VLAKVARKFONTEIN Colliery
Pillar Mining Project:

Groundwater
Impact Assessment

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Executive Summary

Ntshovelo Mining Resources (Pty) Ltd will apply for the mining right to the remaining coal of the Vlakvarkfontein coal resource. The project entails the extraction of unmined Seam-2 and Seam-4 pillars, and remaining roof/floor coal from the old Arbour Colliery where mining ceased in the 1940s. The proposed mining area (referred to as the "VVF-Pillar Pit" in this report) is located adjacent/west of the current Vlakvarkfontein Coal Mine pit ("VVF-Current Pit"), which has been operational for more than seven years. A coal processing plant is also envisaged for the project. The only other mining in the Vlakvarkfontein coal resource is by *Wescoal Pty Ltd*, to the south of the proposed VVF-Pillar Pit, and southwest of the VVF-Current Pit, is nearing completion.

The hydrogeology of the study area has been studied in detailed since 2009. Three important numerical groundwater flow and contaminant transport modelling studies have been performed. During each study, detailed geochemical laboratory testing and geochemical trend modelling were performed, to predict long-term post-mining mine water quality trends.

Prior to the commencement of mining in 2010 the area represented an impacted groundwater environment where historical opencast and underground mining had resulted in contaminated water contained in the old workings. Acid mine drainage seepages prevailed to the south toward the Klipspruit.

The most important aspects considered in this study were 1) post-mining decant, 2) where to place coal discard, and 3) the potential impacts on external groundwater users' drinking water. These aspects were investigated through numerical groundwater modelling.

There is a clear advantage in placing coal discard into the VVF-Pillar Pit below the long-term in-pit mine water level. If a discard dump is placed on surface, it will require decant management measures, including engineered liner and capping systems. Toe seepages at the discard dump is expected to have sulphate concentrations >5000mg/L over the long-term problem. This will have to be managed. The proposed alternative of placing discard back into the pillar area below the long-term in-pit water table, will generate slightly higher in sulphate concentrations (2000mg/L to 1700mg/L; i.e. 300mg/L difference) over the first 30years, where after the difference will be smaller.

The south-eastern corner of the *Wescoal* pit will form the main decant zone. If the barrier pillar between the Wescoal pit and the VVF-Pillar Pit is mined, the in-pit groundwater level will be at least 5m lower, and more water will decant at the mentioned main decant area. The applicable modelling scenario assumed that if discard is placed back into the pit, when the pillar is mined, if there will be enough space, sufficiently deep, below the long-term in-pit mine water level.

VVF-Pillar Pit mining will impact on the local village groundwater supply through dewatering of the local aquifers. Over the long-term, a groundwater contamination plume is likely to spread in the direction of the village. By mining the barrier pillar with *Wescoal* along the southern boundary of the VVF-Pillar Pit, the potential contamination impact on the local village can be reduced (the reason being that the final in-pit mine water level will be lower than if the pillar remains, because the decant elevation at the *Wescoal* pit boundary is lower – thus the driving mechanism for the contamination plume to the north, will be reduced). A decision in this regard will have to be taken soon after the commencement of mining of the VVF-Pillar Pit.

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1. INTRODUCTION

1.1. Background

After *Ntshovelo Mining Resources (Pty) Ltd* determined the technical and financial viability to recover coal from the old underground mining areas at Vlakvarkfontein Colliery, a decision was taken to apply for the mining right to this resource. The project entails the extraction of unmined Seam-2 and Seam-4 pillars, and remaining roof/floor coal from the old Arbour Colliery where mining stopped in the 1940s. See Figures 1.1 and 1.2.

The proposed pit will include Seam-2 and Seam-4 coal resources to the west (bounded by Dwyka outcrops), south (boundary with *Wescoal* mining), east (border with current Vlakvarkfontein pit, where infrastructure development commenced in 2010), and north (Arbour informal settlement).

Groundwater Square became involved in the project during mid-2016, through attending various planning meetings at Vlakvarkfontein Colliery and discussions with *ECMA Consulting (Pty) Ltd* and *Geo Soil Water (Pty) Ltd*.

As part feasibility (Phase-1 investigation), *Groundwater Square* provided a report in March 2017, with the following objectives:

- Determine the water volume in underground workings;
- Understand the coal seam elevation thicknesses, depth, dip, quality, etc.;
- Identify the main groundwater risks;
- Liaise with the project team on mining & rehabilitation approaches and mitigation measures.

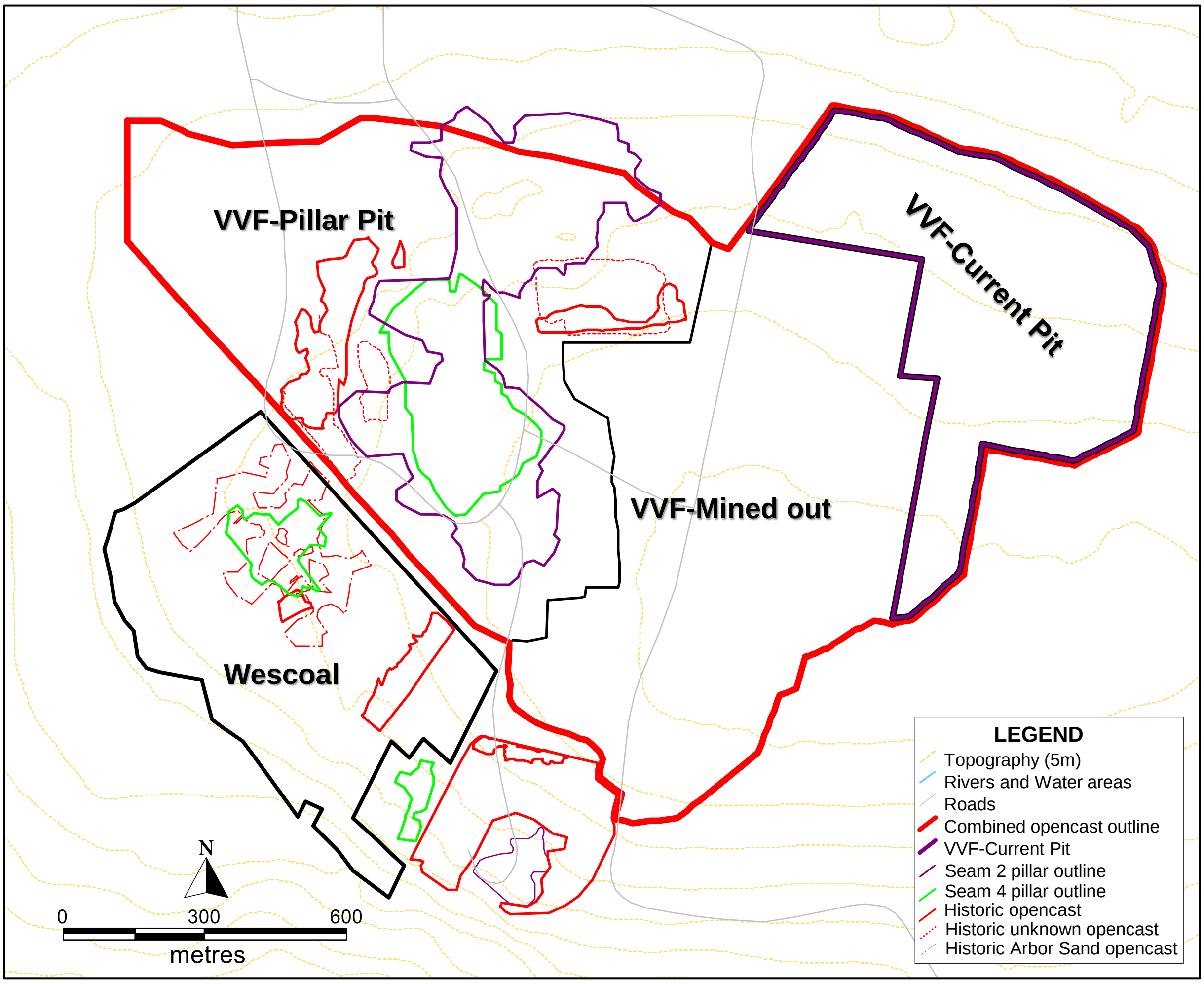


Figure 1.1 ***Vlakvarkfontein Colliery, indicating current mining in the VVF-Current Pit, proposed mining of the VVF-Pillar Pit and neighbouring Wescoal mining***

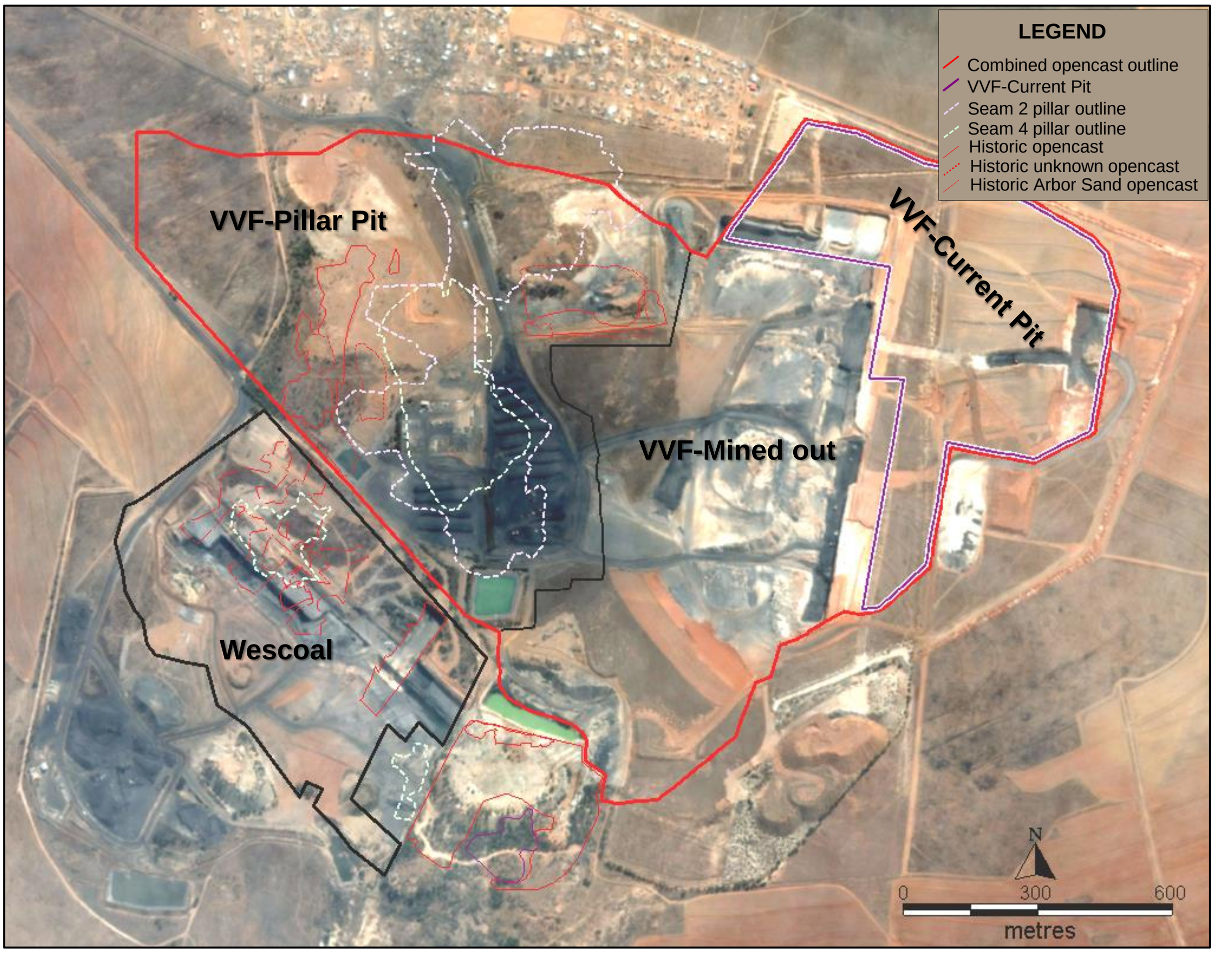


Figure 1.2 Vlakvarkfontein Colliery, layout depicted against Google Earth aerial photograph (Aug 2016)

This report constitutes Phase 2 of the project (impact assessment), with the following main objectives:

- Perform long-term post-mining decant scenario(s) of the mining complex (i.e. all mining by Vlakvarkfontein and its neighbours);
- Verify the potential long-term decant locations (and associated volumes and quality);
- Determine long-term post-mining interaction with neighbours;
- Incorporate latest geochemical assessment;
- Evaluate long-term post-mining impact mitigation measures;
- Provide input on water volumes for the operational water balance and water storage.

A distinction is drawn between the current mining area (referred to as "VVF-Current Pit") and the proposed pillar mining area (referred to as "VVF-Pillar Pit"). The VVF-Current Pit and VVF-Pillar Pit will eventually form one opencast. The two pits are indicated in Figures 1.1 and 1.2. The neighbouring *Wescoal* mining is located to the south-west, downstream of the VVF-Pillar Pit. This was originally intended as two separate pits (two different mining companies), but *Wescoal* has been mining it as one unit.

1.2. Historical Mining and Life-of-mine (LOM) Plan

The following serve as background to the groundwater impact assessments:

- Historic mining (see Figures 1.3 to 1.6):
  - Opencast and underground mining date back to the 1940's;
  - More-recently – seemingly for a period of a few years, until 1992 – sand and coal mining took place, leaving 3 open pits;

  - DWAF rehabilitated a major slot of Seam-2 and Seam-4 mining in the western coal reserve during 2005-2006 (Figures 1.3 & 1.6 depict the situation prior to this rehabilitation);
  - The site layout against aerial photo backdrop (dating back to the 1990's) is included as Figure 1.3. The disturbed surface areas and open pits are clearly distinguishable;
- Infrastructure development of the Vlakvarkfontein Mine commenced during early 2010;
- According to the 2013 mine plan of the VVF-Current Pit – prior to targeting the pillar area – the design (Ref: *GEMECS* and *ECMA Consulting*, 2013) was for a 134ha pit:
  - The deepest coal (Seam-2) determined the pit size, because the Seam-4 was not present over the entire pit;
  - Assuming that all historical mining is known, a 70m wide barrier pillar currently separates the opencast from historical underground mining to the west (i.e. the barrier between the VVF-Current Pit and pillar area, which is now the target for this investigation);
  - A 9m wide barrier pillar separates the VVF-Current Pit opencast from historical opencast mining to the south at the closest point, but is 35m wide on the western side of the southern border;
- Mine access and progression for the VVF-Current Pit:
  - A Box-cut was constructed in the centre-west;
  - Mining then progressed eastward along a west-east-cut;
  - The current mining strategy is to mine along a north-south direction (topsoil-, subsoil-, and overburden stripping can be seen in Figure 1.2), progressing eastward; with additional mining in the eastern and northern portions of the reserve;
  - The mine layout is continually being revised based on additional geological exploration drilling, and economically viable coal (the aerial photo backdrop in Figure 1.2 is ±1year old).

Prior to the commencement of mining of the VVF-Current Pit, mine water had always collected in opencasts as can be seen in both old and recent aerial photographs (see Figures 1.3, 1.5 and 1.6). Drilling and physical observations concluded that historical underground areas in the centre of the area, directly west of VVF were flooded. Historical underground areas south of VVF were partially flooded, and the water quality was most-likely influenced by oxygen ingress. Prior to mining, decant was observed along a wide front, south of VVF, south of the historical opencast/underground areas in the south. It was however possible to distinguish between two main areas of decant (see Figures 1.5 and 1.6):

- Main-decant-zone-east (south of VVF-Current Pit):
  - Located directly south of VVF-Current Pit where historical opencast mining and Seam-2 underground mining by Sterling-TVL was undertaken;
  - Due to the opencast-mining by VVF from 2010, the first decant area dried up within two years;
- Main-decant-zone-west (south of VVF-Pillar Pit):
  - Located between poplar trees, west of Main-decant-zone-east, south of historical opencast and Seam-4 underground mining by Sterling-TVL;
  - The second decant area formed due to the small section of historical shallow Seam-4 underground mining along the south-eastern portion of the Wescoal pit (adjacent to VVF). This underground was very shallow such that the soil profile did not form any barrier to seepages from the underground. Directly to the north of the underground the unrehabilitated opencast pit contained water which contributed to the underground workings water balance (and possibly some water from the historic section south of VVF);
  - Due to the mining by Wescoal (commenced mining in April 2013), the second decant area dried up.

  (The image interpretation included as Figure 1.6, is an Aster satellite image of 2002, with highlighted channels 3 (red), 1 (green) and 9 (blue)).

The local village can be seen in aerial photographs in Figures 1.2, 1.3, 1.4, 1.6, 1.7, 4.1 and 4.4 (also an indication of its expansion from only a few houses, over the past 8years).

Additional information is provided in Section 4.1 (Desktop Study).

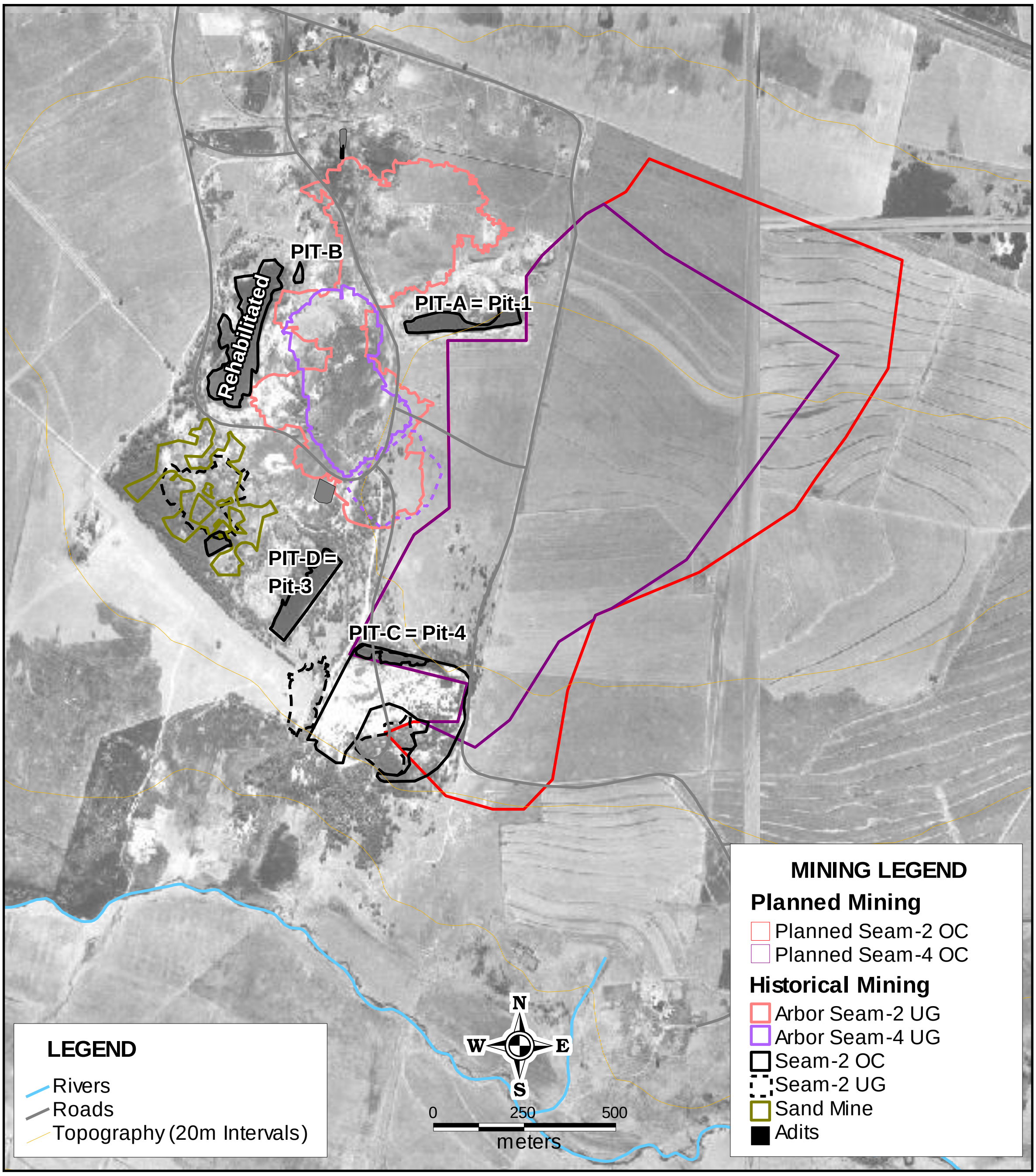


Figure 1.3 Vlakvarkfontein 2009 mine design and historical mining, depicted against 1990's aerial photo backdrop

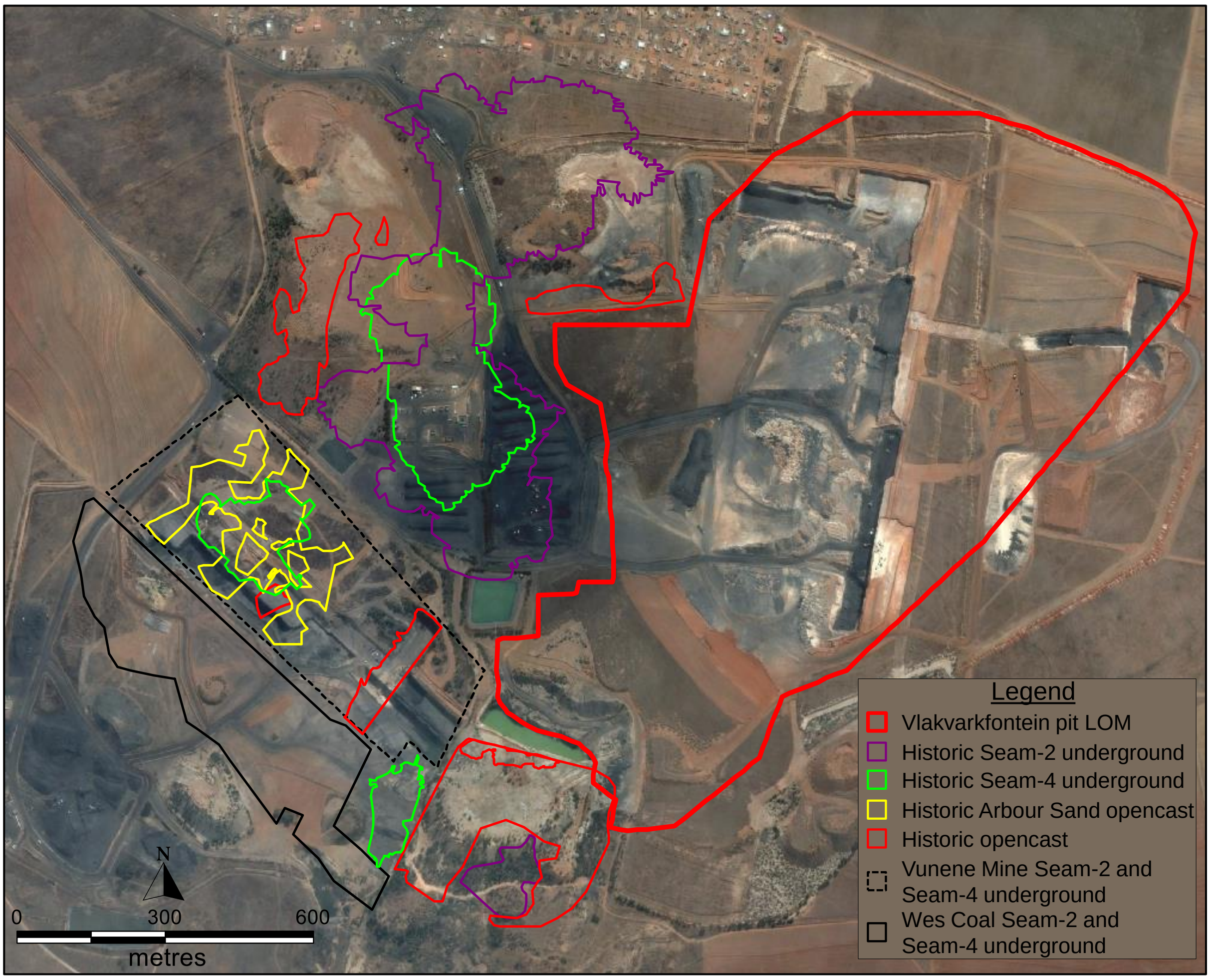


Figure 1.4 Vlakvarkfontein 2013 mine design and historical mining, depicted against 2013 aerial photo backdrop

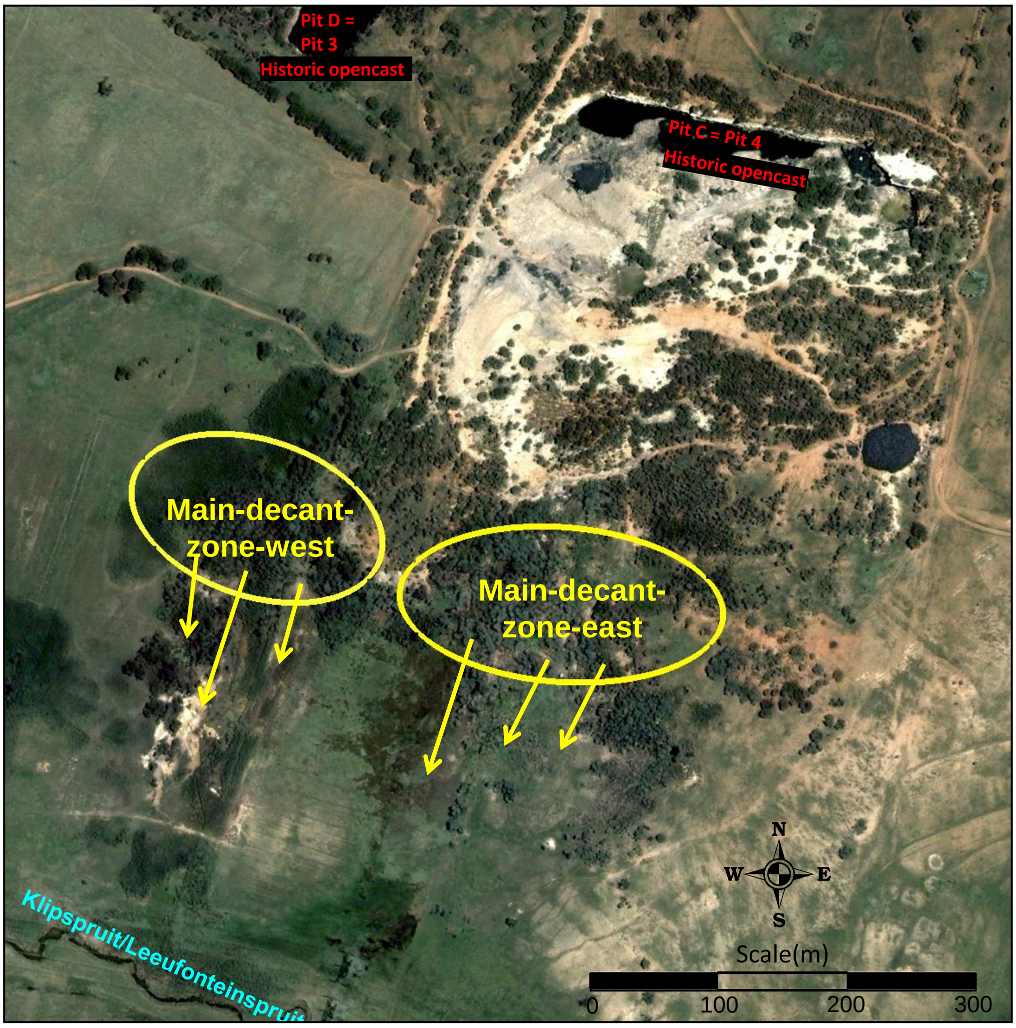


Figure 1.5 Main decant zone prior to VVF mining, 2009

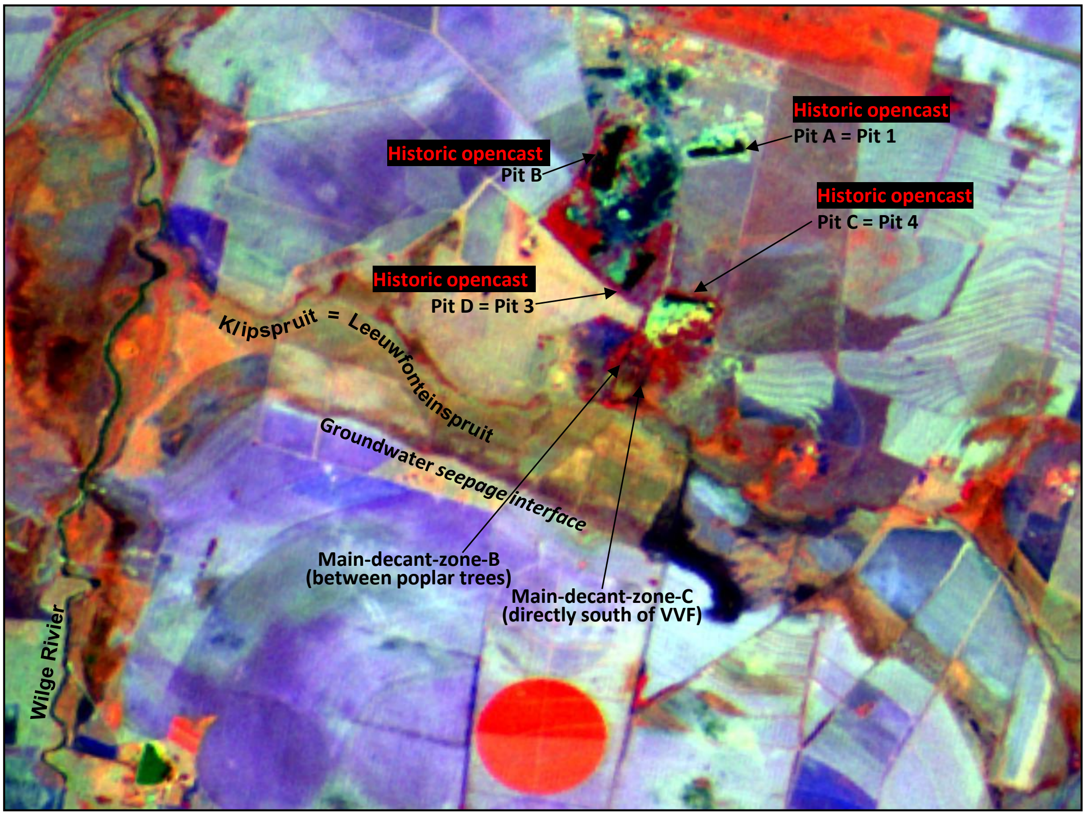


Figure 1.6 Satellite Main decant zone prior to VVF mining, 2009

1.3. Life-of-Mine (LOM) Plan

The LOM plan for the VVF-Current Pit and the VVF-Pillar Pit are indicated in Figure 1.7.

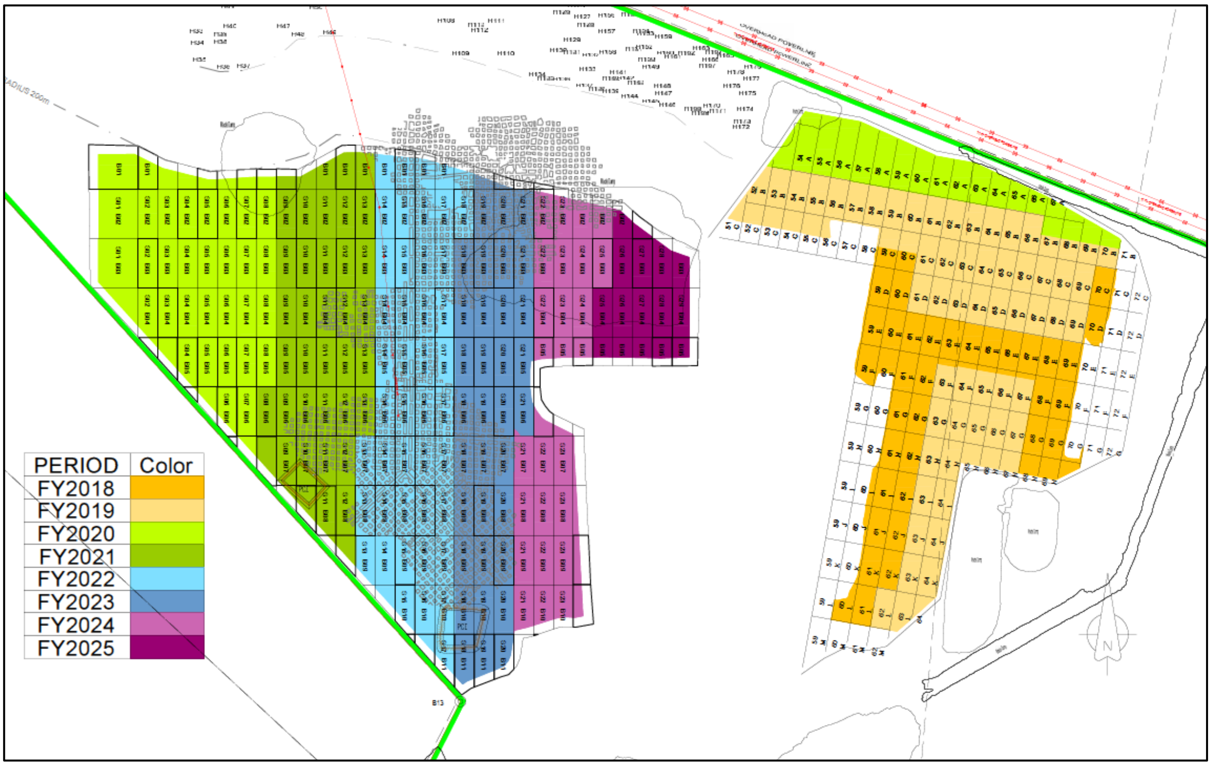


Figure 1.7 ***Seam-2 LOM mine plan for both the VVF-Current Pit and the VVF-Pillar Pit (Ref: ECMA, Sept 2017. LOM_06S2COAL_E-W.pdf)***

2. GEOGRAPHICAL SETTING

2.1. Topography and Drainage

As can be seen in Figure 2.1, pre-mining topographical elevations range between 1480mamsl and 1570mamsl. The lowest elevation on the mining area is 1538mamsl.

The natural topographical slope is relatively flat (2%) on the highest elevations. The topographical slope steepens toward the river system. Near the Klipspruit (also known as the Leeuwfonteinspruit) in the south, the topographical slope exceeds 10%. Due to the steepening topographical gradient in the south, the topographical elevations along the pit perimeter are significantly higher than the elevations 50m downstream.

Steeper topographical gradients downstream of the mining area, historically resulted in the formation of decant zones, which will again be important during the post-mining situation. Although the pillar project area is located on relatively flat surface, and above the historical decant zones, it will eventually be interconnected with the VVF-Current Pit, thus also contributing to this pit water balance (and potentially to the south to the Wescoal mining area).

The lowest surface topography to the west and south, is the main limiting factor for the extent of the coal resource.

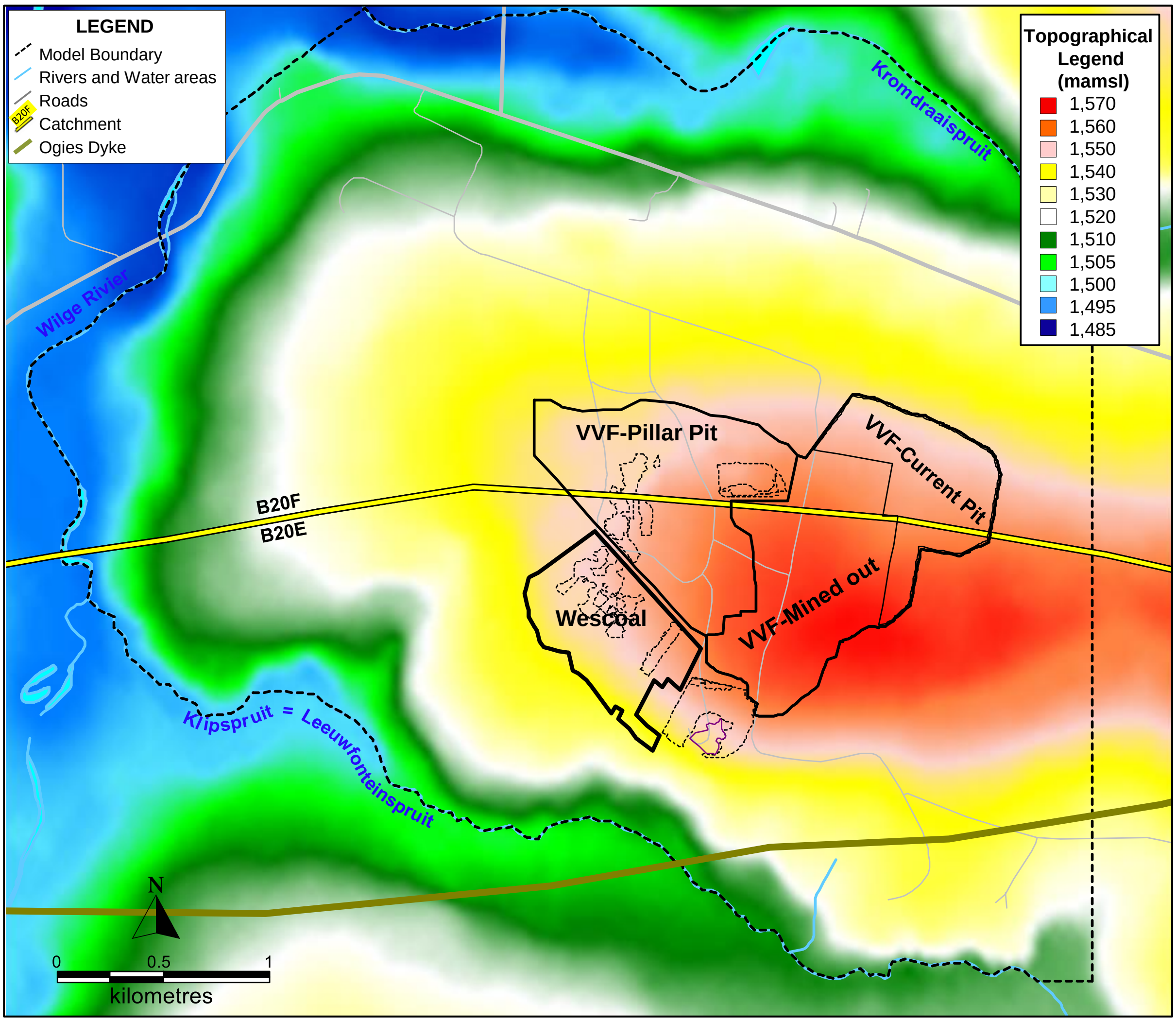


Figure 2.1 Vlakvarkfontein mining depicted against thematic depiction of regional surface topography (also indicating local river system)

The Vlakvarkfontein reserve is situated on the regional water divide of Quaternary catchments B20F (north) and B20E (south), with natural drainage primarily to the north and south in the VVF-Current Pit area, and also drainage to the west from the VVF-Pillar Pit area.

The local rivers are indicated in Figures 1.2 and 2.1. The reserve is bounded to the south by the west-flowing Klipspruit (also known as the Leeuwfonteinspruit, 6km downstream of Leeuwfontein Coal Mine and Stuart Colliery). Coinciding with the Klipspruit's intersection of the reserve is the west-east orientated Ogies dyke. To the north (north of R555), the area is bounded by a tributary of the Wilge River (west flowing, downstream of Kendal Power Station). This tributary is locally referred to as the Kromdraaispruit. Both streams flow into the north-flowing Wilge River. The three streams/rivers are situated respectively 700m to the south, 1.4km to the north and 3km to the west.

2.2. Climate

According to the WRC (1994) the proposed Vlakvarkfontein Mine is situated in quaternary catchments B20F and B20E, both with Mean Annual Precipitation (MAP) of 670mm/a. It is bounded by quaternary catchments B20C (MAP=675mm/a), B20A (MAP=661mm/a), B20G (MAP=669) and B11F (MAP=692). According to the data retrieved from the South African Weather Bureau Services (Stations: Delmas-Vlakplaas, Delmas-Witklip and Ogies) a Mean Annual Precipitation of 700mm/a prevailed over the past 50years.

Consequently, a MAP of 700mm/a applied to all relevant calculations in this study.

According to the WRC (1994), the mean annual evaporation varies between 1600mm/a and 1700mm/a.

3. SCOPE OF WORK

Given the requirement for a groundwater impact assessment report, in support of the mining license application and update to the water use license (WUL), this groundwater impact assessment report was compiled. In view of ongoing monitoring by *LWES* (2017) and previous groundwater impact assessments by *Groundwater Square* a small field work component was required.

Water was sampled from dedicated boreholes into underground workings (existing monitoring and exploration drilling).

Although the impact assessment could be based upon previous geochemical work, it was advisable that the unique geochemical properties of the pillar area (due to historical mining) be studied to a sufficient level of detail, to predict long-term geochemical trends. A selection of coal samples (from the exploration phase) was submitted for geochemical testing. Given the previous detailed geochemical evaluations of 2009 and 2013, and the additional work for this report, the geochemical study was comprehensive.

The following terms of reference applied to the project:

- Attend start-up meetings, site visits and workshops;
- Collect data relevant to the study, including:
  - Geology;
  - Geometry (XYZ) of coal seam floors;
  - Current and LOM mine layouts;
  - Relevant site information from visual inspection and discussions;
- Computerise/analyse/interpret data;
  - Interpret/describe aquifer conditions/hydraulic attributes;
- Review project objectives and modelling scenarios, and discuss with Mine Management;
- Perform geochemical assessment:
  - Collect overburden, coal, discard samples for laboratory analyses (from exploration drilling);
  - Perform laboratory testing (inclusive of XRD/XRF/ABA/NAG/%S);
  - Evaluate potential for AMD;
  - Perform oxygen diffusion and geochemical trend numerical modelling to determine the expected long-term variations in mine water quality;
- Perform groundwater modelling assessment:
  - Compile conceptual model of groundwater movement;
  - Compile and calibrate detailed numerical 3D model(s) to quantify/assess individual impacts on groundwater flow and volumes;
  - Incorporate geochemical assessment data in numerical models, to enable prediction of contaminant movement;
- Groundwater impact calculations:
  - Identify and describe mining related impacts on the groundwater situation;
  - Calculate impacts on the groundwater situation with available information, analytical equations and numerical modelling;
  - Ensure that cumulative aspects relating to the nearby existing/historical/new mining are addressed;
- Provide guidance on:
  - Water monitoring;
  - Mitigation measures;
- Interact with project team and provide feedback;
- Compile report.

A waste classification study was compiled by another consultant.

Disclaimer – The current state of hydrogeological knowledge was presented as accurately as possible using available information and new information generated during the exploration and groundwater data gathering phases. *Groundwater Square* exercised due care and diligence in gathering and evaluating relevant information. *Groundwater Square* will not accept any liability in the event of encountering unexpected aquifer conditions during mining or additional groundwater studies. Any unauthorized dissemination or reuse of the groundwater specialist impact assessment report will be at the user's sole risk and with the condition that *Groundwater Square* will not accept any liability for any and all claims for losses or damages and expenses arising out of or resulting from such unauthorized disclosure or reuse.

4. METHODOLOGY

The groundwater impact assessment relied primarily on numerical groundwater modelling, supplemented by spreadsheet calculations, geochemical laboratory testing and modelling. The basis of these assessments, were field studies at Vlakvarkfontein over the past decade by *Groundwater Square*, including hydrocensus, hydrogeological drilling, geophysical surveys, pump testing and groundwater monitoring.

The original numerical groundwater flow and transport model were compiled in 2009. The model was reconstructed in 2013 for an updated groundwater impact assessment. The numerical model grid was further refined/ adapted for this impact assessment, to provide for the latest life of mine (LOM) plan, and interpretation of *Wescoal* mining along the south-western region of the coal resource.

It was important to update the geochemical evaluation to be representative of the proposed VVF-Pillar Pit. A relatively detailed geochemical assessment was originally performed in 2009, and then updated in 2013. For this study, it was again updated with information from the proposed pillar mining area. In all three instances, static testing and kinetic column leach testing were performed. In each instance, numerical geochemical modelling was performed to simulate mine water quality trends for various geochemical conditions (e.g. thickness of unsaturated zone, time for areas to flood, percentage discard in backfill material, etc.). Given the number of geological samples (see Section 4.6) the geochemical evaluation represents a detailed evaluation, representative of the whole resource area.

Recommendations in this report took cognizance of *DWS* best practice guidelines.

4.1. Desk Study

This desk study contains information from the recent Phase-1 feasibility study (Ref: GW2_069d(feas), June 2017) as well as previous groundwater impact assessment and monitoring reports by *Groundwater Square* since 2009 (e.g. Ref: GW2_069, 2009; Ref: GW2_069b, 2013; Ref: GW2_202, 2011/2012/2013).

Historical mining during the 1940s and early 1990s are described in Section 1.2. Formal mining of the Vlakvarkfontein resource since 2010 and the life-of-mine (LOM) plan are discussed in Section 1.3.

The following relates to decant of contaminated mine water to the south of VVF, prior to mining of the VVF-Current Pit:

- As far as could be determined, mine water always collected in opencast pits as can be seen in both old and recent aerial photographs;
- Drilling and physical observations established that:
    - Historical underground areas in the centre of the area, directly west of VVF, were flooded;
    - Historical underground areas south of VVF, were partially flooded (prior to mining by *Wescoal*) and the water quality was most-likely influence by oxygen ingress;
- Prior to mining of the VVF-Current Pit, decant was observed along a wide front, south of VVF, south of the historical opencast/underground areas in the south. It was however possible to distinguish between 2 main areas of decant (see Figures 1.3 and 1.4):
    - Main-decant-zone-east – directly south of VVF where historical opencast mining and Seam-2 underground mining by Sterling-TVL was undertaken;
    - Main-decant-zone-west – between poplar trees, west of Main-decant-zone-east, south of historical opencast (not yet back-filled, containing water) and Seam-4 underground mining by Sterling-TVL was undertaken;
    - The image interpretation included as Figure 1.6, is an Aster satellite image of 2002, with highlighted channels 3 (red), 1 (green) and 9 (blue);
    - Additional information on the 2 decant areas are provided in Sections 1 and 7.

In addition to the information sharing that occurred during several project meetings between July 2016 and February 2017, basic information on exploration boreholes (location, depth, intersection of historic underground workings, etc.) and the geological model, was provided by *CCIC*.

During the drilling phase, *Groundwater Square* visited exploration boreholes as summarised in Table 4.1 and indicated in Figures 4.1 and 4.2. Where possible, the water column in exploration boreholes were profiled in terms of electrical conductivity (EC), followed by water sampling (i.e. where possible, mine water was sampled). Water quality information is attached as Appendix 2.

Table 4.1 Pertinent groundwater information from exploration boreholes

Borehole ID	Hole depth (m)		Groundwater						Seam-2	
	Measured	Drilled	Level (m)	Elevation (mamsl)	Sample depth (m)	Quality			Top	Bot
						pH	EC (mS/m)	SO4 (mg/L)		
VVN16-01	9.14	18.63	5.91	1539.1						
VVN16-02	13	15.83	4.31	1541.7	No					
VVN16-010	30.45	30.93	9.96	1541.0	No	4.6	110	662	11.4	14.0
VVN16-013	28.51	29.43	13.59	1539.4	27	6.6	61	291		
VVN16-014	34.4	34.40	15.03	1540.5	30	5.4	118	613		
VVN16-015 (17m)					17	3.0	233	882		
VVN16-015 (30m)	31.2	35.43	14.95	1540.0	30	3.0	280	1346		
VVN16-016	27.5	30.85	12.63	1540.4	26.3	5.3	167	1094	21.7	
VVN16-017		27.86	13.6	1539.4	23	5.8	100	604		

Table 4.2 Geochemical samples collected from exploration boreholes

Borehole ID	Sample depth (m)		Description
	From	To	
VVN16-010	14.73	15.29	Sandstone
VVN16-010	18.02	18.40	Shale
VVN16-010	21.03	21.41	Shale
VVN16-010	21.69	21.93	
VVN16-010	21.93		Full Seam-2
VVN16-010	28.38	28.70	Seam-2 Floor
VVN16-016	18.15	18.85	Shale
VVN16-016	18.95	19.35	
VVN16-016	20.98	21.68	Seam-2 Roof
VVN16-016	21.68	24.85	Seam-2

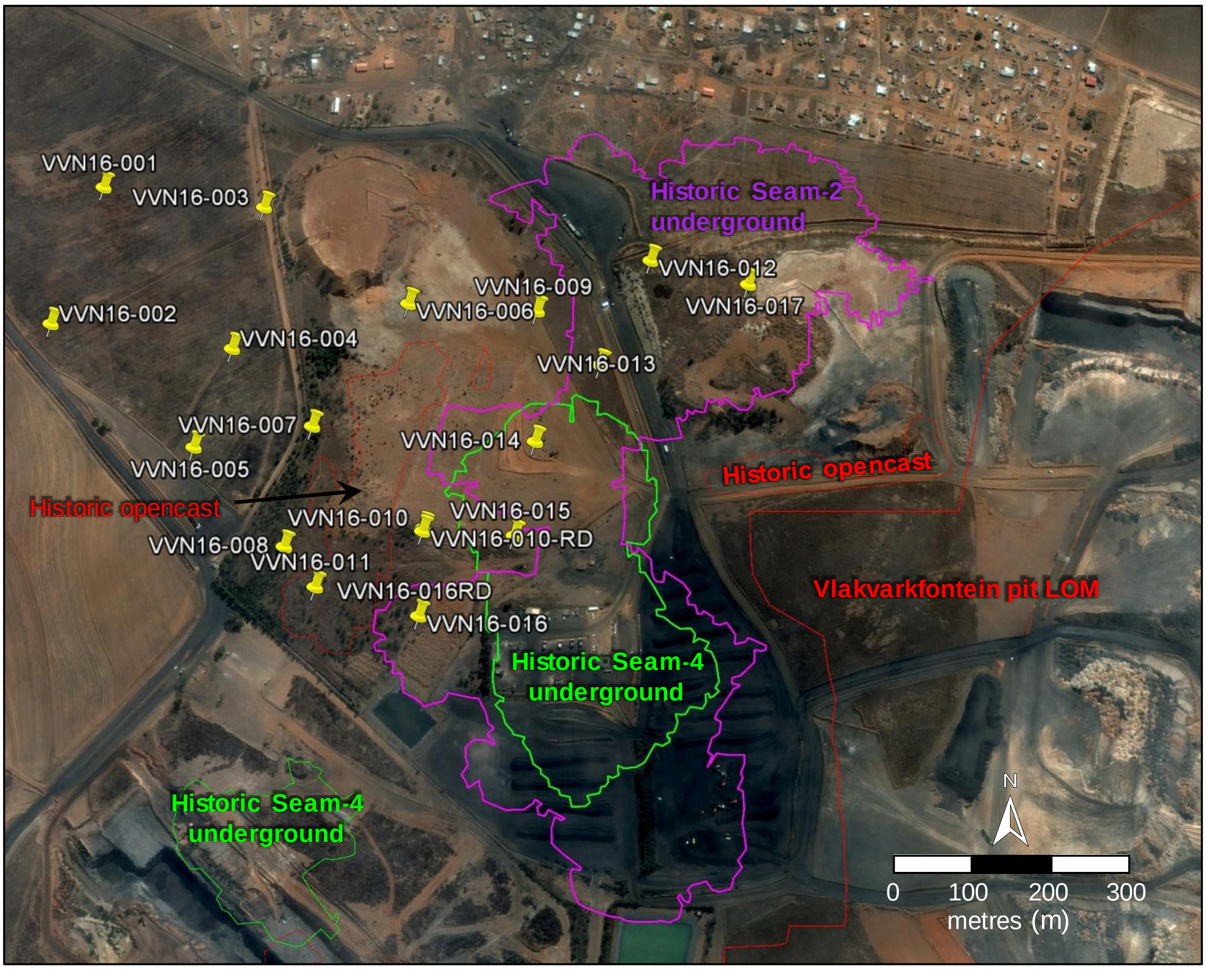


Figure 4.1 Vlakvarkfontein mining depicted against August 2016 aerial photo backdrop, also indicating exploration borehole localities in relation to mining

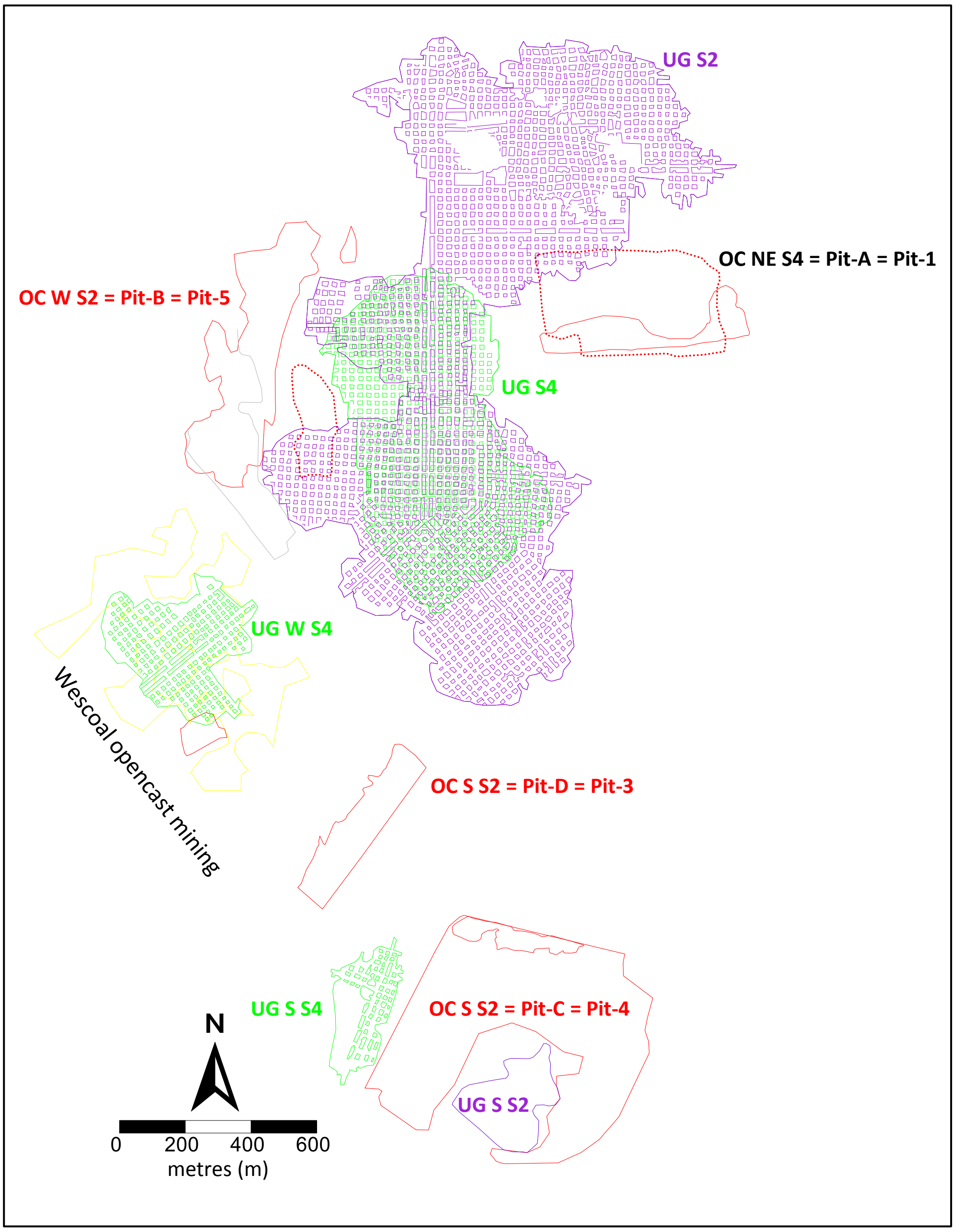


Figure 4.2 Historical underground and opencast mining units for which water volumes were calculated in Table 4.1

Based on discussions with *ECMA* and *CCIC*, it is believed that historic mining of the Seam-4 and Seam-2, dating back to the 1940's, probably targeted a horizon, which, in many cases, did not necessarily include the best coal. It is unlikely that the "select" seam was targeted in its entirety. Coal remained in the roof to provide roof support (due to shallow mining, roof collapses may have occurred otherwise) and that is in most cases the best Seam-2 coal. Irrespective of coal thickness, it would have been rare for the mining height to exceed 2.5m. Exploration drilling results by *CCIC* provided evidence to suggest that the unmined portion of the coal seams were always located in the roof (which does not suggest that the "select" section of the Seam-2 was mined).

In the pillar area, coal Seam-2 contours vary by 8m to 10 m over approximately 1km, compared to the surface topography which ranges by approximately 13m. The deepest coal seams occur in the central region of the historic Seem-2 underground working and in the extreme southeast; i.e. the Seam 2 coal floor slopes from both the north and south, to the central region, with a small portion of lower lying coal in the south-east. The surface topography primarily slopes to the west and northwest.

Inter-mine flow between the historic underground Seam-4 and Seam-2 workings and neighbouring opencasts to the east (VVF-Current Pit) and south (Wescoal), is probably relatively small for the current dewatered mining situation.

Measured groundwater levels in exploration boreholes indicated that the Seam-2 underground workings are flooded, but that the Seam-4 workings are probably 80% to 90% flooded. This was deduced by considering the mine water elevations (as partially reflected by the groundwater level in exploration holes), which varied between 1539.5mamsl and 1540.5mamsl, compared to the maximum height of the Seam-4 coal floor of 1541mamsl (i.e. roof elevation of ±1543.5mamsl).

It was estimated that between 160,000m^3 to 180,000m^3 water is contained in the Seam-4 workings and 584,000m^3 in the Seam-2 workings.

The current pre-mining mine water level is ≥8m lower than the potential decant points of the VVF-Pillar Pit. Mine water volumes were calculated for the historic opencast and underground mining areas indicated in Figure 4.3 and Table 4.3.

Table 4.3 Summary of mine water volumes contained in historical opencast and underground mining units – see location of mining units in Figure 4.2

Name on map	Historic mining unit	Area (m^2)	Space/void (ratio)	Mining height (m)	Storage capacity (m^3)
UG S2	Seam-2 underground	311 500	0.75	2.5	584 000
UG S4	Seam-4 underground	106 500	0.75	2.5	200 000 *
OC NE S4 = Pit-A = Pit-1	Opencast northeast, Seam-4 mined; also known as Pit-A or Pit-1	40 600	0.20	20	162 000
OC W S2 = Pit-5 = Pit-B	Opencast west, Seam-2 mined; also known as Pit-B or Pit-5	36 400	0.20	20	146 000
UG W S4	Underground west, Seam-4 mined	31 540	0.75	2.5	59 000
OC S S2 = Pit-D = Pit-3	Opencast south, Seam-2 mined; also known as Pit-D or Pit-3	15 000	0.20	8	24 000
OC S S2 = Pit-C = Pit-4	Opencast south, Seam-2 mined; also known as Pit-C or Pit-4	Located adjacent to historical decant zone in the south.			
UG S S2	Seam-2 underground				
UG S S4	Underground south, Seam-4 mined	Mined by *Wescoal*			

* Maximum volume; workings are likely to be 80% to 90% flooded.

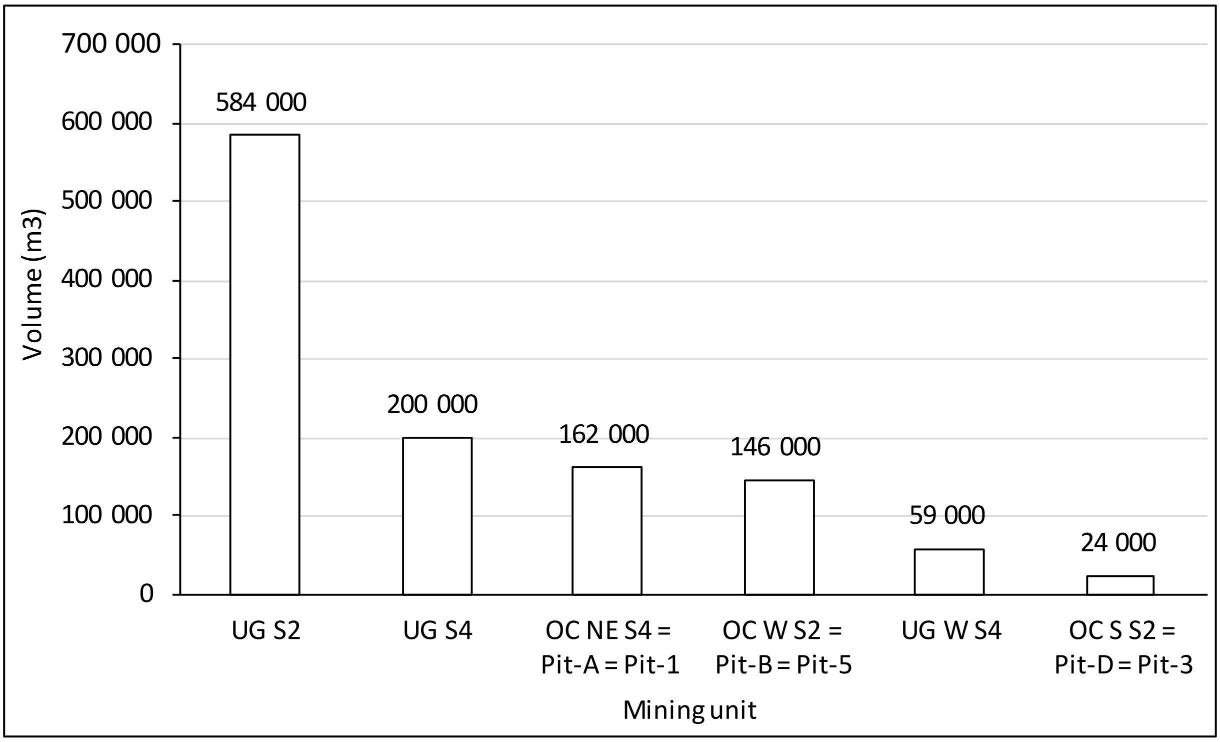


Figure 4.3 Summary of mine water volumes contained in historical opencast and underground mining units – see location of mining units in Figure 4.2

Additional information on water volumes, dip of coal seams and dewatering strategies are provided in separate Phase-1 feasibility report (Ref: GW2_069(feas), June 2017).

4.2. Hydro-census

Hydrocensus information of external groundwater users within a 1km radius of the Vlakvarkfontein Mine layout was gathered during September 2009. All hydrocensus information are summarised in Tables 4.4A-C. The position of boreholes and springs are depicted in Figure 4.4. A total of 18 boreholes including 1 exploration borehole, 2 dug-wells, 2 fountains and 1 mine water decant point were surveyed.

Groundwater Square was contracted to monitor external users annually till December 2012, and the village water supply borehole, EUB-6, more frequently (see locations in Figure 4.4). *GSW* continued with the annual sampling till 2016, when *LWES* took over the responsibility (locations indicated in Figure 4.5). The important EUB-6 village water supply hole is monitored as "tap water". Other important water supply points to the local community, currently monitored by *LWES*, are "playground" and "Arbor Community". Photographs of external users' locations are included as Figures 4.6A-B (Ref: GSW, 2016).

