Cabanga Environmental cc

Geohydrological Impact Assessment for Underground Mining Activities at Tumelo Colliery

Final Report

Report date: 12 February 2020

SHANGONI AquiScience

A division of Shangoni Management Services Pty Ltd

www.shangoni.co.za

Project: Geohydrological Impact Assessment

Client: Cabanga Environmental cc

Site: Tumelo Colliery

Location: Hendrina, Mpumalanga

Project Number: AS-CAB-TUM-19-08-22

Report type: FINAL

Compiled by: Ockie Scholtz, *Pr.Sci.Nat*. (*M.Sc Geohydrology*)

Report date: 12 February 2020

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DECLARATION OF INDEPENDANCE

I, Ockert F. Scholtz declare that

General declaration:

- I act as the independent specialist in this application.
- I will perform the work relating to the application in an objective manner, even if this results in views and findings that are not favourable to the applicant.
- I declare that there are no circumstances that may compromise my objectivity in performing such work.
- I have expertise in conducting the specialist report relevant to this application.
- I have no, and will not engage in, conflicting interests in the undertaking of the activity.
- I undertake to disclose to the applicant and the competent authority all material information in my possession that reasonably has or may have the potential of influencing - any decision to be taken with respect to the application by the competent authority; and - the objectivity of any report, plan or document to be prepared by myself for submission to the competent authority.

Signature of the specialist: Ockert F. Scholtz, *Pr.Sci.Nat*

Shangoni AquiScience, a division of Shangoni Management Services (Pty) Ltd

Name of company:

12 February 2020

Date:

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1. INTRODUCTION AND BACKGROUND

Shangoni AquiScience, a division of Shangoni Management Services (Pty) Ltd ("Shangoni"), was appointed by Cabanga Environmental cc ("Cabanga"), to conduct a specialist geohydrological investigation and impact study for Tumelo Colliery located near Hendrina in the Mpumalanga Province.

Tumelo Colliery is an existing underground coal mine exploiting the No. 2 Seam by bord and pillar methods. Tumelo Colliery currently holds a valid mining right, reference number MP 30/5/1/2/2/10115MR, and associated EMPr (Digby Wells & Associates, 2008). The Mining Right Area includes various portions of the farm Boschmanskop 154 IS and extends over an area of 462.2117 Ha. The mine was placed under care and maintenance at the end of February 2014 for a period of five (5) years. Bord and Pillar mining of 2 Seam re-commenced during the first quarter of 2019.

The No. 2 seam is accessed via a box-cut decline positioned slightly upslope of the Boschmanskop Dam. Coal is conveyed to surface where it is crushed and screened on site before being trucked off site. Supporting infrastructure on site, includes:

- Access and haul roads;
- Workshop area incl. stores, fuel storage and waste management areas;
- Administrative complex incl. change house and lamp room;
- Sewage Package Plant;
- Crushing and Screening Plant;
- Weighbridge;
- Coal stockpile area (RoM);
- Clean and dirty water diversion drains;
- Pollution control dam (PCD);
- Overburden stockpile;
- Erikson Dam;
- Substation; and
- Pump station.

Tumelo Colliery investigated the feasibility of mining No 4 Seam and proved it to be more financially viable to rather exploit the No. 2 Seam further by employing partial pillar extraction (partial stooping). No additional infrastructure is required for the project and thus no new environmental Listed Activities will be triggered. However, as the partial pillar extraction of the No. 2 Seam will result in a change of Scope and the nature of the environmental impacts, the EMPr will need to be amended as per Regulation 31 of the EIA Regulations, 2014.

As part of the process to update the EMPr, an updated geohydrological assessment is required.

This specialist groundwater report provides information not only to update the EMPr but also for an associated Water Use Licence Application ("WULA). The main objectives of the study were to provide baseline groundwater and relevant environmental conditions as well as qualifying and quantifying the potential impacts posed by the proposed activities on the groundwater regime.

The reporting format conforms to the format of the *Regulations Regarding the Procedural Requirements for Water Use Licence Applications and Appeals*, NO. R. 267, as published by the Department of Water Affairs ("DWS") on 24 March 2017 and Appendix 6 of the NEMA EIA Regulations (specialist reporting).

2. GEOGRAPHICAL SETTING

The study area is in the Eastern Highveld region of Mpumalanga, characterised by gently undulating plains with wide to narrowly incised valleys, such as the Olifants River valley. Typically, this landscape is associated with surface water features such as rivers, streams, wetlands and pans.

Tumelo Colliery is located 15 km north-west of the town of Hendrina and 5 km south-east of Hendrina Power Station. The properties covered by the Mining Right Application is listed in Table 1 and the mine location and general layout are shown in Figure 1 and Figure 2.

Table 1: Summary of the Properties covered by the Mining Right Application (MWP, 2019)

<table>
<tr><th>Mining Area</th><th>Farm</th><th>Portion</th><th>Surface Owner</th><th>Title Deed</th><th>Property Extent (Ha)</th><th>Extent incl. in MR (Ha)</th></tr>
<tr><td>The Remainder of Portion 10</td><td>Boschmans kop 154 IS</td><td>10 (RE)</td><td>Tumelo Exploration (Pty) Ltd</td><td>T108163/2006</td><td>135.0015</td><td>135.0015</td></tr>
<tr><td rowspan="2">The Remainder of Mineral Area 1</td><td rowspan="2">Boschmans kop 154 IS</td><td>6</td><td>Tumelo Coal Mines (Pty) Ltd</td><td>T334586/2007</td><td>161.6182</td><td>145.5447</td></tr>
<tr><td>Portion 21 (of Portion 6)</td><td>Optimum Coal Mine (Pty) Ltd</td><td>T10787/2009</td><td>29.3884</td><td>0.2857</td></tr>
<tr><td rowspan="3">The Remainder of Portion 14, 23 & a portion of Portion 26</td><td rowspan="3">Boschmans kop 154 IS</td><td>14 (RE)</td><td>Tumelo Coal Mines (Pty) Ltd</td><td>T334586/2007</td><td>150.0259</td><td>150.0259</td></tr>
<tr><td>Portion 23 (of Portion 14)</td><td>Optimum Coal Mine (Pty) Ltd</td><td>T10787/2009</td><td>30.4911</td><td>30.4911</td></tr>
<tr><td>Portion 26 (of Portion 14)</td><td>Jan Hendrik Uys</td><td>T4681/2008</td><td>257.8224</td><td>0.8628</td></tr>
</table>

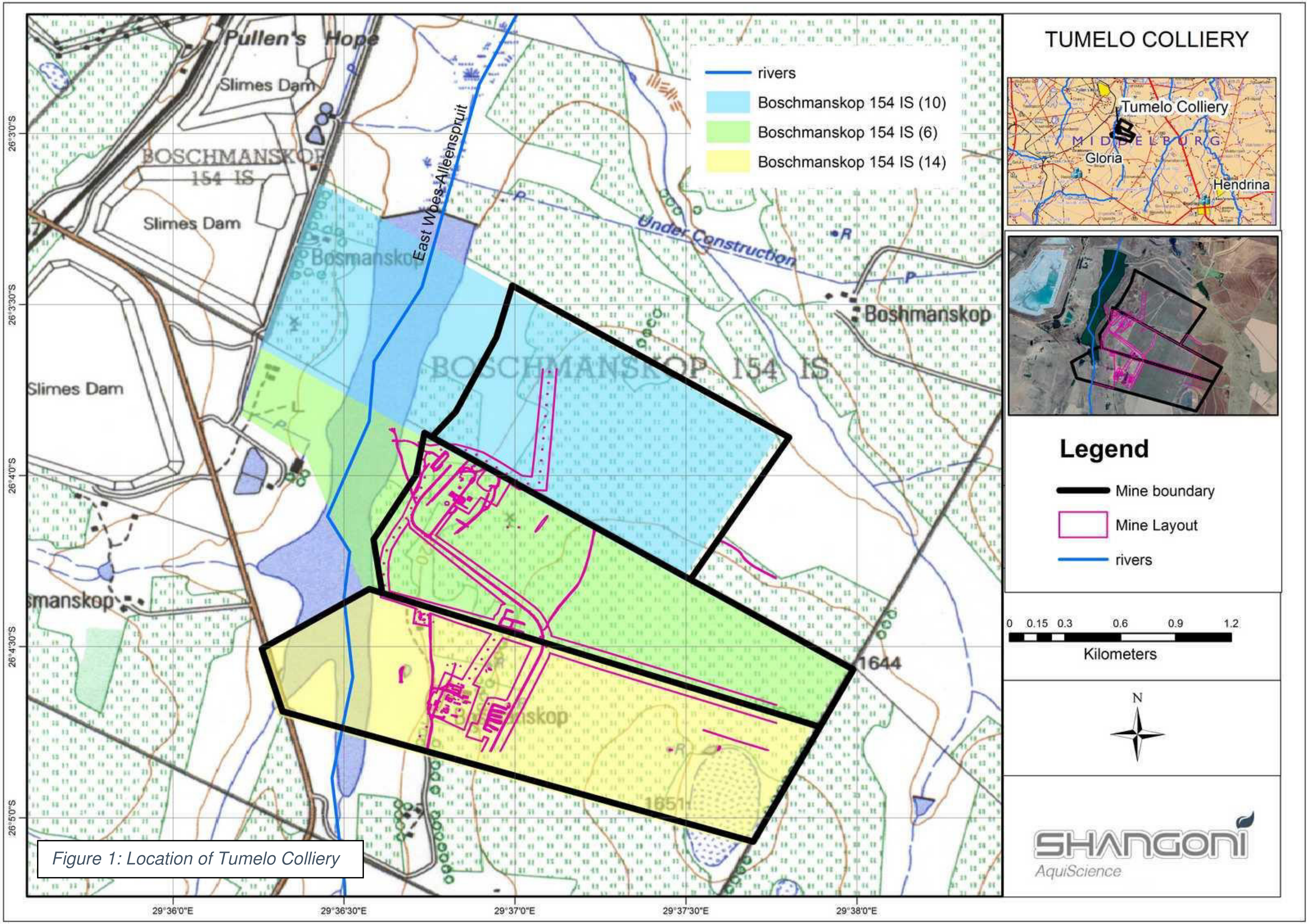


Figure 1: Location of Tumelo Colliery

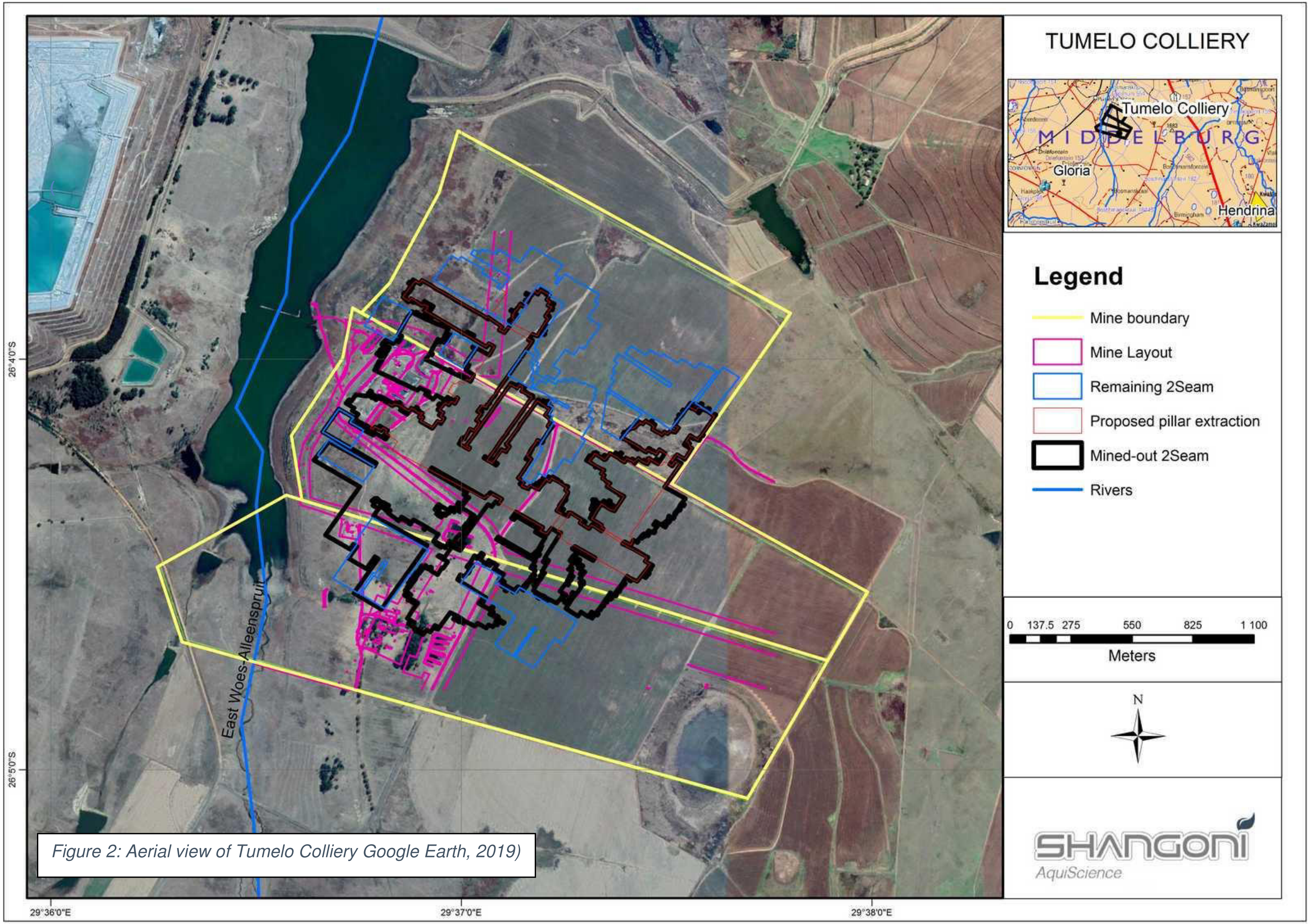


Figure 2: Aerial view of Tumelo Colliery Google Earth, 2019)

2.1 Topography and drainage

The topography is slightly undulating. Surface elevations range from 1650 on the south-eastern border to 1605 meters above mean sea level ("mamsl") on the western border. Based on the surface contours displayed in Figure 3, Tumelo is located on a slight N-S water divide, and flow, which will follow the contours perpendicularly from high to low, will be towards the Boschmanskop Dam and the drainage lines located to the immediate west and east from the mine. The landscape is also associated with other surface water features such as wetlands and pans (Scientific Aquatic Services, 2019; Draft report).

The topography is usually a good first indication of the groundwater flow directions, and hydraulic heads in an unconfined or semi-confined aquifer often come very close to surface in topographic lows and sometimes even form wetlands and natural springs.

The study area is in the B12B quaternary catchment of the primary Limpopo-Olifants River catchment of South Africa (Figure 4). Several river systems drain the catchment area, the most prominent being the Klein-Olifants River, Woes-Alleenspruit and Rietkuilspruit. In the immediate vicinity of the study area, two smaller drainage systems, East-Woes-Alleenspruit and an unnamed tributary, are located to the immediate east and west of the mine. Both these features flow north for 15 km until it drains into the Woes-Alleenspruit. Another prominent water feature is the Boschmanskop Dam. This dam, located to the immediate west of the mine, was constructed to divert clean water from a neighbouring opencast operation. A neighbouring farmer has unlimited access to the water in this dam and uses it for centre pivot irrigation. The mine also uses water from the dam for production purposes and as an emergency supply for domestic use.

Another dam, situated on a neighbouring mine's property, is in the valley of the western river and forms the boundary on that side of the proposed mining area. Along the south eastern boundary there is a steep drop into a basin containing a pan with an endorheic drainage system.

Additional information pertaining to water management for the B12B quaternary is shown in Table 2 (GRDM).

The statuses of the ecosystem function/categories (E or F) are an indication of the already impacted nature of the catchment, which is generally impacted on by extensive mining related activities. The categories are defined as:

E *Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive.*

F *Critically / Extremely modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.*

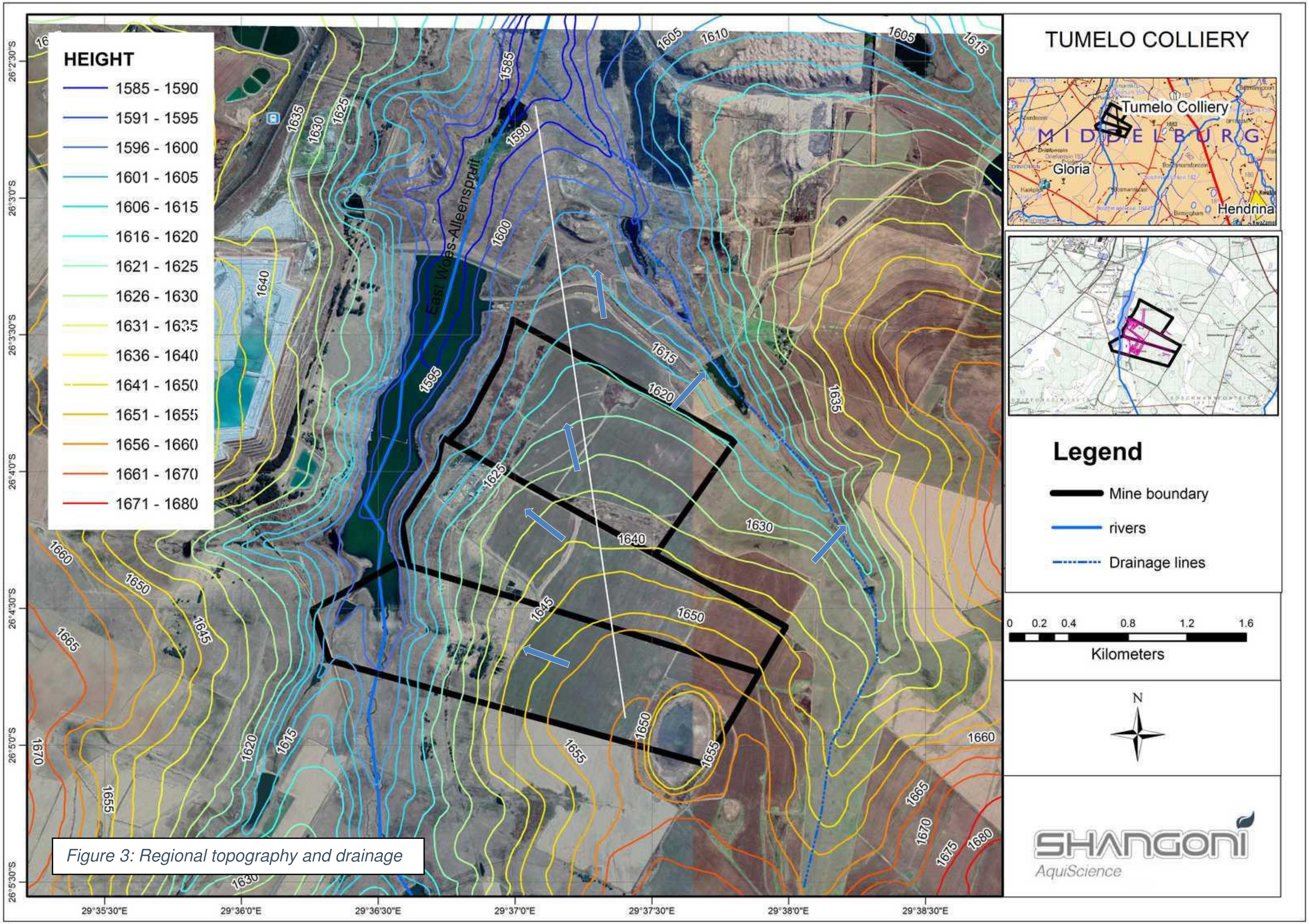


Figure 3: Regional topography and drainage

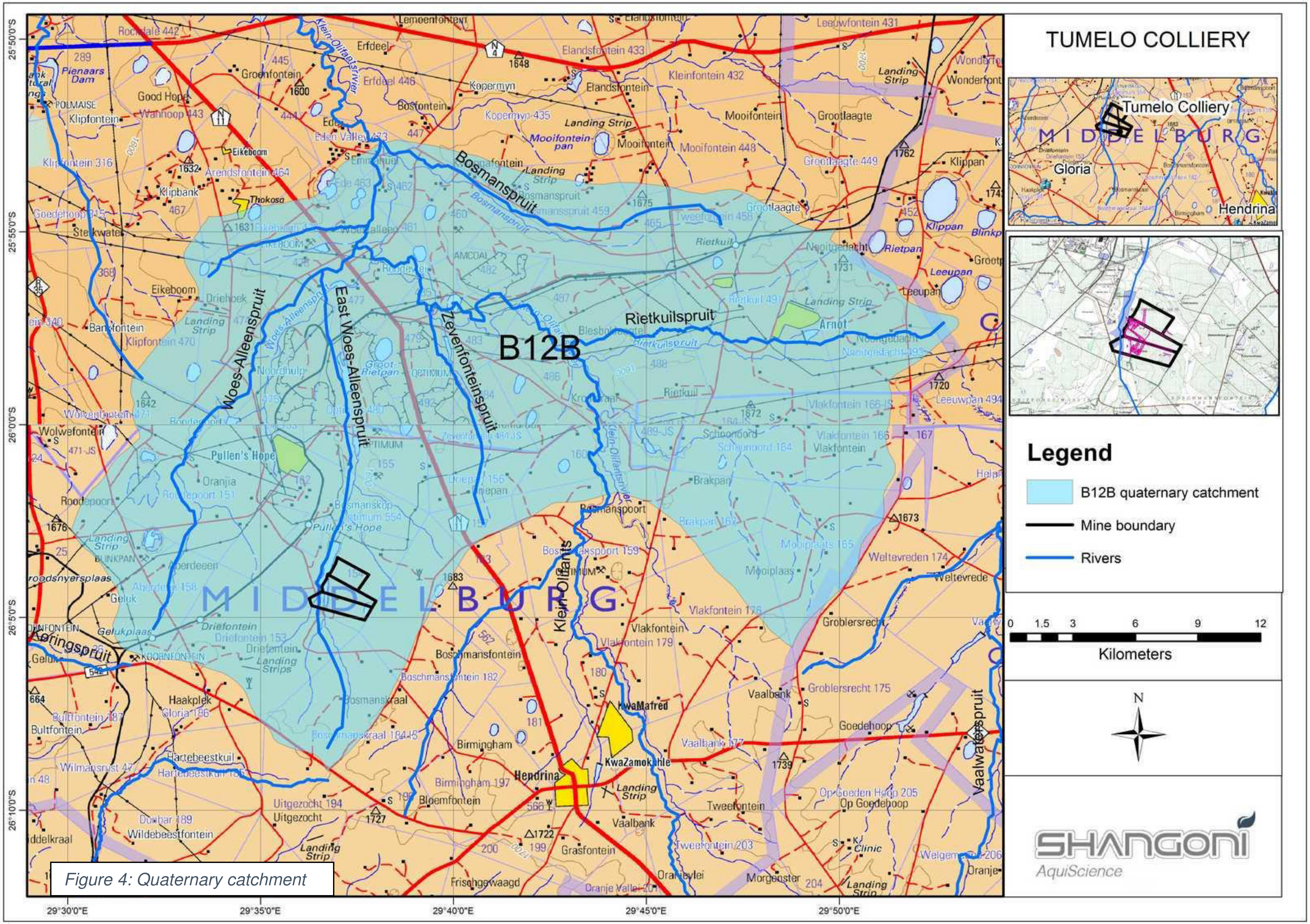


Figure 4: Quaternary catchment

Table 2: Catchment information (GRDM)

Attribute/Catchment	B12B
Quaternary catchment area (km^2)	658.5
Mean annual rainfall (mm/a)	697
Mean annual runoff (mm/a)	28
Baseflow (mm/a)	7
Mean annual evaporation (mm/a)	1400 - 1500
Total groundwater use (Mm^3/a)	0.125
Ecoregion	Highveld
Present Eco Status Category	E or F
Recharge (mm/a)	52
Exploitation potential (Mm^3/a)	6
Vegetation type	Moist Sandy Highveld Grassland
Soil	SaClLm
Groundwater General Authorization $m^3/ha/a$	75

Livestock use is by far the greatest groundwater user in the catchment, making up more than 75% of the total usage (Table 3).

Table 3: Total groundwater use in the B12B quaternary catchment (GRDM)

Type of use	Value (Mm^3/a)
	B12B
Authorised use	0
Total use	0.1247
Rural use	0.03
Municipal use	0
Irrigational use	0
Livestock use	0.0947
Mining use	0
Industry use	0
Aquatic ecosystem use	0

2.2 Climate

The study area is in the Mpumalanga Province of South Africa and the Eastern Plateau Highveld climate zone. The province is characterised by a mild to warm summer rainfall climate and cool to cold winters. Sharp frost is a common occurrence during winter. The hottest months in the region have been measured in December and January, whilst the coldest months are June and July. The days during summer are generally warm, but a substantial drop in temperature occurs during the winter nights.

The mean annual precipitation of the site is approximately 690 mm and annual evaporation 1522 mm (S-Pan). The monthly average rainfall, rainfall days, and evaporation rates are presented in Table 4. The Mpumalanga Highveld has distinct wet and dry seasons. 91% of the site's mean annual rainfall falls between October and April. Roughly 70% of the area's mean annual evaporation occurs in this period.

Table 4: Mean monthly rainfall, rain days and evaporation data (gauge number 0478546 – van Dyksdrift)*

Month	Ave Rainfall (mm)	Ave rain days	Ave Evaporation (mm S-Pan)
January	116.5	10.4	167.4
February	96.3	7.8	139.6
March	74.8	7.1	137.7
April	42.8	4.5	105.9
May	16.3	2.1	89.2
June	7.6	1.2	72.4
July	6.6	0.9	79.3
August	6.9	1.0	105.0
September	24.2	2.8	136.1
October	67.8	7.0	164.1
November	112.6	10.4	154.8
December	110.6	10.3	170.5
Mean Annual	**687**		**1522**

*– van Dyksdrift is located approximately 30 km SW of the site

The Department of Human Settlements, Water and Sanitation ("DHSWS") requires that a climatic water balance that incorporates a list of years which have the wettest six months of the year, either November to April or May to October be provided. In this case November to April is wetter than May to October. The ten wettest six months between November and April are listed in Table 5.

Table 5: Wettest years between November and April (Midgley et al., 1990)

Rating	Year	Total rainfall between November and April (mm)
Wettest year	1955	975.4
2nd wettest year	1975	913
3rd wettest year	2000	880.1
4th wettest year	1939	875.8
5th wettest year	1946	777.9

Rating	Year	Total rainfall between November and April (mm)
6th wettest year	1952	762.5
7th wettest year	1967	754.6
8th wettest year	1949	721.4
9th wettest year	1980	717.3
10th wettest year	1959	708.8

3. SCOPE OF WORK

The aims of the project were to i) determine baseline geohydrological conditions; ii) assess probable water related impacts; and iii) to propose management plans and monitoring protocols to pro-actively manage all future potential water related impacts.

4. METHODOLOGY

The focus areas required to assess the geohydrological conditions were:

- Description of baseline environmental conditions.
- Determination of baseline (*status quo*) geohydrology of the area, which included a desktop study of the groundwater conditions and relevant environmental factors.
- Development of a conceptual model based on current geohydrological conditions.
- Construction and calibration of a steady state groundwater flow model which describes status quo groundwater flow conditions in steady state.
- Determination of the Darcy flux and seepage velocity and rate at which groundwater contamination will migrate.
- Development of a numerical transport model to simulate and predict migration of a worst-case pollution plume using different pollution control scenarios.
- Risk assessment of the geohydrological impact resulting from the partial stooping phase of mining. This include the description of possible negative groundwater related impacts during operation and decommissioning. Since no new infrastructure will be developed, impacts during the construction phase was not included.
- Recommendations on a groundwater management framework and monitoring programme which will assist in the development of rehabilitation measures based on physical, hydraulic and hydro-geochemical information as gathered and predicted in the preceding phases.

To meet the aims and objectives for the current project, the following phases were completed:

<u>Phase 1 - Fieldwork</u>

- Conduct an initial site visit and hydrocensus to assess ground- and surface water utilisation and baseline groundwater properties (water quality and levels).

- Conduct geophysical testing on possible lineaments that may act as preferential flow pathways for the movement of groundwater (and pollutants).
- Determine hydraulic properties of the saturated zone by conducting permeability testing on suitable boreholes.

Phase 2 – Reporting and Impact Assessment

- Baseline description of geohydrology for the study area.
- Combine and interpret available topographical, geohydrological and related information.
- Assessment of potential sources of pollution.
- Development of a conceptual geohydrological model for the project areas.
- Development of a steady state numerical model and transient state pollution transport model.
- Identify impacts and rate them in a risk assessment.
- Recommendation of a suitable monitoring programme.
- Post-closure management plan.

4.1 Desk Study

A desk study was conducted to gather all relevant environmental information, including topographical, hydrological and geohydrological data. Data/information was also gathered from previous relevant studies conducted for the area as well as data published in the public domain.

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 suggested that aquifer classification forms a very useful planning tool that can be used to guide the management of groundwater issues.

4.1.1 Aquifer classification

The South African Aquifer System Management Classification is presented by five major classes listed below and defined in Table 6:

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

Table 6: 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 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.	Moderately yielding aquifer (1-5 l/s) of acceptable quality or high yielding aquifer (5-20 l/s) of poor-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.	

4.1.2 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:

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

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 7.

Table 7: 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 or just below it.
- 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.

4.2 Hydrocensus

A hydrocensus was performed on and around the study areas to identify groundwater users, groundwater potential and baseline data. The survey was conducted in August and October 2019.

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

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

Data captured during the hydrocensus can be viewed in Section 5.4 of the report.

4.3 Geophysical survey and results

4.3.1 Methodology followed

A geophysical survey was conducted to site suitable locations for drilling of monitoring and/ or characterisation boreholes. Two geophysical techniques were employed in this study, namely the electromagnetic ("EM") and magnetic methods. Five (5) geophysical traverses equalling 3 km in total length (Figure 5) were conducted on 23 and 24 October 2019. Intercoil spacing for the EM was 20 m.

