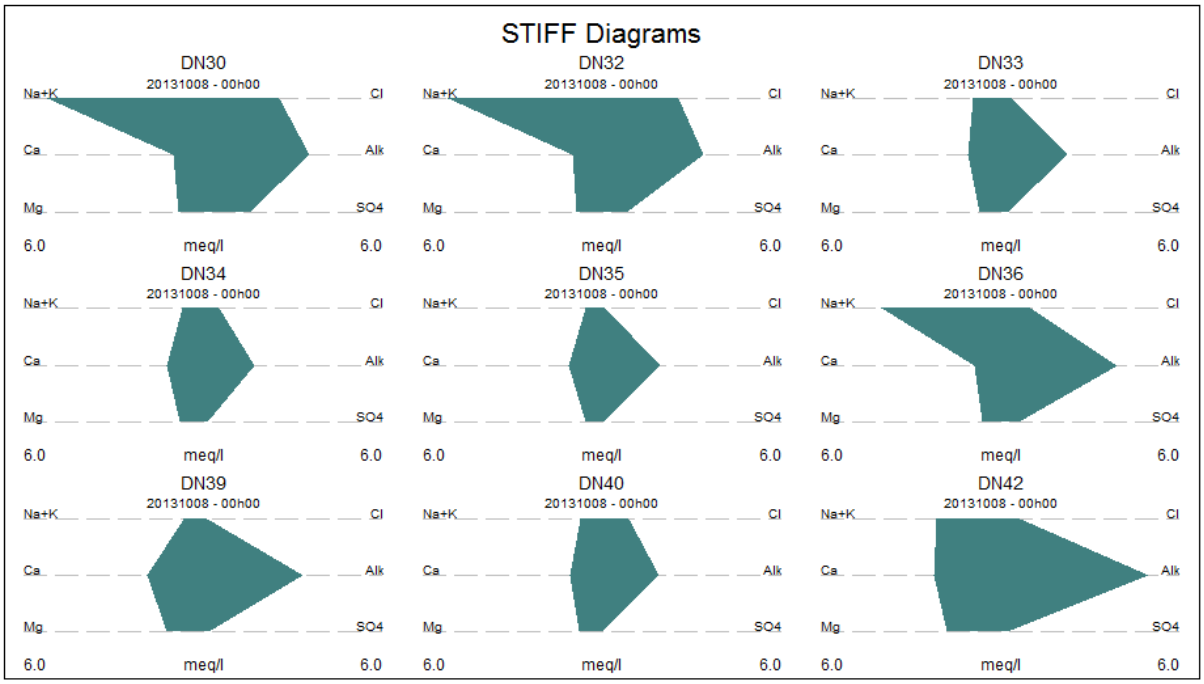

Figure 18: Stiff diagrams displaying major cation and anion distributions in meq/l for portion 46 and 47 hydrocensus boreholes

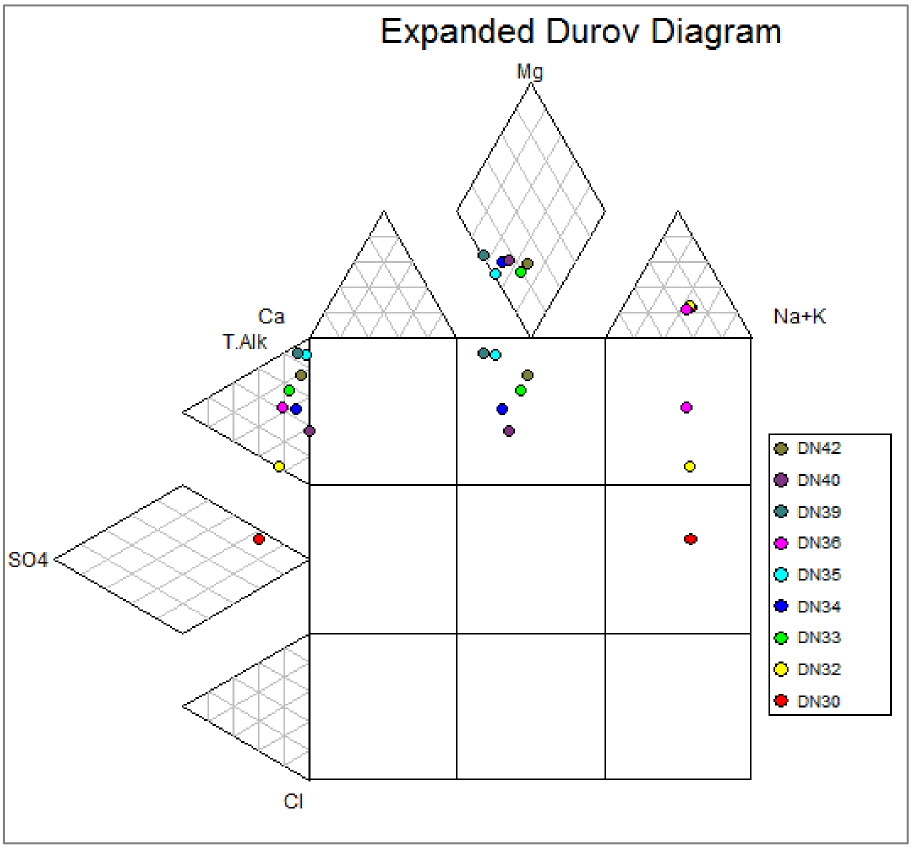

Figure 19: Expanded Durov diagram displaying ratios of major cations and anions in meq/l for portion 46 and 47 hydrocensus boreholes

6.4 Aquifer types, thickness and yields

An aquifer is comprised of a geological formation, or group of geological formations, or part of a formation that contains sufficient saturated permeable material to store and transmit water and to yield economical quantities of water to boreholes or springs. It is the storage medium from which groundwater is abstracted. *It should be managed properly and at all times be protected from over-exploitation and contamination.* The thickness and extent of an aquifer is influenced by fracture extent, orientation, aperture, as well as the thickness of the geological layers.

From studying the borehole logs of the exploration boreholes and aquifer tests, three aquifers can be distinguished within the study area:

i) Perched unconfined/semi-confined aquifer
ii) Weathered and fractured semi-confined sandstone aquifer
iii) Dolomitic confined aquifer

6.4.1 Shallow unconfined/perched aquifer

A shallow unconfined aquifer occurs within the soil horizon above the weathered bedrock zone. This unconfined or semi-confined aquifer is formed as a result of vertical seepage of water through the soil profile where it reaches the relatively impermeable clayey layer occurring at approximately 5 mbgl. The water will then seep horizontally in a downgradient direction on this contact zone. This layer is sometimes referred to as a perched aquifer. Usually this layer is poorly developed and is generally not considered as an aquifer given its inability to sustain reasonable or useful quantities of groundwater.

Slug tests were performed on three of the exploration boreholes to determine the aquifer parameters of this upper aquifer zone. With the slug test the hydraulic conductivity and transmissivity of this zone was determined from the rate of recovery of the water level in the boreholes after a 'slug' of water was displaced in the boreholes. Figure 20 illustrates the hydraulic data of the tests captured vs time. The slug test data was interpreted using the Bouwer and Rice method (Bouwer and Rice, 1976) and the software package Flow Characteristic Method (FC_Excel) developed by the Institute of Groundwater Studies for the determination of aquifer parameters and sustainable yields in fractured rock environments.

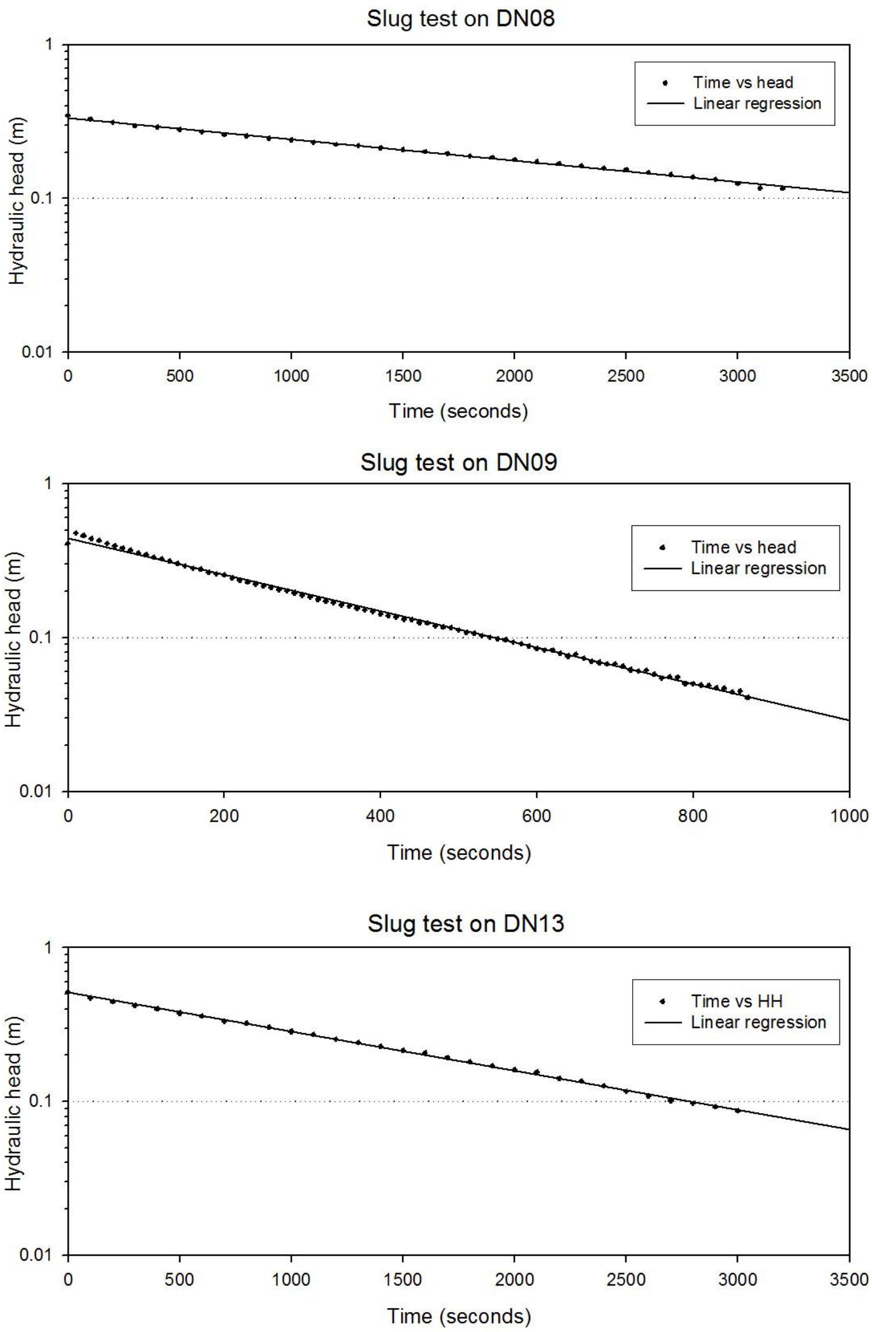

Figure 20: Time series graphs for hydraulic head recovery following slug tests on exploration boreholes

This shallow unconfined system has very low hydraulic conductivities and transmissivities and will therefore yield very little groundwater and can as a result not be regarded as an aquifer or be exploited as such. Table 15 illustrates the hydraulic conductivities and transmissivities calculated for this zone. The transmissivities were calculated using the Cooper and Jacob method using an aquifer thickness of 5 m. Average values for hydraulic conductivity and transmissivity were calculated to be 0.023 m/d and 0.115 m^2/d with probable groundwater yields of <0.05 l/s.

Table 15: Hydraulic parameters for the shallow unconfined zone

Borehole ID	Hydraulic conductivity (m/d)	Transmissivity (m^2/d)	Probable yield (l/s)
DN08	0.009	0.045	<0.05
DN09	0.05	0.25	<0.05
DN13	0.01	0.05	<0.05
Average	**0.023**	**0.115**	**<0.05**

6.4.2 Fractured semi-confined Karoo aquifer

The second aquifer system is an intergranular and fractured, semi-confined Karoo type aquifer of Ecca (shale/sandstone/tillite) origins occurring between 10 and 15 mbgl and with a thickness of approximately 80-100 m. Groundwater is confined to joints and fractures and flow in the matrix rock and usually has very low hydraulic conductivity and low yields. However, high yields do occasionally occur especially where dolerite intrusions (of Karoo age) have resulted in significant fracturing of the host rock. Of all un-weathered sediments in the fractured aquifer, the coal seam often has the highest hydraulic conductivity.

The Ecca overlies the Dwyka tillite which may form a separate aquifer but because of its negligible aquifer forming properties it is generally discussed as one with the Ecca aquifer. The aquifer permeability of the Dwyka tillite is estimated to be between 0.0002 and 0.0148 m/d (Hodgson and Krantz, 1998). The thickness of this aquifer varies from 0.5 to 30 m thick averaging at 8 m.

A constant rate pumping test was performed on the farm borehole DN21 (Figure 21) which intersects the Karoo Ecca and possibly the Dwyka aquifer. The transmissivity of the borehole was calculated using the Cooper and Jacob method (Cooper and Jacob, 1946) and the software package FC_Excel. The borehole was pumped at a low rate of 0.1 l/s for 130 min with maximum drawdown of 2.14 m achieved.

The aquifer can be regarded as heterogeneous having a good fracture network formed in the consolidated and mostly impervious matrix as a result of tectonic and depositional stresses. Movement of groundwater is mostly restricted to fracture and aperture flow although seepage through the sandstone/shale matrix may also contribute to the aquifer albeit very little. The transmissivity for the Karoo fractured aquifer is relatively low with a value of 3.9 m^2/d and a yield of approximately 0.5 – 1.0 l/s. The hydraulic conductivity (K) of the borehole was calculated using the transmissivity calculated and using an aquifer thickness (b) of 80 m by substituting the equation for calculating transmissivity, i.e. $T = Kb$ to read $K = T/b$ (refer to equations 2 & 3).