Table 4.4A Hydrocencus - Owner Information

Map Nr	Name of Owner	Address	Contact Person	Phone Numbers	Farm Name	Farm Number
EUB-1	Bertie Trutor	PO Box 621, Ogies, 2230	Bertie Trutor	079 877 5942	Vandyksput	214 IR
EUB-2	Bertie Trutor	PO Box 621, Ogies, 2230	Bertie Trutor	079 877 5942	Vandyksput	214 IR
EUB-3	Bertie Trutor	PO Box 621, Ogies, 2230	Bertie Trutor	079 877 5942	Vandyksput	214 IR
EUB-4	Bertie Trutor	PO Box 621, Ogies, 2230	Bertie Trutor	079 877 5942	Vandyksput	214 IR
EUB-5	Bertie Trutor	PO Box 621, Ogies, 2230	Oupa Masilela	079 877 5942	Vandyksput	214 IR
EUB-6	Arbor Village		R.P. Molalathoko	083 330 8893	Vlakvarkfontein	213 IR
EUB-8	Arbor Village		R.P. Molalathoko	083 330 8893	Vlakvarkfontein	213 IR
EUB-9	Arbor Village		R.P. Molalathoko	083 330 8893	Vlakvarkfontein	213 IR
EUB-10	J.J. Potgieter		Jaco	083 442 0150	Vlakvarkfontein	213 IR
EUB-11	Arbor Mine				Vlakvarkfontein	213 IR
EUB-12	J.A.G. Duvenage	PO Box 127, Kendal,	J.A.G. Duvenage	082 640 2830	Vlakvarkfontein	213 IR
EUB-13	J.G. Prinsloo	PO Box 298, Kendal,	A. Barnard	083 309 1390	Vlakvarkfontein	213 IR
EUB-14	C.B. Vosloo		C.B. Vosloo	072 484 5194	Vlakvarkfontein	213 IR
EUB-15	C.B. Vosloo		C.B. Vosloo	072 484 5194	Vlakvarkfontein	213 IR
EUB-16	Bertie Trutor	PO Box 621, Ogies, 2230	Bertie Trutor	079 877 5942	Vandyksput	214 IR
EUB-17					Vlakvarkfontein	213 IR
EUB-18					Vlakvarkfontein	213 IR
EUB-P1	J.J. Potgieter		J.J. Potgieter		Vlakvarkfontein	213 IR
EUB-P2	Arbor Village		R.P. Molalathoko	083 330 8893	Vlakvarkfontein	213 IR
EUF-1	J.J. Potgieter		J.J. Potgieter		Vlakvarkfontein	213 IR
EUF-2	C.B. Vosloo		C.B. Vosloo	072 484 5194	Vlakvarkfontein	213 IR

Table 4.4B Hydrocensus – Location information

Map Nr	XCoord WGS84 (LO29)	YCoord WGS84 (LO29)	Elevation (mamsl)	Drainage Region	Site Type	Information Source	Site Status	Site Purpose	User Consumer	User Application	Equipment
EUB-1	10020	2881565	1520	B20F	B	G	G	P	N	DA	S
EUB-2	9854	2881741	1528	B20F	B	G	G	P	N	DA	S
EUB-3	9246	2882030	1533	B20F	B	G	G	P	N	DA	S
EUB-4	7971	2882110	1534	B20F	B	G	G	P	N	DA	S
EUB-5	11108	2881647	1514	B20F	B	G	G	P	N	DA	S
EUB-6	10842	2882174	1545	B20F	B	G	G	P	N	DA	S
EUB-8	11895	2881723	1526	B20F	B	G	U	P	N		N
EUB-9	11906	2881741	1529	B20F	B	G	D	P	N		N
EUB-10	11515	2883365	1547	B20E	B	G	G	P	N	AD	S
EUB-11	10550	2883092	1565	B20F	B	G	U	P	N	TM	N
EUB-12	9243	2884837	1532	B20E	B	G	G	P	N	DA	S
EUB-13	8493	2885037	1536	B20E	B	G	G	P	N	DA	S
EUB-14	9953	2884594	1531	B20E	B	G	U	P	N		W
EUB-15	10076	2884746	1525	B20E	B	G	G	P	N	DA	S
EUB-16	12728	2881028	1502	B20F	B	G	G	P	N	DA	S
EUB-17	9834	2883624	1575	B20E	B	G	D	P	N	-	N
EUB-18	9769	2883605	1571	B20E	B	G	D	P	N	-	N
EUB-P1	11557	2884510	1506	B20E	D	G	G	P	N	DA	N
EUB-P2	11897	2881709	1526	B20F	D	G	G	P	N	DA	N
EUF-1	11565	2884521	1507	B20E	F	G	G	P	N	AS	N
EUF-2	10047	2884680	1519	B20E	F	G	U	P	N	-	N

Table 4.4C Hydrocensus – Water related information

Nr on Map	BH Diameter (m)	Collar Height (m)	Depth (m)	Date	Time	Water level (mbc)	Sampled (Y/N0	COMMENTS: P=People; LSU=Large Stock; SSU=Small Stock; D=Dairy; G=Garden; N=Nursery
EUB-1	0.165	0.13	-	20090918	1244	9.69	Y	Three houses, office, workshop, 10 staff houses, P=40, G=3
EUB-2	0.165	0.35	-	20090918	1255	-	N	Three houses, office, workshop, 10 staff houses, P=40, G=4
EUB-3	0.165	0.10	-	20090918	1300	9.50	Y	12 Staff houses, P=60
EUB-4	0.165	0.24	-	20090918	1315	11.56	N	P=12, G=1
EUB-5	0.165	-	-	20090918	1345		N	Oupa Masilela move into house
EUB-6	0.165	R 0.20	-	20090918	1355	21.81	Y	Water supply to village, water treatment plant, Arbor Primary School = 235 pupils
EUB-8	0.165	-	-	20090918	1407	-	N	Sealed village water supply borehole
EUB-9	0.165	-	-	20090918	1410	-	N	Borehole destroyed
EUB-10	0.165	0.27	-	20090918	1435	5.62	Y	G=1, P=3, LSU=240
EUB-11	0.165	0.30	40.50	20090918	1500	9.73	N	Mine borehole
EUB-12	0.165	0.07	7.00	20090918	1550	3.80	Y	G=2, P=10, LSU=100, SSU=20 Pump 1Hr/d
EUB-13	0.165	0.15	-	20090918	1610	11.83	Y	G=1, P=13, LSU=400, Pump 3hr/d @ 0.6L/s
EUB-14	0.165	0.82	-	20090918	1620	-	N	Broken windmill
EUB-15	0.165	1.05	18.00	20090918	1635	2.15	Y	G=1, P=3, Pump 0.5hour/day to 5000L reservoir
EUB-16	0.165	0.17	-	20090918	1720	4.465	Y	10 Staff houses
EUB-17	0.165	-	-	20090918	1625	-	N	Destroyed (old windmill)
EUB-18	0.165	-	-	20090918	1627	-	N	Destroyed
EUB-P1	2	0.00	1.60	20090907	1540	1.10	Y	Two houses, P=14, SSU=33, LSU = 240
EUB-P2	2	0.39	6.00	20090918	1405	2.13	N	Dug-well at Arbor Village shop
EUF-1	-	0.00	-	20090907	1600	0.00	N	20x8M Kidney shaped wet area, No flow, LSU = 240
EUF-2	-	0.00	-	20090918	1640	0.00	N	Flow=0.6L/s

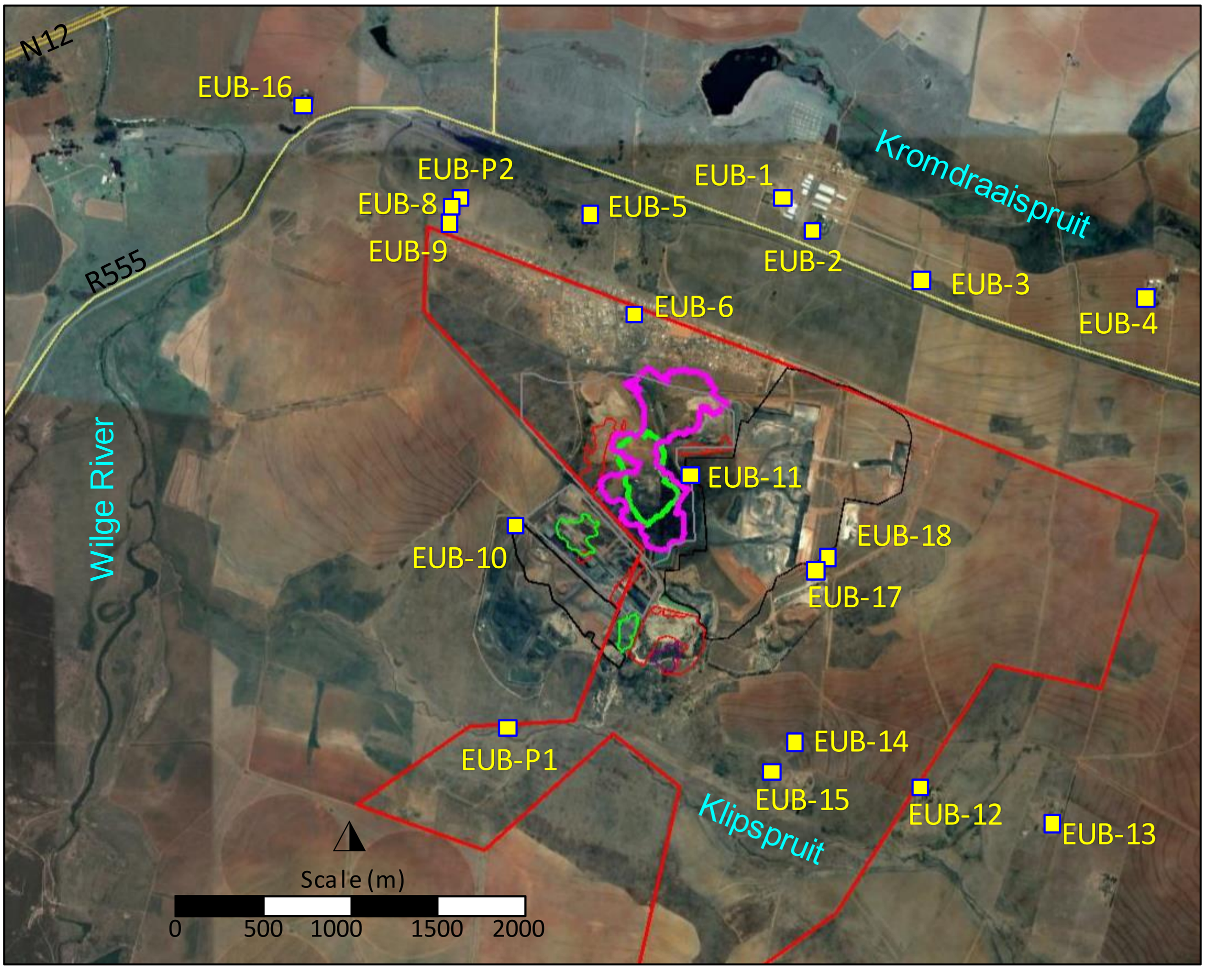


Figure 4.4 ***External users identified by Groundwater Square (Ref: GW2_069, 2009), depicted against an August 2016 Google Earth aerial photograph***

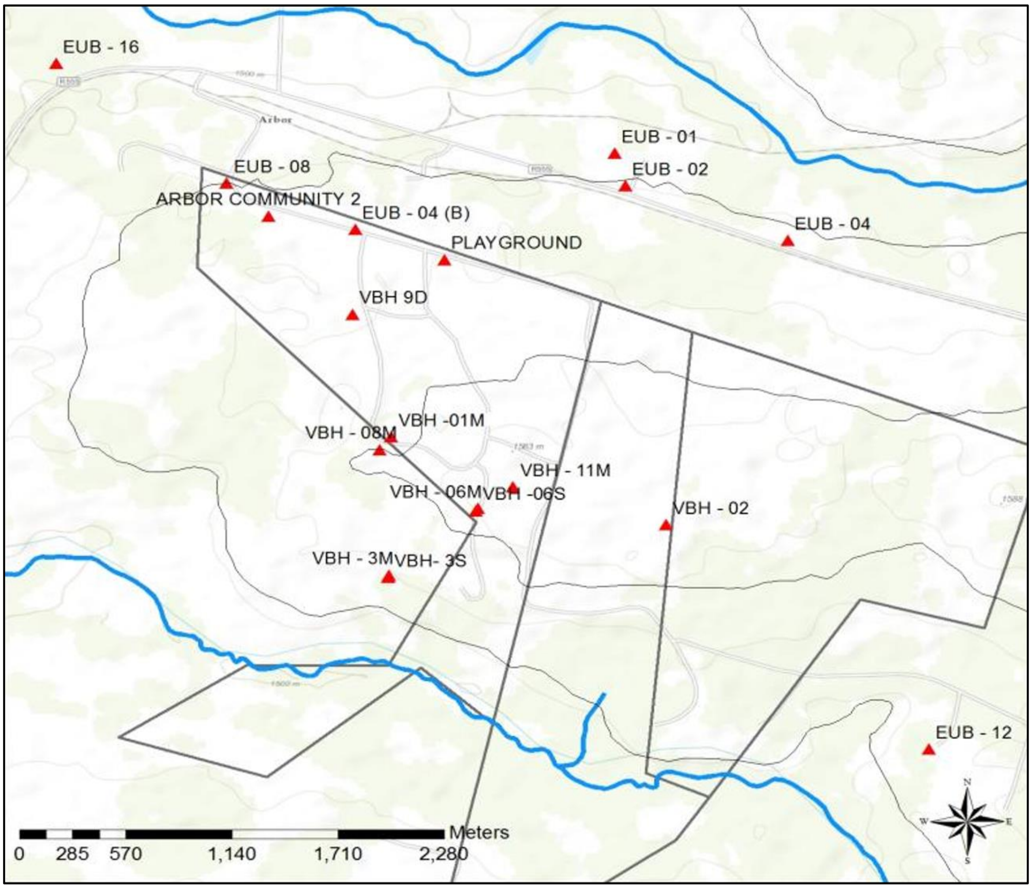


Figure 4.5 ***LWES groundwater monitoring system, also indicating locations of external users (Ref: LWES, 2017)***

Figure 4.6A Photographs of external users' locations (Ref: GSW, 2016)

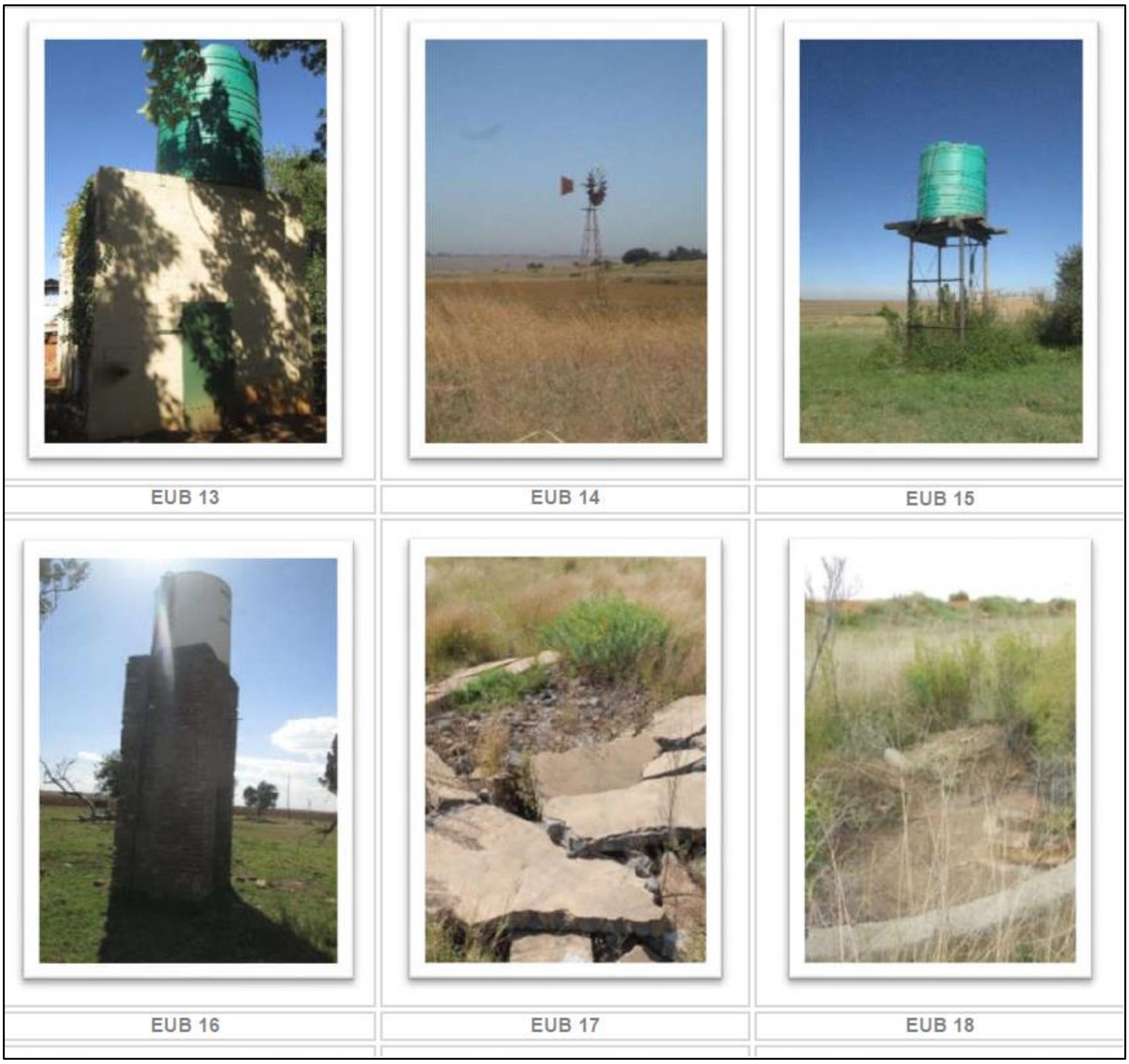


Figure 4.6B Photographs of external users' locations (Ref: GSW, 2016)

4.3. Geophysical Survey and Results

Geophysical surveys were commissioned in August 2009. The objective of this survey, apart from experimenting with the applicability of the relevant methods to map the old mine workings, was to delineate any preferential groundwater flow zones, i.e. dykes, sills and faults transecting the proposed mining area.

The following geophysical surveys were commissioned in August 2009:

- Magnetic (see Figure 4.7):
  - The magnetic survey successfully identified the Ogies dyke and a diabase sill;
  - No other linear features could be identified;
- Continuous electromagnetic (see Figure 4.8):
  - The electromagnetic survey was very successful in identifying the areas, which were most prominently disturbed within the top-most 6m of the soil profile;
- DC resistivity and gravity methods (see Figure 4.9):
  - The Underground mining could be identified with mixed success using the resistivity survey, specifically as a result of the disturbed overburden/soils/rehabilitation. It appeared as if the best results were obtained in the identification of the Seam-4;
  - The gravity survey was not successful and was abandoned after the first day.

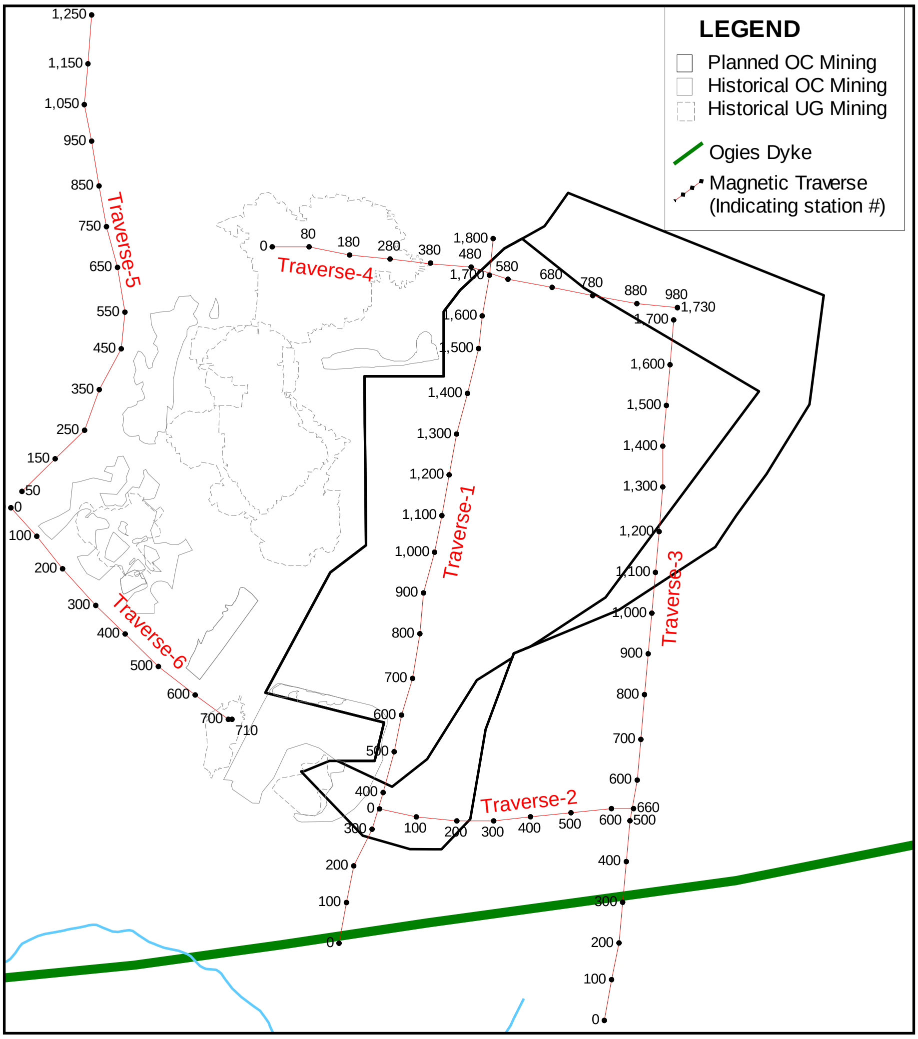


Figure 4.7 ***Geophysical traverse lines –magnetic (Ref:GW2_069, 2009)***

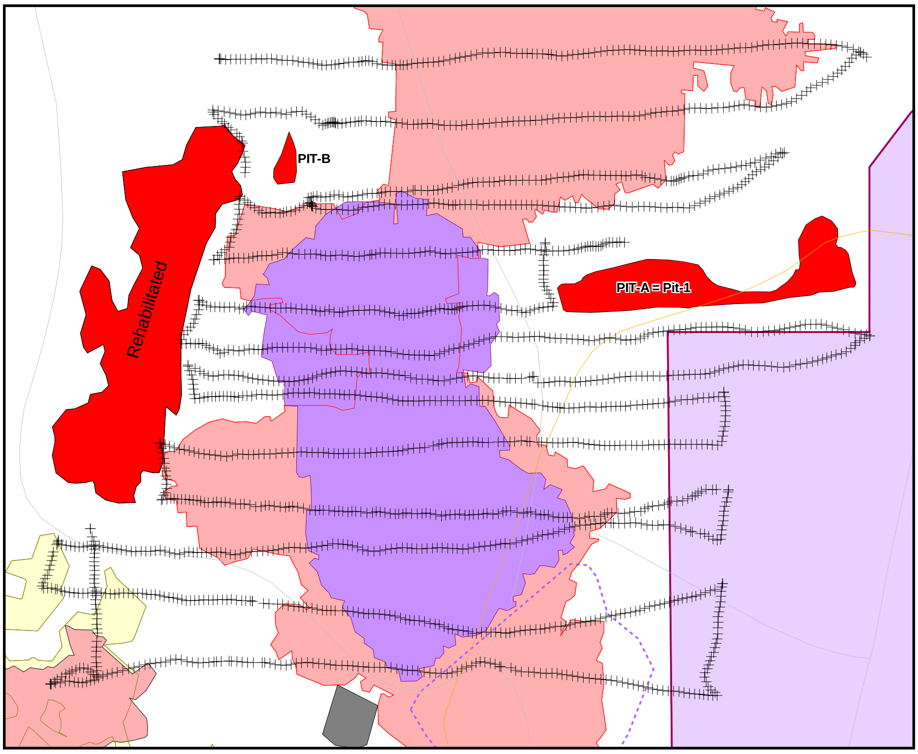


Figure 4.8 ***Geophysical traverse lines – EM-31 electromagnetic (Ref:GW2_069, 2009)***

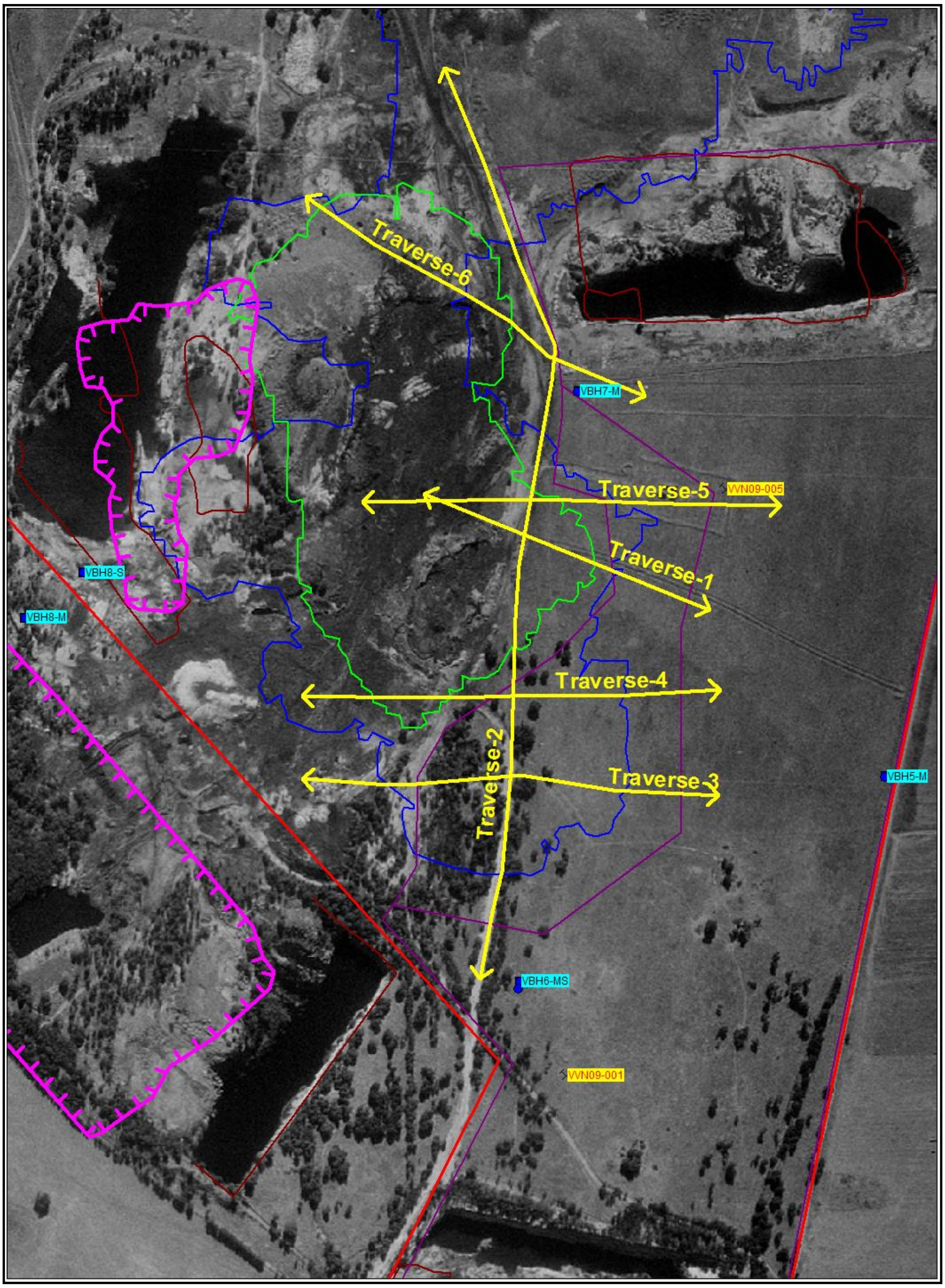


Figure 4.9 ***Geophysical traverse lines – Lund resistivity method (gravimetric = Traverse-1&2). Except for the biggest void to the west, which was backfilled/ rehabilitated by DWAF in 2006, all pits on the aerial photo backdrop were "open" in 2009 (Ref:GW2_069, 2009)***

4.4. Drilling and Siting of Boreholes

Baseline groundwater information was gathered from 12 hydrogeological boreholes that were drilled during the 2009 groundwater study, and subsequent drilling during 2013 to upgrade the monitoring system. Borehole localities in relation to the site layout and historical opencast/underground mining are indicated in Figure 4.10 Pertinent hydrogeological information are listed in Tables 4.5A-B

During the 2017 exploration drilling phase, *Groundwater Square* visited exploration boreholes as summarised in Section 4.1 (Tables 4.1 & 4.2, indicated in Figure 4.1). Where possible, the water column in exploration boreholes were profiled in terms of electrical conductivity (EC), followed by water sampling (i.e. where possible, mine water was sampled). Water quality information and EC profiling results are attached as Appendices 1 and 2.

Four additional monitoring localities have been recommended to Mine Management, as indicated in Table 4.6 and Figures 4.10& 4.11. The drilling information from these will be available after the submission of this impact assessment report.

Table 4.5A Pertinent hydrogeological information – physical borehole parameters (Ref: GW2_069, 2009 & 2013)

Borehole Number	Coordinate (WGS84)			Borehole depth (m)		
	X	Y	Z	End of hole	Overburden	Weathered rock
VBH-1M	-10186	-2882739	1556	31	2	15
VBH-1S	-10185	-2882737	1556	6	1	
VBH-2M	-9768	-2883715	1569	31	1	14
VBH-3M	-11111	-2884005	1535	30	3	7
VBH-3S	-11110	-2884005	1535	6	3	
VBH-4M	-9700	-2883129	1559	35	2	11
VBH-5M	-10327	-2883411	1566	48	8	25
VBH-6M	-10679	-2883616	1561	35	1	17
VBH-6S	-10680	-2883618	1561	6	2	
VBH-7M	-10620	-2883047	1560	41	1	17
VBH-8M	-11156	-2883267	1552	30	2	7
VBH-8S	-11096	-2883219	1552	12	>12	
VBH-9D	-10445	-2882570	1545	75	14	14
VBH-10M	-11298	-2882686	1549	40	1	9
VBH-11M	-10512	-2883485	1563	27	6	24

Table 4.5B Pertinent hydrogeological information – hydraulic and chemical parameters (Ref: GW2_069, 2009 & 2013)

Borehole Number	Groundwater level (m)	Water strike		Hydraulic conductivity (m/d)	Water quality *				
		Depth (m)	Yield (L/s)		EC (mS/m)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	SO4 (mg/l)
VBH-1M	7.280	10-12	0.02	0.034	14	13	2	6	7
VBH-1S	DRY								
VBH-2M	13.100	19-22	0.01	0.083	12	8	3	2	1
VBH-3M	5.620	25-26	0.01	0.055	41	38	2	20	92
VBH-3S	5.495				142	96	8	101	640
VBH-4M	10.120	11-19	0.58	1.260	16	10	4	8	1
VBH-5M	13.530	19-31	0.18	0.041	8	6	4	3	3
VBH-6M	12.815	14-17	0.18	0.074	14	16	2	5	<1
VBH-6S	DRY								
VBH-7M	10.820	13-18	0.1	0.277	18	16	1	4	1
VBH-8M	5.440	10-12	0.020	0.260	494	406	9	388	2831
VBH-8S	4.780			3.660	629	472	3	355	4399
VBH-9D	13.36			0.010	15	12	6	<2	2
VBH-10M	9.07	30-31	0.23	0.008	7	1	1	<2	1
VBH-11M	26.35			0.300	5	1	1	<2	<1

* At the time of drilling

Table 4.6 Proposed additional monitoring points, to be drilled during November 2017

Borehole Number	Description / Location	Longitude	Latitude
VBH-12M	Southern decant area	28.8935	-26.0682
VBH-13M	In-between historical OC & UG	28.8936	-26.0549
VBH-14M	Barrier pillar with Wescoal	28.8920	-26.0598
VBH-15M	Northern potential decant area	28.9079	-26.0538

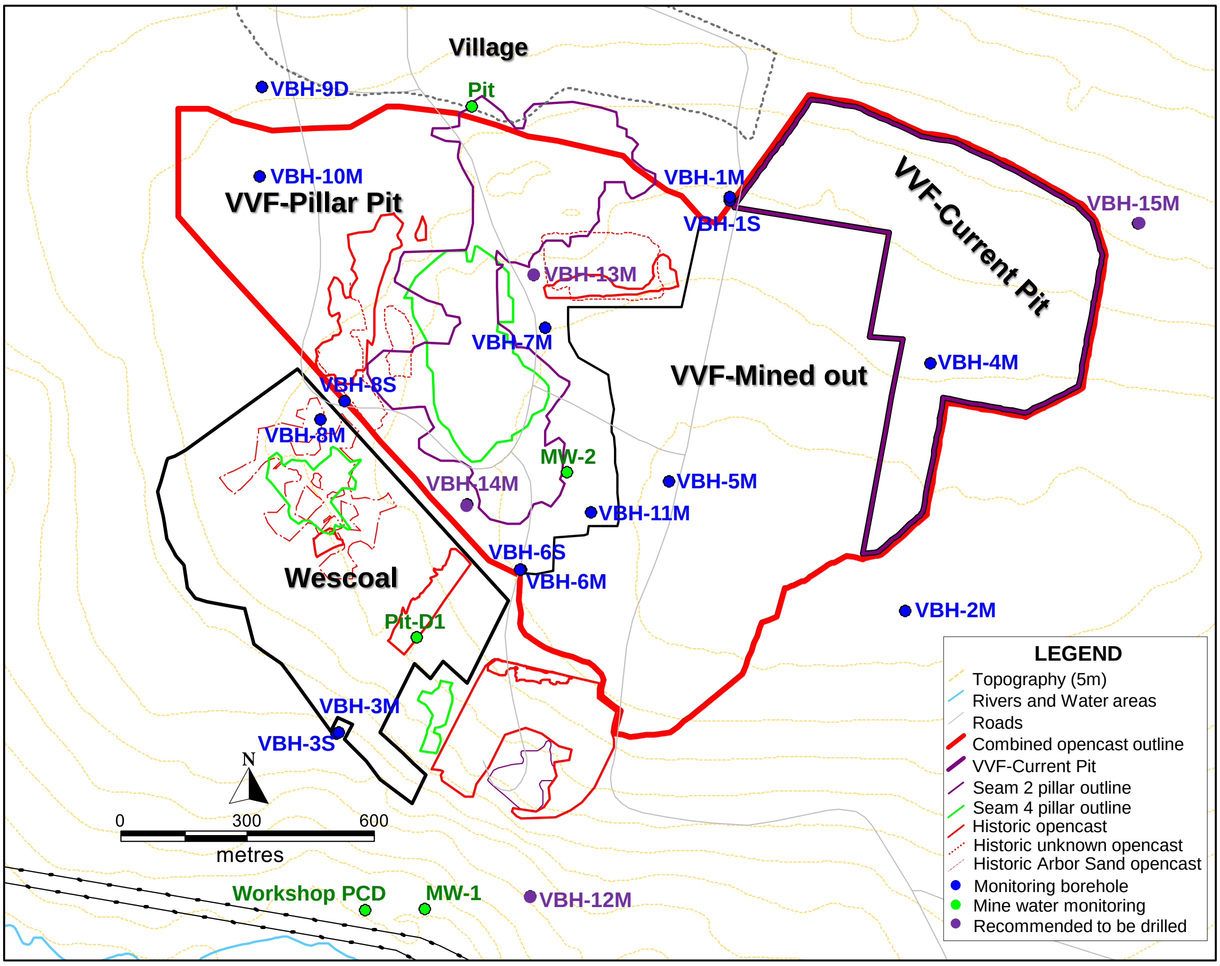


Figure 4.10 Monitoring borehole localities commissioned in 2009 and 2013, and recommended to be drilled during November 2017

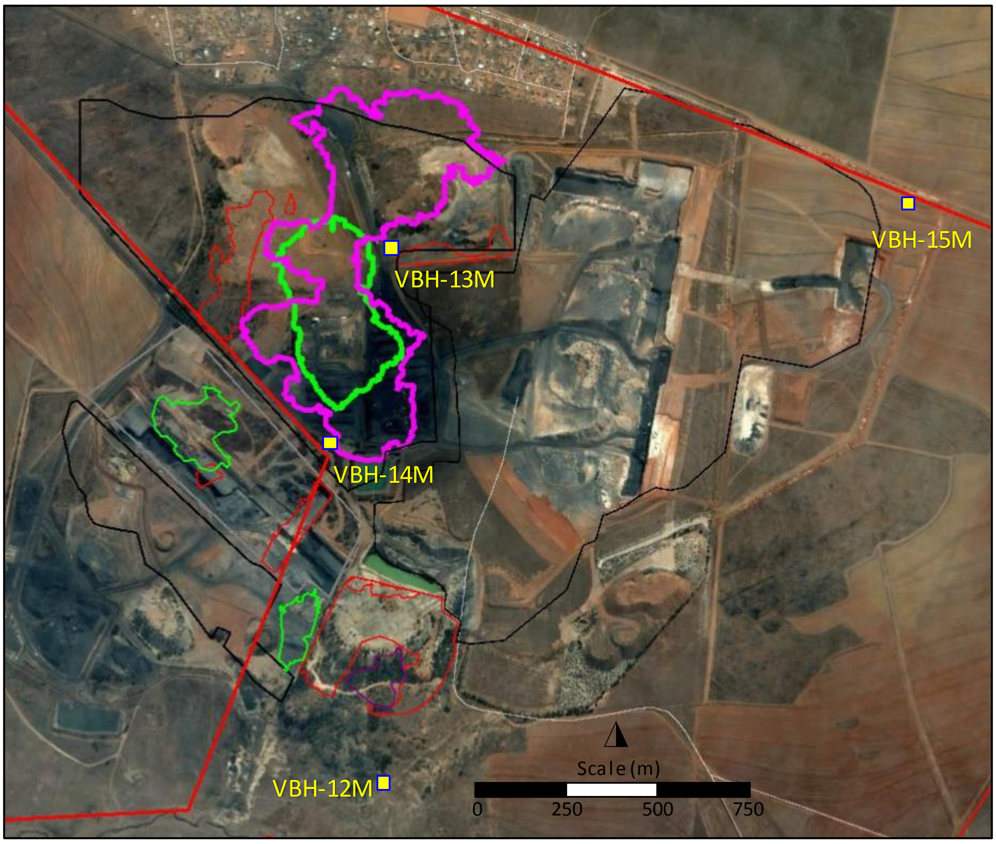


Figure 4.11 Proposed additional monitoring points, to be drilled during November 2017

4.5. Aquifer Testing

Due to the low-yielding coal-bearing Karoo-Ecca aquifers, pumping tests were not regularly performed.

On 08/08/2013 a 24hr (1440min) pumping test, with a 6hr recovery, was performed on the 75m deep borehole VBH-9D. This borehole had a very thin sandstone layer and did not intersect any coal. Dwyka tillite was intersected only 13m deep, with lavas from 28m to 75m deep.

It was concluded that borehole VBH-9D can be pumped continuously at a low rate of 0.11L/s over a 24hr period. The very low hydraulic conductivity values of 0.008m/d (late portion of test) to 0.03m/d, correlated with a value of 0.01m/d determined through slug-testing. This is four times lower than the representative hydraulic conductivity value for the local sandstone aquifers (0.04m/d).

4.6. Sampling and Chemical Analysis

Groundwater level and groundwater quality information since 2009 are included as Appendices 1 & 2. This information is discussed in Sections 5.4 and 5.5.

4.7. Groundwater Recharge Calculations

Recharge values were based on the following:

- Previous hydrogeological assessments in the surrounding coal fields served as a guide for potential recharge, taking cognisance of the specific topographical setting, relatively course-grained sandstone rock, and surrounding geology;
- Several independent calculations (e.g. decant volumes prior to mining);
- Numerical groundwater model calibration:

  - In light of the fact that observed groundwater levels (varying between 0m and 12m) are not deeper than the shallow weathered zone aquifer (Aquifer-1), calibration was essentially achieved for this layer;
  - The numerical groundwater flow model was calibrated through simulating observed groundwater levels through the optimum combination of rainfall recharge and aquifer hydraulic conductivity;
  - Recharge values are summarised in Section 7.6;
  - Interestingly, lower than expected recharge were calibrated to rehabilitated areas; most-likely due to quick rainfall run-off from rehabilitated areas, evapotranspiration potential of a huge number of trees, and evaporation from the open pits filled with water;
  - Rainfall recharge is expected to be in the order of:
    - For rehabilitated mining areas, 15%;
    - For underground mined out areas, 5%;
    - In the vicinity of the open pits, where the groundwater table will be influenced, 5%;
- Natural chloride concentrations range between 1mg/L and 4mg/L, which are extremely low. In a typical sandstone setting, this would indicate that rainfall recharge might be >10% of MAP. However, in the case of Vlakvarkfontein, these low concentrations most-likely relate to shallow groundwater movement (i.e. very short residence times) in an aquifer system where the mineralogy had been largely depleted (see geochemical discussion in Section 5.2).

Given the shallow nature of mining, it is believed that natural rainfall recharge to the underground workings should be in the order of 5% of mean annual precipitation. This equates to a value of 10,900m^3/a or 30m^3/d (based on an area of 311,500m^2 and rainfall of 700mm/a).

Compared to the volume stored in the underground workings (>750,000m^3, which equates to ±60 times the annual rainfall recharge) this volume will contribute only a small additional volume to the water balance during the time of mining.

4.8. Groundwater Modelling

During the 2013 groundwater study, several modelling scenarios where performed to determine the potential effect that mining will have on the long-term post-mining decant. One important finding was that groundwater/mine water will flow southward from the historic unmined underground areas toward the *Wescoal* mining area, through a barrier pillar.

None of these 2013 modelling scenarios considered opencast-mining of the historic workings, and surroundings, or the mining of the barrier pillar. Although the opencast mining of VVF-Pillar Pit had not yet been evaluated, it was believed that the mine water flow would increase through the barrier pillar (if not mined), toward *Wescoal* (due to the size of the opencast, depth of highwall compared to only underground mining, and increased rainfall recharge). The barrier pillar between *Wescoal* and the new VVF-Pillar Pit (mined-out underground) will act as a dam wall which will restrict groundwater flow from north to south, with a higher groundwater table to the north compared to *Wescoal* in the south.

If the barrier pillar is mined out, it will probably mean that the water balance of the entire complex will probably shift to some extent from east to west; creating additional decant at the southern boundary of *Wescoal*, and less decant at historical mining area south of VVF-Current Pit. The main reason is a lower decant point at the *Wescoal* pit perimeter. This scenario may potentially result in a worse pit water quality due to a thicker unsaturated zone in the rehab.

Modelling scenarios in Section 7 evaluated the above-mentioned considerations.

4.9. Groundwater Availability Assessment

With reference to DWAF's 1: 500 000 Hydrogeological map series of the Republic of South Africa, Sheet 2526 Johannesburg (1999), the following regional characteristics:

- The nature of the water-bearing rock / surface, sub-surface lithology is indicated as predominantly arenaceous rocks (sandstone) surrounded and underlain predominantly by pyroclastic rocks (tuff, agglomerate and breccia; and less to a lesser extent by acid / intermediate rocks;
- The saturated interstice (storage medium) / aquifer type is indicated as intergranular and fractured;

- The borehole yield class (median l/s - excluding dry boreholes) is indicated to range between 0.1 and 0.5l/s.

With reference to DWAF's map: Groundwater Resources of the Republic of South Africa, SHEET 1 & 2, (1995), the following regional characteristics:

- The probability of drilling a successful borehole (Accessibility) is indicated as ranging between 40 and 60%. A borehole is deemed successful if upon completion it yields more than 0.1l/s;
- The probability of drilling a successful borehole, yielding more than 2l/s (Exploitability) is indicated as 20–30%.

With reference to DWAF's map: Groundwater Harvest Potential of the Republic of South Africa, 1996, the following regional characteristics:

- The maximum volume of groundwater (m^3/km^2/annum) that may annually be abstracted per surface area of an aquifer system to preserve a sustained abstraction is indicated as 4000 to 6000 m^3/km^2/annum.
- The average borehole yield (geometric mean of blow yield l/s) is indicated as 0.6 to 0.8 l/s;
- The major factor restricting the harvest potential is indicated as being the volume of effective storage.

5. PREVAILING GROUNDWATER CONDITIONS

5.1. Geology

5.1.1 Regional Geology

It is not the purpose of this report to provide a detailed geological description. However, several regional and local geological aspects are relevant to the hydrogeological evaluation.

As can be seen in Figure 5.1, the largest portion of the Vlakvarkfontein reserve boundary area north of the Ogies dyke is located on a coal bearing Vryheid Formation (Pv) outlier, which is bound to the north and the east by the Selons River Formation (Vse) of the Rooiberg Group and the Loskop Formation (Vlo), regarded as the last phase of sedimentation associated with the Transvaal sequence (which rests upon the former; as well as two Post-Transvaal diabase sill outcrops (Vdi)). The western and southern bounds are formed by granite of the Lebowa Granite Suite (Mle), which includes all the granitic rocks of the Bushveld Complex. A small outcrop of Dwyka sediments (C-Pd – grey hatching) constitutes the central southern portion of this outlier north of the Ogies Dyke. Alluvial (yellow hatching) deposition is indicated along the Klipspruit transecting the southernmost portion of the reserve.

The Vlakvarkfontein reserve falls within the Springs-Witbank Coalfield, comprising sediments of the Dwyka Group and the central lithostratigraphic coal-bearing unit of the Ecca Group, namely the Vryheid Formation. Together they represent part of the Karoo Supergroup, which were deposited on an undulating pre-Karoo floor comprising primarily of felsites of the Bushveld Complex and other ancient strata such as the Waterberg Group and Transvaal Supergroup sedimentary rocks. These had a significant influence on the nature, distribution and thickness of many Karoo Supergroup sedimentary formations, including coal seams.

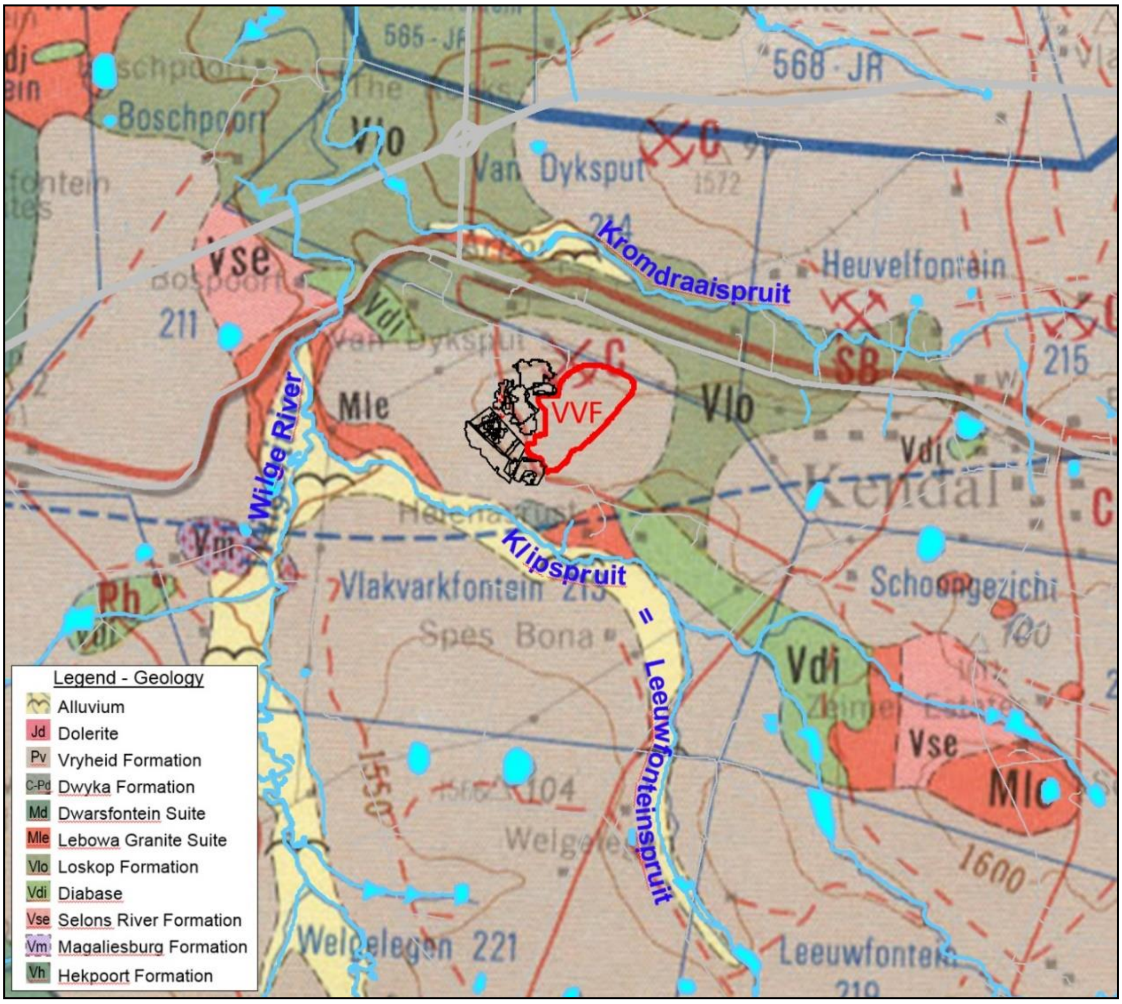


Figure 5.1 ***Regional geology (Council for Geoscience), indicating historic mining (Ref: GW2_069, 2013)***

Apart from the Ogies dyke and the basal diabase sills no other linear features were identified.

5.1.2 Local Geology

Both the Seam-2 and Seam-4 coal seams were historically mined underground (board-and-pillar extraction) and opencast mining by the Arbor Coal and Sterling TVL Collieries mining companies. Three of the five classically recognized coal seams of the Witbank Coalfield do not occur in the Vlakvarkfontein Coal Reserve (Seam-1, Seam-3 and Seam-5). The Seam-2 and Seam-4 are on average 3.2m and 4.4m thick respectively with an inter-burden thickness ranging between 8m and 11m (average 9m).

The soil profile, which is on average approximately 3.2m (varying between 0m and 9m deep), is underlain by fine- to medium-grained weathered sandstone (9m to 12.5m deep).

5.2. Acid Generation Capacity

The unique geochemical properties of the pillar area (due to historical mining) were studied in the contexts of the comprehensive 2009 and 2013 geochemical assessments. *Groundwater Square* appointed *Geostratum* to perform an environmental geochemical assessment of the Vlakvarkfontein Colliery. The assessment is attached as Appendix 3. A summary of the findings are presented in this section.

In 2017, 10 samples were collected from one borehole. In 2013, 33 samples were collected from seven boreholes, 11 samples were collected from the pit, and 5 samples were collected from the low-grade Seam-4 coal stockpile. In total, 59 samples were submitted for mineralogical, acid-base as well as leaching tests. In addition, impacted mine water qualities, as collected since 2009, were evaluated.

Mineralogical composition:

- *Sandstone:* Quartz is the dominant mineral in the sandstone with the result that SiO_2 is the dominant oxide in the rock. Microcline and kaolinite were present as major minerals in one sample with the result that Al_2O_3 and K_2O were slightly higher relative to the other samples (where these two minerals were mostly present as minor minerals). Other minor and accessory minerals in the sandstone included calcite, dolomite, pyrite and siderite;
- *Carbonaceous shale:* Most of the carbonaceous shale samples contained more than 10% carbon. The mineralogy of the shale samples was dominated by kaolinite with some major quartz, with the result that Al_2O_3 and SiO_2 were the dominant oxides in the rock. Other minor and accessory minerals in the shale included microcline, muscovite, calcite, dolomite, pyrite and siderite. Slightly elevated traces in the shale included Cu and Cr;
- *Coal:* Coal samples were dominated by high carbon content (>50%), and contained major kaolinite and quartz, with accessory microcline, muscovite, calcite, dolomite, pyrite. P2O5 and Cr were slightly elevated in the coal. Coal had a much higher pyrite content (average total S% >0.9% from ABA test results) than the associated waste rock;
- Alunite was present in 4 samples from one borehole as a secondary mineral. This indicated that these rocks were subjected to acidic drainage at some stage. All 4 samples also had a significant pyrite content and almost no neutralisation potential.

Acid-base accounting (ABA) testing indicated that most of the clastic waste rocks samples (±64.5% of all waste rock) have a very low sulphide content and will not generate acidic drainage. 35.5% of the clastic waste rocks have a moderate sulphide content and have a low to medium potential to generate acidic drainage. The backfill will, therefore, be a heterogeneous mixture of acid generation and non-acid generation rocks. The neutralisation potential of the non-acid generating rock is however not sufficient to prevent significant acidification of the backfill situated within the oxic zone.

All coal samples had a high sulphide content and will generate acidic drainage over the long term.

Kinetic leach testing was performed to indicate which metals may leach from the material under especially acidic conditions. The initial acidic leachate with elevated sulphate was due to the leaching of secondary sulphate minerals from the sandstone. The columns test of the coal samples had initial circumneutral leachate which became acidic after a few weeks.

The following metal(loids) leached at slightly elevated concentrations during the acidic leaches: Al, Mn, Fe, Cu, Co, Ni, Pb and Se. Ni and Mn leached persistently from the columns.

Waste rock will have a much lower potential to generate acidic drainage than coal (most waste rock has a low %S and has no potential to acidify). However, waste rock also has a very limited ability to neutralise the acid mine drainage of coal and discard material. This is in accordance to previous studies at Vlakvarkfontein.

Based on mine water samples that were collected from exploration boreholes during November 2016, mine water in the Seam-2 workings currently has a pH of <5.4, and mine water in the Seam-4 workings has a pH of ±3. Sulphate concentrations probably range between 800mg/L and 1500mg/L.

It should be noted that mine water quality in the rehabilitated historic opencast areas (to the west of the underground areas) probably have pH ranging from <3 to 4.5; and sulphate concentrations >3000mg/L (as monitored in boreholes VBH-8M and VBH-8S).

Summarising comments from Appendix 3, on the potential mine water drainage quality:

- Assuming no discard is backfilled into the VVF-Pillar Pit, and the pit is mined in isolation:
  - The pit will have an average unsaturated zone of only 3.5m deep (with limited resultant oxygen infiltration);
  - Initially, the pit water will have a sulphate concentration of maximum 1500mg/L, which will increase to between 2200mg/L–3300mg/L in the backfill, as the pit water level rises over the next 30 years;
  - Sulphate concentrations will improve to below 1000mg/L in the first 100years after closure;
- With discard backfilling (for the same 3.5m unsaturated zone as above):
  - The initial sulphate in the pit water is expected to be approximately 2000mg/L-2500mg/L; improving to approximately 1600mg/L over the long-term;
  - It is however important that discard is backfilled only in the deepest parts of the pit at least 10m below the decant elevation;
- Elsewhere, assuming a maximum unsaturated zone of 15.5m deep, over the long-term:
  - Sulphate concentration of between 3000 and 3300mg/L are expected if no discard is placed in the pit;
    Sulphate concentration of between 3000 and 3500mg/L are expected if discard is placed in the pit;
- *Discard Dump*:
  - The discard has a high pyrite and sulphate mineral content and seepage from the discard dump will have an average sulphate concentration of between 4500-6000mg/L;
  - However, it is possible that spikes in the sulphate may occur of up to 10 000mg/L;
- Metals:
  - In neutral pit water metals (e.g. Al, Fe and Mn) will be present at concentrations of below 1mg/L;
  - Where acidification occurs in the discard dump, seepage will have Al, Fe and Mn concentrations above 10mg/L, even up to 1000mg/L;
  - In acidic seepage, the concentration of trace metals Co and Ni will also become elevated (0.1mg/L-2mg/L;
- All geochemical scenarios (mine water with-and-without discard, and for the discard dump) indicated pH levels lowering from 6 to 4 over the first 30years, followed by a further drop to pH 3.5 to 4.5 over the long-term (100years);
- Geochemical trends are discussed in detail in Appendix 3, and presented as trend graphs in Section 7. Several recommendations are included in Section 12.

5.3. Hydrogeology

5.3.1 Unsaturated Zone

The unsaturated zone refers to the zone between the surface topography and the groundwater table; i.e. the depth to the groundwater table. Although natural groundwater levels typically vary between 0m and 12m below surface (average 5m), groundwater level elevations emulate the surface topography. In low-lying areas such as rivers and streams, groundwater levels are <2m deep. In high-lying areas, groundwater levels may be >10m deep. The depth to the groundwater table as observed during various drilling phases are summarised in Figure 5.4 (Section 5.4).

It has been observed that the depth of the groundwater table fluctuates in accordance with the rainfall seasonality as can be seen in the trend graph included as Figure 5.2. However, in some boreholes, groundwater levels have been influenced by nearby mining or by groundwater abstraction.

The thickness of the unsaturated zone over rehabilitated mining areas has a very important influence on the long-term geochemical trends.

5.3.2 Saturated Zone

Because the shallow weathered zone aquifer varies between 20m and 35m deep; based on rock weathering status observed during drilling and the intersection of water-strikes, it follows that the most productive saturated zone typically varies between 12 to 30m thick.

As the case for the unsaturated zone, the saturated zone thickness will therefore depend on the type of geology, topographical setting, dewatering due to nearby mining and any groundwater abstraction.

5.3.3 Hydraulic Conductivity

Slug tests were performed on all boreholes drilled by *Groundwater Square* (see Section 4.4). The unique hydraulic conductivity values for each geological unit, are presented in Section 7.6.

The major groundwater flow units/aquifers, listed in Tables 7.2A-D, 7.3A-D & 7.4, were identified and calibrated during the 2009 groundwater study and confirmed during the 2013 study. Numerical modelling for this study did not indicate that the parameters may be substantially different.

Provision was made for the different types of geology in the area and the depth below surface (i.e. degree of weathering and fracturing). Experience in neighbouring coal fields also contributed to the decision.

5.4. Groundwater Levels

Groundwater level monitoring data is attached as Appendix 1. Figures 5.2 and 5.3 have been included to indicate depth below surface as well as groundwater level elevations. Figure 5.4 serve as a summary of the depth the groundwater table at the time when boreholes were drilled.

The effect of rainfall seasonality (typically 2.5m) is evident as well as the dewatering that occurs when a borehole is located in close proximity to opencast mining areas (e.g. boreholes VBH-1M, VBH-4m and VBH-7M). Groundwater levels in-and-around the mining area will lower by 12m to 20m, thus further impacting on the surrounding groundwater levels and potentially also influence nearby borehole yields.

This is an important consideration in view of the groundwater supply to the neighbouring village.

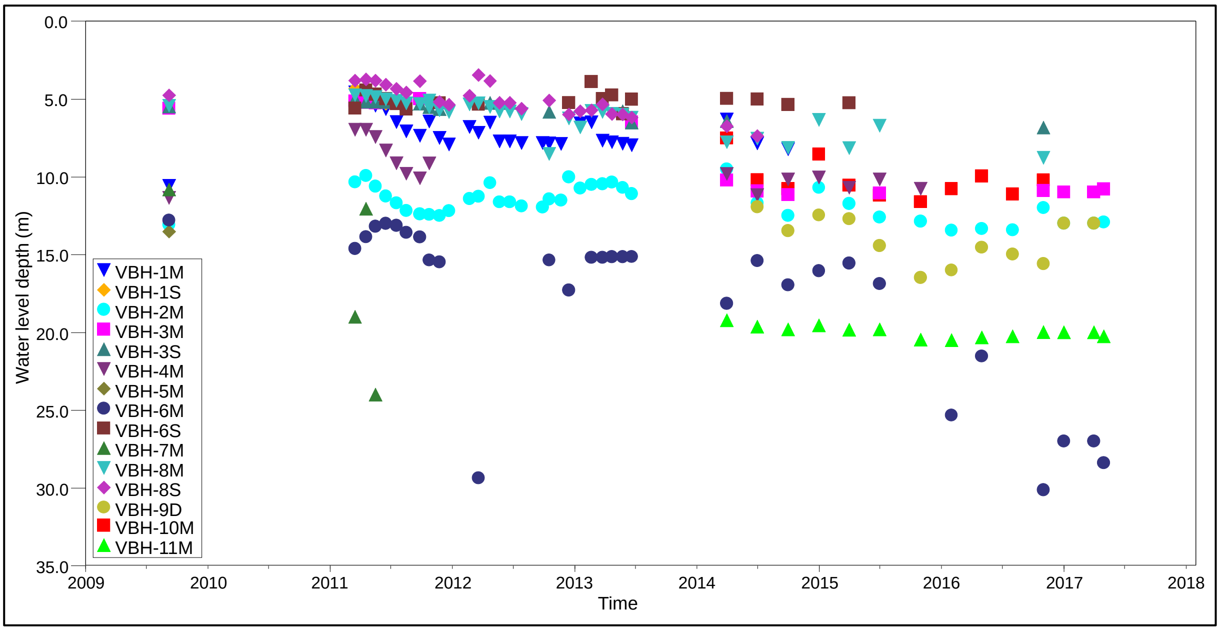


Figure 5.2 **Groundwater level depths(m) for monitoring boreholes**

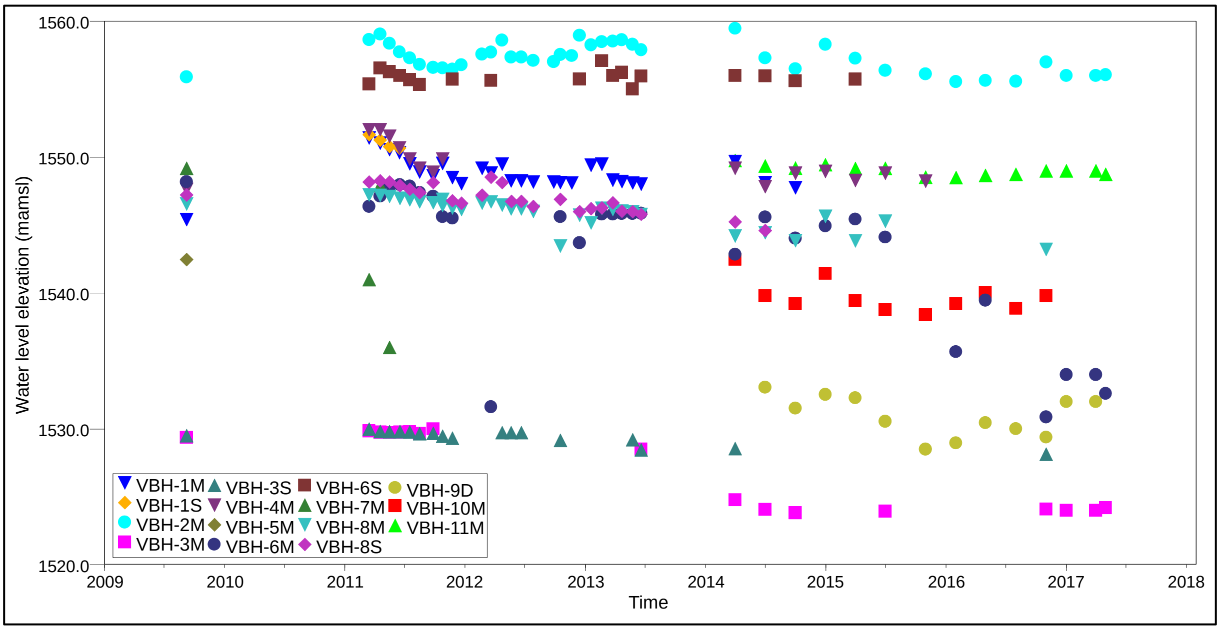


Figure 5.3 *Groundwater level elevations(mamsl) for monitoring boreholes*

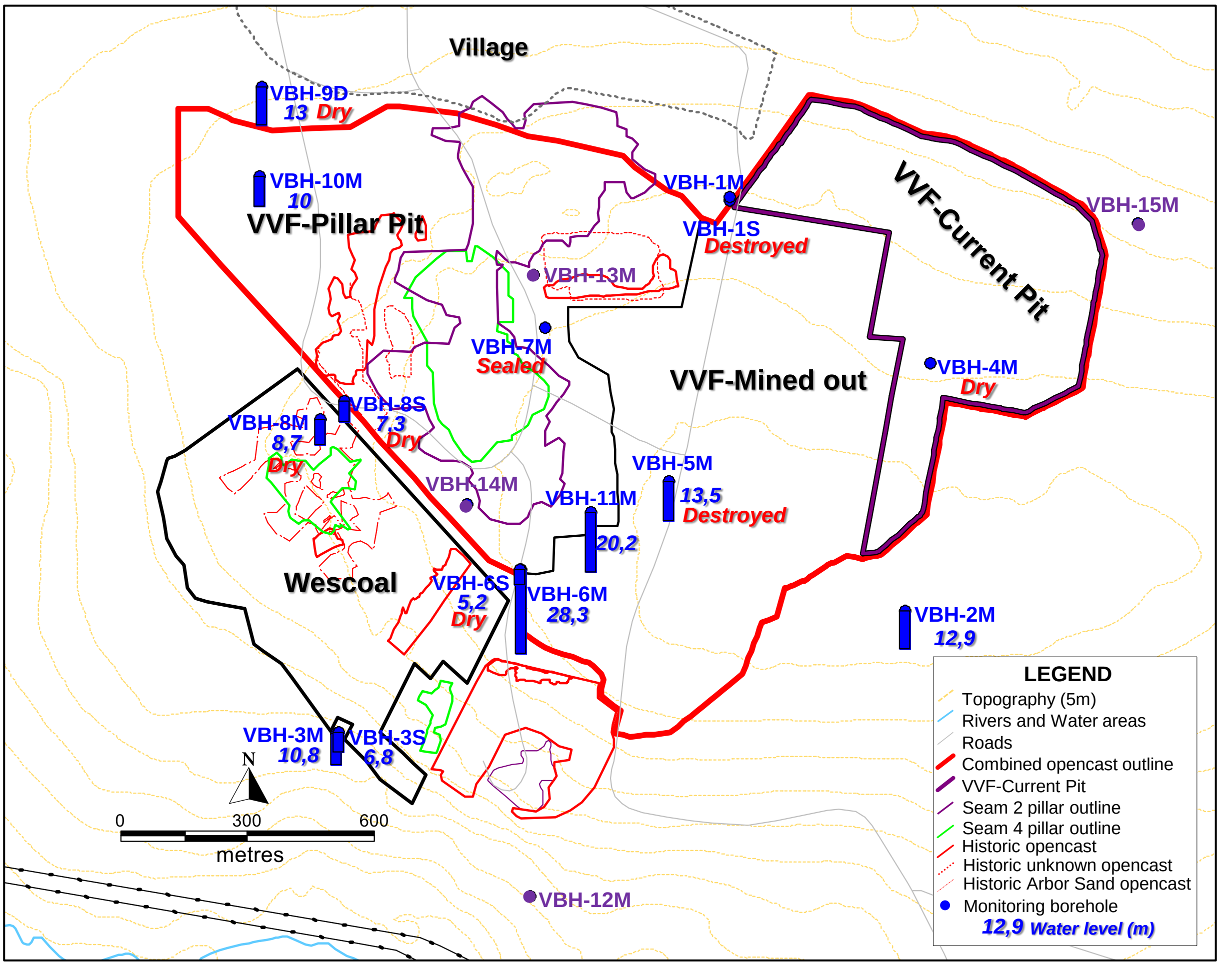


Figure 5.4 *Thematic depiction of groundwater level depths(m) for monitoring boreholes*

5.5. Groundwater Potential Contaminants

The main indicator for groundwater contamination is sulphate. During the various stages of geochemical transformation, sulphate will be associated with sodium, calcium and magnesium. Total Dissolved Solids (TDS) or Electrical Conductivity (EC), indicates the total salt load.

Other contaminant indicators associated with sulphate, are pH levels. When low-pH conditions prevail, increased metals concentrations may manifest, such as iron (but they also include additional metals as indicated in the geochemical assessment, Appendix 3).

5.6. Groundwater Quality

Groundwater quality monitoring data is attached as Appendix 2. SO_4, pH and EC concentrations trend graphs have been included as Figures 5.5 to 5.7, for groundwater, mine water and surface water data.

AMD conditions that currently exist in the western-most historical opencasts, that were rehabilitated/ backfilled by DWA in 2006 (pH of 3 to 5; SO_4 of 3000mg/L to 4600mg/L). Underground mine water samples were collected from exploration boreholes during November 2016. Mine water in the Seam-2 workings currently has a pH of <5.4, and mine water in the Seam-4 workings has a pH of ±3. Sulphate concentrations probably range between 800mg/L and 1500mg/L).

The worst water quality observed in boreholes VBH-8M/S are attributed to historical mining and the 2006 backfilling of opencast void by waste material. The marginally elevated concentrations in boreholes VBH-B3 and VBH-B7 are attributed to historical mining but not the same extent as other areas where oxygen and discard had a major influence on concentrations.

The deteriorating groundwater quality trends in VBH-6M can be explained in terms of active mining and direction of groundwater flow.

Historical decant from the old Arbor mining areas dried up within two years of the commencement of mining at Vlakvarkfontein; thus, reducing the impact on the Klipspruit. The recent increases in concentrations in the river, are attributed to mining activities 6km upstream of VVF.