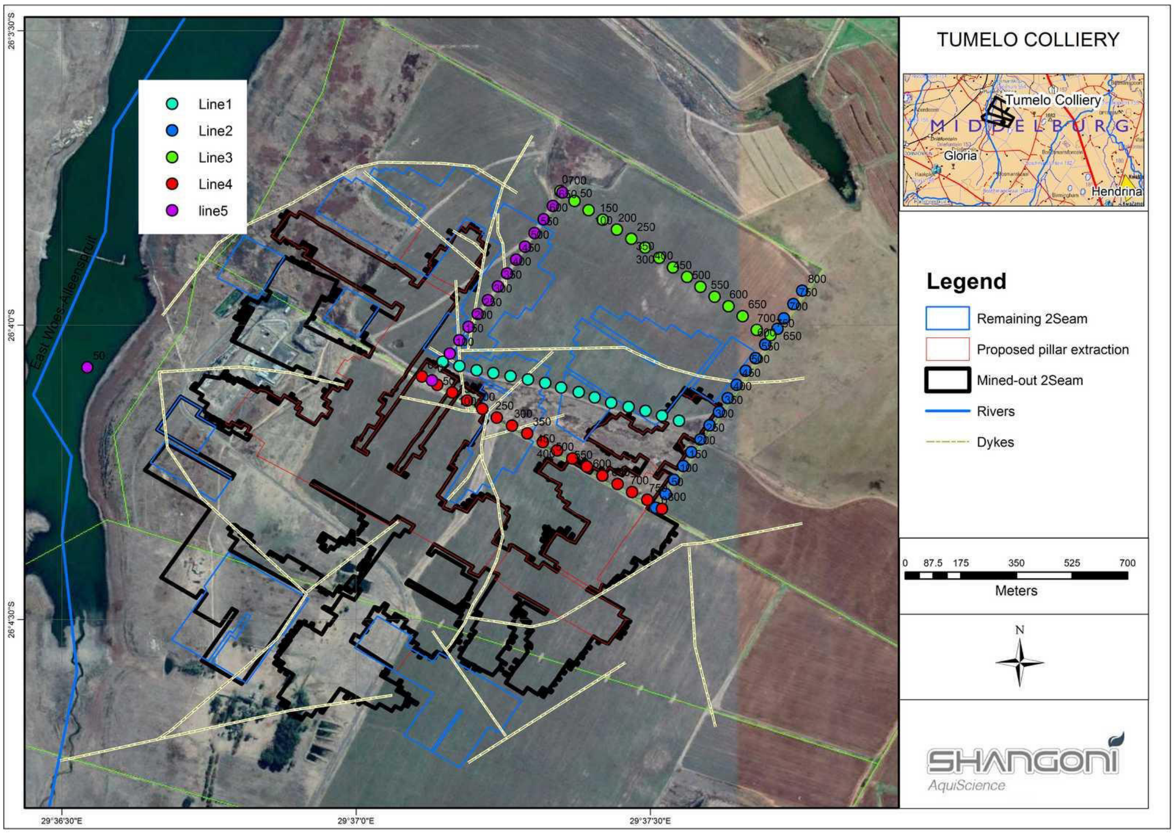


Figure 5: Electro-magnetic (EM) and magnetic geophysical traverses conducted

The Magnetic method attempts to differentiate between lateral differences in the earth's magnetic field. These differences or anomalies indicate different types of underlying rock formations and/or variations in depth of these different formations. The magnetic surveys are normally done in a linear traverse and are normally applied in the following situations:

- Tracing of intrusive dolerite or diabase dykes or sills;
- Tracing of contact zones between different formations; and
- Tracing of possible fault zones.

The Electromagnetic method attempts to measure the conductivity of rock. The application in groundwater exploration can be found in the fact that there is a relationship between the conductivity of a formation and the porosity thereof, the connection between pores, the volume of water in the pore and the conductivity of the water in the pore. The method can be used to do lateral profiling of strata and is applied in the following situations:

- Identification of thin linear zones of conductivity, fracture zones, fault zones, weathered dykes and contact zones of different hydrological regimes; and
- The identification of contamination plumes.

4.3.2 Geophysical Results

No geological or intrusive anomalies were evident from the 1: 50 000 geological map sheet. However, the client mapped suspected geological anomalies, which were superimposed on a map, during the exploration phase of the mine. These are suspected dolerite dykes and could have created preferential flow pathways within the host rock when it intruded. Geophysical traverses were subsequently planned on some of these suspected dolerite dykes using magnetics and electro-magnetics. The data generated can be viewed in in Figures 6 – 10.

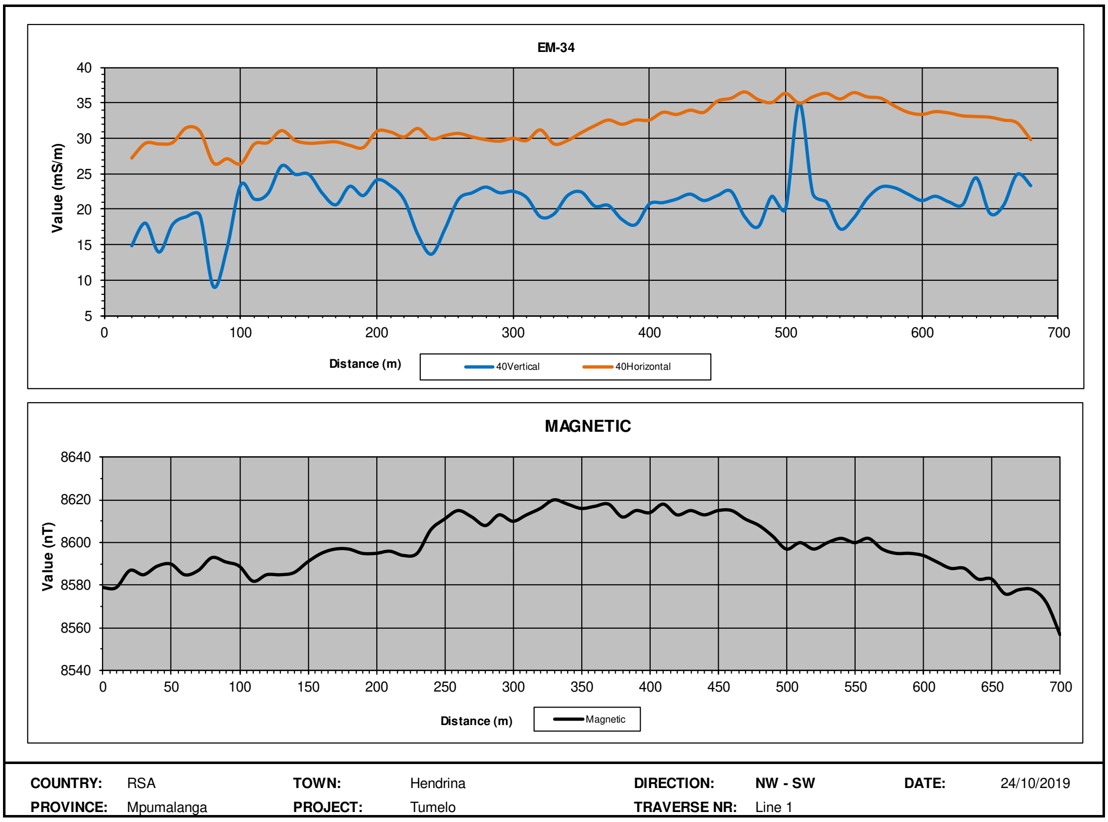
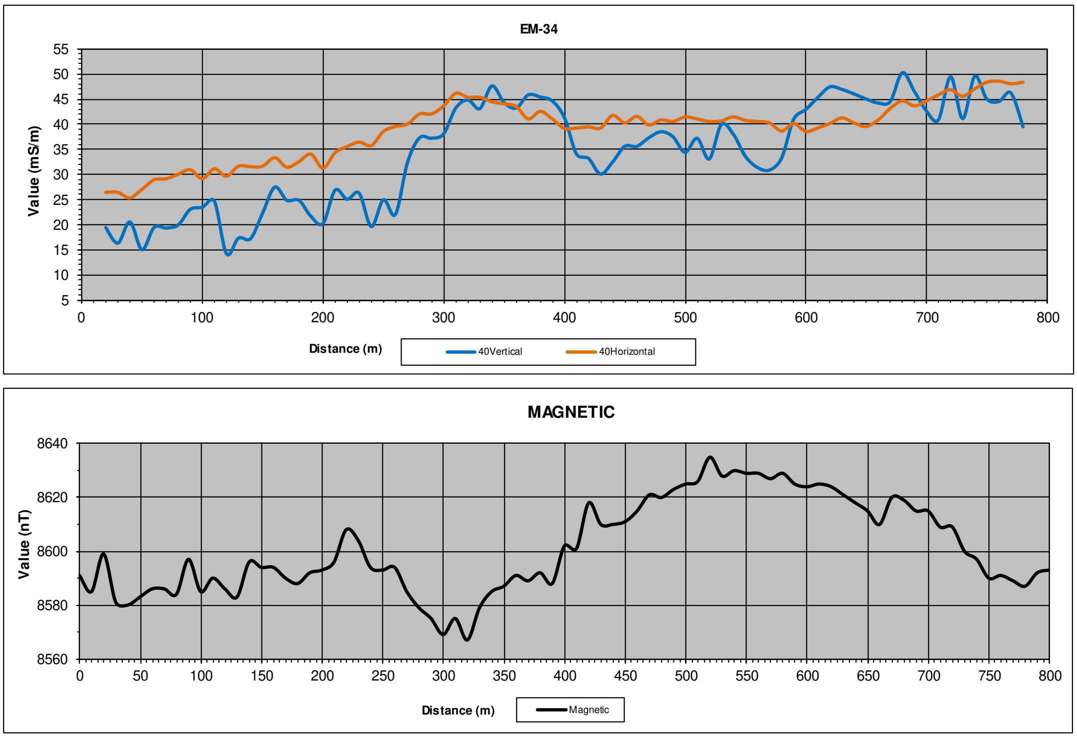
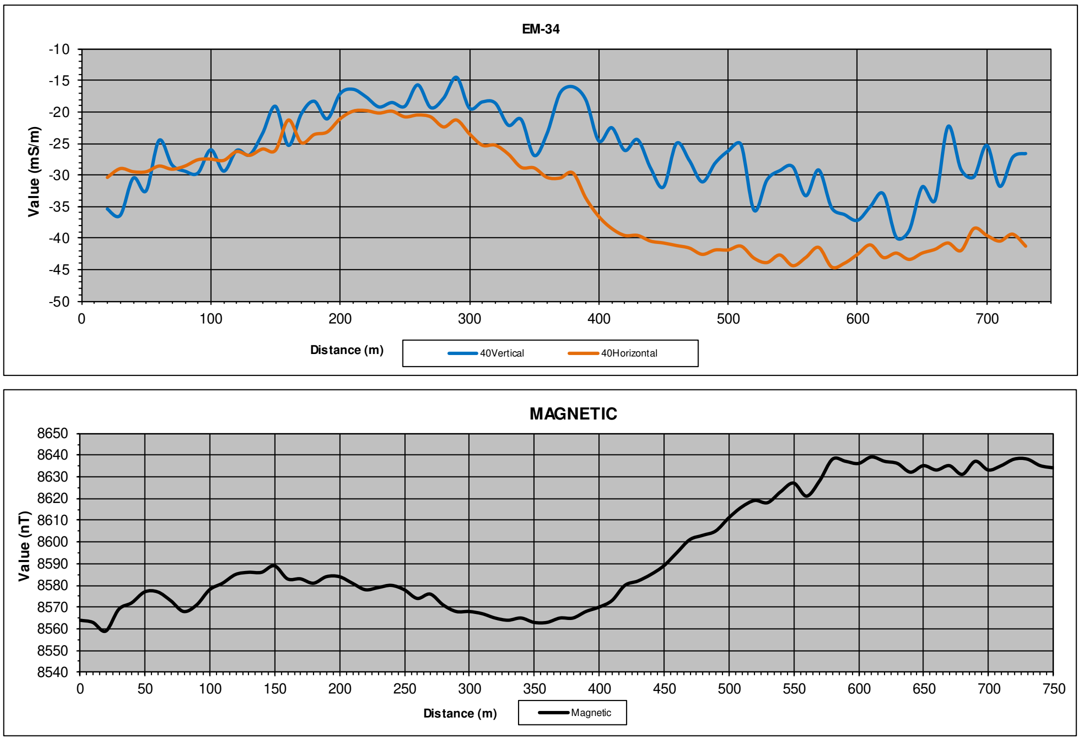


Figure 6: EM and magnetic data for Line 1



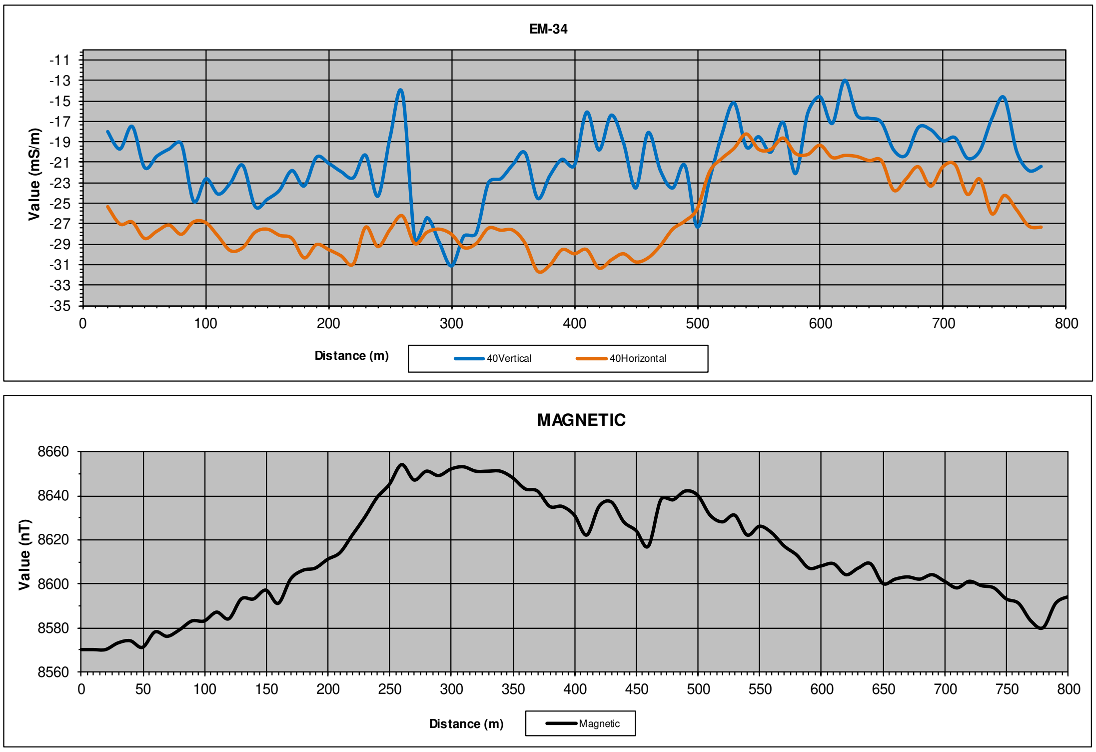
COUNTRY:	RSA	**TOWN:**	Hendrina	**DIRECTION:**	**S - NE**	**DATE:**	24/10/2019
PROVINCE:	Mpumalanga	**PROJECT:**	Tumelo	**TRAVERSE NR:**	Line 2		

Figure 7: EM and magnetic data for Line 2



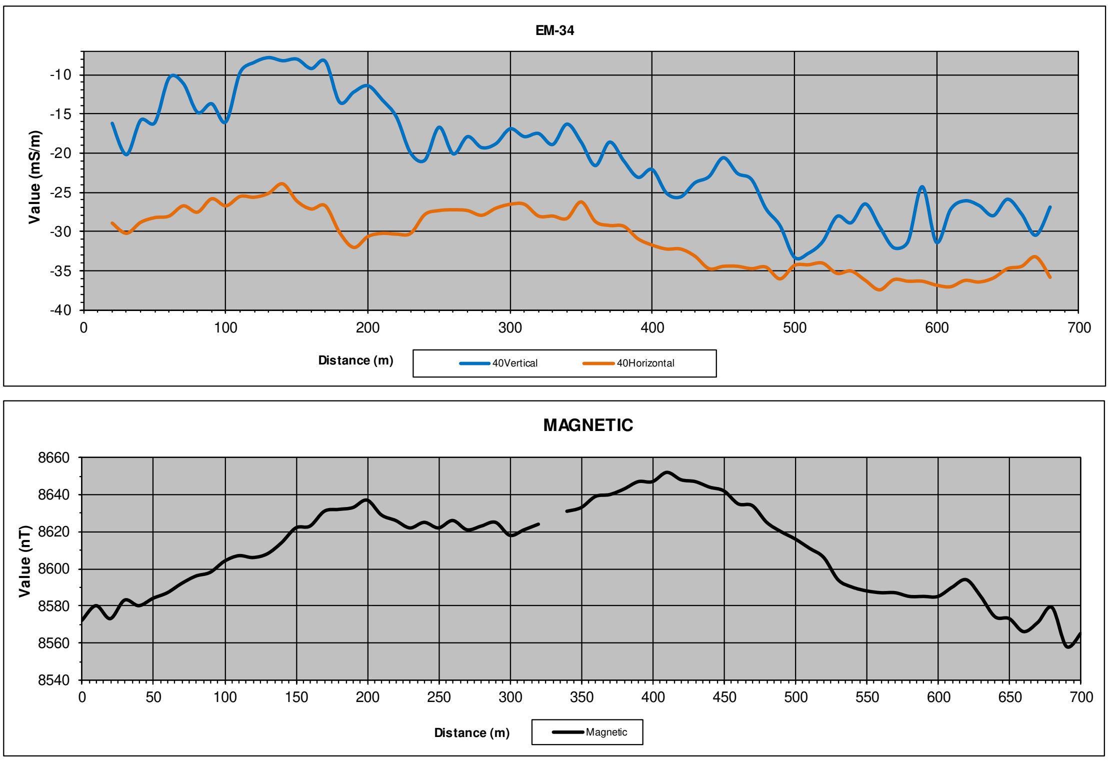
COUNTRY:	RSA	**TOWN:**	Hendrina	**DIRECTION:**	**NW - SE**	**DATE:**	23/10/2019
PROVINCE:	Mpumalanga	**PROJECT:**	Tumelo	**TRAVERSE NR:**	Line 3		

Figure 8: EM and magnetic data for Line 3



COUNTRY:	RSA	**TOWN:**	Hendrina	**DIRECTION:**	NW - SE	**DATE:**	23/10/2019
PROVINCE:	Mpumalanga	**PROJECT:**	Tumelo	**TRAVERSE NR:**	Line 4		

Figure 9: EM and magnetic data for Line 4



COUNTRY:	RSA	**TOWN:**	Hendrina	**DIRECTION:**	NW - SE	**DATE:**	24/10/2019
PROVINCE:	Mpumalanga	**PROJECT:**	Tumelo	**TRAVERSE NR:**	Line 5		

Figure 10: EM and magnetic data for Line 5

4.4 Drilling and siting of boreholes

No new boreholes were drilled for this study. The investigation relied heavily on current monitoring boreholes and boreholes surveyed during the hydrocensus.

4.5 Aquifer testing

4.5.1 Falling Head Aquifer Tests

Falling head tests were conducted on two (2) monitoring boreholes to determine the hydraulic conductivity (K) of the aquifer. Falling head tests are 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 in pressure. The test was performed by suddenly raising the static water level in the borehole with the aid of a certain volume of water. The water replaces its own volume in the borehole, thus increasing the pressure. The equilibrium in the water level is thus 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 permeability of the aquifer can be measured. 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. The results can be viewed in Section 5.3.3.

4.6 Sampling and chemical analysis

Ground- and surface water samples were taken during the hydrocensus that was conducted in October 2019. Samples were taken using relevant and industry standards and all samples were delivered to a SANAS accredited water laboratory. The results are presented and discussed in Section 5.6.

4.7 Groundwater recharge calculations

Recharge is defined as the addition of water to the saturated zone, either by the downward percolation of precipitation or surface water and/ or the lateral migration of groundwater from adjacent aquifers. The main source of recharge into the shallow primary aquifers is direct rainfall recharge that infiltrates the aquifer through the overlying unsaturated zone. Recharge to the deep Karoo aquifer is limited to vertical seepage from the shallow Karoo aquifer through permeable fracture systems that link the two aquifers hydraulically. Due to the heterogeneous nature of such fracture systems, it is assumed to be highly variable and some aquifers may be connected while others may be not.

The groundwater recharge was estimated using the RECHARGE programme, which include using qualified guesses as guided by various schematic maps. The following recharge values as in Table 8 were inferred from the RECHARGE software programme (van Tonder and Xu, 2000).

Table 8: Recharge values inferred for the study area (RECHARGE, van Tonder and Xu, 2000)

Method/reference	Recharge (%)	Recharge (mm/a)
Geology[1]	3.00	20.1
Vegter[2]	4.86	30.56
Acru[3]	4.55	30.49
Harmonic mean	**3.95**	**26.03**

Notes: *Recharge per annum were calculated using a MAP figure of 670 mm.*

[1] Sandstone/shale/mudstone = 80%; hard rock 20%; soil cover <0.5% = 20%, soil cover >0.5% = 80%

[2] Vegter 1995

[3] Agricultural Catchments Research Unit

According to the various sources used, the recharge of the study area varies between 3% and 4.86% with an average (harmonic mean) recharge of 3.95% of MAP. In general, recharge into the Karoo sandstones are relatively low with various factors controlling the recharge but typically range between 0.5 and 3% of MAP. However, the presence of intrusive bodies or faulting zones may exert a significant influence on the rate of recharge to the subsurface since they provide preferential pathways for water to recharge the underlying aquifer.

4.8 Groundwater modelling

A groundwater model was developed for the project. The chosen software code, model set-up, assumptions and results are described in detail in Section 7 of this report.

The numerical groundwater model, despite all efforts and advances in software and algorithms, remains a very simplified representation of the very complex and heterogeneous interacting aquifer systems underlying the mining area. The integrity of a numerical model depends strongly on the formulation of a sound conceptual model and the quality and quantity (distribution, length of records etc.) of input data. Nonetheless, a numerical model can be used successfully to assess the effectiveness of various management and remediation options/techniques, especially if the shortcomings in information and assumptions made in the construction and calibration of the model are clearly listed and kept in mind during modelling.

The main purpose is thus not to try and predict what the exact groundwater level or pit inflow of a certain element will be at a certain position at a specific moment in future. The heterogeneity of the natural groundwater system, especially the secondary fractured rock aquifer environment underlying the mining area, is simply too great to accurately incorporate and simulate accurately in the model. The purpose is rather to evaluate what the relative magnitude or contribution of certain impacts or different pollution sources will be on the larger groundwater regime and then to determine which remediation options would have the most beneficial effects.

4.9 Groundwater availability assessment

In a typical geohydrological setting, groundwater flow and aquifer development are closely linked to the geology. The regional study area is underlain by rocks of the Vryheid Formation of the Ecca Group of rocks consisting predominantly of mudrock, rhythmite, siltstone and fine to coarse-grained sandstone and five mineable coal seams. The geology of the Vryheid formation is not favourable for good yielding aquifers except where faults or dykes have created preferential flow pathways for the movement of groundwater. A further discussion on aquifer hydraulic parameters and yields are discussed in sections 5.3 and 6.2.

5. PREVAILING GROUNDWATER CONDITIONS

A variety of anthropogenic activities affect groundwater flow and chemistry, the extent of which can only be quantified if the pre-mining situation was known. The purpose of this section is, therefore, to describe the pre-mining environment to such an extent that it can be used as baseline information in the quantification of the impact of mining on the groundwater regime. The area under investigation is, however, not unaffected as mining has Tumelo is an already existing mine.

The current physical, hydrochemical and geochemical properties of the groundwater regime in the region are explained in the following sections.

5.1 Geology

5.1.1 Regional geology

The 2628 East Rand 1:250 000 geological map indicates that the study area is directly underlain by rocks of the Vryheid Formation (Figure 11) belonging to the Ecca Group of the Karoo sequence of rocks believed to be 400 million years old. The Karoo Supergroup comprises mainly of a sedimentary succession of sandstone, siltstone, shale, mudstone, coal, diamictite 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. Coal 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. This succession of sedimentary rocks generally overly the well-consolidated conglomerates/diamictites of the Dwyka Formation, but in places the Ecca Group rocks rest directly on the felsites and granites of the pre-Karoo Basement rocks.

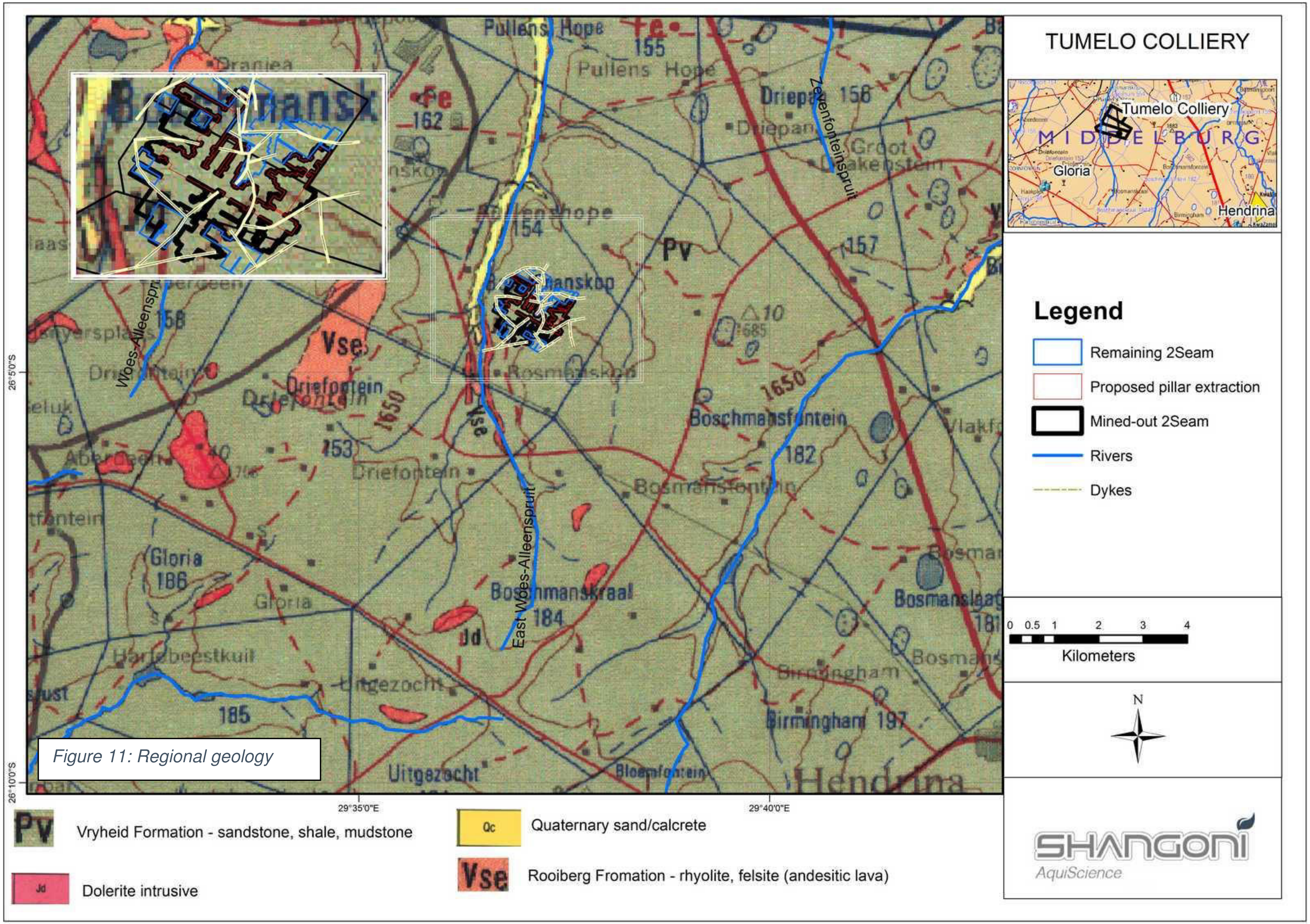


Figure 11: Regional geology

At places, sediments of the Vryheid Formation overlie the uneven Dwyka floor, which is controlled by the topography of the pre-Karoo platform upon which the Karoo sediments were deposited. The Vryheid Formation, which is present throughout the Witbank area, attains some 140 m at the thickest point and contains several coal seams, of which four (No. 1, 2, 4 & 5 Seams) are considered to have economic potential.

The pre-Karoo rocks, consisting mainly of felsites of the Bushveld Igneous Complex, have been glacially sculptured to give rise to uneven basement topography. The thin veneer sediments of the Dwyka Formation, which overlies the pre- Karoo, are generally not thick enough to ameliorate the irregularities in the placated surface and, therefore, affected the deposition of the younger Vryheid Formation sediments. Typically, coarse-grained sandstones are a characteristic of the sediments in the Witbank Area.

5.1.2 Local geology

The No 2 Seam ranges in thickness from 0.65 to 5.21 m. In general, the thickest coals are normally found in the palaeo-valleys and the thinnest coal along the palaeo-ridges. In this area, the valley bottom has been in filled by mudstone or siltstone and has replaced the bottom part of the seam. As a result, the thickest development of coal is found along the flanks of the poloidally, that trends approximately north–south across the eastern side of the property. The thinnest coals are associated with the palaeo-ridge found along the western side of the property (Digby Wells, 2008).

This pattern has been modified by the presence of the dolerite sill that is found either at or close to the seam elevation in the northern, eastern and southern parts of the property. This sill has devolatilised, burnt or displaced the seam leaving only a central area of potentially mineable coal. Within this central area the coal ranges in thickness from 0.91 to 5.21 m with an average of 3.49 m. The coal steadily thickens from the extreme west to east, where in the east, the seam ranges in thickness from 2.87 to 5.21 m (Digby Wells, 2008).

The seam appears to be relatively clean because few partings are recorded, and they do not have a common location in the seam. The few-recorded partings are random in distribution and lenticular in nature and should not cause a serious problem during mining. The elevation of the floor of seam ranges from 1540 to 1590 m above sea level. The highest point is in the southwest, from where the seam steadily dips to the east at about 2.7 degrees or 1 in 19 for about 700 m. It then flattens in the north south trending palaeo-valley. The depth of the seam is controlled by the surface topography and the seam floor topography. The seam ranges in depth from 17 to 106 m deep. It is shallowest in the southwest. The depth steadily increases to the east then flattens in the palaeo-valley. There is a slight increase in depth from north to south as a result of the slight drop in elevation of the seam and increase in the surface elevation to the south (Digby Wells, 2008).