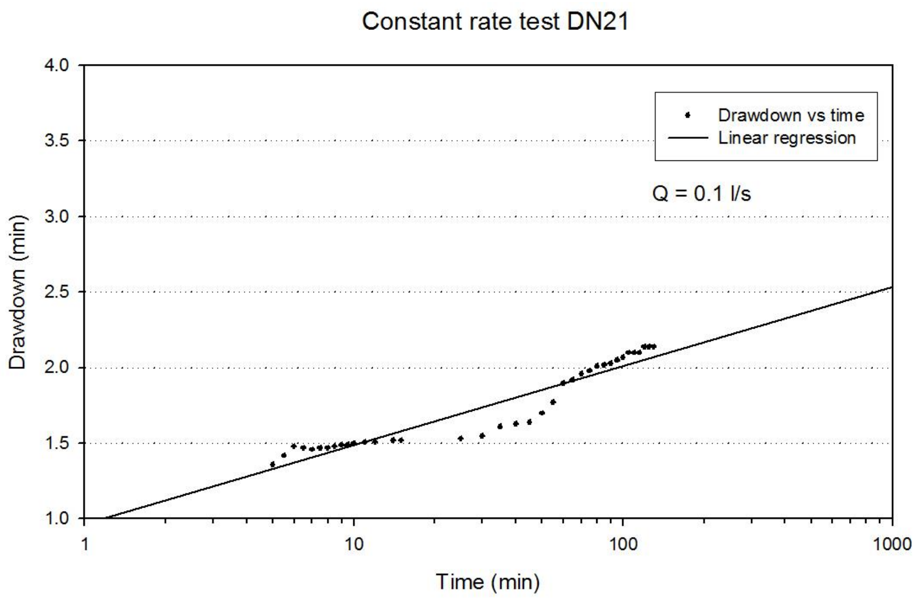

Figure 21: Drawdown data vs. time for the constant rate pumping test for DN21

The fractured rock aquifer is considered to be a more reliable source of groundwater compared to the weathered zone aquifer. The yield from this borehole/aquifer would be sufficient to supply drinking, sanitation and irrigation (small scale) water for a household but would not be sufficient to be exploited for mining related process water. The hydraulic parameters and proposed yield is summarised in Table 16.

Table 16: Hydraulic parameters for DN21 and the weathered and fractured Karoo aquifer

Borehole ID	Hydraulic conductivity (m/d)	Transmissivity (m^2/d)	Yield (l/s)
DN21	0.049	3.9	0.5 – 1.0

6.4.3 Dolomitic confined aquifer

Although no dolomite was intersected during the exploration phase, dolomite is expected to be present at approximately 80 – 150 mbgl. This assumption is made based upon the fact that boreholes drilled in similar and nearby environments did intersect dolomite at approximately 80 – 150 mbgl.

The aquifer is comprised of dolomite which forms part of the basement rocks of the Transvaal Supergroup and the Chuniespoort Group (Malmani subgroup) of rocks which is located directly below the Dwyka Group tillites. The Dwyka tillite forms a hydraulic barrier between the overlying mining activities and the basement aquifer, due to its low hydraulic conductivity. The continuity of the dolomite aquifer is interrupted by vertical to sub-vertical geological structures such as dykes which create low permeability to impermeable compartmental barriers.

The dolomites of the Chuniespoort Group represent the most important aquifers in South Africa. This is generally due to the exceptionally high storage capacity (storativity) and often high permeable characteristics of weathered dolomite. Dolomitic groundwater storage mostly occurs in dolomitic compartments and fractures derived from dolomitic dissolution/chemical weathering, which in extreme cases, result in the development of open cavities and caves (karstification). The continuity of the dolomite sequence is often interrupted by geological structures in the form of vertical and sub-vertical intrusive dykes resulting in significant fracturing of non-karstified dolomite. Boreholes intersecting these compartments (or fractures) often yield significant quantities of groundwater.

The chemical weathering of dolomitic rock is generally associated with weakly acidic rainwater which results from carbon dioxide diffusion forming carbonic acid. The carbonic acid dissolves the dolomite as it percolates through planes of weakness such as faults, fractures and joints associated with deformation. The dolomite dissolves according to the following chemical reaction:

$$3CaCO_3.2MgCO_3 + 5H_2CO_3 \longrightarrow 3Ca(HCO_3)_2 + 2Mg(HCO_3)_2$$

dolomite + carbonic acid $\longrightarrow$ calcium-bicarbonate + magnesium bicarbonate

The borehole is approximately 150 m deep believed to have intersected dolomite. The pump test data and can be viewed in Figure 22. A high transmissivity value of 372 m^2/d was calculated from the drawdown data which is typical for dolomitic aquifers. Yields will typically in range between 10 – 20 l/s.

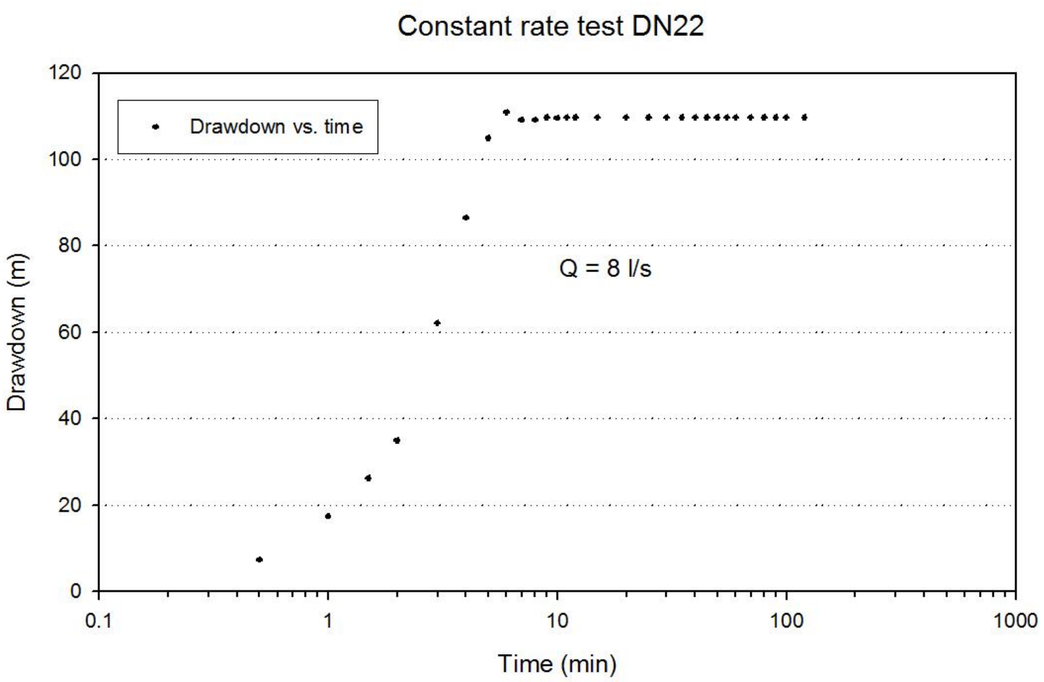

Figure 22: Drawdown data vs. time for the constant rate pumping test for DN22

6.4.4 Summary of aquifers present

Three (3) aquifers are present in vicinity of the study area composed of with differing lithologies and therefore differing in aquifer properties and hydraulic parameters. The types and characteristics are summarised in Table 17.

Table 17: Aquifer types present at Droogefontein

Aquifer	Type	Geology	K (m/d)	T (m^2/d)	S*	Yield (l/s)
Shallow perched	Unconfined (primary)	Quaternary Soil/clay	0.023	0.115	-	~0.05
Weathered/fractured	Semi-confined	Karoo sandstone (Ecca)	0.049	3.9	0.0005	0.5 – 1.0
Karstic/fractured	Confined	Malmani dolomite	0.1-10	372	0.01	~10 l/s

* Storativity cannot be accurately determined from a single borehole without making use of observation boreholes. The values given are based on typically encountered for the specific formations.

6.5 Hydraulic gradients and velocity

The direction and rate of groundwater flow is determined by the groundwater gradients and aquifer transmissivity. Under natural/steady state conditions groundwater will flow from higher to lower hydraulic gradients. Steep hydraulic gradients and high aquifer transmissivity will allow for greater groundwater seepage velocities. The groundwater gradients are important for use in geohydrological studies as it is used in estimations of the Darcy Flux and seepage velocity used in contaminant transport modeling, i.e. in determining the rate at which groundwater and pollutants move through a matrix.

Similar to surface water, where gradients are steeper (contours closer to each other) groundwater velocities will be greater. Portion 26 and its immediate surroundings are situated in a valley bottom with gradients decreasing from north-west to east and from east to west. The gradients are relatively high but remain relatively similar from both directions. The groundwater flow directions with gradients calculated can be viewed in Table 18. Groundwater gradients from northwest to east range from 0.89% to 1.67% with an average of 1.19% while seepage rates from east to west range between 0.87% and 1.39% with an average of 1.16%.

Table 18: Estimated groundwater gradients and flow directions

Seepage direction	Gradient (%)
Northwest to east	0.89
Northwest to east	1.03
Northwest to east	1.67
Average	**1.19**
East to west	0.87
East to west	1.21
East to west	1.39
Average	**1.16**

The rate of movement of ground water is important in many problems, particularly those related to pollution. For example, if a harmful substance is introduced into an aquifer upgradient from a supply well, it becomes a matter of great urgency to estimate when the substance will reach the well. The velocity at which groundwater (and pollutants) move can be calculated using a combination of i) Darcy’s Law, ii) the velocity equation and iii) effective porosity (water can only move through the openings of rocks). Combining the above, an equation for the seepage velocity can be obtained:

$$\mathrm{v} = \frac{Ki}{\emptyset}$$

Eq. 6

where: v = flow velocity

K = hydraulic conductivity

i = hydraulic gradient

ø = effective porosity (probable)

Average hydraulic conductivities for the primary unconfined and Karoo aquifers were used in the calculation while a liberal effective porosity of 0.1 was used to obtain a worst case scenario for seepage velocity. The groundwater seepage rates calculated are shown in Table 19.

Table 19: Groundwater gradients and seepage rates

Aquifer	Hydraulic gradient	Ave hydraulic conductivity (m/d)	Seepage velocity (m/d)	Seepage velocity (m/a)
Primary unconfined	0.009	0.02	0.002	0.70
Secondary semi-confined	0.012	0.05	0.006	2.15

It should be noted that because of the heterogeneity of fractured rock environments resulting from preferential flow paths formed by intrusive dykes and other igneous intrusions, the transport velocities could be orders of magnitude greater than the average velocities shown above.

6.6 Groundwater recharge estimation

The groundwater recharge was estimated using the following methods:

1. CMB method (calculation)
2. GRDM

The first approach adopted is the CMB (Chloride Mass Balance) approach. This method is based on the principle that chloride behaves as a conservative tracer and is neither absorbed nor lost as it flows from precipitation to groundwater. Thus the method assumes that chloride in recharge water percolating vertically through the unsaturated zone and into the aquifer is derived entirely from precipitation (i.e. no chloride is derived from the soil or unweathered zone) and the chloride concentration of groundwater is controlled by evapotranspiration processes. Thus the proportion of rainfall that occurs as recharge can be quantified as the ratio between the two concentrations.

A recharge percentage based on the CMB method for the aquifer in vicinity of Droogefontein was estimated using the harmonic mean of Cl concentrations from the hydrocensus boreholes including the Cl concentration in rainfall estimated for the area. The harmonic mean calculated and the estimated concentration of Cl in rainfall is shown in Table 20 together with the calculated recharge percentage using the CMB method and the recharge reported in the GRDM.

Table 20: Values used in the CMB equation for estimating recharge

[Cl] Harmonic mean	[Cl] in rainfall	CMB	GRDM
13.65 mg/l	0.5 mg/l	3.7% 25.57 mm/a	5.1% 35.24

CMB = R% = 100 x Cl_p / Cl_{GW}

Using a rainfall of 691 mm/a a recharge estimation of 3.7% or 25.57 mm/a was calculated for the catchment using the CMB–method while a recharge of 5.1% or 35.24 mm/a are documented in the GRDM database. It is suspected that the higher recharge percentage documented in the GRDM of 5% also includes the dolomitic aquifers with a higher recharge probability compared to the Karoo sandstone; the recharge calculated with CMB method is most probably more accurate for Droogefontein. Therefore a recharge of 3.7% was deemed to be the most realistic value for the study area.

6.7 Geochemical Characterisation

A geochemical characterisation procedure was conducted on the overburden which will be generated by the coal mining activities to evaluate its risk potential towards the receiving surface and groundwater environments. The tests included:

- An Acid Rain leach to determine the geochemical composition of materials (major and trace elements) which may leach under acidic conditions; and
- The acid rock drainage, neutralisation and leaching potential of over- and underburden including the coal seams.

6.7.1 Coal mining and acid rock drainage

Coal deposition is associated with pyrite being formed. Mining activity will expose the pyrite to oxidising agents such as oxygen and ferric iron (Fe^{3+}). A variety of mining wastes, most notably tailings, overburden and slimes contain sulphidic material (mostly pyrite) which may oxidise to produce acid rock drainage (ARD). The result is sulphuric acid generation which acidifies water it comes in contact with. This has a number of negative consequences and most notably includes the solubilisation of a variety of trace metals and metalloids. A number of factors control the generation of ARD, but the most important are the relative abundance of acid producing minerals (generally the sulphides) and acid consuming minerals (generally carbonates), moisture content/ingress and exposure to air. As ARD has the potential to impact significantly on surface and groundwater quality, it is necessary to quantify the potential that waste rock has to generate ARD during any geochemical characterisation.

ARD is produced when sulphidic minerals are oxidised and hydrated (exposed to oxygen and water) resulting in increased salinity, acidity and metal solubility. Precipitated secondary minerals are common to ARD environments. However, the precipitated salts can re-dissolve following oxidation resulting in mineral dissolution. Secondary salts can be classified as acid producing, non-acid producing and acid buffering. The formation of the soluble salts Al^{3+}, Ca^{2+}, Mg^{2+}, Fe^{2+}, Fe^{3+} and Mn^{2+} sulphate salts influence the pH of a solution because of their capacity to generate or consume protons (Lottermoser, 2003). ARD typically has pH values below 2.3 and ionic concentrations exceeding 10 000 mg/l (Caruccio et. al., 1981). Pyrite (FeS_2) is recognized as the major source of ARD. Acidic water has been found associated with many mine wastes including underground flows, mine decant, wastes and ore stockpiles. During the oxidation process of sulphide ores, the sulphidic component (S_2^-) in pyrite is oxidised to sulphate (SO_4^{2-}); acidity (H^+) is generated and ferrous iron (Fe^{2+}) ions are released (Stumm and Morgan, 1996). The following reaction steps show the general accepted sequence of pyrite oxidation (Stumm and Morgan, 1996):

1 Acidity (H^+), ferrous iron (Fe^{2+}) and sulphate (SO_4) are released into the water when the mineral pyrite (FeS_2) is exposed to water and oxygen:

$$FeS_2(s)+3.5O_2+H_2O \rightarrow Fe^{2+} + 2SO_4^{-2} + 2H^+$$

2 The highly soluble Fe^{2+} species oxidise to relatively insoluble ferric iron (Fe^{3+}) in the presence of oxygen – the reaction is slow but is increased by microbial activity:

$$Fe^{2+}+0.25O_2+H^+ \rightarrow Fe^{3+} + 0.5H_2O$$

3 Fe^{3+} is then hydrolysed by water (at pH >3) to form the insoluble precipitate ferrihydrate $Fe(OH)_3(s)$ (also known as yellow-boy) and more acidity:

$$Fe^{3+}+3H_2O \rightarrow FeOH_3(s) + 3H^+$$

4. In addition to reacting directly with oxygen, pyrite may also be oxidised by dissolved Fe^{3+} to produce additional Fe^{2+} and acidity:

$$FeS_2(s)+14Fe^{3+} \rightarrow 15Fe^{2+} + 2SO_4^{2-} +16H^+$$

Reaction 4 uses up all available Fe^{3+} and the reaction may cease unless more Fe^{3+} is made available (Appelo and Postma, 1999). Reaction 2, the reoxidation of Fe^{2+}, can sustain the pyrite oxidation cycle (Nordstrom and Alpers, 1999). The rate determining step is the oxidation of Fe^{2+} to Fe^{3+} (reaction 2), usually catalysed by autotrophic bacteria.