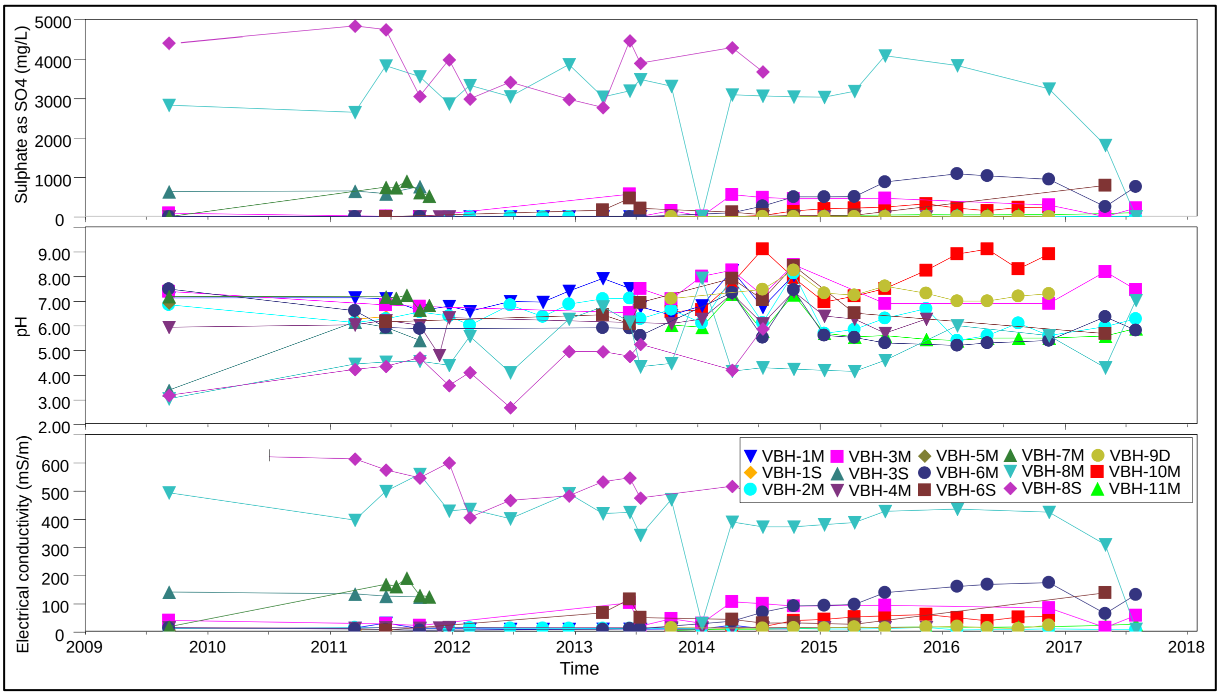


Figure 5.5 ***Electrical conductivity (mSm), pH and Sulphate (SO_4) concentration for monitoring boreholes***

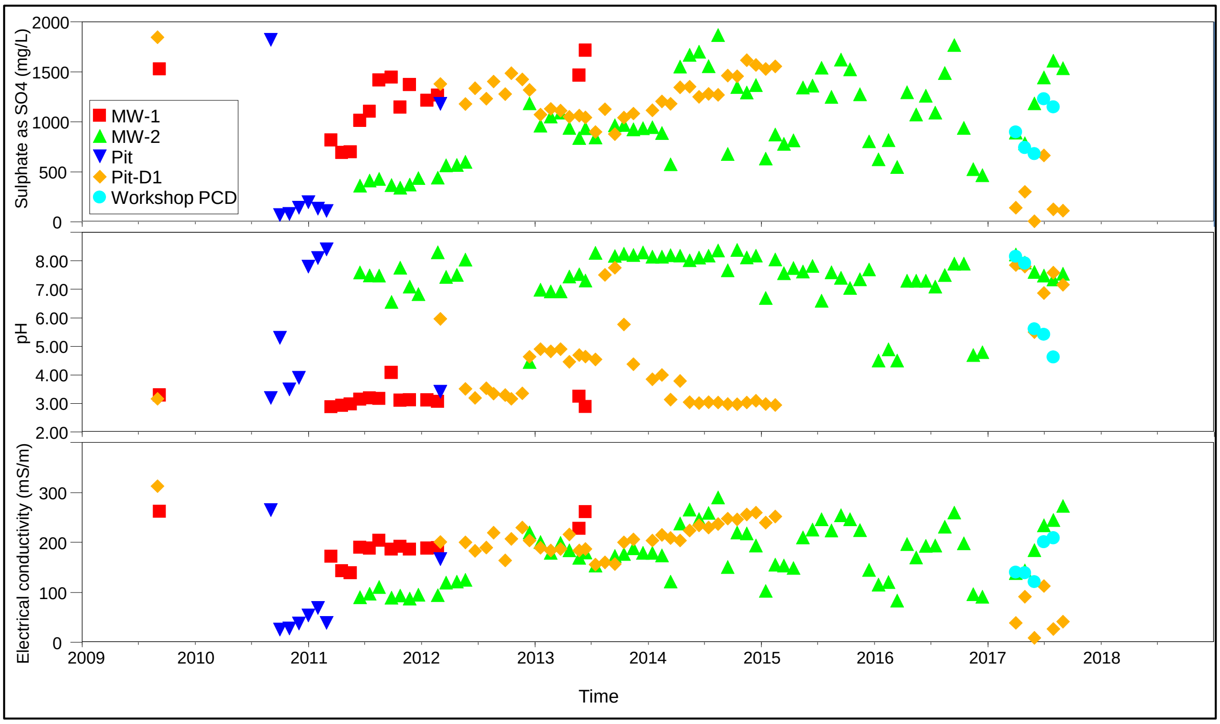


Figure 5.6 ***Electrical conductivity (mSm), pH and Sulphate (SO_4) concentration for mine water monitoring***

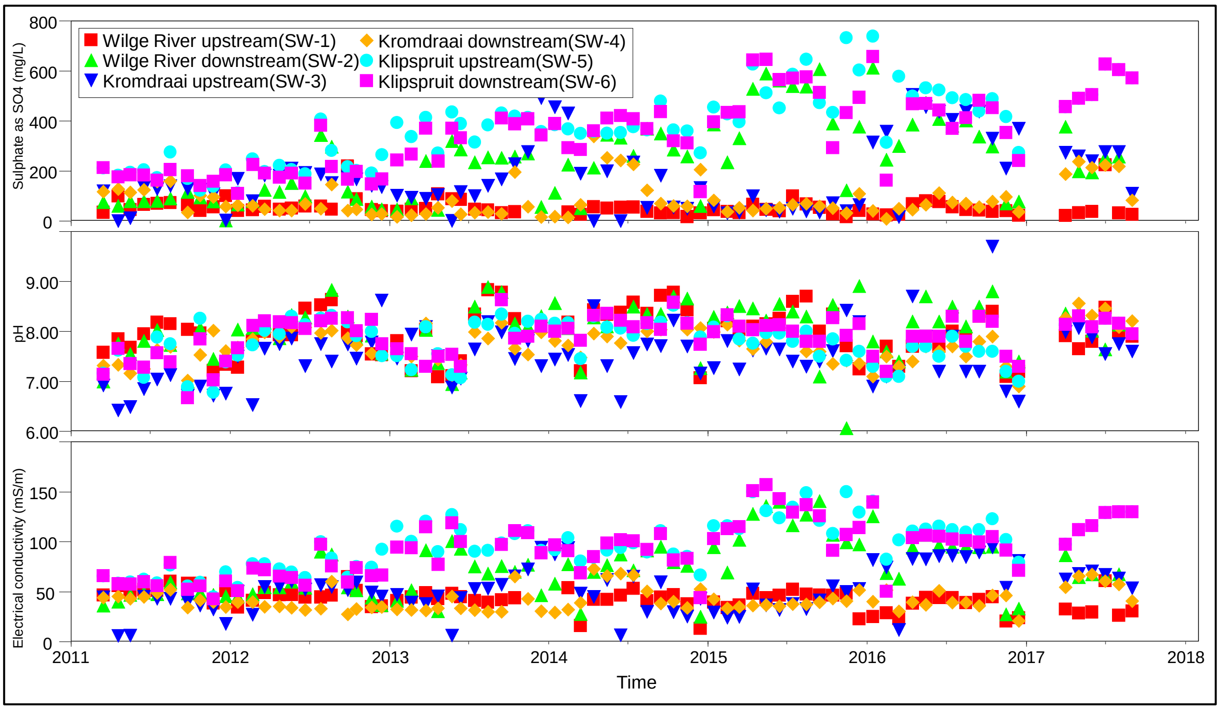


Figure 5.7 ***Electrical conductivity (mSm), pH and Sulphate (SO_4) concentration for surface water monitoring***

6. AQUIFER CHARACTERISATION

6.1. Groundwater Vulnerability

The aquifer(s) underlying the study area were classified in accordance with "A South African Aquifer System Management Classification, WRC Report No KV 77/95, December 1995."

With reference to the Map: Aquifer Classification of South Africa, the following regional characteristics:

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**.

Aquifer susceptibility, a qualitative measure of the relative ease with which a groundwater body can be potentially contaminated by anthropogenic activities and which includes both aquifer vulnerability and the relative importance of the aquifer in terms of its classification is classified as **medium**.

6.2. Aquifer Classification

Classification was done in accordance with the following definitions for Aquifer System Management Classes:

Sole Aquifer System:

An aquifer which is used to supply 50% or more of domestic water for a given area, and for which there is no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.

Major Aquifer System:

Highly permeable formations, usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (less than 150*mS/m* Electrical Conductivity).

Minor Aquifer System:

These can be fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important for local supplies and in supplying base flow for rivers.

Non-Aquifer System:

These are formations with negligible permeability that are regarded as not containing ground water in exploitable quantities. Water quality may also be such that it renders the aquifer unusable. However, ground water flow through such rocks, although imperceptible, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.

Ratings for the Aquifer System Management and Second Variable Classifications:

Aquifer System Management Classification		
Class	**Points**	**Project 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 Weathering/Fracturing		
Class	**Points**	**Project Area**
High:	3	-
Medium:	2	-
Low:	1	1
Note:		

Ratings for the Ground Water Quality Management Classification System:

Aquifer System Management Classification		
Class	**Points**	**Project 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		
Class	**Points**	**Project Area**
High:	3	-
Medium:	2	2
Low:	1	-

The project area aquifer(s), in terms of the above definitions, is classified as a **minor aquifer system**.

6.3. Aquifer Protection Classification

Level of ground water protection based on the Ground Water Quality Management Classification:

GQM Index = Aquifer System Management x Aquifer Vulnerability

GQM Index	Level of Protection	Project 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 Ground Water Quality Management Index of 4 for the project area, indicating that **medium** level ground water protection may be required.

In terms of DWAF's overarching water quality management objectives which is ***(1)*** protection of human health and ***(2)*** the protection of the environment, the significance of this aquifer classification is that if any potential risk exists, measures must be put in place to limit the risk to the environment, which in this case is the protection of the Primary Underlying Aquifer, the streams which drains the study area, and the External Users' of ground water in the area.

7. GROUNDWATER MODELLING

7.1. Software Model Choice

The 2013 FEFLOW finite element numerical groundwater flow model was revised for this assessment to simulate various scenarios and calculate aspects such as:

- Groundwater flow directions;
- Decant areas/volumes/quality;
- Interaction between opencast mining areas operated by different mining companies (i.e. flow through barrier pillars separating mining areas).

Additional information on the numerical model is provided in Section 4.

7.2. Model Set-up and Boundaries

Opencast mining of the VVF Seam-2 and Seam-4 commenced in 2010. No underground mining was ever envisaged.

The original 2009 numerical groundwater model for VVF (Ref: GW2_069, 2009), which did not provide for the *Wescoal* opencast operations, was updated in 2013 (Ref: GW2_069b, 2013). The 2013 model determined the influence of the new neighbouring mining and tested various mitigation measures.

For this assessment, the numerical groundwater model was revised to determine the revised LOM for the current VVF-Current Pit as well as for the pillar area (proposed VVF-Pillar Pit) and the fact that Wescoal performed opencast mining to the south of the pillar area, leaving a barrier pillar with the VVF-Pillar Pit.

The following information relate to the model setup:

- The numerical model grid consisted of 8 layers and 1.5 million mesh elements to accommodate the complex geometry of the coal seams and aquifer layers:
  - Karoo-Ecca Aquifer-1 listed in Tables 7.2A-D, 7.3A-D & 7.4, were incorporated as the top 5 model-layers where the Karoo is present;
  - Where present, the underlying Dwyka was represented by the bottom 3 model-layers;
  - Model-layers were incorporated/adapted to reflect the expected changing aquifer hydraulics with depth for both the Karoo- and non-Karoo geology;
  - The maximum depth across the model domain was chosen as 70m deep;
  - The historical underground mining areas were incorporated as discrete elements, which enabled the simulation of free-flow;
- Post-mining aquifer parameters were incorporated as follows:
  - Opencast mining was assumed to have an aquifer hydraulic conductivity of 1000 times higher than the shallow weathered zone aquifer;
  - Recharge on all rehabilitated opencast mining was assumed 10% of MAP;
  - The Ogies dyke 180m to the south of VVF was assumed/identified as a major groundwater flow barrier at depths exceeding 5m. Although the vertical contact zones of the dyke with the neighbouring rock may be considered as preferential flow zones, it was not incorporated as such, mainly because groundwater flow is perpendicular to the west-east orientated Ogies dyke and the hydraulic properties of the contact zones were not investigated. Future groundwater evaluations may take a different approach;
  - No provision was made for preferential flow zones along dykes or faults as none (excluding the Ogies dyke) could be identified;
  - The extent of the model grid and cell size of minimum 8m (3m in model sensitive zones) was believed to be sufficient to simulate groundwater flow accurately enough for this report;
- Steady-state groundwater flow modelling was performed to simulate pre-mining groundwater level elevations and flow directions;
- Steady-state and transient groundwater flow modelling were performed to simulate post-mining groundwater level elevations and flow directions;
- Transient flow modelling was performed to assess groundwater base-flow volumes during mining.

Boundary conditions as employed in the numerical groundwater flow and transport model are summarised in Table 7.1.

Table 7.1 Numerical model boundaries

Boundary	Boundary type	Comment
East – northern half	No-flow	Perpendicular to groundwater flow
West – Wilge River	Seepage face	Seepage to surface if groundwater should rise above the stream/riverbed elevation/surface
South – Klipspruit		
North – tributary of Wilge River (locally referred to as the Kromdraaispruit		

7.3. Groundwater Elevation and Gradient

Pre-mining groundwater flow directions/gradients are presented in Figures 7.1A-B. Post-mining groundwater flow directions/gradients for the main flow scenarios (i.e. mining VVF-Current Pit and VVF-Pillar Pit as one unit [Scenarios-1&3], and also mining the barrier pillar with *Wescoal* [Scenarios-2&4]) are presented in Figures 7.2 and 7.3 (determined through numerical groundwater modelling, described in Section 7.8).

Given the groundwater gradients southeast of the *Wescoal* pit (7.7%), northwest of VVF-Pillar Pit (3.8%) and north of VVF-Current Pit (3.2%), groundwater seepage velocities after mining will range between 5.8m/a and 14m/a (see porosity and hydraulic conductivity values in Section 7.6). In other areas the groundwater gradients are smaller at 2%, resulting in a groundwater seepage of 3.7m/a.

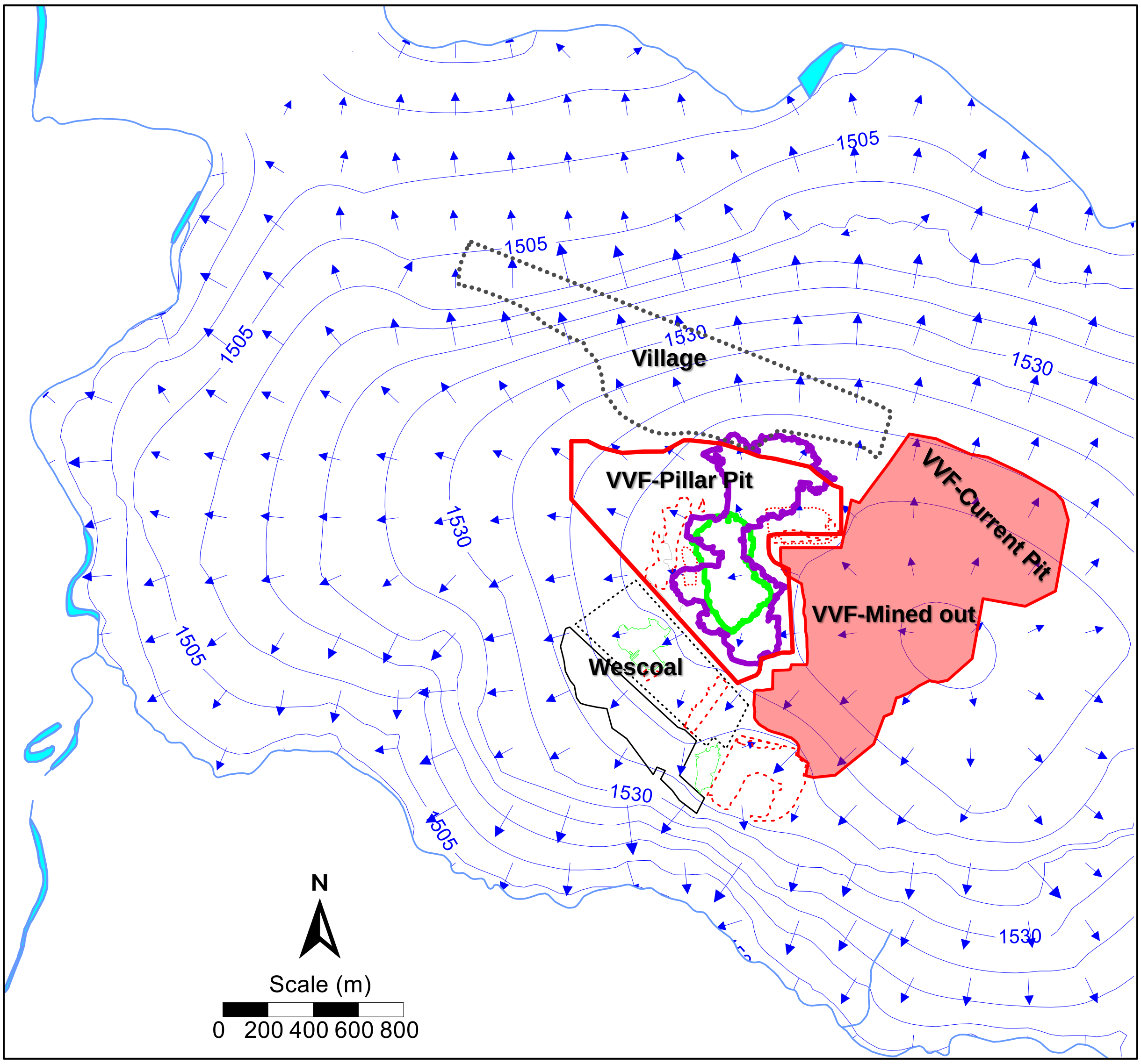


Figure 7.1A Steady state pre-mining groundwater levels (mamsl) and flow directions

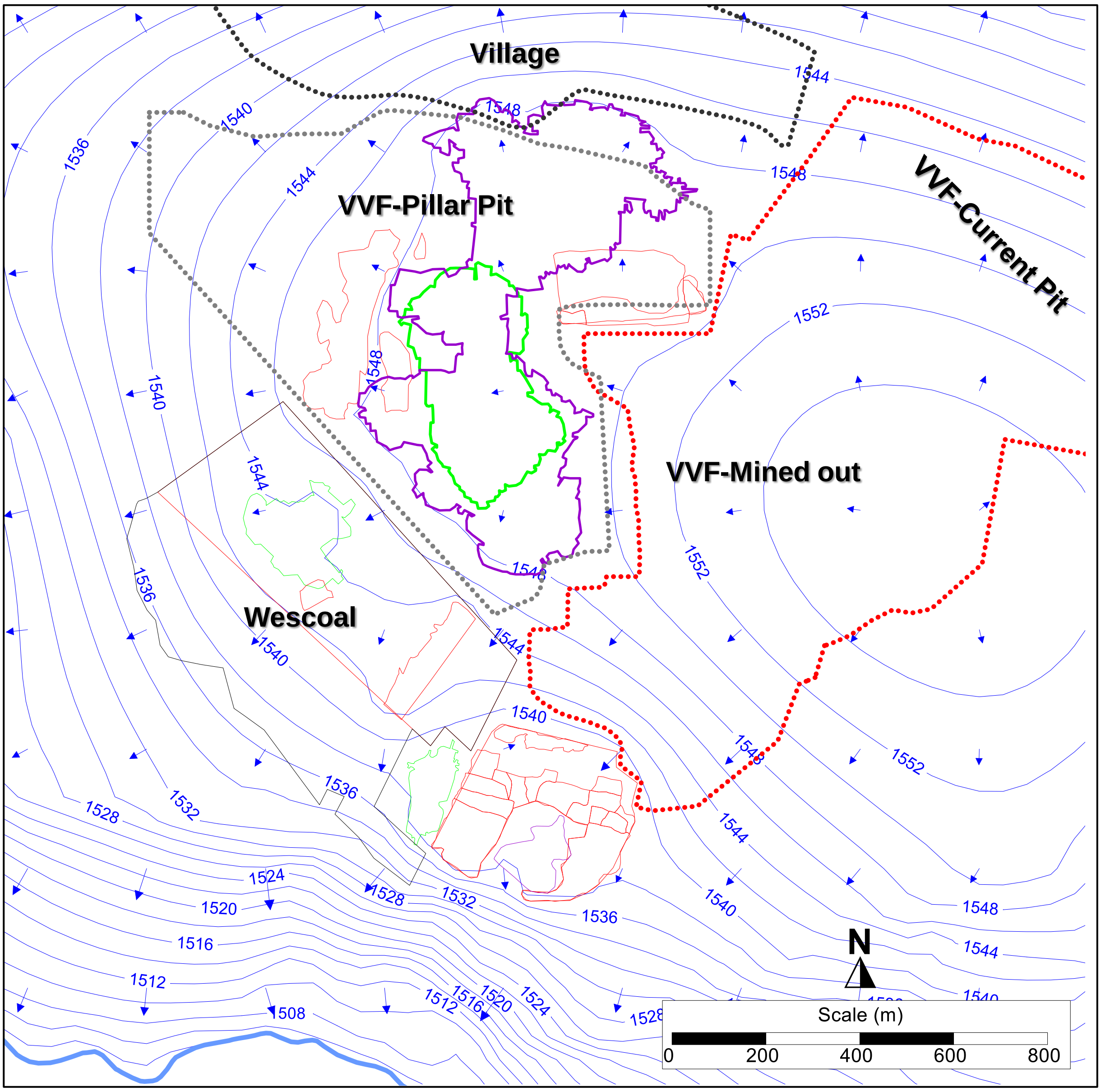


Figure 7.1B ***Steady state pre-mining groundwater levels (mamsl) and flow directions – localised view***

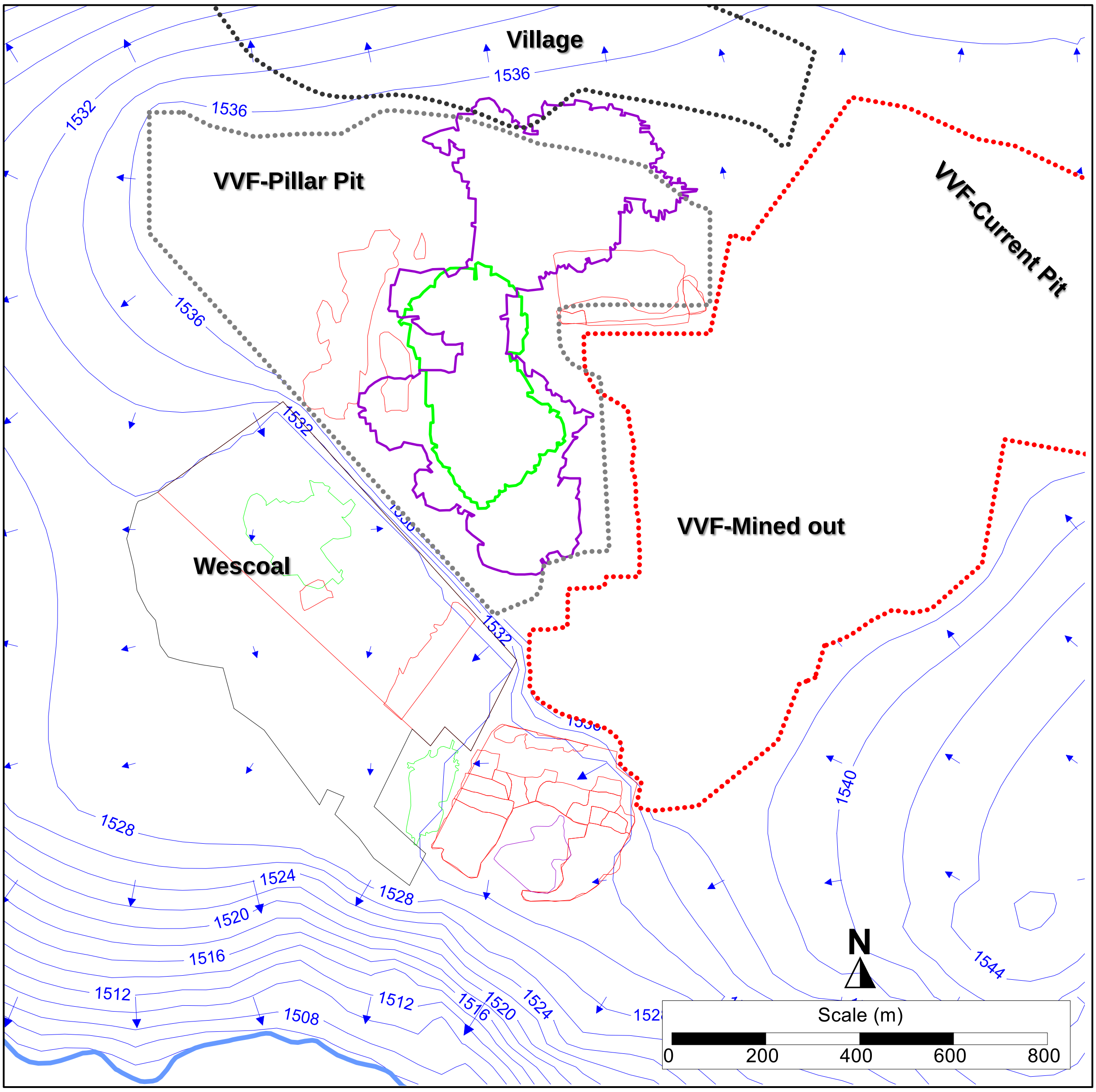


Figure 7.2 ***Scenario-1 and Scenario-3 (VVF-Current Pit and VVF-Pillar Pit mined as one opencast): Steady state post-mining groundwater levels (mamsl) and flow directions***

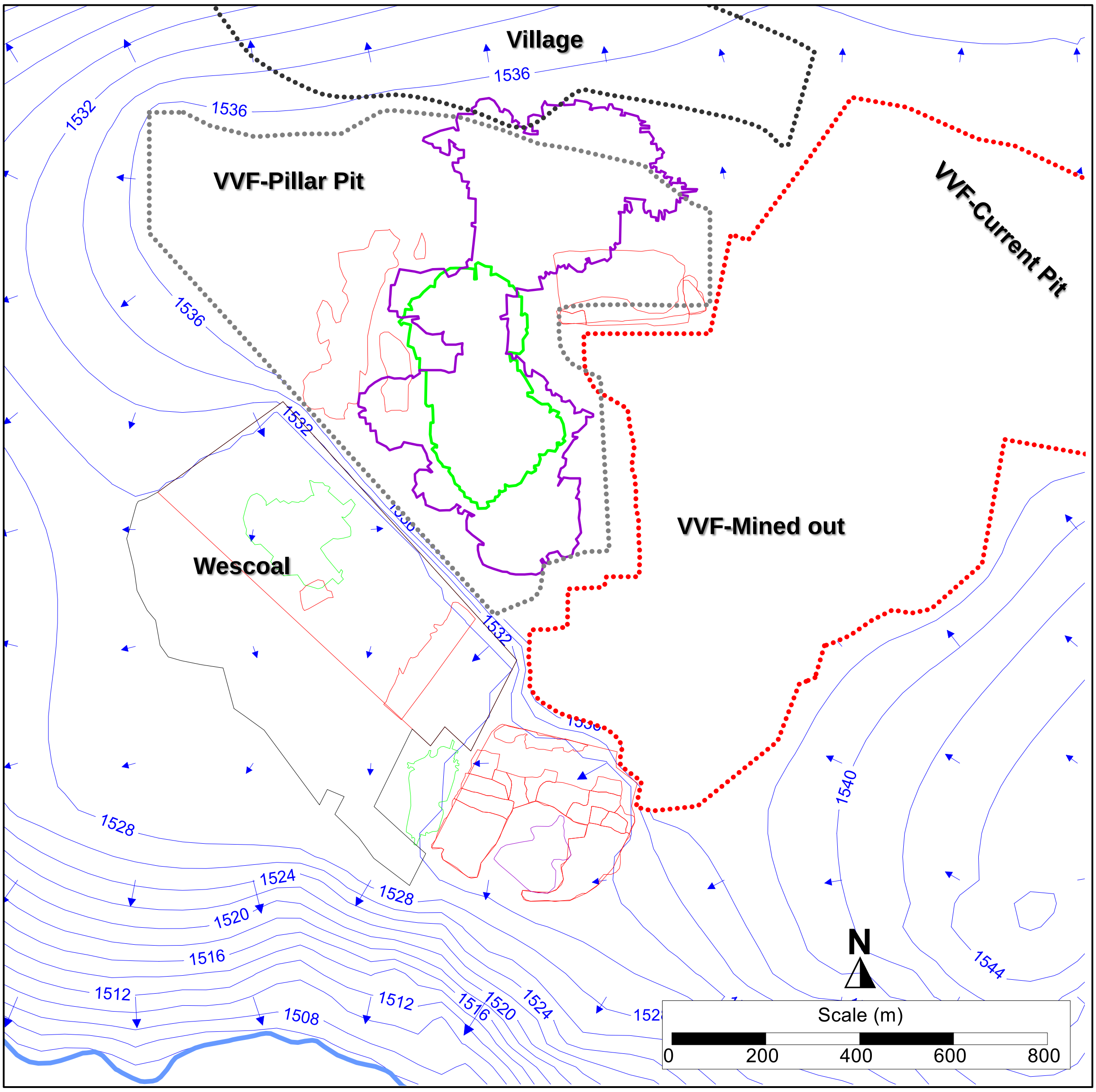


Figure 7.3 ***Scenario-2 and Scenario-4 (VVF-Current Pit, VVF-Pillar Pit and Wescoal Pit forming one opencast after mining of barrier pillar): Steady state post-mining groundwater levels (mamsl) and flow directions***

7.4. Geometric Structure of the Model

Three cross-sections through the VVF-Current Pit, VVF-Pillar Pit, neighbouring Wescoal mining and historic mining areas, were compiled to illustrate the aquifer geometry, groundwater flow and potential decant areas. Locations of cross-section lines are indicated in Figure 7.4, and the cross-sections are included as Figure 7.5.

Coal seam elevations in relation to the surface topography and surrounding streams are very important, i.e. aquifer geometry. With reference to the cross-sections, the following observations relate to the aquifer geometry:

- The relatively flat coal seam floor contours, compared to the pre-mining topographical gradient are evident on the cross-sections; further illustrated through comparison of the Seam-2 elevations and Seam-2 depth (see Figures 7.6 and 7.7);
- The lowest topographical elevations along the VVF-Current Pit and planned VVF-Pillar Pit pit-perimeters are 1557mamsl (southern perimeter) and 1543mamsl (western perimeter) respectively:
- The northern VVF-Current Pit perimeter will be at a lower elevation (1547.5mamsl; ±10m lower) than the lowest elevation along the southern perimeter:
  - However, decant to surface is not expected to the north due to:
    - The final in-pit post-mining groundwater level elevation is expected to be several metres lower than the surface topography at the northern perimeter;
    - The steep topographical gradient downstream of the southern pit perimeter – where mining historically took place – will lower the groundwater levels in this area;
- Sub-surface decant will occur in several directions, away from the combined pit, in the form of a contamination plume;
- The anticipated post-mining decant elevation for the combined VVF Pit but will be along the south-eastern border at 1538mamsl, which is lower than the pit elevation at the perimeter, due to the manifestation of subsurface seepage/decant, through historically mining zone to the south; where the low-permeable diabase and granite rock, downstream of mining will force the groundwater contamination plume to surface (as per the mechanisms prior to mining);
  - With the exception of a very small section along the eastern-most boundary of the pit (where the floor is very steep), the whole pit floor will eventually be flooded naturally to 1538mamsl;
  - However, if the barrier pillar with Wescoal is mined, the in-pit level will be lower (±1530mamsl);
- The thickness of the unsaturated zone in each opencast (i.e. the zone above the groundwater table, where acid-generating material may be in contact with oxygen) has important consequences for the long-term decant water quality;
- Measured groundwater levels prior to mining, provided valuable information on the potential post-mining situation:
  - Groundwater levels in the Vlakvarkfontein opencast mining area varied between 1545mamsl and 1552mamsl;
  - Groundwater levels in the historical opencast north of the Vlakvarkfontein opencast (Pit-A = Pit-1 = 1549mamsl) were approximately 10m higher than in the historical opencast south of the Vlakvarkfontein opencast (Pit-C = Pit-4 =1538mamsl);
  - The lower water levels in the southern historical Pit-C was attributed to sub-surface decant, which discharged to surface, downstream of the historical pit perimeter;
    - Due to the steep topographical gradient in the south, the topographical elevations along the pit perimeter are significantly higher than the elevations 50m downstream;
    - Elevations in the Klipspruit (=Leeuwfonteinspruit) varies between 1505mamsl and 1509mamsl directly south of VVF-Current Pit;
    - As explained before, groundwater seepages downstream of the pit perimeter and historical mining, therefore lowers the groundwater table such that it will not decant to surface at the pit perimeter, but exits the pit as base-flow below surface until it reaches the seepage zone;
- In a post-mining scenario, as discussed above, the in-pit groundwater level will most-likely be naturally restricted to 1538mamsl; with seepage zones also forming at lower elevations:
  - Prior to the commencement of mining in 2010, it was not clear what portion of the seepage originated down-gradient of the 1535mamsl measurement, because seepage water originating higher up against the topography flowed down the hill toward the Klipspruit;
  - The actual final/post-mining rehabilitation elevations (i.e. post-mining topography) will be lower than pre-mining (as indicated on the cross-sections);
- Figure 7.8 serves as a summary of all pertinent elevations.

The volumes of water that can be stored during the post-mining situation in each pit are summarised as stage curves in Figure 7.9:

- The volumes of water and backfill material that can be stored in the VVF-Pillar Pit, below the decant elevation (1538mamsl; see modelling in Section 7), are 1.8Mm^3 and 9Mm^3 respectively;
- The volumes of water and backfill material that can be stored in the VVF-Pillar Pit, below the decant elevation if the Wescoal barrier pillar is mined (1530mamsl; see modelling in Section 7), are 0.8Mm^3 and 3.2Mm^3 respectively;
- If the discard material must be placed 10m below the decant elevation (1528mamsl), the volume of backfill material that can be stored in the VVF-Pillar Pit, is 1.9Mm^3.

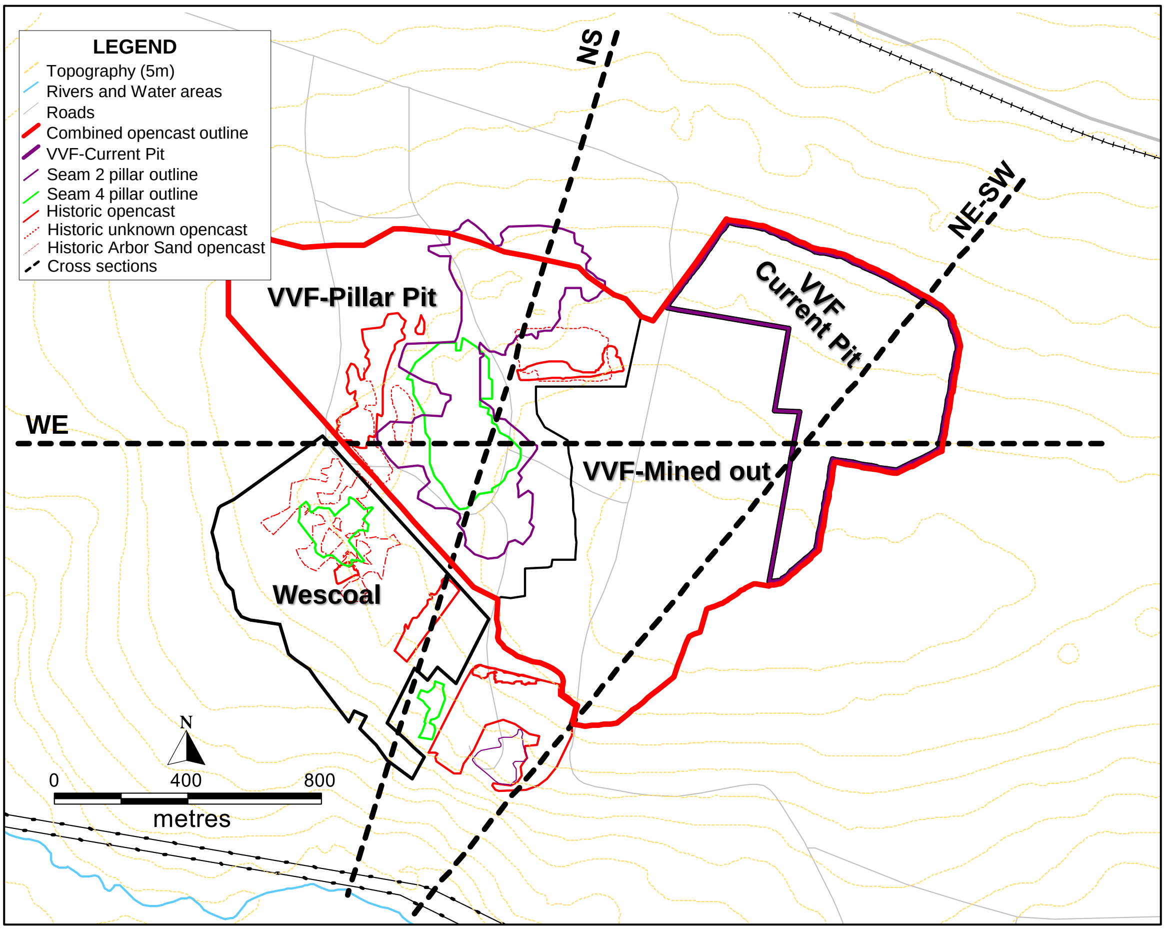


Figure 7.4 Location of cross-sections

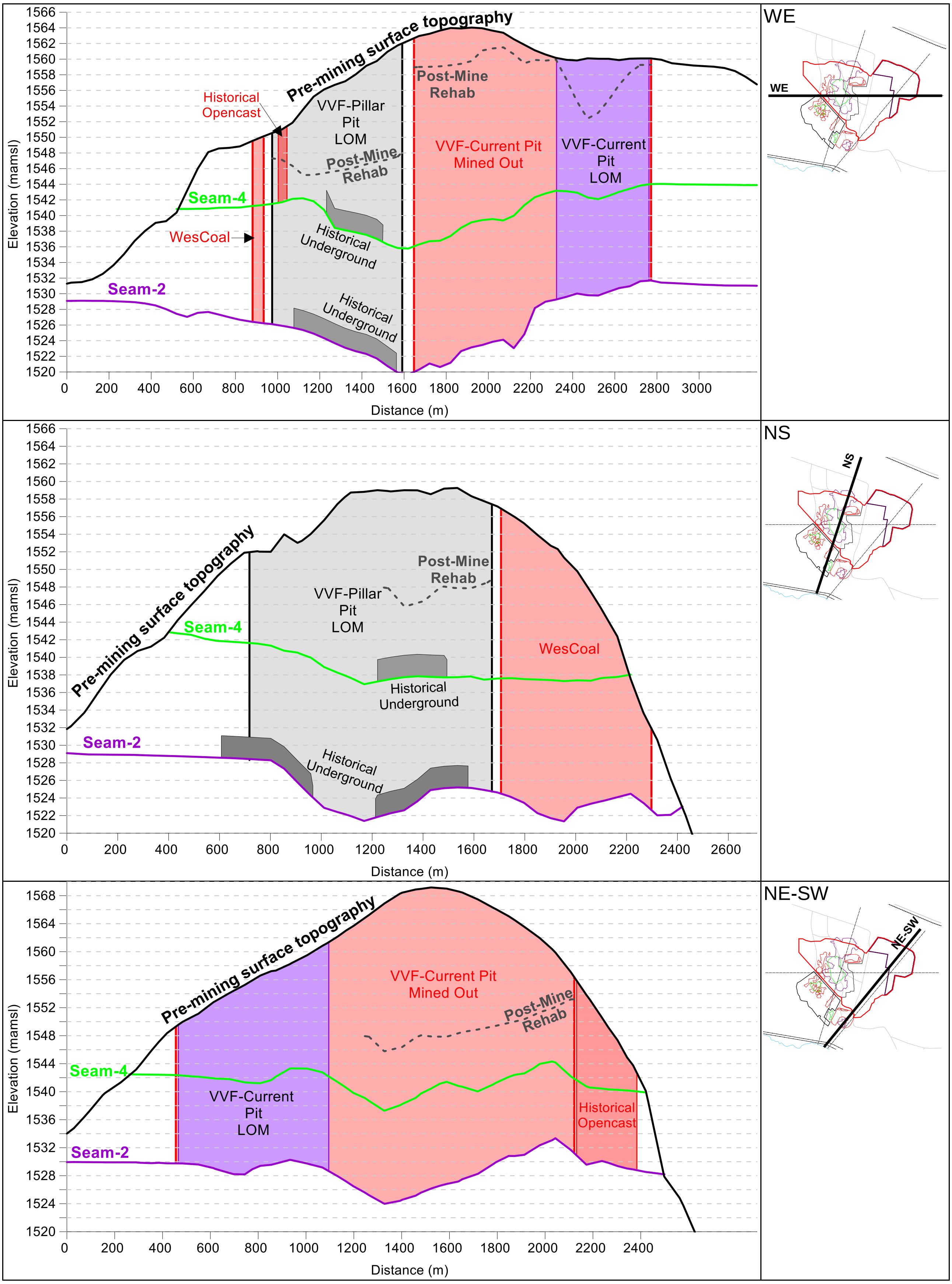


Figure 7.5 Cross-sections

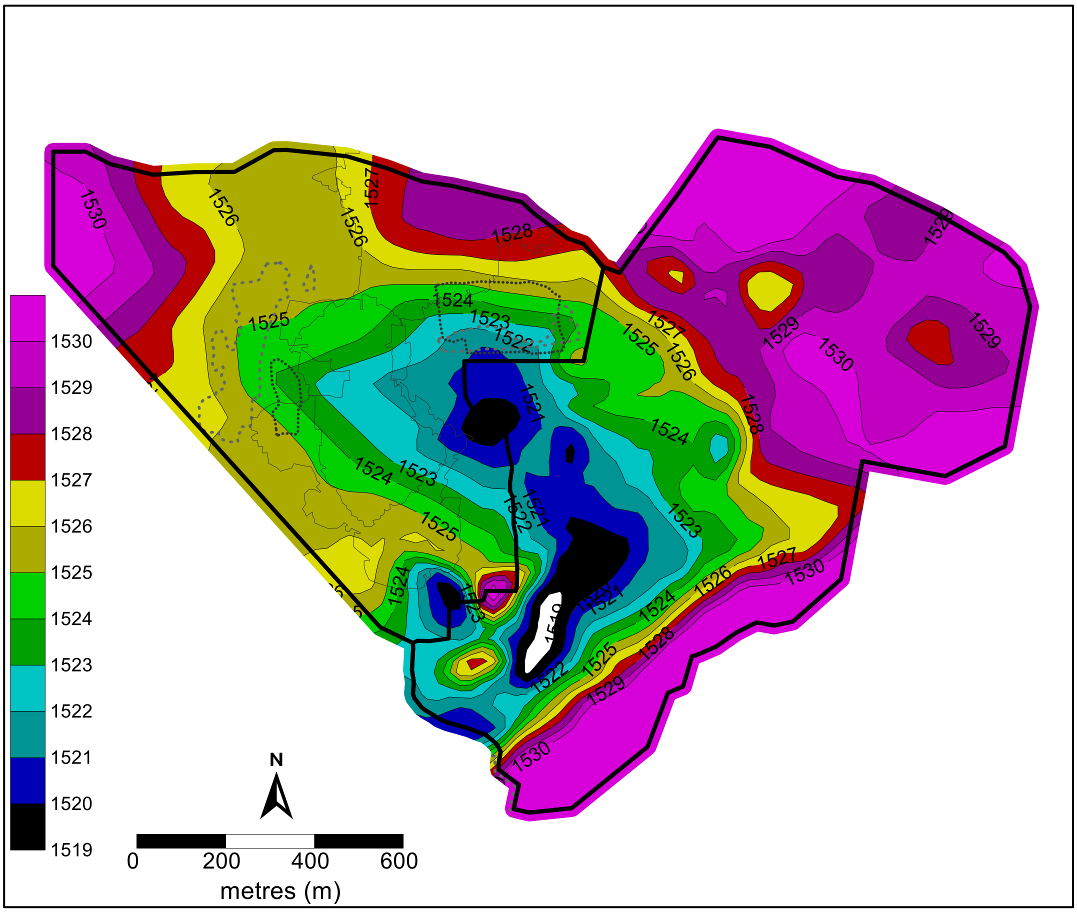


Figure 7.6 Elevations (mamsl) of Seam-2 floor

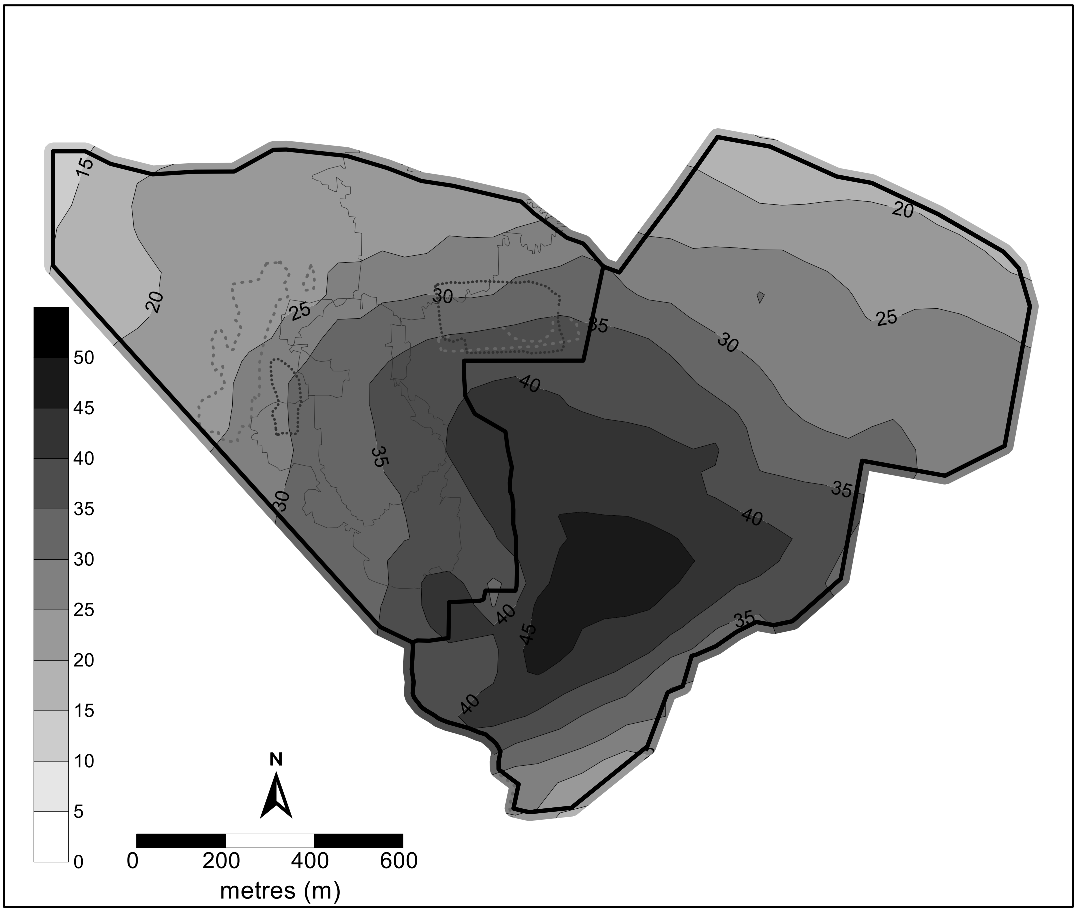
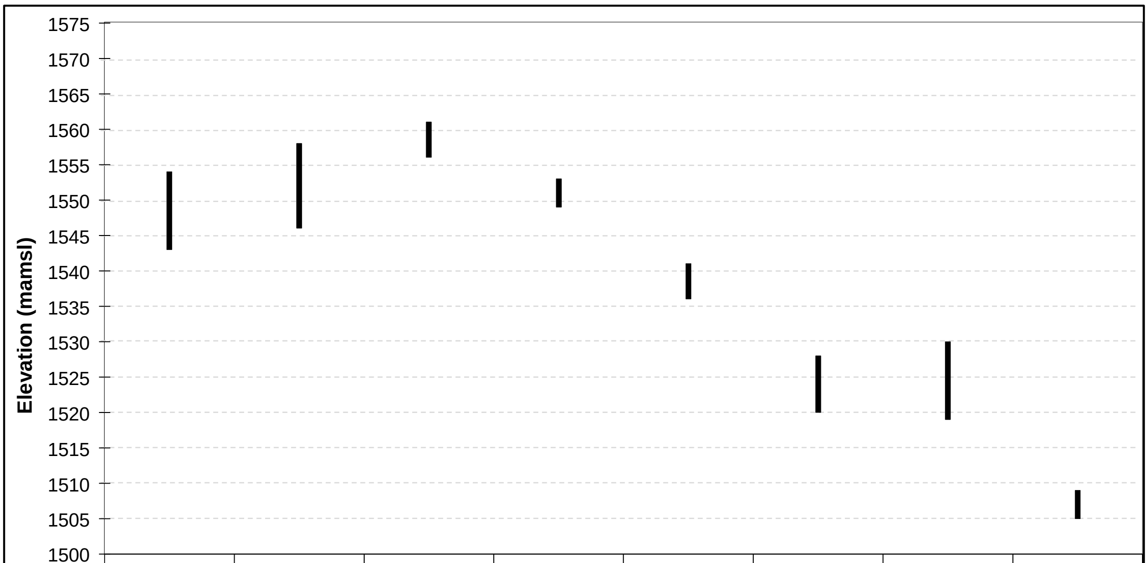
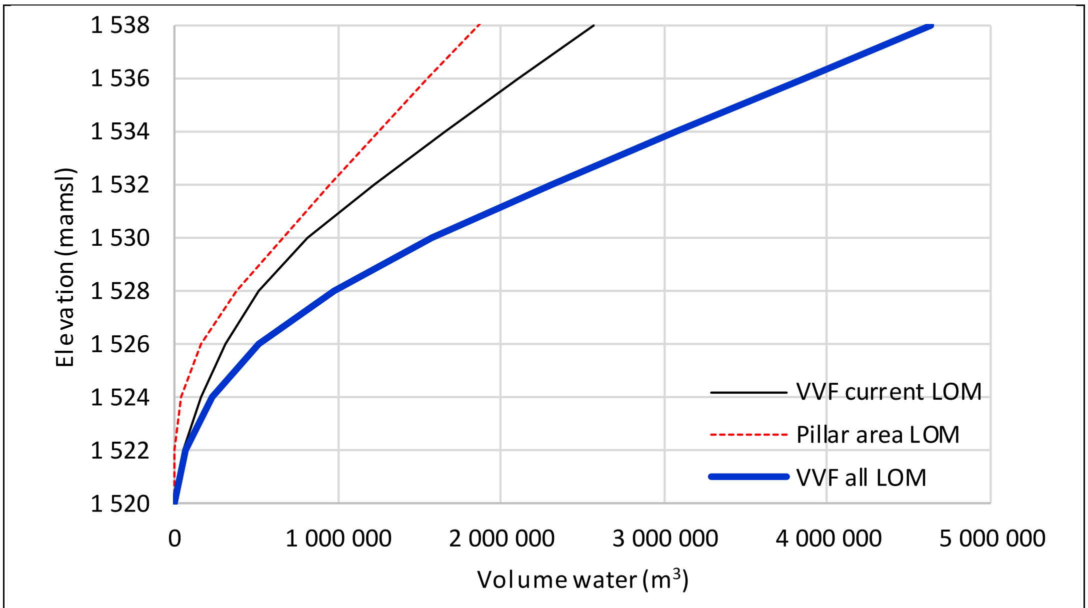


Figure 7.7 Depth (m) to Seam-2 floor below original surface topography



	Northern Perimeter	Southern Perimeter	Historical OC Mining E	Historical OC Mining W	Historical Mining (Seam-4)	Historical Mining (Seam-2)	Pit Floor (Seam-2)	Leeuwfontein spruit
Max	1554	1558	1561	1553	1536	1520	1519	1509
Min	1543	1546	1556	1549	1541	1528	1530	1505

Figure 7.8 Comparison of pertinent elevations (mamsl)



Elevation (mamsl)	Material below elevation (m^3)			Water below elevation (m^3)		
	VVF-Current Pit	VVF-Pillar Pit	Combined Pit	VVF-Current Pit	VVF-Pillar Pit	Combined Pit
1 520	25 000	1 000	28 000	5 000	0	6 000
1 522	260 000	30 000	323 000	55 000	6 000	67 000
1 524	746 000	221 000	1 086 000	158 000	45 000	226 000
1 526	1 489 000	780 000	2 501 000	315 000	159 000	520 000
1 528	2 444 000	1 891 000	4 697 000	517 000	385 000	976 000
1 530	3 842 000	3 241 000	7 581 000	813 000	660 000	1 576 000
1 532	5 767 000	4 697 000	11 102 000	1 220 000	957 000	2 307 000
1 534	7 854 000	6 168 000	14 799 000	1 662 000	1 256 000	3 075 000
1 536	9 991 000	7 639 000	18 545 000	2 114 000	1 556 000	3 854 000
1 538	12 156 000	9 110 000	22 321 000	2 572 000	1 856 000	4 639 000

Figure 7.9 Stage curves, indicating the volume of water that can be stored (assuming a porosity of 20%)

7.5. Groundwater Sources and Sinks

Rainfall is the only natural water source to the groundwater balance. No other/artificial water is generated otherwise (i.e. no irrigation or rivers draining over the area).

Groundwater abstraction from boreholes for the informal settlement, mine water pumping from the pit (for dust suppression or storage in the pollution control dam), and natural evaporation from the pit are the only sinks to the groundwater resource.

7.6. Conceptual Model

The major groundwater flow units/aquifers, listed in Tables 7.2A-D, 7.3A-D & 7.4, were identified and calibrated during the 2009 groundwater study and confirmed during the 2013 study. Numerical modelling for this study did not indicate that the parameters may be substantially different.

Table 7.2A Aquifer layers – Karoo-Ecca

Aquifer	Average depth	Description	Comment
Aquifer-1	≤42m (varying in thickness)	Shallow weathered zone aquifer, which includes the overburden material of 1m-8m thick (average 5m thick)	Unconfined to semi-confined conditions. Groundwater levels are shallower after wet rainfall periods or in close proximity to rivers/streams

Table 7.2B Aquifer layers – Karoo-Ecca Seam-4 and Seam-2

Aquifer	Average thickness	Description	Comment
Seam-4 and Seam-2	Avg. = 4.5m (both seams)	Typical to find water-strikes on top and bottom contacts	Only restricted to the surroundings of historical and planned mining. Most water-strikes on Seam-4

Table 7.2C Aquifer layers - Dwyka

Aquifer	Average depth	Description	Comment
Dwyka-Aquifer-1	<4m thick	Non-fractured "fresh" aquifer, immediately below Seam-2	Possibly more permeable than Dwyka-Aquifer-2, if found at shallow depths (as is the case in the vicinity of Vlakvarkfontein)
Dwyka-Aquifer-2	>>	Non-fractured "fresh" aquifer, below Dwyka-Aquifer-1	The physical characteristics are indicative of an extremely low hydraulic conductivity and low storativity

Table 7.2D Aquifer layers and dykes, which surround the mining area

Aquifer	Average depth	Description	Comment
Ogies Dyke	<5m	Ogies dyke shallower than 5m below surface	Ogies dyke potentially weathered at shallow depths
	>5m	Ogies dyke deeper than 5m below surface	Ogies dyke assumed non-weathered and non-fractured below 5m
Alluvium	<5m	Alluvial deposits	To the south along the Klipspruit
Transvaal			(Selons River and Loskop Formations)
Granite			Bushveld Complex
Diabase			Post-Transvaal

Table 7.3A Aquifer layer parameters - Ecca

Aquifer Layer	Thickness (m)	Hydraulic conductivity (m/d) [m/s]	Storativity	Porosity	Rainfall Recharge (m/d) {mm/a} [%of MAP]
Ecca-Aquifer-1	≤42m (varying in thickness)	(0.04) [4.8×10^{-7}]	0.04	0.08	(3.8×10^{-5}) {14} [2] to (4.8×10^{-5}) {17.5} [2.5]

Table 7.3B Aquifer layer parameters – Ecca-Seam-2

Aquifer Layer	Thickness (m)	Hydraulic conductivity (m/d) [m/s]	Storativity	Porosity	Rainfall Recharge (m/d) {mm/a} [%of MAP]
Seam-4 and Seam-2	Avg. = 4.5m (both seams)	(0.09) [1.0×10^{-6}]	0.02	0.06	Not applicable

Table 7.3C Aquifer layer parameters – Dwyka

Aquifer Layer	Thickness (m)	Hydraulic conductivity (m/d) [m/s]	Storativity	Porosity	Rainfall Recharge (m/d) {mm/a} [%of MAP]
Dwyka-Aquifer-1	4m	(0.01) [1.2×10^{-7}]	0.01	0.03	Not applicable
Dwyka-Aquifer-2	>>	(0.002) [2.3×10^{-8}]	0.01	0.03	

Table 7.3D Aquifer layers and dykes, which surround the mining area

Aquifer Layer	Thickness (m)	Hydraulic conductivity (m/d) [m/s]	Storativity	Porosity	Rainfall Recharge (m/d) {mm/a} [%of MAP]
Ogies Dyke	<5m	(0.04) [4.8×10^{-7}]	0.01	0.03	(3.8×10^{-5}) {14} [2]
	>5m	(9×10^{-4}) [1×10^{-8}]	0.01	0.03	
Alluvium	<5m	(0.06) [7×10^{-7}]	0.07	0.10	
Transvaal	<30m	(0.06) [7×10^{-7}]	0.04	0.08	
	>30m	(0.03) [3.5×10^{-7}]	0.04	0.08	
Granite	<30m	(0.002) [2.3×10^{-8}]	0.01	0.03	(1.9×10^{-5}) {7} [1]
Diabase	<30m	(0.04) [4.8×10^{-7}]	0.04	0.08	

Table 7.4 Additional aquifer hydraulic conductivity and recharge values used in the Regional-Model Post-mining situation

Ecca-Aquifer-1	Hydraulic conductivity (m/d) [m/s]	Rainfall Recharge (m/d) {mm/a} [%of MAP]
Opencast backfill/rehabilitated	(5) [5.8×10^{-5}]	Significant tree coverage: (1.0×10^{-4}) {35} [5] No tree coverage: (2.9×10^{-4}) {105} [15]
Underground Mining	Free-flow	(4.8×10^{-5}) {17.5} [2.5]
Rehabilitated areas – not opencast mined	(0.04) [4.6×10^{-7}]	Significant tree coverage: (1.0×10^{-4}) {36.5} [5]
Old adits	(0.45) [5.0×10^{-6}]	(1.0×10^{-4}) {36.5} [5]
Old Sand mine	(0.5) [5.8×10^{-6}]	Significant tree coverage: (7.5×10^{-5}) {27} [4]

7.7. Numerical Model

Numerical modelling was performed for the pre-mining, operational phase, and post-mining for a period of 100years after mine closure. Four numerical modelling scenarios were performed for the post-mining situation, to study the placement of coal discard back into the pit, as well as to determine the effect if the barrier pillar with Wescoal is mined; see summary in Table 7.5.

Figure 7.10 serve as a summary of the geochemical sulphate concentration trends for the four modelling scenarios as well as for the placement of discard on surface (see discussion in Section 5.2). Note that discard cannot be placed in the VVF–Current Pit because it will be impractical given the current status of rehabilitation.

Table 7.5 Description of main modelling scenarios

Model scenario	Mining included in modelling		Model results - post-mining	
	Mine Wescoal barrier pillar	**Place discard into VVF-Pillar Pit**	**Groundwater levels**	**SO_4 plumes**
Scenario-1	No	No	Figure 7.2	Figure 7.13A
Scenario-2	Yes	No	Figure 7.3	Figure 7.13B
Scenario-3	No	Yes	Figure 7.2	Figure 7.12, Figure 7.13C
Scenario-4	Yes	Yes	Figure 7.3	Figure 7.13D

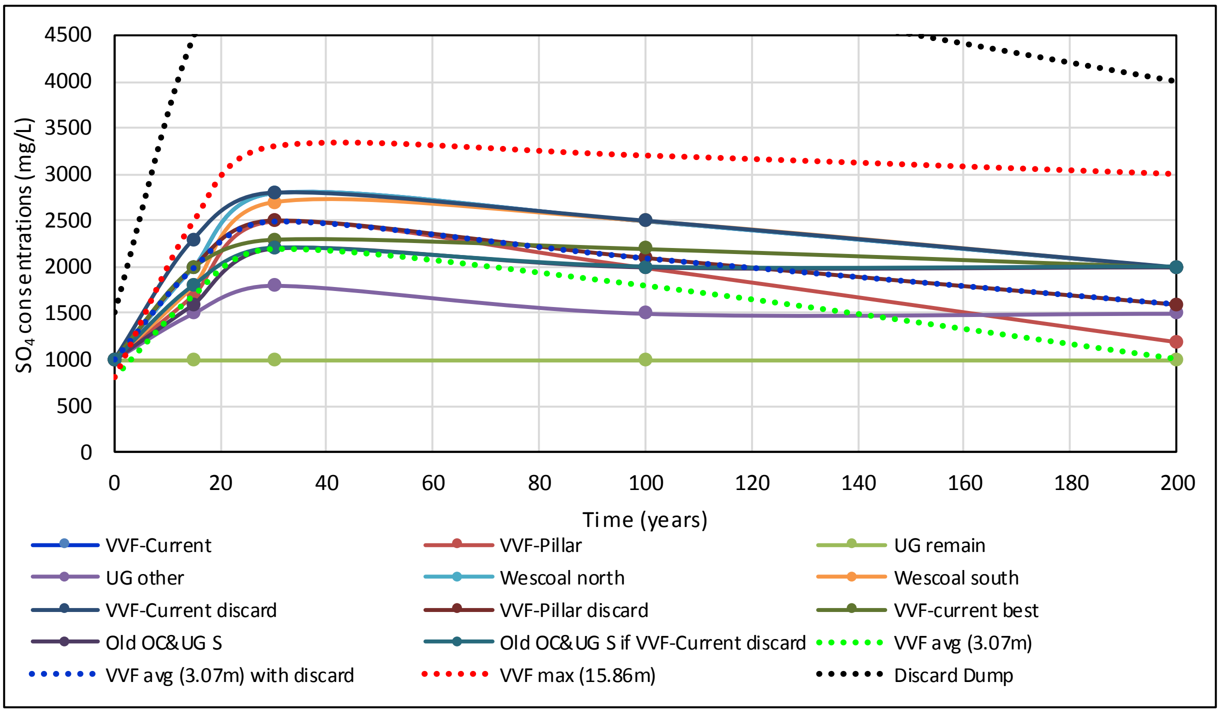


Figure 7.10 Geochemical trends

7.8. Results of the Model

7.8.1 Pre- Mining

Pre-mining groundwater level elevations and groundwater flow directions are depicted in Figure 7.1A-B.

Prior to mining, groundwater flow was radially outward from the coal resource area to the north, east and south. Along the eastern extremities of the coal resource, groundwater flow was from east, in a westward direction toward the resource. Most importantly groundwater flow, in the most critical impact area, around the southern regions, was predominantly to the south.

7.8.2 During Mining

Due to the current contaminated situation inside the proposed pillar mining area, mining of the VVF-Pillar Pit does not constitute a loss of a groundwater resource. During mining, groundwater flow will be toward mining, resulting in the following groundwater impacts:

- A dewatering cone will develop around the VVF-Pillar Pit; expanding on the current dewatering cone:
  - This zone indicates the area within which groundwater levels may be impacted/ lowered, but does not necessarily mean that all groundwater flow will be toward the mining area; i.e. while groundwater flow in the immediate vicinity of the pit will be toward the pit, groundwater flow will still be away from the mining area in certain areas, but groundwater levels will be lower than prior to mining and the rate of groundwater flow will be smaller:
  - The dewatering cone will gradually expand in the shallow weathered zone aquifer, with a maximum impact zone as indicated in Figure 7.11:
    - During mining, groundwater levels in the immediate vicinity of the pits will be influenced most, typically limited to 200m from the pit perimeter for the first few years (2years to 4years), gradually expanding over time;
    - During the early stages of dewatering the biggest groundwater level drawdown effect will be observed at the Pit boundary, depending on the Pit floor depth below the groundwater table (≤30m);
    - Eventually, the drawdown at 400m will typically not be distinguishable from seasonal groundwater trends, and only applies to areas where the Pit floors are deepest below the natural groundwater table (note that the dewatering zones of influence in Figure 7.11, represent likely and worst-case scenarios);
  - The village drinking water supply is likely to be impacted;
- Storage of underground mine water:
  - There will be insufficient space to store all water pumped from the historical underground areas. Management measures will probably include a combination of treat-and-discharge, in-pit storage, PCD storage, as well as early utilisation of this water in the plant;
  - A maximum in-pit storage level of 1525mamsl in the rehabilitated VVF-Current Pit is recommended, to prevent decant during the operational phase; whilst mining is progressing in the eastern regions of the VVF-Pillar Pit:
    - In-pit storage of this water, is unlikely to have an impact on local groundwater levels and groundwater quality;
    - The fact that the barrier pillar between the current VVF-Current Pit and the VVF-Pillar Pit will only be mined during the final stages of mining (i.e. to form one pit), may provide an opportunity for in-pit water storage of water contained in the flooded historical mined-out underground areas;
- No decant will occur during mining, unless excessive volumes of water stored in-pit;
- Groundwater inflow:
  - The groundwater contribution to the pit water balance are provided in Tables 7.6 and 7.7;
  - Due to the shared mining boundaries with VVF-Current Pit and *Wescoal*, the current mine water balance cannot simply be extrapolated in relation to the size of the final pit;
  - Direct rainfall recharge to mine-out voids/backfill/rehab needs to be factored in for the total pit water balance;
  - The mine may experience a water deficit during prolonged dry rainfall spells (as experienced periodically to date);
  - Evaporation, can have a significant impact on the mine water balance during certain times of the year, and can potentially reduce the rainfall recharge component by 50% to 100% during dry summer rainfall periods; thus, also exceeding the groundwater inflow component.

The following comments related to the anticipated mine water quality during the mining phase:

- The surrounding aquifers are not expected to be impacted in terms of groundwater quality during the mining phase, due to groundwater flowing toward the dewatered mining area:
  - This will also be the case if discard and filter cake is stored in-pit (when the AMD processes may already commence);
- Placement of discard (with reference to the long-term impacts of discard, addressed in Section 7.8.3):
  - Due to the poor water quality that will leach from the discard, AMD toe seepages are likely to occur if placed on undisturbed/unmined ground, with the potential to contaminate the groundwater system if not properly lined;
  - Assuming a discard dump is placed on rehabilitated opencast areas:
    - It is not known how efficient the discard dump can be lined;
    - If the discard dump is unlined, or the liner is compromised due to uneven settlement, AMD can be captured in the pit;
- Operational phase water quality of the VVF-Pillar Pit is likely to be worse than the current VVF-Current Pit, due to:
  - Mine water in the rehabilitated historic opencast areas, to the west of the underground areas, is highly contaminated where (pH probably ranges from <3 to 4.5 and sulphate concentrations exceed 3000mg/L);
  - Based on mine water samples that were collected from exploration boreholes during November 2016, mine water in the Seam-2 workings currently has a pH of <5.4, and mine water in the Seam-4 workings has a pH of ±3 (sulphate concentrations probably range between 800mg/L and 1500mg/L).