The roof of the seam generally consists of a sandstone or interlaminated sandstone and siltstone. It is considered these will form a moderately strong to strong roof. Systematic roof support is recommended until the roof characteristics are firmly established during mining (Digby Wells, 2008).

A rock mechanical study was prepared for Tumelo by Mr. D. Lees, Senior Rock Engineer from Geomech Consulting (Pty) Ltd. In the report (Geomech Consulting, 2019), a number of the future mining areas were identified not be not viable for pillar extraction due to the presence of structures / features on surface which must be protected in the long term. They also established that the risk of sinkhole formation is high in areas in which the seam occurs at a depth of less than 40 m and have subsequently been excluded entirely from this investigation.

5.1.3 Dykes, sills and faults

Abundant dolerite intrusions are present in the Ecca sediments. These intrusions comprise sills, which vary from being concordant to transgressive in structure, and feeder dykes. The sills usually precede the dykes, with the latter being emplaced during a later period of tensional forces within the earth's crust. Although these structures serve as aquitards and tend to compartmentalise the Karoo aquifers, the contact zones with the pre-existing geological formations also serve as groundwater conduits. Tectonically, the Karoo sediments are practically undisturbed. No dykes are visible on the 1: 250 000 geological map (2628), but a dolerite sill is present underlying the study area (EMPr, 2006). The sill has devolatilised, burnt or displaced the seam leaving only a central area of potentially mineable coal.
A ring-shaped, dolerite dyke with low hydraulic permeability separates the Tumelo underground mine workings from the downslope Bosmanskrans Dam. The dyke is located roughly 15 m below natural ground level and overlying the dyke is a more permeable weathered zone (~15 m). Advantageously this dyke isolates the migration of potentially contaminated groundwater from the Tumelo workings towards the dam, as well as counteracts movement of water from the dam towards the mine workings. However, the dyke, forming this low permeable barrier, also acts as a water 'sink' by capturing regional groundwater flow emanating upslope. This results in groundwater flowing along natural geological bedding plains damming up against the dyke. Due to this, the damming water is forced upwards along the dyke and through the overlying weathered layer, where it can migrate towards the Boschmanskop Dam (Delta H, 2012). Several other dyke structures were also mapped by Tumelo.

5.2 Acid generation capacity

5.2.1 Coal mining and the potential of acid mine drainage

Acid mine drainage ("AMD") occurs when sulphide minerals, such as pyrite (FeS_2), are exposed to air and water and undergo oxidation. This occurs primarily in coal (and gold) mines. After air contact in the presence of sulphide (mostly pyrite) this water is often acidic due to the production of sulphuric acid. The production of AMD depends on the rate of pyrite/sulphide oxidation, the presence of acidophilic bacteria and the influence of carbonate minerals in the host rock. Moreover, upon infiltration by rainwater, mine spoil heaps can leach highly acidic AMD water that mobilizes toxic metal species and contaminates groundwaters. AMD can lower the pH to approximately 2 and total dissolved solids (TDS) in the order of 4000- 5000 mg/l. Sulphate (SO_4) is the dominant ion in solution and the largest contributor to the high salinity. Acidification has several negative consequences and most notably includes the solubilisation of a variety of trace metals and metalloids in toxic concentrations.

Acidic water has been found associated with many mine wastes including underground flows, mine decant and mine reside deposits. 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 in the process and ferrous iron (Fe^{2+}) ions are released. The following reaction steps show the general accepted sequence of pyrite oxidation (Stumm and Morgan, 1996):

1 Acidity (H^+), Fe^{2+} and SO_4 are released into the water when the mineral 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 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, FeS_2 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 re-oxidation 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.

1. 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 Fe^{2+} to Fe^{3+}. This is an abiotic process when pH is >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 Fe^{3+} 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. Sulphides are the main reaction minerals that contribute to the formation of AMD.

The generation, release, mobility and attenuation of AMD are complex processes governed by a combination of physical, chemical and biological factors. Whether it ultimately enters the environment depends largely on the characteristics of the sources, pathways and receptors involved. A generalised conceptual model of sources, pathways and receiving environments is shown in Figure 12. The sources include the mine and process wastes and mine and process facilities that contain reactive sulphide and potentially neutralising minerals involved in mitigation of acidity. The characteristics and relative abundance of these sulphide minerals, which play a critical role in determining the nature of the discharge being generated, may vary as a function of commodity and ore deposit type, type of mining and waste disposal strategy. The pathways and transport mechanisms are related to climate and seasonal effects and its hydraulic characteristics. The receptors (i.e., the receiving environment) may also alter the nature of the mine drainage. Examples of receiving environments include groundwater, surface water, pans and wetlands. All these receiving environments can alter the original characteristics of the mine discharge through a combination of physical mixing and chemical and biological reactions.

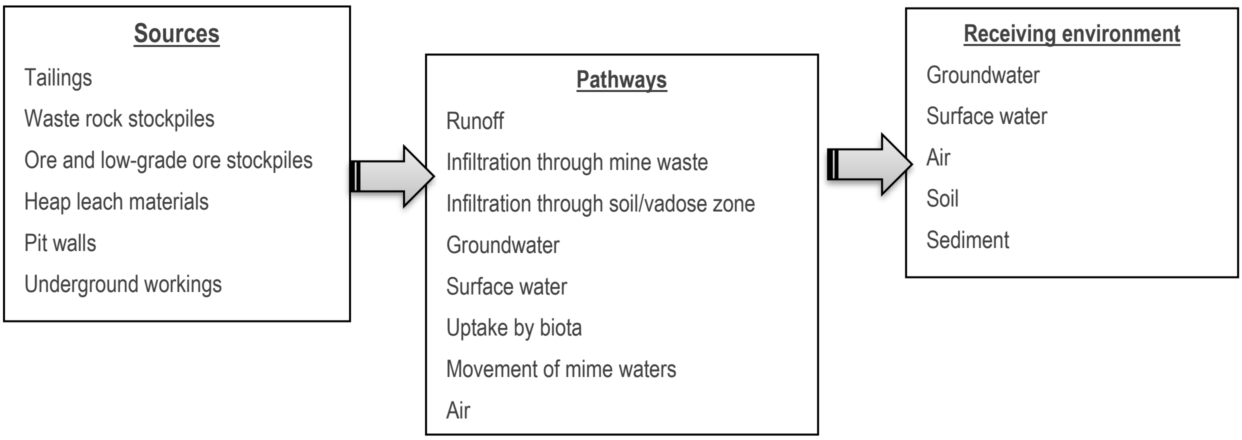


Figure 12: Generalised conceptual model of sources, pathways and receiving environment at a mine or processing site

AMD when generated is very difficult and costly to remediate and once the process has succeeded past reaction 2 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 AMD reaction sequence will therefore continue until all the pyrite has been oxidised. It is therefore important to mitigate and have effective management measures in place to control or prevent AMD generation at the source.

5.2.2 Acid potentials at Tumelo

No new geochemical work was conducted for this study. However, a comprehensive geochemical assessment, which included *inter alia* acid potentials, were conducted by Golder (2014). Based on their findings, they concluded that although all coal seams recorded acid potentials that exceed neutralisation potentials, the presence of carbonate minerals (calcite and dolomite), will neutralise local acidity should it be formed. Based hereupon, it is unlikely that decant water from the mine will be acidic, but it will potentially be high in TDS, contributed largely by sulphate (SO_4).

5.3 Hydrogeology

5.3.1 Unsaturated zone (vadose zone)

The characteristics of vadose zone vulnerability dominating factors are closely related to the migration and transformation mechanisms of contaminants in the vadose zone, which directly affect the state of the contaminants percolating to the groundwater. The permeability and thickness of the unsaturated zone are some of the main factors determining the infiltration rate, the amount of runoff and consequently the effective recharge percentage of rainfall to the aquifer. The type of material forming the unsaturated zone as well as the permeability and texture will significantly influence the mass transport of surface contamination to the underlying aquifer(s). Factors like ion exchange, retardation, biodegradation and dispersion all play a role in the unsaturated zone.

The thickness of the unsaturated zone was determined by subtracting the undisturbed static water levels in the study area from the topography. Water level measurements showed that the depth to water level, and thus the unsaturated zone, generally varies between 3 and 15 m below ground level.

5.3.2 Saturated zone

5.3.2.1 Weathered horizon

The weathered zone hosts the unconfined to semi-confined shallow weathered aquifer or hydro-stratigraphic zone. The zone is on average 15 – 20 m thick and water levels are often shallow (few meters below ground level). Due to direct rainfall recharge and dynamic groundwater flow through the unconfined aquifer in weathered sediments, the water quality is generally good, but also vulnerable to pollution. A weathered water bearing horizon is defined as groundwater saturated strata which possesses a secondary porosity associated with weathering of rock strata. The weathered water bearing horizon may or may not be hydraulically connected with the regional fractured water bearing horizon, depending on the presence, thickness and weathering of confining layers (typically horizontal sills or shale layers). Water intersections in the weathered aquifer are mostly above or at the interface of fresh bedrock, where less permeable layers of weathering products and capillary forces limit the vertical percolation of water and promote lateral water movement. Groundwater daylights as springs (contact springs) where the flow path is obstructed by impermeable layers or where the surface topography cuts into the groundwater level at e.g. drainage lines (free draining springs).

The weathered horizon is typically not regarded as good aquifers but suitable for household supply, with yields ranging between 0.1 and 1.0 l/s but typically less than 0.5 l/s. Where the weathered aquifer does become significant is from a pollution transport perspective.

5.3.2.2 Fractured horizon

A fractured water bearing horizon is defined as a groundwater saturated stratum displaying secondary porosity due to fracturing. Fractured horizons are common in sandstone and shale host rock of the Karoo sequence. The permeability within fresh matrix rocks (sandstone and shale) is extremely low and the matrix is not expected to allow any significant groundwater flow. Therefore, groundwater flow in the sedimentary rocks is expected only along weathered zones and fractures.

The fractured horizon is confined but may be semi-confining at places of extreme weathering. The aquifer depth extends from a depth of ±20-100 mbs with limited yields at depth, indicating the absence of major water bearing fractures and low permeability at depth. The aquifer can be regarded as heterogeneous having a moderate fracture network formed in the consolidated and mostly impervious matrix because of depositional stresses. Movement of groundwater is mostly restricted to fracture flow.

The fractured rock aquifer is a more reliable source of groundwater compared to the weathered zone aquifer. Typical characteristics of the fractured flow aquifer include:

- They are present as either confined or semi-confined aquifers. In the former instance, the aquifer is overlain by sediments or rock of a confining nature, thus limiting direct recharge from rainfall.
- Natural Karoo aquifers in the study area typically have a low hydraulic conductivity, but are known to be highly heterogeneous with yields ranging from 0.5 up to 5 l/s.
- Higher yields are typically associated with higher hydraulic conductivities along contact zones with intrusive rocks.
- The contact zones of dolerite dykes with the host rock provide preferential flow pathways, while the dolerite itself is rather impermeable or semi-permeable (hydraulic conductivity of 0.00086 m/d or $1x10^{-8}$ m/s). This setting promotes groundwater flow along, but not across the dykes or sill.

- Depending on the residence time of water in the aquifer, groundwater quality is good to moderate.
- Recharge from rainfall is generally low and averages between 0.5 to 4% of the annual rainfall.
- Characteristics of the aquifer vary greatly over short distances.
- Contaminant transport through fracture flow aquifers is comparatively fast.
- There is hardly any attenuation of pollutants in fractures.

5.3.2.3 Dwyka horizon

The succession of sedimentary rocks generally overly the well-consolidated glacial tillites of the Dwyka Group, but in places the Ecca Group rocks rest directly on the felsites and granites of the pre-Karoo basement rocks. The permeability of fresh tillite is generally and widely regarded as very low. The Dwyka tillite 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 0.015 m/d. Due to its low hydraulic conductivity, the Dwyka tillite where present, forms a hydraulic barrier between the overlying mining activities and the basal floor.

5.3.2.4 Pre-Karoo aquifer

The pre-Karoo rocks, consisting mainly of felsites of the Bushveld Igneous Complex, are present below the Dwyka group tillites/diamictite. At places, the Ecca Group rocks do, however, rest directly on the felsites and granites of the pre-Karoo Basement rocks. Groundwater is mostly present in very small and low yielding fractures. The pre-Karoo is considered not to be a reliable source of groundwater given its great depth, compactness of the host rock and inability to fracture, inferior quality associated with felsites and granites (mostly fluoride), and low recharge because of the overlying impermeable Dwyka tillite. However, reliable sources of groundwater may be encountered on bedding plane fractures or lithological contact zones.

5.3.3 Hydraulic conductivity

Aquifer transmissivities for the Tumelo Coal site as referenced by Golder (2011, 2013) are given in Table 9.

Table 9: Hydraulic parameters for the Tumelo aquifers

Aquifer	K (m/d)	T (m^2/d)	S
Weathered zone	0.1		
Dyke contact zone		6 - 125	3E-04
Karoo to base of Coal Seam No. 1	0.1 – 0.25		3E-04
Karoo below Coal Seam No. 1			5E-04
Pre-Karoo	0.01 – 0.1		1E-04 – 3E-04

5.4 Groundwater levels

Groundwater levels were measured during the hydrocensus survey as undertaken during October 2019. Groundwater levels including other details captured can be viewed in Table 10 below. A map showing the positions of the localities surveyed are shown in Figure 13.

Table 10: Hydrocensus information

Borehole ID	Coordinates			SWL (m)	Hydraulic head (mamsl)	Application/ Description	Owner	Sample Taken Y/N	Status
	y	x	Z (mamsl)						
Privately owned									
H/BH 01	-26.075650	29.640780	1644	7.76	1636.24	Stock water	W.A De Klerk	Y	Windpump
H/BH 02	-26.062770	29.653910	1668	NAWL	-	Water supply	W.A De Klerk	Y	Windpump
H/BH 03	-26.072570	29.653170	1686	45.53	1640.47	Water supply	W.A De Klerk	Y	Submersible
H/BH 04	-26.093360	29.619870	1661	NAWL	-	Stock water	T. Davel	N	Windpump
H/BH 05	-26.074010	29.593090	1657	NAWL	-	Water supply	J.A Uys	Y	Windpump
H/BH 07	-26.102920	29.597110	1655	7.81	1647.19	Water supply	W.Davel	Y	Submersible
H/BH 08	-26.092640	29.589770	1658	13.06	1644.94	Stock water	W.Davel	Y	Windpump
H/BH 09	-26.083560	29.589220	1665	NAWL	-	Stock water	W.Davel	Y	Windpump
Monitoring									
DS 06	-26.065080	29.613090	1612	15.03	1596.97	Monitoring	Tumelo Mine	N	Not Equipped
H/BH 06	-26.067910	29.597280	1653	6.55	1646.45	Monitoring	Eskom	Y	Not equipped
DS 04	-26.064770	29.612260	1610	8.56	1601.44	Monitoring	Tumelo Mine	N	Not Equipped
TC 01	-26.065940	29.612550	1613	2.70	1610.3	Monitoring	Tumelo Mine	N	Not Equipped
DS 03	-26.066170	29.611890	1612	5.27	1606.73	Monitoring	Tumelo Mine	N	Not Equipped
DS 05	-26.066170	29.611300	1609	6.80	1602.2	Monitoring	Tumelo Mine	N	Not Equipped
DS 01	-26.065390	29.611740	1610	8.82	1601.18	Monitoring	Tumelo Mine	N	Not Equipped
H/BH 11	-26.068280	29.644920	1667	23.10	1643.9	Monitoring	Tumelo Mine	N	Not Equipped
BMKGW 04	-26.082948	29.623731	1666	17.29	1648.71	Monitoring	Tumelo Mine	N	Not Equipped
BNKGW 03	-26.076040	29.633010	1648	8.78	1639.22	Monitoring	Tumelo Mine	N	Not Equipped
H/BH 10	-26.067690	29.616420	1634	21.92	1612.08	Water supply	Tumelo Mine	Y	Submersible

Borehole ID	Coordinates			SWL (m)	Hydraulic head (mamsl)	Application/ Description	Owner	Sample Taken Y/N	Status
	y	x	Z (mamsl)						
Surface wate/pit									
SW 01	-26.051940	29.653220	1634	N/A	n/a	North Dam	Unknown	Y	N/A
SW 02	-26.062200	29.611120	1608	N/A	n/a	Boschmanskop Dam N	Unknown	Y	N/A
SW 03	-26.066200	29.610690	1608	N/A	n/a	Boschmanskop Dam S	-	Y	N/A

NAWL No access to water level due to obstruction or casing

n/a not applicable

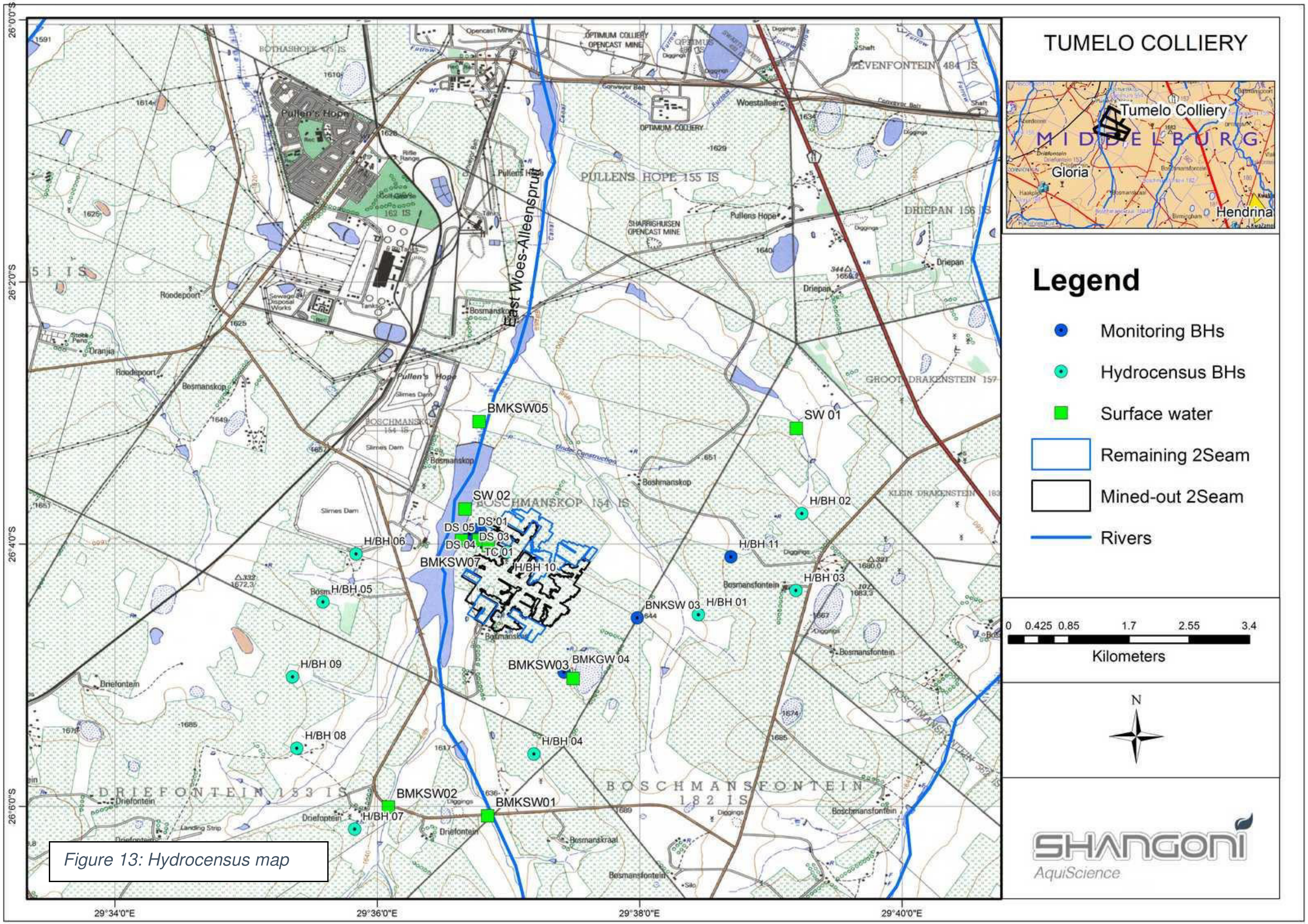


Figure 13: Hydrocensus map

Nineteen (19) boreholes and three (3) dams were surveyed during the field hydrocensus. Water levels measured range between 2.70 and 45.53 meters below surface ("mbs"). Hydraulic head elevations range between 1540 and 1634 mamsl. Averaged calculated water levels below surface are 13.35 mbs and average hydraulic heads are 1625 mamsl (calculated for static and dynamic levels). Borehole depths range between 25 and 90 m.

Figure 14 shows the measured water levels and hydraulic head elevations graphically.

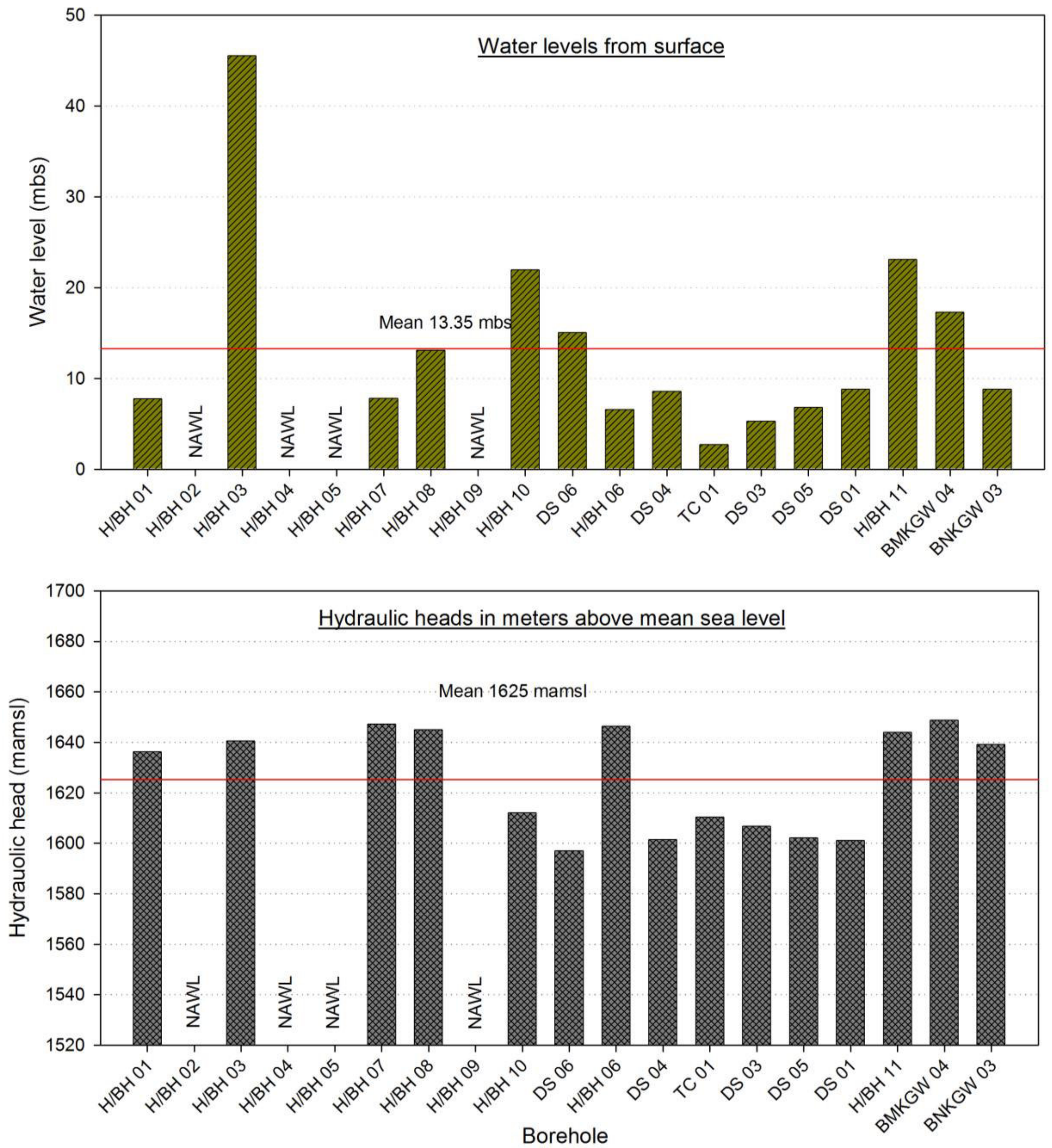


Figure 14: Groundwater levels from surface and hydraulic heads in meters above mean sea level

Figures 15 and 16 show linear regressions between the hydraulic heads of the aquifers and topography. A fair correlation of 0.84 was achieved for the all hydraulic heads calculated and the topography. Some water levels recorded are, however, suspected to be dynamic heads, that is either influenced by pumping (or recovering) or possibly within a dewatering zone (cone of depression). These dynamic heads were subsequently removed and a better correlation of 0.99 was achieved. It can therefore be assumed with confidence that the natural groundwater flow mimics surface water flow directions.

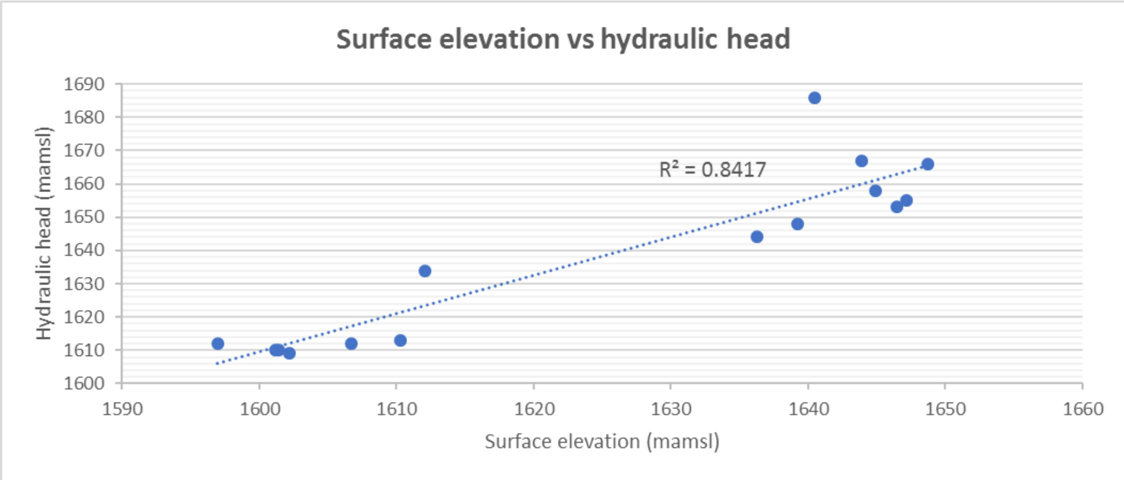


Figure 15: Linear regression between topography and hydraulic heads

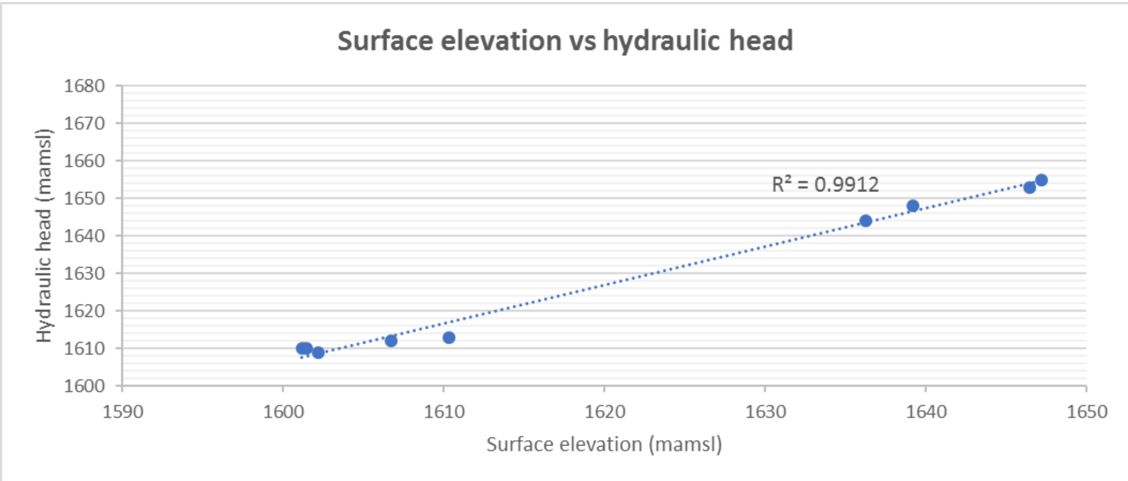


Figure 16: Linear regression between topography and hydraulic heads with suspected dynamic levels removed

5.5 Groundwater potential contaminants

No new geochemical work was conducted for the project. However, this specialist groundwater study relied heavily on the detailed geochemical investigation and characterisation assessment conducted by Golder (2014) on underground workings at Tumelo Colliery. The following assessments were conducted:

- Environmental mineralogy (desktop study only);
- Whole rock geochemistry;
- Leachate assessment;

- Water quality analyses of water underground; and
- Acid base accounting.

Their findings, specifically related to 2 Seam, are summarised in the sections below:

5.5.1 Environmental mineralogy

- The sulphide mineral pyrite (FeS_2), the most common sulphide mineral associated with AMD, is present in varying amounts. Concentrations vary between 1.1% and 23.1%.
- Carbonates in the form of calcite ($CaCO_3$), dolomite ($CaMgCO_3$) and siderite, an iron carbonate ($FeCO_3$) are present in substantial amounts. These minerals are common sources of acid neutralisation and acidic buffers.
- Bassanite ($2CaSO_4 \cdot H_2O$), a highly soluble chemical species found as a secondary mineral in acidic environments, are also present in substantial amounts.

The presence of these minerals may be an indication that acidic and saline leachate, attributed mostly by SO_4, Ca, Mg and others, may form.

5.5.2 Whole rock geochemistry

Multi-element scans were carried out on solid samples to identify elements that are present in concentrations that warrant further investigation. The assay results from the solid samples were compared to the average crustal abundance for each element to provide a measure of the extent of element enrichment (Golder, 2014). It must be noted that element enrichment does not necessarily mean that an element would be a concern for the environment, water quality or public health as it is used to identify any significant element enrichments that warrant further examination.