5. The overall reaction as given by Nordstrom and Alpers (1999) is:

$$FeS_2(s)+3.75O2 + 3.5H2O \rightarrow Fe(OH)_2(s) + 2SO_4^{2-} +4H^+$$

Acidity (H^+), Fe and SO_4^{2-} are the end products of the above reactions. Reaction (1) is an abiotic process occurring at a pH >4.5 due to spontaneous oxidation of the pyrite. Process (2) is the transformation of ferrous iron (Fe^{2+}) to ferric iron (Fe^{3+}). This is an abiotic process when pH >4.5, but slows down and becomes biotic at pH <4.5. At a pH below 2.5 the biotic process is most prominent. Reaction (3) produces ferric hydroxide (yellow boy), and further lowers the acidity by releasing protons (H^+). The ferric iron oxidises the pyrite in reaction 4 even when oxygen in absent.

Process (2) is the rate limiting process in this mechanism. This process requires oxygen, therefore, the prevention of oxygen ingress and the creation of reducing conditions within the workings is crucial to slow down the oxidation of pyrite and the resulting low pH conditions. However, if the reaction has proceeded past reaction 2 to where Fe^{3+} is produced oxygen is no longer required for the reaction to continue. Fe^{3+} will continue to oxidise the pyrite releasing Fe, SO_4 and acidity until all the pyrite, or other sulphidic mineral, has been oxidised.

The contaminant generation potential is pronounced where the source minerals of contaminants are in direct contact with water and oxygen underground. The opencast mining operations expose reactive minerals to water and oxygen. Sulphides are the main minerals which react and contribute to the formation of ARD.

Mining sections that are not in contact with groundwater flow paths i.e. flooded or stagnant sections are unlikely to contribute to ARD formation. ARD formation may be enhanced and continue at high rates if there are active flow paths through sections. Where water is flowing through moist sections, ideal conditions for sulphide mineral oxidation exist.

Many sulphide ores have a mixture of sulphide minerals such as pyrrhotite (FeS), arsenopyrite (FeAsS), chalcopyrite ($CuFeS_2$), galena (PbS), cobaltite (CoAsS), gersdorffite (NiAsS) and millerite (NiS). If pyrite is dominant it initiates acid formation resulting in leaching of metal sulphides and oxides. The end result of AMD is therefore a mixture of very acidic pH, high SO_4 and soluble and precipitated Fe including toxic heavy or trace metals, metalloids and/or radionuclides in solution (Nordstrom and Alpers, 1999). Sulphidic waste rock dumps and tailings dams are proposed to be the major sources of ARD. This is due to their sheer volume, porosity and surface to volume ratios increased by mining and blasting.

6.7.1.1 Mine residue deposits and ARD

Tailings dams and waste rock dumps are considered the major sources of ARD due to their great surface area and surface to volume ratio of the material. ARD development in these wastes is influenced by the properties of the waste material and complex weathering reactions (Lottermoser, 2003). Surface mine wastes usually contain perched aquifers with subsequent saturated and unsaturated zones well above the underlying bedrock (Younger *et al*., 2002). The dynamics within these waste piles generally result in the formation of AMD if sulphidic minerals are present. The flow of water is influenced by the physical properties of the waste material. Precipitation together with oxygen percolates through the unsaturated zone filling small pores and covering particle surfaces. Where large rock fragments are present, a significant volume of interstitial pores are created. In the saturated zone, water movement is channelled through voids, channels and conduits. Consequently, the hydraulic properties are influenced by the dump structure and size of fragments (Lottermoser, 2003).

Wetting and drying cycles control the drainage of waters from these sulphidic mining wastes. A simplified model by which drainage is described by the initial wetting through meteoric water followed by run-off, drainage and evaporation, resulting in the formation of secondary minerals, is shown in

Figure 23 (Perkins *et al*. 1997) Intense wetting of these minerals will result in dissolution releasing acidity and metals into solution.

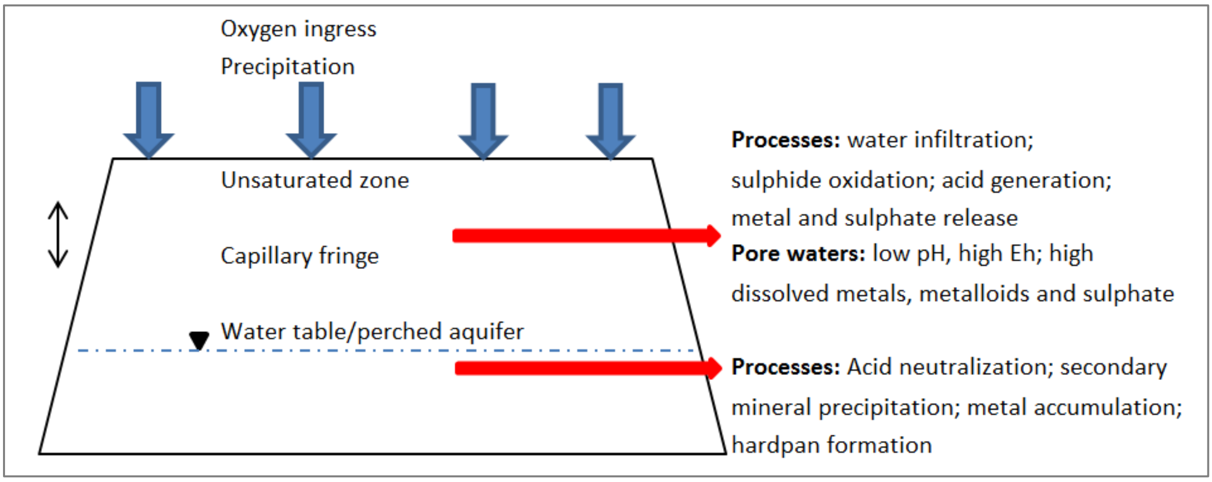

Figure 23: Simplified dynamics of ARD formation in waste rock dumps

Perkins *et al*. (1997) described the wetting-drying cycle and the subsequent leaching of waste to consist of four sequential stages:

1. Sulphide oxidation and destruction followed by the formation of secondary minerals.
2. Precipitation percolating into the dump and seasonal run-off resulting in the weathering of minerals.
3. Drainage of water from the dump towards underlying aquifers especially if uncapped, unlined or the lining has been breached or if it is permeable at its base.
4. Evaporation of pore water again resulting in the formation of secondary minerals.

Leaching from waste rock dumps containing carbonaceous material and sulphides will allow for oxidation and hydration resulting in the generation of acidity (H^+), sulphates (SO_4^{2-}) and ferric (Fe^{3+}) and ferrous (Fe^{2+}) iron species and the movement of other conservative contaminants (Na^+ and Cl^-) with groundwater in a downstream direction from the source. The resulting acidity (pH may be as low as 2.3), will mobilise reactive metal contaminants which will move slower than groundwater velocities creating typical pollution plumes. Such plumes, if let to develop extensively can migrate in a downgradient direction polluting aquifers and surfacing at seepage points, contaminating surface waters along the way. Within wetland systems, oxidation of Fe^{2+} to Fe^{3+} will result in the precipitation of ferric hydroxide (FeOH), typically as a gel, which can coat the reactive surfaces of the plants and sediment, thereby greatly reducing the ability of the wetland to remove pollutants by adsorption. In addition, the high salt load is often toxic to aquatic life.

ARD when generated is very difficult costly to remediate and once the process has succeed reaction 2 (see Section 6.7.1) and has precipitated Fe^{3+} oxygen is no longer the rate limiting step since Fe^{3+}

can chemically oxidise pyrite in the absence of oxygen - the ARD reaction sequence will continue until all the pyrite has been oxidised. It is therefore important to mitigate and have effective management measures in place to control ARD generation at the source.

6.7.2 Acid Base Accounting

The ABA analyses (Table 21 & 22) indicate that the over and underburden consisting of Ecca sandstone and Dwyka tillite is generally of a Type III rock which is non-acid forming (Table 23). They contain little or are totally devoid of sulphide minerals with Neutralising Potential Ratios (NPR) ranging between 1.3 and 26.93. The possibility of ARD formation from the sandstone and tillite facies is therefore unlikely.

Mudstones also belonging to the Ecca did record relative abundance of sulphur with 0.24% and 0.47% for the two samples. Although the sample from DN17 sampled at 42 m contains a significant abundance of sulphur at 0.47% its potential to neutralise acid generation is high (NP = 96.25). Its potential to generate acid is therefore uncertain and is therefore classified as a Type II / Type III rock type. The remaining mudstone sample contain significantly lower neutralising minerals with a net negative neutralising potential (NNP = -2.25) and a NPR of less than one (0.70). It is therefore classified as being a rock type with intermediate and possible potential to generate ARD (Type II).

All the coal samples from the upper, middle and lower seams contain high levels of sulphur ranging between 0.67% and 3.45%. The upper and bottom seams both recorded net negative neutralising potentials and NPRs of less than one; this together with the high abundance of sulphur, label the upper and bottom seams as Type I rock types and has a high risk of ARD generation. Even though the middle seam also recorded a significant abundance of sulphur (0.67%) it recorded a net positive neutralising potential (NNP) of 14.81 and a NPR of 1.71. The bottom seam is therefore classified as a Type II rock type with the possibility of ARD generation. ARD may be likely in Type II rocks especially if the neutralising minerals is insufficiently reactive or is depleted at a rate faster than that of sulphides.

Table 21: Acid base accounting results for over- and underburden

Acid – Base Accounting Modified Sobek (EPA-600)	Sample Identification					
	DN15 9m SNDS	DN15 23m SNDS	DN15 53m TLLT	DN17 9m SNDS	DN17 40m MDSN	DN17 42m MDSN / CB
Paste pH	5.8	7.2	7.0	7.1	6.7	7.8
Total Sulphur (%) (LECO)	<0.01	0.06	0.03	<0.01	0.24	0.47

Acid Potential (AP) (kg/t)	0.31	1.88	0.94	0.31	7.50	14.69
Neutralization Potential (NP)	1.50	50.50	1.25	-0.50	5.25	96.25
Nett Neutralization Potential (NNP)	1.19	48.63	0.31	-0.81	-2.25	81.56
Neutralising Potential Ratio (NPR) (NP:AP)	4.80	26.93	1.33	1.60	0.70	6.55
Rock Type	III	III	III	III	II	II / III

If NNP (NP – AP) < 0, the sample has the potential to generate acid

If NNP (NP – AP) > 0, the sample has the potential to neutralise acid produced

SNDS sandstone

TLLT tillite

MDSN mudstone

CB coal bearing

Table 22: Acid base accounting results for coal samples from the upper, middle and bottom seams

Acid – Base Accounting Modified Sobek (EPA-600)	**Sample Identification**			
	DN16 Upper	**DN16 Middle**	**DN19 Bottom**	**DN19 Bottom***
Sample Number	**20580**	**20581**	**20582**	**20582D**
Paste pH	6.7	6.9	7.2	7.1
Total Sulphur (%) (LECO)	3.45	0.67	0.81	0.81
Acid Potential (AP) (kg/t)	107.81	20.94	25.31	25.31
Neutralization Potential (NP)	43.00	35.75	9.50	10.25
Nett Neutralization Potential (NNP)	-64.81	14.81	-15.81	-15.06
Neutralising Potential Ratio (NPR) (NP : AP)	0.40	1.71	0.38	0.40
Rock Type	I	II	I	I

*Duplicate quality control sample

If NNP (NP – AP) < 0, the sample has the potential to generate acid

If NNP (NP – AP) > 0, the sample has the potential to neutralise acid produced

Table 23: Rock Classification

TYPE I	Potentially Acid Forming	Total S(%) > 0.25% and NP:AP ratio 1:1 or less
TYPE II	Intermediate (uncertain)	Total S(%) > 0.25% and NP:AP ratio 1:3 or less
TYPE III	Non-Acid Forming	Total S(%) < 0.25% and NP:AP ratio 1:3 or greater

The carbonaceous (mudstones) and coal samples indicate acid forming tendencies and should be handled and managed in such a way as to minimise and prevent pollution towards the receiving surface and groundwater environments. It is recommended that the concurrent rehabilitation of the box cuts and open pit follow pre-existing *in-situ* profiles. Coal spoils and carbonaceous materials should be placed in the bottom of the pit beneath the water table to limit the ingress of oxygen to create a reducing environment thus reducing the generation of ARD. This should be followed by the sandstone layers with high neutralising capacity, and lastly a good cover of clay and topsoil. The low permeability clay layer encapsulates the carbonaceous material placed at the bottom of the mined out cuts. Leaching of the neutralising minerals in the middle or top layers will result in neutralisation of the ARD effects should they occur in the lower carbonaceous material. Although these management measures may reduce contamination, horizontal groundwater seepage and minimal surface water infiltration may result in contamination over the medium and long-term. Effective monitoring of surface and groundwater should serve as early warning systems should ARD occur.

6.7.3 Acid Rain leach

The results of the acid rain leach procedure can be viewed in Appendix B. In terms of sulphate (SO_4), relatively similar results were recorded compared to the ABA results. The Ecca sandstone layers did not record any SO_4 exceeding detection limits while the carbonaceous mudstones (Ecca), the Dwyka tillites and the Vryheid Formation top and bottom coal seams (Ecca), recorded relative high levels of SO_4. The middle seam did not record SO_4 exceeding detection limits. Chloride (Cl) was also recorded in relative abundant levels in the coal samples. Nitrate (NO_3) and fluoride (F) did not record levels exceeding the limits of detection in any of the samples.

The ICP-OES scan on the leachate of the acid rain leach on the over and underburden (sandstone, mudstone and/ or tillite) revealed the following metals to be present in significant quantities:

- aluminium (Al), boron (B), barium (Ba), calcium (Ca), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), nickel (Ni), lead (Pb), silica (Si), strontium (Sr) and zinc (Zn)

The ICP-OES scan on the coal samples (top, bottom and/ or lower seams) revealed the following metals to be present in significant quantities:

- Al, B, Ba, Ca, Mg, Mn, Ni and Sr

The above-mentioned major and minor metals are shown to be potentially leachable when subjected to mildly acidic conditions and should be incorporated into the monitoring programme. Monitoring is further discussed under Section 8.