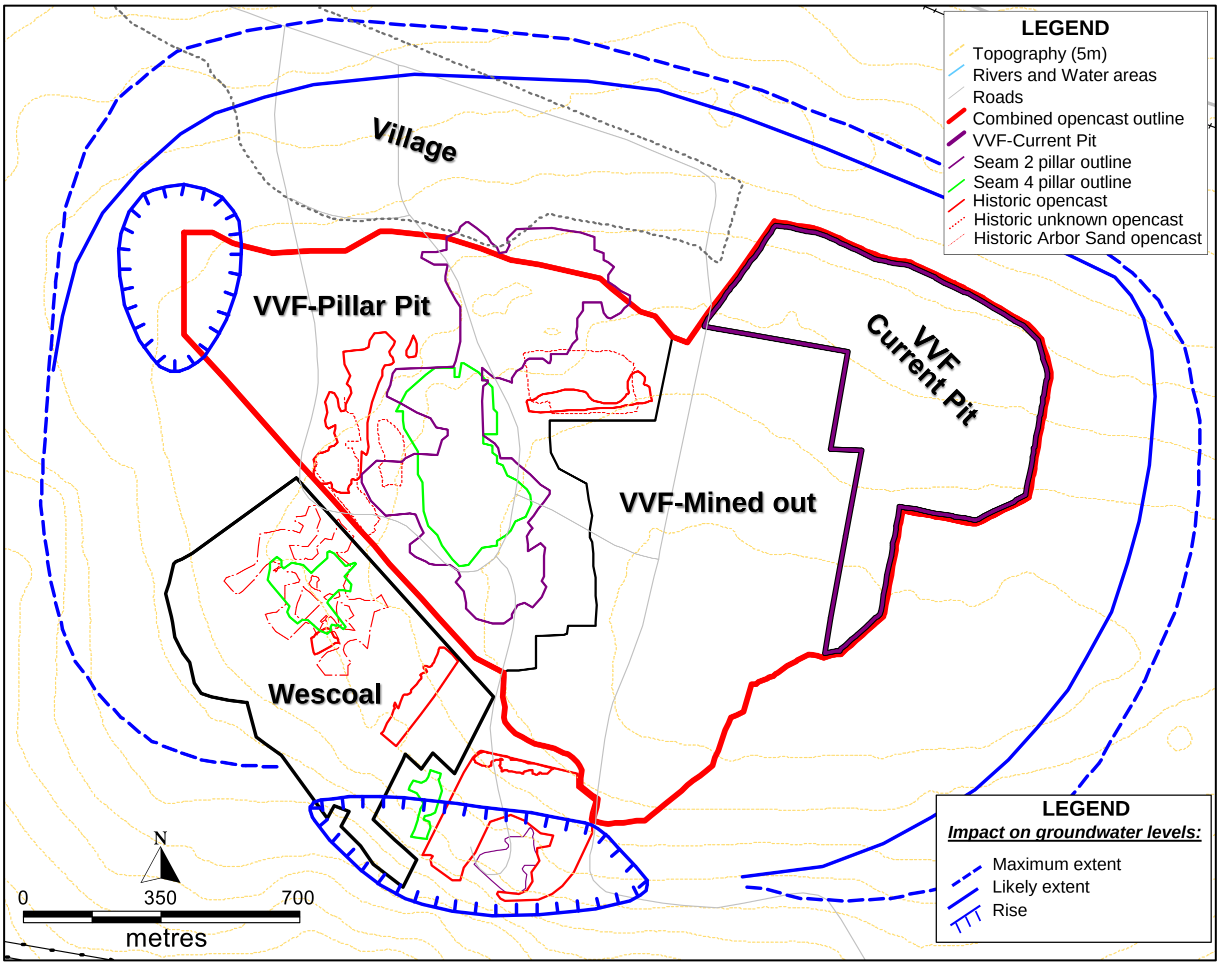


Figure 7.11 Groundwater levels impact zones during mining and post-mining

Table 7.6 Numerical modelling predictions of groundwater inflow into the two main opencast pits

	Comment	**Average (m3/d)**	**Range (m3/d) Dry to wet rainfall cycles**
VVF-Current Pit	After all mining has been completed early 2019	600	0 - 1100
VVF-Pillar Pit	Does not account for mine water that has to be pumped out. Shared boundaries to dewatered areas east (i.e. dewatered VVF-Current Pit) and south (*Wescoal*).	500	0 - 800
Total		1100	0 - 1900

Table 7.7 Groundwater inflow volumes for the pillar area only

Year	Comment	Cumulative (m3/d)	
		Average	Dry to wet rainfall cycle range
Year 1 (FY2020)	Box-cut up to first 4months of mining	Increase to 200	0 - 400
	End of first year	420	0 – 660
Year 2 (FY2021)		540	0 – 900
Year 3 (FY2022)		640	0 – 1000
Year 4 (FY2023)	No increase in inflows due to effects of dewatered areas to east (VVF-Current Pit) and south (Wescoal).	500	0 – 800
Year 5 (FY2024)		500	0 – 800
Year 6 (FY2025)		500	0 – 800

7.8.3 Post-Mining

Figures 7.2-7.3 depict the anticipated post-mining steady-state groundwater levels and groundwater flow directions for the mining-scenarios listed in Table 7.5. Groundwater levels are indicated in the critical zone around the VVF-Current Pit, VVF-Pillar Pit, *Wescoal* Pit and the decant area immediately to the south.

Prior to the commencement of VVF mining, decant was observed in two areas as indicated in Figures 1.3, 1.5 and 1.6. Main-decant-zone-east is located directly south of the VVF-Current Pit where historical opencast mining and Seam-2 underground mining by Sterling-TVL was undertaken. Main-decant-zone-west is located between poplar trees, south of the *Wescoal* Pit, west of Main-decant-zone-east, south of historical opencast and Seam-4 underground mining by Sterling-TVL.

Post-mining flooding level of all opencasts are likely to occur within 30years after the cessation of mining; the bigger the volume of water stored in-pit at the end of mining (i.e. backfill material may be partially flooded to a certain elevation), the sooner before flooding occurs. All indications are that the combined VVF-Current Pit and VVF-Pillar Pit will flood to a level of 1538mamsl. If the barrier pillar with *Wescoal* is mined the final level will be 5m deeper, because the decant elevation at *Wescoal* is 5m lower than the numerically simulated in-pit mine water level of the combined VVF-Current Pit and VVF-Pillar Pit.

The following differences in groundwater flow characteristics are emphasized for the mining scenarios after the cessation of mining:

- Historical mining (i.e. prior to VVF mining) did not alter groundwater flow directions significantly; the most significant effect being that:
  - Higher recharge to opencast regions resulted in slightly faster groundwater flow (i.e. higher seepage/decant volumes) in the main decant zones;
  - AMD generation in opencasts and the southern underground regions, however, contaminated the groundwater system to the south;
- The expected effect of VVF-Current Pit and VVF-Pillar Pit:
  - Additional recharge to the rehabilitated opencast will increase the decant volumes (and salt load) to the two decant areas (south);
  - Additional groundwater flow toward the pit could also be expected at the eastern pit perimeter, due to lower groundwater levels in the opencast;
  - Because groundwater levels inside the pit will be lower than the original pre-mining levels over most of the area, the surrounding aquifers will remain dewatered to a certain extent:
    - The likely zone of influence is indicated in Figure 7.11;
    - The village drinking water supply is likely to be impacted;
    - Along the north-western corner of the VVF-Pillar Pit, and south of the VVF-Current Pit, groundwater levels are likely to be higher than pre-mining. However, this does not indicate that decant will occur;

- The expected effect of VVF-Current Pit and VVF-Pillar Pit, and mining of the barrier pillar with the *Wescoal* pit:
  - The final in-pit groundwater level is expected to be at 5m to 8m lower than the decant level of 1838mamsl, if the barrier pillar is not mined (see comparative groundwater level elevations in Figures 7.2 and 7.3;
  -
  - Given the steeper groundwater gradients around the pit, slightly higher groundwater flow toward the pit will occur, compared to a scenario where the barrier pillar is not mined;
  - The likely zone of influence will not be worse than indicated in Figure 7.11 (i.e. the village drinking water supply is likely to be impacted);
- Even if the VVF-Pillar Pit is not mined, the addition of the *Wescoal* opencast will/have altered groundwater flow as far as 500m north of the opencast due to the large area where preferential flow can occur in historical opencast and underground regions:
  - Groundwater flow directions and velocities around the south-western and southern regions of the VVF-Current opencast will be altered toward the southwest (i.e. toward *Wescoal*);
  - Even groundwater flow which would have been to the south from the southern VVF-Current Pit boundary, will be attracted to the *Wescoal* opencast due to the difference in groundwater elevations;
  - Consequently, a significant portion of decant that would have taken place to the Main-decant-zone-east (i.e. directly south of the VVF-Current Pit), are expected to change course to the Main-decant-zone-west south of the *Wescoal* Pit (between the poplar trees, west of Main-decant-zone-east);
- The 2013 numerical groundwater model investigated the effect that a barrier wall would have on the post-mining decant situation (installed to heights of 1535mamsl and 1540mamsl):
  - Smaller groundwater inflows into the VVF opencast will occur if the top elevation of the barrier wall is 1540mamsl compared to 1535mamsl (i.e. higher post-mining groundwater levels in the VVF opencast will result in smaller inflows into the pit);
  - Assuming it does not leak (i.e. installed to below the pit floor), the barrier wall will reduce groundwater flow velocities to the south significantly;
  - The following relates to the efficiency of the wall:
    - The mean annual recharge to the VVF pit at 10% of MAP is estimated at 255m^3/d (3L/s), which is very small compared to the water that can leak through a crack;
    - The Dwyka tillite formation below the pit floor is known to have higher hydraulic conductivity values at depths <30m (the eastern portion of the pit floor along the southern border of the VVF pit is relatively shallow – this is also a region where there is only a 9m barrier pillar [with blasting fractures] between VVF-Current Pit and the historical opencast); thus potentially leaking contaminated mine water to the decant areas where it will have to be controlled/treated;
    - Groundwater studies in the surrounding geological/hydrogeological environment has identified the preferential flow zones and high yielding fractures on geological contact below the Karoo aquifers.

Given the post-mining groundwater flow directions, contamination plumes will potentially spread towards the northwest of the VVF-Pillar Pit, and to the south. Smaller plumes will extend north of VVF-Current Pit and southwest of *Wescoal*. Groundwater flow from the east will be towards the VVF opencast, and no plume is expected to develop in this direction.

Due to historical opencast/underground mining and associated acid mine drainage (AMD) decant (pH of 2.8 to 3.2; SO_4 of 1000mg/L to 1500mg/L), aquifers to the south have already been contaminated. This occurred through contaminated groundwater flow from the historic underground mining areas as well as contaminated surface run-off (decant from the underground areas), which historically drained overland towards the Klipspruit (also known as the Leeuwfonteinspruit). The overland flow of contaminated water infiltrated through the soil profile to contribute to the contamination mechanism to the groundwater resource in this area. Therefore, the groundwater plume to the south will develop into an aquifer which has already been contaminated. To be able to portray the contamination plume to the south, the already impacted aquifers are not indicated. However, it will not be possible to observe the contaminant movement to the south, into the already contaminated aquifers.

It is important to note that prior to the mining of Vlakvarkfontein by *Mbuyelo*, the highest elevations at which AMD decant seepages occurred, south of the VVF-Current Pit, ranged between 1535mamsl and 1538mamsl. Here, the contamination plume was forced to surface against the relatively impermeable granite rock. The AMD decant then flowed overland to the Leeuwfonteinspruit (1505mamsl to

1509mamsl). This area south of the VVF-Current Pit, will again serve as a natural decant area after the cessation of mining. South of the VVF-Pillar Pit, these decant elevations are probably lower by approximately 5m to 8m. This decant cannot be prevented without active manipulation of the in-pit water level, such as through pumping or evaporation. Strategies to deal with the pumped water, include reuse and treatment. If the water is not pumped, the decant water should be diverted to a point where it can be handled.

The contaminant contribution from VVF-Pillar Pit will be smaller than the extreme AMD conditions that currently exist (prior to mining) in the western-most historical opencasts that were rehabilitated/ backfilled by DWA in 2006 (pH of 3 to 5; SO_4 of 3000mg/L to 4600mg/L). The worst water quality observed in boreholes VBH-8M/S are attributed to historical mining and the 2006 backfilling of opencast void by waste material. Underground mine water samples were collected from exploration boreholes during November 2016. Mine water in the Seam-2 workings currently has a pH of <5.4, and mine water in the Seam-4 workings has a pH of ±3. Sulphate concentrations probably range between 800mg/L and 1500mg/L).

The following additional comments relate to the post-mining groundwater contamination:

- Groundwater quality trends:
  - All geochemical scenarios (mine water with-and-without discard, and for the discard dump) indicated pH levels lowering from 6 to 4 over the first 30years, followed by a further drop to pH 3.5 to 4.5 over the long-term (100years) – see estimated range for pH and sulphate concentrations in seepage in Table 7.8;
  - Post-closure evolution stages in AMD are summarised in Table 7.9;
  - Geochemical trends for various scenarios/pits are summarised in Figure 7.10;
- Not all decant will occur at the Pit perimeter:
  - Sub-surface decant (i.e. the formation of a groundwater contamination plume) will occur primarily to the northwest and south (i.e. in the direction of groundwater flow);
  - Some of this water will decant to surface before the final in-pit water level is reached;
- The spread of groundwater contamination will be influenced by the low hydraulic conductivity of the hard rock (0.04m/d), rock porosity (relatively high for this course-grained aquifer; >0.08), and groundwater gradients:
  - Section 7.3 describes groundwater gradients southeast of *Wescoal* pit (7.7%), northwest of VVF-Pillar Pit (3.8%) and north of VVF-Current Pit (3.2%) – in some areas the groundwater gradient is only 2%;
  - Groundwater seepage velocity in the shallow weathered zone aquifer was therefore calculated as ranging between 3.7m/a and 14m/a (= 370m to 1400m in 100years);
- Assuming the barrier pillar with the *Wescoal* pit is not mined, and discard is backfilled into the VVF-Pillar Pit (i.e. Scenario-3):
  - The groundwater SO_4 contamination plume indicated in Figure 7.13C is therefore the expected worst-case outcome after 100years (see development of contamination plume after 20years, 30years, 50years and 100years for Scenario-3, in Figure 7.12);
  - Figures 7.13A, B & C depict the concentrations after 100years for all four modelling scenarios;
  - As can be seen in Figures 7.13A and 7.13C, there is very little difference in the spread of groundwater contamination plumes for scenario where the VVF-Pillar Pit contains no discard, compared to when discard is placed back into the pit sufficiently deep below the final in-pit groundwater level;
- If the barrier pillar with the *Wescoal* pit is mined (Scenario-2 and Scenario-4):
  - The spread of groundwater contamination to the northwest will be restricted as indicated in Figures 7.13B and 7.13D, due to the lower in-pit post-mining mine water level; resulting in smaller groundwater gradients to the northwest;
  - The disadvantage of the scenario is that additional decant will occur directly to surface, especially along the south-eastern boundary of *Wescoal* (discussed in following paragraphs);
  - (The applicable modelling scenario assumed that if discard is placed back into the pit, when the pillar is mined, there will be enough space, sufficiently deep below the long-term in-pit mine water level);
- As mentioned in Section 5.4, in-pit groundwater quality will vary over time as various minerals are depleted from the rock and rehabilitated backfill material. Water quality will vary in terms of pH and several anions/cations. SO_4 will be the most-important contamination indicator;
- This study concluded that SO_4 concentrations will eventually on average be at 2100mg/L after 100years, if discard is deposited in the VVF-Pillar Pit, and slightly better (2000mg/L) if no discard is placed in the pit. As can be seen in Figure 7.10, a 300mg/L difference in concentrations for discard backfill into the pit compared to no discard, will occur during the first 30years while the mine is flooding (2000mg/L compared 1700mg/L).

- A comparison of Scenario-3 (Figure 7.13C), with the other three scenarios, after 100years, are provided in Figures 7.13A, B and D;
- Figure 7.14 serve as a summary of the potential post-mining groundwater quality impacts, indicating the following:
  - If the *Wescoal* pillar is not mined (scenario-1 and scenario-3) – likely and maximum impacts zones;
  - If the *Wescoal* pillar is mined (scenario-2 and scenario-4) – maximum impact zone.

A decant zone analysis was performed for Scenario-3 (discard backfill into VVF-Pillar Pit, and no mining of *Wescoal* barrier pillar), through identifying 23 possible decant areas (depicted in Figure 7.15 – the important zones where most decant was/will be expected are highlighted) where groundwater pressures may be above the surface topography. The following aspects are important for the post-mining environment:

- The following areas were considered:
  - Directly downstream/south of mining;
  - Adjacent to the Klipspruit (also known as the Leeuwfonteinspruit) in the south;
  - Central regions of the potential decant zone;
- The two historical decant zones that were mentioned previously in this report, do not necessarily correlate exactly with the 23 possible decant zones (e.g. Main-decant-zone-east coincides with portions of zones 18, 19 and 22);
- Figure 7.15 graphically depicts the important decant zones where long-term (100years) most decant can be expected for Scenario-3 (discard backfill into the VVF-Pillar Pit, no mining of barrier pillar):
  - For simplification, zones which will decant very small volumes and/or only uncontaminated natural groundwater base-flow, are not indicated);
  - Decant volumes, concentrations and salt load for scenario-3 are provided in Table 7.10 and Figures 7.16A-C;
  - The post-mining steady-state decant volumes to these individual zones, for the other three modelling scenarios, are also summarised in Table 7.10; i.e. serving as a comparison of the volumes and concentrations for each modelling scenario in these areas;
- If the groundwater contamination plumes are compared to the decant analysis, it is clear that decant will have by far the most critical impact on the surface water environment.

If a discard dump is placed on surface, the leachate concentrations will be significantly higher than when placed below the water table in the pit. Already after 30years, concentrations will be 5400mg/L in the dump, compared to 2500mg/L if placed deep enough below the decant elevation (see Figure 7.10).
The placement of a discard dump:

- If a discard dump is placed on surface:
  - The dump will require seepage management measures (e.g. engineered liner and capping systems), especially if placed on undisturbed/uncontaminated ground:
    - Toe seepages at the discard dump are expected to remain at sulphate concentrations >5000mg/L for at least 100years, which will have to be managed;
  - If the dump is placed on rehabilitated mining areas without a liner system:
    - Although the discard seepage water quality may have a limited effect on the pit water quality if the discard dump is placed directly on rehabilitated opencast areas, lasting effects/impacts will include visual effects, the potential for erosion and toe seepages;
- The proposed alternative of placing discard back into the pillar area below the long-term in-pit water table, will generate slightly higher in-pit sulphate concentrations (2000mg/L to 1700mg/L; i.e. 300mg/L difference) over the first 30years, where after the difference will be smaller;
- There is a clear advantage in placing coal discard into the VVF-Pillar Pit below the long-term in-pit mine water level.

Table 7.8 Estimated range for pH and sulphate concentrations in seepage*

Material	Average seepage from material over model time		
Average waste rock backfill. Discard backfill: None.	AMD Stage	Stage 1/Stage 2	Stage 2/Stage3
	Time	0 – 30 years	30 – 100 years
	pH	6 – 4	3.5 – 4.5
	SO_4	1 500 up to 2 200 (average pit) 1 500 up to 3 300 (maximum unsat zone)	2 200 down to 1 000 (average pit) 3 300 down to 3 000 (maximum unsat zone)
Average waste rock backfill. Discard backfilled at least >10 m below decant elevation	AMD Stage	Stage 1/Stage 2	Stage 2/Stage3
	Time	0 – 30 years	30 – 100 years
	pH	6 – 4	3.5 – 4.5
	SO_4	2 500 (average pit) 2 500 up to 3 500 (maximum unsat zone)	2 500 down to 1 600 (average pit) 3 500 - 3 000 (maximum unsat zone)
Discard dump	AMD Stage	Stage 1/Stage 2	Stage 2/Stage3
	Time	0 – 30 years	30 – 100 years
	pH	6 – 4	3.5 – 4.5
	SO_4	500 up to 4 500	4 500 – 5 500 (seepage)

* It was assumed that all discard is backfilled with a neutral pH which may require some addition of calcitic lime.

Table 7.9 Post-closure evolution stages in acid-mine drainage (AMD)

Component	AMD Stage 1	AMD Stage 2	AMD Stage 3
	Mineralogical reactions and products		
Pyrite	Oxidation of pyrite.	Oxidation of pyrite. SO_4 reaches maximum concentration in interstitial water.	Depleted in upper oxidation zone. Some weakly exposed pyrite still present. SO_4 decrease from maximum.
Calcite and dolomite	Dissolution	Depleted in upper oxidation zone. Some weakly exposed carbonate minerals may however still be present.	Depleted in upper oxidation zone. Some weakly exposed carbonate minerals may however still be present.
Gypsum	Precipitation controls SO_4	Dissolve, contribute to SO_4 in solution.	Depleted in upper oxidation zone.
Al-Fe-sulphates	None	Precipitation	Some dissolute while other keep precipitating.
Metals Al, Fe, Mn	Precipitate/adsorp although there will be a slight increase in concentration below pH 7.	Elevated because these metals become major cations. Not enough base metals to go into solution.	Decrease from maximum.
Trace metals Co, Ni, Pb, Se	More mobile species like Co, and Ni increases.	Elevated	Decrease from maximum.
pH	8 - 5.5 Near neutral	Acidic in seepage from unsaturated zone.	Acidic in seepage from unsaturated zone.
	Water quality changes		
pH	8 - 5.5	3.5 - 5.5 (range)	3.5 - 5.5 (range)
Alkalinity (as $CaCO_3$)	50 – 450	<50	<50
Ca	100 up to 750	750 down to 300	500 - 300 (range)
Mg	50 up to 350	150 - 350 (range)	150 - 350 (range)
Na	50 up to 150	50 - 150 (range)	50 - 150 (range)
K	50 up to 150	50 - 150 (range)	50 - 150 (range)
SO_4	Not above 2 200mg/L See previous table	See previous table	See previous table
Al	< 10	10 - 1000	10 - 1000
Fe	< 10	10 - 1000	10 - 1000
Mn	< 10	10 - 1000	10 - 1000
Ni	< 0.1	0 - 2	0 - 2
Co	< 0.1	0 - 2	0 - 2

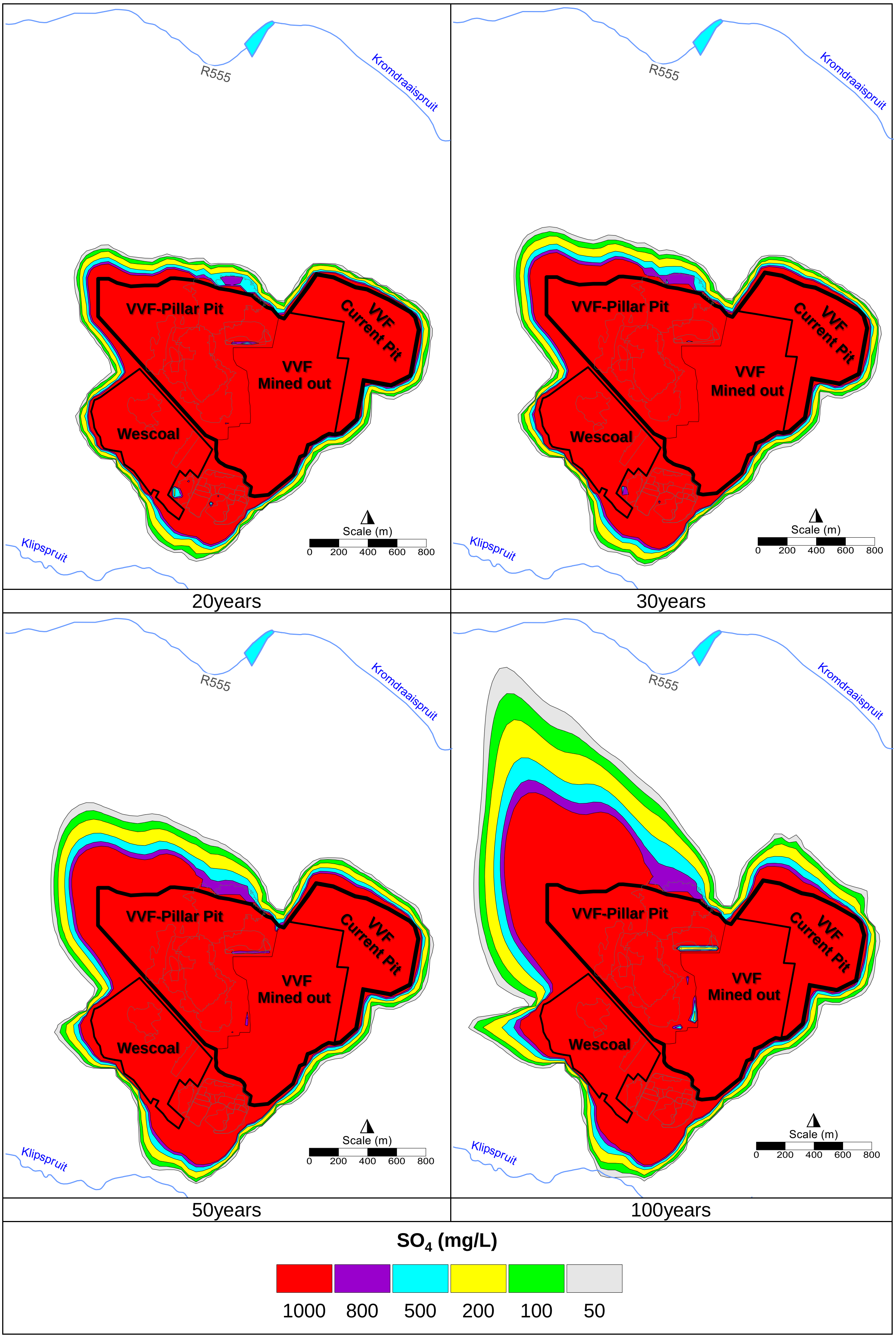


Figure 7.12 Scenario-3 (place discard into VVF-Pillar Pit, do not mine barrier pillar with Wescoal): VVF opencast SO_4 contamination plume 20/30/50/100years after the cessation of mining

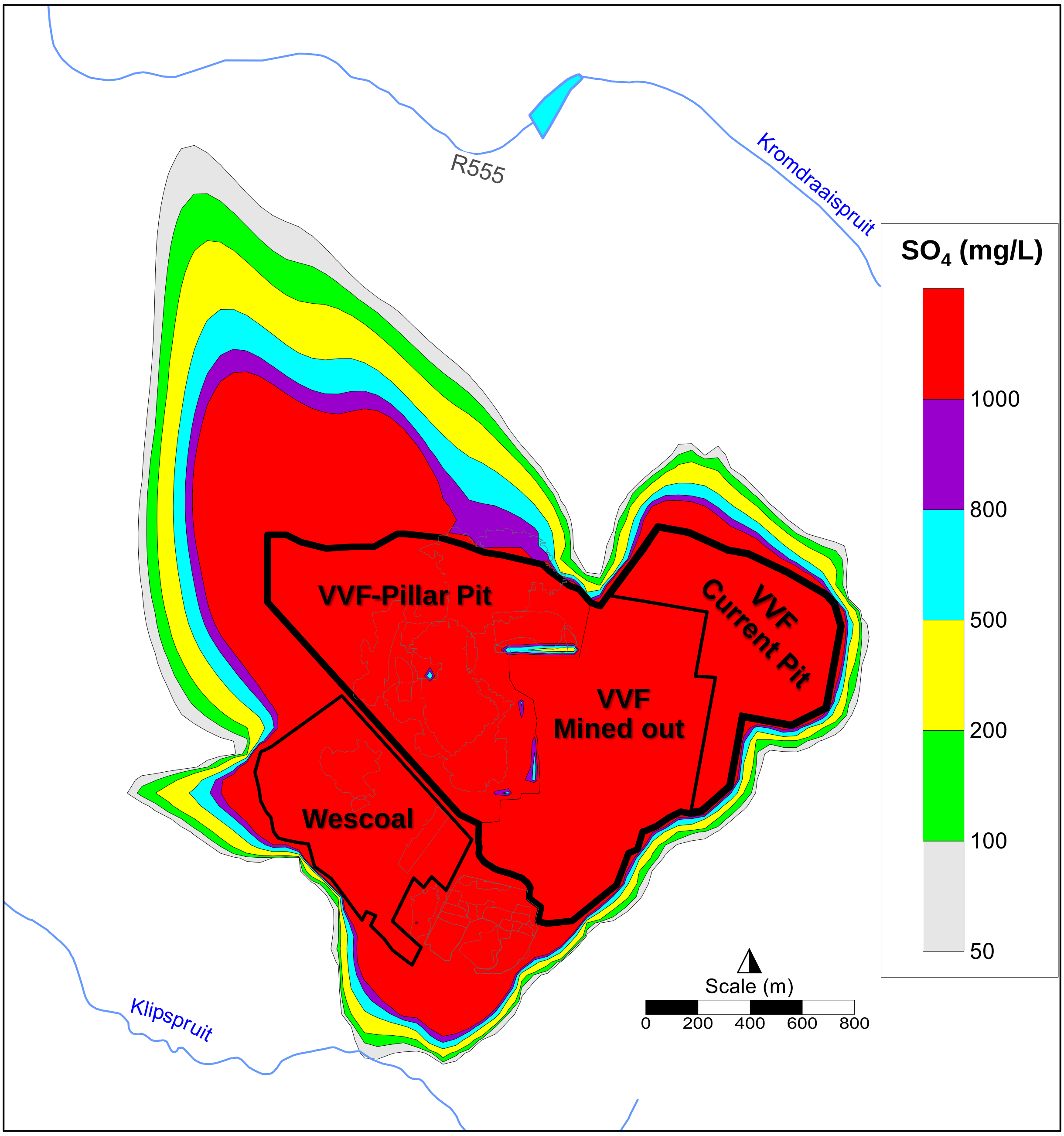


Figure 7.13A *Scenario-1 (no discard, do not mine barrier pillar with Wescoal): VVF opencast SO_4 contamination plume 100years after the cessation of mining*

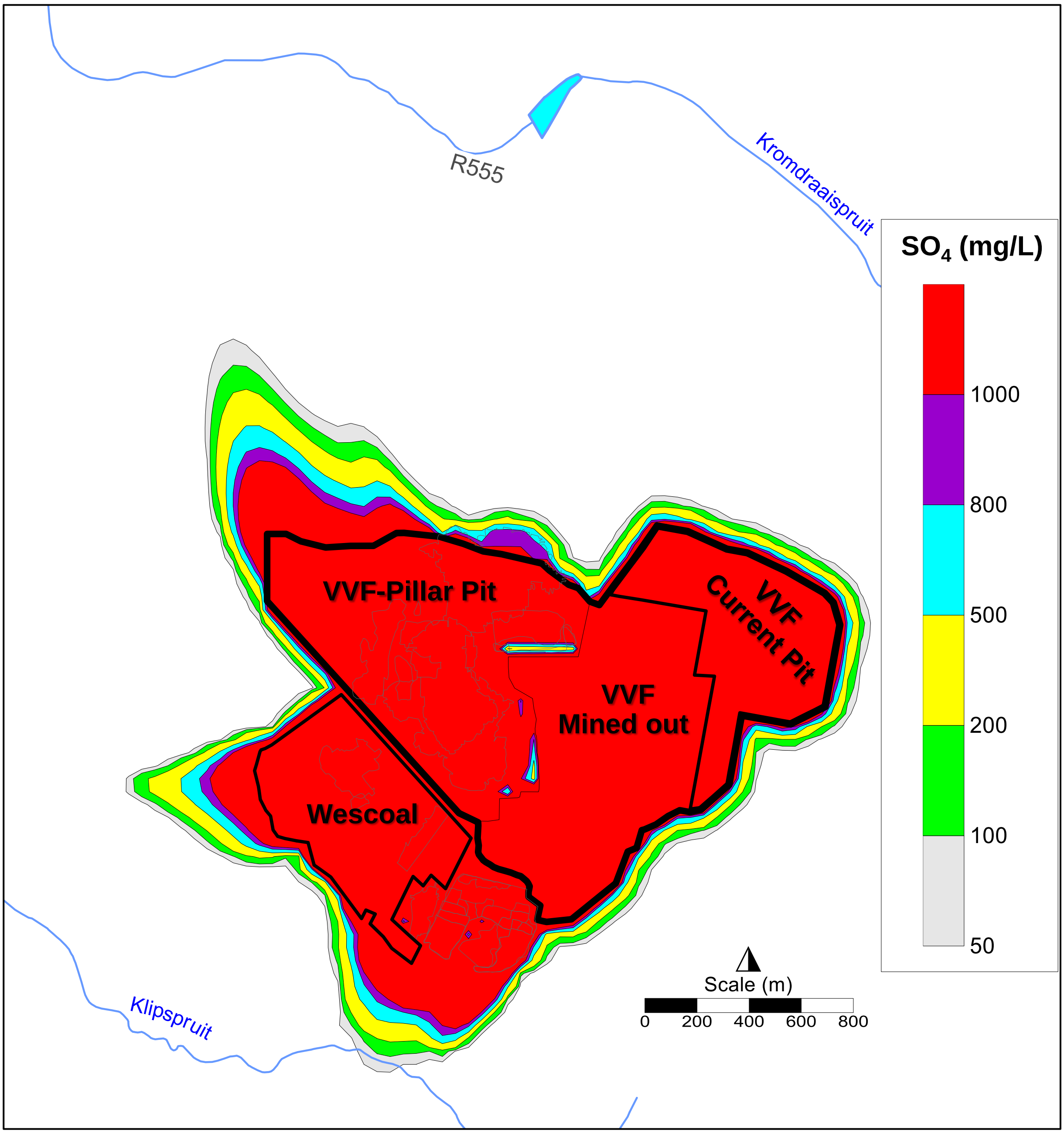


Figure 7.13B ***Scenario-2 (no discard, mine barrier pillar with Wescoal): VVF opencast SO_4 contamination plume 100years after the cessation of mining***

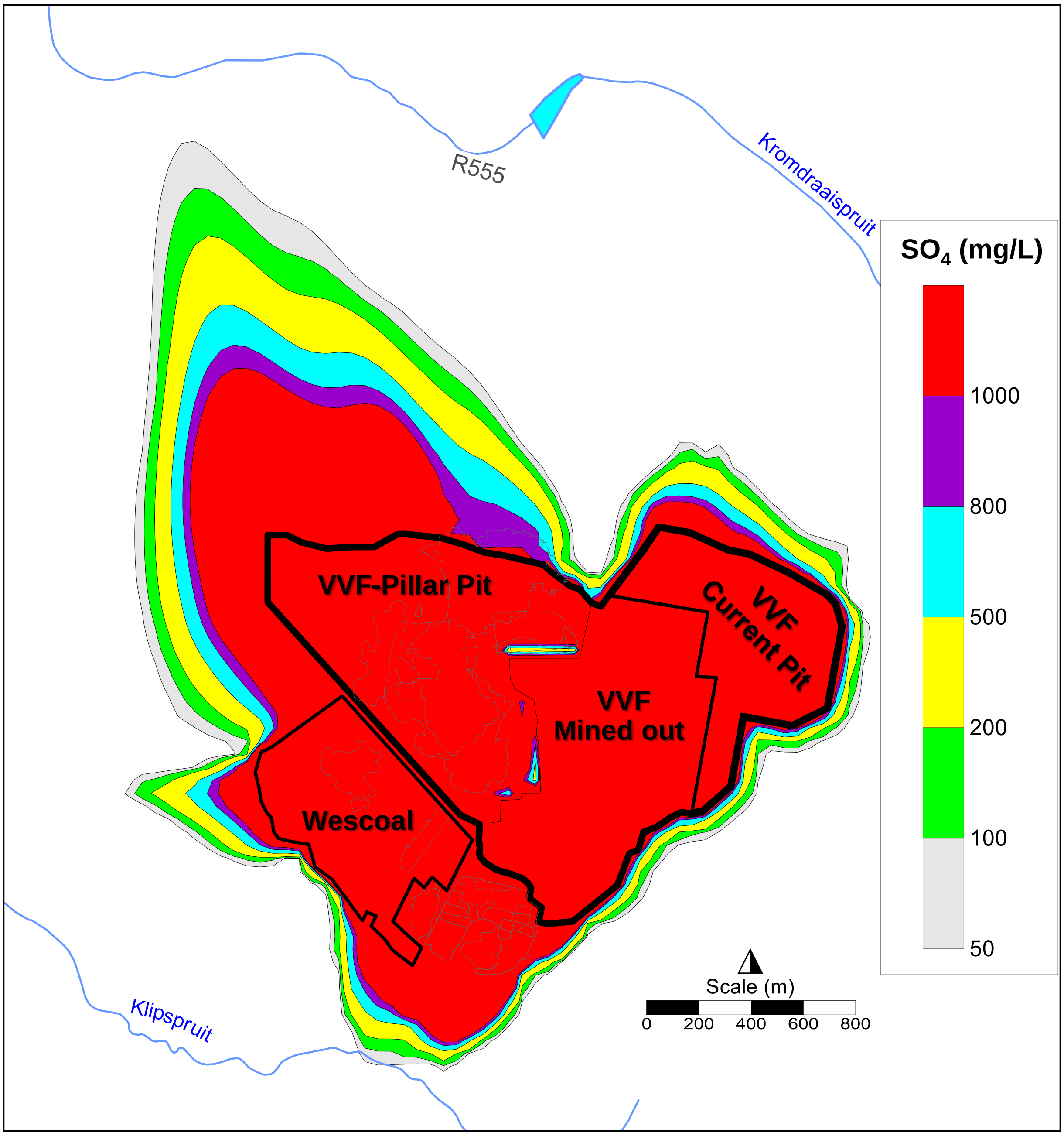


***Figure 7.13C** Scenario-3 (place discard into VVF-Pillar Pit, do not mine barrier pillar with Wescoal): VVF opencast SO_4 contamination plume 100years after the cessation of mining*

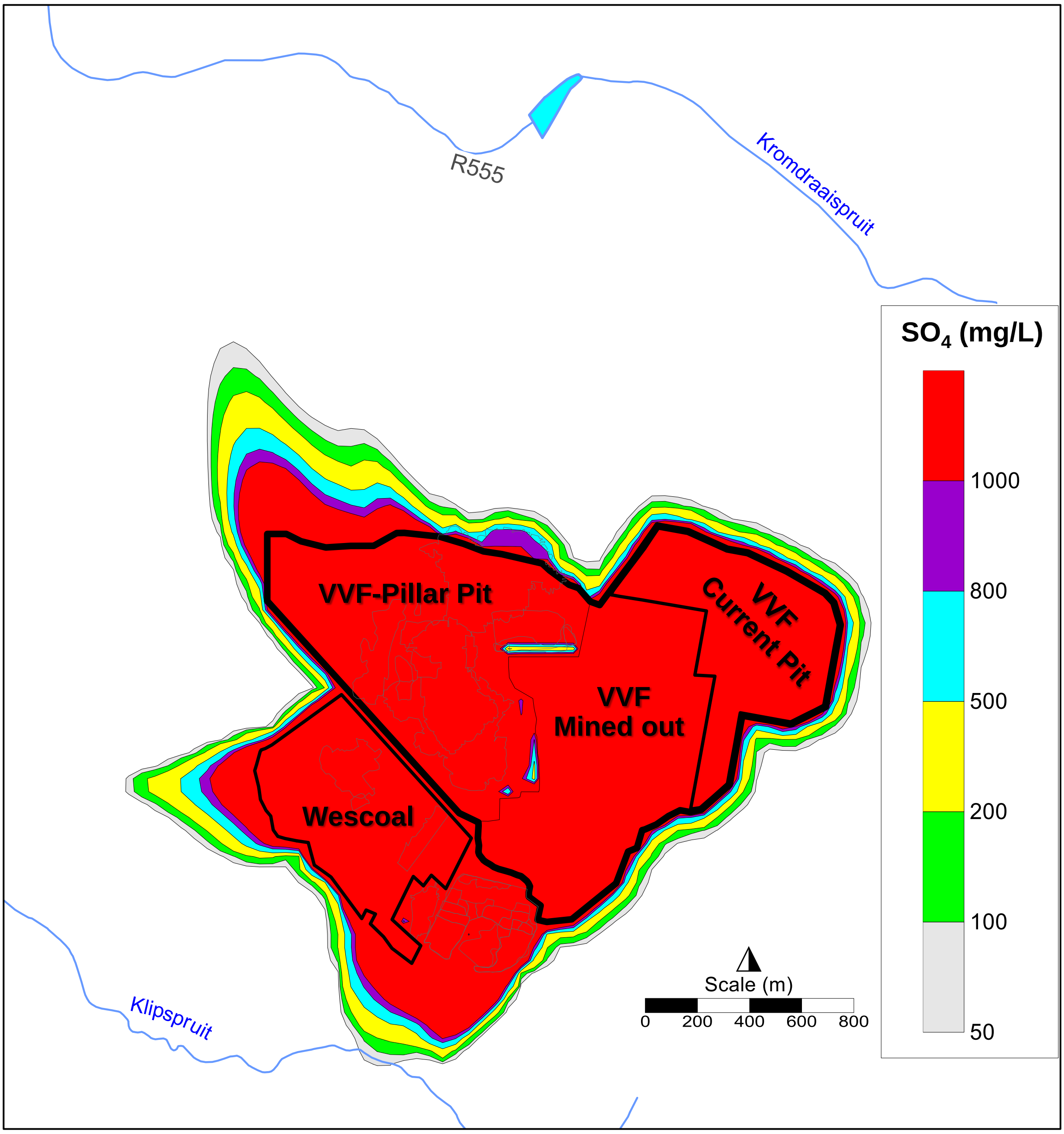


Figure 7.13D ***Scenario-4 (place discard into VVF-Pillar Pit, mine barrier pillar with Wescoal): VVF opencast SO_4 contamination plume 100years after the cessation of mining***

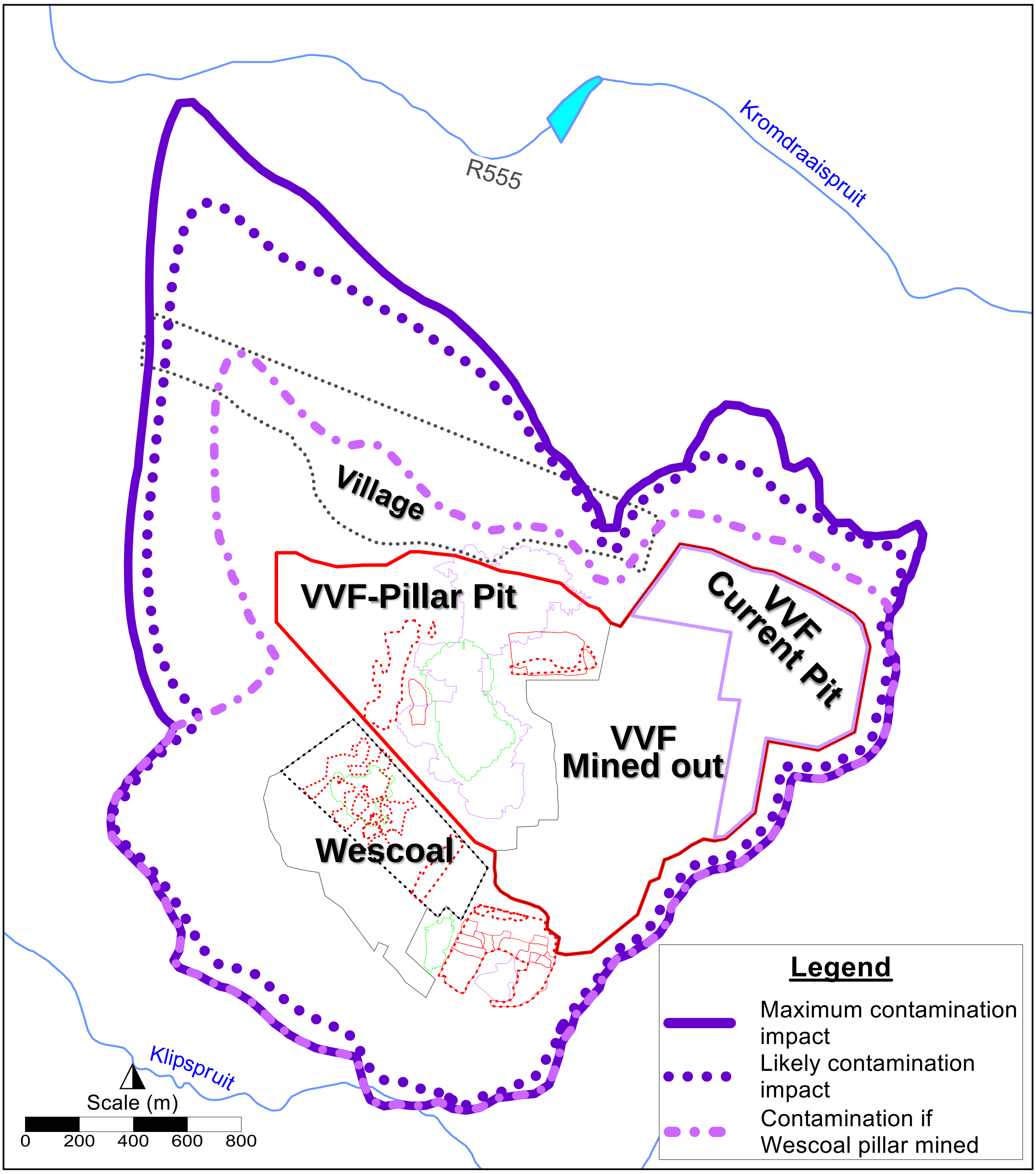


Figure 7.14 Groundwater quality impact zones – post-mining

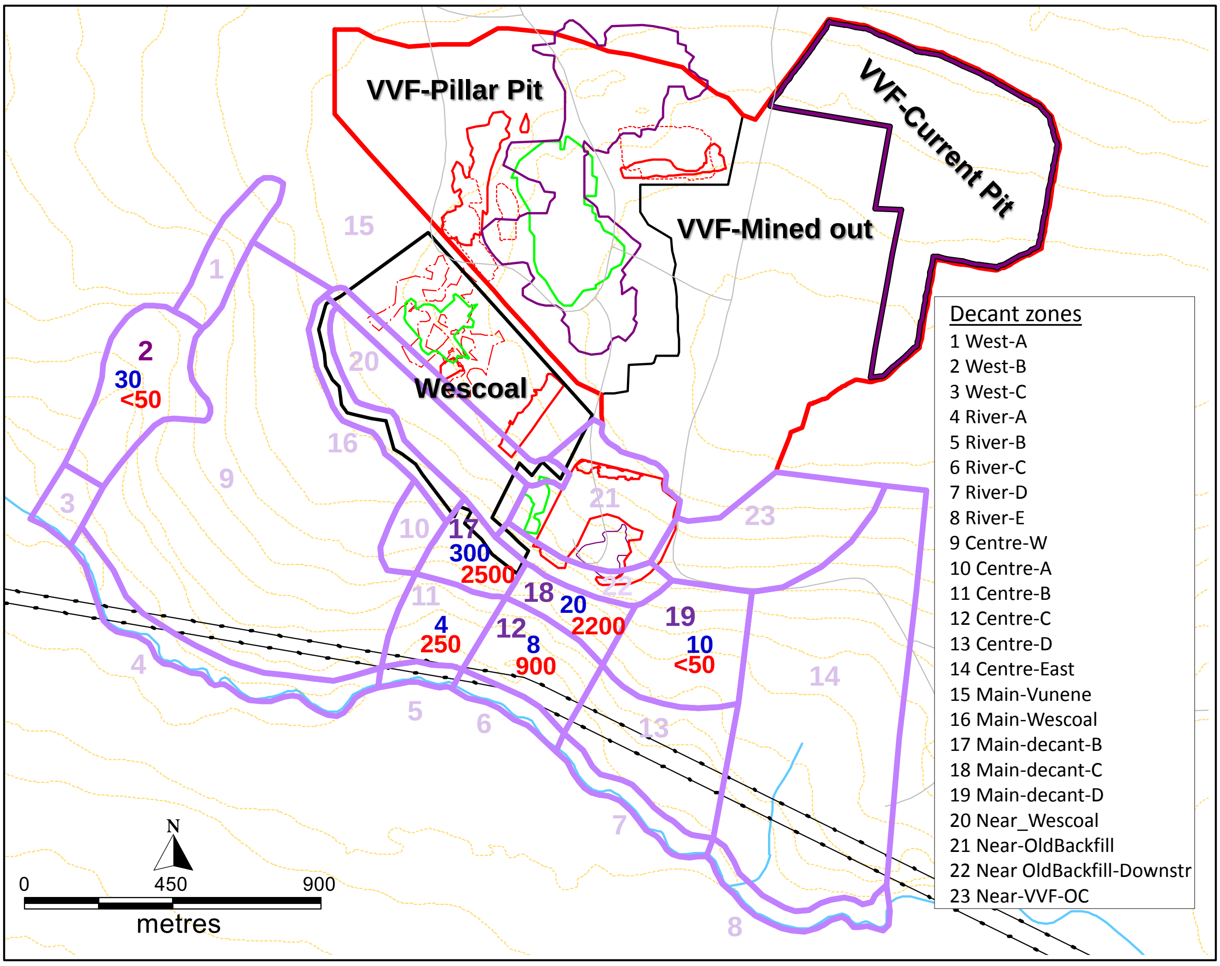


Figure 7.15 ***Scenario-3 (place discard into VVF-Pillar Pit, do not mine barrier pillar with Wescoal): Potential decant zones during the pre-mining situation and various post-mining scenarios***

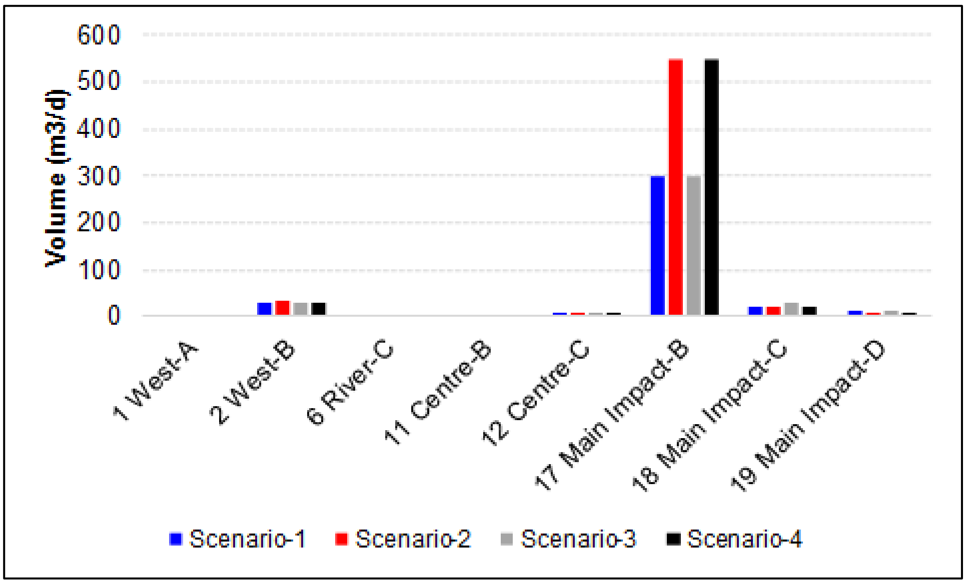


Figure 7.16A ***Summary of potential decant volumes (m^3/d) to main decant impact zones for the various mining scenarios***

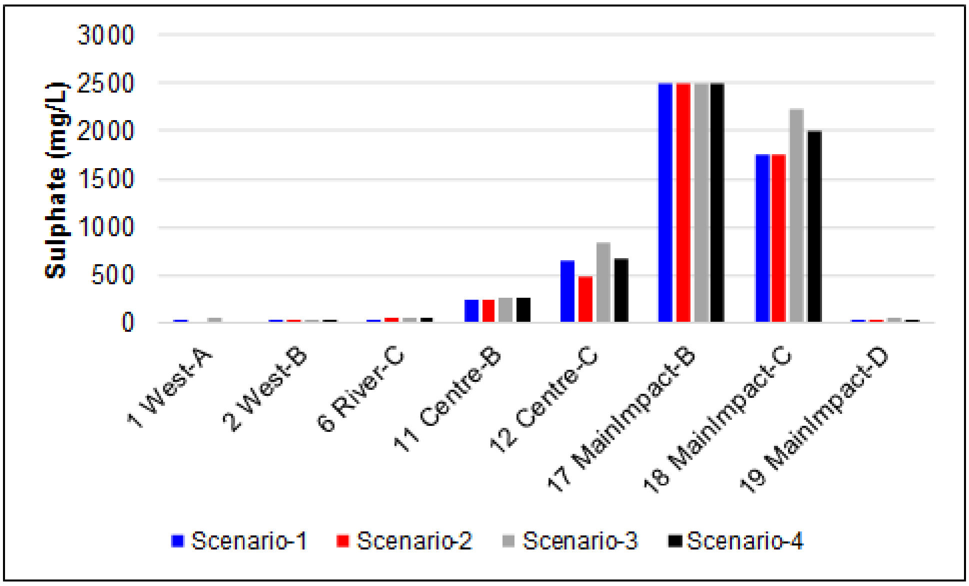


Figure 7.16B Summary of potential sulphate concentrations (mg/L) to main decant impact zones for the various mining scenarios

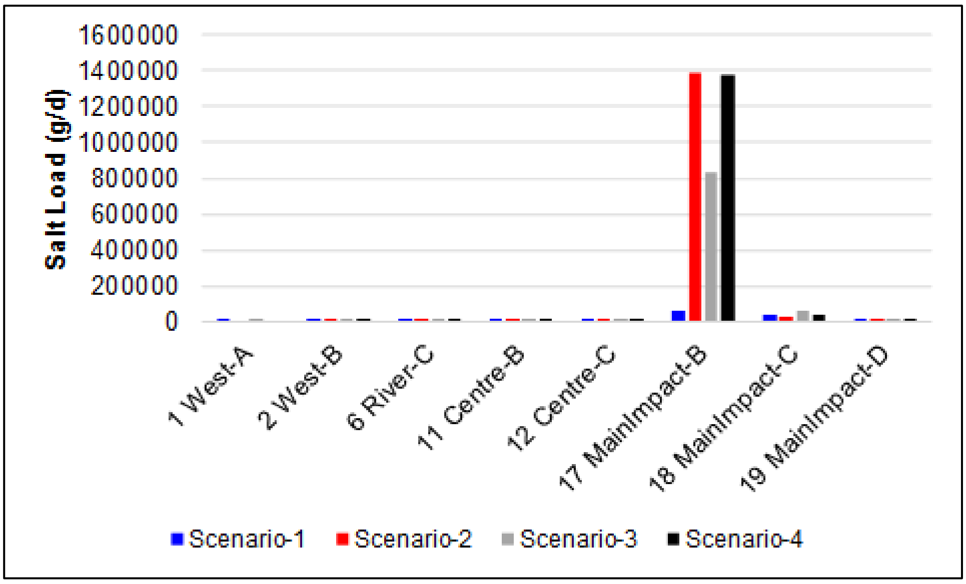


Figure 7.16C Summary of potential salt loads (g/d) to main decant impact zones for the various mining scenarios

Table 7.10 Post-mining steady-state decant volumes to important decant zones

Decant Zone	Volume (m^3/d)		SO4 (mg/L)			
	Scenario-1 & Scenario-3	Scenario-2 & Scenario-4	Scenario-1	Scenario-2	Scenario-3	Scenario-4
Mine barrier pillar	No	Yes	No	Yes	No	Yes
Place discard into VVF-Pillar Pit	No/Yes	No/Yes	No	No	Yes	Yes
1 West-A	1	0	<50			
2 West-B	30	33	<50			
6 River-C	3	3	<50			
11 Centre-B	4	4	250			
12 Centre-C	8	8	660	480	900	680
17 Main Impact-B	300	550	2500			
18 Main Impact-C	20	20	1750	1750	2200	2000
19 Main Impact-D	10	7	<50			

8. GEOHYDROLOGICAL IMPACTS

Risk assessment tables were compiled with the help of a spreadsheet that was provided by EIMS. The project alternatives are listed in Table 8.1 and the risk assessments for each alternative in the remainder of the images that are included in this section.

The following is relevant to the process alternatives for consideration in the EIA phase:

- Regarding the filter cake, both the option to stockpile for use as non-select product (Alternative P2a) as well as the option for disposal (Alternative P2b) will be assessed in the EIA phase.
- For the disposal of carboniferous wastes (wash plant waste rock and possibly filter cake), the option of disposal of beneficiation plant waste rocks and filter cake to pit (Alternative P3d) appears to be most suitable at this stage because no new dump on surface will be required and this will assist with rehabilitation volumes.
- Disposal to a surface waste disposal facility located on old rehabilitated mine area (Alternative P3a) may also be assessed if disposal to the open pit is deemed to be an issue from an environmental perspective. In the event that designing the dumps on rehabilitated areas becomes problematic, the option of disposal to a surface waste disposal facility located on un-mined area (Alternative P3b) will also be considered.
- In terms of dewatering options, both Pump-treat-discharge (Alternative P4a) and Pump-store - treat-discharge (Alternative P4b) will be assessed in the EIA phase. Depending on feedback from further consultation with the DWS, one of these alternatives may be excluded from the EIA.

Table 8.1 Project alternatives

***Process alternatives* - Mining methods.**	**P1a**	**Open Cast**
	P1b	Underground mining methods / in-situ pillar extraction
Filter cake	P2a	Stockpile for use as non-select product.
	P2b	Disposal (see P3)
Disposal of carboniferous wastes (wash plant waste rock and possibly filter cake)	P3a	Disposal to surface waste disposal facility-located on old rehabilitated mine area.
	P3b	Disposal to surface waste disposal facility-located on un-mined area.
	P3c	Disposal of wash plant waste rock to pit and filter cake to surface disposal site.
	P3d	Disposal of beneficiation plant waste rocks and filter cake to pit.
Old underground workings - Dewatering options	P4a	Pump-treat-discharge
	P4b	Pump-store (in existing penstock area)-treat-discharge
Wash plant water supply	P5a	Water obtained from dirty water containment facilities (e.g. penstock storage area, PCD's etc)
	P5b	Water from ground or surface water resources (e.g. borehole abstraction).

8.1. Construction Phase

8.1.1 Impacts on Groundwater Quantity

8.1.2 Impacts on Groundwater Quality

8.1.3 Groundwater Management

8.2. Operational Phase

8.2.1 Impacts on Groundwater Quantity

A. Groundwater Quantity - Alternative P2a					
Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P2a**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	1	1	Magnitude of Impact	1	1
Extent of Impact	1	1	Reversibility of Impact	1	1
Duration of Impact	3	3	Probability	2	1
Environmental Risk (Pre-mitigation)					3.00
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					1.50
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					1.75

C. Groundwater Quantity - Alternative P2b

Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P2b**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	1	1	Magnitude of Impact	1	1
Extent of Impact	1	1	Reversibility of Impact	1	1
Duration of Impact	3	3	Probability	3	1
Environmental Risk (Pre-mitigation)					4.50
Mitigation Measures					
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Environmental Risk (Post-mitigation)					1.50
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					1.75

E. Groundwater Quantity - Alternative P3a

Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P3a**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	1	1	Magnitude of Impact	1	1
Extent of Impact	1	1	Reversibility of Impact	3	2
Duration of Impact	3	3	Probability	2	1
Environmental Risk (Pre-mitigation)					4.00
Mitigation Measures					
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Environmental Risk (Post-mitigation)					1.75
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					2.04

P. Groundwater Quantity - Alternative P3b

Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P3b**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	1	1	Magnitude of Impact	3	2
Extent of Impact	1	1	Reversibility of Impact	3	2
Duration of Impact	3	3	Probability	3	2
Environmental Risk (Pre-mitigation)					7.50
Mitigation Measures					
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Environmental Risk (Post-mitigation)					4.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					4.67

R. Groundwater Quantity - Alternative P3d

Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P3d**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	1	1	Magnitude of Impact	1	1
Extent of Impact	1	1	Reversibility of Impact	1	1
Duration of Impact	3	3	Probability	2	1
Environmental Risk (Pre-mitigation)					3.00
Mitigation Measures					
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Environmental Risk (Post-mitigation)					1.50
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					1.75

T. Groundwater Quantity - Alternative P4a

Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P4a**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	1	1	Magnitude of Impact	1	1
Extent of Impact	1	1	Reversibility of Impact	1	1
Duration of Impact	3	3	Probability	2	1
Environmental Risk (Pre-mitigation)					3.00
Mitigation Measures					
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Environmental Risk (Post-mitigation)					1.50
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					1.75

V. Groundwater Quantity - Alternative P4b

Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P4b**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	2
Extent of Impact	3	3	Reversibility of Impact	2	2
Duration of Impact	3	3	Probability	3	2
Environmental Risk (Pre-mitigation)					-8.25
Mitigation Measures					
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Environmental Risk (Post-mitigation)					-5.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					2
Issue has received a meaningful and justifiable public response					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.33
Final Significance					-6.67

8.2.2 Impacts on Groundwater Quality

B. Groundwater Quality - Alternative P2a					
Impact Name	**Groundwater Quality**				
Alternative	**Alternative P2a**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	1	1
Extent of Impact	1	1	Reversibility of Impact	1	1
Duration of Impact	3	3	Probability	3	2
Environmental Risk (Pre-mitigation)					-4.50
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-3.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					-3.50

D. Groundwater Quality - Alternative P2b					
Impact Name	**Groundwater Quality**				
Alternative	**Alternative P2b**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	2
Extent of Impact	1	1	Reversibility of Impact	2	2
Duration of Impact	3	3	Probability	3	3
Environmental Risk (Pre-mitigation)					-6.75
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-6.00
Degree of confidence in impact prediction:					Low
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					-7.00

F. Groundwater Quality - Alternative P3a

Impact Name	**Groundwater Quality**				
Alternative	**Alternative P3a**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	3
Extent of Impact	1	1	Reversibility of Impact	3	3
Duration of Impact	3	3	Probability	4	3
Environmental Risk (Pre-mitigation)					-10.00
Mitigation Measures					
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Environmental Risk (Post-mitigation)					-7.50
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					-8.75

Q. Groundwater Quality - Alternative P3b

Impact Name	**Groundwater Quality**				
Alternative	**Alternative P3b**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	4	3
Extent of Impact	2	2	Reversibility of Impact	3	3
Duration of Impact	3	3	Probability	5	4
Environmental Risk (Pre-mitigation)					-15.00
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-11.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					-12.83

S. Groundwater Quality - Alternative P3d					
Impact Name	**Groundwater Quality**				
Alternative	**Alternative P3d**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	2	2
Extent of Impact	2	2	Reversibility of Impact	2	2
Duration of Impact	3	3	Probability	4	3
Environmental Risk (Pre-mitigation)					-9.00
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-6.75
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					-7.88

U. Groundwater Quality - Alternative P4a					
Impact Name	**Groundwater Quality**				
Alternative	**Alternative P4a**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	2	3
Extent of Impact	3	3	Reversibility of Impact	2	4
Duration of Impact	3	3	Probability	3	2
Environmental Risk (Pre-mitigation)					-7.50
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-6.50
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					2
Issue has received a meaningful and justifiable public response					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.33
Final Significance					-8.67

W. Groundwater Quality - Alternative P4b					
Impact Name	**Groundwater Quality**				
Alternative	**Alternative P4b**				
Phase	**Operation**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	2	3
Extent of Impact	2	2	Reversibility of Impact	2	4
Duration of Impact	3	3	Probability	3	2
Environmental Risk (Pre-mitigation)					-6.75
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-6.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					2
Issue has received a meaningful and justifiable public response					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.33
Final Significance					-8.00

8.2.3 Impacts on Surface Water

8.2.4 Groundwater Management

8.3. Decommissioning Phase

8.3.1 Groundwater Quantity

A. Groundwater Quantity - Alternative P2a					
Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P2a**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	1	1	Magnitude of Impact	1	1
Extent of Impact	1	1	Reversibility of Impact	1	1
Duration of Impact	1	1	Probability	2	1
Environmental Risk (Pre-mitigation)					2.00
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					1.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					1.17

C. Groundwater Quantity - Alternative P2b					
Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P2b**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	1	1	Magnitude of Impact	1	1
Extent of Impact	1	1	Reversibility of Impact	1	1
Duration of Impact	1	1	Probability	3	1
Environmental Risk (Pre-mitigation)					3.00
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					1.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					1.17

E. Groundwater Quantity - Alternative P3a					
Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P3a**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	1	1	Magnitude of Impact	1	1
Extent of Impact	1	1	Reversibility of Impact	2	2
Duration of Impact	1	1	Probability	2	1
Environmental Risk (Pre-mitigation)					2.50
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					1.25
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					1.46

P. Groundwater Quantity - Alternative P3b

Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P3b**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	1	1	Magnitude of Impact	3	2
Extent of Impact	1	1	Reversibility of Impact	3	2
Duration of Impact	1	1	Probability	3	2
Environmental Risk (Pre-mitigation)					6.00
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					3.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					3.50

R. Groundwater Quantity - Alternative P3d

Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P3d**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	1	1	Magnitude of Impact	1	1
Extent of Impact	1	1	Reversibility of Impact	1	1
Duration of Impact	1	1	Probability	2	1
Environmental Risk (Pre-mitigation)					2.00
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					1.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					1.17

T. Groundwater Quantity - Alternative P4a

Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P4a**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	4	3
Extent of Impact	3	3	Reversibility of Impact	2	2
Duration of Impact	1	1	Probability	4	4
Environmental Risk (Pre-mitigation)					-10.00
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-9.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					2
Issue has received a meaningful and justifiable public response					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.33
Final Significance					-12.00

V. Groundwater Quantity - Alternative P4b

Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P4b**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	4
Extent of Impact	3	3	Reversibility of Impact	2	2
Duration of Impact	1	1	Probability	3	2
Environmental Risk (Pre-mitigation)					-6.75
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-5.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					2
Issue has received a meaningful and justifiable public response					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.33
Final Significance					-6.67

8.3.2 Groundwater Quality

B. Groundwater Quality - Alternative P2a					
Impact Name	**Groundwater Quality**				
Alternative	**Alternative P2a**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	1	1
Extent of Impact	1	1	Reversibility of Impact	1	1
Duration of Impact	1	1	Probability	3	2
Environmental Risk (Pre-mitigation)					-3.00
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-2.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					-2.33

D. Groundwater Quality - Alternative P2b					
Impact Name	**Groundwater Quality**				
Alternative	**Alternative P2b**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	1	1
Extent of Impact	1	1	Reversibility of Impact	1	1
Duration of Impact	1	1	Probability	3	2
Environmental Risk (Pre-mitigation)					-3.00
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-2.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					-2.33

F. Groundwater Quality - Alternative P3a

Impact Name	**Groundwater Quality**				
Alternative	**Alternative P3a**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	3
Extent of Impact	1	1	Reversibility of Impact	3	3
Duration of Impact	1	1	Probability	4	3
Environmental Risk (Pre-mitigation)					-8.00
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-6.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					-7.00

Q. Groundwater Quality - Alternative P3b

Impact Name	**Groundwater Quality**				
Alternative	**Alternative P3b**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	4	3
Extent of Impact	2	2	Reversibility of Impact	3	2
Duration of Impact	1	1	Probability	5	5
Environmental Risk (Pre-mitigation)					-12.50
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-10.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					-11.67

S. Groundwater Quality - Alternative P3d

Impact Name	**Groundwater Quality**				
Alternative	**Alternative P3d**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	2	2
Extent of Impact	2	2	Reversibility of Impact	2	2
Duration of Impact	1	1	Probability	4	3
Environmental Risk (Pre-mitigation)					-7.00
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-5.25
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					-6.13

U. Groundwater Quality - Alternative P4a

Impact Name	**Groundwater Quality**				
Alternative	**Alternative P4a**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	2	3
Extent of Impact	3	3	Reversibility of Impact	2	4
Duration of Impact	1	1	Probability	3	2
Environmental Risk (Pre-mitigation)					-6.00
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-5.50
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					2
Issue has received a meaningful and justifiable public response					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.33
Final Significance					-7.33

W. Groundwater Quality - Alternative P4b

Impact Name	**Groundwater Quality**				
Alternative	**Alternative P4b**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	2	4
Extent of Impact	2	2	Reversibility of Impact	2	4
Duration of Impact	1	1	Probability	3	2
Environmental Risk (Pre-mitigation)					-5.25
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-5.50
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					2
Issue has received a meaningful and justifiable public response					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.33
Final Significance					-7.33

8.4. Post-mining Phase

8.4.1 Groundwater Quantity

A. Groundwater Quantity - Alternative P2a					
Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P2a**				
Phase	**Rehab and closure**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	1	1	Magnitude of Impact	1	1
Extent of Impact	1	1	Reversibility of Impact	1	1
Duration of Impact	3	3	Probability	1	1
Environmental Risk (Pre-mitigation)					1.50
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					1.50
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					1
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is unlikley that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.00
Final Significance					1.50

C. Groundwater Quantity - Alternative P2b					
Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P2b**				
Phase	**Rehab and closure**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	1	1	Magnitude of Impact	1	1
Extent of Impact	1	1	Reversibility of Impact	1	1
Duration of Impact	3	3	Probability	2	1
Environmental Risk (Pre-mitigation)					3.00
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					1.50
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					1.75

E. Groundwater Quantity - Alternative P3a					
Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P3a**				
Phase	**Rehab and closure**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	1	1	Magnitude of Impact	1	1
Extent of Impact	1	1	Reversibility of Impact	2	2
Duration of Impact	3	3	Probability	2	1
Environmental Risk (Pre-mitigation)					3.50
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					1.75
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					2.04

P. Groundwater Quantity - Alternative P3b					
Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P3b**				
Phase	**Rehab and closure**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	1	1	Magnitude of Impact	3	2
Extent of Impact	1	1	Reversibility of Impact	3	2
Duration of Impact	3	3	Probability	3	2
Environmental Risk (Pre-mitigation)					7.50
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					4.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					4.67

R. Groundwater Quantity - Alternative P3d					
Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P3d**				
Phase	**Rehab and closure**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	1	1	Magnitude of Impact	1	1
Extent of Impact	1	1	Reversibility of Impact	1	1
Duration of Impact	3	3	Probability	2	1
Environmental Risk (Pre-mitigation)					3.00
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					1.50
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					1.75

T. Groundwater Quantity - Alternative P4a					
Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P4a**				
Phase	**Rehab and closure**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	4	3
Extent of Impact	3	3	Reversibility of Impact	2	2
Duration of Impact	3	3	Probability	4	4
Environmental Risk (Pre-mitigation)					-12.00
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-11.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					2
Issue has received a meaningful and justifiable public response					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.33
Final Significance					-14.67

V. Groundwater Quantity - Alternative P4b					
Impact Name	**Groundwater Quantity**				
Alternative	**Alternative P4b**				
Phase	**Rehab and closure**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	2
Extent of Impact	3	3	Reversibility of Impact	2	2
Duration of Impact	3	3	Probability	3	2
Environmental Risk (Pre-mitigation)					-8.25
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-5.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					2
Issue has received a meaningful and justifiable public response					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.33
Final Significance					-6.67

8.4.2 Groundwater Quality

B. Groundwater Quality - Alternative P2a					
Impact Name	**Groundwater Quality**				
Alternative	**Alternative P2a**				
Phase	**Rehab and closure**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	1	1
Extent of Impact	1	1	Reversibility of Impact	1	1
Duration of Impact	3	3	Probability	2	1
Environmental Risk (Pre-mitigation)					-3.00
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-1.50
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					1
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is unlikley that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.00
Final Significance					-1.50

D. Groundwater Quality - Alternative P2b					
Impact Name	**Groundwater Quality**				
Alternative	**Alternative P2b**				
Phase	**Rehab and closure**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	1	1
Extent of Impact	1	1	Reversibility of Impact	1	1
Duration of Impact	3	3	Probability	3	2
Environmental Risk (Pre-mitigation)					-4.50
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-3.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					-3.50

F. Groundwater Quality - Alternative P3a					
Impact Name	**Groundwater Quality**				
Alternative	**Alternative P3a**				
Phase	**Rehab and closure**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	2
Extent of Impact	1	1	Reversibility of Impact	3	3
Duration of Impact	3	3	Probability	3	3
Environmental Risk (Pre-mitigation)					-7.50
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-6.75
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					-7.88

Q. Groundwater Quality - Alternative P3b

Impact Name	**Groundwater Quality**				
Alternative	**Alternative P3b**				
Phase	**Rehab and closure**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	4	4
Extent of Impact	2	2	Reversibility of Impact	3	3
Duration of Impact	3	3	Probability	5	4
Environmental Risk (Pre-mitigation)					-15.00
Mitigation Measures					
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Environmental Risk (Post-mitigation)					-12.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					-14.00

S. Groundwater Quality - Alternative P3d

Impact Name	**Groundwater Quality**				
Alternative	**Alternative P3d**				
Phase	**Rehab and closure**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	1
Extent of Impact	2	2	Reversibility of Impact	3	2
Duration of Impact	3	3	Probability	4	3
Environmental Risk (Pre-mitigation)					-11.00
Mitigation Measures					
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Environmental Risk (Post-mitigation)					-6.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					-7.00

U. Groundwater Quality - Alternative P4a					
Impact Name	**Groundwater Quality**				
Alternative	**Alternative P4a**				
Phase	**Rehab and closure**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	2	3
Extent of Impact	3	3	Reversibility of Impact	2	4
Duration of Impact	3	3	Probability	3	2
Environmental Risk (Pre-mitigation)					-7.50
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-6.50
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					2
Issue has received a meaningful and justifiable public response					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.33
Final Significance					-8.67

W. Groundwater Quality - Alternative P4b					
Impact Name	**Groundwater Quality**				
Alternative	**Alternative P4b**				
Phase	**Rehab and closure**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	2	3
Extent of Impact	2	2	Reversibility of Impact	2	4
Duration of Impact	3	3	Probability	3	2
Environmental Risk (Pre-mitigation)					-6.75
Mitigation Measures					
Edit this once pasted into the report					
Environmental Risk (Post-mitigation)					-6.00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					2
Issue has received a meaningful and justifiable public response					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cummulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.33
Final Significance					-8.00

8.4.3 Cumulative Impacts

8.4.4 Groundwater Management

9. MOTIVATON FOR UNLINED WASTE ROCK STOCKPILES

WSP performed a Waste Classification of waste rock, as prescribed by the "Norms and Standards" (N&S) guideline documentation, for the Assessment of Waste for Landfill and N&S for Disposal of Waste to Landfill", promulgated under the National Environmental Management: Waste Act, 2008 (NEM:WA).