Golder (2014) found that the coal samples are in addition to arsenic (As), chromium (Cr), lead (Pb), manganese (Mn) and sulphur (S), previously identified as a potential contaminant of concern (PCOC); enriched in bismuth (Bi), lithium (Li), molybdenum (Mo), phosphorous (P), selenium (Se), tellurium (Te), thallium (Th), uranium (U) and tungsten (Tu). Other PCOCs include aluminium (Al), cadmium (Cd) and nickel (Ni).

5.5.3 Leachate assays

Golder (2014) performed deionised water and NAG (hydrogen peroxide) leach tests on the coal samples in order to obtain indications of the elements that could be mobile in potential leachate. Note that these short-duration (static) leach tests measure readily soluble components of geological materials but do not predict long term water quality since *in-situ* mineralisation often develop over considerably greater periods of time and water to solids are in reality different from the static tests *in-situ* (INAP, 2010).

Results indicate that leaching of the coal will likely produce drainage with potentially raised levels of As, boron (B), cobalt (Co), calcium (Ca), fluoride (F) and Mn. Lead (Pb) and Mo may be leached locally in some parts of the seam. Aluminium (Al) and iron (Fe) do not appear to be mobile at the circum-neutral pH values. Other PCOCs as identified in the whole rock chemistry assays were recorded in very low concentrations or below detection limits and will in all probability not be present in leachate or seepage water.

5.5.4 Water quality analyses of water accumulating underground

Five underground water samples were collected by Golder (2014) to evaluate the chemistry of water that has accumulated in the underground voids. As expected, the water has a Na-SO_4 water signature, typical of mine water with circum-neutral to slightly alkaline pH (7.3-8.2) and mildly brackish (150 – 850 mg/l). The SO_4 concentrations are relatively high ranging between 249 and 466 mg/l and so is Na ranging between 121 and 147 mg/l. Fluoride (F) also recorded in high to elevated concentrations, 3.6 – 5 mg/l.

5.6 Water Quality

During the hydrocensus (refer to sections 4.2 and 5.4), samples were taken from surveyed localities and analysed for chemical quality. The hydrochemical data of the sampled localities are displayed in tables 11 and 12.

Groundwater monitoring data was also made available by the client and the latest data received (June 2019) is displayed in Table 13.

Stiff diagrams and an Expanded Durov diagram can be viewed in figures 17 to 19.

5.6.1 Groundwater quality of hydrocensus boreholes

Based on the groundwater quality data of hydrocensus boreholes displayed in table 11 the following:

- A circum-neutral pH to slightly alkaline levels and non-saline groundwater were measured.
- EC and TDS are in the low ranges and mineralisation of major cations and anions are also low, although Ca is relatively raised in HBH7 to HBH10 and Na in HBH01-HBH03 and HBH05 and HBH06. These slightly raised levels are geology related and/or difference in borehole depths and remain well within domestic guidelines.
- Nutrients, including nitrate (NO_3), ammonium (NH_4) and phosphate (PO_4) are low to undetected and well within relevant use guidelines.
- A relatively raised iron (Fe) concentration of 0.53 mg/l was recorded for HBH01 but is well within health-based domestic guidelines. It is not uncommon for Fe to be slightly raised in groundwater due to reducing or low oxygen levels. All other trace metals recorded in low to undetected levels.

- Total hardness levels range between 27.4 and 146 mg $CaCO_3$/l and can be classified as soft to moderately hard. At the higher end of the spectrum, scaling in hot water appliances may result.
- Groundwater from all the hydrocensus boreholes remain well within SANS 241: 2015 drinking water guidelines.
- Based on the Stiff diagrams in Figure 17 and Expanded Durov diagram in Figure 18, the water signatures are Ca(Mg)-HCO_3^- or Na-HCO_3^- water types typical of fresh, clean, relatively young groundwater that has started to undergo magnesium (Field 2) or sodium (sometimes in sodium enriched granites or other felsic rocks; Field 3) ion exchange.

5.6.2 Water quality of surface water (hydrocensus)

Three (3) surface water localities were surveyed and sampled during the hydrocensus on 23 October 2019. Two (2) samples were taken from the Boschmanskop Dam, one north (SW02) and the other south (SW3) of the dam wall. One sample was taken from a dam (SW01) located approximately 4 km to the north-east of Tumelo Colliery. Based on the data displayed in Table 12, the following:

- SW1 recorded a slightly alkaline pH of 9.14 while SW02 and SW03 recorded circum-neutral pH levels of 7.95 and 8.07, respectively.
- EC and TDS levels are relatively raised for the surface water localities and based on the Stiff diagrams in Figure 19, the chemistry is dominated by the Ca cation and the SO_4 anion.
- SO_4 in SW1 exceed SANS 241: 2015 drinking water quality standards with a concentration of 555 mg/l.
- Trace metals recorded in parts per billion (ppb) or undetected concentrations while F levels recorded in undetected to medium levels. A relatively raised F concentration of 1.11 mg/l was recorded for SW3.
- The water can be classified as hard to very hard.
- The water profiles are typical of clean water that has mixed with mineralised water rich in SO_4, which is a typical profile of mine affected water (Field 5 of Expanded Durov diagram; refer to Figure 18).

5.6.3 Water quality of groundwater monitoring boreholes

A water monitoring programme, consisting of surface and groundwater quality, is implemented at Tumelo Colliery. Monthly surface and quarterly groundwater monitoring are conducted by Aquatico Scientific (Pty) Ltd. Groundwater monitoring data for June 2019 was supplied by the client and displayed in Table 13. Based on the data, the following:

- The pH levels are circum-neutral but substantial salinity (TDS & EC) variances exist. TDS range between 150 and 639 mg/l and EC between 19 and 84 mS/m. The greatest salinity was recorded for TC01, a monitoring borehole located downstream from the pollution control dam (referenced as BMKSW06 in the Aquatico monitoring reports), while a relatively similar salinity concentration was recorded for DS3.

- Based on the Stiff diagrams (refer to Figure 17) and the Expanded Durov diagram (refer to Figure 18), both TC01 and DS3 are typical of affected groundwater displaying Ca-SO_4 and Ca(Na)-SO_4 water types, respectively.
- Nitrate (NO_3) is raised in borehole BMKGW03 (deep borehole adjacent to pan) with a concentration of 9.33 mg N/l.
- DS04 recorded relatively high Na concentrations and plot in Field 4 of the Expanded Durov diagram. The profile is typical of 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.
- All other groundwater profiles are typical of fresh, recently recharged water that has undergone Mg (Field 2) or Na (Field 3) ion exchange.

Table 11: Water quality of hydrocensus boreholes surveyed on 23 October 2019

Locality / Guideline Parameter	Unit	SANS 241:2015[a]	HBH01	HBH02	HBH03	HBH05	HBH06	HBH07	HBH08	HBH09	HBH10
pH	-	≥ 5 and ≤ 9.7	7.04	7.29	7.60	7.78	8.86	7.51	7.74	8.00	7.76
EC	mS/m	≤ 170	23.0	24.4	28.2	28.1	28.6	27.0	33.7	32.2	39.8
TDS	mg/l	≤ 1200	117	130	139	143	153	140	169	178	198
Calcium (Ca)	mg/l	-	6.41	7.86	15.7	11.8	3.84	20.7	20.9	30.2	33.6
Magnesium (Mg)	mg/l	-	2.77	3.64	6.07	6.44	3.41	6.47	13.6	11.9	15.1
Sodium (Na)	mg/l	≤ 200	33.7	35.9	28.6	32.5	48.3	19.7	22.7	21.1	20.2
Potassium (K)	mg/l	-	2.38	4.53	4.51	4.64	3.26	6.23	4.13	4.11	5.23
Alkalinity	mg/l	-	94.2	112	129	127	72.6	119	152	141	179
Chloride (Cl)	mg/l	≤ 300	7.53	6.36	4.10	4.70	39.3	6.67	7.61	11.0	8.89
Sulphate (SO_4)	mg/l	≤ 500	0.55	2.56	1.97	6.16	8.59	8.81	6.27	12.8	7.43
Nitrate as N (NO_3-N)	mg/l	≤ 11	1.37	0.41	<0.35	<0.35	0.38	<0.35	0.43	0.51	<0.35
Ammonium as N (NH_4-N)	mg/l	≤ 1.5	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45
Phosphate as P (PO_4)	mg/l	-	0.04	0.03	0.07	<0.03	<0.03	0.03	<0.03	<0.03	<0.03
Fluoride (F)	mg/l	≤ 1.5	0.43	0.17	<0.09	0.12	0.56	0.26	0.36	0.11	0.25
Aluminium (Al)	mg/l	≤ 0.30	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Iron (Fe)	mg/l	≤ 2	0.53	<0.01	<0.01	<0.01	0.05	0.02	0.19	0.02	<0.01
Manganese (Mn)	mg/l	≤ 0.4	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01
Chromium (Cr)	mg/l	≤ 0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Copper (Cu)	mg/l	≤ 2.0	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nickel (Ni)	mg/l	≤ 0.07	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc (Zn)	mg/l	≤ 5.0	0.03	0.24	<0.01	<0.01	<0.01	0.03	0.05	<0.01	<0.01
Total Hardness	mg $CaCO_3$/l	-	27.4	34.6	64.2	56.0	23.6	78.3	108	124	146

Table 12: Water quality of surface water surveyed on 23 October 2019.

Locality / Guideline Parameter	Unit	SANS 241:2015[a]	SW01	SW02	SW03
pH	-	≥ 5 and ≤ 9.7	9.14	7.95	8.07
EC	mS/m	≤ 170	123	81.7	123
TDS	mg/l	≤ 1200	838	530	762
Calcium (Ca)	mg/l	-	75.4	45.6	75.0
Magnesium (Mg)	mg/l	-	82.6	39.1	78.4
Sodium (Na)	mg/l	≤ 200	54.7	56.5	57.7
Potassium (K)	mg/l	-	13.1	14.9	12.5
Alkalinity	mg/l	-	54.6	78.8	110
Chloride (Cl)	mg/l	≤ 300	24.5	46.1	45.6
Sulphate (SO_4)	mg/l	≤ 500	555	280	426
Nitrate as N (NO_3-N)	mg/l	≤ 11	<0.35	<0.35	<0.35
Ammonium as N (NH_4-N)	mg/l	≤ 1.5	<0.45	<0.45	<0.45
Phosphate as P (PO_4)	mg/l	-	<0.03	<0.03	<0.03
Fluoride (F)	mg/l	≤ 1.5	<0.09	0.47	1.11
Aluminium (Al)	mg/l	≤ 0.30	<0.01	<0.01	<0.01
Iron (Fe)	mg/l	≤ 2	0.01	<0.01	0.01
Manganese (Mn)	mg/l	≤ 0.4	<0.01	0.02	<0.01
Chromium (Cr)	mg/l	≤ 0.05	<0.01	<0.01	<0.01
Copper (Cu)	mg/l	≤ 2.0	<0.01	<0.01	<0.01
Nickel (Ni)	mg/l	≤ 0.07	<0.01	<0.01	<0.01
Zinc (Zn)	mg/l	≤ 5.0	<0.01	<0.01	<0.01
Total Hardness	mg $CaCO_3$/l	-	528	275	510

Table 13: Water quality of Tumelo monitoring boreholes as monitored in June 2019 (From Aquatico, 2019)

Locality / Guideline Parameter	Unit	SANS 241:2015[a]	BKMGW3	BMKGW04	DS1	DS3	DS4	DS5	DS6	TC01
pH	-	≥ 5 and ≤ 9.7	7.34	8.35	8.33	7.78	8.09	8.45	8.5	8.27
EC	mS/m	≤ 170	19	20.6	40.2	70.6	36.6	51.2	35	84.4
TDS	mg/l	≤ 1200	150	191	294	507	277	371	248	639
Calcium (Ca)	mg/l	-	6.96	16.9	22.8	35.1	11.1	38.7	31.7	105
Magnesium (Mg)	mg/l	-	6.02	7.84	14.1	45.9	10.7	20.4	15.2	50.6
Sodium (Na)	mg/l	≤ 200	8.88	13.6	52.2	59.9	46.2	47.2	26.2	28.9
Potassium (K)	mg/l	-	4.14	7.3	5.47	6.82	4.71	5.43	5.88	7.05
Alkalinity	mg/l	-	20.6	111	208	59.4	70.2	161	148	113
Chloride (Cl)	mg/l	≤ 300	7.28	3.41	12.6	17.6	41.5	28.2	21.6	17.8
Sulphate (SO_4)	mg/l	≤ 500	5.94	3.46	28.7	294	45	97.5	23.5	346
Nitrate as N (NO_3-N)	mg/l	≤ 11	9.33	0.21	0.097	0.21	4.87	0.407	0.325	0.248
Ammonium as N (NH_4-N)	mg/l	≤ 1.5	0.76	0.20	<0.03	0.04	0.031	0.031	0.028	0.028
Phosphate as P (PO_4)	mg/l	-	0.11	<0.003	<0.003	<0.003	<0.003	<0.003	0.006	<0.003
Fluoride (F)	mg/l	≤ 1.5	0.13	0.53	0.27	0.13	0.60	0.33	0.48	0.56
Aluminium (Al)	mg/l	≤ 0.30	0.022	<0.001	<0.001	<0.001	0.015	<0.001	<0.001	<0.001
Iron (Fe)	mg/l	≤ 2	0.054	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Manganese (Mn)	mg/l	≤ 0.4	0.02	0.116	0.006	0.015	<0.001	<0.001	<0.001	<0.001
Total Hardness	mg $CaCO_3$/l	-	42	74	115	277	72	180	142	472

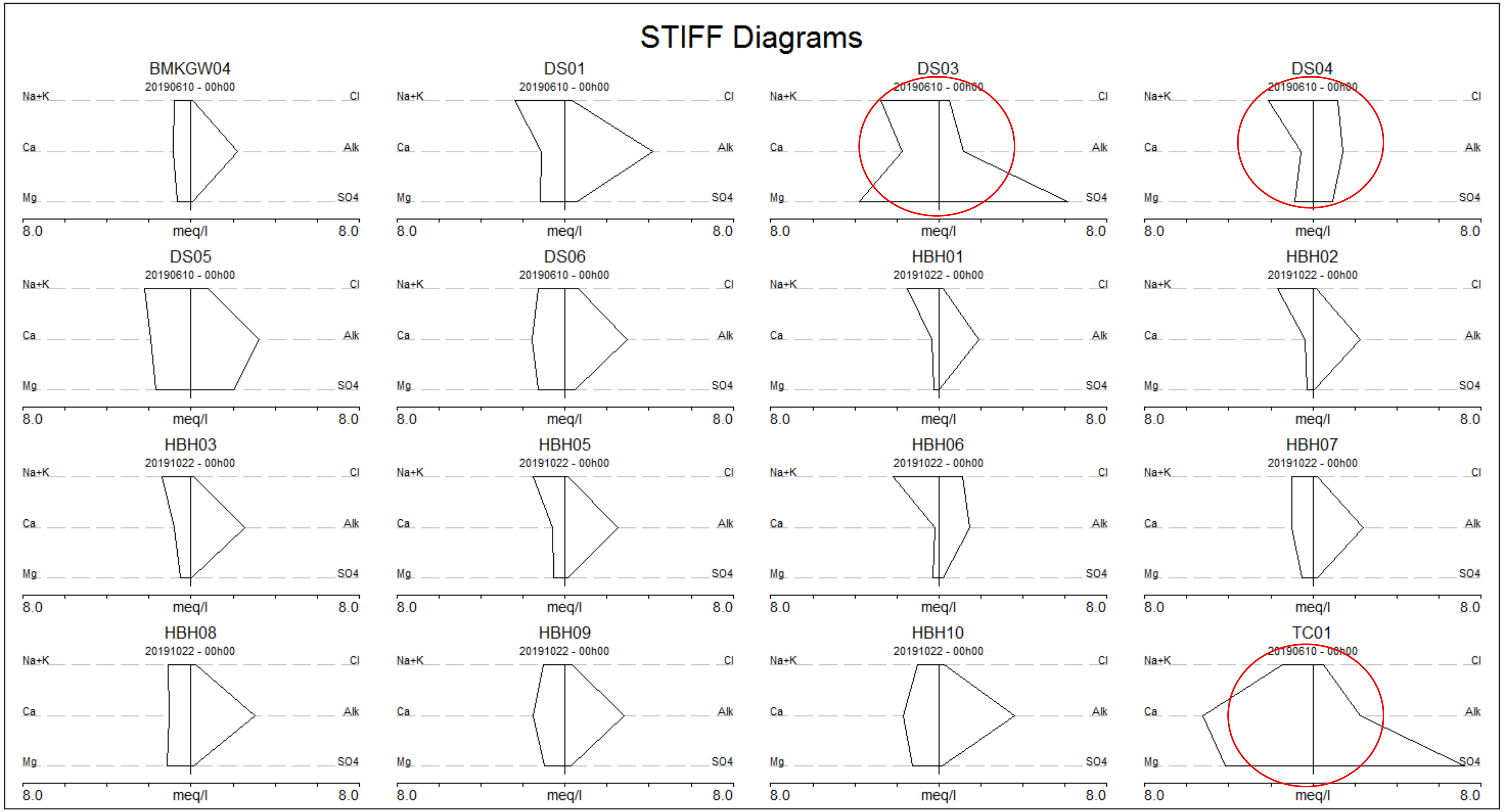


Figure 17: Stiff Diagrams for groundwater based on meq/l

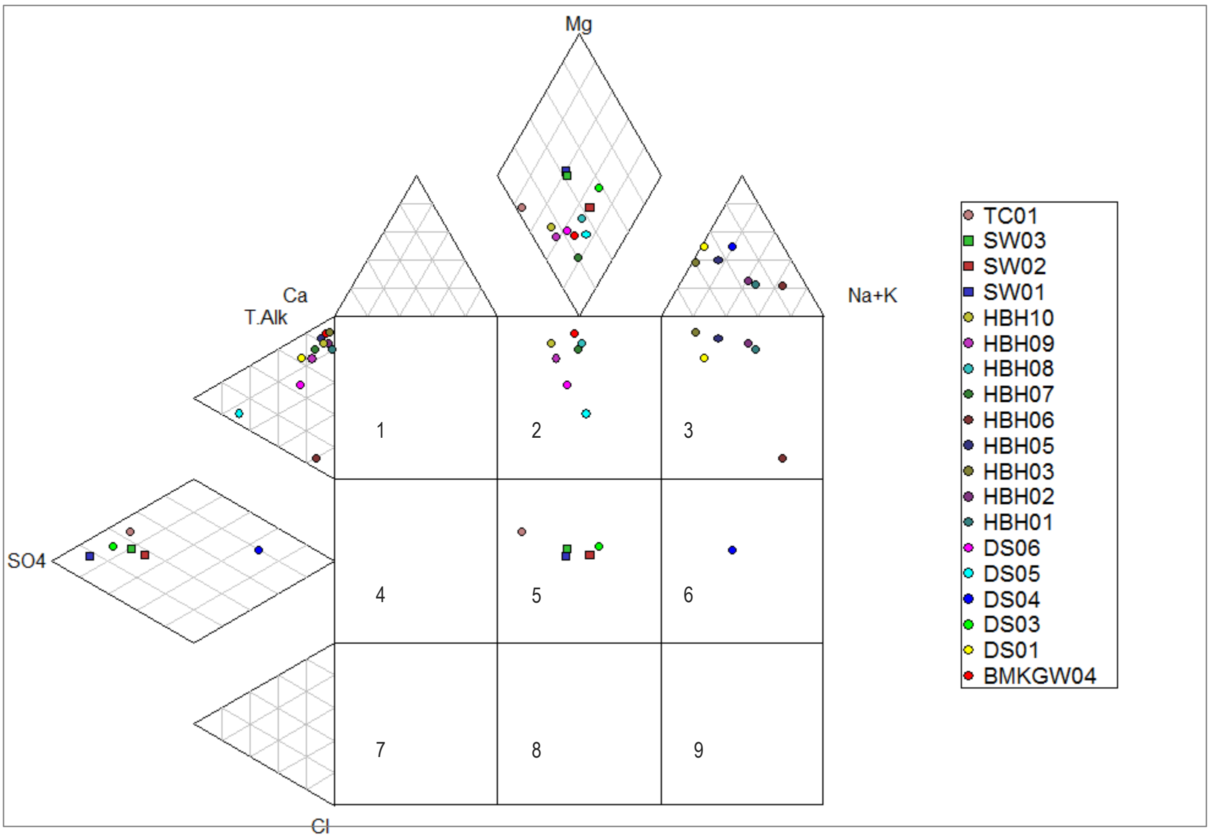


Figure 18: Expanded Durov diagram showing relative ratios in meq/l

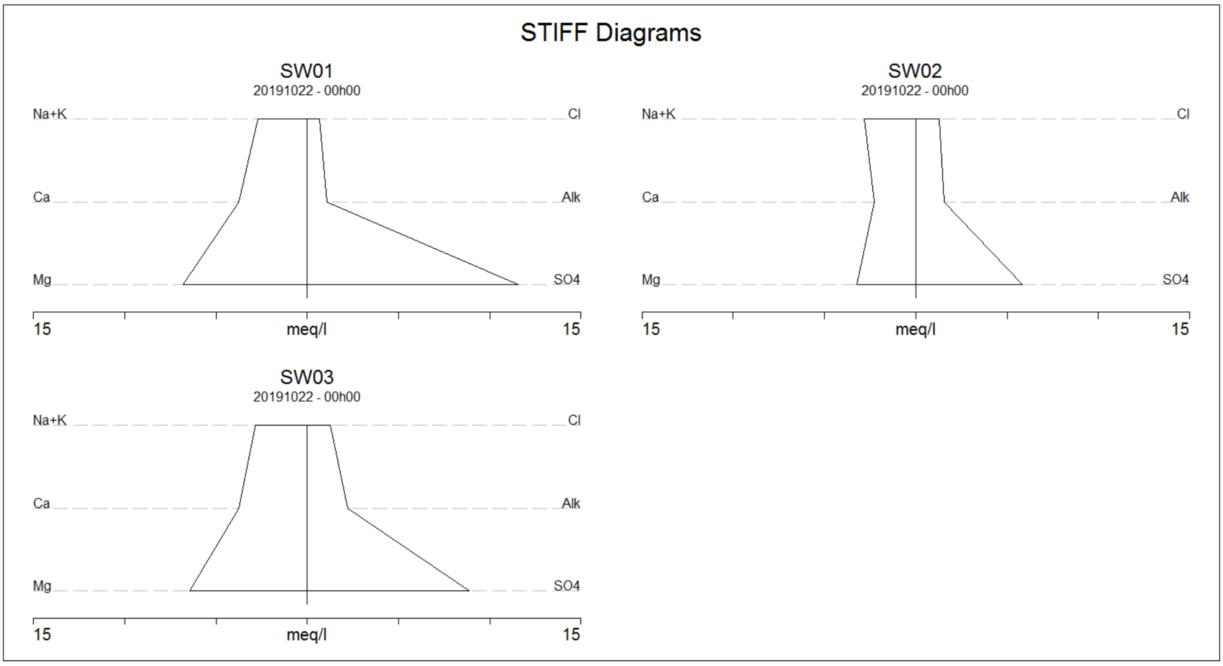


Figure 19: Stiff diagrams for surface water at Tumelo

6. AQUIFER CHARACTERISATION

6.1 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:

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

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 14.

Table 14: 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.

Table 15 summarizes the aquifer classification vulnerability scores for the aquifer/s in vicinity of the project area. The final DRASTIC score of 99 indicates that the fractured aquifer in the region has a medium susceptibility to pollution and a medium level of aquifer protection is therefore required.

Table 15: DRASTIC vulnerability scores (fractured aquifer)

Factor	Range/Type	Weight	Rating	Total
D	5 - 15 m	5	7	35
R	5 - 10 mm	4	3	12
A	Fractured	3	6	18
S	clay loam/silty loam	2	2	4
T	0-2%	1	10	10
I	Karoo (northern)	5	4	20
C	-	3	-	-
DRASTIC SCORE = 99				

6.2 Aquifer classification

The then Department of Water and Sanitation ("DWS"), currently the Department of Human Settlements, Water and Sanitation ("DHSWS"), has characterised South African aquifers based on the rock formations in which they 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:

2. **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.
3. **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.
4. **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.

5. **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 are 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.

According to the 1: 25 000 hydrogeological map (2526) for Johannesburg (map not shown) the study area is predominantly 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. Higher yields could however occur where groundwater is held in good water yielding fractures but these seem to be largely absent in the immediate vicinity.

The different modes of undisturbed/natural groundwater occurrences associated with the study area include:

- Joints and fractures occurring in contact zones related to the heating and cooling of country rock, caused by the intrusion of dykes and sills;
- Along sedimentary or sedimentary / igneous rock contacts. A contact may either be open, weathered or fractured due to movement along the contact, or fractured due to heating and subsequent cooling related to large extrusive or intrusive events; and
- Minor groundwater occurrences are often encountered in association with coal seams.

According to the regional aquifer classification map of South Africa, the surrounding Karoo aquifer has been identified as a minor aquifer with good groundwater quality (<300 mg/l TDS), a medium to high vulnerability and a medium to high susceptibility towards contamination. Drill logs indicate that the study area is underlain by three types of aquifers. Based on the ‘undisturbed’ underlying hydrogeology of the project area the aquifers can classified according to Parsons (1995) and system as follows:

i) Shallow perched unconfined aquifer
    a. Non-aquifer
ii) Weathered unconfined aquifer
    a. Minor aquifer
iii) Fractured confined or semi-confined aquifer in the Vryheid Formation
    a. Minor aquifer

The occurrences and classification of the respective undisturbed aquifer types underlying the wider study area are shown in Table 16 below.

Table 16: Principle groundwater occurrences and classification according to the Parsons (Parsons, 1995) classification system for undisturbed aquifers

Aquifer	Type	Lithology	Groundwater occurrence	Depth (m)	Probable yield (l/s)	Classification
Shallow weathered	Unconfined	Semi consolidated material	Weathered rock	~3~20	0.1	**Minor aquifer**
Intergranular and/ or Fractured	Confined/ semi-confined	Ecca Group: Vryheid Formation shale/sandstone	Seepage water between host rock particles Discontinuities – fractures, fissures, joints	~20 ~ 100	0.1 – 2.0	**Minor aquifer**

6.3 Aquifer protection classification

In order to achieve the Groundwater Quality Management Index a point scoring system as presented in tables 17 and 18 was used for the naturally occurring undisturbed aquifers in the wider study area.

The occurring aquifer, in terms of the above definitions, is classified as a minor aquifer system. The vulnerability, or the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer is classified as medium to high. The level of groundwater protection based on the Groundwater Quality Management Classification is shown in Table 19:

Table 17: Ratings for the Aquifer System Management and Second Variable Classifications

Aquifer System Management Classification		
Class	**Points**	**Study Area**
Sole Source Aquifer System	6	
Major Aquifer System	4	
Minor Aquifer System	2	2
Non-Aquifer System	0	
Special Aquifer System	0-6	
Second Variable Classification (fractured)		
High	3	
Medium	2	2
Low	1	

Table 18: Ratings for the Groundwater Quality Management (GQM) Classification System

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

GQM Index = Aquifer System Management x Aquifer Vulnerability:

2 X 2 = 4

Table 19: GQM index for the study area

GQM Index	Level of Protection	Study Area
<1	Limited	
1-3	Low level	
3-6	**Medium level**	**4**
6-10	High level	
>10	Strictly non-degradation	

The ratings for the Aquifer System Management Classification and Aquifer Vulnerability Classification yield a GQM index of 6 for the study area, indicating that **medium level groundwater protection** is required to adhere to DHSWS's water quality objectives. Reasonable and sound groundwater protection measures are recommended to ensure that no cumulative pollution affects the aquifer, during short- and long-term. DHSWS'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; and
- Boschmanskop Dam, East-Woes-Alleenspruit and associated drainages and wetlands.

7. GROUNDWATER MODELLING

7.1 Software Model Choice

The numerical flow and mass transport groundwater models were constructed to simulate current aquifer conditions and impacts in addition to providing a tool for evaluating different long-term management options. A three-dimensional numerical groundwater flow model was developed using the modelling software package PMWIN Pro (Processing Modlfow Professional for Windows).

In general, a model area or domain is represented by several nodes and elements. Hydraulic properties are assigned to these nodes and elements and an equation is developed for each node, based on the surrounding nodes. A series of iterations are then run to solve the resulting matrix problem utilising a pre-conditioning conjugate gradient (PCG) matrix solver for the current model. 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 measured heads. The model is said to have “converged” when errors reduce to within an acceptable range.

7.2 Model Setup and Boundary

Initially, an aquifer delineation will indicate the lateral extent of the aquifer(s) in the area. An aquifer can be delineated by means of the following:

i. Mapping structures such as intrusive dykes, progressive sills or displacement faults that act as groundwater flow barriers to form aquifer compartments, and
ii. Using high or low topographical areas over which flow is not possible.

Method (i) is probably the most accurate for delineating aquifer boundaries but intricate detail is needed to map the structures of an area and these are seldom available. Therefore, the modelling area was selected based on method (ii) – the use of natural groundwater barriers and flow boundaries, such as topographical highs and drainage features. The rationale for using topographical highs as groundwater boundaries was the fact that a good Bayesian correlation exist between hydraulic heads and topography for the study area. It can therefore be assumed with confidence that groundwater flow mimics surface water flow with topographical highs and lows functioning as groundwater barriers or discharge areas.

The model domain and aquifer boundaries can be viewed in Figure 20.