7. Site conceptual model

The site conceptual model was developed using a risk based approach, whereby impact source areas were identified, pathways characterised and potential receptors identified. Both the mining and post mining scenarios are addressed. In the mining phase, drawdown of the groundwater level will be the main impact, while pollution emerging from the backfilled opencast is considered the most important post mining impact. The conceptual model for Droogefontein portion 26 is illustrated in Figure 24.

7.1 Groundwater impacts

7.1.1 Potential sources of water pollution

The potential impact source areas were identified as the following:

- Opencast pit
- Waste rock dump
- Workshops
- Pollution control dams
- Bulk diesel and oil storage facilities

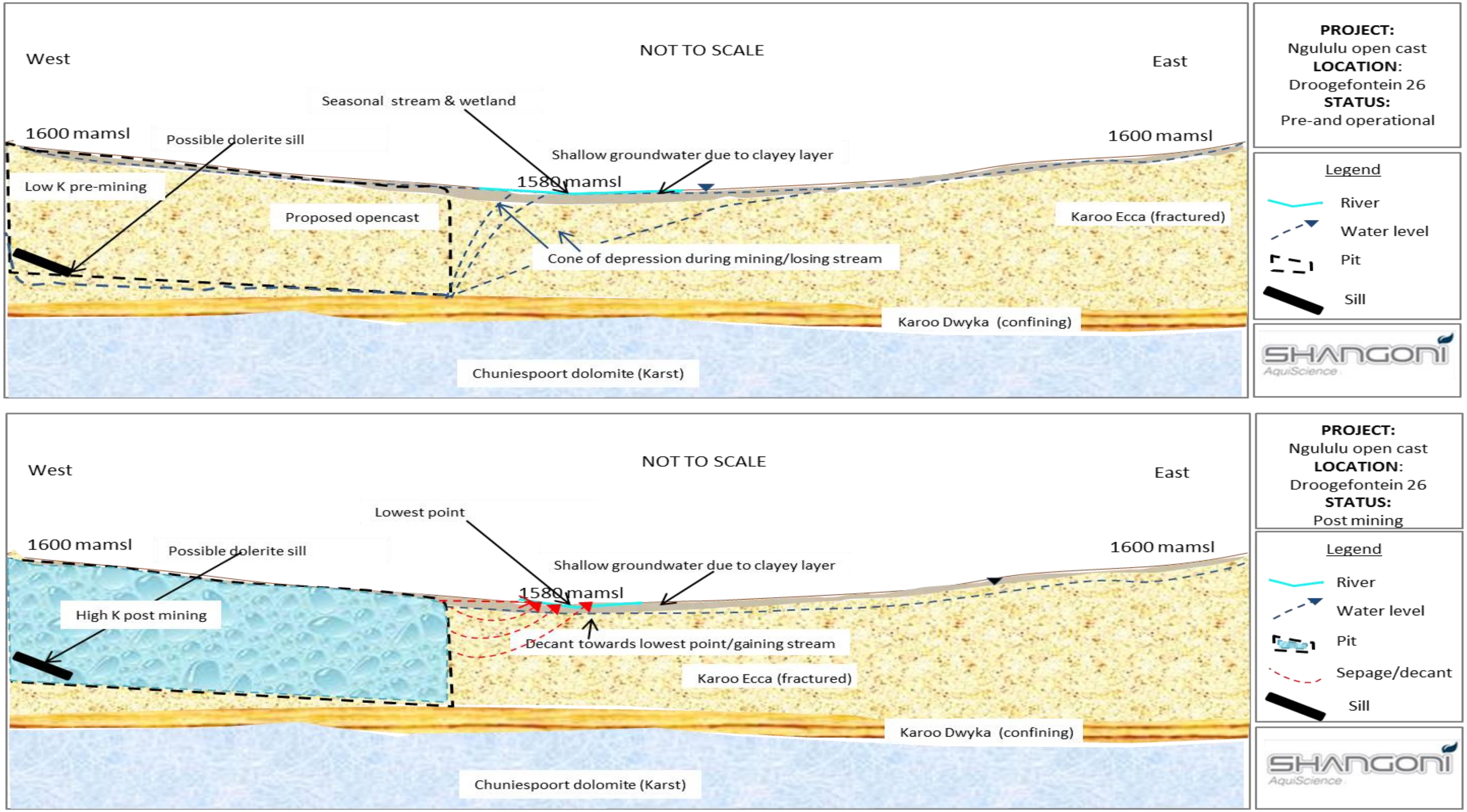

Figure 24: Conceptual model illustrating conditions during pre-, operational- and post mining

7.1.1.1 Opencast pit

Operational Phase

During the **operational phase** the opencast will have to be dewatered to allow access to coal seams. Dewatering can be done by installing dewatering boreholes at the perimeter of the mine, and/or dewatering from a sump(s) at the mine floor elevation. Irrespective of the method used, the end result is that the local groundwater in and immediately around the opencast will be at the elevation of the bottom of the ore body by the end of mining. This depression in the groundwater will result in a cone of depression around the opencast, with the radius depending on the hydraulic conductivity of the host material. The open pit will therefore function as a sink with all groundwater in the cone of depression being drawn radially inwards towards the pit. The hydraulic conductivity is relatively low so the cone of depression would be localised around the immediate vicinity of the pit. Because groundwater will flow towards the pit groundwater will not follow its normal path as during pre-mining the mine void will continue to act as a groundwater sink until a new groundwater level equilibrium has been reached, well after closure. *No groundwater or receiving surface water quality impacts will therefore be associated with the open pit during the operational phase.*

Closure

Post mining, the groundwater will return to pre-mining levels, or even above pre-mining levels in the lower sections of the backfilled cuts. This is due to the very high hydraulic conductivity of the backfilled material in comparison to the undisturbed bedrock material that will tend to flatten the water level in the opencast. Should the water level in the lower sections rise above the surface level, decanting will result at the lowest topographical point. Furthermore, normal groundwater flow from the backfilled opencast to the seasonal/intermittent stream/wetland will resume. If the backfilled material is sulphide containing, these outflows will most likely be contaminated with mainly SO_4^{-2} and selected metals, and could also be acidic depending on the neutralisation potential of the material and reactivity of the sulphides.

No receptor boreholes are situated in a downgradient direction from the proposed open pit. The main concern post closure would be decant into the wetland/drainage system to the east when water has filled the pit and hydraulic heads have returned to normal (pre-mining levels). This natural drainage system feeds the Aston Lake to the south-west which is used for recreational activities such as fishing. The Aston Lake in turn feeds the Blesbokspruit which is classified as a RAMSAR protected site.

High recharge values are associated with the backfilled areas and high hydraulic conductivity values can be expected from the compressed spoils and waste rock. Recharge is usually higher in the backfilled mine voids compared to the pre-mining aquifer and after filling up, the discharge is usually higher than before the disruption by mining. The effective recharge is especially higher for opencast mining and can be as much as 5 to 15 times the natural recharge without the effect of mining. With the proposed open cast mining activities at Droogefontein portion 26, the recharge pattern will thus be changed dramatically. Due to the irregular sizes and shapes of the backfilling material the effective porosity of the rehabilitated opencast pit may vary between 20% and 30%.

Surface elevations indicate two possible **decant zones** along contours (Figure 25) on site thus appropriate mitigation measures will have to be put in place to reduce the risk of AMD generation (See Section 9.5). If the backfilled material is sulphide containing, these outflows will most likely be contaminated with mainly SO_4^{-2} and selected metals, and could also be acidic depending on the neutralisation potential of the material and reactivity of the sulphides. ARD could impact on the water quality while potentially negatively impacting on receiving water users and the wetland area downgradient and to the east of the proposed pit area. A high risk is associated with the leaching of ARD in the long term with costly methodology for cleaning. Decanting will most probably occur after closure when the pit has been backfilled and recharged to water level equilibrium. The time to decant will depend on certain factors such as effective porosity, transmissivities and recharge volumes as discussed above. During the backfilling process material is placed back into the opencast pits in such a manner as to return the pit areas to their original pre-mining hydraulic state. Despite all the measures taken, the backfilled opencast pits will have higher transmissivities than the surrounding environment due to the irregular sizes and shapes of the backfill material. The backfilled pit areas will therefore act as preferred flow paths for groundwater.

Surfer 8 was used to calculate the time to decant of the opencast pit, after which hand calculations were used to calculate the fill volumes with expected porosity values (Table 24). Using these values it was calculated that the pit could fill in approximately 70 years whereafter decant may occur.

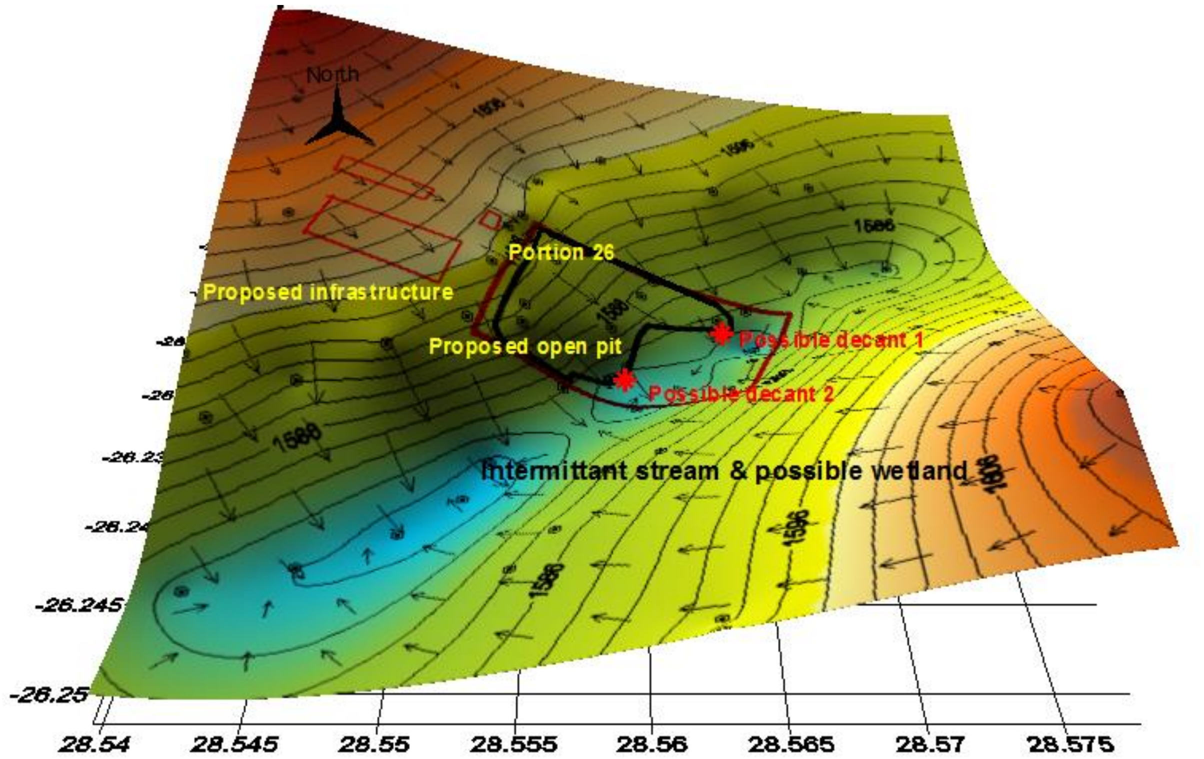

Figure 25: Possible decant positions of the open cast pit at Droogefontein portion 26

Table 24: Time to decant in years after closure

Decant elevation	Pit surface (m^2)	Fill volume (m^3)	Ave annual rainfall mm/a	Recharge (10%) Best case	Recharge (13%)	Recharge (16%) Worse case
				Porosity (30%)	Porosity (25%)	Porosity (20%)
1579	509 694	20 605 336	691	112	72	47

7.1.1.2 Waste rock dumps

The major controlling factor for ARD development in waste rock dumps is the presence of and ratio between sulphidic and neutralisation minerals. Another factor which should be taken into consideration is the distribution in the particle sizes of waste material as it governs the dominant processes responsible for ARD generation, oxidation and hydration. As rainfall infiltrates into the rock dumps, fines are either washed out or consumed through sulphide oxidation and neutralisation, while larger particles weather to smaller particles. Preferential flow paths in the dump (between particles) may result in rapid drainage of water and thus reduce the effectiveness of neutralisation. Oxygen diffusing into and circulating in voids between particles together with water films covering particles provide optimum conditions for sulphide oxidation, especially as the dumps are unsaturated. Dust

originating from the rock dumps may also settle on surface water bodies and contribute to pollution. Rock dumps have a large potential to generate ARD due to more exposure to the atmosphere.
In general the material underlying waste rock dumps (soil horizon) have a lower permeability than the material of the waste rock dump itself. As a result, percolation of infiltrating water through the rock dump into the subsurface may be limited. The leachate generated from the dump will thus contribute to surface runoff and contribute to seepage in the soil/weathered horizon. It can be assumed that mounding of the phreatic surface (water table) in the rock dump will be pronounced, thereby increasing outflow from the dumps. The soil below the rock may continue to act as a secondary source even once the all the rock has been removed (although the removal of the rock would be unlikely).

The ABA test conducted on the inter- and overburden obtained from the geological core drilled during exploration were tested for acid and neutralisation potential including an acid rain leach test to assess the potential for metal solubilisation under acid conditions. It was found that a low acid generating potential can be expected from the over- and underburden with the exception of the carbonaceous mudstones. The sandstone and tillite indicated to have a low to medium neutralisation potential that will help neutralise the acid generation. Stockpiles containing carbonaceous material should therefore be handled with care during operations and mine residue kept away from the pit once mined. The impacts can be rated as high risk long term.

With concurrent backfilling, the pre-mining *in-situ* sequence should remain to a certain extent. It is recommended that coal spoils and carbonaceous mudstones kept separate from the sandstone and tillite horizons and be re-placed at the bottom beneath the water table to limit oxidation and therefore the generation of ARD. This should be followed by the sandstones with the higher neutralising capacity and lastly a topsoil and clay cover to limit water ingress.

7.1.1.3 Workshops

Workshops, fuel dispensing areas, septic tanks and waste disposal sites may contribute to the contamination potential of the mine. Hydrocarbons may be found in elevated levels in the soil, groundwater and surface water in the area where they are handled (workshops and fuel dispensing areas). Although waste disposal sites and septic tanks do not contribute largely to the potential contaminant load of the proposed mine, they may impact in localised areas around the sites. The potential impacts include groundwater, surface water and soil. It is currently unknown whether the above mentioned contaminant sources will exist on the site and where they will be located.

7.1.2 Dewatering (water users close proximity or downstream user)

With the construction of the initial box-cut, dewatering of the aquifer will begin to occur, but only within the immediate vicinity of the box-cut. The aquifer structure will be destroyed wherever the box-cut intersects the aquifer. The dewatering of the aquifer within the immediate vicinity of the pits cannot be prevented, unless the groundwater level elevation is below the base of the mine which is unlikely given the low groundwater levels in the vicinity of the proposed open pit. The destruction of the aquifer structure cannot be prevented.