Given the *WSP* waste rock classification, the N&S methodology recommends a "Type 3" liner system. This entails a 300mm thick finger drain of geotextile covered aggregate, 100mm protection layer of silty sand or a geotextile of equivalent performance, 1.5mm thick HDPE geomembrane, 300mm clay liner (2 x 150mm thick layers), under drainage and a monitoring system in base preparation layer.

Three elements/compounds of concern were identified which marginally exceed N&S guideline concentrations; resulting in this very costly design:

- Manganese (lab = 0.653ppm, LCT0 guideline = 0.5ppm);
- Nickel (lab = 0.08ppm, LCT0 guideline = 0.07ppm);
- Total organic carbon (lab = 6.19%, Threshold guideline = 3%).

Based on the following *Groundwater Square* believes that the environmental impact on the groundwater system, from the waste rock, will be insignificant:

- The actual laboratory results of the waste classification, and applicability of the N&S procedures; in terms of the science, scientific application, applicability, relevance and validity thereof;
- Drawing from numerical modelling of groundwater studies performed by *Groundwater Square*;
- Location of waste rock in relation to mining, and current impacted situation;
- Short life-of-mine (LOM) of 6years.

Given the financial implications of such a strict lining system, this serves as motivation for an application for exemption from a liner system for the waste rock. In view of the numerical modelling results and monitoring information, sufficient reasons could be found to motivate for an exemption. The groundwater level cone of depression and dewatering around the perimeter of the pit; as well as groundwater flow directions during the operational phase, specifically over the area where the waste rock will be located, was sufficient evidence that the waste rock will have no impact beyond the mining footprint, as groundwater flow will be towards the pit and not into the surrounding groundwater resource. The maximum potential pollution plume that may result from the waste rock was described for the 6year operational phase, as well as another 1year after mining, to allow for the final rehabilitation.

Note that this motivation does not apply to materials that may be excavated from historical mining areas; specifically, carbonaceous backfill. It is assumed that these materials will be placed directly back into the pit, as deep as possible below the long-term decant elevation.

9.1. Threshold Values

The following serve as summarising comments to the results obtained from the Waste Classification laboratory results:

- As listed above, laboratory analysis for manganese and nickel marginally exceeded the stringent LCT0 guideline by less than 20%, while total organic carbon was recorded as approximately double the threshold value;
- The rocks in question have no potential for acid generation potential, and pH is likely to be neutral;
- Although sulphate concentrations (the main contaminant indicator for coal mines) were not determined from rock samples, geochemical studies for Vlakvarkfontein determined sulphate concentrations of <30mg/L through the reagent water extraction leach, and 35mg/L-44mg/L during weeks 10-20 of a column leach test (i.e. determining concentrations under accelerated conditions); thus very low concentrations, if compared to environmental guidelines for drinking water of 250mg/L.

It is important to understand the actual risks of the mine and associated materials. The waste classification procedure (according to GNR 635) has three main deficiencies, which warrant consideration in the evaluation of the waste classification results:

- Acid mine drainage (AMD) will not occur from the waste rock material, thus significantly reducing the potential for elevated metals concentrations to leach;

- Site-specific conditions are not considered (the risk to the environment, should be scientifically based), such as:
  - The potential for the waste rock to contaminate, i.e. rate of water infiltration to underlying aquifer and actual seepage water quality;
  - Hydrogeology; e.g. groundwater flow direction/velocity, depth of unsaturated zone, potential for contaminant movement and stockpile water balance;
  - Size (aerial extent) of waste rock and duration of placement:
- Total concentration threshold (TCT) values, specified in the Norms and Standards, are more stringent than the average concentrations of elements in the upper continental crust (AUC), including rock (sub)-outcrops:
  - The AUC serves as a background reference for the geochemical composition of rock near the earth's surface. Almost all natural rock and soils in the earth crust would classify as Type 3 waste based upon the TCT0 value.

9.2. Groundwater Levels and Flow Directions

During mining, groundwater levels will be toward mine voids for an area of at least 200m along the eastern, northern and western boundaries of the VVF-Mined Pit and the VVF-Pillar Pit. Any waste rock material that will be placed on mined-out areas, cannot have an impact beyond the footprint areas, as groundwater flow/seepages will be vertically downward into the pit, where in-pit management measures are in place to remove excess water This dewatered situation will prevail for several years after the cessation of mining; long after final rehabilitation has been completed (i.e. long after the removal of the waste rock stockpiles, which will serve as rehabilitation material).

It is clear that groundwater flow directions will be towards mined-out areas from all waste rock storage areas. Any contamination that might occur (unlikely situation), will therefore move in the direction of the pit.

The groundwater levels beneath the in-pit waste rock footprint areas will be >20m (up to 40m in places) due to the dewatered situation. The saturated zones, where waste rock will be placed alongside the pit, will be at least 10m-12m deep.

9.3. Groundwater Quality and Contaminant Mechanism

The groundwater quality in the proposed waste rock stockpile areas, alongside the pits are <30mg/L sulphates, at a neutral pH.

The potential contaminant mechanism from the waste rock to the receiving groundwater environment, will be along the following pathway (see schematic diagram included as Figure 9.1):

- Step-1: A portion of natural rainfall water penetrates the waste rock from above (the remainder evaporates and runs off the stockpiles);
- Step-2: Moisture will move vertically downward under gravitation, through cracks, and void spaces in the finer material. Most of the moisture/water will be retained/absorbed onto sandy particles in rocks and finer material:
  - Evaporation will occur from these materials due to heat and wind action, during dryer periods;
  - A small moisture component might migrate downward under gravitation if the "field capacity" of these materials is exceeded (i.e. conditions must be sufficiently wet to overcome cohesion forces);
  - Small sulphate concentrations, of maximum 50mg/L will leach from the waste rock material, as determined from geochemical testing;
  - Based on N&S procedure, concentrations will be "elevated" for manganese (0.653ppm), nickel (0.08ppm) and total organic carbon (6.19%);
- Step-3: Approximately 15% of the mean annual precipitation (15% of 700mm/a = 105mm/a) can typically be expected to seep into the unsaturated zone, which consist of a soil profile approximately ≥5m thick and a further 5m to 15m highly weathered rock:
  - These seepages from the waste rock, will migrate downward under gravitation, if the "field capacity" of these materials is exceeded;
  - Considering Darcy's law, applied to seepage velocity (= hydraulic conductivity x hydraulic gradient / porosity), any contamination in the moisture will be retarded by the porosity in the unsaturated zone, and the fact that the unsaturated hydraulic conductivity will be smaller than the saturated hydraulic conductivity – consequently it may be several years before the

concentrations in the bottom part of the unsaturated zone, will equal the concentrations leached from the waste rock;

- Step-4: Moisture which moved vertical downward, through the unsaturated profile, will eventually reach the groundwater level, while the remainder of the seepages will form an unsaturated (and partially saturated) zone above the groundwater table;
- Step-5: Once the groundwater table has been reached, seepages will mix with the groundwater in the saturated aquifers, and flow north, in the direction of the proposed open pit.

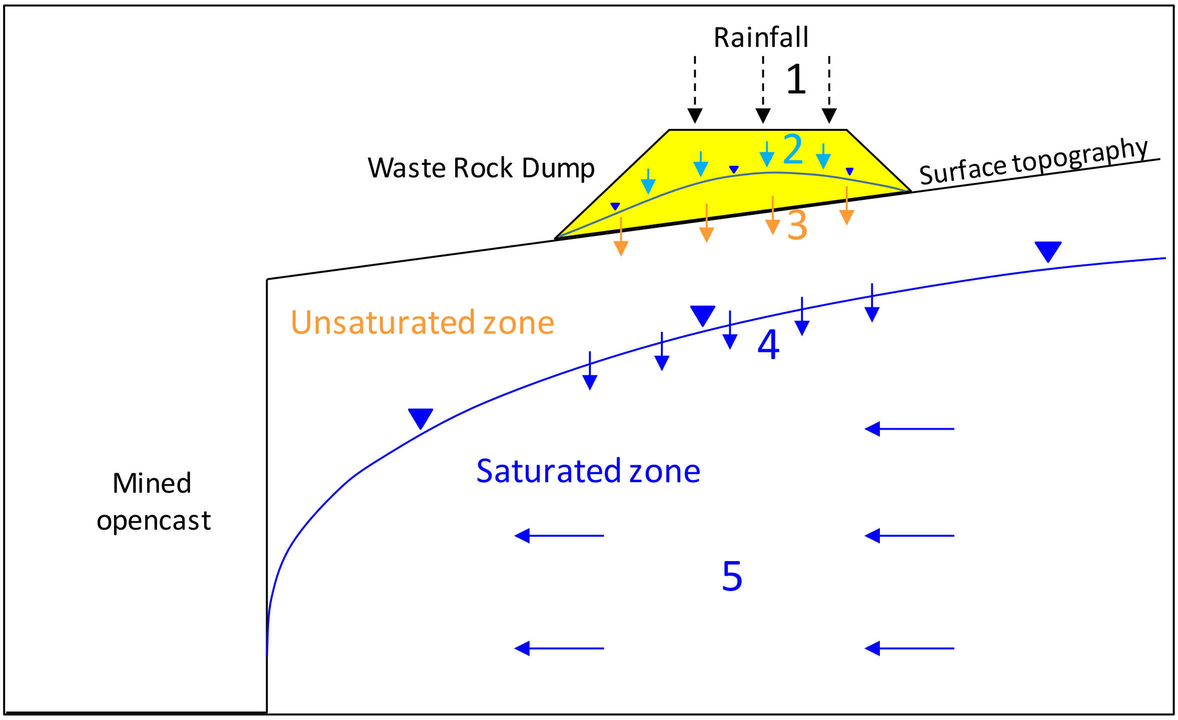

Figure 9.1 Schematic diagram of contaminant mechanism

9.4. Maximum Possible Impact

Sulphate is the main contaminant indicator for coal mines. Given that low-pH-AMD conditions are not expected, metals such as Fe, Mn and Al were not considered.

Even if the "elevated" N&S laboratory results for manganese (0.653ppm), nickel (0.08ppm) and total organic carbon (6.19%) concentrations can be replicated under natural conditions, it will take many years before the bottom of the unsaturated zone to reflect such concentrations. Organic carbon will also naturally break down, dependant on the geochemical and organic conditions.

Due to the slow rate at which any contamination can move downward, compared to the much larger groundwater flow component towards the open pit (referred to in Step-4 and Step-5), the groundwater quality will reflect much lower concentrations.

There are several very important mitigation factors for any contamination, which may result from the proposed waste rock. Mixing continues gradually with distance from any contamination source, and the continuous groundwater flow underneath the waste rock toward will dilute concentrations.

Considering a worst-case where all contamination, instantaneously mix into the aquifer each year, without considering clean upstream groundwater, the water quality concentrations in the aquifer should gradually increase. It is however estimated that concentrations in the aquifer will be <20% of the leach concentrations, 10years after the placement of waste rock on surface. This was determined through consideration of the rainfall recharge rate, uncontaminated aquifers, the N&S laboratory testing, saturated aquifer thickness, aquifer porosity, etc. Consequently, the aquifer will not be contaminated above the LCT0 threshold values.

Groundwater seepage velocity has been determined to range between 5.8m/a and 14m/a. Therefore, over the period that the waste rock stockpile will be operational (6year operational and 1year rehabilitation) the contamination plume will probably not exceed 100m from the stockpiles, at concentrations lower than the LCT0 threshold values. This movement will be in the direction of the pit.

Although a maximum impact is discussed above, waste rock material should not leach the main contaminant indicators at elevated levels and will not be acidic (i.e. no elevated metal concentrations).

9.5. Recommendations

It is recommended, without any reservation, that an exemption should be granted from a liner system for the waste rock stockpile. The impact on groundwater quality is expected to be insignificant. It is likely that no groundwater quality impact will be observed.

10. GROUNDWATER MONITORING SYSTEM

10.1. Groundwater Monitoring Network

10.1.1 Source, Plume, Impact and Background Monitoring

The monitoring system has been designed to distinguish between the following types of monitoring boreholes (see Tables 10.3 to 10.5 in Section 10.2):

- Source = nearest to potential contamination sources;
- Plume = monitoring the progression/break-through water quality trend curves;
- Background = upstream to serve as reference.

The dewatering effect during mining will have to be monitored with the existing groundwater monitoring system; potentially expanding the monitoring system to provide additional/relevant monitoring.

10.1.2 System Response Monitoring Network

The plume monitoring boreholes serve as an early warning system to take remedial action if contamination occurs. Options include, an alternative water supply (e.g. a new borehole or treated water) or contamination movement should be prevented (e.g. through groundwater abstraction, trenches, etc.). These holes, together with the source monitoring boreholes will indicate drastic changes in the groundwater levels; especially important with regard to the village drinking water supplies.

Due to the slow changes that normally occur in groundwater quality and natural groundwater level fluctuations, quarterly groundwater monitoring should be sufficient to identify any changes which may require action. Boreholes that supply drinking water may, however, become unusable more abruptly, if such holes are reliant on single water fractures, which may become dewatered during droughts, or excessive pumping. Fortunately, the groundwater supply to the local village is utilised continuously, which will prompt an immediate complain to the mine.

Investigations should be conducted to determine the reasons for sudden changes in groundwater quality and groundwater levels.

10.1.3 Monitoring Frequency

It is recommended that groundwater levels in the regular boreholes be measured quarterly, but if groundwater level trends exceed expected rainfall seasonality, the frequency should be increased to monthly. Water quality samples should be collected quarterly, except for drinking water supply to the mine and local village, which require monthly monitoring.

Drinking water supply boreholes and external users' boreholes in the local village, should be monitored monthly. Elsewhere, external users' boreholes should be monitored annually.

10.2. Monitoring Parameters

Water quality monitoring parameters are summarised in Table 10.1 and 10.2 for the mining phase and post-mining phases respectively. Note, as explained in Section 10.1, there is a distinction between the monitoring of regular mining boreholes and monitoring intervals for external users (originally identified during the 2009 hydrocensus), consisting of village boreholes and holes further away.

Table 10.1 Water quality monitoring parameters – during mining

	General		External users		Drinking water **	
	Groundwater levels	**Groundwater quality**	**Groundwater levels**	**Groundwater quality**	**Groundwater levels**	**Groundwater quality**
Current mining phase	Quarterly	Quarterly (List 1) Annually (List 2)	Annually	Annually (List 1)	Monthly	Monthly (List 1) Annually (List 2)

"List 1": pH, EC, TDS, Ca, Mg, Na, K, Cl, SO_4, NO_3, Tot.Alk. Si, Fe, Mn, Al, ICP-scan
"List 2": TPH or similar to identify hydrocarbon contamination
** Both external users in the village and mine water

Table 10.2 Water quality monitoring parameters – post-mining

	General		External users		Drinking water	
	Groundwater levels	**Groundwater quality**	**Groundwater levels**	**Groundwater quality**	**Groundwater levels**	**Groundwater quality**
1st year after mining	Quarterly	Quarterly (List 1) Annually (List 2)	Annually	Annually (List 1)	Monthly	Monthly (List 1) Annually (List 2)
Until rehabilitation finalised	Six-monthly	Six-monthly (List 1) Annually (List 2)	Annually	Annually (List 1)	Six-monthly	Six-monthly (List 1) Annually (List 2)
Long-term decision after consultation with DWS*	-	-	-	-	-	-

"List 1": pH, EC, TDS, Ca, Mg, Na, K, Cl, SO_4, NO_3, Tot.Alk. Si, Fe, Mn, Al, ICP-scan
"List 2": TPH or similar to identify hydrocarbon contamination
* Until a decision is taken about the long-term through consultation with DWS

10.3. Monitoring Boreholes

Groundwater monitoring points and surface water monitoring points in Tables 10.3-10.5, were compiled from the Water Use License (WUL), the 2015 Integrated Water and Waste Management Plan (IWWMP), and additional recommendations following from this report.

After the next annual hydrocensus, and verification of holes drilled/destroyed/purpose, a final list of monitoring localities should be compiled.

A list of surface water monitoring sites is provided in Table 10.5.

See Figure 10.1 to 10.3 for monitoring localities.

Table 10.3 Mine monitoring boreholes

Borehole Number	Coordinate (WGSLO29)			Depth (m)	Sampling depth (m)	Comment
	X	Y	Z			
VBH-1M * &	10186	2882739	1556	31	21	Mined-out
VBH-1S * &	10185	2882737	1556	6		Mined-out
VBH-2M * &	9768	2883715	1569	31	21	
VBH-3M * &	11111	2884005	1535	30	11	
VBH-3S * &	11110	2884005	1535	6	5.5	
VBH-4M * &	9700	2883129	1559	35	27	Mined-out
VBH-5M * &	10327	2883411	1566	48	40	Mined-out
VBH-6M * &	10679	2883616	1561	35	To be confirmed	
VBH-6S * &	10680	2883618	1561	6	To be confirmed	
VBH-7M * &	10620	2883047	1560	41	26	Re-open hole casing-collar if possible
VBH-8M * &	11156	2883267	1552	30	11	
VBH-8S * &	11096	2883219	1552	12	8	
VBH-9D * &	10445	2882570	1545	75	To be confirmed	
VBH-10M * &	11298	2882686	1549	40	To be confirmed	
VBH-11M * &	10512	2883485	1563	27	To be confirmed	
VVN09016 &	10445	2882570	1551	18.45		Destroyed exploration borehole
BH-ROM &	10546	2883150				Not yet drilled. To reassess purpose.
BH-Stock &	10932	28832400				Not yet drilled. To reassess purpose.
BH-N- Decant &	9546	2882595				Not yet drilled. To reassess purpose.
BH-In-pit &						Not yet drilled. To reassess purpose.
VBH-12M *	10657	2884410	1525			Drilled during November 2017
VBH-13M *	10643	2882930	1556	25		Drilled during November 2017
VBH-14M *	10796	2883465	1558	20		Drilled during November 2017
VBH-15M *	9197	2882880	1551	26		Drilled during November 2017

* Listed in WUL; & Listed in IWWMP; # Recommended in this report

Table 10.4 Hydrocensus/external users' boreholes

Map Nr	XCoord WGS84 (LO29)	YCoord WGS84 (LO29)	Elevation (mamsl)	Depth (m)	Sampling depth (m) **	Comment
EUB-1 * &	10020	2881565	1520	18.45		
EUB-2 * &	9854	2881741	1528	-		
EUB-3 * &	9246	2882030	1533	-		
EUB-4 * &	7971	2882110	1534	-		
EUB-5 * &	11108	2881647	1514	-		
EUB-6 &	10842	2882174	1545	-		Village borehole
EUB-8 * &	11895	2881723	1526	-		
EUB-9 * &	11906	2881741	1529	-		
EUB-10 &	11515	2883365	1547	-		Demolished
EUB-11 &	10550	2883092	1565	40.50		Demolished
EUB-12 * &	9243	2884837	1532	7.00		
EUB-13 * &	8493	2885037	1536	-		
EUB-14 &	9953	2884594	1531	-		
EUB-15 &	10076	2884746	1525	18.00		
EUB-16 * &	12728	2881028	1502	-		
EUB-17 &	9834	2883624	1575	-		Demolished
EUB-18 &	9769	2883605	1571	-		Demolished
EUB-P1	11557	2884510	1506	1.60		
EUB-P2	11897	2881709	1526	6.00		
T464	9933	2883522				Unknown reason/origin
EUF-1 *	11565	2884521	1507	-		Probably intermittent flow
EUF-2 *	10047	2884680	1519	-		Probably intermittent flow

* Listed in WUL

** Sampling depth to be confirmed or sample under application conditions

Table 10.5 Mine water and surface water monitoring

Site name	Coordinate (WGSLO29)		Frequency
	X	Y	
Klipspruit Upstream	-26.0788	28.91146	Monthly
Klipspruit Downstream	-26.0693	28.8862	Monthly
Kromdraai Upstream	-26.0432	28.9153	Monthly
Kromdraai Downstream	-26.035	28.88324	Monthly
Wilge River Upstream	-26.0987	28.85865	Monthly
Wilge River Downstream	-26.0455	28.868	Monthly
MW-01	-26.0685	28.89101	Monthly
MW-02	-26.0609	28.8935	Monthly
Pit-D01	-26.06209	28.91286	Monthly

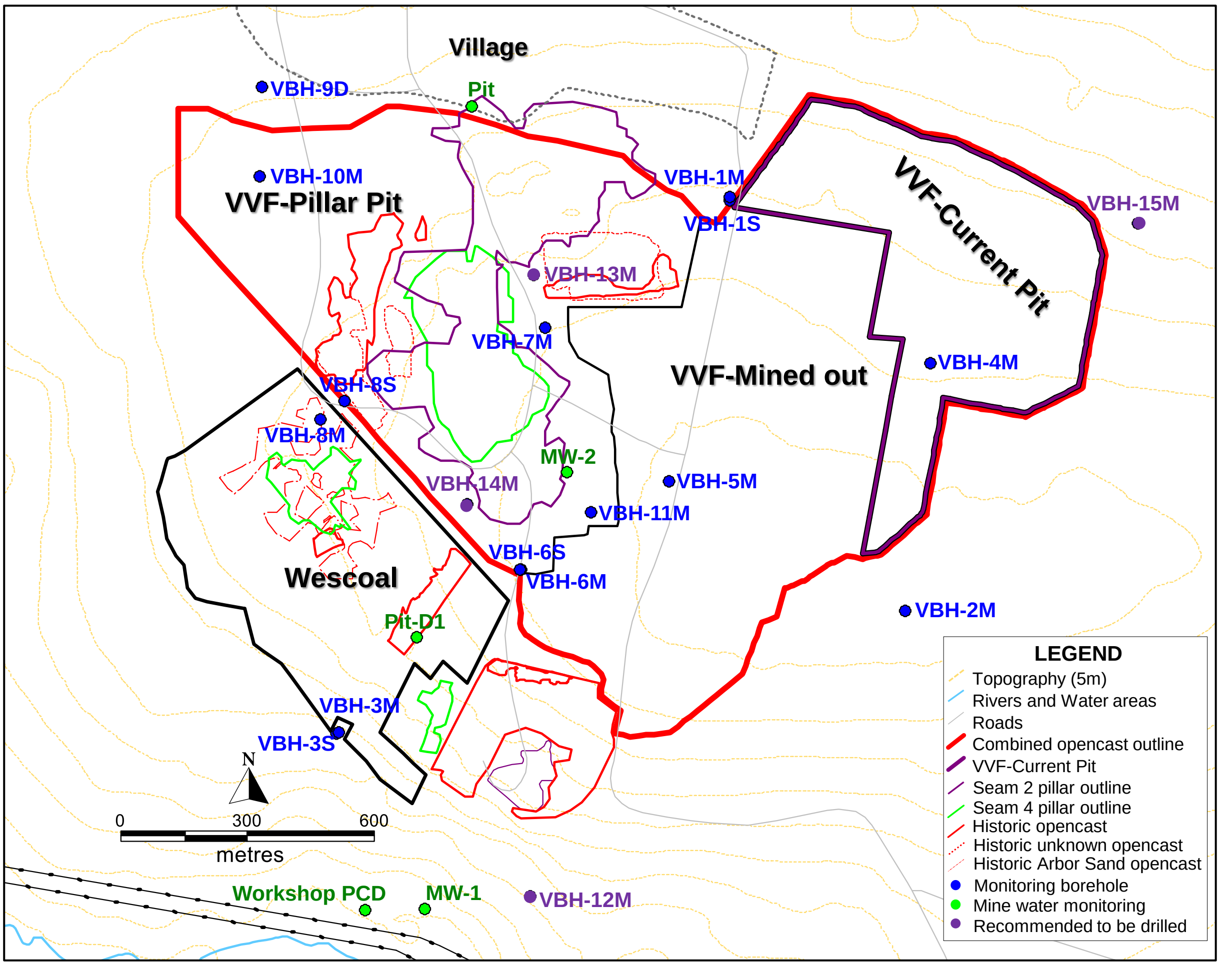

Figure 10.1 ***Recommended groundwater monitoring boreholes – also showing destroyed boreholes (which do not have to be re-drilled) and recommended boreholes (drilled during November 2017)***

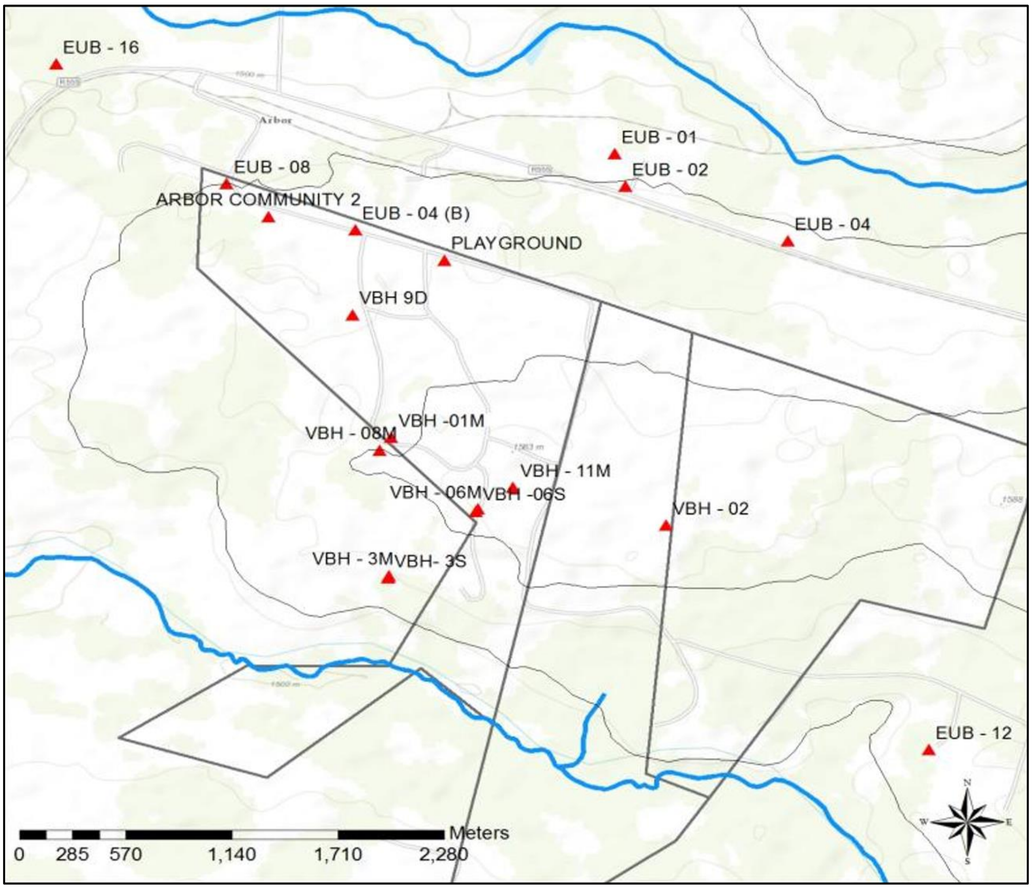

Figure 10.2 LWES groundwater monitoring system, also indicating locations of external users (Ref: LWES, 2017)

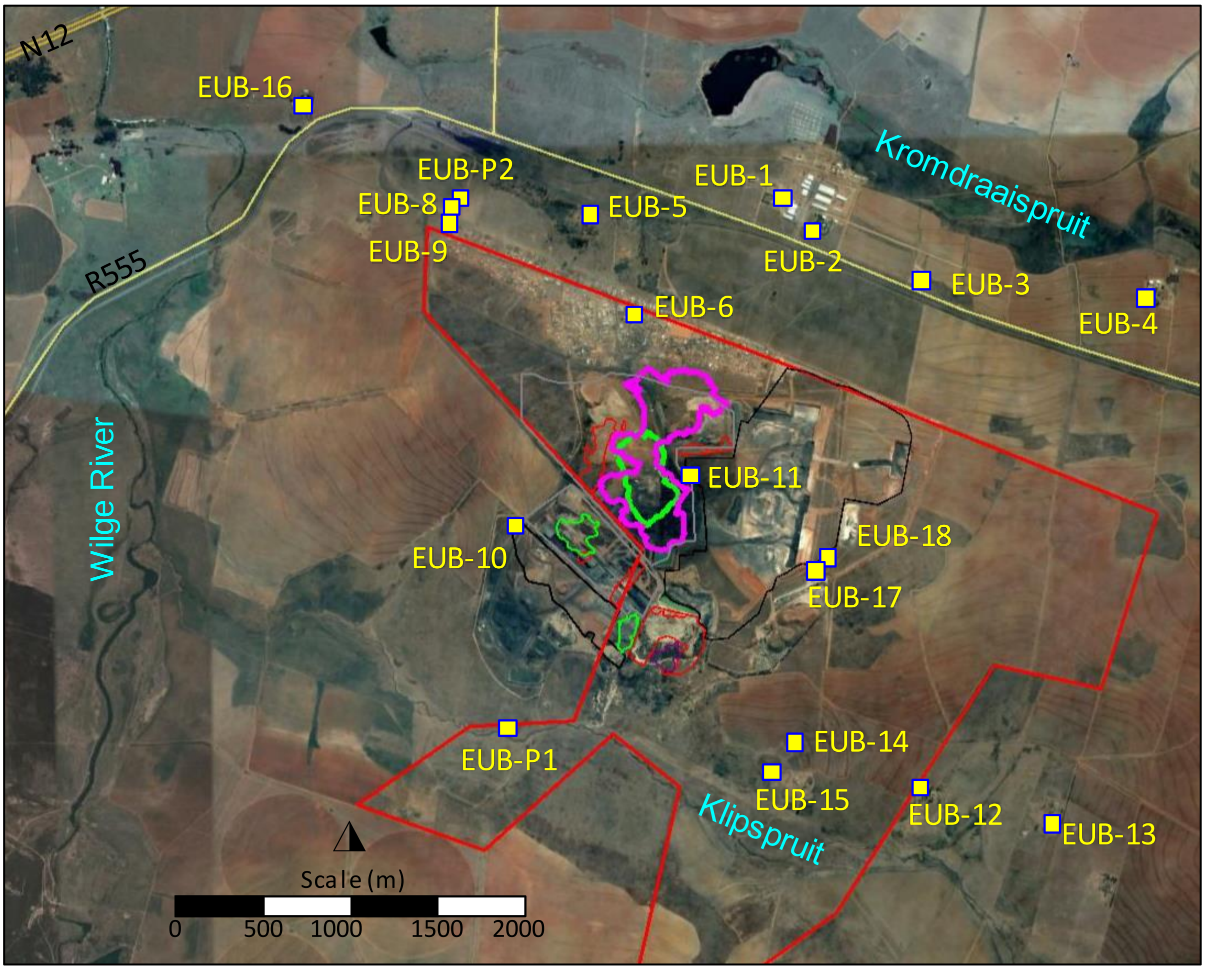

Figure 10.3 External users identified by Groundwater Square (Ref: GW2_069, 2009), depicted against an August 2016 Google Earth aerial photograph

11. GROUNDWATER ENVIRONMENTAL MANAGEMENT PROGRAMME

11.1. Current Groundwater Conditions

Prior to the commencement of mining in 2010, the area represented an impacted groundwater environment where historical opencast and underground mining had resulted in contaminated water contained in the old workings. Acid mine drainage seepages prevailed to the south toward the Klipspruit.

Currently, the main impacts relate to the dewatering of the local aquifer surrounding the current mining of VVF-Current Pit. The historical decant toward the Klipspruit dried up within two years of mining. Due to groundwater flow being toward the mining area, groundwater contamination has not spread

11.2. Predicted Impacts of Mining

If mining continues in the VVF-Pillar Pit to form one pit with the VVF-Current Pit, dewatering of the local aquifers will expand. Mining will impact on the local village groundwater supply through dewatering of the local aquifers. Groundwater contamination from the opencast pit should not impact on the local groundwater supply.

Groundwater contamination may occur through AMD toe seepages, if a discard dump is placed on surface.

11.3. Mitigation Measures

During the operational phase the most-important mitigation measures relate to:

- Groundwater monitoring recommendations in Section 10 are important.
- The placement of discard material:
  - If discard is placed on undisturbed/uncontaminated ground, a liner system will be required to prevent the contamination of the local groundwater system, and toe seepages should be collected (numerical modelling can confirm that, due to the short duration of mining, the liner system does not necessarily have to be designed for zero infiltration):
    - Any seepages and rainfall runoff originating from stockpiles should be identified and captured/diverted to the dirty water system;
    - Dirty water should be removed as quickly as possible to reduce the driving mechanism for contaminant migration;
  - If the dump is placed on rehabilitated mining areas without a liner system, the discard seepage water will mix with pit water and pumped out if necessary;
  - If the discard is paced in mined-out areas – the preferred option – it should be placed sufficiently deep below the long-term decant elevation (e.g. 10m);
- In line with pollution prevention and minimisation strategies, the following principles should apply if filter cake material is stored on-site as non-select product:
  - Source reduction through general site maintenance:
    - Product should be moved off-site as quickly to prevent continuous seepages from occurring;
    - The site should be maintained to be free draining. Where relevant, areas should be compacted/shaped;
    - Rainfall runoff should be separated into clean and dirty water (rainfall falling on the site should be allowed to drain quickly/freely, and contaminated water should then be captured in the mine dirty water system and re-used where possible);
    - Clean upstream rainfall water runoff should be diverted around the site;
  - Treatment:
    - Unless monitoring indicates otherwise, treatment is not required/recommended at this stage;
  - Secure disposal:
    - All dirty water collected on the site should be re-used or stored during operation;
- The preparation of the in-pit overburden-backfill material to limit the post-mining impact (i.e. adhering to the principles of source reduction, treatment and secure disposal):

   - The geochemical assessment indicated that the addition of lime in the backfill will reduce the long-term post mining groundwater quality impact, though improving the anticipated low-pH conditions and lowering sulphate and metal concentrations (a decision in this regard will have to be taken);
- The storage of contaminated operational mine water:
   - This water will be pumped to surface water dams where it can be reused;
   - In-pit water storage in low-lying areas may also be pursued;
   - Cognisance should be taken of highly contaminated mine water in the rehabilitated historic opencast areas, to the west of the underground areas, where (pH probably ranges from <3 to 4.5 and sulphate concentrations exceed 3000mg/L);
- Contaminated mine water, contained in historical Seam-2 and Seam-4 underground areas, will have to be pumped out prior to reaching these areas, as mining progresses from the west:
   - Because the Seam-4 and Seam-2 underground workings are probably interconnected (e.g. through boreholes or ramps), the Seam-4 mine workings should therefore be pumped first;
   - Cognisance should be taken of pillar failure, which can result in sudden water inrushes from areas where water was stored in underground dams during the 1940s historical mining phase;
   - Based on preliminary discussions:
      - A portion of the water will be treated and released into the Klipspruit;
      - The coal processing plant will require water;
      - The remainder of the water will be stored in-pit in the penstock area, and in the lined pollution control dams;
- A decision on the benefits of mining the barrier pillar between VVF-Pillar Pit and *Wescoal* can be pursued after the commencement of mining in the VVF-Pillar Pit (i.e. although numerical simulated, the mining of the *Wescoal* pillar is not considered at this stage).

<u>Penstock/Sump</u>

An in-pit penstock/sump was constructed in the south of the VVF-Current Pit, which can be utilised to pump mine water to surface from this low-lying region of the pit.

The sump can also constitute a possible long-term/post-mining water management option; where mine water is pumped from the rehabilitated backfill to reduce seepage to the south.

<u>AMD Prevention</u>

AMD can be reduced through the addition of calcitic lime to the backfill material (to buffer pH) or treating decant water. In terms of cost and volume, the required tonnage of calcitic lime to be added to the entire pit would be impracticable in terms of cost and volume. Target areas may include where discard is placed in the pits.

One option that should be pursued, is the placement of coal-fire station fly ash on top of the backfilled opencast. However, it might be highly impractical, and detailed research is required to investigate, especially, the geochemistry and water balance of such a scenario. Due to the long-term benefits of flushing acid-generating minerals from backfill material, this option should be carefully evaluated in terms of the potential impact on the local surface water environment and ecosystem. One aspect to consider is that water should first flow through the ash (e.g. rainfall recharge) before entering acid generating material, such as backfill. If decant water is treated in this way, it is advisable not to use ash, unless properly researched, but rather add calcitic lime.

<u>SA National Development Plan</u>

Water will remain a critical component of the National Development Plan initiative of the South African Government, as it can stimulate economic growth. Local farmers have been utilising the local surface water environment for decades to irrigate crops. The irrigation infrastructure consists of the river system, purpose build canals and -dams, as well as pump stations.

The VVF opencast (and surrounding mining environment) can potentially be incorporated into this system to store water for long periods, from where it can be utilised for irrigation; obviously ensuring that the water is of acceptable quality. It can potentially be beneficial for future generations, thus stimulating job creation in the local surroundings.

Detailed planning and research is required, and planning should not contradict the WUL and rehabilitation plans.

Decant Prevention Measures

In-pit evaporation from a final void or large enough in-pit-shaped evaporation can minimise the opencast water balance. Such a design is not currently planned. If such a design is pursued, it should account for rainfall that would fall directly on the evaporation area and the rainfall deficit that occurs on an annual basis.

A fundamental design criteria of in-pit evaporation areas, relates to the slopes above- and below the anticipated in-pit groundwater level. The slopes would be steeper above the groundwater level to minimise rainfall run-off. The slopes below the anticipated groundwater would be more gradual to optimise evaporation and evapotranspiration by plants, to account for the fluctuating in-pit groundwater levels on a seasonal basis. In practice, it will be very difficult to construct a large in-pit evaporation area.

11.3.1 Lowering of Groundwater Levels during Mining Operation

It is not possible to prevent the dewatering of the aquifers surrounding the proposed opencast mining (see anticipated zone of dewatering in Figure 7.11, Section 7.8.2). As soon as groundwater monitoring indicates a dewatered state of boreholes which supply external groundwater users (e.g. the local village boreholes), an alternative water sources should be provided.

It is important that an alternative water supply has to be identified prior to the occurrence of such an event. One option is to consider a geophysical and drilling programme to the north of the mine, where the geology is different to the Karoo aquifers, as a successful borehole for water supply to the village.

11.3.2 Rise of Groundwater Levels Post-Mining Operation

As discussed in Section 12, groundwater levels around the decant zones are anticipated to be higher than prior to mining. Decant will be contaminated, resulting an overland run-off towards the Klipspruit.

Because this decant cannot be prevented (unless water is evaporated somewhere in the pit, or water is pumped from the pit), and in line with best practice guidelines, water management measures should be introduced to reduce the impact of the source (i.e. specifically addressing water quality).

With reference to comments made on the South African National Development Plan (see introduction to Section 11), consideration should be given to utilise this water for irrigation projects in the area.

11.3.3 Spread of Groundwater Pollution Post-Mining Operation

The anticipated spread of groundwater contamination is discussed in Section 7.8.2 (see anticipated migration of groundwater in Figures 7.12 and 7.13A-D, and maximum groundwater contamination impact zones in Figure 7.14).

The spread of groundwater contamination can be restricted through active manipulation of the groundwater flow directions; e.g. pumping from boreholes or installation of a trench. However, this will require a huge rehabilitation fund. It is therefore important that an alternative supply has to be identified prior to the occurrence of such an event (also see recommendation in Section 11.3.2).

12. POST CLOSURE MANAGEMENT PLAN

The impact assessments and management of the impacts contained in this report (Sections 5 and 6), adhere to the DWAF series of Best Practice Guidelines (BPGs), which was developed for mines in line with International Principles and Approaches towards sustainability. The series of BPGs were grouped as outlined below (directly quoted from the documents):

- BEST PRACTICE GUIDELINES dealing with aspects of DWAF's water management HIERARCHY:
  - H1. Integrated Mine Water Management;
  - H2. Pollution Prevention and Minimisation of Impacts;
  - H3. Water Reuse and Reclamation;
  - H4. Water Treatment;
- BEST PRACTICE GUIDELINES dealing with GENERAL water management strategies, techniques and tools, which could be applied cross-sectoral:
  - G1. Storm Water Management;
  - G2. Water and Salt Balances;
  - G3. Water Monitoring Systems;
  - G4. Impact Prediction;
  - G5. Water Management Aspects for Mine Closure;
- BEST PRACTICE GUIDELINES dealing with specific mining ACTIVITIES or ASPECTS, which address the prevention and management of impacts from:
  - A1. Small-scale Mining;
  - A2. Water Management for Mine Residue Deposits;
  - A3. Water Management in Hydrometallurgical Plants;
  - A4. Pollution Control Dams;
  - A5. Water Management for Surface Mines;
  - A6. Water Management for Underground Mines.

One of the functions performed within the hierarchy of decision making is to inform interested and affected parties on good practice at mines.

12.1. Remediation of Physical Activity

Groundwater monitoring recommendations in Section 10 are important.

The following recommendations are noteworthy in terms of adhering to the principle of pollution prevention and source reduction:

- All remaining material of the coal processing plant area should be removed, and placed into the bottom of a mining area below the final post-mining groundwater level;
- The expertise of a soil scientist should be called upon to assess the base/foundation layer and underlying soils in terms of the degree of contamination (in the context of the general soil contamination of surrounding soils):
  - In the event that salts are identified, a decision should be taken on the need (and best method) to rehabilitate the footprint areas (e.g. placement of foundation layer into the bottom of the pit);
  - Topsoil should be placed back to restore the site to its original status/soil-condition.

12.2. Remediation of Storage Facilities

It is recommended that discard material be placed in mined-out areas, sufficiently deep below the long-term decant elevation. However, if permission is not granted for this, contaminated toe seepages of sulphate concentrations exceeding 5000 mg/L should be prevented, through covering the discard dump with an engineered capping system to prevent rainfall infiltration. This approach adheres to the principle of source reduction. Groundwater monitoring recommendations in Section 10 are important.

In line with pollution prevention and minimisation strategies, the following principles should apply if filter cake material and discard remain on site as a discard dump:

- Groundwater monitoring recommendations in Section 10 are important;
- Source reduction through:
  - Capping of the dump;

  - General site maintenance, allowing free draining, and capturing of dirty water (runoff and seepages originating from the dump);
- Storage, treatment and/or reuse of contaminated water (e.g. such as the irrigation projects mentioned in Section 12.5).

12.3. Remediation of Environmental Impacts

The area to the south of the VVF-Current Pit was historically contaminated where decant run-off formed visible salts on surface and influenced the local vegetation. It is recommended that limited/optimal surface rehabilitation be performed, such as the placing of a thin topsoil layer and ensuring that the area is covered by indigenous plants (i.e. also removal of invading plant species). This will prevent contaminated rainfall runoff over the contaminated soils.

Other than the remediation of surface disturbances no other environmental impacts was identified.

12.4. Remediation of Water Resources Impacts

The Vlakvarkfontein Mine does not impact directly on the local surface water resources; specifically, the Klipspruit (also known as the Leeuwfonteinspruit) which drains contaminated mine water which originates 6km upstream. Mining, which commenced in 2010, improved the situation, in that decant to the south dried up within two years of the commencement of mining.

12.5. Backfilling of the Pits

Due to a material deficit, the post-mining surface topographical contours in the VVF-Pillar Pit will be lower than the pre-mining situation. This will be beneficial in terms of the potential of the pit to generate AMD. A recent rehabilitation design by Golder (September 2017), recommended that the VVF-Pillar Pit should drain to the west, from where surface water run-off will naturally continue to flow westward. Free drainage of surface water runoff will reduce the post-mining natural rainfall recharge, which will be beneficial in terms of the potential volume of contaminate decant water that will have to be mitigated.

If the discard is paced in mined-out areas – the preferred option – it should be placed sufficiently deep below the long-term decant elevation (e.g. 10m). Considering the decant elevation of 1538mamsl if the barrier pillar with Wescoal remains unmined, this level is 1528mamsl. The stage curve, included as Figure 7.9 (Section 7.6), estimated the available storage volume as approximately 1.9Mm^3.

13. Conclusions and Recommendations

See executive summary

14. Assumptions and Limitations

See executive summary

The numerical groundwater flow and transport model is believed to be sufficiently representative of the local aquifers and groundwater conditions, to predict the post-mining decant situation to a sufficient level of accuracy.

The following main assumptions applied to this study:

- Data and information were presumed sufficiently accurate:
  - Where relevant, datasets (e.g. hydraulic testing, water monitoring, surface topography and aquifer geometry) from previous groundwater studies;
  - The basis of the impact assessments, were field studies (e.g. hydrocensus, hydrogeological drilling, geophysical surveys, pump testing and groundwater monitoring) by Groundwater Square at Vlakvarkfontein over the past decade; supplemented in this study by the drilling of four additional monitoring holes, and the collection of various water/geochemical samples;
  - Project consultants ECMA, GeoSoilWater, GEMECS, CCIC, and EIMS supplied the following information (through discussions, spreadsheets, presentations and electronic CAD drawings):
    - Latest mining scheduling and life-of-mine plans;
    - Infrastructure layout and design;
    - Geological model of coal seams;
    - Groundwater monitoring database;
    - Bulking factor of rehabilitated backfill material;
  - During several visits to the Vlakvarkfontein Colliery, the current water situation was discussed with Mine Personal and mentioned project consultants; providing valuable insight into the future mine water balance;
  - The life-of-mine of neighbouring Wescoal mining company was determined from Google Earth aerial photographs and mining plans provided in the past by Wescoal;
- Inter-mine flow calculations with adjacent Wescoal, assumed certain design criteria for barrier pillars (width and depth) parameters, as well as hydraulic aquifer parameters not severely altered by blasting;
- Aquifer parameters of geological units:
  - Although aquifer parameters vary over orders of magnitude over short distances (e.g. fracture flow compared to flow through the solid portions of the rock matrix), the values utilised in the groundwater model for similar geological units of similar depths, will be representative of groundwater flow over distances applicable to typical mining impacts;
  - Where aquifer information was judged to be incomplete (i.e. hydraulic aquifer parameters of geological units within the numerical groundwater model domain, other than Karoo Ecca rock, within which coal mining is taking place), knowledge of Mpumalanga coal fields was applied;
  - Visual inspection of borehole cores retrieved during exploration drilling of the Selons River Formation to the south, indicated a very low hydraulic conductivity;
  - The Ogies dykes Ogies dyke was assumed non-weathered and non-fractured below 5m deep;
- The existing and proposed pit areas are devoid of major geological structures, such as faults and dykes;
- Conceptually, the groundwater flow field is well understood;
- The extent of historic underground mining, was based on historical mine maps. This will have no bearing on the post-mining groundwater flow impact assessment as the whole area will be mined;
- The current interaction of mining with the surrounding aquifers will continue as the mine expands to the north and west into the pillar area;
- Geochemical evaluation:
  - Geochemical samples were representative of the backfilled spoils, mined coal seams and the complete litho-stratigraphical profile;
  - Given the scientific integrity of the geochemical modelling considerations and technique, geochemical trend predictions are therefore within an acceptable range of accuracy.

The following limitations applied to the study:

- Rainfall seasonality will influence the mine water balance, and the compounding effect of sequential wet or dry rainfall periods may result in much larger than average decant for such extreme wet periods, and zero decant during extreme droughts. An indication of "relatively" wet and dry cycles were provided in the report, but it is not possible to provide for extreme events, such as 100/1000year extremes;

- The sequence of mining will affect the mine water balance; especially relevant with regard to the storage of mine water from the historical underground workings;
- No accurate data exists of how much groundwater has been pumped from the boreholes which supply the local village;
- It is very important to perform groundwater level and groundwater quality monitoring, to verify modelling predictions, and timeously correct assumptions in the unlikely event that the groundwater system behaves differently to expectations.

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Water Use License (WUL) 2016

Integrated Water and Waste Management Plan (IWWWMP) 2015

Appendix 1

Groundwater Levels Data

Site name	Date	Water Level (m)
VBH-10M	01-04-2014	7.53
VBH-10M	01-07-2014	10.20
VBH-10M	01-10-2014	10.78
VBH-10M	01-01-2015	8.56
VBH-10M	01-04-2015	10.56
VBH-10M	01-07-2015	11.21
VBH-10M	01-11-2015	11.61
VBH-10M	01-02-2016	10.78
VBH-10M	01-05-2016	9.96
VBH-10M	01-08-2016	11.13
VBH-10M	01-11-2016	10.22
VBH-11M	01-04-2014	19.23
VBH-11M	01-07-2014	19.63
VBH-11M	01-10-2014	19.80
VBH-11M	01-01-2015	19.55
VBH-11M	01-04-2015	19.83
VBH-11M	01-07-2015	19.81
VBH-11M	01-11-2015	20.46
VBH-11M	01-02-2016	20.50
VBH-11M	01-05-2016	20.33
VBH-11M	01-08-2016	20.26
VBH-11M	01-11-2016	19.99
VBH-11M	01-01-2017	20.00
VBH-11M	01-04-2017	20.00
VBH-11M	01-05-2017	20.25
VBH-1M	07-09-2009	10.58
VBH-1M	17-03-2011	4.57
VBH-1M	19-04-2011	4.94
VBH-1M	17-05-2011	5.44
VBH-1M	17-06-2011	5.66
VBH-1M	18-07-2011	6.49
VBH-1M	17-08-2011	7.08
VBH-1M	26-09-2011	7.36
VBH-1M	25-10-2011	6.45
VBH-1M	24-11-2011	7.49
VBH-1M	22-12-2011	7.93
VBH-1M	22-02-2012	6.81
VBH-1M	20-03-2012	7.16
VBH-1M	23-04-2012	6.52
VBH-1M	21-05-2012	7.73
VBH-1M	21-06-2012	7.73
VBH-1M	27-07-2012	7.83
VBH-1M	27-09-2012	7.82
VBH-1M	17-10-2012	7.85
VBH-1M	21-11-2012	7.89
VBH-1M	14-12-2012	No Sample
VBH-1M	18-01-2013	6.57
VBH-1M	20-02-2013	6.51
VBH-1M	25-03-2013	7.68
VBH-1M	22-04-2013	7.79
VBH-1M	24-05-2013	7.88
VBH-1M	20-06-2013	7.97
VBH-1M	01-04-2014	6.32
VBH-1M	01-07-2014	7.85
VBH-1M	01-10-2014	8.24
VBH-1M	01-01-2015	Demolished
VBH-1M	01-04-2015	Demolished
VBH-1M	01-07-2015	Demolished
VBH-1M	01-11-2015	Demolished
VBH-1M	01-02-2016	Demolished
VBH-1M	01-05-2016	Demolished
VBH-1M	01-08-2016	Demolished
VBH-1M	01-11-2016	Demolished
VBH-1S	17-03-2011	4.34

Site name	Date	Water Level (m)
VBH-1S	19-04-2011	4.73
VBH-1S	17-05-2011	5.22
VBH-1S	17-06-2011	5.32
VBH-1S	17-08-2011	Dry
VBH-1S	26-09-2011	Dry
VBH-1S	25-10-2011	Dry
VBH-1S	24-11-2011	Dry
VBH-1S	22-12-2011	Dry
VBH-1S	22-02-2012	Dry
VBH-1S	20-03-2012	Dry
VBH-1S	23-04-2012	Dry
VBH-1S	21-05-2012	Dry
VBH-1S	21-06-2012	Dry
VBH-1S	27-07-2012	Dry
VBH-1S	27-09-2012	Dry
VBH-1S	17-10-2012	Dry
VBH-1S	21-11-2012	Dry
VBH-1S	18-01-2013	Dry
VBH-1S	20-02-2013	Dry
VBH-1S	25-03-2013	Dry
VBH-1S	22-04-2013	Dry
VBH-1S	24-05-2013	Dry
VBH-1S	20-06-2013	Dry
VBH-2M	07-09-2009	13.10
VBH-2M	17-03-2011	10.35
VBH-2M	19-04-2011	9.94
VBH-2M	17-05-2011	10.63
VBH-2M	17-06-2011	11.26
VBH-2M	18-07-2011	11.69
VBH-2M	17-08-2011	12.18
VBH-2M	26-09-2011	12.41
VBH-2M	25-10-2011	12.44
VBH-2M	24-11-2011	12.52
VBH-2M	22-12-2011	12.20
VBH-2M	22-02-2012	11.42
VBH-2M	20-03-2012	11.27
VBH-2M	23-04-2012	10.40
VBH-2M	21-05-2012	11.63
VBH-2M	21-06-2012	11.63
VBH-2M	27-07-2012	11.89
VBH-2M	27-09-2012	11.96
VBH-2M	17-10-2012	11.45
VBH-2M	21-11-2012	11.53
VBH-2M	14-12-2012	10.03
VBH-2M	18-01-2013	10.74
VBH-2M	20-02-2013	10.50
VBH-2M	25-03-2013	10.47
VBH-2M	22-04-2013	10.36
VBH-2M	24-05-2013	10.70
VBH-2M	20-06-2013	11.10
VBH-2M	01-04-2014	9.52
VBH-2M	01-07-2014	11.70
VBH-2M	01-10-2014	12.50
VBH-2M	01-01-2015	10.70
VBH-2M	01-04-2015	11.73
VBH-2M	01-07-2015	12.61
VBH-2M	01-11-2015	12.87
VBH-2M	01-02-2016	13.45
VBH-2M	01-05-2016	13.35
VBH-2M	01-08-2016	13.42
VBH-2M	01-11-2016	12.00
VBH-2M	01-01-2017	13.00
VBH-2M	01-04-2017	13.00
VBH-2M	01-05-2017	12.93

Site name	Date	Water Level (m)
VBH-3M	07-09-2009	5.62
VBH-3M	17-03-2011	5.15
VBH-3M	19-04-2011	5.24
VBH-3M	17-05-2011	5.27
VBH-3M	17-06-2011	5.24
VBH-3M	18-07-2011	5.22
VBH-3M	17-08-2011	5.33
VBH-3M	26-09-2011	5.00
VBH-3M	24-11-2011	Dry
VBH-3M	22-12-2011	Dry
VBH-3M	22-02-2012	Dry
VBH-3M	20-03-2012	Dry
VBH-3M	23-04-2012	Dry
VBH-3M	21-05-2012	Dry
VBH-3M	21-06-2012	Dry
VBH-3M	27-07-2012	Dry
VBH-3M	27-09-2012	Dry
VBH-3M	17-10-2012	Dry
VBH-3M	21-11-2012	Dry
VBH-3M	14-12-2012	Dry
VBH-3M	18-01-2013	Dry
VBH-3M	20-02-2013	Dry
VBH-3M	25-03-2013	Dry
VBH-3M	22-04-2013	Dry
VBH-3M	24-05-2013	Dry
VBH-3M	20-06-2013	6.50
VBH-3M	01-04-2014	10.23
VBH-3M	01-07-2014	10.93
VBH-3M	01-10-2014	11.17
VBH-3M	01-01-2015	No Access
VBH-3M	01-04-2015	No Access
VBH-3M	01-07-2015	11.06
VBH-3M	01-11-2015	No Access
VBH-3M	01-02-2016	No Access
VBH-3M	01-05-2016	No Access
VBH-3M	01-08-2016	No Access
VBH-3M	01-11-2016	10.90
VBH-3M	01-01-2017	11.00
VBH-3M	01-04-2017	11.00
VBH-3M	01-05-2017	10.80
VBH-3S	07-09-2009	5.49
VBH-3S	17-03-2011	5.00
VBH-3S	19-04-2011	5.18
VBH-3S	17-05-2011	5.19
VBH-3S	17-06-2011	5.20
VBH-3S	18-07-2011	5.22
VBH-3S	17-08-2011	5.33
VBH-3S	26-09-2011	5.30
VBH-3S	25-10-2011	5.53
VBH-3S	24-11-2011	5.66
VBH-3S	22-12-2011	Dry
VBH-3S	22-02-2012	Dry
VBH-3S	20-03-2012	Dry
VBH-3S	23-04-2012	5.25
VBH-3S	21-05-2012	5.25
VBH-3S	21-06-2012	5.25
VBH-3S	27-07-2012	Dry
VBH-3S	27-09-2012	Dry
VBH-3S	17-10-2012	5.83
VBH-3S	21-11-2012	Dry
VBH-3S	14-12-2012	Dry
VBH-3S	18-01-2013	Dry
VBH-3S	20-02-2013	Dry
VBH-3S	25-03-2013	Dry

Site name	Date	Water Level (m)
VBH-3S	22-04-2013	Dry
VBH-3S	24-05-2013	5.79
VBH-3S	20-06-2013	6.52
VBH-3S	01-04-2014	6.43
VBH-3S	01-07-2014	Dry
VBH-3S	01-10-2014	Dry
VBH-3S	01-01-2015	No Access
VBH-3S	01-04-2015	No Access
VBH-3S	01-07-2015	Dry
VBH-3S	01-11-2015	Dry
VBH-3S	01-02-2016	No Access
VBH-3S	01-05-2016	No Access
VBH-3S	01-08-2016	No Access
VBH-3S	01-11-2016	6.85
VBH-4M	07-09-2009	11.35
VBH-4M	17-03-2011	6.98
VBH-4M	19-04-2011	6.98
VBH-4M	17-05-2011	7.46
VBH-4M	17-06-2011	8.31
VBH-4M	18-07-2011	9.13
VBH-4M	17-08-2011	9.81
VBH-4M	26-09-2011	10.10
VBH-4M	25-10-2011	9.14
VBH-4M	01-04-2014	9.82
VBH-4M	01-07-2014	11.18
VBH-4M	01-10-2014	10.17
VBH-4M	01-01-2015	10.04
VBH-4M	01-04-2015	10.71
VBH-4M	01-07-2015	10.18
VBH-4M	01-11-2015	10.77
VBH-4M	01-02-2016	Dry
VBH-4M	01-05-2016	Dry
VBH-4M	01-08-2016	Dry
VBH-4M	01-11-2016	Dry
VBH-5M	07-09-2009	13.53
VBH-5M	17-03-2011	Not found, mined out
VBH-5M	17-08-2011	Destroyed
VBH-6M	07-09-2009	12.81
VBH-6M	17-03-2011	14.63
VBH-6M	19-04-2011	13.87
VBH-6M	17-05-2011	13.20
VBH-6M	17-06-2011	13.02
VBH-6M	18-07-2011	13.14
VBH-6M	17-08-2011	13.60
VBH-6M	26-09-2011	13.89
VBH-6M	25-10-2011	15.37
VBH-6M	24-11-2011	15.48
VBH-6M	22-12-2011	Dry
VBH-6M	22-02-2012	Dry
VBH-6M	20-03-2012	29.37
VBH-6M	23-04-2012	Dry
VBH-6M	21-05-2012	Dry
VBH-6M	21-06-2012	Dry
VBH-6M	27-07-2012	Dry
VBH-6M	27-09-2012	Dry
VBH-6M	17-10-2012	15.37
VBH-6M	21-11-2012	Dry
VBH-6M	14-12-2012	17.30
VBH-6M	18-01-2013	Muddy
VBH-6M	20-02-2013	15.20
VBH-6M	25-03-2013	15.19
VBH-6M	22-04-2013	15.15
VBH-6M	24-05-2013	15.15
VBH-6M	20-06-2013	15.14
VBH-6M	01-04-2014	18.16
VBH-6M	01-07-2014	15.40
VBH-6M	01-10-2014	16.96
VBH-6M	01-01-2015	16.05
VBH-6M	01-04-2015	15.56
VBH-6M	01-07-2015	16.89
VBH-6M	01-11-2015	Dry
VBH-6M	01-02-2016	25.33
VBH-6M	01-05-2016	21.53
VBH-6M	01-08-2016	Dry
VBH-6M	01-11-2016	30.13
VBH-6M	01-01-2017	27.00
VBH-6M	01-04-2017	27.00
VBH-6M	01-05-2017	28.39
VBH-6S	17-03-2011	5.61
VBH-6S	19-04-2011	4.45
VBH-6S	17-05-2011	4.72
VBH-6S	17-06-2011	5.00
VBH-6S	18-07-2011	5.31
VBH-6S	17-08-2011	5.66
VBH-6S	26-09-2011	Dry
VBH-6S	25-10-2011	Dry
VBH-6S	24-11-2011	5.26
VBH-6S	22-12-2011	Dry
VBH-6S	22-02-2012	Dry
VBH-6S	20-03-2012	5.36
VBH-6S	23-04-2012	Dry
VBH-6S	21-05-2012	Dry
VBH-6S	21-06-2012	Dry
VBH-6S	27-07-2012	Dry
VBH-6S	27-09-2012	Dry
VBH-6S	17-10-2012	Dry
VBH-6S	21-11-2012	Dry
VBH-6S	14-12-2012	5.25
VBH-6S	18-01-2013	Muddy
VBH-6S	20-02-2013	3.90
VBH-6S	25-03-2013	5.00
VBH-6S	22-04-2013	4.76
VBH-6S	24-05-2013	5.98
VBH-6S	20-06-2013	5.04
VBH-6S	01-04-2014	4.99
VBH-6S	01-07-2014	5.02
VBH-6S	01-10-2014	5.38
VBH-6S	01-01-2015	Dry
VBH-6S	01-04-2015	5.26
VBH-6S	01-07-2015	Dry
VBH-6S	01-11-2015	Dry
VBH-6S	01-02-2016	Dry
VBH-6S	01-05-2016	Dry
VBH-6S	01-08-2016	Dry
VBH-6S	01-11-2016	Dry
VBH-7M	07-09-2009	10.82
VBH-7M	17-03-2011	19.00
VBH-7M	19-04-2011	12.06
VBH-7M	17-05-2011	24.00
VBH-7M	24-11-2011	Not in use
VBH-7M	22-12-2011	Not in use
VBH-7M	22-02-2012	Not in use
VBH-7M	20-03-2012	Not in use
VBH-7M	23-04-2012	Not in use
VBH-7M	21-05-2012	Not in use
VBH-7M	21-06-2012	Not in use
VBH-7M	27-07-2012	Not in use
VBH-7M	27-09-2012	Not in use
VBH-7M	17-10-2012	Not in use
VBH-7M	21-11-2012	Not in use
VBH-7M	18-01-2013	Not in use - hole sealed
VBH-7M	20-02-2013	Not in use - hole sealed
VBH-7M	25-03-2013	Not in use - hole sealed
VBH-7M	22-04-2013	Not in use - hole sealed
VBH-7M	24-05-2013	Not in use - hole sealed
VBH-8M	07-09-2009	5.44
VBH-8M	17-03-2011	4.76
VBH-8M	19-04-2011	4.81
VBH-8M	17-05-2011	4.88
VBH-8M	17-06-2011	5.02
VBH-8M	18-07-2011	5.12
VBH-8M	17-08-2011	5.27
VBH-8M	26-09-2011	5.33
VBH-8M	25-10-2011	5.54
VBH-8M	25-10-2011	5.10
VBH-8M	24-11-2011	5.73
VBH-8M	22-12-2011	5.84
VBH-8M	22-02-2012	5.36
VBH-8M	20-03-2012	5.27
VBH-8M	23-04-2012	5.52
VBH-8M	21-05-2012	5.80
VBH-8M	21-06-2012	5.80
VBH-8M	27-07-2012	5.98
VBH-8M	27-09-2012	Dry
VBH-8M	17-10-2012	8.54
VBH-8M	21-11-2012	Dry
VBH-8M	14-12-2012	6.26
VBH-8M	18-01-2013	6.83
VBH-8M	20-02-2013	5.76
VBH-8M	25-03-2013	5.83
VBH-8M	22-04-2013	5.96
VBH-8M	24-05-2013	6.00
VBH-8M	20-06-2013	6.20
VBH-8M	01-04-2014	7.79
VBH-8M	01-07-2014	7.55
VBH-8M	01-10-2014	8.14
VBH-8M	01-01-2015	6.34
VBH-8M	01-04-2015	8.16
VBH-8M	01-07-2015	6.71
VBH-8M	01-11-2015	Dry
VBH-8M	01-02-2016	Dry
VBH-8M	01-05-2016	Dry
VBH-8M	01-08-2016	Dry
VBH-8M	01-11-2016	8.78
VBH-8M	01-05-2017	Dry
VBH-8S	07-09-2009	4.78
VBH-8S	17-03-2011	3.82
VBH-8S	19-04-2011	3.74
VBH-8S	17-05-2011	3.83
VBH-8S	17-06-2011	4.09
VBH-8S	18-07-2011	4.35
VBH-8S	17-08-2011	4.59
VBH-8S	26-09-2011	3.86
VBH-8S	24-11-2011	5.20
VBH-8S	22-12-2011	5.38
VBH-8S	22-02-2012	4.80
VBH-8S	20-03-2012	3.47
VBH-8S	23-04-2012	3.85
VBH-8S	21-05-2012	5.25
VBH-8S	21-06-2012	5.25
VBH-8S	27-07-2012	5.63
VBH-8S	27-09-2012	Dry
VBH-8S	17-10-2012	5.10
VBH-8S	21-11-2012	Dry
VBH-8S	14-12-2012	6.00
VBH-8S	18-01-2013	5.79
VBH-8S	20-02-2013	5.73
VBH-8S	25-03-2013	5.35
VBH-8S	22-04-2013	5.97
VBH-8S	24-05-2013	6.00
VBH-8S	20-06-2013	6.20
VBH-8S	01-04-2014	6.75
VBH-8S	01-07-2014	7.39