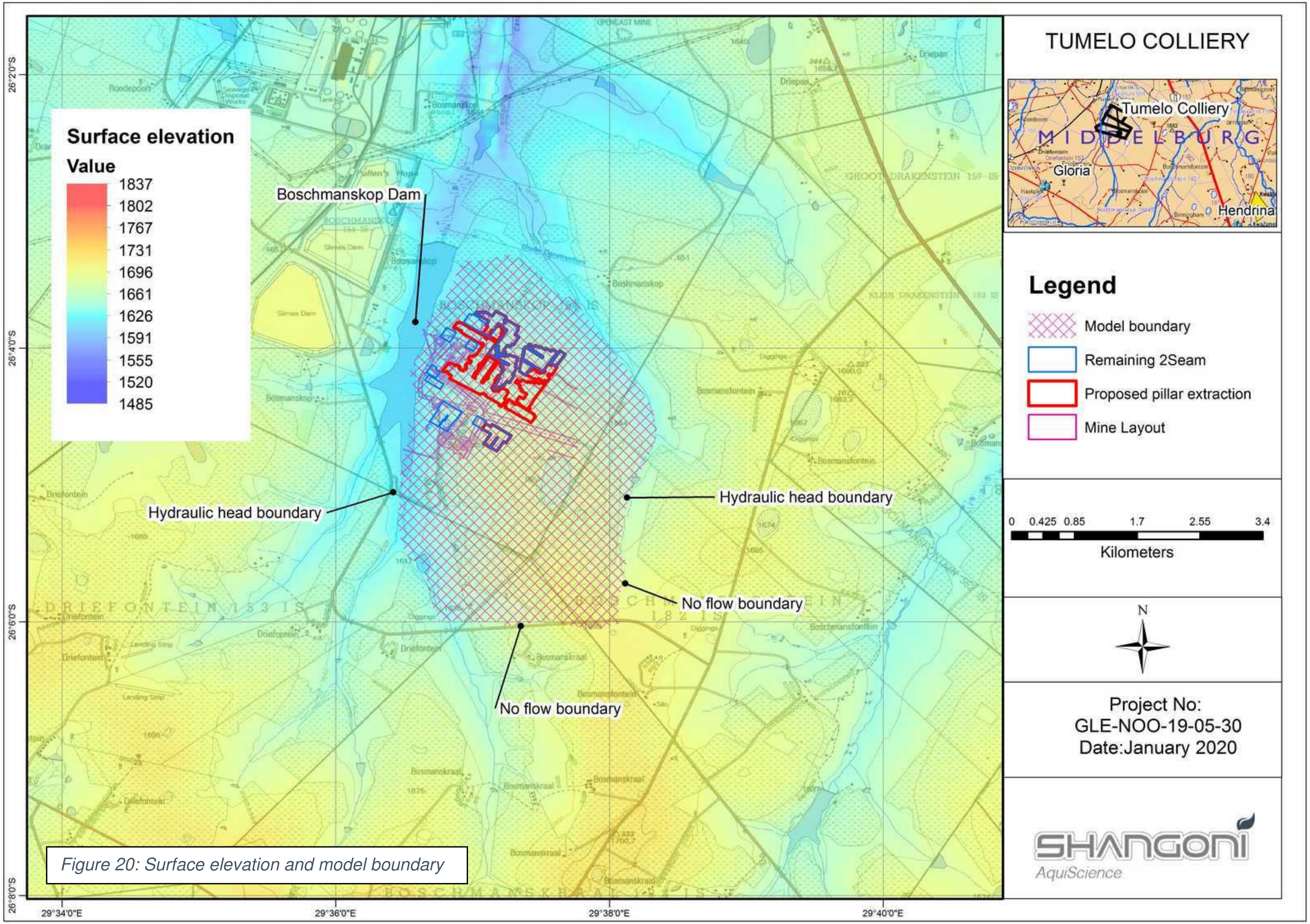


Figure 20: Surface elevation and model boundary

7.3 Groundwater elevation and gradients

The groundwater elevations or hydraulic heads were calculated by subtracting static water levels from the topography. The data as shown in Table 20 indicate that the hydraulic heads vary between 1597 to 1648 mamsl with the highest hydraulic head and lowest head corresponding to higher and lower lying surface elevations. The average hydraulic head for the study area based on the hydrocensus boreholes is 1625.2 mamsl.

The hydraulic heads were used to construct a regional hydraulic head contour map for the aquifer from which flow directions were interpolated. Where data points lacked, an interpolation technique known as Kriging was used to interpolate data points at locations with respect to data points in close relation to it (mathematically related to regression analysis). The contour map is shown in Figure 21. Based on the contours and flow vectors, the first estimations of groundwater flow are relatively similar to surface topography and flow being largely controlled by the water divide.

Table 20: Calculated hydraulic heads for hydrocensus and monitoring boreholes

Site ID	Y	X	Z (mamsl)	Water Level (mbgl)	Measured Head (mamsl)
H/BH 01	-26.075650	29.640780	1644	7.76	1636.24
H/BH 02	-26.062770	29.653910	1668	NAWL	-
H/BH 03	-26.072570	29.653170	1686	45.53	1640.47
H/BH 04	-26.093360	29.619870	1661	NAWL	-
H/BH 05	-26.074010	29.593090	1657	NAWL	-
H/BH 07	-26.102920	29.597110	1655	7.81	1647.19
H/BH 08	-26.092640	29.589770	1658	13.06	1644.94
H/BH 09	-26.083560	29.589220	1665	NAWL	-
H/BH 10	-26.067690	29.616420	1634	21.92	1612.08
DS 06	-26.065080	29.613090	1612	15.03	1596.97
H/BH 06	-26.067910	29.597280	1653	6.55	1646.45
DS 04	-26.064770	29.612260	1610	8.56	1601.44
TC 01	-26.065940	29.612550	1613	2.70	1610.3
DS 03	-26.066170	29.611890	1612	5.27	1606.73
DS 05	-26.066170	29.611300	1609	6.80	1602.2
DS 01	-26.065390	29.611740	1610	8.82	1601.18
H/BH 11	-26.068280	29.644920	1667	23.10	1643.9
BMKGW 04	-26.082948	29.623731	1666	17.29	1648.71
BNKGW 03	-26.076040	29.633010	1648	8.78	1639.22

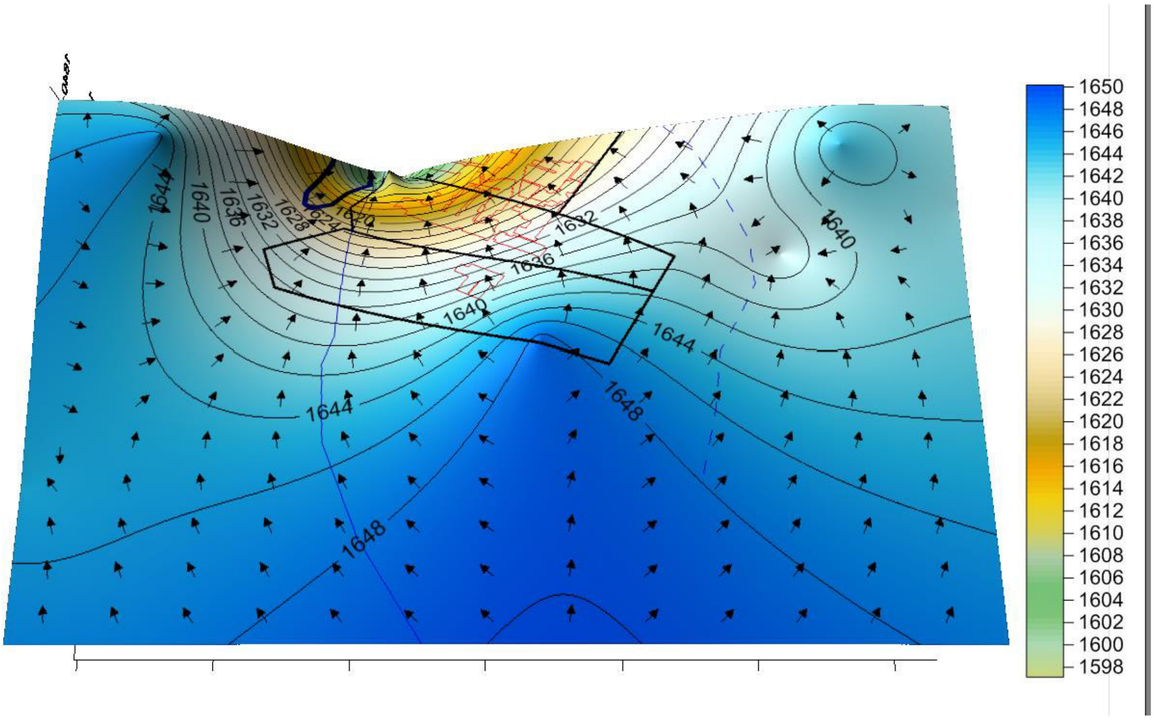


Figure 21: Interpolated hydraulic head contour and vector map

7.4 Geometric structure of the model

Different types of boundaries were used for different borders of the model. These boundaries have been delineated in Figure 1. To the east and west, tributaries of the Woes-Alleenspruit form the fixed-head boundaries of the model. The Northern boundary is unconventionally close to the target modelling area. This boundary was placed in such proximity to the mining area due to the large dam forming a groundwater boundary. To the south no distinct boundaries occurred, therefore a general head boundary was used.

The first model layer is approximately 20 m in thickness throughout the modelled area and represents the shallow weathered zone aquifer. The second layer represents the deeper fractured rock type aquifer hosted within the older Karoo and Vaalian group rocks and was assigned a uniform thickness of 100 m. The geometric structure of the model is shown in Table 21.

Table 21: Geometric structure of the model

Grid size	Easting = 4 500 m, Northing = 5 780 m
Rows and Columns	Rows = 578, Columns = 450
Cell size	10 m by 10 m
Layers	Layer 1: Confined/Unconfined, Layer 2: Confined

The reader is referred to sections 7.7 and 7.8 for model calibration and transient results.

7.5 Groundwater sources and sinks

Depending on the prevailing gradient between groundwater in the shallow aquifer and the surface water stage in a river, groundwater might discharge into surface waters or vice versa. Groundwater sources are predominantly from rainfall recharge at an average of between 0.5 to 4% and discharges as baseflow into wetlands, rivers and streams, but this occurrence is mostly between the weathered aquifer and the natural surface water system. The main groundwater sources in the wider area of interest are:

- direct rainfall recharge of the shallow weathered aquifer with vertical leakage to the fractured aquifer;
- potential leakage from surface water courses and unlined dams; and
- regional groundwater inflow.

The main groundwater sinks in the model domain are:

- groundwater seepage towards surface waters;
- regional groundwater outflow;
- shallow interflow and groundwater fed pans, wetlands and natural drainage systems; and
- Underground voids created by mining.

The main sources and sinks for the relevant catchment areas are shown below in Table 22.

Table 22: Recharge and baseflow figures for the catchment area

Quaternary catchment	Area	MAP	Recharge		Baseflow	
	Km^2	mm/a	mm/a	Mm^3/a	mm/a	Mm^3/a
B12B	658.5	697	52	34.37	7	4.63

7.6 Conceptual model

The first step in any modelling exercise is the development of a conceptual geohydrological 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 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.

The geology in any geohydrological setting forms the basis for groundwater flow and aquifer development. The geohydrology in the study area is no exception and will conform thereto.

A conceptual model was developed based on the review of available data and the information gathered during the field investigations. The model is a simplified representation of the geohydrological conditions and processes taking place in the study area and forms the cornerstone for understanding and describing the geohydrological environment and its behaviour. It describes the simplifying assumptions necessary to represent the real-world system in a numerical model.

7.6.1 Local geology

The geology governs the aquifer formation through the weathering and fracturing processes. Drilling records and borehole logs provide valuable data in assessing the geology of the mining area.

The undisturbed geological sequence from top to bottom are:

- Ecca Group: Vryheid Formation interbedded with sandstones, siltstone, mudstone and shale with coal in places.
- Diamictite of the Dwyka Group:
- Pre-Karoo igneous rocks of the Bushveld Complex.

Several dykes have been mapped by the client and preferential flow pathways with well-developed secondary fractured aquifers may be present adjacent to the dykes.

7.6.2 Geohydrology

Three distinct undisturbed saturated groundwater regions are recognized underlying the study area, and include:

i. Perched aquifer, mostly associated within wetlands;
ii. Weathered aquifer;
iii. Fractured aquifer.

Mining of the coal seams has also resulted in the creation of an artificial aquifer system in the underground voids.

Groundwater flow directions largely correlate with surface flow. It therefore tends to follow relatively similar gradients and flow patterns compared to surface topography. First estimations of groundwater flow patterns are largely towards the major drainage systems and the Boschmanskop Dam. Groundwater leaves the aquifer as discharge contributing to flow within the bases of these systems (groundwater contribution baseflow). A good correlation of 0.99 was achieved between static hydraulic heads and surface elevation. Groundwater elevations therefore mimic surface topography, and groundwater flows from higher lying ground towards lower lying springs or valleys including surface water drainage (e.g. Boschmanskop Dam, East-Woes-Alleenspruit and Klein-Olifants River), where it surfaces or accumulates in the alluvial and hill wash deposits.

The groundwater levels within the weathered and fractured aquifer are relatively shallow being of semi-confined to confined nature. Ferricrete underly the study area at certain places and acts as a confining aquiclude or aquitard (in places) that separate the weathered aquifer from the fractured aquifer resulting in piezometric heads to form, some of which may be artesian (Figure 22). A dolerite sill ranging in thickness from 5 to 13 m are present underlying the study area (Digby Wells, 2008). The sill is generally confined to specific horizons and will also act as a largely impermeable barrier for groundwater movement.

Several wetlands occur within the study area and although a hydropedology study was not part of the scope, it is expected based upon first estimations that the weathered and fractured are largely disconnected from each other and, therefore, only the weathered and/ or perched aquifer is hydraulically connected to the wetlands.

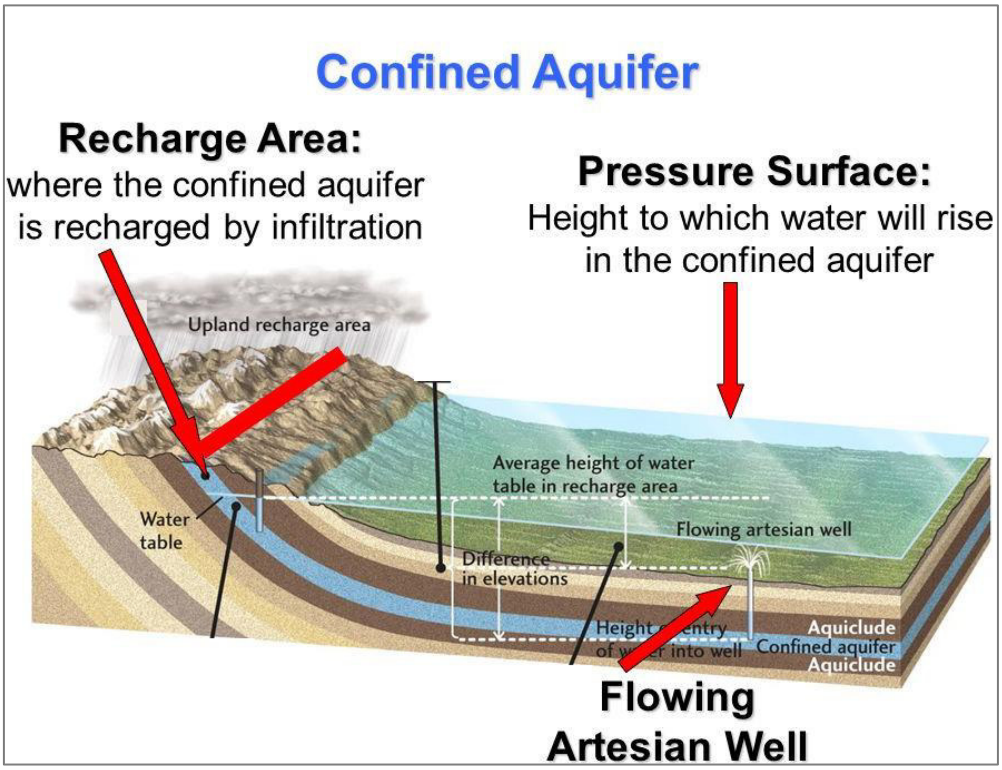


Figure 22: Confined aquifer pressure surface

7.6.3 Recharge

Groundwater recharge represents infiltration of rainwater through the overlying geology into the aquifer. There are several processes occurring at surface that contribute to the amount of recharge to groundwater from rainfall. Figure 23 presents a simplified water balance for illustrative purposes. Precipitation (P) that falls on the land surface enters various pathways of the hydrologic cycle. Some water can be temporarily stored on the land surface in wetlands, perched aquifers and water puddles (ΔSW), some will be evaporated directly from surface (ET) or from wetlands, perched aquifers and puddles (ETW). Some water will drain across the land surface to stream channels (run-off, RO) and some water will infiltrate through porous surface soil and seep into the ground. Water is stored in the vadose (unsaturated) zone from where it can be accessed by vegetation via the roots and used by the plants (transpired). Water infiltrating the soil/rock matrix reaching the water table is called groundwater recharge (RCH) and contributes to groundwater storage (ΔSGW).

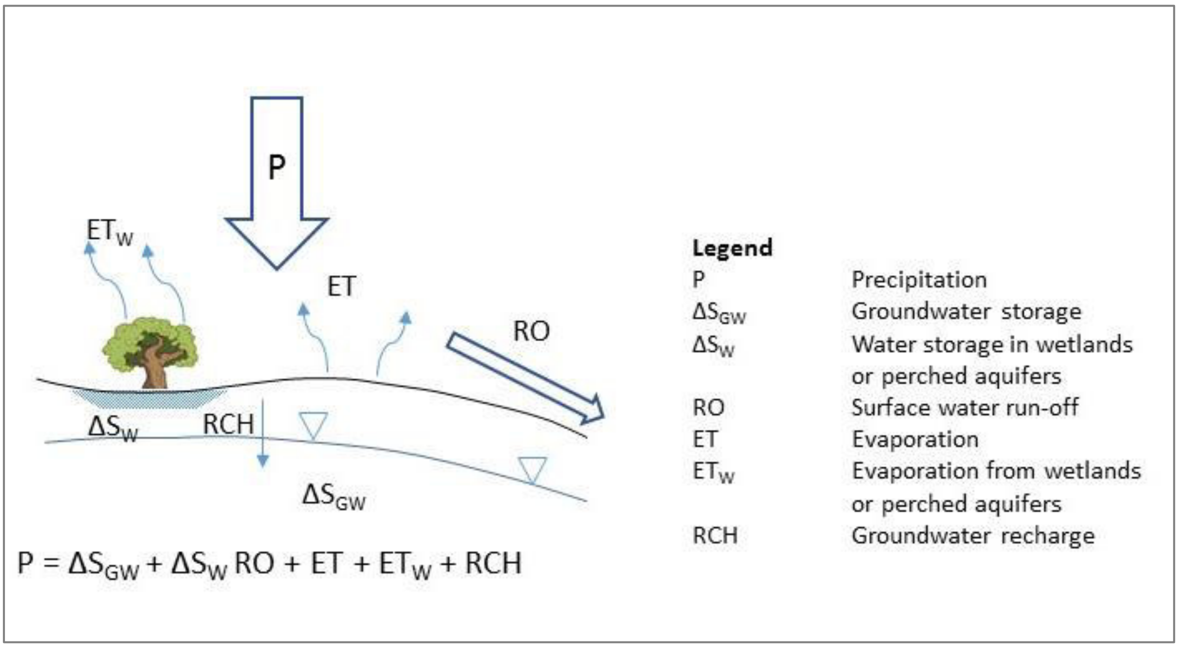


Figure 23: Surface processes related to precipitation and groundwater recharge

The collection of direct field measurements for groundwater recharge is difficult and was not included in the field investigation.

The percentage recharge to the 'undisturbed' Karoo aquifers is estimated to be in the order of 0.5 – 3% of the annual rainfall. Recharge in this Karoo aquifer system is therefore highly variable and different recharge figures can be found from one area to the next. This is due to variations in the composition of the overlying and weathered sediments and heterogeneity of the competent and fractured sandstone matrices.

The following mechanisms are expected to contribute to groundwater recharge in the study area:

- Direct infiltration of rainfall through the overlying unconsolidated material and the weathered matrix.
- Significantly higher recharge compared to ambient is expected within disturbed sediments and from overburden stockpiles present while lesser recharge is expected from built-up or concreted/tarred surfaces.

7.6.4 Hydraulic properties

The Karoo aquifer underlying the study area is not a well-developed aquifer. While the sandstone/shale matrix contain considerable volumes of water due to intergranular spaces present and possess a relatively large porosity, the absence of connectedness between the pores, known as effective porosity, is very low. The consequence is that a hydraulic conductivity within the matrix is very low and groundwater flow therefore tend to be restricted to fractures.

An aquifer test conducted by GCS (2013) reveal low transmissivity of 8.221 E-04 m_2/d and very low yield of 0.03 l/s. Golder (2011, 2013) documented hydraulic conductivities of the weathered aquifer to be 0.1 m/d. Aquifer permeabilities tend to decrease with depth and up to the No. 1 coal seam, hydraulic conductivities are in the range of 0.1 to 0.25 m^2/d but below 1 Seam, 0.002 to 0.025 m/d was recorded. In contrast, in the immediate vicinity of dolerite dykes, the permeability can be substantially greater and could range between 6 and 125 m^2/d (Golder, 2011, 2013).

Falling head tests conducted by Shangoni also reveal aquifers with low to reasonable permeabilities with hydraulic conductivities of between 0.040 to 1.5 m/d recorded.

7.7 Numerical model

7.7.1 Steady state model calibration

Recharge coefficients and aquifer parameters were estimated as input to the steady state calibration model. The hydraulic parameters of these units were assigned to the model-based aquifer hydraulic properties and first model calibration and sensitivity runs. Where data was lacking, literature-based parameters were sourced. The model calibrated parameters are shown in Table 23.

Table 23: Steady state calibration model hydraulic zones and parameters

Matrix transmissivity layer 1	1.4 m^2/day
Matrix transmissivity layer 2	0.4 m^2/day
Transmissivity of faults	5 m^2/day
Transmissivity of dykes	0.1 m^2/day
Storage coefficient layer 1	0.05
Storage coefficient layer 2	0.005
Specific yield Layer 1	0.2
Effective porosity layer 1	15%
Effective porosity layer 2	8%
Effective recharge	±1.8% of MAP

During the steady state calibration of a flow model, changes are made primarily to the hydraulic properties (transmissivity) and effective recharge until an acceptable correlation is achieved between the measured groundwater elevations and those simulated by the model. These model-simulated groundwater elevations are then specified as initial groundwater levels and form the basis for the transient state model simulations.

Notes:

- Steady state simulation – the model runs until groundwater levels reach a state of equilibrium, i.e. total groundwater inflow from natural sources (rivers, recharge etc.) is equal to the total volume of groundwater outflow through natural sinks (baseflow to rivers, evapotranspiration etc.).

- Transient state simulation – the model runtime is predetermined and specified according to desired scenario and groundwater levels are now affected by sinks and sources other than natural. The mine voids, for example, are inserted as drains above which the model water levels cannot rise.

Groundwater level information used in the steady state calibration of the flow model was obtained from the dedicated groundwater monitoring program. A satisfactory correlation was achieved. The correlation between measured and simulated steady state water levels are indicated in Figure 24 and shows a 98% correlation. The calibrated groundwater elevations were exported from the flow model and used to construct a contour map of the steady state (i.e. unaffected) groundwater elevations as indicated in Figure 25.

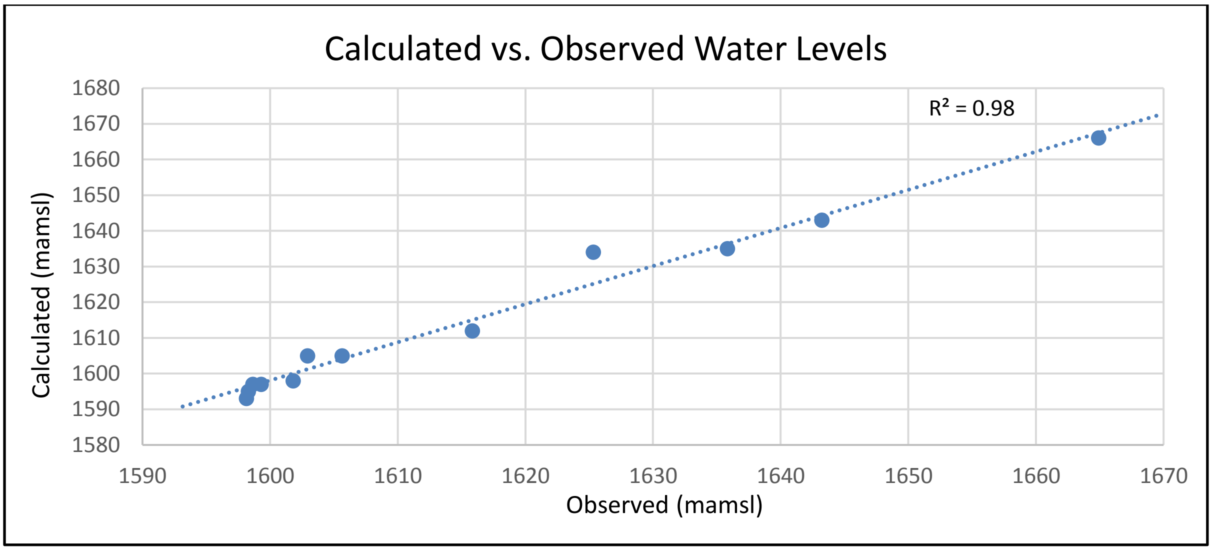


Figure 24: Correlation between calculated and observed hydraulic heads

The steady state flow model shows groundwater flow to be largely towards the surface drainages, consistent with the conceptual model, on gentle gradients ranging between 0.005 to 0.095.

TUMELO COLLIERY STEADY STATE HYDRAULIC HEADS

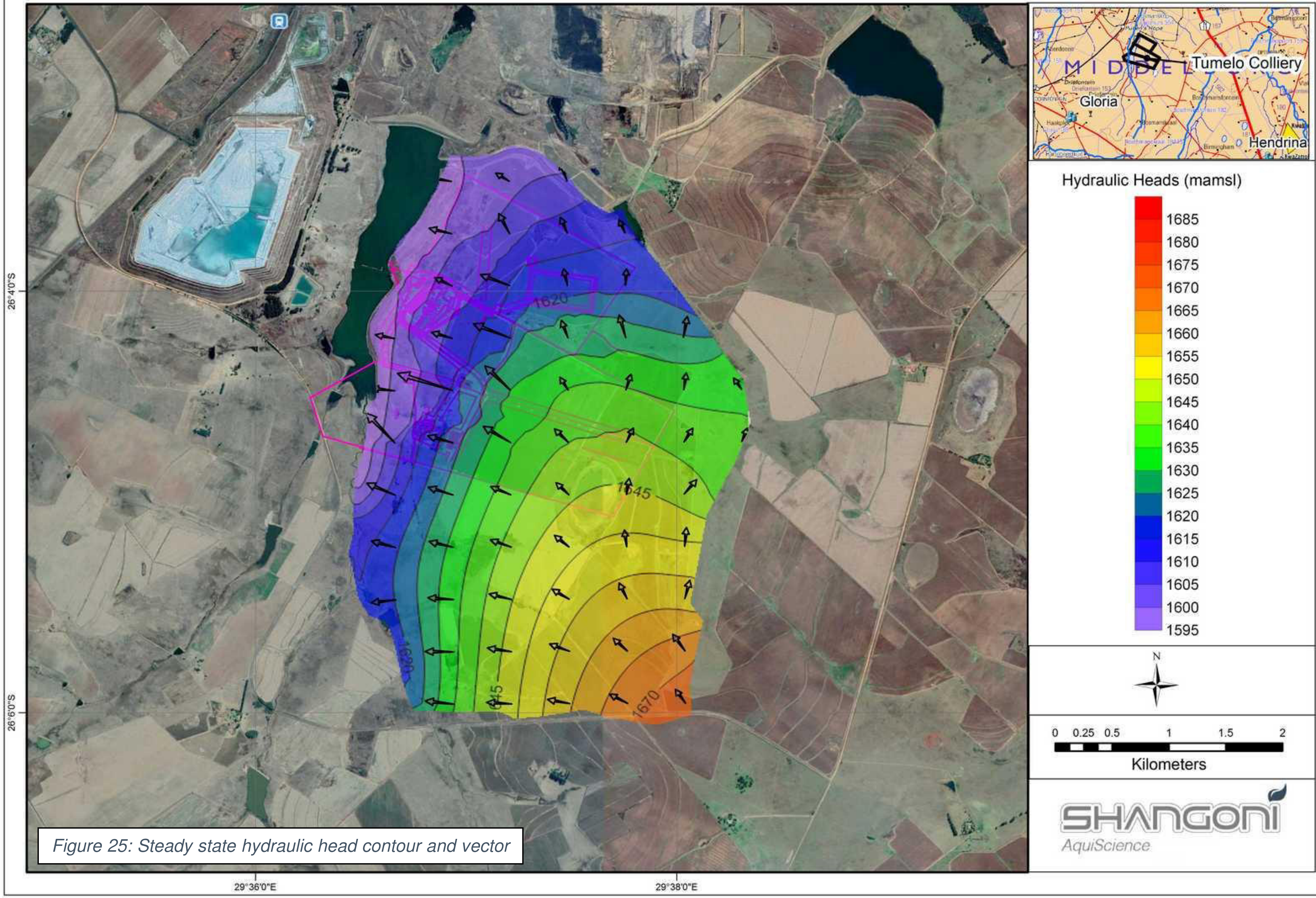


Figure 25: Steady state hydraulic head contour and vector

7.7.2 Transient flow model

Impacts on groundwater levels occur as a result of mine dewatering and the flow model was used to simulate these impacts (i.e. groundwater depression cone). The extent of the groundwater level impacts is governed by the hydraulic properties (transmissivity) of the aquifer host rock, storativity and time. The influence of transmissivity on the radius/extent of the water level impacts is explained by means of the following equation:

R(t) = 1.5(Tt/S)1/2

Where R = Radius (m),
T = Aquifer transmissivity (m2/d),
t = Time (days),
S = Storativity.

From the equation it is clear that an increase in transmissivity will lead to an increase in the radius of influence (extent of depression cone). Impacts on groundwater levels are therefore expected to extend along transmissive geological structures, which is why structural geological information plays such an important role in the construction of an accurate flow model. Furthermore, such structures may also greatly increase groundwater discharge into the mine voids.

A stress period (SP) in the model is a period where groundwater flow and mass transport conditions are constant. All time-dependent parameters in the model, such as drains, rivers, aquifer recharge, contaminant sources, sinks and contaminant concentrations remain constant during a stress period. The total mine runtime of 12.5 years was subdivided into four individual stress periods. The conditions simulated in each stress period are indicated in Table 24.

In order to better illustrate the impact of the mining and related activities on the surrounding groundwater levels, initial/steady state groundwater elevations were subtracted from the simulated groundwater elevations at the end of stress periods 2, 3, 4 and 5.

Table 24: Transient model stress periods

Stress period	Simulation time (days)	Simulation time (years)	Year	Comments
1	3 650	10	2008	Pre-mining.
2	3 285	9	01/2009 - 04/2019	Active Mining and care-and-maintenance.
3	365	1	04/2019 -04/2020	Active Mining.
4	365	1	04/2020 - 04/2021	Active Mining.
5	515	1.5	04/2021 - 09/2022	Active Mining.
6	18 250	50	09/2022 - 2072	Pillar extraction and post-closure.