During the operational phase the open pit mining will be active which will cause the dewatering of the surrounding aquifer(s), the degree of which will depend upon the depth and extent of the open pit. The existing aquifers include the i) shallow weathered/perched aquifer; ii) Karoo sandstone/mudstone fractured aquifer; iii) Dwyka tillite aquifer; and the iv) Malmani dolomite aquifer.

Pit dewatering will result in a cone of depression of approximately 1 km (worst case scenario) wide. The aquifers affected by the cone of depression will depend on the final depth of the pit. It is expected that the pit will not exceed a depth of 40 m which is above the depth of the Dwyka tillite and Malmani dolomite. Receptor boreholes drilled through the Dwyka tillite aquifer into the Malmani dolomite should therefore not be affected by the cone of depression even if they are situated within the 1 km radius, as is the case of the high yielding boreholes, DN20 & DN22 on Droogefontein 242 portions 33 and 39. The mine must however ensure that the Dwyka tillite layer be kept intact as it will not only affect water users but may also result in flooding from the Malmani aquifer and require large scale dewatering if not managed properly.

The only boreholes which may be affected related to the dewatering activities are **DN21 and DN25** situated approximately 100 m and 740 m upgradient (west) from the proposed pit open pit. DN21 is used for small scale irrigation (gardening) while DN25 is used a domestic source. The drawdown in DN25 is however expected to be minimal given its location relative to the open pit.

It should be noted that due to the heterogeneity of the parent material, significant weathering or fracturing may be present which will result in a highly conductive bedrock material. The possibility remains that the groundwater level may be drawn down to below the stream/wetland which may consequently affect the drawdown of groundwater to the east of the wetland/stream. However, during the hydrocensus no receptor boreholes were surveyed within the expected 1 km dewatering zone of influence. As a result, even if the drawdown exceeds to below the stream bed level, the risk of influence on receptors situated to the east would be limited.

7.2 Pathways

The pathway to exposure to receptors is described as a sequence of pathways between the point of release at the source and to the receptor. Pathways along which contaminants may be mobilized and migrate towards ground and surface receptors include:

- The vadose zone (unsaturated zone).
- The saturated zone, perched and Karoo aquifer.
- Groundwater contribution to baseflow.
- Weathered or fractured aquifer.
- Seepage from processes.
- Surface runoff as seepage or storm water.

From a hydrogeological point of view it is expected that potential contaminants may be mobilised either as i) rain directly as runoff; ii) leachate into groundwater via the unsaturated zone and eventually into the saturated groundwater zone; iii) seepage from mine residue deposits onto surface and possibly into the groundwater; and iv) mobilised into surface water from groundwater contribution to baseflow. Seepage from surface spills, dams or ponds into the vadose zone and fracture systems of deeper aquifers can lead to the contamination of aquifers and also the wetland system.

7.3 Receptors

Any user of a groundwater or surface water resource that is affected by drawdown of the groundwater level or pollution from any of the above mentioned sources is defined as a receptor.
The following receptors may be found:

- Groundwater users by means of borehole abstraction.
- '*Dwars in die Wegvlei*' wetland system (Present Ecological Status = C).
- Water courses: water users, fauna and flora.
- Privately owned boreholes DN21 and DN25.
- Aston Lake.

The main water uses in the vicinity of the mine are domestic and agricultural, while the nearby *'Dwars-in-die-Wegvlei'* is a sensitive water course, classified as a Type C wetland (Limosella Consulting, September 2013). The wetland/stream is likely to be a gaining and losing stream depending on the season. A lowering of the groundwater level could result in a total local reduction of inflow to the wetland impacting its functionality. Furthermore, contaminated surface and groundwater is likely to impact on the *'Dwars-in-die-Wegvlei'* water quality. If the stream is gaining after mine closure then potential pollution (ARD) emanating from the mine activities may impact on its integrity and quality. During wet seasons surface water from the stream flows towards the Aston Lake which is used for recreational activities. If substandard quality decants into the drainage line, which is generally expected from coal mines, the dam may be at risk of water quality deterioration.

8. Numerical groundwater model

8.1 Flow model

Numerical flow and mass transport groundwater models were constructed to simulate current aquifer conditions and impacts and to provide a tool for evaluating different management options for the future. A risk analysis was also be performed where effects of different flow and concentration parameters as well as management options could be evaluated. The main purpose with the model is to simulate pollution transport in the shallow, weathered zone aquifer. Groundwater seepage and drawdown simulations are also conducted for the shallow weathered aquifer.

It is important to note a few aspects of the numerical modeling exercise:

- The numerical model is a very simplified representation or simulation of the actual situation.
- Measured aquifer parameters are used to calibrate the numerical model and the level of confidence of model calculations is only as good as the information (accuracy, distribution, frequency etc.) on which it is based and the conceptual understanding of the groundwater regime.
- Where time-series monitoring data is not available for model calibration (as is the case at the Droogefontein Project) the level of confidence of predictions cannot be very high, especially where predictions are made far into the future.
- With the lack of time-series monitoring information, the predictions of flow and mass transport from the numerical model for the project should be **considered only qualitatively and not much value can be attached to the quantitative results**.
- Quantitative predictions should only be used towards the end of the life of mine when a long time-series monitoring record has been developed that can be used for model calibration and refinement.

The modeling package PMWIN Pro (Processing Modflow Professional for Windows) was used for the simulation. The regional Droogefontein project model that includes the proposed new mining activities covers an area of ±32.6 km^2 (6 by 5.4 km). The model was run in steady state conditions until representative transmissivity and recharge distributions were obtained with a simulated hydraulic head distribution closely mimicking the average measured conditions. Two model layers were constructed in the model. Layer 1 simulates the upper weathered zone aquifer conditions, which has both the characteristics of a primary and secondary aquifer. Layer 2 represents the Karoo fractured rock, or secondary aquifer. The aquifer parameters that were assigned to the model are given in Table 25.

Table 25: Numerical flow model parameters

Parameters	Layer 1	Layer 2
Properties	Confined/Unconfined	Confined
Thickness (m)	10	150
Recharge (m/d): High topographical areas	0.000016	None
Recharge (m/d): Valley bottom discharge areas	0	None
Transmissivity of general rock matrix (m^2/d)	2	0.5
Storage Coefficient	0.05	0.01

After the model was run and the steady state solution was used to calibrate simulated water levels with the available measured water level information, a groundwater mass transport model was constructed. Calibration of the flow model was aided largely by existing flow and water level information which are situated within the same geological environment. The calibration results are indicated in Figure 26. A correlation of 87% between calculated and observed water level elevations was achieved with the steady state calibration of the flow model.

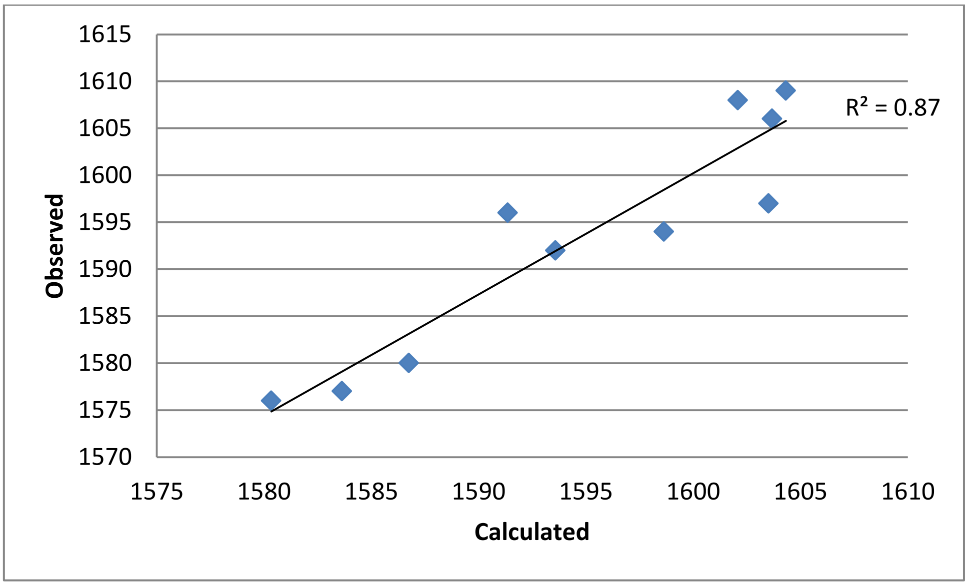

Figure 26: Calculated vs. observed hydraulic heads

The model simulation was subdivided into 9 different stress periods. A stress period in the model is a period where groundwater flow and mass transport conditions are constant. All time dependent parameters in the model, like drains, rivers, aquifer recharge, contaminant sources, sinks and contaminant concentrations remain constant during the course of a stress period. For the proposed new mining area at Droogefontein portion 26, the conditions in Table 26 were used to divide the simulation into stress periods in the transient state model run after steady state was simulated:

Table 26: Stress periods in the numerical model

Stress Period	Duration	Conditions and impacts
1 – 8	±837 days each	Mining commences at block 1 and continues to block 8. Mining is planned for 19.5 years and therefore the stress periods were approximated as 837 days in length.
9	421 days	Block 9 is significantly smaller than the previous 8 blocks and therefore has been assigned a period of 421 days.

8.1.1 Drawdown cone of depression

Mine dewatering will have an impact on the groundwater volumes available in the aquifers surrounding the proposed mine area. As the opencast pit mining areas develop, the zone of influence of the groundwater level drawdown will migrate and expand as the groundwater system attempts to retain a state of equilibrium that is continuously disturbed by the on-going mine dewatering. Initially, groundwater levels within the opencast pit areas will be drawn down to the pit floor elevation causing groundwater flow directions to be centred towards the pit area. The groundwater flow gradients towards the pit area will increase, thereby increasing the groundwater flow velocities. With the development of the additional opencast pits and underground region, and concurrent rehabilitation, groundwater flow will be directed toward the next opencast pits.

The cone of depression caused by pit dewatering was modelled by exporting the end of mine groundwater levels. These groundwater levels were used to construct a groundwater contour map of the simulated cone of depression as shown in Figure 27.

The extent of the dewatering cone was modelled for the period of life of mine and after 50 years shown Figure 27 and Figure 28, respectively. Privately owned boreholes that potentially could be impacted on are also indicated in the figures. (Note that boreholes DN01 to DN19 are all exploration boreholes). The model qualified and delineated the groundwater drawdown cone (zone in which the groundwater level is lowered as a result of abstraction) during mine dewatering over time. During the operational phase the cone of depression extends approximately 600 m in all directions from the pit perimeter. According to model simulations, water levels to the south and east of the mine lease have already started to recover at mine closure, which is the direct result of increased recharge to the backfilled opencast pits.

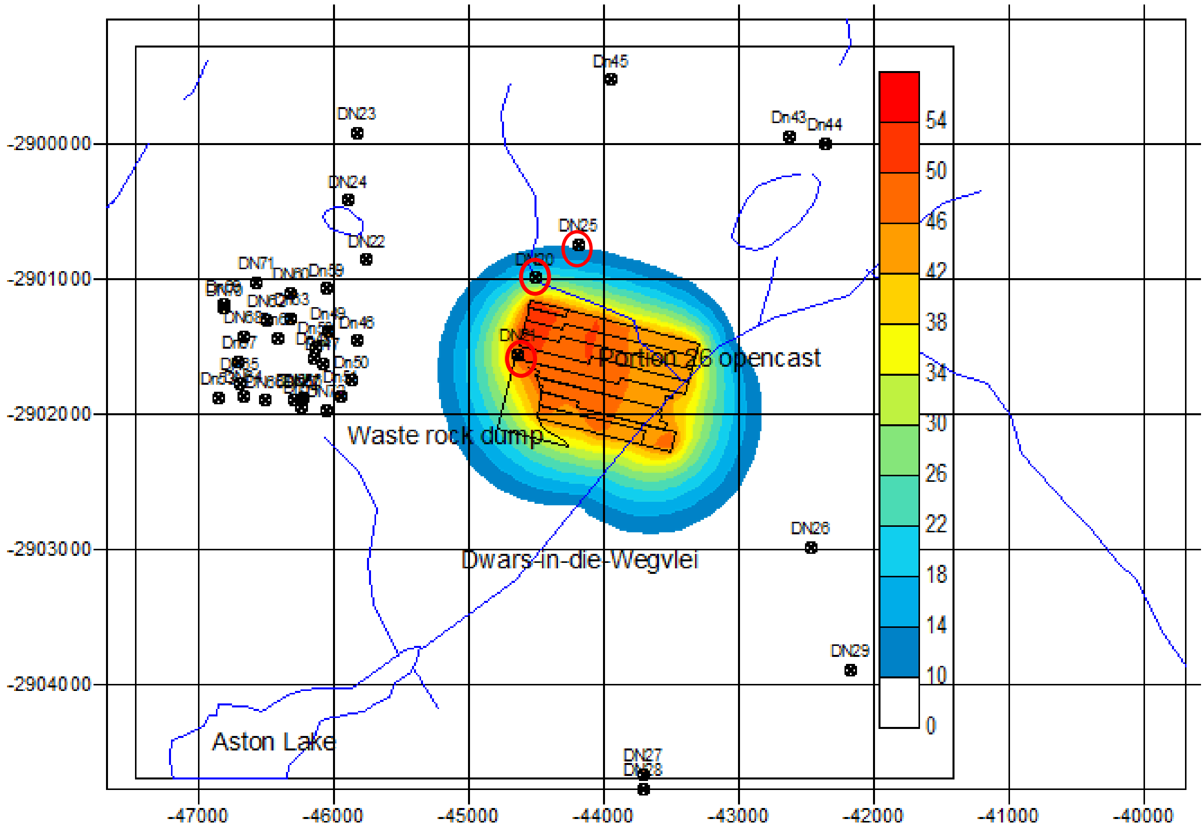

Figure 27: Simulated cone of depression

The primary receptors of groundwater in this area are irrigation and domestic users. The main risk posed by the mine on the groundwater receptors are the dewatering activities during the operational phase of mining and may include **DN21** and **DN25** as shown in Table 27 below. However, any boreholes drilled into the dolomitic for the mine bulk water supply may impact on borehole **DN20** that is currently used for agricultural activities on the nearby farm (S&M Boerdery) owned by Mr. Thinus van Dyk. If water supply boreholes are drilled into the Karoo aquifer, long-term abstraction will undoubtedly impact on boreholes DN21 and DN25. The model also shows that the groundwater levels at the *'Dwars-in-die Wegvlei'* wetland and drainage region will reach a drawdown of approximately 40 m during mine dewatering. This will definitely impact on the functionality of the wetland.