Site name	Date	Water Level (m)
VBH-8S	01-10-2014	Dry
VBH-8S	01-01-2015	Dry
VBH-8S	01-04-2015	Dry
VBH-8S	01-07-2015	Dry
VBH-8S	01-11-2015	Dry
VBH-8S	01-02-2016	Dry
VBH-8S	01-05-2016	Dry
VBH-8S	01-08-2016	Dry
VBH-8S	01-11-2016	Dry
VBH-9D	01-07-2014	11.94
VBH-9D	01-10-2014	13.48
VBH-9D	01-01-2015	12.47
VBH-9D	01-04-2015	12.71
VBH-9D	01-07-2015	14.44
VBH-9D	01-11-2015	16.49
VBH-9D	01-02-2016	16.02
VBH-9D	01-05-2016	14.55
VBH-9D	01-08-2016	14.99
VBH-9D	01-11-2016	15.61
VBH-9D	01-01-2017	13.00
VBH-9D	01-04-2017	13.00
VBH-9D	01-05-2017	Dry

Appendix 2
Groundwater Quality Data

Table A2.1 Major Indicators and Elements

Site Name	Date	pH	EC (mS/m)	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO4 (mg/L)	TALK (mg/L)	NO3 (as N) (mg/L)	F (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)
1 - Target Level (<)		5.5														
2 - Target Level (>)		9.5	150	1000	150	70	200	50	200	400		10.0	1.0	0.20	0.10	0.30
3 - Critical Level (<)		4.0														
4 - Critical Level (>)		11.0	370	2400	300	100	400	100	600	600		20.0	1.5	2.00	1.00	0.50
Arbor Community	01-05-2017	7.7	19	126	11	9	13	2	6	50	12	6.0	<0.263	<0.004	<0.001	
Arbor Community	01-06-2017	7.0	1	<10	0	0	1	0	1	1	<1.99	0.4	<0.263	<0.004	<0.001	
Arbor Community	01-07-2017	6.6	22	117	11	9	12	2	5	34	11	8.6	<0.263	<0.004	0.01	
Arbor Community	01-08-2017	6.3	20	156	12	10	17	3	13	46	19	10.0	<0.263	<0.004	0.00	
Arbor Community	01-09-2017	7.8	21	124	12	9	12	2	7	34	17	8.5	<0.263	<0.004	0.01	
BS-S1	18-09-2009	7.9	26	122	19	11	15	2	5	7	103	0.4	0.5	0.51	<0.01	0.34
Drinking water	01-04-2017	6.5	2	<10	1	1	1	0	1	1	3	0.5	<0.263	<0.004	<0.001	
Drinking water	01-05-2017	6.5	1	<10	1	1	1	0	1	1	<1.99	0.8	<0.263	<0.004	<0.001	
Drinking water	01-06-2017	6.5	21	130	11	9	13	2	6	45	12	8.3	<0.263	<0.004	0.02	
Drinking water	01-07-2017	7.5	1	<10	1	1	1	<0.015	1	2	2	0.3	<0.263	<0.004	<0.001	
Drinking water	01-08-2017	6.3	2	11	1	1	1	<0.015	2	4	<1.99	0.4	<0.263	<0.004	<0.001	
Drinking water	01-09-2017	7.1	1	<10	1	0	1	0	<0.557	<0.141	4	<0.194	<0.263	<0.004	<0.001	
LS-S1	18-09-2009	8.0	51	342	47	33	21	3	12	147	132	0.4	0.5	0.10	0.01	0.09
MW-1	07-09-2009	3.3	262	2046	234	107	13	11	5	1530	0	0.4	1.6	2.43	28.90	119.00
MW-1	16-03-2011	2.9	172	1080	95	43	5	13	4	816	0	0.4	1.7	27.30	17.20	62.20
MW-1	19-04-2011	2.9	143	912	77	35	4	9	4	693	0	0.0	1.5	19.70	13.90	59.10
MW-1	17-05-2011	3.0	139	928	75	31	4	8	2	699	0	0.4	1.5	23.20	13.00	67.30
MW-1	17-06-2011	3.2	190	1340	140	63	8	12	3	1013	0	0.3	1.1	9.56	14.10	82.10
MW-1	18-07-2011	3.2	188	1461	182	61	8	10	3	1104	0	0.0	1.0	10.40	14.90	72.00
MW-1	17-08-2011	3.2	204	1816	171	3	10	12	3	1417	0	<0.01	0.8	9.58	14.00	113.00
MW-1	26-09-2011	4.1	186	1859	155	74	9	12	3	1446	0	0.3	0.0	9.08	13.80	144.00
MW-1	24-10-2011	3.1	192	1509	163	66	10	13	5	1146	0	0.3	<0.01	10.60	13.50	88.80
MW-1	23-11-2011	3.1	186	1800	173	70	9	13	4	1372	0	0.3	1.1	6.54	14.00	132.00
MW-1	18-01-2012	3.1	188	1584	158	58	7	12	3	1214	0	0.1	<0.01	5.87	13.10	108.00
MW-1	22-02-2012	3.1	189	1657	157	68	9	12	3	1267	0	0.2	0.0	13.20	14.60	107.00
MW-1	24-05-2013	3.3	228	1888	193	91	13	10	4	1464	0	0.8	0.0	1.51	7.67	94.44
MW-1	13-06-2013	2.9	261	2279	254	111	14	12	3	1716	0	6.7	<0.01	8.61	13.62	112.97
MW-2	17-06-2011	7.6	91	591	108	30	8	16	4	361	62	9.6	0.6	<0.01	<0.01	0.03
MW-2	18-07-2011	7.5	98	675	128	32	8	16	3	413	67	10.9	0.7	0.01	0.01	0.08
MW-2	17-08-2011	7.5	111	748	159	41	8	15	4	433	74	12.9	0.7	0.03	<0.01	0.03
MW-2	26-09-2011	6.6	90	625	113	46	11	14	4	367	64	9.8	0.9	0.98	0.07	0.07
MW-2	24-10-2011	7.8	94	589	112	37	12	15	4	343	68	8.6	0.8	0.02	<0.01	0.03
MW-2	23-11-2011	7.1	88	624	117	42	13	3	4	375	61	4.6	0.7	<0.01	<0.01	0.02
MW-2	22-12-2011	6.8	96	677	107	46	18	3	4	438	50	2.9	0.8	<0.01	<0.01	0.02
MW-2	22-02-2012	8.3	95	670	113	49	14	17	3	441	47	0.9	0.7	0.02	0.02	0.08
MW-2	20-03-2012	7.4	120	883	167	58	13	19	3	565	78	1.8	0.6	0.01	<0.01	0.05
MW-2	23-04-2012	7.5	122	860	130	57	15	3	3	571	85	1.8	0.1	<0.01	<0.01	0.04
MW-2	21-05-2012	8.0	125	927	164	64	13	20	3	601	94	1.1	0.1	<0.01	<0.01	<0.01
MW-2	14-12-2012	4.5	220	1879	381	114	5	21	7	1186	180	12.3	0.3	<0.01	1.49	<0.01
MW-2	18-01-2013	7.0	201	1587	309	99	7	23	13	962	199	11.8	0.3	<0.01	1.65	<0.01
MW-2	20-02-2013	6.9	179	1598	292	103	7	19	16	1055	54	14.8	0.2	<0.01	4.03	<0.01
MW-2	25-03-2013	6.9	199	1677	311	108	9	22	4	1091	117	12.5	0.0	<0.01	3.23	<0.01
MW-2	22-04-2013	7.5	185	1468	286	83	6	20	4	942	148	7.9	0.0	<0.01	0.89	<0.01
MW-2	24-05-2013	7.5	169	1374	268	83	12	20	3	839	158	10.7	0.0	<0.01	0.48	0.09
MW-2	13-06-2013	7.3	180	1521	317	94	13	22	3	937	150	9.3	0.3	0.85	0.25	0.03
MW-2	15-07-2013	8.3	154	1087		92			<1.408	845	145	5.8	0.2	<0.006		<0.006
MW-2	15-09-2013	8.2	173	1586	307	106	8	22	<1.408	965	168	10.6	0.4	<0.006		<0.006
MW-2	15-10-2013	8.3	177	1453	258	93	3	18	<1.408	970	104	9.1	0.3	<0.006		<0.006
MW-2	15-11-2013	8.2	188	1493	295	103	11	22	8	927	120	6.3	0.2	<0.006		<0.006
MW-2	15-12-2013	8.3	179	1454	282	100	11	22	8	937	90	3.7	0.3	<0.006		<0.006
MW-2	15-01-2014	8.2	179	1468	281	101	15	26	8	947	87	2.4	0.2	<0.006		<0.006
MW-2	15-02-2014	8.2	174	1427	280	98	12	22	7	890	112	5.6	0.3	<0.006		<0.006
MW-2	15-03-2014	8.2	122	1029	194	65	9	16	5	577	155	6.8	0.3	<0.006		<0.006
MW-2	15-04-2014	8.2	238	2406	429	148	15	28	8	1554	216	8.7	<0.183	<0.006		<0.006
MW-2	15-05-2014	8.0	266	2658	536	176	16	33	4	1672	207	14.0	0.2	<0.006		<0.006
MW-2	15-06-2014	8.1	247	2517	450	154	18	32	7	1703	143	9.7	0.2	<0.006		<0.006
MW-2	15-07-2014	8.2	259	2455	503	153	14	27	6	1558	191	3.4	<0.183	<0.006		<0.006
MW-2	15-08-2014	8.4	290	2791	561	181	19	37	10	1868	110	4.9	0.2	<0.006		<0.006
MW-2	15-09-2014	7.7	151	1274	242	76	11	25	8	680	225	7.2	0.4	<0.006		<0.006
MW-2	15-10-2014	8.4	220	2092	368	136	16	28	8	1351	172	13.4	0.3	<0.006		<0.006
MW-2	15-11-2014	8.1	218	2014	370	114	14	27	9	1296	166	17.0	0.3	<0.006		<0.006

Site Name	Date	pH	EC (mS/m)	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO4 (mg/L)	TALK (mg/L)	NO3 (as N) (mg/L)	F (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)
1 - Target Level (<)		5.5														
2 - Target Level (>)		9.5	150	1000	150	70	200	50	200	400		10.0	1.0	0.20	0.10	0.30
3 - Critical Level (<)		4.0														
4 - Critical Level (>)		11.0	370	2400	300	100	400	100	600	600		20.0	1.5	2.00	1.00	0.50
MW-2	15-12-2014	8.2	194	1992	381	135	16	23	8	1368	55	5.3	<0.183	<0.006		<0.006
MW-2	15-01-2015	6.7	103	896	171	46	6	8	5	633	23	3.0	0.2	<0.006		<0.006
MW-2	15-02-2015	8.1	156	1334	231	85	11	19	8	875	89	15.7	0.4	<0.006		<0.006
MW-2	15-03-2015	7.6	154	1220	238	91	12	21	8	782	55	13.0	0.3	<0.006		<0.006
MW-2	15-04-2015	7.7	149	1169	201	80	12	19	4	814	32	8.6	<0.496	<0.009		<0.005
MW-2	15-05-2015	7.6	210	1908	344	122	14	20	3	1344	56	5.1	<0.496	<0.009		<0.005
MW-2	15-06-2015	7.8	226	1963	345	144	15	21	4	1362	71	2.9	<0.496	<0.009		<0.005
MW-2	15-07-2015	6.6	247	2132	371	128	13	19	9	1542	42	3.3	0.0	0.60	4.90	0.12
MW-2	15-08-2015	7.6	224	1916	327	98	12	19	8	1251	182	16.4	1.1	0.00	2.70	0.15
MW-2	15-09-2015	7.4	254	2515	549	172	20	27	6	1624	102	6.6	0.4	0.00	7.80	0.23
MW-2	15-10-2015	7.1	247	2216	481	97	12	16	5	1527	72	1.3	0.0	0.05	4.86	0.12
MW-2	15-11-2015	7.4	225	1939	330	81	12	22	8	1276	203	6.2	0.5	0.00	0.86	0.07
MW-2	15-12-2015	7.7	145	1242	245	56	9	10	11	807	103	0.0	0.0	0.09	1.43	0.08
MW-2	15-01-2016	4.5	116	915	184	38	5	5	14	626	7	27.1	0.0	0.40	3.30	6.07
MW-2	15-02-2016	4.9	121	1072	181	49	5	6	3	816	5	2.4	0.1	0.30	2.20	1.34
MW-2	15-03-2016	4.5	84	734	129	31	3	4	1	551	5	5.6	0.0	0.80	1.30	4.00
MW-2	15-04-2016	7.3	197	1759	289	97	14	17	5	1296	37	2.4	0.0	0.00	1.00	0.21
MW-2	15-05-2016	7.3	170	1543	295	93	13	14	5	1075	43	2.1	0.0	0.00	1.60	0.64
MW-2	15-06-2016	7.3	193	1826	353	96	11	16	4	1262	83	0.0	0.0	0.00	1.50	0.16
MW-2	15-07-2016	7.1	194	1749	344	95	12	18	5	1092	180	2.2	0.0	0.10	0.90	0.16
MW-2	15-08-2016	7.5	232	2266	449	155	15	21	5	1489	109	19.3	0.0	0.10	3.20	0.19
MW-2	15-09-2016	7.9	260	2494	424	152	16	22	5	1770	101	0.0	0.9	0.10	3.70	0.13
MW-2	15-10-2016	7.9	198	1484	277	78	12	17	0	941	159	0.0	0.0	0.00	0.50	0.11
MW-2	15-11-2016	4.7	97	738	148	35	4	5	1	530	7	6.9	0.0	0.10	1.40	1.17
MW-2	15-12-2016	4.8	92	673	148	34	4	5	2	467	8	3.8	0.0	0.20	1.20	1.19
MW-2	01-04-2017	8.2	139	1402	265	102	10	20	4	894	135	5.7	0.3	<0.004	<0.001	
MW-2	01-05-2017	7.9	144	1257	251	93	10	19	4	786	124	4.3	<0.263	<0.004	<0.001	
MW-2	01-06-2017	7.6	185	1721	316	140	11	19	4	1186	49	3.5	0.3	<0.004	5.99	
MW-2	01-07-2017	7.5	234	2048	385	146	11	18	4	1447	40	2.7	0.3	<0.004	6.27	
MW-2	01-08-2017	7.4	245	2288	433	162	13	20	5	1611	50	2.8	0.6	<0.004	8.50	
MW-2	01-09-2017	7.6	273	2203	433	162	13	20	4	1538	38	2.1	0.4	<0.004	9.63	
Pit	01-09-2010	3.2	265		315	157	16		19	1820						
Pit	01-10-2010	5.3	26		26	10	4		7	69						
Pit	01-11-2010	3.5	28		24	9	10		5	80						
Pit	01-12-2010	3.9	38		35	16	1		5	142						
Pit	01-01-2011	7.8	54		63	28	1		5	197						
Pit	01-02-2011	8.1	69		125	37	10		5	133						
Pit	01-03-2011	8.4	39		31	15	10		6	110						
Pit	01-03-2012	3.4	167	1655	343	74	5	3	4	1182	0	0.0	0.0	<0.01	27.60	0.58
Pit-A1	01-09-2009	3.7	80	575	45	24	4	7	2	443	0	1.2	0.8	0.28	11.20	37.90
Pit-A2	01-09-2009	3.7	80	571	45	24	4	7	2	434	0	1.1	0.7	0.27	13.20	42.80
Pit-B	01-09-2009	4.0	31	166	28	10	1	3	1	121	0	0.1	0.3	0.04	1.16	3.14
Pit-C1	01-09-2009	3.2	47	144	12	4	2	4	2	111	0	0.3	0.2	0.52	1.71	8.50
Pit-C2	01-09-2009	3.3	45	141	12	4	2	4	1	108	0	0.3	0.2	1.78	1.68	8.48
Pit-D1	01-09-2009	3.2	313	2540	394	168	16	12	4	1847	0	1.0	0.9	6.28	28.60	59.60
Pit-D1	01-03-2012	6.0	201	1889	308	100	9	11	4	1379	16	2.5	0.0	0.61	17.00	30.70
Pit-D1	21-05-2012	3.5	200	1600	232	97	11	12	4	1180	0	2.1	<0.01	0.67	16.00	33.20
Pit-D1	21-06-2012	3.2	183	1790	265	100	11	13	5	1337	0	1.5	0.3	0.96	9.25	36.66
Pit-D1	27-07-2012	3.5	190	1692	263	103	11	13	6	1233	0	1.6	<0.01	1.43	7.97	39.30
Pit-D1	21-08-2012	3.4	220	1911	306	102	8	12	7	1404	0	2.0	<0.01	4.33	6.17	45.55
Pit-D1	27-09-2012	3.3	164	1744	260	101	10	14	6	1278	0	1.4	<0.01	3.87	19.40	36.07
Pit-D1	17-10-2012	3.2	207	1991	289	109	7	14	2	1488	0	1.2	<0.01	4.33	20.50	41.83
Pit-D1	21-11-2012	3.4	230	1928	289	110	6	13	15	1425	0	<0.01	0.8	5.86	22.40	40.10
Pit-D1	14-12-2012	4.6	204	1828	301	104	4	15	29	1320	0	5.2	<0.01	<0.01	13.30	16.90
Pit-D1	18-01-2013	4.9	189	1535	274	97	7	16	24	1074	4	5.3	<0.01	<0.01	9.43	6.23
Pit-D1	20-02-2013	4.8	184	1628	281	104	8	17	17	1132	8	9.9	0.6	<0.01	8.83	2.75
Pit-D1	25-03-2013	4.9	187	1587	274	94	9	17	13	1114	7	9.4	0.4	<0.01	9.08	3.69
Pit-D1	22-04-2013	4.5	216	1474	258	83	7	16	5	1051	0	6.9	0.5	<0.01	9.13	2.86
Pit-D1	24-05-2013	4.7	184	1524	286	85	11	16	3	1064	15	6.3	0.2	0.04	8.57	3.75
Pit-D1	13-06-2013	4.7	187	1518	301	90	11	17	3	1045	6	6.7	0.3	0.67	4.91	5.01
Pit-D1	15-07-2013	4.6	156	992		91			<1.408	900	<8.258	5.7	1.1	0.52		3.32
Pit-D1	15-08-2013	7.5	160	1592	307	99	10	18	3	1128	14	13.5	0.3	<0.006		<0.006
Pit-D1	15-09-2013	7.8	157	1453	263	88	8	22	<1.408	879	177	17.6	0.5	<0.006		<0.006
Pit-D1	15-10-2013	5.8	200	1480	308	106	4	17	<1.408	1043	<8.258	11.7	0.3	<0.006		0.09
Pit-D1	15-11-2013	4.4	206	1546	307	107	13	20	7	1084	<8.258	13.7	0.6	0.35		1.55
Pit-D1	15-01-2014	3.9	204	1575	300	106	15	21	6	1116	<8.258	9.9	0.8	0.36		7.92
Pit-D1	15-02-2014	4.0	215	1692	301	109	16	22	7	1207	13	8.7	0.9	0.37		7.17
Pit-D1	15-03-2014	3.1	209	1615	278	103	12	16	6	1181	<8.258	2.7	<0.183	6.30		18.50
Pit-D1	15-04-2014	3.8	204	1796	287	106	13	17	7	1347	<8.258	2.7	<0.183	5.98		20.20
Pit-D1	15-05-2014	3.1	224	1803	287	106	12	17	2	1352	<8.258	2.0	1.0	7.09		24.30
Pit-D1	15-06-2014	3.0	234	1681	265	102	13	17	5	1252	<8.258	2.0	<0.183	8.37		24.40
Pit-D1	15-07-2014	3.1	230	1755	293	117	12	17	5	1281	<8.258	1.7	<0.183	10.40		27.10
Pit-D1	15-08-2014	3.0	237	1744	284	114	14	19	8	1271	<8.258	1.8	<0.183	12.10		28.10
Pit-D1	15-09-2014	3.0	248	1987	320	119	17	22	9	1462	<8.258	1.7	<0.183	14.20		31.30

Site Name	Date	pH	EC (mS/m)	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO4 (mg/L)	TALK (mg/L)	NO3 (as N) (mg/L)	F (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)
1 - Target Level (<)		5.5														
2 - Target Level (>)		9.5	150	1000	150	70	200	50	200	400		10.0	1.0	0.20	0.10	0.30
3 - Critical Level (<)		4.0														
4 - Critical Level (>)		11.0	370	2400	300	100	400	100	600	600		20.0	1.5	2.00	1.00	0.50
Pit-D1	15-10-2014	3.0	246	1987	312	133	15	20	8	1456	<8.258	1.3	<0.183	16.40		34.40
Pit-D1	15-11-2014	3.0	256	2137	313	121	13	17	8	1618	<8.258	2.8	<0.183	15.20		37.10
Pit-D1	15-12-2014	3.1	260	2090	311	124	13	18	9	1571	<8.258	2.2	<0.183	13.60		37.30
Pit-D1	15-01-2015	3.0	240	2022	299	118	13	17	8	1531	<8.258	1.3	<0.183	5.40		37.30
Pit-D1	15-02-2015	3.0	252	2032	280	127	13	17	8	1555	<8.258	1.7	<0.183	4.15		35.40
Pit-D1	01-04-2017	7.9	39	267	41	21	4	9	3	142	39	4.7	<0.263	<0.004	1.29	
Pit-D1	01-05-2017	7.8	92	667	107	40	6	18	3	302	76	32.8	0.3	<0.004	0.87	
Pit-D1	01-06-2017	5.5	9	56	5	3	2	3	5	8	<1.99	6.5	<0.263	0.24	0.05	
Pit-D1	01-07-2017	6.9	113	910	143	57	16	13	3	665	10	1.7	<0.263	<0.004	5.05	
Pit-D1	01-08-2017	7.6	27	206	36	12	7	6	4	126	20	0.7	<0.263	<0.004	0.55	
Pit-D1	01-09-2017	7.2	42	224	36	10	10	9	2	113	6	9.1	<0.263	<0.004	0.47	
Pit-D2	01-09-2009	3.2	312	2503	409	149	16	12	4	1821	0	<0.01	1.0	6.34	27.30	56.90
Playground	01-05-2017	7.0	63	433	58	38	19	7	7	258	24	7.3	<0.263	<0.004	<0.001	
Playground	01-06-2017	6.7	51	294	35	24	20	8	7	153	23	7.5	<0.263	<0.004	0.01	
Playground	01-07-2017	6.4	69	493	61	41	20	7	7	311	24	6.8	<0.263	<0.004	0.04	
Playground	01-08-2017	6.2	63	502	64	42	21	8	10	305	27	7.6	<0.263	<0.004	0.04	
Playground	01-09-2017	7.3	38	244	26	24	7	8	7	81	16	18.4	<0.263	<0.004	0.32	
VBH-1M	07-09-2009	7.1	14	77	13	6	4	3	2	7	43	4.2	<0.01	0.03	0.09	<0.01
VBH-1M	16-03-2011	7.1	14	68	16	3	3	2	3	1	63	0.8	0.0	0.04	0.15	0.03
VBH-1M	17-06-2011	7.1	32	192	64	5	3	2	3	7	151	4.3	0.1	0.16	0.07	0.02
VBH-1M	26-09-2011	6.6	12	73	16	5	3	1	2	0	69	0.7	0.1	0.02	0.14	0.02
VBH-1M	22-12-2011	6.8	12	59	11	3	4	3	2	3	50	<0.01	0.0	<0.01	0.13	<0.01
VBH-1M	22-02-2012	6.6	11	65	11	4	3	3	2	1	47	2.3	0.1	0.74	0.14	0.48
VBH-1M	21-06-2012	7.0	10	47	6	4	2	2	6	0	22	2.5	<0.01	<0.01	0.07	<0.01
VBH-1M	27-09-2012	7.0	10	44	9	3	1	2	4	0	35	0.7	<0.01	<0.01	0.10	<0.01
VBH-1M	14-12-2012	7.4	10	54	9	4	5	2	5	0	41	1.3	0.2	<0.01	<0.01	<0.01
VBH-1M	25-03-2013	7.9	11	59	8	4	5	1	2	<0.01	43	2.8	0.1	<0.01	0.02	<0.01
VBH-1M	13-06-2013	7.5	10	51	8	3	3	2	2	<0.01	46	0.9	0.1	0.47	0.08	0.07
VBH-1M	15-07-2013	6.8	10	32		3			<1.408	10	18	1.5	<0.183	1.00		<0.006
VBH-1M	15-10-2013	6.4	11	16	5	3	0	1	<1.408	7	<8.258	6.2	0.9	2.83		<0.006
VBH-1M	15-01-2014	6.8	10	49	8	4	0	3	6	0	26	2.0	<0.183	<0.006		<0.006
VBH-1M	15-04-2014	8.2	24	167	38	5	3	2	6	14	95	4.1	0.4	<0.006		<0.006
VBH-1M	15-07-2014	6.8	11	73	10	3	3	2	3	11	37	0.6	0.9	1.69		<0.006
VBH-1M	15-10-2014	8.1	10	61	9	4	2	2	5	5	33	0.9	0.3	0.10		<0.006
VBH-1S	16-03-2011	6.3	8	52	6	3	2	1	3	3	31	1.6	0.1	2.80	0.62	<0.01
VBH-1S	17-06-2011	6.4	9	55	7	3	4	1	4	4	13	5.1	0.1	0.46	0.18	0.02
VBH-2M	07-09-2009	6.9	12	53	8	2	4	3	3	1	24	4.7	<0.01	0.03	0.07	<0.01
VBH-2M	16-03-2011	6.1	15	93	7	8	4	1	4	1	28	10.3	0.0	4.97	0.47	0.01
VBH-2M	17-06-2011	6.3	15	89	7	9	4	2	4	7	46	6.3	0.1	0.38	0.28	0.32
VBH-2M	26-09-2011	6.6	14	78	9	8	5	4	4	0	63	2.6	0.1	0.06	0.36	0.05
VBH-2M	22-12-2011	6.4	15	86	9	10	5	3	4	3	43	5.9	0.1	<0.01	0.28	<0.01
VBH-2M	22-02-2012	6.0	15	96	8	8	4	2	4	6	31	9.1	0.9	2.37	0.35	0.39
VBH-2M	21-06-2012	6.8	13	65	8	7	2	3	9	0	28	4.3	<0.01	<0.01	0.08	<0.01
VBH-2M	27-09-2012	6.4	14	81	9	8	1	2	5	3	35	6.7	<0.01	<0.01	0.26	<0.01
VBH-2M	14-12-2012	6.9	13	75	7	8	2	0	8	0	15	9.1	0.2	<0.01	<0.01	<0.01
VBH-2M	25-03-2013	7.1	13	78	8	6	2	1	4	<0.01	13	10.9	0.2	<0.01	0.11	<0.01
VBH-2M	13-06-2013	7.1	13	70	8	7	2	1	3	<0.01	25	7.3	0.1	0.47	0.14	0.04
VBH-2M	15-07-2013	6.3	12	40		7			<1.408	3	25	5.1	0.2	1.85		<0.006
VBH-2M	15-10-2013	6.7	13	50	7	7	0	1	<1.408	<0.132	33	3.1	<0.183	<0.006		<0.006
VBH-2M	15-01-2014	6.1	12	45	7	6	1	1	8	0	17	5.1	0.3	0.07		<0.006
VBH-2M	15-04-2014	8.0	17	61	6	5	3	2	7	1	24	6.1	1.6	4.54		<0.006
VBH-2M	15-07-2014	6.1	12	57	6	6	3	2	5	3	26	4.0	1.1	2.62		<0.006
VBH-2M	15-10-2014	8.1	12	74	7	7	3	3	7	<0.132	46	1.7	0.2	<0.006		<0.006
VBH-2M	15-01-2015	5.7	10	49	5	8	3	1	8	3	14	6.3	0.2	0.36		<0.006
VBH-2M	15-04-2015	5.9	11	43	5	5	2	1	4	<0.957	21	4.8	<0.496	0.37		<0.005
VBH-2M	15-07-2015	6.3	12	79	6	6	2	2	7	2	52	0.0	0.0	2.30	0.40	0.13
VBH-2M	15-11-2015	6.7	16	110	9	8	3	5	2	0	82	0.0	0.5	0.00	0.40	0.00
VBH-2M	15-02-2016	5.4	7	39	4	3	1	1	2	15	10	2.2	0.0	0.10	0.30	0.07
VBH-2M	15-05-2016	5.6	8	40	5	5	3	2	4	2	15	4.7	0.0	0.20	0.20	0.07
VBH-2M	15-08-2016	6.1	8	56	6	6	3	2	3	0	29	6.4	0.0	0.40	0.20	0.10
VBH-2M	15-11-2016	5.6	11	80	7	6	4	1	4	11	24	22.7	0.0	0.10	0.10	0.00
VBH-2M	01-05-2017	6.0	9	56	5	5	3	1	5	5	13	5.5	<0.263	<0.004	0.06	
VBH-2M	01-08-2017	6.3	9	51	5	5	3	2	5	5	26	2.2	<0.263	0.20	0.26	
VBH-3M	07-09-2009	7.4	41	253	38	20	6	6	2	92	127	2.6	0.4	0.03	0.27	<0.01
VBH-3M	17-06-2011	6.8	29	159	32	10	6	5	3	15	134	0.4	0.5	4.47	0.63	0.01
VBH-3M	26-09-2011	6.8	23	3	28	8	6	4	2	<0.01	118	0.1	0.6	0.19	0.14	0.07
VBH-3M	13-06-2013	6.5	104	860	150	60	8	7	2	573	88	0.7	<0.01	0.69	0.66	0.05
VBH-3M	15-07-2013	7.5	21	116		9			<1.408	8	100	0.2	0.4	<0.006		<0.006
VBH-3M	15-10-2013	7.1	46	269	46	24	<0.03	4	<1.408	158	38	0.1	0.3	0.29		<0.006
VBH-3M	15-01-2014	8.0	31	230	26	14	16	3	13	15	141	0.6	0.7	<0.006		<0.006
VBH-3M	15-04-2014	8.3	107	947	145	68	12	10	5	564	140	0.4	0.7	1.35		<0.006
VBH-3M	15-07-2014	7.2	100	888	153	65	12	10	4	488	146	0.3	0.9	10.10		<0.006
VBH-3M	15-10-2014	8.5	92	816	122	59	11	9	5	460	147	0.1	0.3	2.20		<0.006
VBH-3M	15-07-2015	6.9	95	786	106	39	10	8	4	468	150	0.0	0.0	0.10	0.30	0.06

Site Name	Date	pH	EC (mS/m)	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO4 (mg/L)	TALK (mg/L)	NO3 (as N) (mg/L)	F (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)
1 - Target Level (<)		5.5														
2 - Target Level (>)		9.5	150	1000	150	70	200	50	200	400		10.0	1.0	0.20	0.10	0.30
3 - Critical Level (<)		4.0														
4 - Critical Level (>)		11.0	370	2400	300	100	400	100	600	600		20.0	1.5	2.00	1.00	0.50
VBH-3M	15-11-2016	6.9	85	631	109	43	14	8	2	296	158	0.0	0.0	0.90	0.00	0.86
VBH-3M	01-05-2017	8.2	15	94	15	8	6	4	3	3	87	0.5	<0.263	<0.004	<0.001	
VBH-3M	01-08-2017	7.5	58	448	85	33	11	7	3	219	144	0.5	0.3	<0.004	0.18	
VBH-3S	07-09-2009	3.4	142	871	96	101	19	9	8	640	0	0.1	0.0	0.65	3.49	1.47
VBH-3S	16-03-2011	6.2	135	956	100	107	22	5	8	655	58	0.4	0.1	24.60	2.29	0.02
VBH-3S	17-06-2011	5.9	127	826	97	93	22	6	7	586	22	0.4	0.1	2.33	2.60	0.08
VBH-3S	26-09-2011	5.4	124	1071	93	78	18	5	9	767	20	0.2	0.0	88.80	3.12	0.03
VBH-4M	07-09-2009	5.9	16	103	10	8	3	2	4	1	5	16.3	<0.01	0.03	0.24	0.02
VBH-4M	16-03-2011	6.0	13	79	9	5	2	1	9	3	6	10.9	0.0	0.03	0.33	<0.01
VBH-4M	17-06-2011	6.2	16	112	15	7	2	1	9	12	12	13.1	0.1	0.27	0.35	0.04
VBH-4M	26-09-2011	6.0	14	98	11	8	4	2	4	0	18	13.2	0.1	0.24	0.29	0.04
VBH-4M	23-11-2011	4.8	15	102	10	7	3	2	4	0	1	16.9	0.0	0.05	0.24	0.13
VBH-4M	22-12-2011	6.3	17	114	12	8	4	2	4	3	5	16.8	0.1	0.01	0.25	<0.01
VBH-4M	15-10-2013	6.1	15	18	8	6	0	0	<1.408	<0.132	<8.258	13.1	<0.183	<0.006		<0.006
VBH-4M	15-01-2014	6.3	15	51	11	7	0	3	9	0	10	11.0	0.2	<0.006		<0.006
VBH-4M	15-04-2014	7.3	17	33	10	7	2	2	7	1	<8.258	13.0	<0.183	<0.006		<0.006
VBH-4M	15-07-2014	6.1	16	60	11	8	3	2	6	4	14	11.1	0.2	0.31		<0.006
VBH-4M	15-10-2014	7.4	16	55	11	8	3	2	7	<0.132	13	11.6	<0.183	<0.006		<0.006
VBH-4M	15-01-2015	6.4	15	61	10	7	3	2	8	8	13	9.9	0.3	<0.006		<0.006
VBH-4M	15-04-2015	6.3	16	56	10	7	2	2	4	4	16	11.0	<0.496	<0.009		<0.005
VBH-4M	15-07-2015	5.7	16	198	10	6	2	2	11	0	148	19.0	0.0	0.30	0.30	0.11
VBH-4M	15-11-2015	6.3	17	162	9	6	2	2	11	0	117	13.7	0.0	0.00	0.20	0.00
VBH-5M	07-09-2009	6.9	8	42	6	3	3	3	4	3	29	1.2	<0.01	0.02	0.08	<0.01
VBH-6M	07-09-2009	7.5	14	68	16	5	3	4	2	0	63	0.9	0.2	0.02	0.03	0.03
VBH-6M	16-03-2011	6.6	10	48	9	3	2	3	4	3	35	1.7	0.0	<0.01	0.06	<0.01
VBH-6M	17-06-2011	5.9	9	52	5	3	4	5	8	6	13	4.1	0.0	0.02	0.05	0.02
VBH-6M	26-09-2011	5.9	6	42	4	4	3	3	3	1	22	2.8	0.6	0.27	0.11	0.06
VBH-6M	25-03-2013	5.9	9	50	3	3	4	3	2	1	9	6.3	0.1	<0.01	<0.01	<0.01
VBH-6M	13-06-2013	5.9	12	64	6	4	4	5	2	2	13	7.2	0.1	0.23	0.04	0.04
VBH-6M	15-07-2013	5.6	12	5		5			<1.408	1	<8.258	8.5	<0.183	<0.006		<0.006
VBH-6M	15-04-2014	7.3	38	201	22	22	11	8	6	102	16	14.0	<0.183	<0.006		<0.006
VBH-6M	15-07-2014	5.5	70	433	50	51	11	11	6	271	25	7.8	<0.183	<0.006		<0.006
VBH-6M	15-10-2014	7.5	93	714	81	72	12	13	7	504	20	6.3	<0.183	<0.006		<0.006
VBH-6M	15-01-2015	5.6	94	738	97	71	12	13	8	505	24	7.2	<0.183	<0.006		<0.006
VBH-6M	15-04-2015	5.5	97	729	96	66	11	10	4	508	25	8.4	<0.496	<0.009		<0.005
VBH-6M	15-07-2015	5.3	140	1151	140	71	11	10	8	885	15	10.2	0.0	0.20	0.90	0.09
VBH-6M	15-02-2016	5.2	161	1432	211	93	13	9	0	1088	17	0.0	0.0	0.10	0.60	0.00
VBH-6M	15-05-2016	5.3	169	1448	236	115	15	14	6	1037	18	6.6	0.0	0.00	0.70	0.00
VBH-6M	15-11-2016	5.4	175	1391	244	112	14	13	6	947	29	24.8	0.0	0.70	0.00	0.00
VBH-6M	01-05-2017	6.4	65	433	59	39	19	7	7	254	24	7.4	<0.263	<0.004	<0.001	
VBH-6M	01-08-2017	5.8	132	1115	188	85	12	13	6	765	30	6.4	<0.263	<0.004	0.96	
VBH-6S	17-06-2011	6.2	6	35	2	3	4	1	1	3	12	2.7	0.0	0.09	0.15	<0.01
VBH-6S	25-03-2013	6.4	67	320	34	32	14	2	5	170	84	1.3	1.0	<0.01	2.39	<0.01
VBH-6S	13-06-2013	6.1	116	683	102	56	15	2	3	467	46	0.8	<0.01	3.46	1.69	0.05
VBH-6S	15-07-2013	6.9	51	287		35			<1.408	214	36	0.3	0.6	2.46		<0.006
VBH-6S	15-04-2014	7.9	44	301	28	25	13	2	8	115	95	3.9	2.4	8.71		<0.006
VBH-6S	15-07-2014	7.1	31	203	22	19	10	3	5	54	88	2.2	<0.183	<0.006		<0.006
VBH-6S	15-10-2014	8.4	33	242	27	22	10	3	6	31	141	1.8	0.2	<0.006		<0.006
VBH-6S	15-04-2015	6.5	27	172	18	15	10	3	5	40	82	0.5	<0.496	<0.009		<0.005
VBH-6S	01-05-2017	5.7	139	1180	211	97	12	13	5	793	33	6.8	<0.263	<0.004	1.05	
VBH-7M	07-09-2009	7.2	18	89	16	4	3	4	1	1	43	8.1	<0.01	0.02	0.17	<0.01
VBH-7M	17-06-2011	7.2	169	1226	255	80	10	8	2	752	191	1.4	0.0	0.30	3.71	0.03
VBH-7M	18-07-2011	7.1	162	1197	255	76	10	8	2	743	161	1.8	0.1	0.67	4.21	0.05
VBH-7M	17-08-2011	7.3	192	1462	334	82	11	8	2	911	177	2.4	0.2	0.18	4.93	0.03
VBH-7M	26-09-2011	6.6	130	1011	196	68	11	3	2	617	144	5.9	0.1	<0.01	3.60	0.03
VBH-7M	24-10-2011	6.8	125	866	190	52	7	8	2	529	110	3.6	0.1	0.36	3.25	<0.01
VBH-8M	07-09-2009	3.0	494	3849	406	388	26	20	9	2831	0	0.2	0.3	96.40	86.90	4.08
VBH-8M	16-03-2011	4.5	397	3657	373	268	20	19	2	2647	0	0.2	0.1	269.00	75.70	0.20
VBH-8M	17-06-2011	4.5	499	5326	460	3	24	29	1	3828	0	<0.01	0.2	516.00	115.00	0.62
VBH-8M	26-09-2011	4.6	560	4730	537	404	19	26	5	3555	0	0.2	0.0	88.80	72.30	45.70
VBH-8M	22-12-2011	4.4	429	3925	427	346	3	25	9	2867	0	0.4	<0.01	54.00	62.20	50.30
VBH-8M	22-02-2012	5.6	436	4656	390	335	22	25	8	3333	17	0.0	0.0	381.00	98.50	5.86
VBH-8M	21-06-2012	4.1	402	4076	384	313	10	20	8	3044	0	<0.01	<0.01	165.41	65.20	66.26
VBH-8M	14-12-2012	6.3	491	5188	446	374	5	18	82	3857	0	0.5	<0.01	166.00	80.30	157.00
VBH-8M	25-03-2013	6.8	420	4136	394	346	11	23	37	3037	9	5.7	0.3	76.50	124.00	43.30
VBH-8M	13-06-2013	6.2	424	4422	392	291	14	27	6	3191	9	8.8	<0.01	262.04	99.44	90.98
VBH-8M	15-07-2013	4.3	343	4137		365			<1.408	3482	<8.258	0.1	<0.183	197.00		103.00
VBH-8M	15-10-2013	4.5	470	4443	460	397	5	21	<1.408	3312	<8.258	<0.057	0.5	211.00		45.70
VBH-8M	15-01-2014	7.9	31	227	26	14	16	3	13	15	139	0.6	0.7	<0.006		<0.006
VBH-8M	15-04-2014	4.2	390	4144	412	349	17	25	7	3093	<8.258	45.0	<0.183	101.00		104.00
VBH-8M	15-07-2014	4.3	373	4066	414	316	16	24	5	3060	<8.258	3.8	<0.183	148.00		88.80
VBH-8M	15-10-2014	4.2	373	4118	394	339	14	21	6	3043	26	0.1	<0.183	263.00		11.10
VBH-8M	15-01-2015	4.2	381	3988	412	296	14	20	8	3032	<8.258	21.5	<0.183	89.50		104.00
VBH-8M	15-04-2015	4.2	388	4088	387	303	12	18	4	3179	<6.18	1.8	<0.496	99.00		91.20

Site Name	Date	pH	EC (mS/m)	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO4 (mg/L)	TALK (mg/L)	NO3 (as N) (mg/L)	F (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)
1 - Target Level (<)		5.5														
2 - Target Level (>)		9.5	150	1000	150	70	200	50	200	400		10.0	1.0	0.20	0.10	0.30
3 - Critical Level (<)		4.0														
4 - Critical Level (>)		11.0	370	2400	300	100	400	100	600	600		20.0	1.5	2.00	1.00	0.50
VBH-8M	15-07-2015	4.6	428	5127	368	272	12	17	20	4082	7	0.0	0.0	271.80	71.30	7.46
VBH-8M	15-02-2016	6.0	436	4716	454	295	18	15	6	3832	17	0.0	0.4	0.00	79.10	0.11
VBH-8M	15-11-2016	5.6	425	4575	470	382	17	20	5	3244	16	0.0	0.0	355.10	67.40	0.36
VBH-8M	01-05-2017	4.3	310	2637	314	204	11	18	5	1816	<1.99	60.3	<0.263	73.40	90.10	
VBH-8M	01-08-2017	7.0	11	67	9	4	4	8	5	6	47	0.5	<0.263	1.26	0.43	
VBH-8S	07-09-2009	3.2	629	5985	472	355	10	3	3	4399	0	<0.01	<0.01	556.00	75.30	113.00
VBH-8S	16-03-2011	4.2	614	6457	390	378	3	2	3	4839	0	0.0	<0.01	715.00	59.20	62.20
VBH-8S	17-06-2011	4.4	575	6444	420	3	10	3	3	4744	0	<0.01	0.1	718.00	55.70	82.50
VBH-8S	26-09-2011	4.7	547	4080	497	341	10	4	4	3054	10	0.0	0.0	88.80	70.70	7.17
VBH-8S	22-12-2011	3.6	600	5398	458	3	3	5	5	3985	0	<0.01	<0.01	472.00	58.80	7.39
VBH-8S	22-02-2012	4.1	406	3946	372	262	10	2	3	2988	0	0.1	0.0	106.00	37.90	133.00
VBH-8S	21-06-2012	2.7	467	4537	375	323	7	3	8	3415	0	<0.01	<0.01	342.18	45.30	16.12
VBH-8S	14-12-2012	5.0	483	4912	476	427	111	3	562	2979	11	0.2	<0.01	287.00	48.80	10.00
VBH-8S	25-03-2013	5.0	533	4616	335	321	58	6	548	2770	14	0.1	0.3	490.00	76.70	<0.01
VBH-8S	13-06-2013	4.8	547	6039	415	351	9	7	4	4464	5	<0.01	<0.01	700.32	77.77	0.99
VBH-8S	15-07-2013	5.3	476	4879		371			<1.408	3897	<8.258	<0.057	<0.183	621.00		<0.006
VBH-8S	15-04-2014	4.2	517	5875	479	431	15	13	12	4287	27	0.4	<0.183	611.00		<0.006
VBH-8S	15-07-2014	5.9	486	4961	353	325	11	10	6	3680	33	0.3	<0.183	543.00		<0.006
VBH-9D	15-10-2013	7.1	15	73	12	6	0	1	<1.408	2	50	2.2	<0.183	<0.006		<0.006
VBH-9D	15-07-2014	7.5	14	89	12	6	4	4	3	6	55	0.3	<0.183	<0.006		<0.006
VBH-9D	15-10-2014	8.3	15	106	12	7	4	6	6	2	68	0.2	0.2	1.00		<0.006
VBH-9D	15-01-2015	7.3	14	119	16	7	4	4	6	5	76	0.3	0.2	0.08		<0.006
VBH-9D	15-04-2015	7.2	18	125	16	7	5	6	3	<0.957	89	0.5	<0.496	1.83		<0.005
VBH-9D	15-07-2015	7.6	14	102	11	5	4	4	4	3	72	0.0	0.0	0.00	0.00	0.00
VBH-9D	15-11-2015	7.3	18	121	13	6	4	6	2	0	90	0.0	0.0	0.00	0.33	0.00
VBH-9D	15-02-2016	7.0	20	130	12	6	5	5	0	0	97	0.0	0.0	5.20	0.50	0.00
VBH-9D	15-05-2016	7.0	15	120	15	6	5	6	2	0	85	0.0	0.3	0.60	0.40	0.08
VBH-9D	15-08-2016	7.2	12	87	11	4	4	4	1	0	63	0.0	0.2	0.20	0.20	0.00
VBH-9D	15-11-2016	7.3	24	187	16	7	6	10	3	0	129	0.0	0.2	15.00	0.60	0.00
VBH-10M	15-10-2013	6.6	7	<4.351	1	1	0	1	<1.408	1	<8.258	0.4	0.7	0.17		<0.006
VBH-10M	15-01-2014	6.6	8	41	5	2	0	3	7	1	20	0.5	0.7	1.61		<0.006
VBH-10M	15-04-2014	7.7	11	75	7	3	4	3	6	4	41	0.4	2.0	4.79		<0.006
VBH-10M	15-07-2014	9.1	18	114	19	7	4	4	3	34	43	0.3	<0.183	<0.006		<0.006
VBH-10M	15-10-2014	7.9	40	247	34	23	6	7	5	146	26	0.1	<0.183	<0.006		<0.006
VBH-10M	15-01-2015	7.0	45	309	43	26	7	7	6	204	16	0.3	<0.183	0.03		<0.006
VBH-10M	15-04-2015	7.2	53	342	50	24	9	6	2	220	32	0.4	<0.496	<0.009		<0.005
VBH-10M	15-07-2015	7.5	57	373	48	20	10	5	4	246	38	0.0	0.0	0.40	0.10	0.06
VBH-10M	15-11-2015	8.2	62	447	48	29	7	8	3	329	23	0.0	0.0	0.34	0.00	0.00
VBH-10M	15-02-2016	8.9	50	330	38	28	7	6	4	219	28	0.0	0.0	0.40	0.10	0.07
VBH-10M	15-05-2016	9.1	40	266	30	27	5	7	2	155	38	0.0	0.0	0.40	0.10	0.00
VBH-10M	15-08-2016	8.3	53	339	36	29	6	8	2	236	21	0.0	0.1	0.10	0.00	0.00
VBH-10M	15-11-2016	8.9	56	369	45	33	7	11	2	240	32	0.0	0.0	0.40	0.10	0.00
VBH-11M	15-10-2013	6.0	5	<4.803	1	1	0	1	<1.408	<0.132	<8.258	1.8	<0.183	<0.006		<0.006
VBH-11M	15-01-2014	5.9	8	20	3	3	1	5	6	8	<8.258	2.2	0.2	<0.006		<0.006
VBH-11M	15-04-2014	7.3	10	47	5	3	3	5	5	12	12	2.5	<0.183	<0.006		<0.006
VBH-11M	15-07-2014	5.8	9	41	3	4	3	5	3	13	9	1.9	<0.183	<0.006		<0.006
VBH-11M	15-10-2014	7.3	12	58	5	6	3	6	5	20	11	2.3	<0.183	<0.006		<0.006
VBH-11M	15-01-2015	5.7	15	80	7	8	4	6	6	34	12	3.3	<0.183	<0.006		<0.006
VBH-11M	15-04-2015	5.6	15	77	7	8	3	6	1	37	12	3.6	<0.496	<0.009		<0.005
VBH-11M	15-07-2015	5.6	16	88	7	6	3	5	3	43	15	4.1	0.0	0.10	0.00	0.06
VBH-11M	15-11-2015	5.5	18	115	8	8	4	6	2	54	13	19.9	0.0	0.28	0.00	0.00
VBH-11M	15-02-2016	5.4	17	91	8	8	5	6	2	50	12	0.0	0.0	0.00	0.00	0.00
VBH-11M	15-05-2016	5.5	17	96	9	10	4	6	2	48	13	3.7	0.0	0.10	0.00	0.00
VBH-11M	15-08-2016	5.5	18	108	9	9	4	5	2	53	13	14.4	0.0	0.10	0.00	0.00
VBH-11M	15-11-2016	5.5	19	137	11	12	4	8	2	53	31	16.0	0.0	0.00	0.00	0.00
VBH-11M	01-05-2017	5.6	24	144	12	14	4	7	2	79	12	4.0	<0.263	<0.004	<0.001	
VBH-11M	01-08-2017	5.9	28	182	17	19	5	8	3	105	16	3.8	<0.263	<0.004	0.06	
VVN09-016	15-08-2009	7.6	51	353	66	22	5	5	8	165	83	6.4	0.1	0.35	0.62	0.67
VVN09-016	01-03-2012	6.0	18	113	17	7	3	3	3	11	16	13.4	0.0	0.03	0.15	0.08
VVN16-010	25-11-2016	4.6	110		112	35	6	6	<5	662	<10	1.0	0.1	75.58	8.68	0.10
VVN16-013	25-11-2016	6.6	61		70	21	5	7	<5	291	24	0.2	0.3	<0.06	2.49	<0.06
VVN16-014	25-11-2016	5.4	118		159	41	5	6	<5	613	<10	0.8	0.2	8.78	8.60	0.57
VVN16-015	25-11-2016	3.0	280		171	82	5	7	<5	1346	<10	0.4	<0.1	80.25	16.42	9.07
VVN16-015	25-11-2016	3.0	233		122	57	3	4	<5	882	<10	1.3	<0.1	30.94	13.40	12.34
VVN16-016	25-11-2016	5.3	167		299	85	12	11	<5	1094	<10	0.4	0.2	106.49	18.88	0.05
VVN16-017	25-11-2016	5.8	100		120	35	6	7	<5	604	<10	0.3	0.5	0.65	10.16	0.20
Workshop PCD	01-04-2017	8.2	140	1398	266	96	12	18	4	898	132	5.3	0.3	<0.004	0.01	
Workshop PCD	01-05-2017	7.9	139	1147	221	85	10	16	4	743	77	5.0	<0.263	<0.004	0.29	
Workshop PCD	01-06-2017	5.6	121	987	194	66	13	11	4	680	13	2.7	0.4	<0.004	3.26	
Workshop PCD	01-07-2017	5.4	201	1719	247	90	109	16	7	1229	27	0.9	1.6	1.23	15.70	

Site Name	Date	pH	EC (mS/m)	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO4 (mg/L)	TALK (mg/L)	NO3 (as N) (mg/L)	F (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)
1 - Target Level (<)		5.5														
2 - Target Level (>)		9.5	150	1000	150	70	200	50	200	400		10.0	1.0	0.20	0.10	0.30
3 - Critical Level (<)		4.0														
4 - Critical Level (>)		11.0	370	2400	300	100	400	100	600	600		20.0	1.5	2.00	1.00	0.50
Workshop PCD	01-08-2017	4.6	209	1625	253	101	68	16	6	1149	30	2.9	0.5	1.82	17.40	
WR-S1	18-09-2009	8.5	49	337	39	32	22	3	11	158	121	0.3	0.4	0.06	<0.01	0.02

Table A2.2A Micro elements, including CN (to continue in Table 2b)

Site Name	Date	Ag (mg/L)	As (mg/L)	B (mg/L)	Ba (mg/L)	Be (mg/L)	Bi (mg/L)	Cd (mg/L)	CN (mg/L)	Co (mg/L)	Cr (mg/L)	Cr 6+ (mg/L)	Cu (mg/L)	Hg (mg/L)	Li (mg/L)
MW-1	16-03-2011			<0.01				0.010		0.75	0.02		0.04		
MW-1	19-04-2011			0.16					<0.01	0.56	<0.01	<0.01	<0.01		
MW-1	17-05-2011		<0.005	0.08		0.02		0.009	<0.01	0.60	0.02		0.06		
MW-1	17-06-2011			<0.01					<0.01	1.10	<0.01	<0.01	<0.01		
MW-1	18-07-2011	<0.01		0.14					<0.01	0.82	0.01	<0.01	0.02		
MW-1	17-08-2011		<0.005						<0.01	0.80	0.01	<0.01	<0.01		
MW-1	26-09-2011		<0.005	<0.01				<0.003	<0.01	1.04	<0.01		0.05	<0.001	
MW-1	24-10-2011		<0.005	0.03				<0.003	<0.01	<0.01	<0.01		<0.01		
MW-1	23-11-2011		<0.005	<0.009	<0.01	<0.01		<0.003	<0.01	0.83	0.02		0.03	<0.001	0.19
MW-1	18-01-2012		<0.005	<0.01				<0.003	<0.01	<0.01	<0.01		<0.01	<0.001	
MW-1	22-02-2012		<0.005	0.03				<0.003	<0.01	0.79	0.01		0.04	<0.001	
MW-1	24-05-2013		<0.005					0.010	0.06	0.85	0.02		<0.01		
MW-1	13-06-2013		<0.005						0.05	1.58	0.02		0.03		
MW-2	17-06-2011			<0.01					<0.01	<0.01	<0.01	<0.01	<0.01		
MW-2	18-07-2011	<0.01		0.19					<0.01	<0.01	<0.01	<0.01	<0.01		
MW-2	17-08-2011		<0.005						<0.01	<0.01	<0.01	<0.01	<0.01		
MW-2	26-09-2011		<0.005	0.09				<0.003	<0.01	<0.01	<0.01		<0.01	<0.001	
MW-2	24-10-2011		<0.005	0.11				<0.003	<0.01	<0.01	<0.01		<0.01		
MW-2	23-11-2011		<0.005	0.04	<0.01	<0.01		<0.003	<0.01	<0.01	<0.01		<0.01	<0.001	0.04
MW-2	22-12-2011		<0.005					<0.003	<0.001	<0.01	<0.01		<0.01	<0.001	
MW-2	22-02-2012		<0.005	0.10				<0.003	<0.01	<0.01	<0.01		<0.01	<0.001	
MW-2	20-03-2012		<0.005	0.08				<0.01	<0.01	<0.003	<0.01		<0.01		
MW-2	23-04-2012		<0.005					<0.003	<0.01	<0.01	<0.01		<0.01		
MW-2	21-05-2012		<0.005					<0.003	<0.01	<0.01	<0.01		<0.01		
MW-2	14-12-2012		<0.005						<0.01	0.09	<0.01		<0.01		
MW-2	18-01-2013		<0.005						<0.01	0.04	<0.01		<0.01		
MW-2	20-02-2013		<0.005						0.07	0.14	<0.01	<0.01	<0.01		
MW-2	25-03-2013		<0.005						<0.01	<0.01	<0.01		<0.01		
MW-2	22-04-2013		<0.005						0.01	<0.01	<0.01	<0.01	<0.01		
MW-2	24-05-2013		<0.005					<0.003	<0.01	0.01	<0.01		<0.01		
MW-2	13-06-2013		<0.005						0.01	0.01	<0.01		<0.01		
Pit	01-03-2012		<0.005						<0.01	2.74	<0.01		0.05		
Pit-D1	01-03-2012		<0.005						<0.01	0.55	<0.01		0.02		
Pit-D1	21-05-2012		<0.005			0.01		<0.003	<0.01	0.66	<0.01		0.03		
Pit-D1	21-06-2012		<0.005						<0.01	0.70	<0.01		0.02		
Pit-D1	27-07-2012		<0.005						<0.01	0.75	<0.01		0.02		
Pit-D1	21-08-2012		<0.005						<0.01	2.38	<0.01		0.03		
Pit-D1	27-09-2012		<0.005						<0.01	0.75	<0.01		0.03		
Pit-D1	17-10-2012		<0.005						<0.01	0.80	<0.01		<0.01		
Pit-D1	21-11-2012		<0.005						<0.01	0.86	<0.01		<0.01		
Pit-D1	14-12-2012		<0.005						<0.01	0.51	<0.01		<0.01		
Pit-D1	18-01-2013		<0.005						<0.01	0.36	<0.01		<0.01		
Pit-D1	20-02-2013		<0.005						0.09	0.32	<0.01	<0.01	<0.01		
Pit-D1	25-03-2013		<0.005						0.03	0.28	<0.01		<0.01		
Pit-D1	22-04-2013		<0.005						0.05	0.24	<0.01	<0.01	<0.01		
Pit-D1	24-05-2013		<0.005					<0.003	<0.01	0.27	<0.01		<0.01		
Pit-D1	13-06-2013		<0.005						0.02	0.36	<0.01		<0.01		
VBH-1M	16-03-2011			<0.01				<0.003		<0.01	<0.01		<0.01		
VBH-1M	17-06-2011			<0.01					<0.01	<0.01	<0.01	<0.01	<0.01		
VBH-1M	26-09-2011		<0.005	<0.01				0.110	<0.01	<0.01	<0.01		0.03	<0.001	
VBH-1M	22-12-2011		<0.005					<0.003	<0.001	<0.01	<0.01		<0.01	<0.001	
VBH-1M	22-02-2012		<0.005	<0.01				<0.003	<0.01	<0.01	<0.01		<0.01	<0.001	
VBH-1M	21-06-2012		<0.005						<0.01	<0.01	<0.01		<0.01		
VBH-1M	27-09-2012		<0.005						<0.01	<0.01	<0.01		<0.01		
VBH-1M	14-12-2012		<0.005						<0.01	<0.01	<0.01		<0.01		
VBH-1M	25-03-2013		<0.005						<0.01	<0.01	<0.01		<0.01		
VBH-1M	13-06-2013		<0.005						<0.01	<0.01	<0.01		<0.01		
VBH-1S	16-03-2011			<0.01				<0.003		0.01	<0.01		<0.01		
VBH-1S	17-06-2011			<0.01					<0.01	<0.01	<0.01	<0.01	<0.01		
VBH-2M	07-09-2009														
VBH-2M	16-03-2011			<0.01				<0.003		0.02	<0.01		<0.01		
VBH-2M	17-06-2011			<0.01					<0.01	<0.01	<0.01	<0.01	<0.01		
VBH-2M	26-09-2011		<0.005	<0.01				<0.003	<0.01	<0.01	<0.01		0.03	<0.001	
VBH-2M	22-12-2011		<0.005					<0.003	<0.001	<0.01	<0.01		<0.01	<0.001	
VBH-2M	22-02-2012		<0.005	<0.01				<0.003	<0.01	0.02	<0.01		<0.01	<0.001	
VBH-2M	21-06-2012		<0.005						<0.01	<0.01	<0.01		<0.01		
VBH-2M	27-09-2012		<0.005						<0.01	0.01	<0.01		<0.01		
VBH-2M	14-12-2012		<0.005						<0.01	<0.01	<0.01		<0.01		
VBH-2M	25-03-2013		<0.005						<0.01	<0.01	<0.01		<0.01		

Site Name	Date	Ag (mg/L)	As (mg/L)	B (mg/L)	Ba (mg/L)	Be (mg/L)	Bi (mg/L)	Cd (mg/L)	CN (mg/L)	Co (mg/L)	Cr (mg/L)	Cr 6+ (mg/L)	Cu (mg/L)	Hg (mg/L)	Li (mg/L)
VBH-2M	13-06-2013		<0.005						0.01	0.02	<0.01		<0.01		
VBH-3M	17-06-2011			<0.01					<0.01	<0.01	<0.01	<0.01	0.01		
VBH-3M	26-09-2011		<0.005	<0.01				<0.003	<0.01	<0.01	0.01		<0.01	<0.001	
VBH-3M	13-06-2013		<0.005						0.01	0.01	<0.01		<0.01		
VBH-3S	16-03-2011			<0.01				<0.003		0.01	<0.01		<0.01		
VBH-3S	17-06-2011			<0.01					<0.01	0.02	<0.01	<0.01	0.03		
VBH-3S	26-09-2011		<0.005	0.09				<0.003	<0.01	0.01	<0.01		0.13	<0.001	
VBH-4M	16-03-2011			<0.01				<0.003		0.04	<0.01		<0.01		
VBH-4M	17-06-2011			<0.01					<0.01	0.02	<0.01	<0.01	<0.01		
VBH-4M	26-09-2011		<0.005	<0.01				<0.003	<0.01	0.03	<0.01		0.06	<0.001	
VBH-4M	23-11-2011		<0.005	<0.009	1.48	<0.01		<0.003	<0.01	0.03	<0.01		<0.01	<0.001	<0.01
VBH-4M	22-12-2011		<0.005					<0.003	<0.001	0.02	<0.01		<0.01	<0.001	
VBH-6M	16-03-2011			<0.01				<0.003		<0.01	<0.01		<0.01		
VBH-6M	17-06-2011			<0.01					<0.01	<0.01	<0.01	<0.01	<0.01		
VBH-6M	26-09-2011		<0.005	<0.01				<0.003	<0.01	<0.01	<0.01		<0.01	<0.001	
VBH-6M	25-03-2013		<0.005						<0.01	<0.01	<0.01		<0.01		
VBH-6M	13-06-2013		<0.005						<0.01	<0.01	<0.01		<0.01		
VBH-6S	17-06-2011			<0.01					<0.01	<0.01	<0.01	<0.01	<0.01		
VBH-6S	25-03-2013		<0.005						0.01	<0.01	<0.01		<0.01		
VBH-6S	13-06-2013		<0.005						<0.01	0.07	<0.01		<0.01		
VBH-7M	17-06-2011			<0.01					<0.01	0.03	<0.01	<0.01	<0.01		
VBH-7M	18-07-2011	<0.01		0.11					0.32	0.05	<0.01	<0.01	<0.01		
VBH-7M	17-08-2011		<0.005						<0.01	0.05	<0.01	<0.01	<0.01		
VBH-7M	26-09-2011		<0.005	<0.01				0.240	<0.01	0.05	<0.01		<0.01	<0.001	
VBH-7M	24-10-2011		<0.005	<0.01				<0.003	<0.01	<0.01	<0.01		<0.01		
VBH-8M	07-09-2009														
VBH-8M	16-03-2011			<0.01				0.070		0.42	<0.01		0.39		
VBH-8M	17-06-2011			1.04					<0.01	0.63	<0.01	<0.01	0.73		
VBH-8M	26-09-2011		<0.005	1.67				<0.003	<0.01	1.93	<0.01		0.88	<0.001	
VBH-8M	22-12-2011		<0.005					0.040	<0.001	3.18	<0.01		0.25	<0.001	
VBH-8M	22-02-2012		<0.005	1.08				<0.003	<0.01	0.93	<0.01		0.28	<0.001	
VBH-8M	21-06-2012		<0.005						<0.01	3.24	<0.01		<0.01		
VBH-8M	14-12-2012		<0.005						<0.01	3.09	0.02		<0.01		
VBH-8M	25-03-2013		<0.005						0.15	6.78	<0.01		<0.01		
VBH-8M	13-06-2013		<0.005						0.26	5.36	<0.01		0.02		
VBH-8S	16-03-2011			2.42				0.290		0.76	<0.01		1.38		
VBH-8S	17-06-2011			2.27					<0.01	1.02	<0.01	<0.01	1.19		
VBH-8S	26-09-2011		<0.005	2.33				<0.003	<0.01	0.28	<0.01		1.54	<0.001	
VBH-8S	22-12-2011		<0.005					0.250	<0.001	<0.01	<0.01		1.02	<0.001	
VBH-8S	22-02-2012		<0.005	1.32				<0.003	<0.01	0.57	<0.01		0.28	<0.001	
VBH-8S	21-06-2012		<0.005						<0.01	<0.01	<0.01		<0.01		
VBH-8S	14-12-2012		<0.005						<0.01	0.02	0.05		<0.01		
VBH-8S	25-03-2013		<0.005						<0.01	<0.01	0.01		<0.01		
VBH-8S	13-06-2013		<0.005						<0.01	<0.01	<0.01		0.01		
VVN09-016	01-03-2012		<0.005						<0.01	0.01	<0.01		<0.01		
VVN16-010	25-11-2016		<0.01	0.06	0.16	<0.01		<0.003		0.16	<0.01		0.20		
VVN16-013	25-11-2016		<0.01	<0.02	0.10	<0.01		<0.003		0.08	<0.01		<0.02		
VVN16-014	25-11-2016		<0.01	0.06	0.14	<0.01		<0.003		0.28	<0.01		0.04		
VVN16-015	25-11-2016		<0.01	0.07	0.02	<0.01		<0.003		0.65	<0.01		0.23		
VVN16-015	25-11-2016		<0.01	0.03	0.02	<0.01		<0.003		0.53	<0.01		0.06		
VVN16-016	25-11-2016		<0.01	0.13	0.09	<0.01		0.003		0.34	<0.01		0.28		
VVN16-017	25-11-2016		<0.01	0.04	0.16	<0.01		<0.003		0.30	<0.01		<0.02		