7.7.3 Mass transport model – Simulated pollution plumes and movement

Mass transport modelling in this situation refers to the simulation of water contamination or pollution due to deteriorating water quality in response to man's disturbance of the natural environment.

In contaminant transport investigations the groundwater flow system is considered in terms of its ability to transport dissolved substances or solutes, which may be natural chemical constituents or contaminants. Solutes are transported by the bulk movement of flowing groundwater, a process termed advection, the driving force being the hydraulic gradient. In highly permeable material such as sand and gravel, advection is the most important transport process. Water will then follow the path of least resistance governed by geology, the hydraulic conductivity and the hydraulic gradient.

Groundwater flow in fractured aquifers such as at the study area is governed by a set of factors different from those in porous aquifers. Unknown preferred pathways, often on a large scale will make transport prediction difficult if not impossible. The ability of groundwater models to develop numerical solutions for a problem that is not directly observable is limited in such aquifers.

When a small volume of solute is released into a fractured aquifer it will spread out from the expected advective flow path. It will form a plume of diluted solute, which broadens along and perpendicular to the flow direction. Two processes contribute to this phenomenon of pollution plume development. The first is molecular diffusion (*Brownian motion*) in the direction of the concentration gradient due to the thermal-kinetic energy of the solute particles (irreversible). The global movement of solutes occurs in the direction of the concentration gradient and is expressed by *Ficks Law*. *Ficks Law* simplifies the diffusive mass flux as the product of concentration gradient and the *diffusion coefficient*. Diffusion processes are relatively slow transport processes. A typical value for the *diffusion coefficient* in free solution is 10^{-9} m^2/sec.

One of the biggest uncertainties encountered during transport modelling of pollutants is the effective porosity of the aquifer, as the aquifer displays no primary porosity characteristics. Porosity is defined as the proportion of a given volume of rock that is occupied by pores and is sometimes expressed as a percentage. Flow within an aquifer can only occur through the *interconnected* pores within a given rock mass, which is termed the *effective porosity*. *Effective porosity* is defined as the ratio of the volume of interconnected pores to the total rock volume. *(Note that the effective porosity of an aquifer is always smaller than its total porosity).*

Groundwater transport models do not solve transport (or flow) in pores. The realistic alternative is to move on to a coarser scale of description by introducing measurable coefficients such as hydraulic gradients. In the continuum approach, the concept of the representative elementary volume (REV) is evoked using averaged values over an appropriate volume.

The receiving point of contaminants migrating through the aquifer along the identified paths must be identified and translated into a site-specific impact and risk assessment. In this way, the direct impact on receiving water bodies can be determined.

An overburden stockpile and RoM product stockpile were identified as potential sources of pollution. Due to the absence of data to assign representative source terms to the pollution sources, a source term of 100% was assigned to the sources.

Several mechanisms provide for potential contaminant release from these stockpiles:

- Precipitation runs over the material and carries dissolved and suspended contaminants to surface water bodies.
- Precipitation percolates into the mine wastes and mobilizes contaminants into underlying soil and aquifers.

7.8 Results of the model

7.8.1 Pre-facility (mining)

As stated previously, Tumelo Colliery started mining in 2009 but was placed under care and maintenance for a period of 5 years between 2014 and 2019. The drawdown that occurred in the weathered and/ or fractured aquifer in the year 2019, before mining re-commenced, is shown in Figure 26. From the figure it is evident that mining did not have a mentionable effect on the groundwater levels in and around the mining area and maximum drawdown (water levels below initial steady state) of 4 m occurred. The drawdown zone of influence is confined to the mining area. Groundwater boreholes are also indicated in the figure and while limited drawdown may be expected in mine monitoring boreholes, the cone of depression does not extend to privately owned boreholes.

7.8.2 During facility (mining)

Mining re-commenced in 2019 and hydraulic heads during mining in 2021 is shown in Figure 27. The zone of influence extends slightly during mining but still has not reached any receptor boreholes. The zone extends approximately 1 km in radius.

The pollution transport as expected from the stockpiles for the year 2022 is shown in Figure 28.

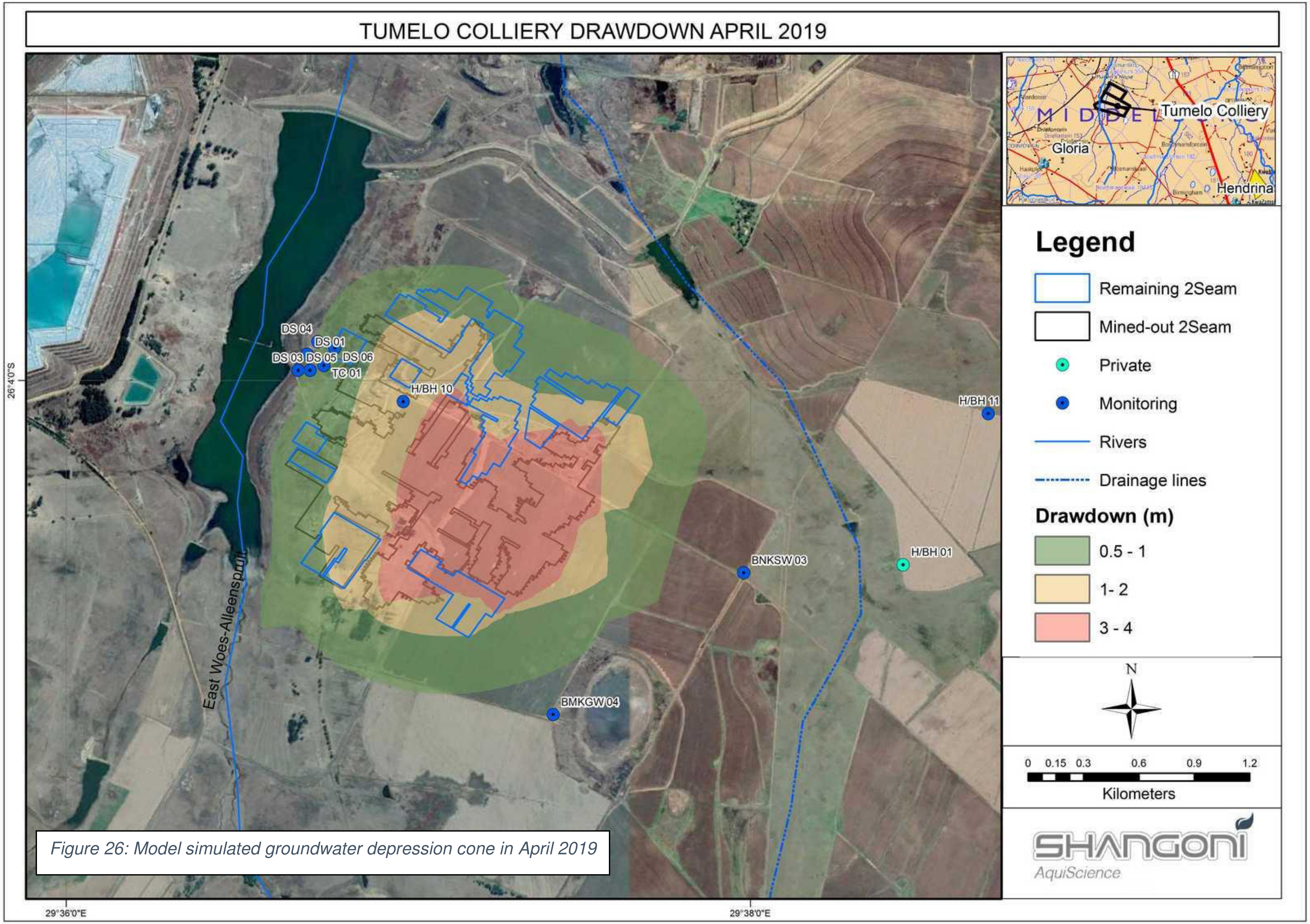


Figure 26: Model simulated groundwater depression cone in April 2019

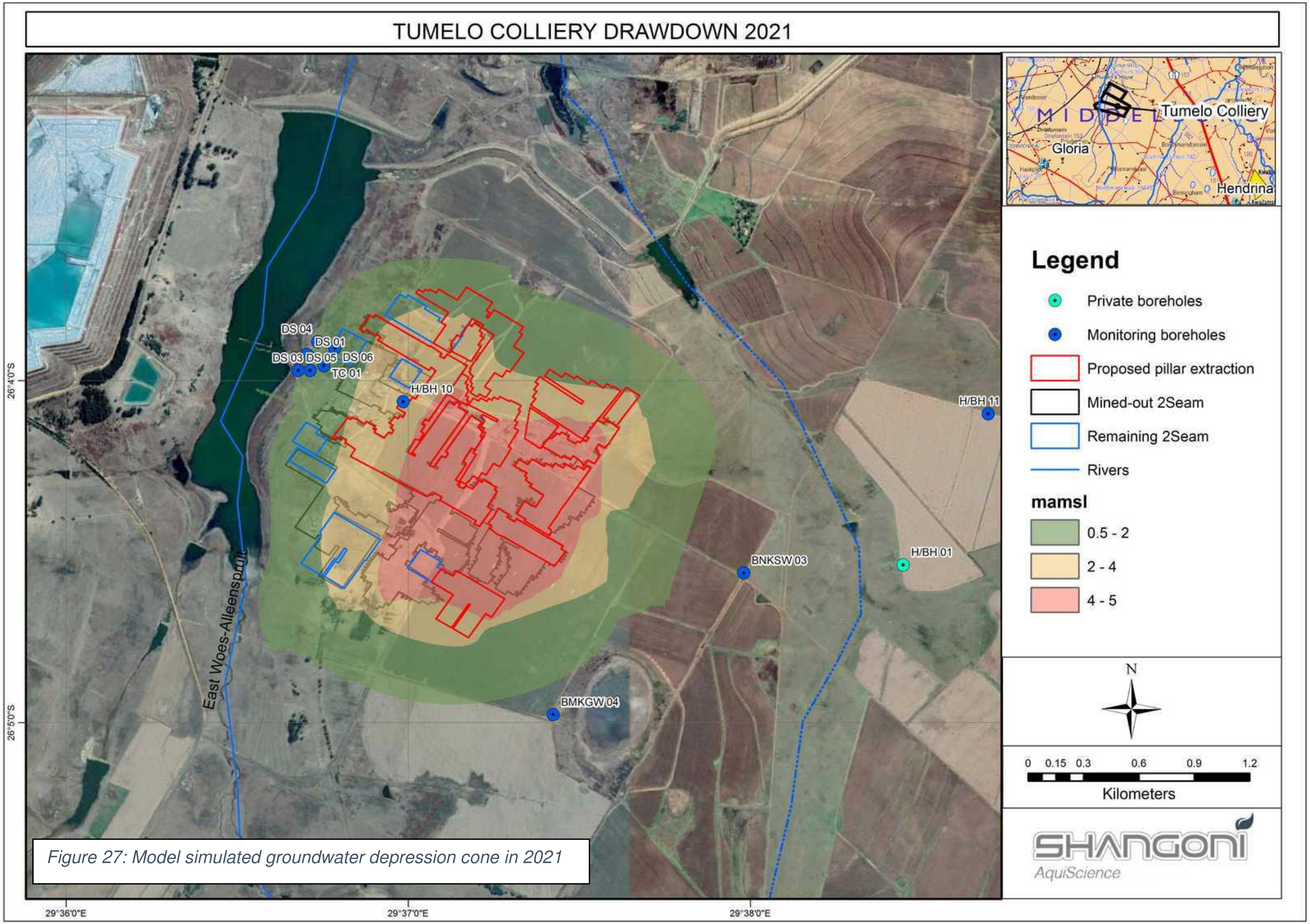


Figure 27: Model simulated groundwater depression cone in 2021

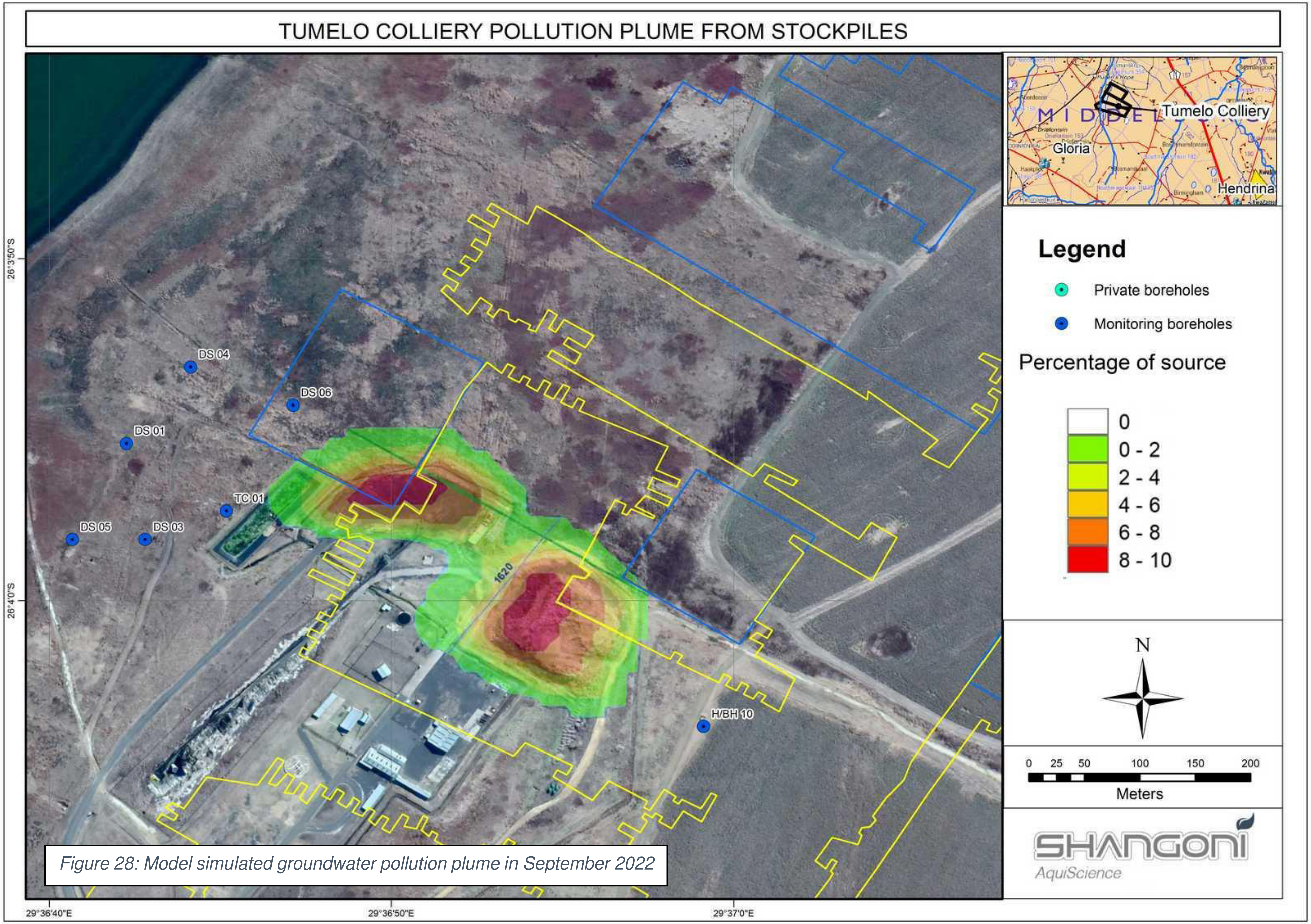


Figure 28: Model simulated groundwater pollution plume in September 2022

7.8.3 Decommissioning and closure

The remaining reserves will be mined using partial pillar extraction (partial stooping) and the last reserves will be removed in 2023. Hydraulic heads were exported from the model for the year in 2023 and the simulated drawdown is shown in Figure 29. It is clear from the figure that the depression cone remains within the mine boundary and except for mine monitoring boreholes, no other boreholes are included within the zone of influence.

Post closure, the mine will no longer remove water from underground and dewatering will cease. For the post closure scenario, the model was set-up to allow water levels to freely recover within the mine voids, by removing drain nodes in the model. During the flooding process, the mine voids (or parts thereof) change from seepage to recharge faces depending on the potential head gradient between the voids and the aquifer, resulting in simultaneous groundwater inflows and outflows.

Partial stooping is envisaged to commence in September 2022 and is expected to commence until October 2023. During partial stooping, when a pillar is extracted, it can no longer support its share of the overburden, and its neighbours must bear the additional weight. Pillar extraction would result in an elevated level of risk of surface subsidence and the geomechanical engineers recommended that no pillar extraction be conducted within a certain horizontal distance of any of the identified surface infrastructure to ensure the long term stability of these structures (Geomech Consulting, 2019). Surface subsidence will create fractures and cracks that will not only increase recharge into the underground voids but also increase the risk of decant due to the creation of preferential flow paths linking the deeper fractured aquifer to surface.

Decant will occur when the mining activities cause such an increase in recharge that the aquifer(s) downgradient from the mine cannot accommodate the increased volumes of water generated as a result of the mine. The effective recharge to the deep aquifer at Tumelo Colliery is expected to increase if surface subsidence occurs, which is at high risk to occur above the partial extraction areas. Decant quality is expected to be non-acidic (circum-neutral) with high to elevated TDS, largely attributed to by SO_4, and high levels of F, Mn and possibly As, B and Fe.

Additional consequences resulting from surface subsidence are disturbances of the flow drivers into the wetlands and loss of post-closure land usages.

If no subsidence occurs recharge into the underground void could range between 1% and 2%, e.g. during bord and pillar mining but could be increased to between 6% and 10% if surface subsidence occurs. These different recharge scenarios were applied to predict mine flooding rates, which is shown in Table 25.

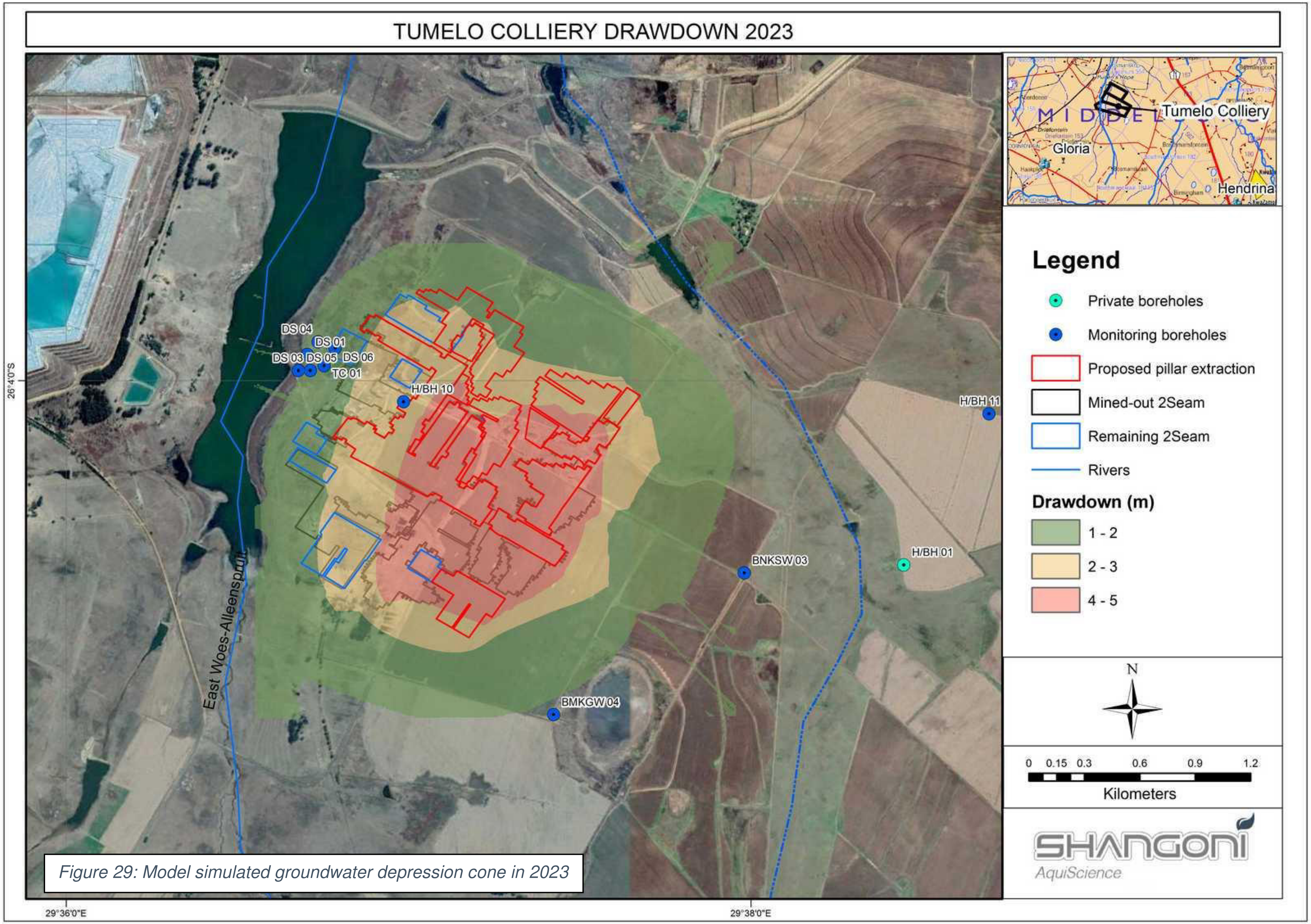


Figure 29: Model simulated groundwater depression cone in 2023

The total volume of groundwater that is required to fill up the mine void is estimated at approximately 2.4 Mm^3. This volume includes the remaining 2 seam and partial extraction areas. The most probable recharge rate into the partial stooping areas, if subsidence does occur, is 8% and based on this recharge value the mine could fill within 48 years where after decanting to surface will occur. The decline is the most obvious location for decant to occur if not sealed correctly, but other positions include decant into the Boschmanskop Dam and at subsidence areas. The estimated decant rate is at 1 l/s.

Table 25: Time to fill estimation

Description	Unit	Partial pillar extraction	Bord-'n-Pillar	Total
Surface area of underground workings	m^2	800 000	650 000	1 450 000
Void volume (after collapse)	m^3	1 250 000	114 000	2 390 000
Best case recharge	m^3/y	6%	1%	36 515
Most probable recharge	m^3/y	8%	1.5%	49 413
Worst case recharge	m^3/y	10%	2%	62 310
Best case time to fill	years	39	262	65
Most probable time to fill	years	29	175	48
Best case time to fill	years	23	131	38

8. GEOHYDROLOGICAL IMPACTS

The groundwater impact assessment focussed on the identification of the major groundwater related impacts that the activities, processes and actions may have on the receiving groundwater environment. The assessment as contained within this report aimed to achieve the following:

- To provide a detailed assessment of the potentially affected groundwater environment.
- To assess impacts on the study area in terms of groundwater criteria.
- To identify and recommend appropriate mitigation measures for potentially significant groundwater related impacts.

The environmental risk of any aspect is determined by a combination of parameters associated with the impact. Each parameter connects the physical characteristics of an impact to a quantifiable value to rate the environmental risk.

The methodology that was employed during the impact assessment follows international best practice. The impact assessment considered the potential impacts of the proposed project activities on groundwater resources, specifically groundwater quality and quantity impacts that could be expected from the activities. It is based on defining and understanding the three basic components of the risk, i.e. the source of the risk, the pathway and the target that experiences the risk (receptor).

After identification of the impacts, the nature and scale of each impact is predicted. The impact prediction provides a basis from which the significance of each impact is determined. Appropriate mitigation measures are subsequently developed with the impact and scale of impact as reference.

Table 26 and Table 27 indicate the methodology to be used to assess the Probability and Magnitude of the impact, respectively, while Table 28 provides the Risk Matrix that will be used to plot the Probability against the Magnitude to determine the Severity of the impact.

The discussion of each impact begins with the background, i.e. a description of the baseline conditions, the proposed project activities, which will cause an impact as well as the sensitive receptors. This is followed by an assessment of the significance of the impacts pre-mitigation, the presentation of recommended mitigation measures, and an assessment of the residual impact that would remain after the implementation of the mitigation measures. Because the mine will not be constructing any additional infrastructure for the mining activities, a construction phase was not included in the risk assessment.

The impact assessment is discussed for each of the following phases:

- Operational Phase
- Decommissioning
- Closure Phase

Table 26: Determining the Probability of impact

FREQUENCY OF ASPECT / UNWANTED EVENT	SCORE	AVAILABILITY OF PATHWAY FROM THE SOURCE TO THE RECEPTOR	SCORE	AVAILABILITY OF RECEPTOR	SCORE
Rare/Never known to have happened, but may happen	1	A pathway to allow for the impact to occur is never available	1	The receptor is never available	1
Unlikely/Known to happen in industry	2	A pathway to allow for the impact to occur is almost never available	2	The receptor is almost never available	2
Possible/< once a year	3	A pathway to allow for the impact to occur is sometimes available	3	The receptor is sometimes available	3
Likely/Once per year to up to once per month	4	A pathway to allow for the impact to occur is almost always available	4	The receptor is almost always available	4
Almost certain/Once a month - Continuous	5	A pathway to allow for the impact to occur is always available	5	The receptor is always available	5

Table 27: Determining the Magnitude of impact

SOURCE								RECEPTOR			
Duration of impact	Score	Extent	Score	Volume / Quantity / Intensity	Score	Toxicity / Destruction Effect	Score	Reversibility	Score	Sensitivity of environmental component	Score
Lasting days to a month	1	Effect limited to the site. (metres);	1	Very small quantities / volumes / intensity (e.g. < 50L or < 1Ha)	1	Non-toxic (e.g. water) / Very low potential to create damage or destruction to the environment	1	Bio-physical and/or social functions and/or processes will remain unaltered.	1	Current environmental component(s) are largely disturbed from the natural state. Receptor of low significance / sensitivity	1
Lasting 1 month to 1 year	2	Effect limited to the activity and its immediate	2	Small quantities / volumes / intensity (e.g.	2	Slightly toxic / Harmful (e.g. diluted brine) / Low potential to create	2	Bio-physical and/or social functions and/or processes might be negligibly altered or enhanced / Still reversible	2	Current environmental component(s) are moderately disturbed from the natural state.	2

SOURCE								RECEPTOR			
Duration of impact	Score	Extent	Score	Volume / Quantity / Intensity	Score	Toxicity / Destruction Effect	Score	Reversibility	Score	Sensitivity of environmental component	Score
		surroundings. (tens of metres)		50L to 210L or 1Ha to 5Ha)		damage or destruction to the environment				No environmentally sensitive components.	
Lasting 1 – 5 years	3	Impacts on extended area beyond site boundary (hundreds of metres)	3	Moderate quantities / volumes / intensity (e.g. > 210 L < 5000L or 5 – 8Ha)	3	Moderately toxic (e.g. slimes) Potential to create damage or destruction to the environment	3	Bio-physical and/or social functions and/or processes might be notably altered or enhanced / Partially reversible	3	Current environmental component(s) are a mix of disturbed and undisturbed areas. Area with some environmental sensitivity (scarce / valuable environment etc.).	3
Lasting 5 years to Life of Organisation	4	Impact on local scale / adjacent sites (km's)	4	Very large quantities / volumes / intensity (e.g. 5000 L – 10 000L or 8Ha–12Ha)	4	Toxic (e.g. diesel & Sodium Hydroxide)	4	Bio-physical and/or social functions and/or processes might be considerably altered or enhanced / potentially irreversible	4	Current environmental component(s) are in a natural state. Environmentally sensitive environment / receptor (endangered species / habitats etc.).	4
Beyond life of Organisation / Permanent impacts	5	Extends widely (nationally or globally)	5	Very large quantities / volumes / intensity (e.g. >	5	Highly toxic (e.g. arsenic or TCE)	5	Bio-physical and/or social functions and/or processes might be severely/substantially altered or enhanced / Irreversible	5	Current environmental component(s) are in a pristine natural state. Highly Sensitive area (endangered species,	5

SOURCE								RECEPTOR			
Duration of impact	Score	Extent	Score	Volume / Quantity / Intensity	Score	Toxicity / Destruction Effect	Score	Reversibility	Score	Sensitivity of environmental component	Score
				10 000 L or > 12Ha)						protected habitats etc.)	

Table 28: Determining the severity of impact

ENVIRONMENTAL IMPACT RATING / PRIORITY					
PROBABILITY	MAGNITUDE				
	1 Minor	2 Low	3 Medium	4 High	5 Major
5 Almost Certain	Low	Medium	High	High	High
4 Likely	Low	Medium	High	High	High
3 Possible	Low	Medium	Medium	High	High
2 Unlikely	Low	Low	Medium	Medium	High
1 Rare	Low	Low	Low	Medium	Medium

8.1 Operational phase

8.1.1 Impacts on groundwater quantity

During the operational phases of mining, removal of groundwater from underground, i.e. dewatering from sumps in underground operations, will be required to remove groundwater from the workings to allow for safe working conditions. The underground bord-&-pillar mine developments coupled with dewatering activities could pose potential risks in terms of:

- impacts of groundwater level change on groundwater users;
- impact of reduced baseflow on surface water and wetlands; and
- potential for subsidence.

Void dewatering will result in a cone of depression and a decline in water levels with a subsequent loss in resource for users. Mining will take place at levels below the groundwater level hence it is likely that the groundwater levels will be impacted. The numerical model simulations indicated a drawdown of between 1 and 4 m at the LoM (max drawdown) in the shallow, weathered aquifer. It must be stressed however that the model was based on absolute worst-case scenarios and the presence of dolerite sills may render certain boreholes isolated from effects of dewatering, but this would need to be confirmed with monitoring.

A total of 8 privately owned boreholes were identified during the hydrocensus. Most boreholes surveyed are privately owned and used for domestic and livestock water and small-scale irrigation. The farmers and communities are dependent on the groundwater (and surface water) resources for everyday domestic purposes and for their livelihoods as groundwater and surface water are their sole source of water. However, none of these boreholes were identified as sensitive receptors as they are not overlying the underground mining activities and are not located within the predicted cone of depression.

The localised dewatering of the deep aquifer on cannot be prevented. Since mining will be underground, it can be expected that the mining will be below the static groundwater levels. Subsidence is unlikely to occur during the operational phases of mining, even when considering partial stooping.

A definite impact can be expected on groundwater quantity due to dewatering. The probability thereof is likely to occur but due to the confining nature of the aquifer at depth the magnitude is rated as low. The impact assessment and final risk rating for impacts on groundwater quantity during the operational phase can be viewed in Table 29.