Table 27: Privately owned boreholes that could potentially be impacted on by the dewatering activities

Borehole	Coordinates	Owner	Property	Use	Aquifer	Yield (l/s)
DN21	S26.22248 E28.55331	SM Boerdery Thinus van Dyk	Droogefontein 242/Ir31	Irrigation (garden)	Karoo	0.1-0.5

DN20	S26.21735 E28.55457	SM Boerdery Thinus van Dyk	Droogefontein 242/Ir31	Livestock watering (chickens) Domestic	Dolomitic	15
DN25	S26.21516 E28.55783	Dan Retief. Schoemans Boerdery	Droogefontein 242/Ir21	Domestic	Karoo	0.1-0.5

The remaining receptor boreholes are either not located within the expected dewatering drawdown cone of depression or are tapping groundwater from the dolomitic aquifer (**DN20**) which will not be affected. No groundwater quality impacts are expected on receptor boreholes as all are located upgradient from the open pit. It is expected that groundwater will decant or contribute to baseflow in the '*Dwars-in-die-Wegvlei'* wetland at closure. However, no receptor boreholes' cone of depression is located within 1 km of the wetland and therefore decant or seepage into the system will therefore pose no risks towards groundwater users. The only risk may relate to users of the Aston Dam situated downstream.

Upon mine closure, pumping of water from the mining pit will cease and water levels will recover to pre mining levels over time (Figure 28).

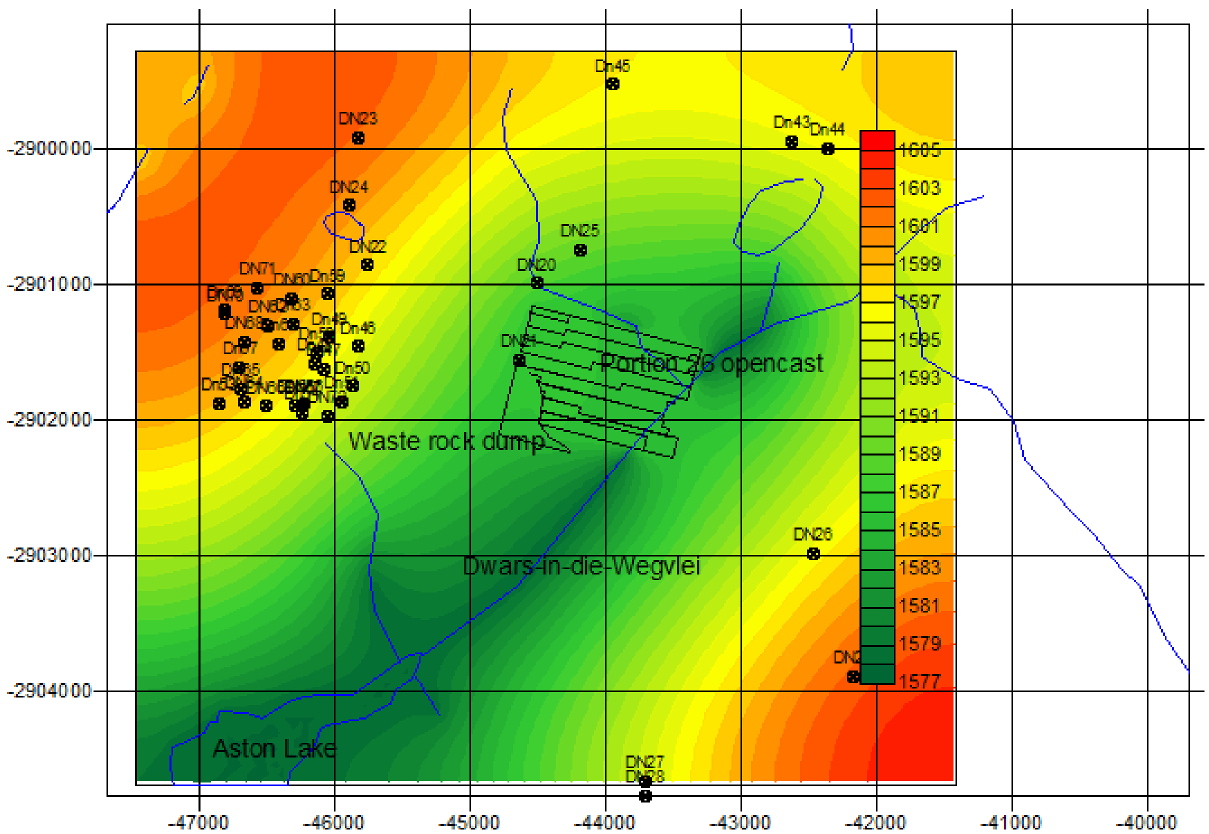

Figure 28: Hydraulic head contour map after 50 years from mine closure

8.1.2 Groundwater balance

Due to the disturbed nature of the material used for rehabilitation the transmissivity of the rehabilitated areas will be higher than that of the surrounding un-mined rock material. This will allow for increased recharge into the recently rehabilitated material compared to the surrounding un-mined areas which will increase the rate of rise of the groundwater level in the rehabilitated material. This artificially increased recharge rate can also lead to increased dewatering requirements as the recharged water seeps from the rehabilitated zone into the active mine voids.

The predicted inflow rates for the opencast pits and underground mining over the LoM are shown in Table 28. The calculations are influenced by the transmissivities and recharge used in the simulations. Total predicted inflow rates at the proposed Droogefontein mine will range from a minimum of 550 m^3/d calculated for Year 9 to a maximum of 1120 m^3/d calculated for Year 1.

Table 28: Groundwater inflow rates to mining areas (m^3/d)

Inflows (m^3/day)	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9	Total m^3/day
Stress period 1	1120									1120
Stress period 2	190	410								600
Stress period 3	80	90	350							520
Stress period 4	60	80	80	270						490
Stress period 5	50	70	60	60	260					500
Stress period 6	50	70	60	50	80	210				520
Stress period 7	50	60	60	40	70	70	150			500
Stress period 8	50	60	50	40	70	60	60	130		520
Stress period 9	50	60	50	40	70	60	60	70	90	550

8.2 Mass transport model – Simulated pollution plumes and movement

In the case of a perched water table or an unconfined / semi-confined aquifer, the hydraulic gradient is equal to the slope of the water table, measured at different points in the aquifer. The hydraulic gradients in the Droogefontein project area were calculated from the difference in elevation of groundwater levels in each area (see also Section 6.5). The averaged hydraulic conductivities of the saturated zone, as calculated from the low rate pumping tests, were used as approximations of the saturated hydraulic conductivity of the project area. The average groundwater flow velocities, more accurately termed the Darcy velocity or Darcy flux were calculated, using equation 6 (see Section 6.5) and given below:

$$v = \frac{Ki}{\emptyset}$$

where: v = flow velocity (m/day)

K = hydraulic conductivity (m/day)	=	0.02
I = average hydraulic gradient	=	0.009
ϕ = probable average porosity	=	0.1

The hydraulic conductivity and the average hydraulic gradient are known parameters. By making use of these values, the average steady state Darcy velocity in the proposed mining areas is estimated at 0.002 m/day (0.7 m/a).

These estimates do not however take into account all known or suspected zones in the aquifer like preferential flow paths formed by igneous contact zones like intrusive dykes that have higher than average flow velocities. In fractured aquifer media, the transport velocity is usually significantly higher than the average velocities calculated with this formula and may increase several meters or even tens of meters per year under steady state conditions. Under stressed conditions such as at groundwater abstraction areas the seepage velocities could increase another order of magnitude.

During active opencast mining and until a new groundwater equilibrium has been reached, the opencast areas act as groundwater sinks and groundwater will move radially inwards towards the pits. This means that during this period poor quality leachate generated by acid rock drainage will move towards the mine voids and cannot drain towards the immediate surroundings. Mining at the proposed Droogefontein project occurs from south to north. Where progressive backfilling has occurred at lower elevations the water level can recover to some extent and cause leachate to move away from the backfilled areas. For this reason the migration of pollution will be simulated at mine closure and 50 years post-closure.

The long-term impacts on quality have been estimated through numerical modeling but have to be confirmed through groundwater monitoring during the operational and closure phases should the mining project go ahead. Two figures were exported from the numerical model to illustrate simulated impacts on the groundwater quality during and after mine closure. The two figures contain TDS concentrations contours at different times in the life-of-mine, namely at mine closure when plume movement has started in some areas and at 50 years after closure when plumes have moved a distance from the sources.

A Total Dissolved Solids (TDS) concentration of 100 (representing 100% of the contaminant) was applied to the mine voids and all other potential source areas. The exact TDS concentration at the end of mining is unknown. The TDS will be the highest at the source and will decrease away from the source as the contamination plume migrates. At active mining areas the mine acts as a groundwater sink area and flow with associated mass transport is radially inwards towards the mined area. Therefore, no pollution movement is possible away from the active mining until the water level has recovered to near pre-mining levels

The mass transport model was constructed by assigning high (worst case scenario) transmissivity, storativity, and recharge values to the backfilled opencast areas. Two potential sources of groundwater contamination were identified within the model boundary and were simulated in the numerical mass transport model, these included: i) the opencast pit/s; and ii) the waste dump. According to flow model simulations (Figure 29), at mine closure, pollution plumes are restricted to the opencast pits. To the south of the mine lease, groundwater levels have however started to recover at the time of mine closure, which explains the movement of pollution plumes.

Only after recovery to decant level post closure will a pollution plume start moving downstream away from the pits. At Droogefontein, the carbonaceous material placed in the pit bottom will largely remain under oxidation conditions since the largest area will not be covered by water due to the dip of the coal floor and sloping surface topography. The source concentrations 50 years after mine closure (Figure 30) indicate the movement of a pollution plume in the north-west direction. Pollution plume movement is however slow and restricted due to overall low aquifer matrix transmissivity and gentle groundwater gradients. An overall decrease in concentrations was simulated, which is the result of contaminant diffusion and dilution with fresh recharge. The plume will move in the direction of the mining sequence until equilibrium is reached whereafter it will follow pre-mining flow which will be towards the drainage line. Water quality deterioration in the rehabilitated pits as a result of acid mine drainage will be significant and decant qualities are expected to be poor with TDS in the range of 2500 to 3 000 mg/l and pH from 2.5 to 4.

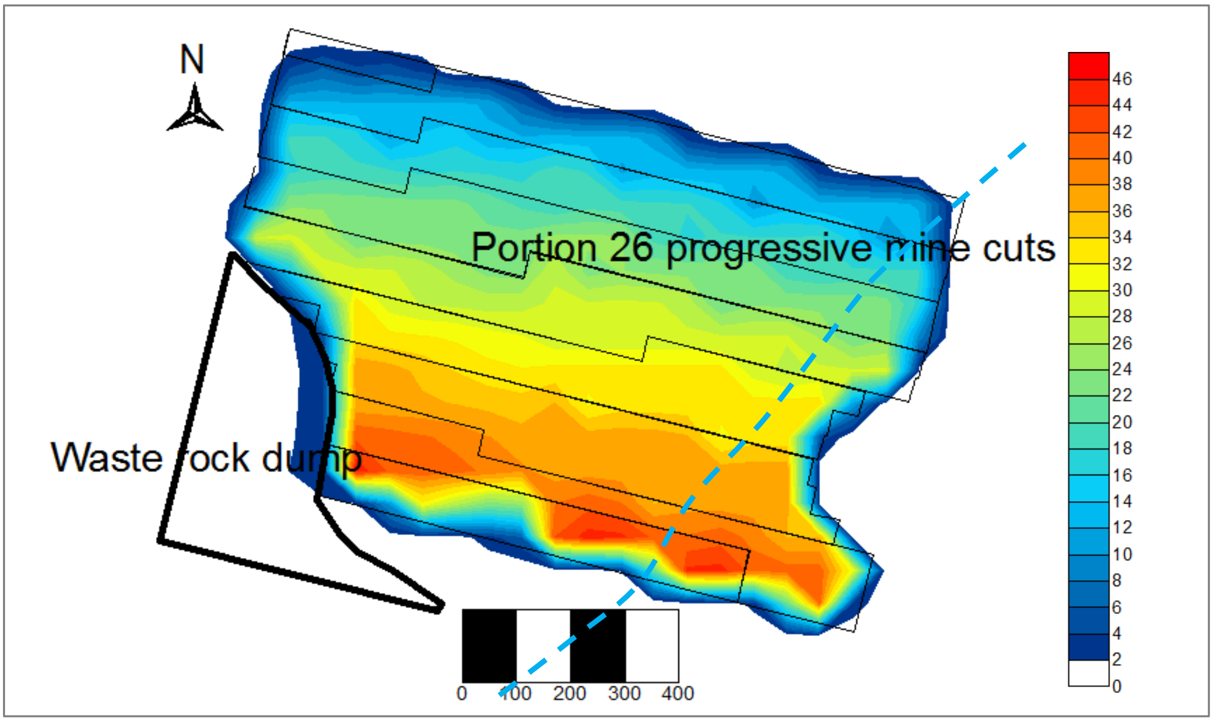

Figure 29: Simulated TDS source concentration contours at mine closure

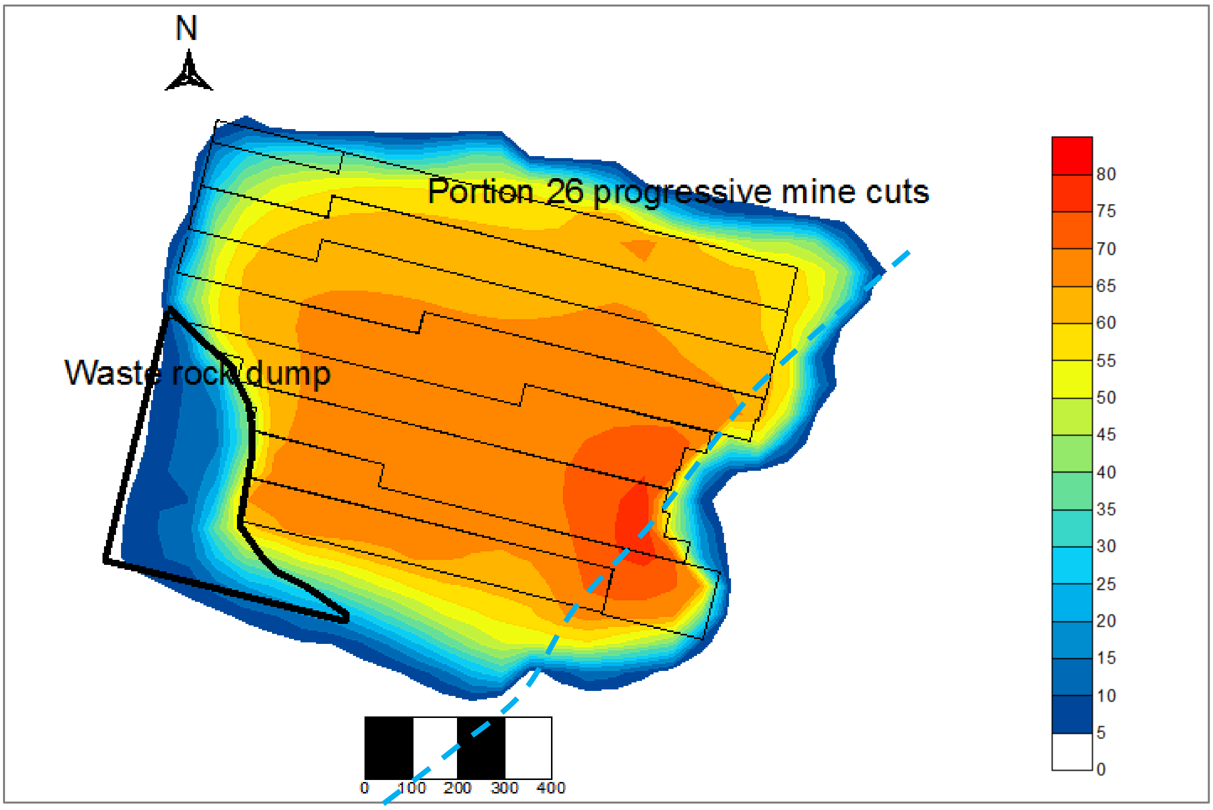

Figure 29: Simulated TDS source concentration contours at 50 years post closure

9. Environmental Impact Assessment

Activities which might potentially have an impact on the groundwater regime are discussed in the following sub sections. A description of the impacts of each activity is given and rated based on previous experience in similar circumstances and the results of the groundwater investigation. The impact assessment methodology is applied for the four phases of mining (construction, operation, decommissioning and closure) for the identified mining activities.