Table A2.2B Micro elements (continued from Table A2.2A)

Site Name	Date	Mo (mg/L)	Ni (mg/L)	Pb (mg/L)	Sb (mg/L)	Se (mg/L)	Si (mg/L)	Sn (mg/L)	Sr (mg/L)	Ti (mg/L)	U (mg/L)	V (mg/L)	Zn (mg/L)
1 - Target Level (<)													
2 - Target Level (>)											0.07		
3 - Critical Level (<)													
4 - Critical Level (>)											0.28		
BS-S1	18-09-2009						13.10						
LS-S1	18-09-2009						17.00						
MW-1	07-09-2009						36.70						
MW-1	16-03-2011		0.61	<0.01		<0.005	27.50		0.86		<0.01	<0.01	0.53
MW-1	19-04-2011		0.45	<0.01			30.20		0.64		<0.01	<0.01	1.00
MW-1	17-05-2011		0.48	0.08			29.10				<0.01		4.38
MW-1	17-06-2011		0.91	<0.01			28.90				<0.01		1.36
MW-1	18-07-2011		0.63	0.03			26.80			<0.01	<0.01	<0.01	1.08
MW-1	17-08-2011		0.63	<0.01			28.60				<0.01	<0.01	<0.01
MW-1	26-09-2011		0.84	<0.01		<0.005	29.00				<0.01	<0.01	1.17
MW-1	24-10-2011	<0.01	<0.01	<0.01			29.80				<0.01		<0.01
MW-1	23-11-2011	<0.01	0.63	0.04	<0.01	<0.005	26.30	<0.01	1.22		<0.01	<0.01	1.29
MW-1	18-01-2012		0.68	<0.01		<0.005	24.50				<0.01	<0.01	<0.01
MW-1	22-02-2012	<0.01	0.70	<0.01		<0.005	29.50				<0.01	0.01	0.60
MW-1	24-05-2013		0.78	0.03			25.38				<0.01		5.34
MW-1	13-06-2013		1.22	<0.01			20.67				0.02		3.93
MW-2	17-06-2011		<0.01	<0.01			3.77				<0.01		<0.01
MW-2	18-07-2011		<0.01	<0.01			4.26			<0.01	<0.01	<0.01	0.09
MW-2	17-08-2011		<0.01	<0.01		<0.01	3.85	<0.01	<0.01		<0.01	<0.01	<0.01
MW-2	26-09-2011		0.01	<0.01		<0.005	0.02				<0.01	<0.01	<0.01
MW-2	24-10-2011	<0.01	<0.01	<0.01			0.20				<0.01		<0.01
MW-2	23-11-2011	0.03	<0.01	<0.01	<0.01	<0.005	0.08	<0.01	1.65		<0.01	<0.01	<0.01
MW-2	22-12-2011		<0.01	<0.01		<0.005	2.01				<0.01	<0.01	<0.01
MW-2	22-02-2012	0.03	<0.01	<0.01		<0.005	1.09				<0.01	<0.01	<0.01
MW-2	20-03-2012		<0.01	0.02			2.05				<0.01		0.18
MW-2	23-04-2012	0.03	0.01	<0.01	<0.01		0.53		1.45		<0.01	<0.01	<0.01
MW-2	21-05-2012	0.03	0.01	<0.01		<0.005	0.34		1.80		<0.01	<0.01	<0.01
MW-2	14-12-2012		0.11	<0.01			4.43				0.02	<0.01	<0.01
MW-2	18-01-2013		0.07	<0.01			4.11				0.02		0.07
MW-2	20-02-2013		0.09	<0.01			4.37				<0.01		0.02
MW-2	25-03-2013		<0.01	<0.01			4.57				<0.01		<0.01
MW-2	22-04-2013		<0.01	<0.01			3.88				<0.01		<0.01
MW-2	24-05-2013		<0.01	<0.01			4.81				<0.01		<0.01
MW-2	13-06-2013		0.03	<0.01			4.84				<0.01		<0.01
Pit	01-03-2012		0.64	<0.01			6.40				<0.01	<0.01	0.51
Pit-A1	01-09-2009						29.60						
Pit-A2	01-09-2009						29.80						
Pit-B	01-09-2009						9.15						
Pit-C1	01-09-2009						22.10						
Pit-C2	01-09-2009						21.40						
Pit-D1	01-09-2009						33.10						
Pit-D1	01-03-2012		0.30	<0.01			13.10				<0.01	<0.01	0.07
Pit-D1	21-05-2012	<0.01	0.35	<0.01		<0.005	13.50		1.79		<0.01	0.01	0.17
Pit-D1	21-06-2012		0.30	<0.01			12.34				<0.01		<0.01
Pit-D1	27-07-2012		0.39	0.01			17.96				<0.01		0.57
Pit-D1	21-08-2012		1.26	<0.01			28.18				<0.01		2.77
Pit-D1	27-09-2012		0.38	<0.01			13.72				<0.01		0.45
Pit-D1	17-10-2012		0.34	<0.01			13.19				<0.01	<0.01	0.61
Pit-D1	21-11-2012		0.37	<0.01			13.40				<0.01	<0.01	0.26
Pit-D1	14-12-2012		0.28	<0.01			7.97				<0.01	<0.01	0.28
Pit-D1	18-01-2013		0.19	0.01			6.61				<0.01		0.20
Pit-D1	20-02-2013		0.19	<0.01			6.24				<0.01		0.14
Pit-D1	25-03-2013		0.11	<0.01			6.50				<0.01		0.11
Pit-D1	22-04-2013		0.15	<0.01			6.20				<0.01		0.11
Pit-D1	24-05-2013		0.18	<0.01			7.51				<0.01		0.16
Pit-D1	13-06-2013		0.24	<0.01			8.57				<0.01		0.20
Pit-D2	01-09-2009						33.80						
VBH-1M	07-09-2009						10.60						
VBH-1M	16-03-2011		<0.01	<0.01		<0.005	2.15		0.13		<0.01		<0.01
VBH-1M	17-06-2011		<0.01	<0.01		<0.01	6.20	<0.01	<0.01		<0.01	<0.01	<0.01
VBH-1M	26-09-2011		<0.01	<0.01		<0.005	2.87				<0.01	<0.01	<0.01
VBH-1M	22-12-2011		<0.01	<0.01		<0.005	2.95				<0.01	<0.01	0.01
VBH-1M	22-02-2012	<0.01	<0.01	<0.01		<0.005	4.34				<0.01	<0.01	0.11
VBH-1M	21-06-2012		<0.01	<0.01			3.29				<0.01		<0.01
VBH-1M	27-09-2012		<0.01	<0.01			2.67				<0.01		<0.01

Site Name	Date	Mo (mg/L)	Ni (mg/L)	Pb (mg/L)	Sb (mg/L)	Se (mg/L)	Si (mg/L)	Sn (mg/L)	Sr (mg/L)	Ti (mg/L)	U (mg/L)	V (mg/L)	Zn (mg/L)
1 - Target Level (<)													
2 - Target Level (>)											0.07		
3 - Critical Level (<)													
4 - Critical Level (>)											0.28		
VBH-1M	14-12-2012		<0.01	<0.01			2.22				<0.01	<0.01	<0.01
VBH-1M	25-03-2013		<0.01	<0.01			2.99				<0.01		<0.01
VBH-1M	13-06-2013		<0.01	<0.01			3.34				<0.01		<0.01
VBH-1S	16-03-2011		<0.01	<0.01		<0.005	0.71		0.07		<0.01	<0.01	<0.01
VBH-1S	17-06-2011		<0.01	<0.01			2.06				<0.01		<0.01
VBH-2M	07-09-2009						12.20						
VBH-2M	16-03-2011		0.01	<0.01		<0.005	2.61		0.12		<0.01		0.14
VBH-2M	17-06-2011		<0.01	<0.01			3.99				<0.01		<0.01
VBH-2M	26-09-2011		0.01	<0.01		<0.005	4.58				<0.01	<0.01	0.03
VBH-2M	22-12-2011		0.01	<0.01		<0.005	4.86				<0.01	<0.01	0.03
VBH-2M	22-02-2012	<0.01	0.02	<0.01		<0.005	5.24				<0.01	<0.01	0.11
VBH-2M	21-06-2012		<0.01	<0.01			3.85				<0.01		<0.01
VBH-2M	27-09-2012		<0.01	<0.01			4.05				<0.01		0.04
VBH-2M	14-12-2012		<0.01	<0.01			3.27				<0.01	<0.01	<0.01
VBH-2M	25-03-2013		<0.01	<0.01			3.55				<0.01		<0.01
VBH-2M	13-06-2013		0.02	<0.01			4.59				<0.01		0.03
VBH-3M	07-09-2009						11.20						
VBH-3M	17-06-2011		<0.01	<0.01			4.42				<0.01		<0.01
VBH-3M	26-09-2011		<0.01	<0.01		<0.005	4.05				<0.01	<0.01	<0.01
VBH-3M	13-06-2013		<0.01	<0.01			4.33				<0.01		<0.01
VBH-3S	07-09-2009						10.90						
VBH-3S	16-03-2011		<0.01	<0.01		<0.005	<0.01		0.60		<0.01	<0.01	<0.01
VBH-3S	17-06-2011		0.01	<0.01			1.34				<0.01		<0.01
VBH-3S	26-09-2011		<0.01	<0.01		<0.005	1.08				<0.01	<0.01	<0.01
VBH-3S	25-03-2013												
VBH-4M	07-09-2009						11.50						
VBH-4M	16-03-2011		0.02	<0.01		<0.005	1.82		0.12		<0.01		0.04
VBH-4M	17-06-2011		0.01	<0.01			2.65				<0.01		<0.01
VBH-4M	26-09-2011		0.02	<0.01		<0.005	4.13				<0.01	<0.01	0.15
VBH-4M	23-11-2011	<0.01	<0.01	<0.01	<0.01	<0.005	5.16	<0.01	0.12		<0.01	<0.01	0.08
VBH-4M	22-12-2011		0.02	<0.01		<0.005	5.33				<0.01	<0.01	0.41
VBH-5M	07-09-2009						16.10						
VBH-6M	07-09-2009						16.10						
VBH-6M	16-03-2011		<0.01	<0.01		<0.005	5.66		0.09		<0.01		0.03
VBH-6M	17-06-2011		<0.01	<0.01			6.67				<0.01		<0.01
VBH-6M	26-09-2011		<0.01	<0.01		<0.005	6.44				<0.01	<0.01	0.02
VBH-6M	25-03-2013		<0.01	<0.01			7.47				<0.01		<0.01
VBH-6M	13-06-2013		0.02	0.01			9.79				<0.01		0.05
VBH-6S	17-06-2011		<0.01	<0.01			2.67				<0.01		<0.01
VBH-6S	25-03-2013		<0.01	<0.01			4.60				<0.01		<0.01
VBH-6S	13-06-2013		0.06	<0.01			7.34				0.02		0.33
VBH-7M	07-09-2009						11.40						
VBH-7M	17-06-2011		<0.01	<0.01			3.92				<0.01		<0.01
VBH-7M	18-07-2011		<0.01	<0.01			4.78			<0.01	<0.01	<0.01	<0.01
VBH-7M	17-08-2011		<0.01	<0.01		<0.01	4.11	<0.01	<0.01		<0.01	<0.01	<0.01
VBH-7M	26-09-2011		0.02	<0.01		<0.005	4.85				<0.01	<0.01	<0.01
VBH-7M	24-10-2011	<0.01	<0.01	<0.01			5.71				<0.01		<0.01
VBH-8M	07-09-2009						15.70						
VBH-8M	16-03-2011		0.17	0.03		<0.005	2.76		3.50		<0.01	<0.01	<0.01
VBH-8M	17-06-2011		<0.01	0.12			4.26				<0.01		<0.01
VBH-8M	26-09-2011		0.40	0.04		<0.005	11.30				<0.01	<0.01	0.41
VBH-8M	22-12-2011		0.60	<0.01		<0.005	12.80				<0.01	<0.01	0.30
VBH-8M	22-02-2012	<0.01	0.11	<0.01		<0.005	3.18				<0.01	0.08	<0.01
VBH-8M	21-06-2012		0.52	0.04			6.83				0.11		0.04
VBH-8M	14-12-2012		1.07	<0.01			10.50				0.07	<0.01	0.80
VBH-8M	25-03-2013		0.95	0.02			8.45				0.07		0.97
VBH-8M	13-06-2013		1.15	0.02			10.05				0.91		1.96
VBH-8S	07-09-2009						43.90						
VBH-8S	16-03-2011		0.52	<0.01		<0.005	9.05		2.48		<0.01	<0.01	0.53
VBH-8S	17-06-2011		0.71	0.06			14.20				<0.01		0.53
VBH-8S	26-09-2011		0.21	0.07		<0.005	6.49				<0.01	<0.01	0.57
VBH-8S	22-12-2011		0.01	<0.01		<0.005	3.93				2.55	<0.01	0.43
VBH-8S	22-02-2012	<0.01	0.39	<0.01		<0.005	31.60				<0.01	0.08	<0.01
VBH-8S	21-06-2012		<0.01	0.09			4.95				1.12		<0.01
VBH-8S	14-12-2012		<0.01	0.04			4.28				0.03	<0.01	0.31
VBH-8S	25-03-2013		<0.01	0.15			3.57				1.96		0.19

Site Name	Date	Mo (mg/L)	Ni (mg/L)	Pb (mg/L)	Sb (mg/L)	Se (mg/L)	Si (mg/L)	Sn (mg/L)	Sr (mg/L)	Ti (mg/L)	U (mg/L)	V (mg/L)	Zn (mg/L)
1 - Target Level (<)													
2 - Target Level (>)											0.07		
3 - Critical Level (<)													
4 - Critical Level (>)											0.28		
VBH-8S	13-06-2013		<0.01	0.04			3.98				5.40		0.21
VVN09-016	15-08-2009						13.80						
VVN09-016	01-03-2012		<0.01	<0.01			5.31				<0.01	<0.01	<0.01
VVN16-010	25-11-2016	<0.01	<0.01	0.01	<0.02	<0.02			0.81			<0.01	0.06
VVN16-013	25-11-2016	<0.01	0.12	<0.01	0.04	<0.02			0.49			<0.01	0.04
VVN16-014	25-11-2016	<0.01	0.36	<0.01	<0.02	<0.02			1.29			<0.01	0.15
VVN16-015	25-11-2016	<0.01	0.29	0.01	<0.02	<0.02			1.45			<0.01	0.28
VVN16-015	25-11-2016	0.04	0.14	<0.01	<0.02	<0.02			0.82			<0.01	0.31
VVN16-016	25-11-2016	<0.01	0.11	<0.01	0.03	<0.02			1.58			<0.01	0.22
VVN16-017	25-11-2016	<0.01		<0.01	<0.02	0.02			1.03			<0.01	0.10
WR-S1	18-09-2009		0.06				11.20						

Table A2.3 TPH, biological and other

Site Name	Date	Biological Oxygen Demand O2 (mg/L)	Chemical Oxygen Demand O2 (mg/L)	Oxygen Absorbed O2 (mg/L)	Dissolved Oxygen O2 (mg/L)	Ortho Phosphate (P mg/L)	N_Ammonia (mg/L)	TPH (mg/L)	Suspended Solids (mg/L)	Standard Plate Count (countmL)	Total Coliforms (cfm/100mL)	Faecal Coliforms (cfm/100mL)
Arbor Community	01-05-2017								<4.5		240	
Arbor Community	01-06-2017								<4.5		110	
Arbor Community	01-07-2017								<4.5		260	
Arbor Community	01-08-2017								12		61	
Arbor Community	01-09-2017								<4.5		23	
BS-S1	18-09-2009						0.08		17.6			
Drinking water	01-04-2017								5		71	
Drinking water	01-05-2017								<4.5		9	
Drinking water	01-06-2017								8		370	
Drinking water	01-07-2017								<4.5		<1	
Drinking water	01-08-2017								<4.5		<1	
Drinking water	01-09-2017								<4.5		<1	
LS-S1	18-09-2009						0.10		10.8			
MW-1	07-09-2009						2.08		24			
MW-1	16-03-2011					<0.01	4.35					
MW-1	19-04-2011					<0.01	2.77					
MW-1	17-05-2011					<0.01	2.67					
MW-1	17-06-2011					<0.01	2.22		5.2			
MW-1	18-07-2011	<0.01				<0.01	2.26		3.2			
MW-1	17-08-2011					<0.01	4.20		0			
MW-1	26-09-2011					<0.01	2.42		63.6			
MW-1	24-10-2011					<0.01	3.13		6.4			
MW-1	23-11-2011		3.00			<0.01	2.89		6			
MW-1	18-01-2012		0.00			<0.01	3.21		0.4			
MW-1	22-02-2012		2.00			<0.01	2.91		17.6			
MW-1	24-05-2013		14.00		7.57	0.02	0.13		0			
MW-1	13-06-2013		5.00			<0.01	0.24		1.6			
MW-2	17-06-2011					<0.01	0.12		2.4			
MW-2	18-07-2011	<0.01				<0.01	0.05		0			
MW-2	17-08-2011					0.05	1.06		4.8			
MW-2	26-09-2011					<0.01	0.25		39.2			
MW-2	24-10-2011					<0.01	0.46		15.2			
MW-2	23-11-2011		9.00			0.03	0.13		14.4			
MW-2	22-12-2011					0.04	0.01		33.2			
MW-2	22-02-2012		10.00			<0.01	0.35		3.6			
MW-2	20-03-2012		7.00			0.02	0.83		0.8	1		0
MW-2	23-04-2012		23.00			<0.01	0.99		5.2			
MW-2	21-05-2012		11.00			<0.01	<0.01		6.8			
MW-2	14-12-2012		32.00		7.29	<0.01	0.02	<0.2	11.2			
MW-2	18-01-2013		36.00		5.70	<0.01	0.02		18.4			
MW-2	20-02-2013		9.00	0.80	7.04	0.01	3.75		24.8			
MW-2	25-03-2013		77.00	7.20	7.24	<0.01	2.98		178.6			
MW-2	22-04-2013		5.00	0.60	7.50	<0.01	1.54		4.8			
MW-2	24-05-2013		4.00		7.57	<0.01	4.15		2			
MW-2	13-06-2013		24.00			<0.01	2.59		38			
MW-2	15-07-2013										3	
MW-2	15-01-2014										7	
MW-2	15-07-2014										8	
MW-2	15-01-2015										4	
MW-2	15-07-2015										1200	
MW-2	15-01-2016										0	
MW-2	01-04-2017								24		6	
MW-2	01-05-2017								1228		<1	
MW-2	01-06-2017								33			

Site Name	Date	Biological Oxygen Demand O2 (mg/L)	Chemical Oxygen Demand O2 (mg/L)	Oxygen Absorbed O2 (mg/L)	Dissolved Oxygen O2 (mg/L)	Ortho Phosphate (P mg/L)	N_Ammonia (mg/L)	TPH (mg/L)	Suspended Solids (mg/L)	Standard Plate Count (countmL)	Total Coliforms (cfm/100mL)	Faecal Coliforms (cfm/100mL)
MW-2	01-07-2017								32			
MW-2	01-08-2017								19			
MW-2	01-09-2017								25			
Pit	01-03-2012		0.00			<0.01	6.25		0			
Pit-A1	01-09-2009						0.20		8.8			
Pit-A2	01-09-2009						0.12		8.8			
Pit-B	01-09-2009						0.21		2.8			
Pit-C1	01-09-2009						0.43		0.4			
Pit-C2	01-09-2009						0.36		0.4			
Pit-D1	01-09-2009						9.46		32			
Pit-D1	01-03-2012		5.00			<0.01	6.41		2.4			
Pit-D1	21-05-2012		0.00			<0.01	3.49		0			
Pit-D1	21-06-2012		27.60			<0.01	4.59					
Pit-D1	21-06-2012				31.00							
Pit-D1	27-07-2012				0.52							
Pit-D1	27-07-2012		54.37			<0.01	5.51		4.4			
Pit-D1	21-08-2012					<0.01	3.09					
Pit-D1	27-09-2012		33.56		3.80	0.06	7.66		5.4			
Pit-D1	17-10-2012		30.29			0.04	6.98		12			
Pit-D1	21-11-2012		3.00		6.79	0.04	0.09		3			
Pit-D1	14-12-2012		11.00		7.30	0.03	0.07		11.6			
Pit-D1	18-01-2013		0.00		5.66	0.02	0.06		3.2			
Pit-D1	20-02-2013		0.00	0.00	7.04	0.02	7.47		2			
Pit-D1	25-03-2013		7.00	0.60	7.31	<0.01	5.31		9.6			
Pit-D1	22-04-2013		3.00	0.20	7.59	<0.01	8.67		2			
Pit-D1	24-05-2013		2.00		7.63	0.04	6.42		2			
Pit-D1	13-06-2013		8.00			<0.01	4.61		10.8			
Pit-D1	15-07-2013										260	
Pit-D1	15-01-2014										17	
Pit-D1	15-07-2014										30	
Pit-D1	15-01-2015										<1	
Pit-D1	01-04-2017								9		1	
Pit-D1	01-05-2017								11		1	
Pit-D1	01-06-2017								490			
Pit-D1	01-07-2017								14			
Pit-D1	01-08-2017								8			
Pit-D1	01-09-2017								16			
Pit-D2	01-09-2009						9.46		29.6			
Playground	01-05-2017								<4.5		<1	
Playground	01-06-2017								<4.5		<1	
Playground	01-07-2017								<4.5		17	
Playground	01-08-2017								<4.5		4	
Playground	01-09-2017								36		<1	
VBH-1M	07-09-2009						1.35		218			
VBH-1M	16-03-2011					0.01	0.90					
VBH-1M	17-06-2011					<0.01	0.01		39.2			
VBH-1M	26-09-2011					<0.01	1.22		82.4			
VBH-1M	22-12-2011					<0.01	1.32		51.2			
VBH-1M	22-02-2012		2.00			<0.01	1.28		146.4			
VBH-1M	21-06-2012		0.00			<0.01	1.04					
VBH-1M	27-09-2012		15.52		4.10	<0.01	0.92		44.2			
VBH-1M	14-12-2012		244.00		6.63	0.02	0.06	<0.2	569.2			
VBH-1M	25-03-2013		57.00	6.00	6.75	<0.01	1.02		40			
VBH-1M	13-06-2013		0.00			<0.01	1.23		39.2			
VBH-1S	16-03-2011					0.01	1.52					
VBH-1S	17-06-2011					<0.01	1.15		122.4			
VBH-2M	07-09-2009						1.07		243			
VBH-2M	16-03-2011					0.01	1.14					
VBH-2M	17-06-2011					<0.01	1.51		221.2			
VBH-2M	26-09-2011					<0.01	1.86		304			
VBH-2M	22-12-2011					<0.01	0.08		194			
VBH-2M	22-02-2012		1.00			<0.01	0.86		207.2			
VBH-2M	21-06-2012		0.00			<0.01	0.46					
VBH-2M	27-09-2012		6.35		4.40	0.09	0.68		22.6			
VBH-2M	14-12-2012		13.00		6.76	<0.01	0.55		56			
VBH-2M	25-03-2013		127.00	12.40	6.86	<0.01	0.39		276			

Site Name	Date	Biological Oxygen Demand O2 (mg/L)	Chemical Oxygen Demand O2 (mg/L)	Oxygen Absorbed O2 (mg/L)	Dissolved Oxygen O2 (mg/L)	Ortho Phosphate (P mg/L)	N_Ammonia (mg/L)	TPH (mg/L)	Suspended Solids (mg/L)	Standard Plate Count (countmL)	Total Coliforms (cfm/100mL)	Faecal Coliforms (cfm/100mL)
VBH-2M	13-06-2013		4.00			<0.01	0.39		63.2			
VBH-2M	01-05-2017								5			
VBH-2M	01-08-2017								15			
VBH-3M	07-09-2009						5.70		181			
VBH-3M	17-06-2011					<0.01	4.54		596.8			
VBH-3M	26-09-2011					<0.01	0.16		202			
VBH-3M	13-06-2013		0.00			<0.01	1.57		40			
VBH-3M	01-05-2017								69			
VBH-3M	01-08-2017								36			
VBH-3S	07-09-2009						1.20		1162			
VBH-3S	16-03-2011					0.01	0.41					
VBH-3S	17-06-2011					<0.01	0.57		234			
VBH-3S	26-09-2011					<0.01	0.70		729			
VBH-4M	07-09-2009						0.42		65.2			
VBH-4M	16-03-2011					<0.01	0.55					
VBH-4M	17-06-2011					<0.01	0.69		90.4			
VBH-4M	26-09-2011					<0.01	0.94		106			
VBH-4M	23-11-2011		0.00			<0.01	0.08		0	1210		0
VBH-4M	22-12-2011					0.02	0.04		5.2			
VBH-5M	07-09-2009						0.45		467			
VBH-6M	07-09-2009						0.19		48.8			
VBH-6M	16-03-2011					0.02	0.06					
VBH-6M	17-06-2011					<0.01	0.01		59.2			
VBH-6M	26-09-2011					<0.01	0.14		444			
VBH-6M	25-03-2013		66.00	7.00	7.14	<0.01	0.15		64			
VBH-6M	13-06-2013		0.00			0.02	0.14		30			
VBH-6M	01-05-2017								5		86000	
VBH-6M	01-08-2017								334			
VBH-6S	17-06-2011					<0.01	0.62		30			
VBH-6S	25-03-2013		83.00	8.60	4.84	<0.01	2.56		117.6			
VBH-6S	13-06-2013		19.00			<0.01	1.08		899.2			
VBH-6S	01-05-2017								93			
VBH-7M	07-09-2009						1.14		409			
VBH-7M	17-06-2011					<0.01	0.92		0.8			
VBH-7M	18-07-2011	<0.01				<0.01	0.81		4.8			
VBH-7M	17-08-2011					<0.01	0.30		42.4			
VBH-7M	26-09-2011					<0.01	0.69		23.6			
VBH-7M	24-10-2011					<0.01	0.65		0.4			
VBH-8M	07-09-2009						0.17		435			
VBH-8M	16-03-2011					<0.01	1.02					
VBH-8M	17-06-2011					<0.01	4.80		132.4			
VBH-8M	26-09-2011					<0.01	1.44		449			
VBH-8M	22-12-2011					0.01	47.57		162			
VBH-8M	22-02-2012		112.00			0.73	35.60		332.8			
VBH-8M	21-06-2012		198.53			<0.01	0.38					
VBH-8M	14-12-2012		104.00		6.60	<0.01	0.08		257.6			
VBH-8M	25-03-2013		167.00	18.00	6.67	<0.01	8.85		259.2			
VBH-8M	13-06-2013		55.00			<0.01	1.40		75.2			
VBH-8M	01-05-2017								86			
VBH-8M	01-08-2017								77			
VBH-8S	07-09-2009						1.20		3448			
VBH-8S	16-03-2011					<0.01	0.47					
VBH-8S	17-06-2011					<0.01	23.98		343.6			
VBH-8S	26-09-2011					<0.01	0.56		240			
VBH-8S	22-12-2011					<0.01	0.32		260			
VBH-8S	22-02-2012		0.00			0.74	23.60		167.2			
VBH-8S	21-06-2012		140.14			0.03	1.20					
VBH-8S	14-12-2012		115.00		6.42	0.03	0.06		254			
VBH-8S	25-03-2013		102.00	10.40	6.16	<0.01	0.55		109.6			
VBH-8S	13-06-2013		138.00			<0.01	0.40		72.8			
VBH-9D	15-10-2013										<1	
VBH-11M	01-05-2017								37			
VBH-11M	01-08-2017								35			
VVN09-016	15-08-2009						5.69		1644			
VVN09-016	01-03-2012		29.00			<0.01	0.04		149			
VVN16-010	25-11-2016					<0.2	3.25					

Site Name	Date	Biological Oxygen Demand O2 (mg/L)	Chemical Oxygen Demand O2 (mg/L)	Oxygen Absorbed O2 (mg/L)	Dissolved Oxygen O2 (mg/L)	Ortho Phosphate (P mg/L)	N_Ammonia (mg/L)	TPH (mg/L)	Suspended Solids (mg/L)	Standard Plate Count (countmL)	Total Coliforms (cfm/100mL)	Faecal Coliforms (cfm/100mL)
VVN16-013	25-11-2016					<0.2	0.73					
VVN16-014	25-11-2016					<0.2	1.55					
VVN16-015	25-11-2016					<0.2	3.46					
VVN16-015	25-11-2016					<0.2	3.45					
VVN16-016	25-11-2016					<0.2	3.98					
VVN16-017	25-11-2016						1.41					
Workshop PCD	01-04-2017								24		220	
Workshop PCD	01-05-2017								48		820	
Workshop PCD	01-06-2017								5270			
Workshop PCD	01-07-2017								2860			
Workshop PCD	01-08-2017								3030			
WR-S1	18-09-2009		10.97			<0.2	0.09		2.8			

Appendix 3 – Geochemical Evaluation

(By Geostratum)

SUMMARY

Geostratum was appointed by Groundwater Square to perform an environmental geochemical assessment of the Vlakvarkfontein Colliery. The following summarizes the report:

Sampling

All test results from 2013 and 2017 were presented in this report. In 2017, 10 samples were collected from one borehole. In 2013, 33 samples were collected from seven boreholes, 11 samples were collected from the pit, and 5 samples were collected from the low-grade Seam-4 coal stockpile. In total, 59 samples were submitted for mineralogical, acid-base as well as leaching tests.

Mineralogical composition

Sandstone: Quartz is the dominant mineral in the sandstone with the result that SiO_2 is the dominant oxide in the rock. Microcline and kaolinite are present as major minerals in one sample with the result that Al_2O_3 and K_2O are slightly higher relative to the other samples (where these two minerals are mostly present as minor minerals). Other minor and accessory minerals in the sandstone include calcite, dolomite, pyrite and siderite.

Carbonaceous shale: Most of the carbonaceous shale samples contains more than 10% carbon. The mineralogy of the shale samples is dominated by kaolinite with some major quartz, with the result that Al_2O_3 and SiO_2 are the dominant oxides in the rock. Other minor and accessory minerals in the shale include microcline, muscovite, calcite, dolomite, pyrite and siderite. Slightly elevated traces in the shale include Cu and Cr.

Coal: The coal samples are dominated by a high carbon content (>50%), and also contain major kaolinite and quartz, with accessory microcline, muscovite, calcite, dolomite, pyrite. P2O5 and Cr are slightly elevated in the coal. The coal has a much higher pyrite content (average total S% >0.9% from ABA test results) than the associated waste rock.

Alunite is present in 4 samples from one borehole as a secondary mineral. This indicates that these rocks were subjected to acidic drainage at some stage. All 4 samples also had a significant pyrite content and almost no neutralisation potential.

Acid-base testing (ABA)

The majority of the clastic waste rocks samples (roughly about 64.5% of all waste rock) have a very low sulphide content and will not generate acidic drainage. 35.5% of the clastic waste rocks have a moderate sulphide content and have a low to medium potential to generate acidic drainage. The backfill will, therefore, be a heterogeneous mixture of acid generation and non-acid generation rocks. The neutralisation potential of the non-acid generating rock is however not sufficient to prevent significant acidification of the backfill situated within the oxic zone.

All coal samples had a high sulphide content and will generate acidic drainage over the long term.

Kinetic leach tests

Kinetic leach testing was performed to indicate what metals may leach from the material under especially acidic conditions. The initial acidic leachate with elevated sulphate is due to the leaching of secondary sulphate minerals from the sandstone. The columns test of the coal samples had initial circumneutral leachate which became acidic after a few weeks.

The following metal(loids) leached at slightly elevated concentrations during the acidic leaches: Al, Mn, Fe, Cu, Co, Ni, Pb and Se. Ni and Mn leached persistently from the columns.

Potential impact on drainage quality (assuming the pillar area is mined as an isolated pit)

Backfilled pit (no discard at the end of the operational phase, the pit water will have a sulphate concentration of up to 1500mg/L. As the pit water level rises in the next 30 years, the sulphate will increases to between 2200–3300mg/L in the backfill. The pit will have an average unsaturated zone of only 3.5m deep (with limited resultant oxygen infiltration) and the sulphate concentration will improve to below 1000mg/L in the first 100 years after closure. For a the deepest regions of the pits, average unsaturated zone of 15.5m deep and will generate a sulphate concentration of between 3000 and 3300mg/L.

Backfilled pit (with discard): With discard backfilling the initial sulphate in the pit water will be at about 2000-2500mg/L. In the average unsaturated zones (3.5m deep) the sulphate concentration will improve

to about 1600mg/L over the long-term. In the maximum unsaturated zone, the sulphate will increases to between 3000-3500mg/L over the long-term. It is however important that the discard is backfilled only in the deepest parts of the pit at least 10m below the decant elevation.

Discard Dump: The discard has a high pyrite and sulphate mineral content and seepage from the discard dump will have an average sulphate concentration of between 4500-6000mg/L. However, it is possible that spikes in the sulphate may occur of up to 10 000mg/L.

In neutral pit water metals (e.g. Al, Fe and Mn) will be present at concentrations of below 1mg/L. Where acidification occurs in the discard dump, seepage will have Al, Fe and Mn concentrations above 10mg/L, even up to 1000mg/L. In acidic seepage, the concentration of trace metals Co and Ni will also become elevated (0.1-2mg/L).

Recommendations

- Coal material in contact with the atmosphere will result in oxidization of the pyrite and eventual acidification of drainage. It is therefore recommended that the coal material is not subjected to atmospheric conditions as far as possible as this will limit the contamination of water seepage from the material. A permanent discard dump on the surface will result in acidification of its seepage water while previous studies have shown that the correct backfilling of discard may result in less water being contaminated;
- Discard backfilled in the pit should be flooded as soon as possible and should be situated several meters below the final pit water level (>10m below the decant elevation) to ensure that limited oxidation takes place;
- The discard must have a neutral (paste) pH when backfilled else it would immediately acidify interstitial water before being covered with water. In this case, it is recommended that calcitic lime is added to the discard. However, the amount of lime required will depend on the degree of oxidation before backfilling and should be determined during the operational phase;
- As much as possible coal should be removed from the opencast mine during the operational phase. Carbonaceous rocks (including interburden and discard) should be placed in the deepest part of the pit and the mined-out section of the pits must be backfilled, compacted and rehabilitated as soon as possible;
- An important management measures relates to the monitoring of the mine waste and surrounding groundwater quality. The following parameters should be measured in surface water on a monthly basis and in groundwater on a quarterly basis:
    - System parameters: pH, TDS, EC, Total alkalinity;
    - Major cations: Ca,mg, Na, K;
    - Anions and compounds: SO_4, Cl, PO_4, NO_3, NH_3;
    - Minor metals: Al, Fe, Mn;
    - Trace metals (only in acidic water): Co, Cu, Ni, Se, Pb.
- The paste pH as well as the acid-base properties of the discard should be monitored throughout the life of the mine. If discard are placed in the pit, piezometers should be installed to monitor both the shallow and deeper pit water level and quality;
- It is recommended that the Vlakvarkfontein Mine actively monitor the Arbor Mine pit water quality as well as its own operational pit water quality. Validation of the geochemical model should take place over the life of the mine with cognizance of the Arbor Mine monitoring data. Calibration and validation of the model results will help the mine to construct an effective closure plan.

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GLOSSARY

Abbreviation	Term	Description
ABA	Acid-base accounting	A procedure where the acid potential (AP) and neutralization potential (NP) of a rock sample is determined and is used to calculate if the material will produce or neutralize acid
AMD	Acid mine drainage	Is formed under natural conditions where geological strata containing sulphur or metal sulphides are exposed to the atmosphere or oxidizing conditions forming acid water (pH <5) laden with metal and sulphates.
AP	Acid Potential	The ability of the rock to produce acid leaches
AUC	Average Upper Crust	AUC is the composition of rocks exposed at the surface by means of establishing weighted averages and determining averages of the composition of insoluble elements in sedimentary or glacial rocks.
EC	Electrical Conductivity	Electrical conductivity is the measure of a material's ability to allow the transport of an electric charge.
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometry	ICP-OES is an analytical technique used for the detection of metals and metalloids in solution down to trace level.
LOI	Loss of Ignition	LOI is a test used in inorganic analytical chemistry, particularly in the analysis of minerals. It consists of strongly heating ("igniting") a sample of the material at a specified temperature, allowing volatile substances to escape, until its mass ceases to change.
NAG	Net-acid Generation	NAG testing determines the balance between the acid producing and the acid consuming components in waste rock material
NNP	Net Neutralization Potential	NNP is the difference between neutralisation potential and acid potential (=NP-AP). The following screening criteria are used: A rock with NNP < 0kg CaCO3/t will theoretically have a net potential for acidic drainage. A rock with NNP > 0kg CaCO3/t rock will have a net potential for the neutralization of acidic drainage.
NP	Neutralization Potential	Is the amount of alkaline material in a rock estimated by an acid reaction followed by titration to determine the ability of a rock to neutralize acid leaches
SANS	South African National Standard	SANS refers to a standard that specifies the performance requirements of a specific product
TDS	Total dissolved solids	Refers to any minerals, salts, metals, cations or anions dissolved in water
XRD	X-ray Diffraction	Is a laboratory-based technique used to identify crystalline materials by a scattering of x-rays to form an interference pattern that is captured and analysed
XRF	X-ray Fluorescence	Is a laboratory-based technique to determine the bulk chemistry of material by means of x-ray interaction with the material

1. INTRODUCTION

Geostratum was appointed by *Groundwater Square* to perform an environmental geochemical assessment of the Vlakvarkfontein Colliery.

The Vlakvarkfontein Colliery is located 70km east of Johannesburg in the Delmas district in the Witbank Coalfield. The opencast mine produces c. 100000t of coal per month. Seam-2 and Seam-4 are targeted at the mining operation.

1.1. Scope of work

The overall objective of the geochemical assessment was to determine the potential for acid rock drainage from the mine waste. This will assist in identifying potential impacts on local water quality, provide the basis for developing waste rock and pit management strategies, and support closure planning. The scope of work was as follows:

- Preliminary assessment including a review of available information and assessment of potential issues and concerns that may be associated with the rock material;

- Development of a sampling plan to collect samples representing the geochemical variability in the rock material;
- Development of an analytical plan including laboratory test methods consistent with international guidelines;
- Interpretation of geochemical test results and quantification of the volume of waste that could generate acid drainage;
- To identify chemical constituents that may be present in future drainage from the mine;
- To determine the long-term impact of the backfilled pit and discard dump. Different modelling scenarios were employed to investigate the effectiveness of some mitigation measures (e.g. waste management strategies).

1.2. Project outline

The project comprised of a sampling, testing as well as a modelling phase. The methodology that was followed in this assessment aimed to address all aspects of the scope of work. However, the assessment often needs to be updated during the life of mine to address any gaps in the assessment and to generate an effective closure plan. The methodology followed for the current assessment is outlined:

- Section 2: Rock samples were collected from drilled boreholes and pits. The samples were prepared and tested according to the test methods summarized in Table 3;
- Section 3.1: The total element content of the samples was determined by means of X-ray fluorescence (XRF) and the major mineral content by X-ray diffraction (XRD);
- Section 3.2: The long-term net acid generation potential of the material was determined by acid-base testing. Both Acid-base accounting (ABA) and Net-acid generation (NAG) tests were performed to calculate whether the material will produce or neutralize acidic drainage;
- Section 3.3: Static leach test: Reagent water extraction test were performed on selected samples in order to identify chemicals that may potentially leach from the material in a once-off leach;
- Section 3.4: Kinetic leach test: Column leach testing was performed on selected samples to identify persistent chemicals that may potentially leach from the material;
- Section 4: Conceptual models for the pit backfill and discard dump were developed. These include the typical physical-chemical processes that will control acid-mine drainage generation. The potential impact on the mine and seepage water from the various facilities was be discussed;
- Section 5: Numerical geochemical modelling was performed to 1) estimate the long-term pit water quality with and without discard backfilling, and 2), to estimate the long-term seepage water quality from the discard dump;
- Conclusions and recommendations were provided in Section 6.

2. SAMPLE DESCRIPTION AND ANALYTICAL PLAN

2.1. Introduction

The coal-bearing strata (Middle Ecca Stage) consist predominantly of fine, medium and coarse-grained sandstone with subordinate mudstone, shale, siltstone and carbonaceous shale. There are five coal seams in the Witbank Coalfield numbered Seam-1 to Seam-5 from bottom to top. Seam2 and Seam-4 are targeted at the mining operation.

2.2. Sampling plan

In Table 1 and 2 the samples collected in 2017 and in 2013 respectively are listed. In 2017, 10 samples were collected from one borehole. In 2013, 33 samples were collected from seven boreholes, 11 samples were collected from the pit, and 5 samples were collected from the low-grade Seam-4 coal stockpile.

Samples collected in 2017:

- 3x sandstone;
- 4x carbonaceous shale;
- 3x coal samples.

Samples collected in 2013:

- 14x sandstone;
- 7x Seam-4 coal ;
- 5x low-grade Seam-4 coal;
- 5x sandstone and shale;
- 8x carbonaceous shale;
- 9x Seam2 coal seam samples.

2.3. Analytical plan

The samples were prepared and submitted for geochemical testing according to the methods summarized in Table 3 by *Metron Laboratory*, *Vanderbijlpark*. The analytical tests comprised of mineralogical, acid-base as well as leaching tests. Acid-base tests were performed on all 59 samples to ensure that the variability in the acid generation potential for each litho-stratigraphical unit could be determined. Based on these results samples from each lithological unit were selected for further testing: 9 samples for X-ray fluorescence, 10 samples for X-ray diffraction; 3 samples for static leach tests; and 3 samples for kinetic leach testing.

Table 1 Rock sample description and photos for samples collected in 2017

Sample ID	Sample description	*	Sample photos
VVN16 – 010 14.73 – 15.29	Sandstone with siltstone lenses		
VVN16 – 010 18.02 - 18.40	Carbonaceous shale with thin sandstone layers		
VVN16 – 010 21.03 - 21.41	Carbonaceous shale		
VVN16 – 010 21.69 - 21.93	Coal		

Sample ID	Sample description	*	Sample photos
VVN16 – 010 21.93	Coal		
VVN16 – 010 28.38 – 28.70	Sandstone with carbonaceous mudstone/siltstone		
VVN16 – 010 18.15 - 18.85	Carbonaceous shale		
VVN16 – 010 18.95 - 19.35	Sandstone with lesser siltstone present		

Sample ID	Sample description	*	Sample photos
VVN16 – 010 20.98 - 21.68	Carbonaceous shale		
VVN16 – 010 21.68 - 24.85	Coal		
* Sandstone = Yellow, Purple = Carbonaceous shale, Coal = Black			

Table 2 Rock sample description for samples collected in 2013

Borehole	Depth	*	Description
VBH-1M	6-9 m		Slightly weathered sandstone
	12-15 m		Slightly weathered sandstone
	15-19 m		Carbonaceous shale
	20-21 m		Highly carbonaceous shale
	21-26 m		Seam2 coal seam
VBH-2M	4-6 m		Slightly weathered sandstone
	12-13 m		Carbonaceous shale
	13-15 m		Carbonaceous shale
	15-16 m		Sandstone and shale
	16-18 m		Seam2 coal seam
VBH-4M	9-10 m		Slightly weathered sandstone
	11-17 m		Seam-4 coal
	18-20 m		Sandstone and shale
	22-24 m		Highly carbonaceous shale
	24-26 m	2	Seam2 coal seam
	26-30 m	2	Seam2 coal seam
VBH-5M	21-24 m		Slightly weathered sandstone
	25-30 m	4	Seam-4 coal
	31-32 m		Coal and shale
	36-39 m		Sandstone and shale
	40-46 m	2	Seam2 coal seam
VBH-6M	13-16 m		Slightly weathered sandstone
	18-23 m	4	Seam-4 coal
	23-24 m		Highly carbonaceous shale
	29-31 m		Highly carbonaceous shale
	31-35 m	2	Seam2 coal seam
VBH-7M	13-16 m		Slightly weathered sandstone
	18-26 m	4	Seam-4 coal
	30-32 m		Highly carbonaceous shale
	34-35 m	2	Seam2 coal seam
	35-39 m	2	Seam2 coal seam

Borehole	Depth	*	Description
VBH-8M	7-11 m	4	Seam-4 coal
	22-28 m	2	Seam2 coal seam
Pit S1 W SST A	Above Seam-4		Weathered sandstone above Seam-4 coal
Pit S1 W SST B	Above Seam-4		Weathered sandstone above Seam-4 coal
Pit S1 W SST C	Above Seam-4		Weathered sandstone above Seam-4 coal
Pit S1 Seam-4 Coal	Coal seam	4	Seam-4 coal
Pit S2 SST	Above Seam-4		Sandstone above Seam-4 coal
Pit S2 Seam-4 Coal	Coal seam	4	Seam-4 coal
Pit S3 Interburden	Between Seam2 and Seam-4		Slightly carbonaceous sandstone and shale interburden
Pit S3 Mica SST	Between Seam2 and Seam-4		Micaceous sandstone interburden
Pit S4 WT SST A	Above Nr 4		Slightly weathered sandstone above Seam-4 coal
Pit S4 WT SST B	Above Nr 4		Weathered Sandstone above Seam-4 coal
Pit S4 Interburden	Below Nr 4		Sandstone and shale
Sample 1	Stockpile	4	Low-grade Seam-4 coal stockpile
Sample 2	Stockpile	4	Low-grade Seam-4 coal stockpile
Sample 3	Stockpile	4	Low-grade Seam-4 coal stockpile
Sample 4	Stockpile	4	Low-grade Seam-4 coal stockpile
Sample 5	Stockpile	4	Low-grade Seam-4 coal stockpile
*** Sandstone = Yellow, Purple = Carbonaceous shale, Coal = Black**			

Table 3 Description of test methods

Test procedure	Expected outcome	Method
Acid-base accounting (ABA) 59 samples	To indicate the long-term potential for AMD assuming all acid is generated by pyrite.	Modified Sobek (Lawrence and Wang, 1996, 1997)
Net-acid generating (NAG) 59 samples	To indicate the net potential for AMD after oxidation with hydrogen peroxide.	ASTM E1915-13
X-ray diffraction 10 samples	Minor to dominant minerals present in rocks.	-
X-ray fluorescence 9 samples	Major oxides and trace elements present in rocks.	ASTM D4326-13
Reagent water leach 3 samples	To determine chemicals of concern that may potentially leach from samples.	Based on ASTM D3987-12 with additional ICP and UV-VIS analyses.
Kinetic Column 3 Columns	Indicate metals that can leach out as well the pyrite oxidation rate. A minimum of 20 weeks is required	Based on ASTM D5744-07

3. ANALYTICAL TEST RESULTS

3.1. Mineralogy and total element analyses

The mineralogical composition of the samples was determined by means of X-ray Diffraction (XRD). The XRD was performed by XRD Analytical and Consulting, Pretoria. The total element analyses were performed by means of X-ray fluorescence (XRF) at the Metron Laboratory, Vanderbijlpark. A simplified classification of the identified minerals is listed in Table 4. The XRD and XRF results are presented in Tables 5 – 7.

Methodology

The following pertains to the XRD method used:

- The samples were prepared for XRD analysis using a back-loading preparation method. They were analysed with a PANalytical Empyrean diffractometer with PIXcel detector and fixed receiving slits with Fe filtered Co-K radiation. The phases were identified using X'Pert Highscore plus software;
- Amorphous phases were not taken into account in the quantification;
- Trace minerals at concentrations below ± 1% are often not detected by means of XRD testing on whole rock samples as the error might become larger than the analyses reported;
- The weight percentages of the minerals were determined using the Rietveld method (Autoquan Program).

The following pertains to the XRF method:

- Samples were analysed using pressed powder pellets;
- Analyses were performed with a Rigaku Supermini 200 with SC and F-PC detectors and fixed receiving slits with Zr of Al filtered Pd-K radiation. The elements were identified using ZSX software;
- LOI is determined by placing samples in weighed crucibles which are then weighed. Weight loss is measured after heating at 750ºC overnight to remove water, organic matter and some sulphides and carbonates. After heating, the firebrick holding crucibles was allowed to cool completely in the oven or furnace before weighing.

Test results

Sandstone [VVN16 – 010 (14.73 – 15.29, 18.95 – 19.35), VHB -4M 9 – 10m, VHB 4M 18 – 20m): Quartz is the dominant mineral in the sandstone with the result that SiO_2 is the dominant oxide in the rock. Microcline and kaolinite are present as major minerals in one sample (VHB 4M 18 – 20m) with the result that Al_2O_3 and K_2O are slightly higher relative to the other samples (where these two minerals are mostly present as minor minerals). Other minor and accessory minerals in the sandstone (especially sample VVN16 – 010 18.95 – 19.35) include calcite, dolomite, pyrite and siderite).

Carbonaceous shale (VVN16 - 010 21.03 – 21.41, VHB-4M - 22-24m): Most of the carbonaceous shale samples contains more than 10% carbon. The mineralogy of the shale samples is dominated by kaolinite with some major quartz, with the result that Al_2O_3 and SiO_2 are the dominant oxides in the rock. Other minor and accessory minerals in the shale include microcline, muscovite, calcite, dolomite, pyrite and siderite. Slightly elevated traces in the shale include Cu and Cr.

Coal (VVN16 - 010 21.93, VBH-4M 11-17m, VBH-4M 24-26m, VBH-4M 26-30m): The coal samples are dominated by a high carbon content (>50%), and also contain major kaolinite and quartz, with accessory microcline, muscovite, calcite, dolomite, pyrite. P_2O_5 and Cr are slightly elevated in the coal. The coal has a much higher pyrite content (average total S% >0.9% from ABA test results) than the associated waste rock.

Alunite is present in 4 samples from borehole VBH-4M as a secondary mineral. This indicates that these rocks were subjected to acidic drainage at some stage. All 4 samples also had a significant pyrite content and almost no neutralisation potential.

Table 4 Simplified classification of identified minerals

Mineral	*	Formula	Mineral type/group	Sub-group
Calcite		$CaCO_3$	Anhydrous Carbonates	Calcite group
Dolomite		$CaMg(CO_3)_2$	Anhydrous Carbonates	Dolomite Group
Kaolinite		$Al_2Si_2O_5(OH)_4$	Phyllosilicate 1:1 layer	Kaolinite group
Quartz		SiO_2	Tectosilicate	Tectosilicates
Muscovite		$KAl_2(AlSi_3O_{10})(OH,F)_2$	Phyllosilicate 2:1 layer	Mica group (Muscovite subgroup)
Smectite		$(0.5Ca,Na)_{0.7}(Al,Mg,Fe)_{4,6}[(Si,Al)_8O_{20}](OH)_4 \cdot nH_2O$	Phyllosilicate 2:1 layer	Smectite group
Microcline		$KAlSi_3O_8$	Tectosilicate	K(Na,Ba) feldspar subgroup
Pyrite		FeS_2	Sulphides	Pyrite Group
Siderite		$FeCO_3$	Anhydrous Carbonate	Calcite group
Alunite		KAl3(SO4)2(OH)6	Anhydrous Sulfates	Alunite Subgroup

*** Mineral Type: Blue = Carbonates, Red = Phyllosilicates, Green = Tectosilicates, Yellow = Sulphides and sulphates**

Table 5 X-ray diffraction results (weight %)

Mineral name	VVN16 – 010 14.73 – 15.29m	VVN16 – 010 21.03 – 21.41m	VVN16 – 010 21.93m	VVN16 – 010 18.95 – 19.35m	VHB-4M 9-10m	VHB-4M 11-17m	VHB-4M 18-20m	VHB-4M 22-24m	VHB-4M 24-26m	VHB-4M 26-30m
*										
Calcite	0.41	0.29	1.85	1.02	-	-	1	-	-	-
(error)	0.22	0.19	0.3	0.23	-	-	-	-	-	-
Dolomite	-	0.33	1.51	4.17	Trace	-	-	-	-	-
(error)	-	0.26	0.33	0.54	-	-	-	-	-	-
Graphite (coal)	-	27.7	61.9	-	-	-	-	-	-	-
(error)	-	6.9	3	-	-	-	-	-	-	-
Kaolinite	6.89	45.1	25.4	15.2	4	62	29	41	46	37
(error)	0.78	4.2	1.98	0.75	-	-	-	-	-	-
Microcline	8.29	4.39	1.1	6.51	Trace	-	19	7	9	1
(error)	0.84	0.87	0.39	0.72	-	-	-	-	-	-
Muscovite	-	7.42	-	4.12	-	-	5	8	7	3
(error)	-	0.87	-	0.48	-	-	-	-	-	-
Pyrite	-	0.2	1.02	0.41	Trace	4	-	1	1	1
(error)	-	0.16	0.16	0.15	-	-	-	-	-	-
Quartz	84.4	14.6	6.73	64.2	95	21	43	38	33	58
(error)	0.99	1.44	0.57	0.99	-	-	-	-	-	-
Siderite	-	-	0.5	4.46	-	-	1	4	2	1
(error)	-	-	0.3	0.3	-	-	-	-	-	-
Alunite	-	-	-	-	-	13	Trace	Trace	1	-
Smectite	-	-	-	-	-	-	1	-	1	-

*** Sandstone = Yellow, Purple = Carbonaceous shale, Coal = Black**

Table 6 X-ray fluorescence major oxides (weight %)

Sample ID	*	LOI	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2
VVN16 – 010 21.03 – 21.41		25.30%	17.9	0.9	5.86	4.03	0.28	0.066	<0.5	0.959	41.1	2.85
VVN16 - 010 21.93		72.90%	4.72	3.68	4.73	0.198	0.077	0.022	<0.5	0.254	10.5	1.04
VVN16 – 010 18.95 – 19.35		6.38%	9.81	7.27	13.5	2.5	0.323	0.296	<0.5	0.953	51.9	4.66
VBH-4M 9-10m		0.9	2.39	0	0.36	0.15	0.02	0.007	0.19	0.012	95.58	0.39

VBH-4M 11-17m		70.58	9.23	0.18	1.53	0.36	0.08	0.001	0.06	0.3	17.37	0.55
VBH-4M 18-20m		8.22	14.39	0.49	3.05	2.9	0.55	0.033	0.21	0.109	69.61	0.7
VBH-4M 22-24m		36.15	14.02	0.21	3.9	1.21	0.43	0.046	0.13	0.108	43.28	0.7
VBH-4M 24-26m		52.98	11.46	0.19	1.96	0.77	0.29	0.016	0.09	0.155	31.78	0.58
VBH-4M 26-30m		37.08	12.53	0.12	1.74	0.59	0.16	0.01	0.14	0.067	46.78	1.01
**AUC	Above AUC		15.4	3.6	11.2	2.8	2.5	0.1	3.3	0.2	66.6	0.6
	3-5 times above AUC		46.2	10.8	33.6	8.4	7.44	0.3	9.81	0.45	-	1.92
	> 5 times higher than AUC		77	17.95	56	14	12.4	0.5	16.35	0.75	-	3.2
* Sandstone = Yellow, Purple = Carbonaceous shale, Coal = Black												

*** AUC = Average Upper Crust (Rudnick and Gao, 2003)*

Table 7 X-ray fluorescence trace elements (ppm) ***

Sample ID	*	LOI	As	Ba	Co	Cr	Cu	F	Nb	Ni	Pb	Rb	Sr	Th	U	V	Zn	Zr
VVN16 – 010 21.03 – 21.41		25.30%	<40	<100	<40	834	232	<1000	<40	53	<40	95.6	389	<100	<100	223	244	312
VVN16 - 010 21.93		72.90%	<40	<100	<40	685	<40	<1000	<40	<40	<40	<40	222	<100	<100	56.7	<40	113
VVN16 – 010 18.5 – 19.35		6.38%	<40	<100	<40	164	<40	<1000	<40	<40	<40	58	175	<100	<100	250	85.2	471
VBH-4M 9-10m		0.9	<4	58	1.5	36	6	<1000	12	3	5.8	7.4	14	3.7	<2	26	4	267
VBH-4M 11-17m		70.6	4.3	867	5.1	56	25	<1000	11	13	7.2	13	975	8.3	6.8	65	12	188
VBH-4M 18-20m		8.22	<4	782	8.3	69	15	<1000	16	17	28	106	141	11	4.6	85	76	316
VBH-4M 9-10m		36.2	<4	406	17	104	27	<1000	15	45	23	63	199	13	5	96	88	211
VBH-4M 24-26m		53.0	<4	331	12	66	20	<1000	13	30	20	42	320	11	5.2	61	55	179
VBH-4M 26-30m		37.1	12	302	23	125	42	<1000	16	90	30	38	151	14	5.2	472	381	243
**AUC	Above AUC		4.8	628	17.3	92	28	557	12	47	17	84	320	10.5	2.7	97	67	193
	3-5 times above AUC		14.4	1884	51.9	276	84	1671	36	141	51	252	960	31.5	8.1	291	201	579
	> 5 times higher than AUC		24	3140	86.5	460	140	2785	60	235	85	420	1600	52.5	13.5	485	335	965
* Sandstone = Yellow, Purple = Carbonaceous shale, Coal = Black																		

*** AUC = Average Upper Crust (Rudnick and Gao, 2003).*
**** Detection limits differ between 2013 and 2017 samples.*

3.2. Acid-base testing

3.2.1 ABA test methodology

Introduction

Acid-base accounting (ABA) is a static test where the net potential of the rock to generate long-term acidic drainage when subjected to atmospheric (oxidizing) conditions is determined. It is mostly applicable to pyrite containing rock excavated and disposed of during mining. The test obviously does not consider site-specific conditions or the timeframe for potential acidification. Rock not subjected to oxidizing conditions at the mine e.g. saturated rock at the mine, may not generate the predicted acidification.

Methodology

The percentage sulphur (%S), the Acid Potential (AP), the Neutralization Potential (NP) and the Net Neutralization Potential (NNP) of the rock material are determined in this test:

- If pyrite is the only sulphide in the rock the AP (acid potential) is determined by multiplying the percentage sulphur (%S) with a factor of 31.25 which is based on the oxidation reaction of pyrite. The unit of AP is kg $CaCO_3$/t rock and indicates the theoretical amount of calcite neutralized by the acid produced;
- The %S was determined through an infrared (IR) detector after sample combustion in an Eltra furnace. The total %S was determined after heating the furnace to ±2200°C and the sulphide %S was determined at 1000°C. The sulphide %S was used to determine the acidification potential of the samples and the acid potential of the sample was therefore not overestimated;
- The NP (Neutralization Potential) is determined by treating a sample with a known excess of standardized hydrochloric or sulfuric acid (the sample and acid are heated to ensure reaction completion). The paste is then back-titrated with standardized sodium hydroxide in order to determine the amount of unconsumed acid. NP is also expressed as kg $CaCO_3$/t rock as to represent the amount of calcite theoretically available to neutralize the acidic drainage;
- NNP is determined by subtracting AP from NP.

For the material to be classified in terms of their acid-mine drainage (AMD) potential, the ABA results could be screened in terms of its NNP, %S and NP:AP ratio as follows:

- A rock with NNP < 0kg $CaCO_3$/t will theoretically have a net potential for acidic drainage. A rock with NNP > 0kg $CaCO_3$/t rock will have a net potential for the neutralization of acidic drainage. Because of the uncertainty related to the exposure of the carbonate minerals or the pyrite for reaction, the interpretation of whether a rock will be net acid generating or neutralizing is more complex. Research has shown that a range from -20kg $CaCO_3$/t to 20kg $CaCO_3$/t exists that is defined as a "grey" area in determining the net acid generation or neutralization potential of a rock. Material with an NNP above this range is classified as *Rock Type IV - No Potential for Acid Generation* and material with an NNP below this range as *Rock Type I - Likely Acid Generating*;
- Further screening criteria could be used that attempts to classify the rock in terms of its net potential for acid production or neutralization. The following screening methods are given in Table 8, as proposed by Price (1997), use the NP:AP ratio to classify the rock in terms of its potential for acid generation;
- Soregaroli and Lawrence (1998) further state that samples with less than 0.3% sulphide sulphur are regarded as having insufficient oxidisable sulphides to sustain long-term acid generation. According to Li (2006), a material with an S% of below 0.1% has no potential for acid generation. Therefore, a material with a %S of above 0.3%, is classified as *Rock Type I - Likely Acid Generating,* 0.2-0.3% is classified as *Rock Type II,* 0.1-0.2% is classified as *Rock Type III*, and below 0.1% is classified as *Rock Type IV - No Potential for Acid Generation*.

Table 8 Screening methods using the NP: AP ratio (Price, 1997)

Potential for acid generation	NP: AP screening criteria	Comments

Rock Type I. Likely Acid Generating.	< 1:1	Likely AMD generating.
Rock Type II. Possibly Acid Generating.	1:1 – 2:1	Possibly AMD generating if NP is insufficiently reactive or is depleted at a faster rate than sulphides.
Rock Type III. Low Potential for Acid Generation.	2:1 – 4:1	Not potentially AMD generating unless significant preferential exposure of sulphides along fracture planes, or extremely reactive sulphides in combination with insufficient reactive NP.
Rock Type IV. No Potential for Acid Generation.	>4:1	No further AMD testing required unless materials are to be used as a source of alkalinity.

3.2.2 NAG test methodology

Introduction

The NAG test provides a direct assessment of the potential for a material to produce acid after a period of exposure (to a strong oxidant) and weathering. The test can be used to refine the results of the ABA predictions. As with the ABA test, the NAG test does not consider site-specific conditions or the timeframe for potential acidification.

Methodology

In the NAG test hydrogen peroxide (H_2O_2) is used to oxidize sulphide minerals to predict the acid generation potential of the sample. The following relates to the methodology:

- In general, the static NAG test involves the addition of 25mL of 15% H_2O_2 to 0.25g of sample in a 250mL wide mouth conical flask or equivalent. The sample is covered with a watch glass, and placed in a fume hood and a well-ventilated area for about 2h;
- Once "boiling" or effervescing ceases, the solution is allowed to cool to room temperature and the final pH (NAG pH) is determined; and
- A quantitative estimation of the amount of net acidity remaining (the NAG capacity) in the sample is determined by titrating it with sodium hydroxide (NaOH) to pH 4.5 (and/or pH 7.0) to obtain the NAG Value;
- In order to determine the acid generation potential of a sample, the screening method of Miller et al. (1997) is used. See Table 9.

Table 9 NAG test screening method (edited from Miller et al., 1997)

Rock Type	NAG pH	NAG Value (H_2SO_4 kg/t)	NNP ($CaCO_3$ kg/t)
Rock Type Ia. High Capacity Acid Forming.	< 4.5	> 10	Negative
Rock Type Ib. Lower Capacity Acid Forming.	< 4.5	≤ 10	-
Uncertain, possibly Ib.	< 4.5	> 10	Positive
Uncertain.	≥ 4.5	0	Negative (Reassess mineralogy) *
Rock Type IV. Non-acid Forming.	≥ 4.5	0	Positive

** If low acid forming sulphides is dominant then Rock Type IV.*

3.2.3 Acid-base test results

Introduction

ABA and NAG test results were performed by *Metron Laboratory*, Vanderbijlpark. The ABA results are presented in Table 10. The results were screened as discussed in Section 3.2.1 above as *Rock Type I to IV*. The average results for each lithology are presented in Table 11. The potential risk of the various samples to generate AMD is presented in Table 12. The NAG test results are presented in Table 13. The results were screened as discussed in Section 3.2.2 as *Rock Type I to IV*. In Figure 2 the NAG value is plotted against the NNP.

Screening results

The NP/AP indicates the potential for the rock to generate acid drainage, whereas the %S indicated whether this drainage will be over the long term. In Figure 1 the red lines, therefore, assess the acid generation potential, while the horizontal yellow line assesses whether this generation will be over a long term. In Figure 2 the NAG value was plotted against the NNP. The NAG test confirms the results of the ABA indicating that the samples acidify during the NAG test when having a negative NNP.

Sandstone: The sandstone has a low sulphide S% and often also a low carbonate mineral content. 88.2% (15 out of 17) of the sandstone samples have no potential to generate acidic drainage (and will generate a very low to no salt load); 5.9% (1 out of 17) of the sandstone have a very low potential to generate acidic drainage; 5.9% (1 out of 17) of the sandstone samples have a medium potential for acidic drainage.

Sandstone and shale: The sandstone is interlayered with shale and bulk samples are also relatively more carbonaceous than sandstone. 40% (2 out of 5) of the sandstone and shale samples have no potential to generate acidic; 20% (1 out of 5) of the sandstone and shale samples have a very low potential to generate acidic drainage; 40% (2 out of 5) of the sandstone and shale samples have a medium potential for acidic drainage.

Carbonaceous shale: This lithological unit is slightly carbonaceous and often situated in close proximity to the coal horizon. 25% (3 out of 12) of the carbonaceous shale samples have no potential to generate acidic drainage; 16.7% (2 out of 12) of the carbonaceous shale samples have a very low potential to generate acidic drainage; 33.3% (4 out of 12) of the carbonaceous shale samples have a medium potential for acidic drainage; 25% (3 out of 12) of the carbonaceous shale samples have a high potential to generate acidic drainage (and generate a high salt load).

Coal: 90% (9 out of 10) of the raw coal samples have a high potential to generate acidic drainage (and generate a high salt load), 10% (1 out of 10) of the coal samples have a medium potential for acidic drainage.

Comparison between ABA and NAG: In Figure 2 the NAG value was plotted against the NNP. The figure indicates that although the coal samples have a slightly positive NNP they will still acidify. The carbonaceous material and sandstone confirm the results of the ABA indicating that the samples acidify during the NAG test when having a negative NNP.

Comparison between ABA and XRD: The XRD indicated the presence of pyrite, calcite and dolomite in some samples. However, the XRD results are only semi-quantitative and the pyrite content was therefore rather calculated from the sulphide S% in the ABA. The calcite and dolomite contents of the waste rock are low and siderite was also identified in most rock samples. Siderite will not contribute to the neutralisation potential of the samples as it generates just as much acid (through oxidation of iron) as that it neutralises by its carbonate. Interesting is the presence of alunite in 4 samples which indicates that these rocks were subjected to acidic drainage at some stage. All 4 samples also had a significant pyrite content and almost no neutralisation potential.

Conclusion

Conclusion - waste rock: The majority of the clastic waste rocks samples (roughly about 64.5% of all waste rock) have a very low sulphide content and will not generate acidic drainage. 35.5% of the clastic waste rocks have a moderate sulphide content and have a low to medium potential to generate acidic drainage. The backfill will, therefore, be a heterogeneous mixture of acid generation and non-acid generation rocks. The neutralisation potential of the non-acid generating rock is however not sufficient to prevent significant acidification of the backfill situated within the oxic zone.

Conclusion - coal material: All coal samples had a high sulphide content and will generate acidic drainage over the long term.