Table 29: Impact assessment on loss of groundwater resource during the operational phases

Environmental impact, extent, duration, significance and degree to which impact will cause irreplaceable loss	Risk rating (before mitigation)			Environmental objective	Degree to which impact can be reversed and the supporting mitigatory action plan	Timeframe	Responsibility	Risk rating (after mitigation)		
	Probability	Magnitude	Severity					Probability	Magnitude	Severity
ENVIRONMENTAL COMPONENT: Geohydrology										
ACTIVITY: Underground bord and pillar and partial stooping										
PROJECT PHASE APPLICABILITY: Planning and Construction ( ); Operation (X); Decommissioning, Closure and Post-Closure ( )										
Impact description: During the operational phase the mining will be active that will require dewatering of the deep aquifer(s). This will result in a cone of depression and a decline in water levels with a potential loss in resource for users. The presence of dolerite sills may render certain boreholes isolated from effects of dewatering, but this would need to be confirmed with monitoring. If impact is confirmed by monitoring, impacts to the community's and farmer's water supply must be mitigated by the client providing an alternative reliable, clean water supply. The localised dewatering of the deep aquifer on cannot be prevented. Since mining will be underground, it can be expected that the mining will be below the static groundwater levels. The deeper aquifer will be drawn down to the bottom of No. 2 Seam but the effects in the shallower aquifer will not be substantial due to their confining nature. In addition, no boreholes are overlying the underground mining activities nor are they located within the zone of dewatering influence.	3	2	M	To minimise the extent of disturbance of the aquifer. To limit impacts on groundwater quantity.	Degree to which impact can be reversed: None Management measures • No specific management measures are proposed other than to continue with water level and quality monitoring in source and receptor monitoring boreholes. Action plans • No specific action plans or mitigation measures are proposed. • If impact is confirmed by monitoring, impacts to the community's and farmers' water supply must be mitigated by the client providing an alternative reliable, clean water supply.	Operational.	Environmental Manger	3	2	M

Environmental impact, extent, duration, significance and degree to which impact will cause irreplaceable loss	Risk rating (before mitigation)			Environmental objective	Degree to which impact can be reversed and the supporting mitigatory action plan	Timeframe	Responsibility	Risk rating (after mitigation)		
	Probability	Magnitude	Severity					Probability	Magnitude	Severity
Water level impacts are expected to be localised and restricted to the site. Reasons for the localisation of the groundwater level impacts are: - The depth at which the planned mining will take place. - The prevention of subsidence and subsequent fracture formation. - The overall low aquifer transmissivity. <u>Duration of impact:</u> Operational phase extending to post closure phase. <u>Degree to which impact may cause irreplaceable loss:</u> None					• Routinely refine, update and validate the conceptual and numerical models developed in this study with updated monitoring data.					

8.2.2 Impacts on groundwater quality

The two most common processes by which groundwater are contaminated include interstitial release and ion exchange release. Coal material contains pyrite and exposure to atmospheric oxygen and rainwater ingress could result in the formation of acidic, saline and metal rich water. However, during the operational phases of mining groundwater that seeps into the underground voids will be abstracted (dewatered) to allow for safe working conditions and stored in the PCD for production use. The residence time underground will, therefore, be limited, and water quality is expected to be good to fair. Some mineralisation is expected to occur, and the pumped water should be maintained in a closed water circuit and not be allowed to seep into or be discharged into the receiving surface environment.

Two potential sources of pollution (overburden and RoM stockpiles) were identified on surface. Modelling of the sources revealed that a pollution plume could develop. Due to the absence of recent geochemical data and the fact that no source monitoring boreholes are present to calibrate the contaminant transport model, a source concentration of 100% were assigned. The model shows that the plume is localised due to the low hydraulic conductivity of the aquifer and no receptor boreholes will be impacted on.

The probability of groundwater pollution occurring during the operational phase of mining is likely, but the magnitude is expected to be low due to the localised nature of pollution. No receptor boreholes will be impacted on. The impact assessment and final risk rating for impacts on groundwater quality during the operational phase can be viewed in Table 30.

8.2.3 Impacts on surface water

No direct impacts are expected on surface water resources during the operational phases of mining. Indirect impacts could occur as a result of discharge of substandard water that does not comply to release standards or from poor housekeeping. Effective stormwater management, especially clean and dirty water separation, is imperative to reduce the risk of affected water flowing into the receiving surface water environment.

The probability of impacts on surface water during the operational phase is unlikely but the magnitude is medium. Effective management and mitigation measures can reduce the risk to low. The impact assessment and final risk rating for impacts on surface water during the operational phase can be viewed in Table 31.

Table 30: Impact assessment on groundwater quality during the operational phase

Environmental impact, extent, duration, significance and degree to which impact will cause irreplaceable loss	Risk rating (before mitigation)			Environmental objective	Degree to which impact can be reversed and the supporting mitigatory action plan	Timeframe	Responsibility	Risk rating (after mitigation)		
	Probability	Magnitude	Severity					Probability	Magnitude	Severity
ENVIRONMENTAL COMPONENT: Geohydrology										
ACTIVITY: Underground bord and pillar and partial stooping										
PROJECT PHASE APPLICABILITY: Planning and Construction										
PROJECT PHASE APPLICABILITY: Operation – X										
PROJECT PHASE APPLICABILITY: Decommissioning, Closure and Post-Closure										
<u>Impact description:</u> Coal surfaces exposed to the atmosphere within underground workings can potentially generate acid mine drainage. Due to low residence times during the operational phases of mining no substantial deterioration in groundwater quality is expected to occur. Seepages from the overburden and RoM stockpiles could be highly mineralised with mostly sulphate. <u>Duration of impact:</u> Operational phase extending to post closure phases. <u>Degree to which impact may cause irreplaceable loss:</u> None	3	2	M	To minimise the extent of disturbance of the aquifer. To limit degeneration of groundwater quality.	Management measures: • Prevent groundwater quality deterioration. Action plans: • Minimize residence time in underground workings by pumping groundwater seepage to surface. • Capture seepages from mine residue facilities and maintain in the affected water circuit. • Maintain water pumped from underground in a closed circuit. • PCDs to be designed so that no polluted water system at the mine is likely to spill into any clean water system more than once in 50 years and will have a minimum of 800 mm freeboard above spillway level.	Operational.	Environmental Manger	2	2	L

Environmental impact, extent, duration, significance and degree to which impact will cause irreplaceable loss	Risk rating (before mitigation)			Environmental objective	Degree to which impact can be reversed and the supporting mitigatory action plan	Timeframe	Responsibility	Risk rating (after mitigation)		
	Probability	Magnitude	Severity					Probability	Magnitude	Severity
					• A groundwater monitoring programme should be incorporated and assessed and updated by a professional geohydrologist on an annual basis. • Should environmentally unacceptable concentrations of constituents of concern be identified during monitoring of the seepage plume, hydraulic plume containment should be initiated. • Maintain water pumped from underground in a closed circuit and do not discharge water that does not comply to release standards.					

Table 31: Impact assessment on surface water during the operational phase

Environmental impact, extent, duration, significance and degree to which impact will cause irreplaceable loss	Risk rating (before mitigation)			Environmental objective	Degree to which impact can be reversed and the supporting mitigatory action plan	Timeframe	Responsibility	Risk rating (after mitigation)		
	Probability	Magnitude	Severity					Probability	Magnitude	Severity
ENVIRONMENTAL COMPONENT: Surface water										
ACTIVITY: Underground bord and pillar and partial stooping										
PROJECT PHASE APPLICABILITY: Planning and Construction										
PROJECT PHASE APPLICABILITY: Operation — X										
PROJECT PHASE APPLICABILITY: Decommissioning, Closure and Post-Closure										
<u>Impact description:</u> No direct impacts are expected on surface water resources during the operational phases of mining. Indirect impacts could occur as a result of discharge of substandard water that does not comply to release standards. <u>Degree to which impact may cause irreplaceable loss:</u> None	2	3	M	To minimise the extent of disturbance of the aquifer. To limit degeneration of groundwater quality.	Management measures: • Minimize seepage, prevent contact between clean and dirty areas, and to recycle contaminated water. • Contain all affected water within the affected water circuit. Action plans: • All contaminated/affected water from the area to be directed to lined pollution control dams (PCDs). • PCDs to comply with GN704. • Intercept seepage from stockpiles. • PCDs to be designed so that no polluted water system at the mine is likely to spill into any clean water system more than once in 50	Operational.	Environmental Manger	1	2	L

Environmental impact, extent, duration, significance and degree to which impact will cause irreplaceable loss	Risk rating (before mitigation)			Environmental objective	Degree to which impact can be reversed and the supporting mitigatory action plan	Timeframe	Responsibility	Risk rating (after mitigation)		
	Probability	Magnitude	Severity					Probability	Magnitude	Severity
					years and will have a minimum of 800 mm freeboard above spillway level. • A monitoring programme should be incorporated and be updated and assessed by a professional geohydrologist on a yearly basis. • Do not discharge contaminated water into the receiving environment that does not comply to relevant release limits.					

8.2.4 Groundwater management

Groundwater management should be dealt with from a risk-based approach and be focussed on the source-pathway-receptor model. Refer to the Conceptual Site Model in Section 7.6 for a more detailed discussion on risk-based approach that should be followed.

Monitoring is crucial to verify whether the activities will impact on the local receiving surface and groundwater regime. Important management measures could include:

- Monitor groundwater in source and receptor boreholes and receiving surface water environment up- and downstream relative to the mine and/ or from pollution sources.,
- Separation of clean and affected water through diversion canals and an affected water management system that collects affected runoff water from dirty management areas.
- All affected water must drain towards the PCD and be re-used in the plant as process water or during dust suppressant activities.
- Minimisation of dirty water management areas and the separation of clean and dirty water management areas.
- Handle and store hazardous material according to manufacturing requirements.
- Train staff and implement correct procedures for the handling of hazardous substances.
- Only qualified staff should handle hazardous materials.
- Contain and clean spillages of hazardous material.
- Store hazardous material correctly and use according to specifications.
- If environmentally unacceptable concentrations of constituents of concern are identified during monitoring, hydraulic plume containment should be initiated.
- Should it be indicated through monitoring and investigation that groundwater users are impacted upon in terms of groundwater quality or quantity, alternative water sources must be made available to such users.

8.3 Decommissioning phase

The decommissioning phase will commence when the mine has reached its life cycle after approximately 4 years. The dewatering activities will cease and water from recharge will be allowed to fill the voids remaining underground. This phase will continue until closure is obtained, at which point in time the Post-Closure Phase will commence. The following activities, which are expected to impact on the surrounding environmental aspect, are anticipated to take place during the decommissioning phase of mining.

- Backfilling the Adit with overburden material.
- Removal of plant.
- Removal of other redundant surface infrastructure (depending on the agreed end land use), and rehabilitation of the remaining footprint areas.

- Monitoring and maintenance of rehabilitated surface land use areas, as well as surface water and groundwater.
- Utilisation and management of the water balance to reflect the actual situation during the Decommissioning Phase.

In view of the expected short timeframe for the decommissioning phase, no measurable impacts on the groundwater quality, quantity or flow regime are foreseen. However, during this phase, a rehabilitation plan must be implemented, and the plan should be compiled in the line with the contents of National Water Act (Act No 36 of 1998) and National Environmental Management Act (Act No 107 of 1998) to avoid or minimise any negative environmental impacts should it occur. A zero-effluent operating principle should be committed to whereby contaminated water will be prevented from entering the receiving environment through actions like recycling, containment and reuse and/or treatment.

8.4 Closure phase

Two types of impacts can remain on groundwater long after mining has been completed, namely groundwater quality and quantity impacts. The former (quality) impact is very common in the coal and gold mining industry where chemical reactions and processes like sulphide oxidation, ion exchange and consequent AMD influence the water quality where water encounters the host rocks in the presence of oxygen and water. The following impacts are generally associated with underground coal mines during decommissioning/ closure.

- Deteriorating groundwater quality within the deeper aquifer affecting current or future receptor boreholes.
- Subsidence, roof collapse and sinkhole formation.
- Decanting of poor-quality water affecting freshwater surface resources such as rivers, streams and/ or wetlands.

8.4.1 Groundwater quantity

When coal, rock and minerals are removed from an underground mine, the overlying earth can sink, i.e. subsidence can occur. The extent of mine subsidence depends on the mining method, local geology, depth of mining and amount of material extracted. Because partial pillar extraction (partial stooping) is proposed, the risks related to subsidence and the formation of sinkholes are rated as high. Mine subsidence can affect built features like homes or roads and environmental features like freshwater resources, most notably wetlands and aquifers. Cracks or fractures on surface will be created resulting in increased recharge. The consequence of increased recharge to the subsurface and mine voids has a benefit of flooding the underground mine faster than would otherwise be expected if no subsidence had occurred. Generally, a management measure for underground coal mines is to flood the mine as quickly as possible. The benefit of flooding is reducing oxidation and subsequently the formation of AMD. Recharge could be up to 10 times greater if subsidence occurs. The disadvantage of this occurring is that decanting will be likely to occur within a shorter time period. The negative impact of decanting outweighs the positive impact of mine flooding and a medium impact is rated for groundwater quantity during the closure phase.

The impact assessment and final risk rating for impacts on groundwater quality during the post-closure phase can be viewed in Table 32.

8.4.2 Groundwater quality

Coal surfaces exposed to the atmosphere within underground workings can potentially generate acid mine drainage. However, the water accumulating in the underground voids is likely be circum-neutral but will be saline with high to elevated SO_4. It is expected that Fe and Mn will also be in the mobile phase and high F is also likely.

The impact assessment and final risk rating for impacts on groundwater quality during the post-closure phase can be viewed in Table 33.

8.4.3 Surface water quality

Decant is expected for Tumelo Colliery after approximately 40 years post-operation. This is likely to occur since roof collapse with associated cracking/fracturing of roof strata or subsidence is expected because of the proposed partial pillar extraction. Although the risk of acid formation is low, the decant water quality is expected to contain high TDS, with SO_4 the greatest contributor, including Ca, F and Mn and possibly other metals such as As, B and Fe in solution. Likely decant points are the incline shaft, the ring dyke structure west of the Boschmanskop Dam as well as cracks or fractures created by subsidence at an elevation of approximately 1610 mamsl. The decant quality will likely be unacceptable for release to the environment until the contrary can be confirmed through measurement. Facilities should be constructed to contain or treat the decant. The Boschmanskop Dam and wetlands are especially at risk of being impacted on by substandard decant water quality. A decant rate of approximately 80 m^3/d is expected. Note that this volume is based on a worst-case scenario as no evapotranspiration was considered.

The impact assessment and final risk rating for impacts on groundwater quality during the post-closure phase can be viewed in Table 34.

Table 32: Impact assessment on groundwater quantity during the closure phase

Environmental impact, extent, duration, significance and degree to which impact will cause irreplaceable loss			Risk rating (before mitigation)			Environmental objective	Degree to which impact can be reversed and the supporting mitigatory action plan	Timeframe	Responsibility	Risk rating (after mitigation)		
			Probability	Magnitude	Severity					Probability	Magnitude	Severity
ENVIRONMENTAL COMPONENT: Geohydrology												
ACTIVITY: Underground mining and partial stooping												
PROJECT PHASE APPLICABILITY	Planning and Construction											
	Operation											
	Decommissioning, Closure and Post-Closure	X										
<u>Impact description:</u> Generally, a management measure for underground coal mines is to flood the mine as quickly as possible. The benefit of flooding is reduced oxygen ingress and the subsequent formation of AMD. Recharge could be up to 10 times greater if subsidence occurs. The disadvantage of this is that decanting will be likely to occur within a shorter time period. The negative impact of decanting outweighs the positive impact of mine flooding and a medium impact is rated for groundwater quantity during the closure phase. <u>Duration of impact:</u> Closure phase <u>Degree to which impact may cause irreplaceable loss:</u> None			4	3	H	To minimise the extent of disturbance of the aquifer. To reduce recharge to mine voids.	Management measures • Reduce recharge to the mine voids. Action plans • Minimise recharge of rainwater into underground voids by creating free draining slopes. • Installation and testing of additional groundwater monitoring boreholes (cluster of shallow and deep piezometers) to monitor the shallow and fractured aquifer. • Update the geohydrological model with new monitoring data to verify predictions made and as management tool for further predictive estimations.	Operational.	Environmental Manger	3	2	M

Environmental impact, extent, duration, significance and degree to which impact will cause irreplaceable loss	Risk rating (before mitigation)			Environmental objective	Degree to which impact can be reversed and the supporting mitigatory action plan	Timeframe	Responsibility	Risk rating (after mitigation)		
	Probability	Magnitude	Severity					Probability	Magnitude	Severity
					• Rehabilitate all high recharge footprints with topsoil and indigenous vegetation. • Conduct surface inspections to ensure that surface subsidence does not occur. • If subsidence occurs and sinkholes are formed during operation or after closure, they should be rehabilitated as soon as possible to minimise water and oxygen inflow from the surface. • Ponding should not be allowed in sinkhole depressions and should be made free draining.					

Table 33: Impact assessment on groundwater quality during the closure phase

Environmental impact, extent, duration, significance and degree to which impact will cause irreplaceable loss	Risk rating (before mitigation)			Environmental objective	Degree to which impact can be reversed and the supporting mitigatory action plan	Timeframe	Responsibility	Risk rating (after mitigation)		
	Probability	Magnitude	Severity					Probability	Magnitude	Severity
ENVIRONMENTAL COMPONENT: Geohydrology										
ACTIVITY: Underground mining and partial stooping										
PROJECT PHASE APPLICABILITY: Planning and Construction										
PROJECT PHASE APPLICABILITY: Operation										
PROJECT PHASE APPLICABILITY: Decommissioning, Closure and Post-Closure — X										
<u>Impact description:</u> Coal surfaces exposed to the atmosphere within underground workings can potentially generate acid mine drainage. However, the water accumulating in the underground voids is likely be circum-neutral but saline with high to elevated SO_4. It is expected that Fe and Mn will also be in the mobile phase and high F is also likely. <u>Duration of impact:</u> Closure phase <u>Degree to which impact may cause irreplaceable loss:</u> Medium	4	3	H	To minimise the extent of disturbance of the aquifer. To limit degeneration of groundwater quality.	Degree to which impact can be reversed: Effective mitigation can slightly reverse impact. Management measures • The deterioration of groundwater within the deep aquifer cannot be prevented. • Sealing of the adit to prevent free recharge of the adit. • The final surface needs to be free draining to minimize recharge. • A rehabilitation plan must be implemented, and the plan should be done in the line with the contents of National Water Act (Act No 36 of 1998) and National Environmental Management Act (Act 107 of	Operational.	Environmental Manger	3	2	M

Environmental impact, extent, duration, significance and degree to which impact will cause irreplaceable loss	Risk rating (before mitigation)			Environmental objective	Degree to which impact can be reversed and the supporting mitigatory action plan	Timeframe	Responsibility	Risk rating (after mitigation)		
	Probability	Magnitude	Severity					Probability	Magnitude	Severity
					1998), to avoid subsequent negative environmental impacts that may occur. Action plans • Effectiveness of existing monitoring borehole positions should be re-evaluated. • Continuation of the monitoring programme to establish post decommissioning trends. • Water abstraction from deep boreholes that are close to the mine workings should be avoided so that contaminants will not migrate towards the abstraction boreholes, and away from the mine voids. • Groundwater levels near the planned mine should be monitored on a regular basis throughout decommissioning and post closure phases. • If impact is confirmed by monitoring, impacts to the community's and farmers' water supply must be mitigated by the client providing an alternative reliable, clean water supply. • Routinely refine, update and validate the conceptual and numerical models developed in this study by incorporation of ongoing monitoring data.					

Table 34: Impact assessment on surface water quality during the post-project phase

Environmental impact, extent, duration, significance and degree to which impact will cause irreplaceable loss	Risk rating (before mitigation)			Environmental objective	Degree to which impact can be reversed and the supporting mitigatory action plan	Timeframe	Responsibility	Risk rating (after mitigation)		
	Probability	Magnitude	Severity					Probability	Magnitude	Severity
ENVIRONMENTAL COMPONENT: Receiving surface water										
ACTIVITY: Underground mining and partial stooping										
PROJECT PHASE APPLICABILITY: Planning and Construction										
Operation										
Decommissioning, Closure and Post-Closure: X										
<u>Impact description:</u> Decant is expected for Tumelo Colliery after approximately 40 years post-operation. This is likely to occur since roof collapse with associated cracking/fracturing of roof strata or subsidence is expected because of the proposed partial pillar extraction. Although the risk of acid formation is low, the decant water quality is expected to contain high total dissolved salts, with SO_4 the greatest contributor, as well as Ca, F and Mn and possibly other metals such as As, B and Fe in solution. Likely decant points are the incline shaft, the ring dyke structure west of the Boschmanskop Dam as well as cracks or fractures created by subsidence at an elevation of approximately 1610 mamsl. The decant quality will likely be unacceptable for release to the environment until the contrary can be confirmed through measurement. Facilities should be constructed to contain or treat the decant from the boxcut and from other areas such as where sinkholes have formed. The Boschmanskop Dam, perched aquifer/s and wetlands are especially at risk to be impacted on by substandard decant quality.	4	4	H	To ensure that there is no deterioration of surface water quality To ensure that all decant is captured, thus reducing the impacts on surface water quality.	Degree to which impact can be reversed: Effective mitigation can slightly reverse impact. Management measures • Sealing of the adit to prevent free recharge of the adit. • Pond formation should be prevented on surface by creating a free-draining surface through landscaping along slopes and filling of holes/fractures/cracks in flat-lying areas. • A rehabilitation plan must be implemented, and the plan should be done in the line with the contents of National Water Act (Act No 36 of 1998) and National Environmental Management Act (Act 107 of	Operational.	Environmental Manger	3	3	M

Environmental impact, extent, duration, significance and degree to which impact will cause irreplaceable loss	Risk rating (before mitigation)			Environmental objective	Degree to which impact can be reversed and the supporting mitigatory action plan	Timeframe	Responsibility	Risk rating (after mitigation)		
	Probability	Magnitude	Severity					Probability	Magnitude	Severity
Duration of impact: Post closure phase Degree to which impact may cause irreplaceable loss: High					1998), to avoid subsequent negative environmental impacts that may occur. • Commit to a zero-effluent operating principle whereby contaminated water will be prevented from entering the receiving surface water environment through actions like recycling, reuse or treatment during the short- and long-term. Action plans • Re-establish surface drainage to the pre-mining conditions as far as practical. • Restore normal infiltration rates to areas where recharge was reduced due to surface compaction, such as at the shaft infrastructure areas. • Effectiveness of existing monitoring borehole positions should be re-evaluated. • Continuation of the monitoring programme to establish post closure trends. • Groundwater levels near the mine should be monitored on a regular basis throughout and post closure phases.					

Environmental impact, extent, duration, significance and degree to which impact will cause irreplaceable loss	Risk rating (before mitigation)			Environmental objective	Degree to which impact can be reversed and the supporting mitigatory action plan	Timeframe	Responsibility	Risk rating (after mitigation)		
	Probability	Magnitude	Severity					Probability	Magnitude	Severity
					• Install monitoring boreholes into different parts of the mine voids to monitor the rebounding water levels. • Regulate rebounding water levels to below maximum critical level to prevent decant. • The occurrence of potential groundwater seepages in the vicinity of the decline and along the ring dyke downstream of the mine should be monitored regularly and contained if necessary. • Conduct surface inspections to ensure that surface subsidence does not occur. • If subsidence occurs and sinkholes are formed during operation or after closure, they should be rehabilitated as soon as possible to minimise water and oxygen inflow from the surface. This will minimise or avoid oxidation reactions and potential acid generation. • Should decanting occur, passive or active treatment plants should be considered. • Routinely refine, update and validate the conceptual and numerical models developed in this study by incorporation of ongoing monitoring data.					

8.4.4 Cumulative impacts

Cumulative impacts of current and potential neighbouring and future mining activities and other industries within the area were neglected due to data limitations. However, given the nature of the project activities and geological and geohydrological context, cumulative impacts are anticipated.

8.4.5 Ground- and surface water management

The main groundwater management objectives and principles should be to prevent, minimise or contain contamination of groundwater quality in aquifers and natural surface water resources. Management activities or mitigation measures to include the following:

- Sealing of the adit to prevent free recharge of the adit.
- Pond formation should be prevented on surface by creating a free-draining surface through landscaping along slopes and filling of holes/fractures/cracks in flat-lying areas.
- A rehabilitation plan must be implemented, and the plan should be done in the line with the contents of National Water Act (Act No 36 of 1998) and National Environmental Management Act (Act 107 of 1998), to avoid subsequent negative environmental impacts that may occur.
- Commit to a zero-effluent operating principle whereby contaminated water will be prevented from entering the receiving surface water environment through actions like recycling, reuse or treatment during the short- and long-term.
- Re-establish surface drainage to the pre-mining conditions as far as practical.
- Restore normal infiltration rates to areas where recharge was reduced due to surface compaction, such as at the shaft infrastructure areas.
- Effectiveness of existing monitoring borehole positions should be re-evaluated.
- Continuation of the monitoring programme to establish post closure trends.
- Groundwater levels near the mine should be monitored on a regular basis throughout and post closure phases.
- Install monitoring boreholes into different parts of the mine voids to monitor the post-closure water levels.
- Regulate rebounding water levels to below maximum critical level to prevent decant.
- The occurrence of potential groundwater seepages in the vicinity of the decline and along the ring dyke downstream of the mine should be monitored regularly and contained if necessary.
- Conduct surface inspections to ensure that surface subsidence does not occur.
- If subsidence occurs and sinkholes are formed during operation or after closure, they should be rehabilitated as soon as possible to minimise water and oxygen inflow from the surface. This will minimise or avoid oxidation reactions and potential acid generation.
- Should decanting occur, passive or active treatment plants should be considered.
- Routinely refine, update and validate the conceptual and numerical models developed in this study by incorporation of ongoing monitoring data.

9. GROUNDWATER MONITORING SYSTEM

9.1 Groundwater monitoring network

9.1.1 Source plume, impact and background monitoring

Prior to the design of any monitoring programme, the current understanding of the groundwater system must be understood in terms of i) flow dynamics and behaviour, ii) potential sources of groundwater and related surface water impacts; iii) receptors that may be affected by impacts to groundwater and surface water; and iv) the pathways that could potentially connect them. No risk exists if an impact source is not linked to a potential receptor.

A deterioration in groundwater quality is the most significant risk associated with the activity.

The source-pathway-receiver model provides a conceptual portrayal of the mode through which contaminants act and the potential harm they may inflict on a receiving water body and/or organism. The conceptual model is used to develop management action plans and reclamation alternatives that are directed towards mitigating potentially harmful effects caused by the contaminants of concern. Refer to the conceptual site model discussion under Section 7.6.2 for a more detailed discussion on interaction between potential sources of contamination and receptors that could be affected using the source – pathway – receptor methodology.

9.1.2 System response monitoring network

A Water Management Plan is required to ensure that the change in mine plan do not impact negatively on groundwater levels and quality to unacceptable levels. It will also serve as early warning systems to implement mitigation measures at early stages to reduce cumulative impacts. To ensure that the groundwater environment is protected, monitoring of water quality and levels are required on an on-going basis.

Monitoring is required for the following purposes:

1. To detect the actual impact on groundwater quality timeously.
2. To assess whether the mitigation measures given in Section 8 are effective, supporting the update of mitigation measures where necessary.
3. Models can be updated and refined based on new information to support adaptive management measures. Model confidence levels can be increased, and groundwater impacts be predicted with more accuracy. With updated and high confidence predictions, the client can act in a pre-emptive manner, thus reducing risks, rather than acting retrospectively when monitoring data reveals a problem.

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

Monitoring in general should follow the risk-based approach to define or characterise the risks that the operations and associated infrastructure may pose on the receiving environment.

Risk assessments involve the understanding of the generation of a hazard, the probability that the hazard will occur, and the consequences should it occur, i.e. understanding 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.

The main objective in positioning monitoring boreholes is to intercept groundwater i) upgradient from the source (background); ii) at the source; iii) moving away/downgradient from the source; and iv) interception at selected intervals towards a final receptor.

9.1.3 Monitoring frequency

Groundwater monitoring should occur on a quarterly frequency and the receiving surface water on a monthly frequency. The frequency is recommended to be initiated for a minimum period of one (1) year where after the programme should be revised. Surface water sources such as the PCD, stormwater, where available and other affected containment facilities should also be monitored on a monthly basis.

9.2 Monitoring parameters

The following parameters are proposed to be included in the water monitoring programme.

- pH, EC
- TDS
- Major cations including Ca, Mg, Na, K
- Major anions including Cl, SO_4, T-Alk (HCO_3^-/CO_3^-)
- Minor cations/metals including As, B, Fe, Al, Mn, F
- Nutrients including PO_4^-, NO_3^-, NH_4^+
- Groundwater levels

An annual ICP scan and is recommended for both surface and groundwater.

9.3 Monitoring boreholes

It is recommended that the status quo surface and groundwater monitoring programme be continued. No new monitroring boreholes are recommended at this stage. However, a series of boreholes drilled into the different areas of the mine voids, especially into the deeper voids, are recommended to monitor the rebounding rate of the water table.

10. GROUNDWATER ENVIRONMENTAL MANAGEMENT PROGRAMME

10.1 Current groundwater conditions

The present/status quo groundwater conditions do not indicate any type of impact on the geohydrological regime. Refer to the conceptual models developed (Section 7.6) and hydrocensus (Section 5.4) and groundwater quality (Section 5.6) discussions for an additional discussion on status quo groundwater conditions.

10.2 Predicted impacts of facility

The predicted impact on the ambient groundwater conditions is primarily associated with a deterioration of the groundwater quality underground and possibly from the overburden and RoM stockpiles on surface. During the operational phases of mining the residence time of water in the voids is expected to be minimal and therefore water quality will be non-acidic with slightly raised salinity, especially SO_4. Fluoride (F) and SO_4 is expected to exceed general discharge standards and will not be allowed to be discharge (to be confirmed by monitoring). Trace metals such as Mn and Fe and possibly As and B may also be raised.

10.3 Mitigation measures

10.3.1 Lowering of groundwater levels during facility operation

During active mining, groundwater filling mine voids will be dewatered to allow for safe working conditions. However, given the confining nature of the deeper aquifers where mining will take place, a substantial drawdown is not expected within the weathered or shallower fractured aquifer into which most privately owned boreholes are drilled. The model predicted a drawdown of between 1- 5 m below steady state water levels. This drawdown will be confined to the mine boundary due to the low permeability of the aquifers. No sensitive receptors' boreholes are located within this zone of influence. The effect of dewatering cannot be prevented, and no mitigation measures are recommended. Monitoring should continue during this phase to confirm the model results.