9.1 Site clearing, removal of topsoil & stockpiling

The following land clearance activities will take place during the construction and operational phases:

- Vegetation clearance,
- Topsoil and sub-soil stripping and stockpiling.

9.1.1 Construction Phase

9.1.1.1 Potential impacts

Site clearing and removal of topsoil, may lead to ponding of surface water in the cleared areas during the wet season and potentially lead to increased infiltration to the aquifers. Oil and lubricants used in machinery during the construction may accidentally spill and pose a possible threat to groundwater. Due to the short exposure and small scale of these possible spills, the impacts will be negligible during the construction phase. The impact assessment as in Section 7.2.1

9.1.2 Operational Phase

9.1.2.1 Potential impacts

The stripping and stockpiling of topsoil and subsoil from the pit and infrastructure surface areas is considered negligible since no chemical interaction is envisaged that could have an adverse impact on groundwater quality. The stripping of topsoil before the advancing pit may result in a very slight increase in groundwater recharge, which is a slight positive effect on the groundwater environment. The duration of the activity is however so limited that the effect will not really be measureable.

Impact Assessment: Land clearance – construction & operational

Parameter	Decription	Rating
Probability	Once per year to up to once per month	3
Duration	Lasting days to a month	1

Extent	Effect limited to the site. (metres)	1
Environment	Limited damage to minimal area of low significance, (e.g. ad hoc spills within plant area). Will have no impact on the environment.	1
Significance	**Low / Negligible**	**4**

9.2 Construction of infrastructure

The following infrastructure will be constructed during the construction phase:

- Coal Handling and Processing Plant
- Co-disposal of mine residue and Dewatered slurry
- Workshops
- Administrative Building,
- Access Roads
- Return water / Dirty water dam
- Waste rock dump

9.2.1 Construction Phase

9.2.1.1 Potential impacts

The construction of the above mentioned infrastructure will cause a very small reduction in recharge to the aquifer due to the compaction of the surface area. This impact is countered by the fact that the runoff water will contribute to the catchment yield. The carbonaceous material found within the mine lease area has the potential to generate acidic leachate, which means that any construction undertaken with carbonaceous material may be a potential source of poor quality leachate.

Oil or fuel spillages from construction machinery may collect in the soils. During rainfall events, hydrocarbon compounds from oils and fuel in the soils may migrate to the subsurface water bodies with water infiltrating through these polluted areas. Due to the short exposure and small scale of these possible spills, the impacts will be negligible during the construction phase.

9.2.1.2 Management measures

- To minimize seepage, prevent contact between clean and dirty areas, and to recycle contaminated water.
- All contaminated water will be contained for re-use and evaporation.
- To minimize the extent of disturbance of the aquifer.
- To prevent degeneration of groundwater quality.
- Vehicles should be maintained at regular intervals.

- Adhere to traffic rules.
- Make use of oil pans in or under vehicles.

9.2.1.3 Action plans

- No construction of any water management measures, such as the return water/dirty water dam or the haul roads will be undertaken with carbonaceous material.
- All dams will be lined in an effort to minimize the seepage of poor quality leachate.
- Clean surface water will not come into contact with dirty water or coal bearing material.
- Implement traffic rules and train.
- Impelment vehicle maintenance.
- Install oil collections pan in or under vehicles

Impact Assessment: Construction of infrastructure – construction phase

Parameter	Decription	Rating
Probability	Once per year	3
Duration	Lasting 1 month to 1 year	2
Extent	Effect limited to the site. (metres)	1
Environment	Limited damage to minimal area of low significance, (e.g. ad hoc spills within plant area). Will have no impact on the environment.	1
Significance	**Low / Negligible**	**4**

9.3 Utilisation of infrastructure

The following activities will take place during the operational phase:

- Utilisation of water and waste management measures and pollution control facilitie (i.e. return water/dirty water dam, etc.).
- Containment and re-use of contaminated water within isolated dirty water management areas.
- Storage and disposal (or removal) of liquid and solid hazardous and non-hazardous waste.
- Utilisation of surface infrastructure (i.e. offices, workshops, etc.).
- Utilisation of haul, access and service roads.
- Maintenance of machinery and vehicles.

9.3.1 Operational phase

9.3.1.1 Potential impacts

Poor quality seepage emanating from the return water/dirty water dam is inevitable and will have the following consequences on the local groundwater regime:

- Groundwater mounding directly underneath the dam/s.
- Downstream movement of a pollution plume within the weathered zone aquifer.
- Spillages of hydrocarbon material could result in groundwater contamination.

9.3.1.2 Management measures

- To minimize seepage, prevent contact between clean and dirty areas, and to recycle contaminated water.
- To contain contaminated water for re-use and evaporation.
- To minimize the extent of disturbance of the aquifer.
- To prevent degeneration of groundwater quality.
- To manage the anticipated impacts associated with the inflow of groundwater to the opencast

9.3.1.3 Action plans

- Wastage of coal-bearing material outside the allocated dirty water management area during the operational phase will be prevented. Haul roads and other compacted surfaces will be kept free of carbonaceous material by cleaning spillages, thereby reducing infiltration of contaminated water.
- Dirty water will be contained in fit-for-purpose designed facilities, which will limit infiltration of contaminated water to the groundwater,
- Water accumulating in the in-pit sump areas will be pumped to the return water dam to limit the quality related impacts,
- Clean surface water will not come into contact with dirty water or coal bearing material.
- The pollution control dam/s should be lined to contain all affected water.
- Store hazardous material in the correct designated and bunded areas, specially designed and constructed for that purpose.
- Train staff and implement correct procedures for the handling of hazardous material.
- Do regular inspections of storage areas.
- Diverting oil contaminated water from the bunded area during rain events to an interception or oil water separation facility.
- Install and maintain and oil trap at fuel storage areas.

Impact Assessment: Utilisation of infrastructure – operational phase

Parameter	Decription	Rating
Probability	Once per year to up to once per month	4
Duration	Lasting 5 years to Life of Organisation	4
Extent	Effect limited to the activity and its immediate surroundings (tens of metres)	2
Environment	Serious medium term environmental effects. Environmental damage can be reversed in less than a year	4
Significance	**High / Moderate**	**17**

9.4 Blasting and development of box cut and pit (incl. dewatering, waste rock dump & stockpiling)

9.4.1 Construction phase

9.4.1.1 Potential impacts

The potential impact of opencast mining and related surface processes and infrastructure is defined by the aquifer potential of the host bedrock and the density of structural discontinuities or zones of preferential groundwater movement. The chemical characteristics of groundwater relate to the mineralogy, grain-size, natural rock cement, porosity and weathering. *In situ* the natural rates of chemical reaction that affect groundwater chemistry are reduced by low flow rates or anoxic conditions. However, the same rock crushed at the surface to produce fine material with a significantly higher surface area in an oxidising environment can produce poor quality leachates.

Drilling and blasting during construction and operational phases of mining, enhances porosity and can increase weathering rates. Under some circumstances there can be links between different aquifer types that cross-contaminate different groundwater types. Blasting activities may impact negatively on the groundwater quality if significant amounts of explosive are spilled or incompletely detonated. The chemical residues in the form of NH_4 and NO_3 may potentially leach to the groundwater table. With the construction of the initial box-cut, dewatering of the aquifer will begin to occur, but only within the immediate vicinity of the box-cut. The aquifer structure will be destroyed wherever the box-cut intersects the aquifer. Due to the short exposure and small scale of these possible spills, the impacts will be negligible during the construction phase.

Groundwater flow paths will be disturbed through physical disruption or saturation of backfilled material along path of opencasit pit development. Recharge will be increased along porous groundwater zones due to an increased head of open water collecting the pit.

The creation of stockpiles and/ or waste rock dump deposits will result in the development of mounding of water within them. This will result in infiltration of mounding water into the phreatic zone, which could be of poor quality, especially wihin the temporary stockpiles and the carbonaceous mudstones.

9.4.1.2 Management measures

- Prevent or contain contamination contamination from blasting activities.
- Prevent seepage from waste rock dumps into the phreatic zone and underlying aquifer.
- Dewatering of the aquifer within the immediate vicinity of the pits cannot be prevented.

9.4.1.3 Action plans

- Handle and store blastingmaterial according to manufacturing requirements.
- Rain staff and implement correct procedures for the handling of blasting material.
- Only qualified staff should handle these materials.
- Ensure that site preparation includes sealing of substrate before developing waste rock and tailings facilities.
- Implement minimum design flood specifications.

Impact Assessment: Blasting and development of box cut and pit - construction phase (including dewatering, waste rock dump & stockpiling)

Parameter	Decription	Rating
Probability	< once a year	4
Duration	Lasting 1 month to 1 year	2
Extent	Effect limited to the activity and its immediate surroundings. (tens of metres)	2
Environment	Minor effects on biological or physical environment. Environmental damage can be rehabilitated internally with / without help of external consultants.	2
Significance	**Medium / Minor**	**12**

9.4.2 Operational phase

9.4.2.1 Potential impacts

During the operational phase, the mine voids generally act as groundwater sink areas and a flow gradient is created towards the mine voids – a cone of depression is formed by the mine voids. Groundwater flows towards the mine from all directions and it is highly unlikely that groundwater users around the mine can be affected by poor quality water from the mine itself. Pollution can migrate downstream and away from other sources such as tailings, return water and slurry dams, waste rock dumps etc. if they fall outside the cone of depression. Groundwater users can thus mostly be affected by groundwater level drawdown due to the formation of the cone of depression. The aquifer properties summarized above however allows for formation depression cones that are usually very limited in extent. The main reasons for the limited extent are the low aquifer transmissivity and the limited aquifer thickness.

The aquifers affected by the cone of depression will depend on the final depth of the pit. It is expected that the pit will not exceed a depth of 45 m which is the depth of the Dwyka tillite. Boreholes drilled through the Dwyka tillite aquifer into the Malmani dolomite should not be affected by the cone of depression even if they are situated within the 1 km radius (cone of depression worse case scenario). The effect of dewatering will not have an affect on receptor boreholes (Karoo aquifer) further from 1 km from the mine (worse case scenario) and futher than 600 m the impact will be negligible. Two boreholes were identified to fit the above-mentioned criteria and include boreholes DN21 (small scale garden irrigation) and DN25 (domestic use).

It must be stressed that the modelling predictions were not based on preferential groundwater flow pathways. It is known that the Ecca Formation is widely intruded by dolerite and/ other igneous intrusions. Such intrusions may result in substantial fracturing and the formation of preferential groundwater flow pathways. If fractures are dewatered through mining, any boreholes drilled into the same fracture might also be seriously impacted on. Unfortunately these effects cannot be predicted and monitoring may be the only means of quantification. Water levels and qualities discussed in this report should be used as baseline and if it can be proven that mining has an influence on water quantity or quality the affected parties should be compensated through additional water supply boreholes.

The main water uses in the vicinity of the mine are domestic and agricultural, while the nearby "*Dwars-in-die-Wegvlei*" is a sensitive water course and classified as a Type C wetland. Groundwater drawdown and the associated impact towards the natual surface water drainage and wetland is a serious concern.

The wetland/stream is likely to be gaining and losing stream depending on the season. A lowering of the groundwater level could result in a local reduction of inflow to the wetland impacting its functionality. The drawdown model indicates that at the time of closure the drawdown in vicinity of the wetland will be approximately 40 mbgl. This will be the result of water draining from beneath the wetland into the areas of lower hydraulic head to the north and northwest. Only after a period of at least 50 years as modelled will ambient conditions return and groundwater will flow towards the area as decant. It is expected that quality of this water may be of relatively substandard quality. Irreversible damage to the wetland may have at this stage already occurred. Impacts from groundwater drawdown may include:

- reduction or elimination of surface water flows;
- water quality/quantity problems associated with discharge of the pumped groundwater back into surface waters downstream from the dewatered area (if discharged);
- degradation of habitat; and
- reduced or eliminated production in domestic supply wells;

Another source of mining induced pollution is blasting activity. Elevated inorganic nitrogen (as NO_3- and/ or NH_4^+) concentrations also pose a large risk of water quality deterioration and receiving environment toxicity. Blasting to access the mineral ore typically involves the use of ammonia-based explosives. Decant when it occurs may not only be affetced by ARD reactions but also contain toxic inorganic nitrogen species.

The creation of stockpiles and/ or waste rock dump deposits will resul in the development of mounding of water within them. This will result in infiltration of water into the phreatic zone, which could be of poor quality, especially wihin the temporary stockpiles and the carbonaceous mudstones.

9.4.2.2 Management measures

- No management action is available to prevent aquifer dewatering.
- Drains and cut-off trenches (storm water management system) around the proposed opencast pits will be implemented before commencing with pit development to prevent clean run-off water from entering the pit.
- Prevent seepage from waste rock dumps and stockpiles into the phreatic zone and underlying aquifer.

9.4.2.3 Action plans

- Interception drainage around the pit.
- The dewatering of the aquifer system cannot be prevented. If the monitoring program indicates that nearby groundwater users are affected by the dewatering, the users need to be compensated for the loss.
- Groundwater pumped from underground is deemed affected and should be contained within the pollution control dam.
- The coal stockpiles will not have an impact on groundwater quality if properly lined.
- Sufficient lined storage space must be available in order that no stockpiling of coal will take place on natural soils.

- Ensure adequte basal sealing of areas where stockpiles and waste rock dumps are to be placed.
- Rehabilitate, seal, drain and revegetate old waste rock and tailings deposits to meet minimum standards to reduce groundwater recharge below dump.
- All external users' boreholes within a 2 km radius of any mining activities must be monitored for water level response.
- A structured compensation protocol, to be compiled in consultation with external users, will be commissioned for the open cast mine area. This protocol will control alternative water supply to external users in the event that their ground water resources have been detrimentally affected.

Impact Assessment: Blasting and development of box cut and pit during operational phase (including dewatering, waste rock dump & stockpiling)

Parameter	**Decription**	**Rating**
Probability	< once a year	4
Duration	Lasting 5 years to Life of Organisation	4
Extent	Impacts on extended area beyond site boundary (hundreds of metres)	3
Environment	Serious medium term environmental effects. Environmental damage can be reversed in less than a year.	4
Significance	**Very high / Major**	**21**

9.5 Concurrent backfilling with overburden

9.5.1 Operational phase

9.5.1.1 Potential impacts

Acid base accounting showed that a strong possibility exist for ARD development in the Droogefontein open pit area from the overburden and coal seams. During the construction and operational phases of mining, the impact on pit and the return water dam quality is believed to be moderate/negligible given the short residence time and contact with carbonaceous material of water in the pit. If the pollution control dam/s is unlined contamination of the upper weathered or perched aquifer may occur but migration thereof will be limited given the hydraulic conductivities of the Karoo type aquifer.

The operational open cast mine will represent a groundwater sink and therefore it is not possible that lateral migration of the contaminated water will occur from the operational open cast mines. The movement of ground water during the operational phase will always be towards the open cast mines.

9.5.1.2 Management measures

- Interception drainage around the pit – minimize surfce area where operations would contaminate water (smaaler disturbed areas mean smaller manageble volumes).
- Groundwater infiltration should be controlled and can be achieved through installation of liners and sufficient surface drainage.
- Minimise the retention time of infiltrated water in the excavated areas to prevent acidification of large volumes of water in the active cuts.
- Continuous rehabilitation should form part of the active mining progress.
- Reduce water infiltration into rehabilitated spoils.

9.5.1.3 Action plans

- Implement and maintain proper storm water management infrastructure.
- Concurrent rehabilitation should follow the pre-mining *in-situ* profile with coal spoils and carbonaceous material placed in the bottom beneath the water table which should be followed by the high neutralising rock (sandstone/tillite) and finally a the clay and topsoil layer.
- Water accumulating in the active cut and excess seepage from spoils/rehabilitated areas, must be pumped out or used during the operational phase as soon as possible, as to prevent the acidification of large volumes of water in the active cuts.
- Water pumped from the operational open cast mines should be categorised as contaminated and should nbe discharged/stored in water pollution control facilities.
- The recharge potential for unlevelled spoils is higher than that for levelled spoils, and is higher on unvegetated areas. Continuous, optimal rehabilitation will effectively minimize recharge to areas disturbed by strip mining.

Impact Assessment: Concurrent backfilling of overburden - operational phase

Parameter	Decription	Rating
Probability	< once a year	4
Duration	Lasting 1 month to 1 year	2
Extent	Effect limited to the activity and its immediate surroundings. (tens of metres)	2
Environment	Minor effects on biological or physical environment. Environmental damage can be rehabilitated internally with /	2

	without help of external consultants.	
Significance	**Medium / Minor**	**12**

9.5.2 Decommisioning phase

9.5.2.1 Potential impacts

Post mining, the groundwater will return to pre-mining levels, or even above pre-mining levels in the lower sections of the opencast. This is due to the very high hydraulic conductivity & preferential groundwater flow paths of the backfilled material in comparison to the undisturbed bedrock material that will tend to flatten the water level in the opencast. Should the water level in the lower sections rise above the surface level, decanting will result at the lowest topographical point. Furthermore, normal groundwater flow from the backfilled opencast to the seasonal/intermittent stream/wetland will resume. ABA analyses of overburden and coal revealed a strong possibility of ARD development consequent to oxidation and hydration. In time acidifying minerals may exhaust neutraling minerals in the substrate resulting in the acidification of water. The quality of decant may therefore be acidic and saline with high levels of heavy metals in solution.

The following impacts may be expected:

- Deterioration of groundwater quality within the back-filled opencast mine workings due to ARD reactions.
- Downstream movement of a deeper groundwater pollution plume.
- Opencast pits will decant into the shallow aquifer or onto the surface/wetland area at the lowest surface elevations intersected by the pits.

Decant of backfilled open pits can in most cases not be prevented and the risk of ARD in coal mining operations remain a significant hazard towards the surface and groundwater regimes. The limiting factor controlling ARD is oxidation of sulphidic minerals such as pyrite. Rehabilitation of the opencast pit areas should aim at duplicating the pre-existing *in situ* soil profile and entails tipping of coal spoils and other carbonaceous material in the bottom of mined-out cuts. This will be followed by placement of clayey overburden in a dry state, compacted by frequent traversing of the surface after flattening by graders, and a final cover of topsoil. The low permeability clay layer encapsulates the carbonaceous material placed at the bottom of the mined out cuts. The carbonacsous materials should be placed below the regional groundwater level in order to create a reducing redox environment and eliminate contact with oxygen, thus reducing ARD to a minimum. Although the carbonaceous materials will be submerged, horizontal groundwater seepage of clean water as well as limited infiltration of surface water will occur and some contamination will ensue over the medium and long-term.

9.5.2.2 Management measures

- Implement rehabilitation plan under supervision of suitably qualified person.
- The rate and extent of ARD formation should be alleviated as far as possible by duplicating the pre-existing *in situ* profile.

9.5.2.3 Action plans

- Mining should remove all coal from the opencasts and separate acid and non-acid forming material as identified in this report.
- Duplicate pre-existing soil/ rock profile by placing coal spoils and other carbonaceous material at the bottom of the pit followed by calyey layer and compaction.
- Rate and volume of water infiltration should be minimised by compaction and capping.
- The final cut or pit should be filled to resemble the pre-mining *in-situ* profiles with the coal spoils and carbonaceous materials (mudstones) in the bottom followed by the higher neutralsing potential rocks such as the sandstones and tillites and finally by a clay and topsoil layer. The clay layer should be as clayey as possible to limit water infiltration.
- Coal spoils and carbonaceous material should be placed beneath the water table to limit the ingress of oxygen.
- All opencasts should be backfilled and flooded as soon as possible to limit the ingress of oxygen and oxidising the remaining pyrite or other sulphidic minerals.
- Measures will be put in place during decommissioning to manage all pit water as part of the mine post-closure water balance.
- The most important aspect which needs to be addressed is the establishment of a facility for the collection and treatment of decanting mine water.
- Establishment of a network of monitoring boreholes placed in the mining area as well as upslope and downslope is required as part of the monitoring programme that must be reported to DWAF and DME in terms of any commitment to monitoring made in the EMPR.
- Implement low maintenance passive pollution control facilities or artificial wetlands to control or elleviate substandard water quality associated with ARD.

Impact Assessment: Concurrent backfilling of overburden - closure

Parameter	Decription	Rating
Probability	< once a year	4
Duration	Lasting 5 years to Life of Organisation	4
Extent	Impacts on extended area beyond site boundary (hundreds of metres)	3

Environment	Very serious, long-term environmental impairment of ecosystem function that may take several years to rehabilitate	5
Significance	**Very high / Major**	**21**

10. Water quality monitoring

The NWA introduced the concept of Integrated Water Resource Management (IWRM), comprising all aspects of the water resource, including water quality, water quantity and the aquatic ecosystem quality (quality of the aquatic biota and in-stream and riparian habitat). The IWRM approach provides for both resource directed and source directed measures. Resource directed measures aim to protect and manage the receiving environment. Examples of resource directed actions are the formulation of resource quality objectives (RQOs), the development of associated strategies to ensure ongoing attainment of these objectives, catchment management strategies and the establishment of catchment management agencies (CMAs) to implement these strategies (DWAF, 2008).

Source directed measures aim to control the impacts at the source through the identification and implementation of pollution prevention, water reuse and water treatment mechanisms. The integration of resource and source directed measures forms the basis of the hierarchy of decision-making aimed at protecting the resource from waste impacts. This hierarchy is based on a precautionary approach and the following order of priority for mine water and waste management decisions and/or actions is applicable (DWAF, 2008):

RESOURCE PROTECTION AND WASTE MANAGEMENT HIERARCHY

Step 1: Pollution Prevention

↓

Step 2: Minimisation of impacts

Water Use and reclamation

Water treatment

↓

Step 3: Discharge or disposal of waste and / or waste water

Site specific risk based approach

Polluter Pays Principle

10.1 Monitoring Principles and the risk based approach

Monitoring in general should follow the risk based approach to define or characterise the risk/s that the mining operation and its infrastructure poses on the receiving environment. This risk based approach is described in detail in the Best Practice Guideline, BPG 4: - Impact Prediction (DWAF, 2008).

Risk assessment entails the understanding of the generation of a hazard, the probability that the hazard will occur and the consequences if it should, i.e. understanding of the complete cause and effect cycle. The most basic risk assessment methodology is based on defining and understanding the three basic components of the risk, i.e. the source of the risk (source term), the pathway along which the risk propagates, and finally the target that experiences the risk (receptor). The risk assessment approach is aimed at describing and defining the relationship between cause and effect.

10.1.1 Defining the source term

In the context of predictions of impact on the water resource at the Droogefontein coal mine, the source term could include any of the following:

- Opencast pit
- Waste rock dump/s
- Workshops
- Pollution control dam/s
- Loading bays
- Coal washing and processing plant
- Bulk diesel and storage facilities

The future behaviour of the source terms is determined by two primary driving forces:

- The geochemistry of the material within the reaction pathway.
- The hydraulic characteristics of the source term which liberate and mobilize the chemical reaction products.

10.1.2 Defining the pathway

In the mining context and with respect to potential impacts on the water resource, the pathway through which contaminants could move would most typically be one or more of the following:

- Movement through the vadose (unsaturated) zone.
- Movement through the aquifer as groundwater.
- Movement through surface runoff in storm water or a watercourse.
- Movement through the opencast.
- Airborne migration of sulphide minerals or other contaminants as dust.

10.1.3 Defining the receptor

The receptors in the context of the water resource would be users of the water resource itself and typical examples could be the following:

- Groundwater user abstracting contaminated groundwater through a borehole for domestic, livestock watering or irrigation use.
- Aquatic fauna and flora in a receiving watercourse.
- Any water user abstracting water from an impacted watercourse.

As it is generally impractical and unnecessary to consider the full range of potential receptors that may be impacted upon by any particular source term, it is appropriate to define a critical receptor – which is usually that water user which is the closest to the source term or which is the most sensitive to contaminants produced by the source term.

10.2 Monitoring Programme

10.2.1 Monitoring points

The main objective in positioning monitoring boreholes is to intersect groundwater prior to (background) and moving away from a pollution source (pathway/plume) and to intercept water levels at select intervals at a receptor (receptor). Depending on the final mine plan it is recommended that sites for source monitoring boreholes be selected by a qualified hydrogeologist in order to intercept preferential flow paths and select monitoring boreholes within the expected perimeter of the modelled impact zones.

All boreholes as included in the hydrocensus should be included for quarterly analyses and water levels on a monthly basis. Surface water quality should be scheduled for a monthly frequency and could include (based upon final mine plan and infrastructure):

- All water uses and discharges

10.2.2 Sample analyses

10.2.2.1 Comprehensive analyses

For all new sites and first time monitoring at existing sites, a comprehensive analysis is required. It is essential that accurate background levels, for as wide a range of constituents as possible, be established at the outset. This will usually include a complete macro analysis as well as an analysis for the trace elements that could reasonably be expected to be present within the environment tested.

The following comprehensive suite is proposed to be analysed for all new **monitoring** localities initially followed by an annual frequency:

Physical parameters (*in-situ*)

- pH, EC

Chemical parameters (in lab)

- pH, EC, TDS
- Ca, Mg, Na, K
- Cl, SO_4, T-Alk (HCO_3^-/CO_3^-)
- Fe, Al, Mn, Cd, Cu, Pb, Ni, Zn Cr, As, V, Si, F
- PO_4^-, NO_3^-, NH_4^+

Organic parameters (in lab)

- TPH (selected only)

10.2.2.2 Indicator analyses

Indicator analysis may be performed once comprehensive analyses have been completed. The process may continue until undesirable trends are uncovered. This will keep analytical costs to a minimum, but still provide enough information upon which further actions can be initiated, if necessary. This should be reviewed on an annual basis to assess whether it is needed to monitor for additional variables.

The following indicator suite is proposed to be analysed on a quarterly frequency:

Physical parameters (*in-situ*)

- pH, EC

Chemical parameters (in lab)

- pH, EC, TDS
- Ca, Mg, Na, K
- Cl, SO_4, T-Alk (HCO_3^-/CO_3^-)
- Fe, Al, Mn
- PO_4^-, NO_3^-, NH_4^+

10.2.3 Water sampling and preservation

The sampling methodology must be developed according to site conditions and for the objective to obtain reliable reputable water chemistry data. Relevant industry accepted sampling methodologies and procedures must be followed to allow for the gathering of reliable results. It is recommended that a qualified hydrogeologist be used for sampling and interpretation purposes and that a SANAS accredited water testing laboratory be used for all water quality analyses.

It is proposed that the relevant sampling procedures as proposed by Weaver (Weaver, 2007) be used for water monitoring. Containers to be used will depend on the analytical analyse required but usually includes plastic for inorganic analysis and glass for organic parameters. The following are general guidelines to be followed:

- Water levels should be measured prior to taking the sample, using a dip meter (mbgl).
- Each borehole to be sampled should be purged (to ensure sampling of the aquifer and not stagnant water in the casing) using a submersible pump or in the event of an obstruction in a borehole, a clean disposable polyethylene bailer. At least three borehole volumes of water should be removed through purging; or through continuous water quality monitoring, until the electrical conductivity value stabilizes.
- Metal samples must be filtered in the field to remove clay suspensions.
- Samples should be kept cool in a cooler box in the field and kept cool prior to being submitted to the laboratory.

10.2.4 Data management and reporting

Monitoring results will be entered into an electronic database as soon as results are available, and at no less than one quarterly interval, allowing:

- Data presentation in tabular format,
- Time-series graphs with comparison abilities,
- Statistical analysis (minimum, maximum, average, percentile values) in tabular format,
- Graphical presentation of statistics,
- Linear trend determination,
- Performance analysis in tabular format,
- Presentation of data, statistics and performance on diagrams and maps, and
- Comparison and compliance to South African Water Quality Guidelines and any other given objectives.

The contents of the report should include the quarterly results at groundwater monitoring positions as well as comments on the effectiveness of the mitigation measures and monitoring program. Reporting to the authorities, if required should be as specified in the permitting/licensing conditions. Any accidental release of pollutants or potential polluting substances should be reported to the relevant authorities as specified in the permitting/licensing conditions.

APPENDIX A

Water quality results

APPENDIX B

Waste rock characterization

APPENDIX C

Hydrocensus information