10.3.2 Rise of groundwater levels post- facility operation

Once the project is completed, the mine will cease pumping water from underground and rehabilitation will commence. As stated previously, the risk of subsidence occurring is rated as high during the post-operational phases. Resultant surface cracks and fractures will increase recharge into the underground voids by as much as 10%. The amount of time to fill the voids will as a result be considerably less as opposed to when no subsidence occurs. Decant is also likely to occur if water levels rise above maximum critical levels, generally 10 -15 m below decant level (1610 mamsl). Several mitigation measures are proposed in this report to mitigate the risk of decant (refer to Section 8.4.5).

10.3.3 Spread of groundwater pollution post- facility operation

Because the underground mine void acts as a sink whereby all groundwater flows toward it rather than from it, no groundwater plume is expected to migrate from the mine. Decant, polluting surface water resources and the weathered aquifer, remains the greatest risk post the operational period.

11. POST CLOSURE MANAGEMENT PLAN

11.1 Remediation of physical activity

Remediation of groundwater impacts due to the physical activity forms part of the recommended rehabilitation of the remaining facilities or footprint areas by reshaping, top-soiling and seeding and removing redundant infrastructure.

11.2 Remediation of storage facilities

It is recommended that the parts or footprints of the facilities remaining after reclamation be rehabilitated. The rehabilitation should entail the re-shaping of the remaining areas to encourage surface run-off (with smooth transitions to the surrounding topography) and prevent any ponding to minimize water ingress. The remaining areas should furthermore be covered with soil and seeded to promote evapotranspiration.

Any remaining surface water storage facilities not required for the management of remaining dirty water run-off, should be re-shaped and rehabilitated (top-soiled and seeded).

11.3 Remediation of water resources impacts

The groundwater monitoring programme as outlined and discussed in this report should be implemented and reviewed regularly and updated if necessary. Monitoring of the groundwater system must be implemented to act as early warning system. Should impacts be identified, management and mitigation measures must be implemented to prevent or reduce potential impacts on the groundwater environment as far as possible. Should environmentally unacceptable concentrations of constituents of concern be identified during monitoring of the seepage plume, hydraulic plume containment should be initiated to reduce impacts on the wetland and other groundwater users. Decant is likely to occur and it is expected to be of a quality not allowed to be discharged into the environment. Any decant should immediately be contained, analysed and treated (if required) before release into the environment. Cracks and fractures resulting from surface subsidence should be immediately sealed and no ponding should be allowed in depressions and should be free draining to limit recharge into the voids.

11.4 Backfilling of the pits

The project entails underground mining. Potential backfilling of pits is therefore not applicable.

12. CONCLUSION AND RECOMMENDATIONS

Shangoni AquiScience, a division of Shangoni Management Services, was appointed by Cabanga Environmental cc, to conduct a geohydrological investigation for the underground mining of 2 Seam using bord and pillar methods and partial pillar removal (partial stooping). The study was compiled using all relevant available information and generated data for the operation and to define the groundwater regime using conceptual and numerical transport models. The models were used to predict and highlight current and foreseeable risks towards the receiving surface and groundwater environment. This specialist geohydrological study was undertaken to fulfil in the requirements of a Water Use Licence Application (WULA) and Environmental Impact Assessment (EIA) for Tumelo Colliery.

The present/status quo groundwater conditions do not indicate any type of impact on the geohydrological regime. Refer to the conceptual models developed (Section 7.6) and hydrocensus (Section 5.4) and groundwater quality (Section 5.6) discussions for an additional discussion on status quo groundwater conditions.

The predicted impact on the ambient groundwater conditions is primarily associated with a deterioration of the groundwater quality underground and possibly from the overburden and RoM stockpiles on surface. During the operational phases of mining the residence time of water in the voids is expected to be minimal and therefore water quality will be non-acidic with slightly raised salinity, especially SO_4. Fluoride (F), Mn and SO_4 is expected to exceed general discharge standards and will not be allowed to discharge (to be confirmed by monitoring).

During active mining, groundwater seeping into mine voids will be dewatered to allow for safe working conditions. However, given the confining nature of the deeper aquifers where mining will take place, a substantial drawdown is not expected. The model predicted a drawdown of between 1- 5 m below steady state water levels. This drawdown will be confined to the mine boundary due to the low permeability of the aquifers. No sensitive receptors' boreholes are located within this zone of influence.

Once the project is completed, the mine will cease to pump water from underground and rehabilitation will commence. As stated previously, the risk of subsidence is rated as high during the post-operational phases. Resultant surface cracks and fractures will increase recharge into the underground voids by as much as 10%. The amount of time to fill the voids will as a result be considerably less as opposed to when no subsidence occurs. Decant is also likely to occur if water levels rise above maximum critical levels, generally 10 -15 m below decant level (1610 mamsl). Several mitigation measures are proposed in this report to mitigate the risk of decant.

Because the underground mining void acts as a sink whereby all groundwater flows toward it rather than from it, no groundwater plume is expected to migrate from the mine. Decant, polluting surface water resources and the weathered aquifer, remains the greatest risk post the operational period.

The specialist groundwater investigation relating to this study concluded and recommended the following:

- The risk of subsidence and decant occurring is rated as high post closure.
- Sealing of the adit to prevent free recharge of the adit.
- Pond formation should be prevented on surface by creating a free-draining surface through landscaping along slopes and filling of holes/fractures/cracks in flat-lying areas.
- A rehabilitation plan must be implemented, and the plan should be done in the line with the contents of National Water Act (Act No 36 of 1998) and National Environmental Management Act (Act No. 107 of 1998), to avoid subsequent negative environmental impacts that may occur.
- Commit to a zero-effluent operating principle whereby contaminated water will be prevented from entering the receiving surface water environment through actions like recycling, reuse or treatment during the short- and long-term.
- Re-establish surface drainage to the pre-mining conditions as far as practical.
- Restore normal infiltration rates to areas where recharge was reduced due to surface compaction, such as at the shaft infrastructure areas.
- Effectiveness of existing monitoring borehole positions should be re-evaluated on closure.
- Continuation of the monitoring programme to establish post closure trends.
- Groundwater levels near the mine should be monitored on a regular basis throughout and post closure phases.
- Install monitoring boreholes into different parts of the mine voids to monitor the post-closure water levels.
- Regulate water levels to below maximum critical level to prevent decant.
- The occurrence of potential groundwater seepages in the vicinity of the decline and along the ring dyke downstream of the mine should be monitored regularly and contained if necessary.
- Conduct surface inspections to ensure that surface subsidence does not occur.

- If subsidence occurs and sinkholes are formed during operation or after closure, they should be rehabilitated as soon as possible to minimise water and oxygen inflow from the surface. This will minimise or avoid oxidation reactions and potential acid generation.
- Should decanting occur, passive or active treatment plants should be considered.
- Routinely refine, update and validate the conceptual and numerical models developed in this study by incorporation of ongoing monitoring data.

A Water Management Plan is required to ensure that the infrastructure do not impact negatively on water quality to unacceptable levels. It will also serve as early warning systems to implement mitigation measures at early stages to reduce cumulative impacts. To ensure that the natural receiving environment is protected, monitoring is required on an on-going basis even during the closure phases.

Based on the findings of the geohydrological assessment, no fatal flaws have been identified that may limit the expansion activities. It is the opinion of the specialist that the proposed project may proceed on condition that all mitigation measures as outlined and discussed in this report be adhered to.

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Appendix A

Details, expertise and curriculum vitae of specialist

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TOTAL CONSULTING EXPERIENCE

11 years

AREAS OF PRACTICE

Groundwater Resource Management

Numerical Groundwater Modelling

Groundwater EIAs

Geophysical investigations

Geochemical investigations

Geochemical modelling

MRDs chemical characterisation

Waste classification

Toxicology studies

Contaminated land

Soil pollution investigations

Peer review

Environmental compliance auditing

Ground- and surface water compliance monitoring

Limnology

Potable water monitoring

CAREER SUMMARY

A professional hydrogeologist with more than 11 years of consulting experience. Ockie Scholtz has gained a wide range of expertise in groundwater resource management. He specialises in all aspects of mining and non-mining related hydrogeological studies including numerical modelling, geophysical studies and borehole siting, groundwater supply and aquifer testing, groundwater impact assessments, groundwater monitoring, site characterisations and baseline studies, fingerprinting and isotope studies. Other specialist fields include geochemistry and geochemical modelling, waste characterisation and classification (mining and non-mining), contaminated land and acid mine drainage studies as well as limnology and surface water monitoring.

Ockie Scholtz acted as substitute lecturer in Introductory Plant Biology for the Advanced Certificate in Education Programme at the University of the Free State in 2006 and was also an assistant researcher for the Centre of Environmental Management at the UFS from 2006 to 2007, where he was involved in biomonitoring and hydrochemical research and consulting. Extensive and valuable industry experience was gained during employment as Aquatic Scientist/Hydrogeologist with Clean Stream Scientific Services (currently Aquatico). There he was project leader of environmental monitoring and pollution investigations that focused on mining and other large-scale multifaceted projects including potable water, surface water, groundwater, soil, the aquatic ecosystem, dust and geo-botany.

Ockie is currently division head of Shangoni AquiScience, the hydrogeological and technical division of Shangoni Management Services (Pty) Ltd, a role he has held since 2012.

EDUCATION

Magister Scientiae in Hydrogeology, University of the Free State	2011
Bachelor of Science (Honours) course work completed and passed in Hydrogeology, University of the Free State	2010
Magister Scientiae (M.Sc) in Botany, University of the Free State	2006
Bachelor of Science (Honours) in Botany, University of the Free State	2004
Bachelor of Science in Zoology, University of the Free State	2003

PROFESSIONAL MEMBERSHIP/ASSOCIATIONS

SACNASP registered as a Water Resources Scientist, Ecologist and Botanist
Professional Member of the Groundwater Division (GWD) of the Geological Society of South Africa (GSSA)

PROFESSIONAL EXPERIENCE

Water Quality / Pollution assessments (Author and Technical Lead)

2007 – 2012

- Author and project leader of a variety of environmental monitoring reports and projects that included groundwater, surface water, potable water and soil.

2012

- Baseline Groundwater Quality and Hydrogeological Assessment in support of a Basic Environmental Impact Assessment for the Proposed Construction of eight (8) New Broiler Houses on portions 14 and 20 of the farm Klipspruit 199 IR, Delmas. Prepared for Tillado Investments.

2013

- Baseline Groundwater Quality Report prepared for DMS Powders, Project AS-DMS-MEY-13-03-07.
- Receiving Surface Water Quality Assessment for Kilbarchan Mine. Prepared for Eskom, February 2013.

2014

- Water Monitoring Programme. Compiled for Chubby Chick Poultry Rendering Facility.
- Ground- and Surface Water Quality Assessment. Compiled for Chubby Chick Rendering Facility.
- Water Monitoring Programme for Afgri Poultry Rendering Facility.
- Report on Hydrochemical Analyses and Assessment of Health and Pollution Risks Associated with a Coal Siding. Compiled for at Brazen Alger.
- Water Quality Monitoring Report for NWK Epko.
- Water Quality Monitoring Reports for NWK Optifeeds, July 2013; June 2014.
- Drinking Water Quality Assessment Report for the Kamoto Copper Company. Prepared for Katanga Mining Limited, June 2014.

2015

- Update of Water Monitoring Programme for DMS Powders.
- Ground- and Surface Water Monitoring for DMS Powders, 2015 to current.
- Baseline Surface Water Quality Assessment for Aquila Steel South Africa.
- Investigation into the Status Quo of Water Quality Verref's Elgin operations. Prepared for Vereeniging Refractories.

2016

- Groundwater Monitoring for South32, Meyerton, 2016 to current.
- Soil and Groundwater Quality Assessment. Prepared for PC Chemicals, Rosslyn Pretoria.
- Baseline Surface Water Quality Monitoring for the PRASA Construction Site in Springs, 2016-2017.

2017

- Baseline Water Quality Monitoring Report for the Polihali Western Access Road (PWAR), Lesotho. 2017-2018.
- Report on Water Quality and Related Information as Part of an Integrated Water and Waste Management

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- Groundwater Quality Snapshot at Mahikeng Landfill. Prepared for New GX.
- Potable Water Quality Monitoring for DMS Powders, 2016 to current.
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2018

- Surface and Groundwater Quality Report. Prepared for Petra Diamonds, Cullinan Mine.
- Long term Surface and Groundwater Monitoring for Black Royalty Minerals: Chilwavhusiku Colliery.

Specialist Groundwater Assessments (Author and Technical Lead)

2012

- Desktop Hydrogeological Investigation associated risks and susceptibility towards the receiving environment, Prepared for Midwest Properties, Oilkol.
- Hydrocensus and Sustainable Yield Determination of Abstraction Boreholes on Portion 10, Springbokkraal 434 IT, Mpumalanga. Prepared for Rondolog.
- Baseline Hydrogeological Study. Prepared for Petra Diamonds Sedibeng Mine.
- Borehole Yield Testing and Zone of Influence Modelling for Afgri Poultry Delmas Abattoir.
- Borehole Yield Testing, Zone of Influence Modelling and Impact Assessment for Afgri Poultry Rendering Facility.
- Borehole Yield Testing and Zone of Influence Modelling for Afgri Poultry Daybreak Abattoir.
- Specialist Groundwater Investigation Phase I: Report on the Potential Risks and the Susceptibility of Ground- and Surface Water to Pollution. Compiled for DMS Powders.
- Specialist Groundwater Investigation Phase II: Borehole Drilling at DMS Powders.
- Desktop Hydrogeological Assessment for Era Bricks Delmas as supporting documentation to the IWULA.
- Desktop Hydrogeological Assessment for Era Bricks Delmas Olifantsfontein as supporting documentation to the IWULA.
- Desktop Hydrogeological Assessment for Era Bricks Silverton as supporting documentation to the IWULA.

2013

- Specialist Groundwater Investigation Phase III: Groundwater Impact Evaluation and Proposal of an Active Monitoring Network. Prepared for DMS Powders.
- Hydrogeological Study on Portion 3 of the farm Rooykop 181to Fulfil in the Requirements of an Integrated Water Use Licence Application. Prepared for Pride Hatchery.
- Hydrogeological Study for Eagles Pride Hatchery to fulfil in the requirements of an Integrated Water Use Licence Application. Prepared for Pride Hatchery.
- Desktop Study on the Susceptibility of the Receiving Groundwater Environment to Potential Pollution Posed by Roodepoort Clay Quarry. Prepared for Ecca Holdings Refractory Minerals.
- Susceptibility of the Receiving Groundwater Environment to Potential Pollution posed by Nooitgedacht Mine. Prepared for Ecca Holdings Refractory Minerals.
- Desktop Study on the Susceptibility of the Receiving Groundwater Environment to Potential Pollution posed by Krugerspost Andalusite Mine. Prepared for Ecca Holdings Refractory Minerals.
- Hydrogeological Impact Assessment for a Proposed Open Cast Coal Mine on the farm Droogefontein portion 26. Prepared for Restigen.
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2014

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- Production Borehole Drill Log at the Afgri Poultry Delmas Abattoir.

- Specialist Hydrogeological Investigation at Greenside Colliery as input to the EMPR. Study conducted for Anglo American Thermal Coal: Greenside Colliery Thandeka Shaft Project.
- Specialist Hydrogeological Investigation for the South Block Extension Project: Landau Colliery Kromdraai Section, July 2014. Compiled to fulfil in the requirements of the Environmental Impact Assessment (EIA) and Environmental Management Programme (EMP) which forms part of the Environmental Authorisation for the Kromdraai SBE.
- Specialist Hydrogeological Investigation as input to the EMPR for the Umlalazi South Block Extension at Landau Colliery: Navigation Section.
- Borehole drilling and supervision. Prepared for Pan African Resources, Evander Gold Mines.
- Desktop Hydrogeological Study for the Hatherley Landfill Site in Tshwane. Prepared for New GX.
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2015

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- Borehole Yield Testing and Hydrogeological Desktop Study for Vosbreed Boerdery on the Farm Rensburghoop 74. Prepared for Vosbreed Boerdery.
- Hydrogeological Assessment and Numerical Groundwater Model for Cullinan Diamond Mine. Prepared for Petra Diamonds.
- Geophysical Investigations for Borehole siting in Richmond and Victoria-West districts. September 2015.
- Borehole yield testing and desktop study for Hawerklip Railway Station as part of the Water Use License Application (WUL). Compiled for Brazen Alger.
- Hydrogeological Investigation as input to the EMPR for the CAPM Orkney Gold Mine. Prepared for China African Precious Metals.

2016

- Desktop Hydrogeological Assessment for a proposed Industrial Development in the Vredenburg district of the Western Cape. Prepared for A.M. Thom.
- Specialist Hydrogeological Investigation at Goedehoop Colliery Brown 1 Shaft.
- Specialist Hydrogeological assessment for underground storage of affected water as supporting documentation for an IWWMP update and WULA a Desktop Study. Prepared for Anglo American Thermal Coal: Greenside Colliery.
- Specialist Hydrogeological Study and Risk Assessment for Anglo Operations (Pty) Ltd: Kleinkopje Colliery: Pit 2a Extension. Report compiled as supporting documentation to an EIA.
- Desktop Hydrogeological Study for Astral Mountain Valley Abattoir in order to classify and characterise the regional hydrogeology of the study area and highlight potential hydrogeological and other water quality risks associated with the poultry abattoir.
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- Report on Aquifer Testing and Numerical Flow Modelling to Determine First Estimate Sustainable Groundwater Yields and Pit Inflows. Prepared for Kibo Mining – Tanzania, Project KIB-RUK-15-05-14.
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2018

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- Hydrogeological Assessment for the Hyde Park Country Estate Development as part of the Water Use Licence Application (WULA). Prepared for Simsi Construction and Project Management.
- Technical Memorandum: Status Quo Groundwater Quality Performance versus Transport Model. Prepared for Petra Diamonds Cullinan Diamond Mine.
- Water Quality Assessment and Analytical Groundwater Drawdown Model. Prepared for Southern Proteins.
- Geophysical investigation inclusive of Resistivity, Electro-Magnetics and Magnetics for production borehole placements. Prepared for Chilwavhusiku Colliery at Rainbow Chickens, Bronkhorstspruit.

Geochemical assessments / Waste management / Contaminated land (Author and Technical Lead)

2014

- Geochemical Study: Solid Waste Assessment on Filter Dust and Slag, January 2014. Prepared for DMS Powders.
- Geochemical Study: Solid Waste Assessment on M9 Slag, M8 Dust, Ballmill Dust, Refractory and Baked Electrode Scrap. Prepared for DMS Powders.
- Geochemical Waste Assessment of a dolomite-tar mixture. Prepared for at Vereeniging Refractories Limited, Vereeniging.
- Hydrogeological and waste characterisation study as input to the IWULA for Annesley Andalusite Mine. Prepared for Rhino Minerals.
- Waste Assessment of Coal Ash stored on site at Afgri Animal Feeds Rendering Facility.
- Mine Residue Classification in support of a WUL and WML application. Prepared for Aquila Meletse Iron Ore.

2015

- Geochemical Mine Residue Classification. Prepared for Petra Diamonds Helam Diamond Mine.
- Mine Residue Geochemical Classification for Bushveld Chrome Resources to identify potential risk to health or environmental impact. Prepared for Chris Viljoen Associates.

2016

- Geochemistry and Waste Classification of No. 7 Dam Tailings Sludge. Prepared for Petra Diamonds Cullinan Mine.
- Ash Dump Classification and Waste Assessment. Compiled for Anglo American Coal SA: New Vaal Colliery in order to obtain exemption from obtaining a Waste Management Licence.
- Residue Stockpile Classification and Characterisation for Landau Colliery. Geochemical Assessment Report compiled for Anglo Operations (Pty) Ltd Landau Colliery.
- Landau Colliery: Mine residue and PCD Classification and Characterisation. compiled for Anglo Operations (Pty) Ltd Landau Colliery.

2017

- Hydrogeological Study and Waste Assessment on Foundry Slag at Olde World Foundry. Prepared for the CSIR.
- Hydrogeological study and Geochemical Waste Assessment for the Hammanskraal Fire Clay Quarry. Prepared for Vereeniging Refractories.
- SANS 10234 Classification of Kriel Colliery's Discard Rock, Waste Coal and Silt Trap Slurry. Compiled for Anglo American Inyosi Coal – Kriel in order to obtain exemption from obtaining a Waste Management Licence, August 2017.
- Waste Assessment of Coal Product Stockpile, Prepared for Canyon Coal, Hakhano Colliery.
- Waste Classification of Coal Discard & Final Pit Discard as part of an Integrated Water Use Licence Application. Prepared for Canyon Coal Hakhano Colliery.
- Geochemical Report on Waste Stream Classification and Compilation of Safety Data Sheets. Compiled for De Beers Venetia Mine.

2018

- Waste Assessment and SANS 10234 Classification on Spent Foundry Sand. Compiled for PCS Foundry.
- Technical Memorandum: Geochemical Classification and Characterisation of G Material to be used for Civil Work at Khwezela Colliery. Prepared for Anglo American Coal, Khwezela Colliery.

Other Specialist Services / Reports (Author and Technical Lead)

2013

- Soil Analysis and Fertiliser Recommendations. Prepared for Vereeniging Refractories Limited, Vereeniging, July 2013.
- Water Management Strategy for Petra Diamonds Group. Project October 2013.

2014

- Environmental Site Inspection on a former BASF Coatings Services Property. Prepared for RMB Private Bank.
- Particle Size Distribution of the Vanderkloof Dam and Orange River as part of the Design Phase of the Proposed Sidala Energy Solutions Hydroelectric Plant between Hopetown and Douglas, April 2014.

2015

- Groundwater in the Karoo: Its Occurrence and Exploration. Guest Speaker at Richmond and Victoria West Farmers' Associations, July 2015.
- Fracking for Shale Gas and Groundwater Contamination Risks, a Karoo Perspective. Guest Speaker at Richmond and Victoria West Farmers' Associations, July 2015.

2016

- Soil Quality Monitoring at Hakhano Colliery to Evaluate the Impact/s of Dust Suppression Products on the Receiving Environment. Prepared for Canyon Coal Hakhano Colliery.
- Aquifer Dependency Ecosystem Functioning Study. Prepared for Kudumane Manganese Resources.

2017

- Report on Chemical and Isotope Analyses and Origin of Water found in Underground Mine Compartments. Prepared for Petra Diamonds, Cullinan Mine.
- Baseline Soil Chemistry on Areas to be Covered by Dust Suppression at Vlakfontein Mine.
- Motivation for Exemption from applying for a Waste Management Licence for Backfilling of Discard Material, Waste Coal and Silt Trap Slurry Compiled for Anglo American Inyosi Coal – Kriel, August 2017.

Environmental Audits (Specialist)

- Kalgold Internal EMP Performance Assessment, August 2012.
- Debswana Orapa Internal Environmental Legal Audit, May 2013.
- Eskom Duvha Environmental Legal Audit, May 2013.
- BHP Middelburg Internal Water Use Licence Audit, August 2013.
- BHP Middelburg Internal EMP Performance Assessment Audit, September 2013.
- De Beers Venetia Internal EMP Performance Assessment Audit, November 2013.
- Anglo Coal Isibonelo Internal EMP Performance Assessment and Water Use Licence Audit, September 2015.
- Eskom Rotek Internal Legal Assessment Audit, October 2015.
- Anglo Coal Zibulo Internal EMP Performance Assessment and Water Use Licence Audit, November 2015.
- Anglo Coal Emalahleni Water Reclamation Plant Internal Water Use Licence Audit, November 2015.
- Anglo Coal New Vaal Colliery Internal EMP Performance Assessment and Water Use Licence Audit, January 2016.

Peer Review / Internal Reviews (Reviewer and Author)

2012

- Review of the Hydrogeological Report for Vergenoeg Mining Company: Nokeng Fluorspar Mine Hydrogeological Specialist Investigation. Compiled for Vergenoeg Mining Company.

2013

- Ecca Nooitgedacht EMP Internal Review for Shangoni Management Services, June 2013.
- Harmony Evander Gold Mine EMP Internal Review for Shangoni Management Services, June 2013.

2015

- Review: Potential groundwater related impacts associated with the operation of Oakleaf Coal Mine in Bronkhorstspruit. Compiled for Rainbow Chickens.
- Review: Comments on the Environmental Management Plan with specific reference to the Hydrogeology Report submitted by Mokale Electrical, August 2015.
- Review of The Groundwater Study for Oakleaf Investment Holdings 95 (Pty) Ltd, titled: Environmental Impact Assessment for the Proposed Development of an Open Pit Coal Mine and Associated Infrastructure near Bronkhorstspruit, Gauteng: Groundwater Assessment. Compiled for Rainbow Chickens.
- Shangoni AquiScience, 2015. Review of The Groundwater Study for Wachtenbietjeskop Colliery, Black Royalty Minerals (Pty) Ltd. Prepared for Rainbow Chickens.
- Peer Review of The Aquatic Study for Meletse Iron Ore. Prepared for Shangoni Management Services.

COURSES ATTENDED

- Environmental Risk Assessment, Monitoring and Management of Cemeteries Workshop. Groundwater Division of the Geological Society of South Africa. Presented by Dr Matthys Dippenaar (May 2018).
- From Groundwater to Mine Water – Environmental Hydrogeology in Mining (Pretoria, 2017). Presented by Dr Christian Wolkersdorfer.
- Groundwater Modelling with Modflow (Johannesburg, 2015).
- Fate and transport modelling using the Geochemist Workbench (Johannesburg, 2015).
- FeFlow modelling software training course (Johannesburg, 2013).
- GHR612 Geochemistry (completed and passed as part of the groundwater Hons curriculum at IGS, UFS, 2010). Lectured by Prof Kai Witthüser.
- GHR613 Geophysics (completed and passed as part of the groundwater Hons curriculum at IGS, UFS, 2010).

Lectured by Dr Francois Fourie and Prof Danie Vermeulen.

- GHR611 Aquifer mechanics (completed and passed as part of the groundwater Hons curriculum at IGS, UFS, 2010). Lectured by Prof Gerrit van Tonder.
- GHR621 Groundwater modelling (completed and passed as part of the groundwater Hons curriculum at IGS, UFS, 2010). Lectured by Prof Ingrid Dennis.
- GHR622 Groundwater management (completed and passed as part of the groundwater Hons curriculum at IGS, UFS, 2010). Lectured by Dr Rainier Dennis.
- First aid (Xstrata, 2011).
- Wetland delineations using Hydropedology techniques (Johan vd Waals, Johannesburg, 2010).
- Resources and Sustainability (Centre for Environmental Management UFS, 2007).
- Physical Environment (Centre for Environmental Management UFS, 2007).
- Biological Environment (Centre for Environmental Management UFS, 2007).
- Informatics (Centre for Environmental Management UFS, 2007).
- Pollution and Rehabilitation (Centre for Environmental Management UFS, 2007).

RESEARCH OUTPUTS

Publications in accredited scientific journals:

1. Scholtz O.F., Scholtz N. and Potgieter G.P. (2007). Citric acid induced phytoextraction of uranium using high biomass crop plants (in Afrikaans). The South African Journalfor Natural Sciences and Technology, Yearly 26, No1. Selected abstracts of papers – Student Symposium for Biological Sciences (Free State University, 2006), pp. 74.

2. Scholtz O.F. and Potgieter G.P. 2008. An overview: Phytoextraction as rehabilitation strategy for metal polluted soils. Navors. nas. Mus., Bloemfontein 24(6): 49-60.

Peer reviewed conference publications:

1. Scholtz N., Scholtz O.F. and Potgieter G.P. (2005). Potential environmental impact resulting from inadequate remediation of uranium mining in the Karoo Uranium Province. In: Uranium in the Environment. Mining Impact and consequences, B.J. Merkel and A. Hasche-Berger (Eds.). Springer-verlag, The Netherlands, 801-811.

National conferences/symposiums:

1. Scholtz O.F., Scholtz N. and Potgieter G.P. (2010). An environmentally safe and cost effective technology to remove uranium from soil: Prospects for the future? Uranium Mini Conference. Geological Society of Namibia, Windhoek.

2. Scholtz O.F., Scholtz N. and Potgieter G.P. (2007). Phytoremediation of metal contaminated soils in the Karoo Uranium Province. Guest speaker: Mining, Explorationand Advances in Interdisciplinary Sciences in Southern Africa, Bloemfontein.

3. Scholtz O.F. and Potgieter G.P. (2005). Heavy metal contamination of the central Karoo district. South African Association of Botany congress, Bloemfontein.

4. Scholtz N. and Scholtz O.F. (2005). Potential environmental impact resulting from inadequate remediation of uranium mining in the Karoo Uranium Province. Fourth Annual Meeting of the Geological Society of South

Africa, Durban.

5. Scholtz O.F. and Potgieter G.P. (2004). An investigation into possible heavy metal contamination of the central Karoo district. Plant Sciences Post-graduate Symposium, University of Johannesburg.

Poster Presentations:

1. Scholtz O.F., Scholtz N. and Potgieter G.P. (2006). Citric acid induced phytoextraction of uranium using high biomass crop plants (in Afrikaans). Yearly Congress of theDepartment Biological Sciences, Bloemfontein, South Africa.

2. Scholtz O.F., Scholtz N. and Potgieter G.P. (2006). Phytoremediation prospects for uranium contaminated soils in the Karoo Uranium Province, South Africa. Geological Society of South Africa, Mozambique.

3. Scholtz N., Scholtz O.F. and Potgieter G.P. (2006). Identification of uranium and molybdenum indicator plants in the Karoo Uranium Province, South Africa. Geological Society of South Africa, Mozambique.

4. Scholtz N. and Scholtz O.F. (2005). Potential environmental impact resulting from inadequate remediation of uranium mining in the Karoo Uranium Province. Uranium Mining and Geohydrology, Germany.

Other presentations:

1. Guest speaker: Mining, Exploration and Advances in Interdisciplinary Sciences in Southern Africa, Bloemfontein (2007).

2. Guest speaker at Victoria West Farmers Union (2014). Groundwater in the Karoo: Its Occurrence and Exploration (2014).

3. Guest speaker at Victoria West Farmers Union (2014): Fracking for Shale Gas: a Karoo Perspective on Groundwater.

4. Guest speaker at Richmond Farmers Union (2014). Groundwater in the Karoo: Its Occurrence and Exploration (2014).

5. Guest speaker at Richmond Farmers Union (2014): Fracking for Shale Gas:a Karoo Perspective on Groundwater.