Table 10 *Acid-base Accounting (ABA) test results (2013 and 2017)*

Sample ID	*	Paste pH	Total %C	Sulphide %S	Total %S	AP $CaCO_3$ kg/t	NP $CaCO_3$ kg/t	NNP $CaCO_3$ kg/t	NP/AP	Rock Type NNP	Rock Type %S	Rock Type NP/AP
VVN16 – 010 14.73 – 15.29		7.53	0.203	0.023	0.046	0.732	0.614	-0.118	0.839	Uncertain	Rock Type IV	Rock Type I
VVN16 – 010 18.02 – 18.40		7.81	11	0.097	0.128	3.03	16.9	13.8	5.56	Uncertain	Rock Type IV	Rock Type IV
VVN16 – 010 21.03 – 21.41		7.91	13	0.105	0.109	3.28	4.27	0.991	1.3	Uncertain	Rock Type II	Rock Type II
VVN16 – 010 21.69 – 21.93		7.33	57.7	0.423	0.534	13.2	40.2	26.9	3.04	Rock Type IV	Rock Type I	Rock Type III
VVN16 – 010 21.93		6.67	62.81	1.26	1.32	39.2	52.1	12.9	1.33	Uncertain	Rock Type I	Rock Type II
VVN16 – 010 28.38 – 28.70		7.53	0.142	0.021	0.042	0.657	0.305	-0.353	0.463	Uncertain	Rock Type IV	Rock Type I
VVN16 – 010 18.15 – 18.85		7.53	11.5	0.104	0.132	3.24	13.8	10.5	4.25	Uncertain	Rock Type II	Rock Type IV
VVN16 – 010 18.95 – 19.35		7.97	1.85	0.157	0.293	4.9	47.6	42.7	9.71	Uncertain	Rock Type II	Rock Type IV
VVN16 – 010 20.98 – 21.68		7.53	9.65	0.087	0.107	2.71	7.06	4.34	2.6	Uncertain	Rock Type IV	Rock Type III
VVN16 – 010 21.68 – 24.85		7.36	56	1.05	1.23	32.7	51.9	19.2	1.59	Uncertain	Rock Type I	Rock Type II
VBH-1M 6-9		5.3	-	-	0.001	0.031	0	-0.031	0	Uncertain	Rock Type IV	Rock Type I
VBH-1M 12-15		6	-	-	0.069	2.156	2.5	0.344	1.16	Uncertain	Rock Type IV	Rock Type II
VBH-1M 15-19		6.7	-	-	0.107	3.344	12.5	9.156	3.74	Uncertain	Rock Type IV	Rock Type III
VBH-1M 20-21		7.1	-	-	1.747	54.594	11.75	-42.844	0.22	Rock Type I	Rock Type I	Rock Type I
VBH-1M 21-26	2	7.2	-	-	0.726	22.688	32.5	9.812	1.43	Uncertain	Rock Type I	Rock Type II
VBH-2M 4-6		7.3	-	-	0.002	0.063	0	-0.063	0	Uncertain	Rock Type IV	Rock Type I
VBH-2M 12-13		7	-	-	0.105	3.281	3	-0.281	0.91	Uncertain	Rock Type IV	Rock Type I
VBH-2M 13-15		5.6	-	-	0.077	2.406	0	-2.406	0	Uncertain	Rock Type IV	Rock Type I

Sample ID	*	Paste pH	Total %C	Sulphide %S	Total %S	AP $CaCO_3$ kg/t	NP $CaCO_3$ kg/t	NNP $CaCO_3$ kg/t	NP/AP	Rock Type NNP	Rock Type %S	Rock Type NP/AP
VBH-2M 15-16		6.1	-	-	0.092	2.875	1.25	-1.625	0.43	Uncertain	Rock Type IV	Rock Type I
VBH-2M 16-18	2	5.5	-	-	0.385	12.031	0.25	-11.781	0.02	Uncertain	Rock Type I	Rock Type I
VBH-4M 9-10		6.1	-	-	0.002	0.063	0	-0.063	0	Uncertain	Rock Type IV	Rock Type I
VBH-4M 11-17	4	5.4	-	-	1.432	44.75	2	-42.75	0.04	Rock Type I	Rock Type I	Rock Type I
VBH-4M 18-20		7	-	-	0.218	6.813	3.25	-3.563	0.48	Uncertain	Rock Type IV	Rock Type I
VBH-4M 22-24		7	-	-	0.469	14.656	2.5	-12.156	0.17	Uncertain	Rock Type I	Rock Type I
VBH-4M 24-26	2	7	-	-	0.55	17.188	0	-17.188	0	Uncertain	Rock Type I	Rock Type I
VBH-4M 26-30	2	6	-	-	0.846	26.438	0	-26.438	0	Rock Type I	Rock Type I	Rock Type I
VBH-5M 21-24		6.5	-	-	0.003	0.094	0	-0.094	0	Uncertain	Rock Type IV	Rock Type I
VBH-5M 25-30	4	5	-	-	1.655	51.719	0	-51.719	0	Rock Type I	Rock Type I	Rock Type I
VBH-5M 31-32		6	-	-	0.549	17.156	0	-17.156	0	Uncertain	Rock Type I	Rock Type I
VBH-5M 36-39		6.3	-	-	0.136	4.25	29	24.75	6.82	Rock Type IV	Rock Type IV	Rock Type IV
VBH-5M 40-46	2	7	-	-	0.38	11.875	16.5	4.625	1.39	Uncertain	Rock Type I	Rock Type II
VBH-6M 13-16		7.3	-	-	0.002	0.063	0	-0.063	0	Uncertain	Rock Type IV	Rock Type I
VBH-6M 18-23	4	7.4	-	-	1.088	34	2.75	-31.25	0.08	Rock Type I	Rock Type I	Rock Type I
VBH-6M 23-24		6.9	-	-	0.726	22.688	2.75	-19.938	0.12	Uncertain	Rock Type I	Rock Type I
VBH-6M 29-31		6.9	-	-	0.225	7.031	8.25	1.219	1.17	Uncertain	Rock Type IV	Rock Type II
VBH-6M 31-35	2	7.7	-	-	0.459	14.344	14	-0.344	0.98	Uncertain	Rock Type I	Rock Type I
VBH-7M 13-16		7.6	-	-	0.002	0.063	0	-0.063	0	Uncertain	Rock Type IV	Rock Type I

Sample ID	*	Paste pH	Total %C	Sulphide %S	Total %S	AP $CaCO_3$ kg/t	NP $CaCO_3$ kg/t	NNP $CaCO_3$ kg/t	NP/AP	Rock Type NNP	Rock Type %S	Rock Type NP/AP
VBH-7M 18-26	4	7.6	-	-	0.566	17.688	15	-2.688	0.85	Uncertain	Rock Type I	Rock Type I
VBH-7M 30-32		7.4	-	-	0.167	5.219	6.25	1.031	1.2	Uncertain	Rock Type IV	Rock Type II
VBH-7M 34-35	2	7.9	-	-	0.756	23.625	65	41.375	2.75	Rock Type IV	Rock Type I	Rock Type III
VBH-7M 35-39	2	7.8	-	-	0.448	14	51.25	37.25	3.66	Rock Type IV	Rock Type I	Rock Type III
VBH-8M 7-11	4	3.9	-	-	2.101	65.656	0	-65.656	0	Rock Type I	Rock Type I	Rock Type I
VBH-8M 22-28	2	6.9	-	-	0.775	24.219	43	18.781	1.78	Uncertain	Rock Type I	Rock Type II
Pit S1 W SST A		4.44	-	-	0.01	0.31	0	-0.31	0	Uncertain	Rock Type IV	Rock Type I
Pit S1 W SST B		5.04	-	-	0.01	0.31	1.29	0.97	4.11	Uncertain	Rock Type IV	Rock Type IV
Pit S1 W SST C		5.18	-	-	0.01	0.31	0.01	-0.3	0.03	Uncertain	Rock Type IV	Rock Type I
Pit S1 Seam-4 Coal	4	4.4	-	-	1.84	57.5	0	-57.5	0	Rock Type I	Rock Type I	Rock Type I
Pit S2 SST		5.71	-	-	0.01	0.31	0	-0.31	0	Uncertain	Rock Type IV	Rock Type I
Pit S2 Seam-4 Coal	4	4.92	-	-	3.09	96.56	2.56	-94	0.03	Rock Type I	Rock Type I	Rock Type I
Pit S3 Interburden		5.5	-	-	0.07	2.19	6.64	4.45	3.04	Uncertain	Rock Type IV	Rock Type III
Pit S3 Mica SST		6.12	-	-	0.15	4.69	0.26	-4.42	0.06	Uncertain	Rock Type II	Rock Type I
Pit S4 WT SST A		5.26	-	-	0.01	0.31	0	-0.31	0	Uncertain	Rock Type IV	Rock Type I
Pit S4 WT SST B		5.31	-	-	0.01	0.31	0	-0.31	0	Uncertain	Rock Type IV	Rock Type I
Pit S4 Interburden		5.32	-	-	0.28	8.75	0	-8.75	0	Uncertain	Rock Type II	Rock Type I
Sample 1 (Low-grade Seam-4 Coal Stockpile)		4.13	-	-	2.16	67.5	0	-67.5	0	Rock Type I	Rock Type I	Rock Type I

Sample ID	*	Paste pH	Total %C	Sulphide %S	Total %S	AP $CaCO_3$ kg/t	NP $CaCO_3$ kg/t	NNP $CaCO_3$ kg/t	NP/AP	Rock Type NNP	Rock Type %S	Rock Type NP/AP
Sample 2 (Low-grade Seam-4 Coal Stockpile)		4.81	-	-	0.9	28.13	0	-28.13	0	Rock Type I	Rock Type I	Rock Type I
Sample 3 (Low-grade Seam-4 Coal Stockpile)		4.95	-	-	0.68	21.25	0	-21.25	0	Rock Type I	Rock Type I	Rock Type I
Sample 4 (Low-grade Seam-4 Coal Stockpile)		5.1	-	-	0.68	21.25	0	-21.25	0	Rock Type I	Rock Type I	Rock Type I
Sample 5 (Low-grade Seam-4 Coal Stockpile)		4.96	-	-	1.85	57.81	0	-57.81	0	Rock Type I	Rock Type I	Rock Type I
* Sandstone = Yellow, Purple = Carbonaceous shale, Coal = Black												

Table 11 Average Acid-base Accounting (ABA) results as per lithology

Year	Lithology	Number of samples	*	Paste pH	Total %C	Sulphide %S	Total %S	AP $CaCO_3$ kg/t	NP $CaCO_3$ kg/t	NNP $CaCO_3$ kg/t	NP/AP	Rock Type NNP	Rock Type %S	Rock Type NP/AP
2017	Sandstone	3		7.68	0.732	0.067	0.127	2.10	16.2	14.1	3.67	Uncertain	Rock Type IV	Rock Type III
	Carbonaceous shale	4		7.70	11.3	0.098	0.119	3.07	10.5	7.43	3.43	Uncertain	Rock Type IV	Rock Type III
	Coal	3		7.12	58.9	0.908	1.03	28.4	48.1	19.7	1.98	Uncertain	Rock Type I	Rock Type II
2013	Weathered sandstone (borehole)	7		6.59	-	-	0.012	0.362	0.357	-0.005	0.166	Uncertain	Rock Type IV	Rock Type I
	Weathered sandstone (Pit)	7		5.29	-	-	0.03	0.936	0.223	-0.713	0.6	Uncertain	Rock Type IV	Rock Type I
	Seam-4 coal (Pit)	2		4.66	-	-	2.46	77.0	1.28	-75.8	0.015	Rock Type I	Rock Type I	Rock Type I
	Low-grade Seam-4 coal stockpile	5		4.79	-	-	1.25	39.19	0.00	-39.19	0.00	Rock Type I	Rock Type I	Rock Type I
	Sandstone and shale (Borehole)	3		6.47	-	-	0.149	4.65	11.2	6.52	2.58	Uncertain	Rock Type III	Rock Type III
	Sandstone and shale (Pit)	2		5.41	-	-	0.175	5.47	3.32	-2.15	1.52	Uncertain	Rock Type III	Rock Type II

Year	Lithology	Number of samples	*	Paste pH	Total %C	Sulphide %S	Total %S	AP $CaCO_3$ kg/t	NP $CaCO_3$ kg/t	NNP $CaCO_3$ kg/t	NP/AP	Rock Type NNP	Rock Type %S	Rock Type NP/AP
	Carbonaceous shale	8		6.83	-	-	0.453	14.2	5.88	-8.28	0.941	Uncertain	Rock Type I	Rock Type I
	No 2/4 coal seam (Borehole)	15		6.55	-	-	0.848	26.5	16.2	-10.3	0.865	Uncertain	Rock Type I	Rock Type I
* Sandstone = Yellow, Purple = Carbonaceous shale, Coal = Black														

Table 12 Potential for various lithologies to generate acid drainage

Lithology	Number of samples	%S > 0.3	%S > 0.3	%S 0.1 - 0.3	%S 0.1 - 0.3	%S <0.1	%S <0.1
		NP/AP < 2	NP/AP > 2	NP/AP <2	NP/AP > 2	NP/AP < 2	NP/AP > 2
Sandstone (2017)	3	-	-	-	33%	66%	-
Sandstone (2013)	14	-	-	7%	-	86%	7%
Sandstone and shale (2013)	5	-	-	40%	20%	20%	20%
Carbonaceous shale (2017)	4	-	-	25%	25%	-	50%
Carbonaceous shale (2013)	8	38%	-	38%	12%	12%	-
Coal (2017)	3	66%	33%	-	-	-	-
Coal S4 (2013)	7	100%	-	-	-	-	-
Coal S2 (2013)	9	78%	22%	-	-	-	-
Low-grade Coal S4 (2013)	5	100%	-	-	-	-	-
Potential for acid mine drainage		Likely/possibly Acid generating. High salt load.	Medium potential for acid generation. Medium to high salt load.	Low to medium potential for acid generation. Low to medium salt load.	Very low potential for acid generation. Very low to low salt load.	No potential for acidic drainage. Very low/no salt load.	No potential for acidic drainage. Very low/no salt load.

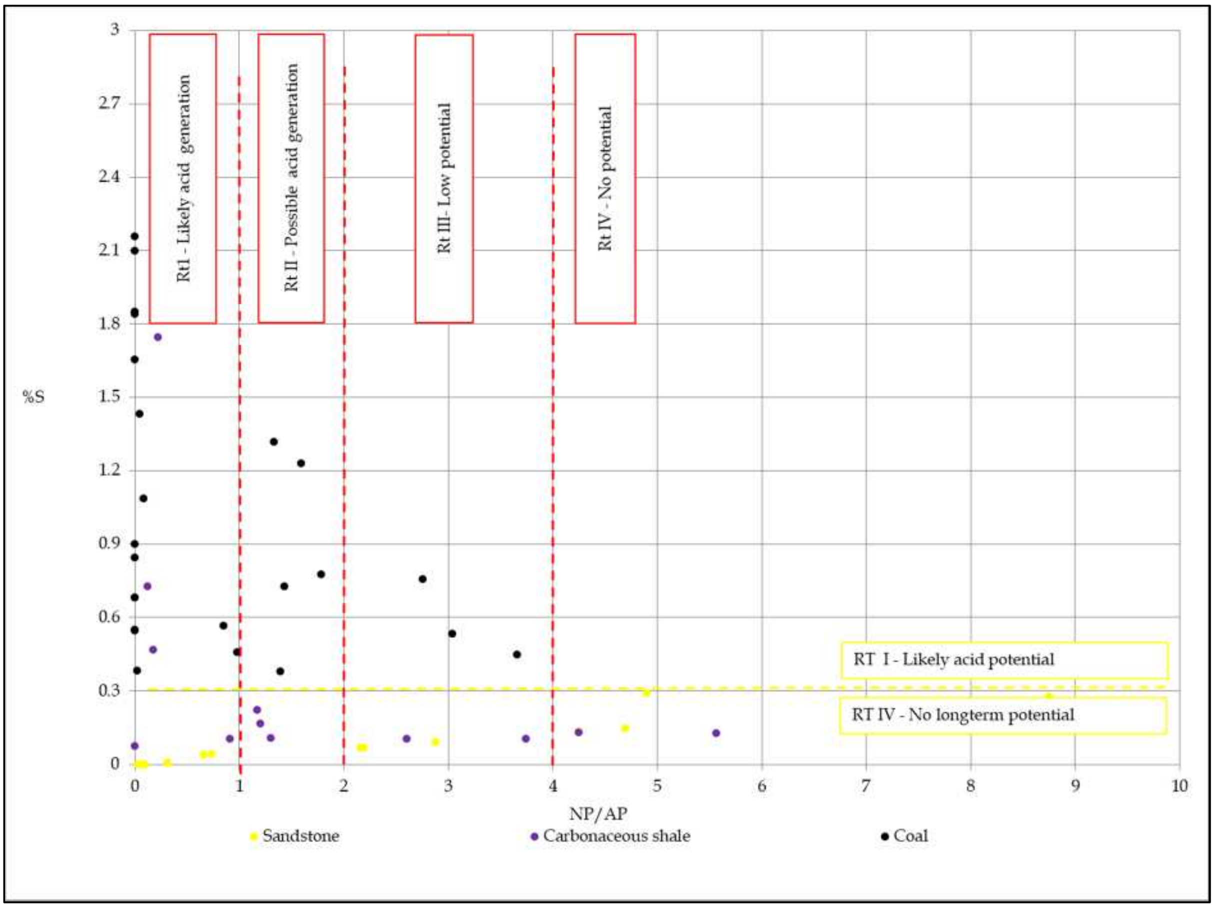

Figure 1 ***Classification of samples in terms of %S (samples below 3%) and NP/AP (samples below 10)***

Table 13 ***Net acid generation (NAG) test results***

Sample ID	*	NAG pH: (H_2O_2)	NAG (kg H_2SO_4/t)	NNP ($CaCO_3$ kg/t)	Rock Type
VVN16 – 010 14.73 – 15.29		3.54	1.61	-0.118	Rock Type Ib
VVN16 – 010 18.02 – 18.40		4.73	0.000	13.8	Rock Type IV
VVN16 – 010 21.03 – 21.41		2.63	12.7	0.991	Uncertain, possibly Ib.
VVN16 – 010 21.69 – 21.93		6.86	0.000	26.9	Rock Type IV
VVN16 – 010 21.93		2.72	19.1	12.9	Uncertain, possibly Ib.
VVN16 – 010 28.38 – 28.70		4.08	1.42	-0.353	Rock Type Ib
VVN16 – 010 18.15 – 18.85		4.31	0.943	10.5	Uncertain, possibly Ib
VVN16 – 010 18.95 – 19.35		7.79	0.000	42.7	Rock Type IV
VVN16 – 010 20.98 – 21.68		2.86	9.60	4.34	Rock Type Ib
VVN16 – 010 21.68 – 24.85		2.84	17.6	19.2	Uncertain, possibly Ib
VBH-4M 9-10m		2.9	10	-0.06	Rock Type Ib
VBH-4M11-17m		2	49	-42.75	Rock Type Ia
VBH-4M 18-20m		2.7	9	-3.56	Rock Type Ib
VBH-4M 22-24m		2.3	70	-12.16	Rock Type Ia
VBH-4M 24-26m		2.2	39	-17.19	Rock Type Ia
VBH-4M 26-30m		2.1	84	-26.44	Rock Type Ia

*** Sandstone = Yellow, Purple = Carbonaceous shale, Coal = Black**

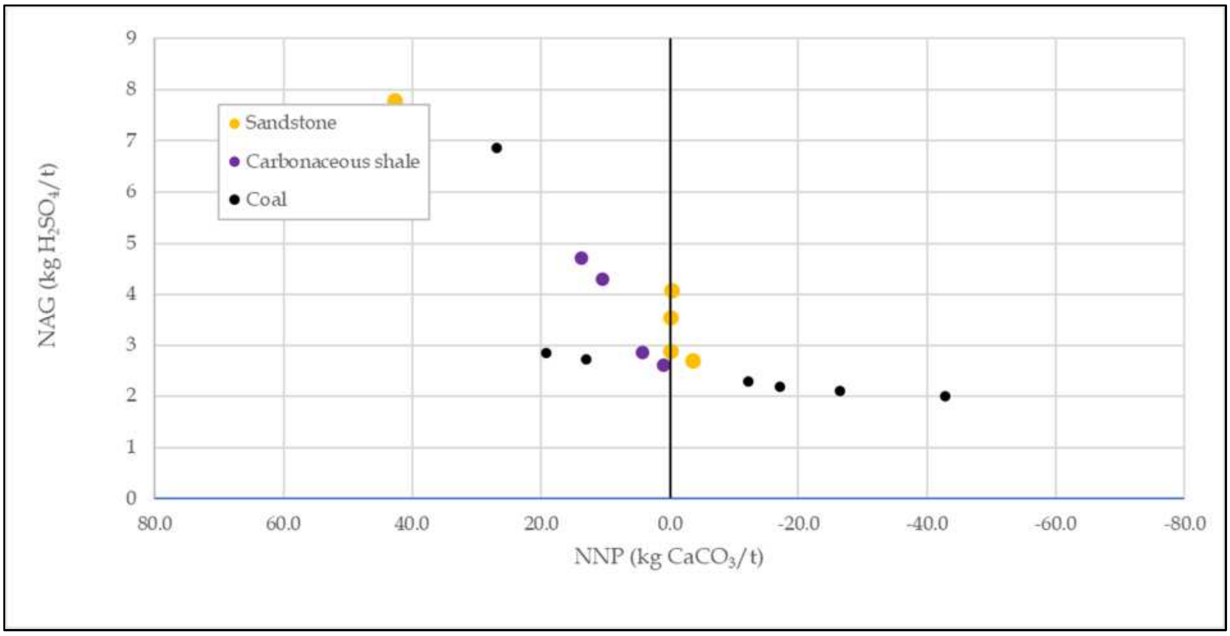

Figure 2 ***Correlation between the NAG values against the NNP***

3.3. Reagent Water Extraction

Introduction

Selected material was submitted for reagent water leach testing. System parameters and anions measured in the leachate are listed in Table 14. ICP-OES analytical results are listed in Table 15.

Methodology

The following pertains to the leaching test method used:

- The material was leached by reagent water extraction according to the AS 4439.3 method for mono-filled waste. A water to rock ratio of 1:20 was used where 100g of the waste sample was extracted with 2000mL of solution for 18h;
- Leaching tests identify the elements that will leach out of waste but do not reflect the site-specific concentration of these elements in actual seepage as a different water to rock ratio and contact time will be present in the field.

Test results

For leaching test results the following observations could be made:

VVN16 - 010 21.03 – 21.41 – (Carbonaceous shale): The pH was neutral and ammonia leached above the SANS drinking water standard. Fluoride leached at marginal levels but below the SANS drinking water standard. Pb leached at elevated concentrations above the SANS drinking water standard.

VVN16 - 010 21.93 (Coal): The pH was neutral and no anions leached at elevated levels. Al leached at marginally elevated levels but below the SANS drinking water standard.

VVN16 - 010 18.95 – 19.35 (Sandstone): The pH was neutral and ammonia and Al leached at marginally elevated concentrations below the SANS drinking water standard.

Conclusion: The static leach test indicates that the samples do not have any significant amount of highly soluble minerals. In a few instances did the anions, ammonia and fluoride, and the metals, Al and Pb, leached at slightly elevated concentrations from samples.

Table 14 System parameters and anions results of the reagent water leach

		Distilled water leach 1:20								
System Parameters	*****	**pH (Value)**	**EC (mS/m)**	**Sulphate as SO_4 (mg/L)**	**Total Alkalinity as $CaCO_3$ (mg/L)**	**Chloride as Cl (mg/L)**	**Orthophosphate as P (mg/L)**	**Nitrate as N (mg/L)**	**Ammonia as N (mg/L)**	**Fluoride as F (mg/L)**
VVN16 - 010 21.03 – 21.41		6.53	5.23	15	<10	<5	<0.2	<0.2	1.93	0.80
VVN16 - 010 21.93		7.46	43.0	137	68.3	10.9	<0.2	<0.2	0.45	0.30
VVN16 - 010 18.95 – 19.35		7.64	12.4	20	36.1	<5	<0.2	<0.2	1.21	0.33
SANS 241-1:2015	0-50% of limit	6 - 8.4	<85	<250	-	<150	-	<5.5	<0.75	<0.75
	50-100% of limit	5-6; 8.4-9.7	85-170	250-500	-	150-300	-	5.5-11	0.75 -1.5	0.75 -1.5
	Above limit	<5 ; >9.7	>170	>500	-	>300	-	>11	>1.5	>1.5

* Sandstone = Yellow, Purple = Carbonaceous shale, Coal = Black

Table 15 ICP-OES results of the reagent water leach (mg/L)

	Distilled water leach 1:20			SANS 241-1:2015		
Sample ID	**VVN16 – 010 21.03 – 21.41**	**VVN16 – 010 21.93**	**VVN16 – 010 18.95 – 19.35**	**0-50% of guideline**	**50-100% of guideline**	**Above guideline**
*						
Al	0.085	0.187	0.238	<0.15	0.15-0.3	>0.3
As	<0.01	<0.01	<0.01	<0.005	0.005-0.01	>0.01
B	0.084	0.115	0.014	<1.2	1.2-2.4	>2.4
Ba	0.027	0.127	0.044	<0.35	0.35-0.7	>0.7
Be	<0.01	<0.01	<0.01	-	-	-
Ca	0.00	0.0	0.0	-	-	-
Cd	<0.003	<0.003	<0.003	<0.0015	0.0015-0.003	>0.003
Co	<0.01	<0.01	<0.01	-	-	-
Cr	<0.01	<0.01	<0.01	<0.025	0.025-0.05	>0.05
Cu	0.043	0.036	0.027	<1	1-2	>2
Fe	<0.06	<0.06	<0.06	<1	1-2	>2
K	3.82	1.11	3.23	-	-	-
Mg	<1	7.66	2.75	-	-	-
Mn	<0.06	0.093	<0.06	<0.2	0.2-0.4	>0.4
Mo	<0.01	<0.01	0.012	-	-	-
Na	<1	<1	<1	<100	100-200	>200
Ni	<0.01	<0.01	<0.01	<0.035	0.035-0.07	>0.07
Pb	0.021	<0.01	<0.01	<0.005	0.005-0.01	>0.01
Sb	<0.02	<0.02	<0.02	<0.01	0.01-0.02	>0.02
Se	<0.02	<0.02	<0.02	<0.02	0.02-0.04	>0.04
Sr	0.036	0.615	0.121	-	-	-
V	0.016	<0.01	<0.01	-	-	-

	Distilled water leach 1:20			SANS 241-1:2015		
Sample ID	**VVN16 – 010 21.03 – 21.41**	**VVN16 – 010 21.93**	**VVN16 – 010 18.95 – 19.35**	**0-50% of guideline**	**50-100% of guideline**	**Above guideline**
*						
Zn	<0.01	<0.01	<0.01	<2.5	2.5-5.0	>5
*** Sandstone = Yellow, Purple = Carbonaceous shale, Coal = Black**						

3.4. Column leach tests

Introduction

Column leach testing was performed on a sandstone sample and two Seam-4 low-grade coal stockpile samples. The ABA and NAG test results of the samples are presented in Table 16. The system parameters, as well as anions measured in leachate from the column, is listed in Table 17 - 19. The ICP-OES results of the leachate are listed in Tables 20 - 22. Changes in the measured pH, EC and sulphate are depicted in Figure 3 - 5.

Methodology

The following pertains to the leaching test methodology:

- Leaching tests were performed on samples by *Metron Laboratory*, Vanderbijlpark;
- The sample was subjected to kinetic leach testing. A rock to water ratio of 2:1 was used where 1kg of the sample was leached with 500mL distilled water weekly. The leachate was analysed for major cations and anions as well as selected trace metal(loid)s;
- Kinetic column leaching test indicate the chemicals that will leach out from the rock material over time and gives an indication of the oxidation rate of the sulphide minerals in the material.

Test results

Sample 1 Seam-4 LG Stockpile: The sample was very carbonaceous with a high sulphide content. The pH was acidic over the entire leaching period. The EC and sulphate were elevated during the initial leach, and from Leach 11, above the SANS drinking water standard. The following metal(loid)s leached persistently from the column: Al, Fe, Mn, Ni, and Se.

Sample 2 Seam-4 LG Stockpile: The samples are carbonaceous with a high sulphide content. The pH was neutral during the initial leaches but became acidic after Leach 7. The EC and sulphate leached at low concentration for the duration of the leaching period. The following metals and metalloids leached at elevated concentrations during the leaches: Ni and Se.

Sandstone column: The sample was comprised of a carbonaceous sandstone VVN16 - 010 18.95 – 19.3 which was chosen for its slightly elevated sulphide content. The pH was below 7 during the initial leaches but more neutral for the duration of the leaching test. The EC, sulphate and ammonia were elevated during the initial leaches, but as leaching progressed, the concentrations lowered and reached more constant concentrations. The initial slightly acidic leachate with elevated sulphate is due to the leaching of secondary sulphate minerals from the rock. The following metals and metalloids leached at elevated concentrations during the initial leaches: Mn, Ni and Pb.

In summary, the column tests indicated that Al, Mn, Fe, Ni, Pb and Se may leach at elevated concentrations from the material under acidic conditions.

Table 16 The ABA and NAG results of the samples used in the columns

Sample	Sample 1 Seam-4 LG Stockpile	Sample 2 Seam-4 LG Stockpile	VVN16 – 010 18.95 – 19.35 (Sandstone)
Paste pH	4.1	4.8	7.97
Sulphide %S	-	-	0.157
Total % S	2.16	0.90	0.293
AP	67.37	28.28	4.9
NP	0.00	0.00	47.6
NNP	-67.37	-28.28	42.7
NP/AP	0.00	0.00	9.71
NAG	-	-	0.00
NAG pH	-	-	7.79

Table 17 Analyses of weekly leach from Sample 1 Seam-4 LG Stockpile

Sample 1 Seam-4 LG Stockpile				
System Parameters		**pH (Value)**	**EC (mS/m)**	**Sulphate as SO_4 (mg/L)**
Leach	**Days**			
0	0	3.25	94.72	245.42
1	7	3.82	61.97	131.11
2	14	4.02	39.53	34.01
3	21	3.71	45.04	49.42
4	28	3.58	36.98	23.81
5	35	3.47	39.25	43.32
6	42	3.31	45.28	36.63
7	49	3.27	50.02	51.31
8	56	3.26	48.93	72.88
9	63	3.16	61.75	95.72
10	70	3.05	82.43	135
11	77	2.75	141.02	377.52
12	84	2.59	144.65	347.61
13	91	2.59	147.98	371.54
14	98	2.58	147.31	358.78
15	105	2.54	158.28	397.05
16	112	2.6	144.21	432.94
17	119	2.55	160.16	498.73
18	126	2.46	194.55	484.77
19	133	2.4	166.16	698.09
20	140	2.46	157.93	463.64
21	147	2.39	192.74	477.6
22	154	2.48	153.46	434.93
23	161	2.43	209.41	457.66
24	168	3.08	188.11	488.76
25	175	2.5	207.76	584.45
26	182	2.46	181.23	444.1
27	189	2.46	186.11	490.35
28	196	2.43	161.61	422.57
	0-50% of limit	6 - 8.4	<85	<250
SANS 241-1:2015	50-100% of limit	5-6; 8.4-9.7	85-170	250-500
	Above limit	<5 ; >9.7	>170	>500

Table 18 Analyses of weekly leach from Sample 1 Seam-4 LG Stockpile

Sample 2 Seam-4 LG Stockpile				
System Parameters		**pH (Value)**	**EC (mS/m)**	**Sulphate as SO_4 (mg/L)**
Leach	**Days**			
0	0	6.76	23.78	72.66
1	7	6.27	25.68	69.13
2	14	6.06	17.2	37.4
3	21	6.25	23.47	56.84
4	28	5.66	19.34	46.75
5	35	6.56	20.26	54.54
6	42	5	21.08	48.67

Sample 2 Seam-4 LG Stockpile				
System Parameters		pH (Value)	EC (mS/m)	Sulphate as SO_4 (mg/L)
Leach	Days			
7	49	4.51	21.83	61.86
8	56	4.33	20.15	50.47
9	63	4.33	23.25	51.86
10	70	4.07	24.06	59.94
11	77	4.01	27.67	62.62
12	84	3.46	28.88	40.23
13	91	3.42	30.18	43.32
14	98	3.44	30.37	43.72
15	105	3.34	33.79	43.9
16	112	3.34	34.13	47.91
17	119	3.29	35.73	43.72
18	126	3.22	39.92	56.63
19	133	3.11	40.09	61.48
20	140	3.05	44.39	63.37
21	147	3.05	47.71	62.39
22	154	3.06	47.92	66.56
23	161	3.06	53.3	64.01
24	168	2.46	56.56	62.5
25	175	3.05	48.13	64.83
26	182	3.09	53.2	64.94
27	189	3.08	51.82	61.45
28	196	3.12	49.79	59.71
SANS 241-1:2015	0-50% of limit	6 - 8.4	<85	<250
	50-100% of limit	5-6; 8.4-9.7	85-170	250-500
	Above limit	<5 ; >9.7	>170	>500

Table 19 Analyses of weekly leach from VVN16 - 010 18.95 – 19.35 (Sandstone)

VVN16 - 010 18.95 – 19.35 (Sandstone)										
System Parameters		pH (Value)	EC (mS/m)	Sulphate as SO_4 (mg/L)	Total Alkalinity as $CaCO_3$(mg/L)	Chloride as Cl (mg/L)	Orthophosphate as P (mg/L)	Nitrate as N (mg/L)	Ammonia as N (mg/L)	Fluoride as F (mg/L)
Leach	Days									
0	0	6.68	137.7	808	10.8	7.3	<0.2	0.46	1.05	0.29
1	7	7.15	85.3	427	11.2	<5	<0.2	0.21	0.58	0.28
2	14	6.72	52.7	231	<10	<5	<0.2	<0.2	0.41	0.25
3	21	6.92	40.0	148	14.5	<5	<0.2	<0.2	0.34	0.24
4	28	7.48	52.7	-	31.0	<5	<0.2	<0.2	0.31	0.57
5	35	7.60	41.8	-	42.0	<5	<0.2	-	<0.2	0.44
6	42	7.68	32.0	124	42.3	<5	<0.2	-	<0.2	0.52
7	49	7.67	27.9	-	50.2	<5	<0.2	-	<0.2	0.31
8	56	7.29	24.3	-	50.5	<5	<0.2	-	<0.2	0.31
9	63	7.27	19.7	-	48.5	<5	<0.2	-	<0.2	0.21
10	70	7.45	18.6	44.0	41.5	<5	<0.2	-	<0.2	0.23
11	77	7.49	25.3	-	68.4	<5	<0.2	-	<0.2	0.46
12	84	7.18	16.8	-	47.2	-	-	-	-	0.29
13	91	7.43	17.6	-	51.3	-	-	-	-	0.25
14	98	7.01	13.9	-	38.4	-	-	-	-	0.15
15	105	7.44	13.7	29.2	37.8	-	-	-	-	0.13
16	112	7.62	13.2	-	25.2	-	-	-	-	0.13
17	119	7.86	12.5	-	40.6	-	-	-	-	0.13
18	126	7.78	12.3	-	36.5	-	-	-	-	0.15
19	133	6.89	12.0	-	47.2	-	-	-	-	0.11
20	140	8.04	12.9	35.8	<10	-	-	-	-	<0.1
21	147	8.06	12.0	-	25.3	-	-	-	-	0.00
SANS 241-1:2015	0-50% of limit	6 - 8.4	<85	<250	-	<150	-	<5.5	<0.75	<0.75
	50-100% of limit	5-6; 8.4-9.7	85-170	250-500	-	150-300	-	5.5-11	0.75 -1.5	0.75 -1.5

VVN16 - 010 18.95 – 19.35 (Sandstone)										
System Parameters		**pH (Value)**	**EC (mS/m)**	**Sulphate as SO_4 (mg/L)**	**Total Alkalinity as $CaCO_3$(mg/L)**	**Chloride asCl (mg/L)**	**Orthophosphate as P (mg/L)**	**Nitrate as N (mg/L)**	**Ammonia as N (mg/L)**	**Fluoride as F (mg/L)**
Leach	**Days**									
	Above limit	<5 ; >9.7	>170	>500	-	>300	-	>11	>1.5	>1.5

Table 20 ICP-OES results of leachate from the Sample 1 Seam-4 LG Stockpile

Parameters (mg/L)	Sample 1 Seam-4 LG Stockpile								SANS 241:2015		
	Leach	0	1	2	3	6	10	14	0-50% of limit	50%-100% of limit	Above limit
	Days	0	7	14	21	42	70	98			
Al		0.763	0.43	0.25	0.29	0.29	0.66	2.42	<0.15	0.15-0.3	>0.3
As		<0.010	<0.010	<0.010	0.02	<0.010	<0.010	<0.010	<0.005	0.005-001	>0.01
B		1.81	0.82	0.54	0.37	0.22	0.15	0.06	<1.2	1.2-2.4	>2.4
Ba		0.17	0.27	0.08	0.15	0.08	0.08	0.03	<0.35	0.35-0.7	>0.7
Be		<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	-	-	-
Ca		80	52	30	37	28	31	14	-	-	-
Cd		<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.0015	0.0015-0.003	>0.003
Co		0.62	0.31	0.16	0.22	0.19	0.27	0.12	-	-	-
Cr		<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	0.025-0.05	>0.05
Cu		0.22	0.06	0.08	0.09	0.22	1.19	1.35	<1	01 Feb	>2
Fe		15	1.41	1.38	0.56	0.57	1.44	46	<1	01 Feb	>2
K		18.4	13.9	9.8	9.6	6.8	4.1	1.1	-	-	-
Mg		19	17	9	11	8	8	3	-	-	-
Mn		0.56	0.42	0.23	0.3	0.24	0.27	0.19	<0.2	0.2-0.4	>0.4
Mo		<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	-	-	-
Na		3	2	<2	<2	<2	<2	<2	<100	100-200	>200
Ni		1.29	0.59	0.45	0.61	0.56	0.85	0.48	<0.035	0.035-0.07	>0.07
Pb		<0.020	<0.020	<0.020	<0.020	<0.020	0.02	0.03	<0.005	0.005-0.1	>0.01
Sb		<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.01	<0.01	0.01-0.02	>0.02
Se		0.03	0.03	<0.020	<0.020	<0.020	<0.020	<0.020	<0.02	0.02-0.04	>0.04
Sr		0.4	0.29	0.16	0.18	0.15	0.17	0.09	-	-	-
V		<0.025	<0.025	<0.025	0.03	<0.025	<0.025	<0.025			
Zn		0.5	0.34	0.17	0.43	0.66	2.03	1.31	<2.5	2.5-5.0	>5
Bi		<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	-	-	-
Li		0.28	0.17	0.09	0.07	0.04	<0.025	<0.025	-	-	-
P		0.06	0.04	0.04	0.08	0.04	<0.025	<0.025	-	-	-
S		147	107	57	69	55	80	93	-	-	-
Si		2.6	4.1	2.4	3.2	2.2	2.4	1.6	-	-	-
Sn		<0.025	0.05	<0.025	0.04	0.03	<0.025	<0.025	-	-	-
Ti		<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	-	-	-
W		<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	-	-	-
Ag		<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	-	-	-
Zr		<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	-	-	-

Table 21 ICP-OES results of leachate from the Sample 2 Seam-4 LG Stockpile column

Sample 2 Seam-4 LG Stockpile									SANS 241:2015		
Parameters (mg/L)	Leach	0	1	2	3	6	10	14	0-50% of limit	50%-100% of limit	Above limit
	Days	0	7	14	21	42	70	98			
Ca		14	14	10	15	14	15	14	-	-	-
Mg		8	8	5	7	7	7	6	-	-	-
Na		2	2	<2	<2	<2	<2	<2	<100	100-200	>200
K		10.5	9.7	7.1	7.7	6	4.9	3	-	-	-
Al		<0.100	<0.100	<0.100	<0.100	<0.100	0.1	0.2	<0.15	0.15-0.3	>0.3
Fe		0.11	0.04	0.07	0.12	0.14	0.08	1.81	<1	01 Feb	>2
Mn		0.13	0.15	0.09	0.12	0.12	0.17	0.13	<0.25	0.25-0.5	>0.5
As		<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.005	0.005-0.01	>0.01
B		1.05	0.74	0.45	0.32	0.21	0.17	0.14	-	-	-
Ba		0.1	0.08	0.05	0.05	0.05	0.09	0.04	-	-	-
Be		<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	-	-	-
Bi		<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	-	-	-
Cd		<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.0015	0.0015-0.003	>0.003
Cr		<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	0.025-0.05	>0.05
Co		0.07	0.06	0.04	0.06	0.06	0.09	0.08	<0.25	0.25-0.5	>0.5
Cu		<0.025	<0.025	0.04	0.03	0.04	0.09	0.35	<1	01 Feb	>2
Li		0.17	0.12	0.07	0.06	0.03	<0.025	<0.025	-	-	-
P		0.04	0.05	0.06	0.07	0.05	0.09	<0.025	-	-	-
Pb		<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	0.04	<0.005	0.005-0.1	>0.01
Mo		<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	-	-	-
Ni		0.21	0.19	0.15	0.24	0.21	0.37	0.53	<0.035	0.035-0.07	>0.07
S		37	42	25	35	29	33	37	-	-	-
Sb		<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.01	0.01-0.02	>0.02
Se		0.02	0.03	<0.020	<0.020	<0.020	<0.020	<0.020	<0.005	0.005-0.01	>0.01
Si		1.3	2.3	1.4	1.8	1.4	1.3	2	-	-	-
Sr		0.12	0.13	0.08	0.12	0.11	0.12	0.12	-	-	-
Sn		0.04	0.06	0.06	0.05	0.07	0.03	<0.025	-	-	-
V		<0.025	0.03	<0.025	0.03	<0.025	<0.025	<0.025	<0.2	0.1-0.2	>0.2
W		<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	-	-	-
Zn		0.15	0.1	0.16	0.13	0.18	0.38	0.86	<2.5	2.5-5.0	>5
Zr		<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	-	-	-

Table 22 ICP-OES results of leachate from the VVN16 - 010 18.95 – 19.35 column

VVN16 - 010 18.95 – 19.35 (Sandstone)										SANS 241-1:2015		
Parameters (mg/L)	Leach	0	1	2	3	6	10	15	20	0-50% of guideline	50%-100% of guideline	Above guideline
	Days	0	1	2	3	15	42	77	112			
Al		<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.15	0.15-0.3	>0.3

VVN16 - 010 18.95 – 19.35 (Sandstone)										SANS 241-1:2015		
Parameters	**Leach**	**0**	**1**	**2**	**3**	**6**	**10**	**15**	**20**	**0-50% of guideline**	**50%-100% of guideline**	**Above guideline**
(mg/L)	**Days**	**0**	**1**	**2**	**3**	**15**	**42**	**77**	**112**			
As		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.005	0.005-0.01	>0.01
B		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<1.2	1.2-2.4	>2.4
Ba		0.056	0.053	0.058	0.043	0.035	0.035	0.036	0.028	<0.35	0.35-0.7	>0.7
Be		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-
Ca		212	94.9	78.2	44.7	35.2	23.7	21.1	16.3	-	-	-
Cd		<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.0015	0.0015-0.003	>0.003
Co		1.54	0.453	0.177	0.095	0.028	<0.01	<0.01	0.013	-	-	-
Cr		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.025	0.025-0.05	>0.05
Cu		<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<1	1-2	>2
Fe		<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	2.08	<1	1-2	>2
K		6.66	3.34	3.87	2.12	1.59	<1	<1	<1	-	-	-
Mg		63.6	36.3	27.8	15.3	9.53	6.72	6.22	5.35	-	-	-
Mn		3.36	1.27	0.659	0.394	0.211	0.089	<0.06	0.133	<0.25	0.25-0.5	>0.5
Mo		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-
Na		2.34	1.07	1.10	<1	1.25	<1	<1	<1	<100	100-200	>200
Ni		2.14	0.656	0.332	0.189	0.066	<0.01	<0.01	<0.01	<0.035	0.035-0.07	>0.07
Pb		<0.01	<0.01	0.022	<0.01	<0.01	<0.01	<0.01	<0.01	<0.005	0.005-0.01	>0.01
Sb		<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.01	0.01-0.02	>0.02
Se		0.026	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.02-0.04	>0.04
Sr		0.796	0.496	0.356	0.262	0.263	0.167	0.136	0.123	-	-	-
V		0.015	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-
Zn		0.821	0.222	0.118	0.069	0.099	0.038	0.017	0.032	<2.5	2.5-5.0	>5

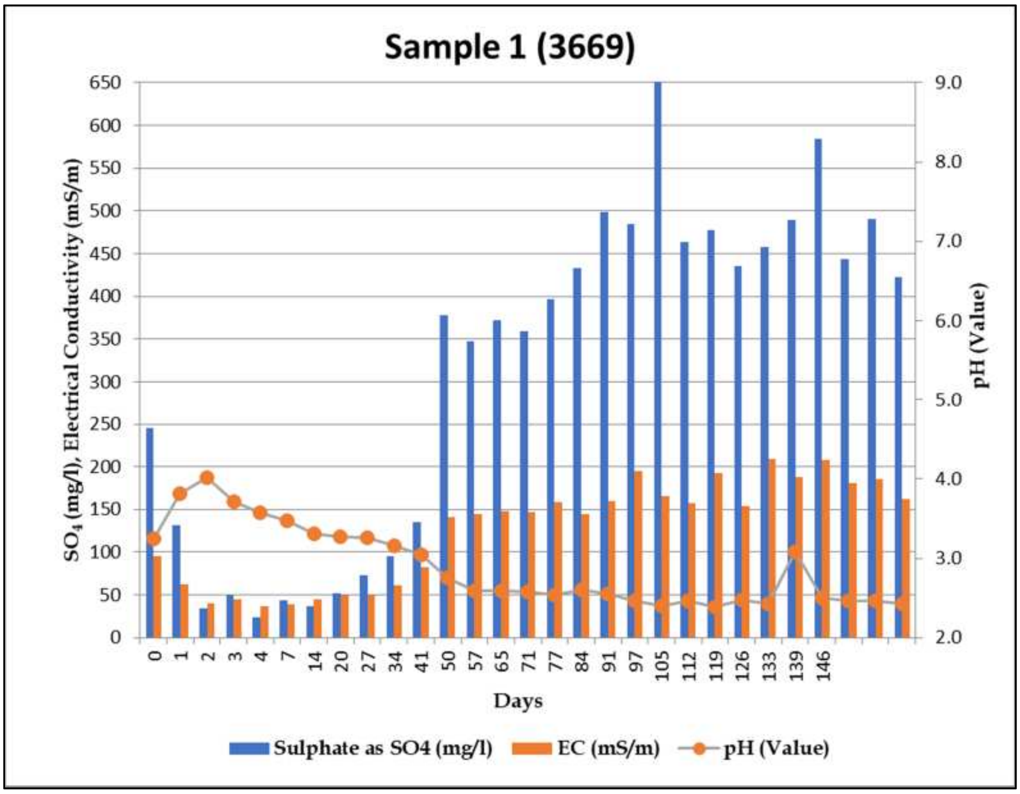

Figure 3 *Seam-4 LG Sample1: Changes in measured pH, EC and sulphate*

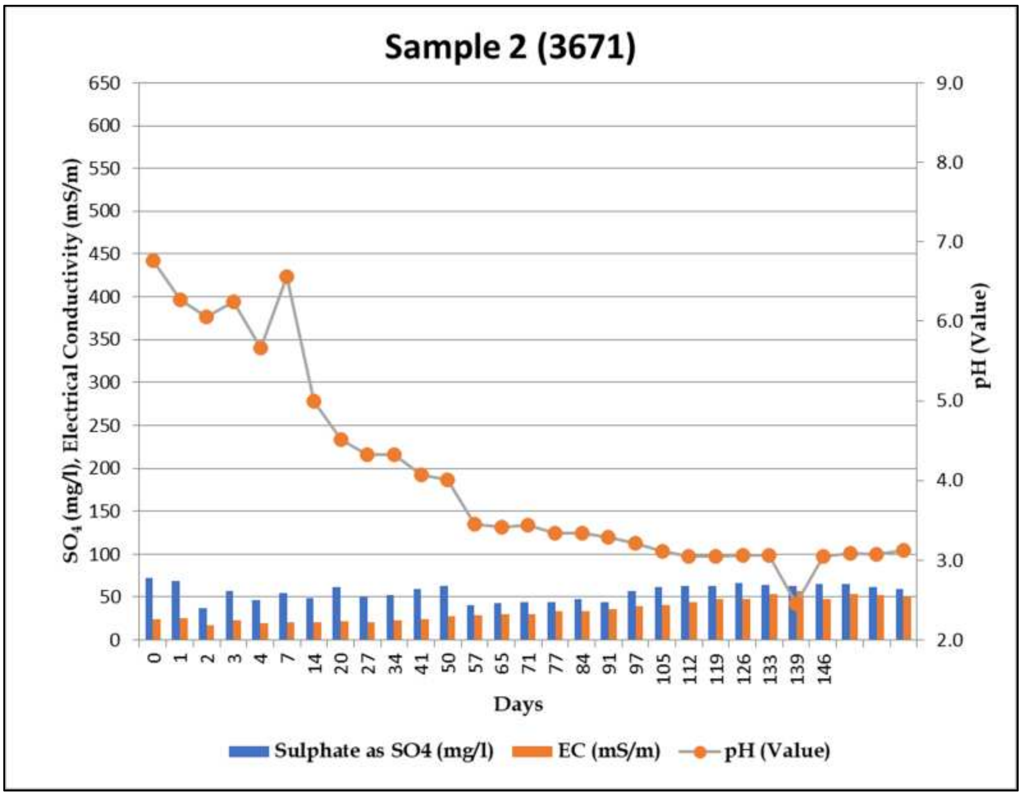

Figure 4 *Seam-4 LG Sample2: Changes in measured pH, EC and sulphate*

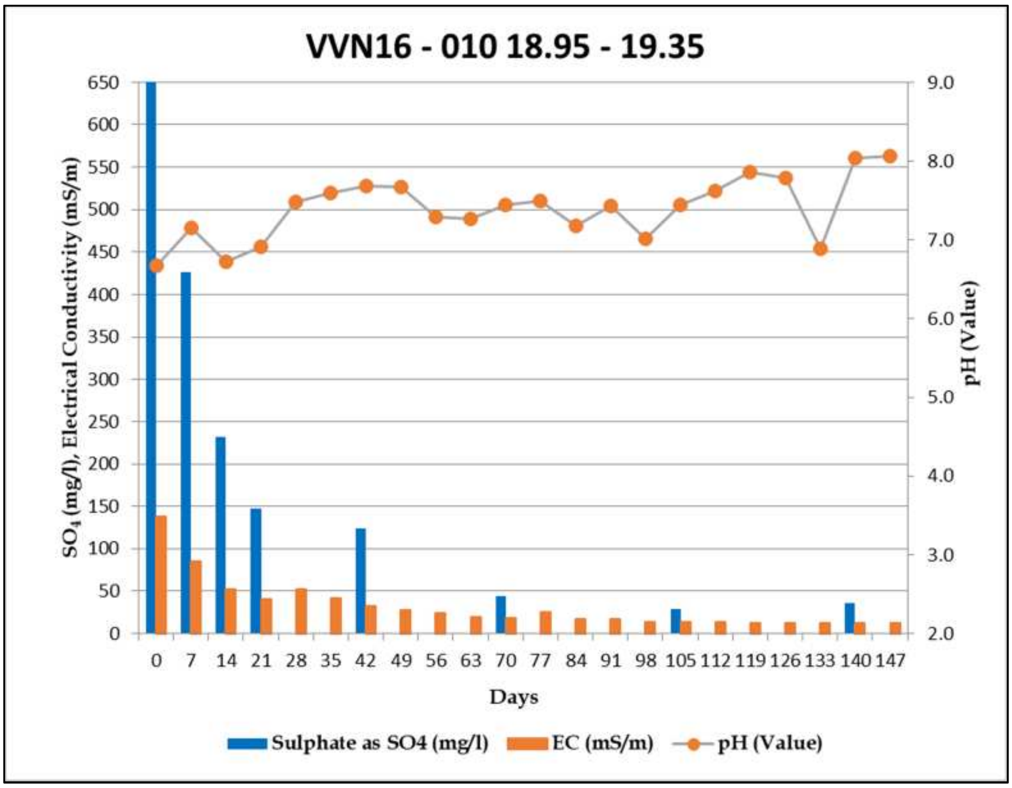

Figure 5 *Sandstone: Changes in measured pH, EC and sulphate*

4. CONCEPTUAL GEOCHEMICAL MODEL

4.1. Mine drainage classification

In general, drainage from disturbed geological material at mines is classified into three types: acid-mine drainage (AMD), saline mine drainage (SMD) and neutral mine drainage (NMD). AMD occurs when a significant degree of pyrite oxidation is present with inadequate neutralisation by other (especially carbonate) minerals in the waste rock. Drainage pH typically has a pH below 5.5-6, often with a high to very high saline drainage. SMD results also from significant sulphide oxidation but a significant carbonate content is present in the rock to maintain circumneutral conditions. Drainage typically has a pH above 5.5-6 with a medium to high saline and metal load. Some metals with amphoteric behaviour may however still be elevated in mine drainage. With NMD low or no sulphide oxidation occur and adequate carbonate minerals are present in the rock to maintain circumneutral drainage. Drainage typically has a pH above pH 5.5-6 with a low saline and a no/low metal load. Some metals with amphoteric behaviour may however still be present.

In Figure 6 the different fields for mine drainage are plotted on a TDS vs. pH diagram. Acid-mine drainage is present below pH 5.5-6 and saline and neutral mine drainage above that. The boundary between fresh and saline water is arbitrary and the US Geological Survey reports the boundary at a TDS concentration of 1000mg/L.

The impact on drainage at a mine depends on the interaction of solid, water and air phases. The drainage quality is a function of the dissolution and reactivity of the minerals, the relative degree of acidification and neutralisation, and the interaction of minerals with oxygen and water.

Disturbed geological material with a high pyrite content (that is also in contact with oxygen) will typically generate a high sulphate load. Whether the drainage will be acidic or saline depends on the presence of enough neutralisation minerals. However, if the mining area is sealed off from the atmosphere (e.g. through flooding) before acidification occurs, then no oxygen ingress is possible with no resultant oxidation of sulphides - the mine will then produce saline or neutral mine drainage.

Disturbed geological material with no pyrite content will usually generate neutral drainage. However, a few amphoteric metals may still form soluble complexes and can potentially still leach from geological materials even under neutral conditions, e.g. Al, Cd, Cr, U.

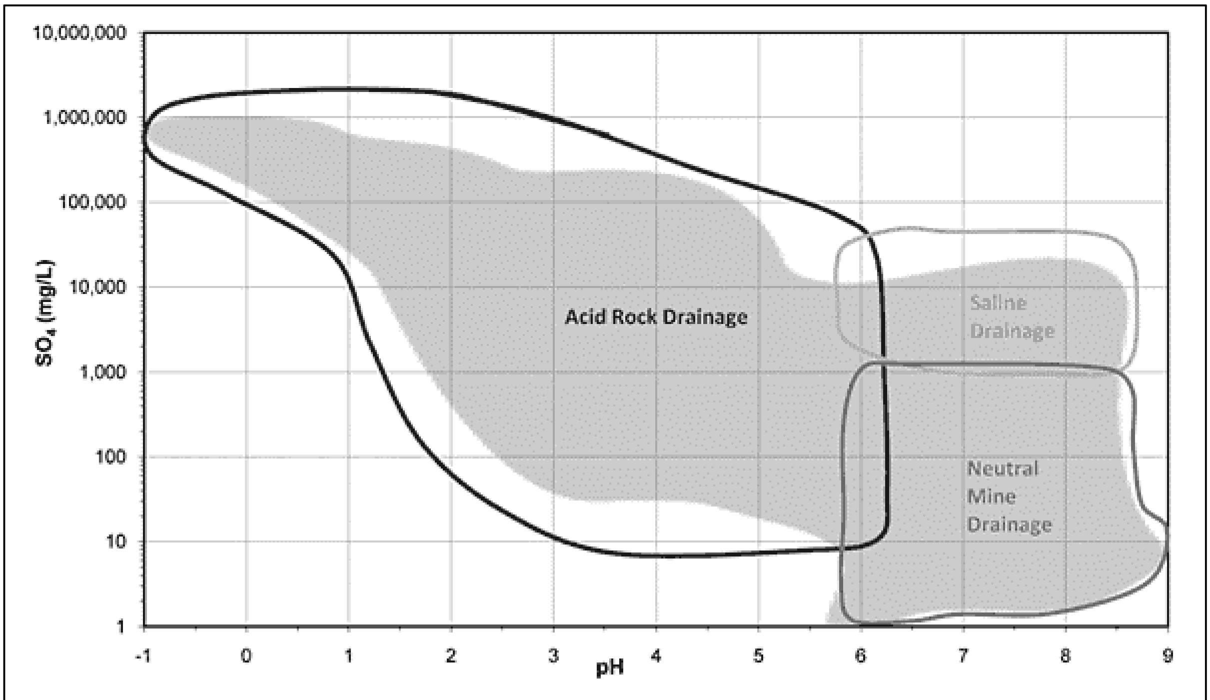

Figure 6 ***Diagram showing mine drainage as a function of pH and TDS (INAP, 2009 adapted from PlumLee, 1999)***

4.2. Impact mechanism

During the operational phase, water is pumped from the opencast pit in order to keep the pit dry. The pumped-out water has a low residence time in the pit (short contact period with rock) and acidification will not necessarily occur during the operational phase. After closure, the mine water level will rise as pumping cease. The waste rock in the pit above the long-term pit water elevation will be unsaturated. Pyrite oxidation will occur in the unsaturated zone as a result of oxygen infiltration.

A conceptual model of the physic-chemical processes that occur in mining waste in contact with the atmosphere is depicted in Figure 7. Oxidation of pyrite will result in a gradient in the oxygen fugacity in the backfill material that will initiates oxygen diffusion (flow from high concentration to low concentration). The oxygen concentration will be at its highest at the top but will become depleted within only a few meters. The oxidation zone will shift deeper into the material as sulphide minerals become depleted. The temperature in the material will eventually rise due to the oxidation of sulphides. Temperature differences will result in differences in gas pressure that initiate the process of oxygen advection.

The mine material will consist of a solid, water and gas phase. Without one of these phases, no acid-mine drainage (AMD) production are possible. The waste rock material (solid phase) is the reactive part of the three phases and contains sulphide minerals that react spontaneously with oxygen and water. Upon oxidation, pyrite will react with the infiltrating oxygen and water to produce Fe^{3+}, SO_4^{2-} and acidity:

$$\text{pyrite} + 3.5H_2O + 3.75O_{2(aq)} \Rightarrow Fe(OH)_{3(ppd)} + 2SO_4^{2-} + 4H^+$$

Water serves as the transport medium for the products of AMD as it percolates through the waste material. The water phase also serves as the medium in which dissolution of neutralizing minerals can take place. The acid produced by the pyrite will be consumed by calcite (and/or dolomite) if present in the rock:

$$\text{calcite} + 2H^+ \Rightarrow Ca^{2+} + CO_{2(g)} + H_2O$$

The Ca^{2+} and SO_4 produced will form gypsum and the above equations could be rewritten as follows:

$$\text{pyrite} + 2\text{calcite} + 5.5H_2O + 3.75O_{2(aq)} \Rightarrow Fe(OH)_{3(ppd)} + 2\text{gypsum} + 2CO_{2(g)}$$

If all the carbonate minerals (generally, calcite and dolomite in the Vryheid Formation) are depleted, the seepage from the material becomes acidic. Silicate minerals can also consume some of the acidity. However, silicate minerals react too slowly to prevent acidification in a material with a significant potential to generate acidic drainage. In acidic seepage, metals will also be leached out at elevated concentrations and the final stage of AMD would have been reached.

An important aspect in the environmental geochemical modelling of a mine is, therefore, to determine whether enough neutralization minerals exists and if not when it will become depleted. It is not possible to determine the timescale for these mineral reactions from the laboratory tests. Even with leach tests neutralization minerals are often not depleted and the tests also do not have the same rock/water/gas ratio than the backfilled material in the mining pit. Numerical kinetic modelling provides the only possible means to model the rock, water and gas phases and to add a time scale to the problem.

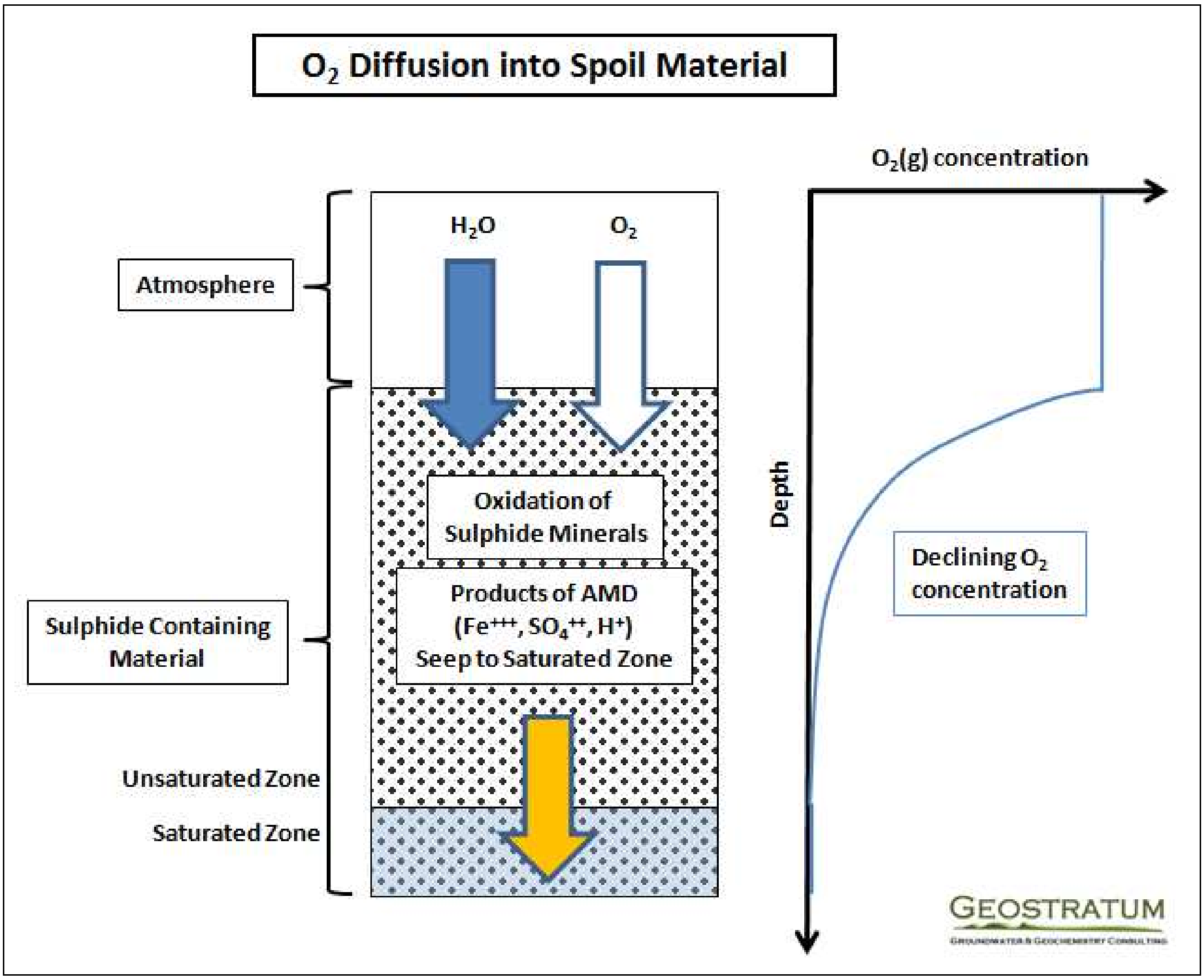

Figure 7 Conceptual model of the physico-chemical processes in mine backfill

5. GEOCHEMICAL MODEL

5.1. Introduction

The objective of the geochemical modelling was to estimate the mine water quality for the Vlakvarkfontein Mine. Analytical results cannot be used directly to establish the changes in the leachate quality from a mine over time. Due to the complexity of the interaction between the solid, water and gas phases, numerical modelling was used to predict the most important parameters of expected Acid Mine Drainage (AMD).

5.2. Model code

The oxygen diffusion into the backfill was modelled using a MATLAB version of PYROX. The code models 1) the diffusion of oxygen through the unsaturated zone, 2) the oxygen consumed by mineral oxidation, and 3) the subsequent sulphate, iron and acidity production.

The interaction between the mineral-, water- and the gas phases was modelled using the Geochemist's Workbench Professional. The Geochemist's Workbench is a set of interactive software tools for solving problems in aqueous geochemistry. This model solves the hydro-chemical and mineral reactions with the equilibrium model as well as the kinetic rate law for mineral dissolution.

5.3. Model scenarios

Four models were compiled as summarized in Table 23. In Model A the long-term leachate quality from the waste rock with the average composition was modelled. In Model B discard was placed at the bottom of the pit, at least more than 10m below the decant elevation. In both models Scenario 1 and 2 simulated the long-term leachate concentrations at an unsaturated zone depth of 3.5m and 15.5m respectively. In Model C Scenario 1 and 2, the seepage quality from a 20m and 30m discard dump was respectively modelled.

35.5% of the clastic waste rocks have a moderate sulphide content and have a low to medium potential to generate acidic drainage. The neutralisation potential of the non-acid generating rock is however not sufficient to prevent significant acidification of the backfill situated within the oxic zone.

Table 23 Description of geochemical model scenarios

Model Scenario	Material	Selected properties
Model A Scenario 1	Average waste rock backfill @ 3.5m. Discard/slurry backfill: None.	Waste rock %S = 0.165
Model A Scenario 2	Average waste rock backfill @ 15.5m. Discard/slurry backfill: None.	Waste rock %S = 0.165
Model B Scenario 1	Average waste rock backfill @ 3.5m. Discard/slurry backfill: The lower 3m of the pit.	Waste rock %S = 0.165 Discard %S = 4.23.
Model B Scenario 2	Average waste rock backfill @ 15.5m. Discard/slurry backfill: The lower 3m of the pit.	Waste rock %S = 0.165 Discard %S = 4.23
Model C Scenario 1	20m discard dump	Discard %S = 4.23
Model C Scenario 2	30m discard dump	Discard %S = 4.23

5.4. Model input

Modelling parameters are summarized in Table 24 and 25. The following comments relate to the model input and related assumptions:

Physical model parameters

- The average pit depth is 20.5m. In Scenario 1 and 2 the unsaturated zone was present down to 3.5m and 15.5m respectively (which presents the average and maximum unsaturated zone depths of the pit);
- Recharge into the backfill was taken at 18% of MAR based on Hodgson and Krantz (1998).

Mineral content

- Several of the input used for the model are based upon test work performed in this study. The samples tested for this study were therefore assumed to be representative of the backfilled waste rock;
- The assigned mineral content of the models is given in Table 26;
- The silicate mineral composition was based on the XRD results performed;
- The carbonate mineral content was calculated from 50% of the NP values;
- The pyrite content was calculated from the sulphide %S, assuming that pyrite is the only sulphide present. Pyrite is also one of the sulphides with the highest acid generation potential;
- The sulphate mineral content of the discard was calculated from the measured sulphate %S.

Table 24 Summary of physical model constraints

Parameters	Model A and B Pit models	Model C Discard dump
Model type	1 D	1 D
Unsaturated zone depth	0 – 3.5m	0 - 30m
Saturated zone depth	3.5 – 20.5 m	-
Area	1m^2	1m^2
Flux (m/a)	124	124
Matrix volume	70%	70%
Moisture content	10% unsaturated zone 30% saturated zone	10% unsaturated zone
Air filled porosity	20% unsaturated zone 0% saturated zone	20% unsaturated zone

Table 25 Assigned mineral content in model (wt %)

Parameter	Average backfill	Discard
Kaolinite	19.2	25.4
Microcline	8.2	1.1
Muscovite	3.4	4.1
Quartz	64.9	6.73
Siderite	1.9	0.5
Smectite	0.2	0.2
Coal	2.2	61.9
Parameter	Weighted Average Waste rock	Discard
Pyrite as %S	0.137	2.72
Sulphate as %S	0.027	0.37
Carbonate as NP $CaCO_3$ kg/t	2.68	48.1

5.5. Geochemical model results

The change in the modelled pit water quality in Model A – B is depicted in Figure 8 and 9 respectively. The change in the discard dump seepage water quality as modelled in Model C is depicted in Figure 10.

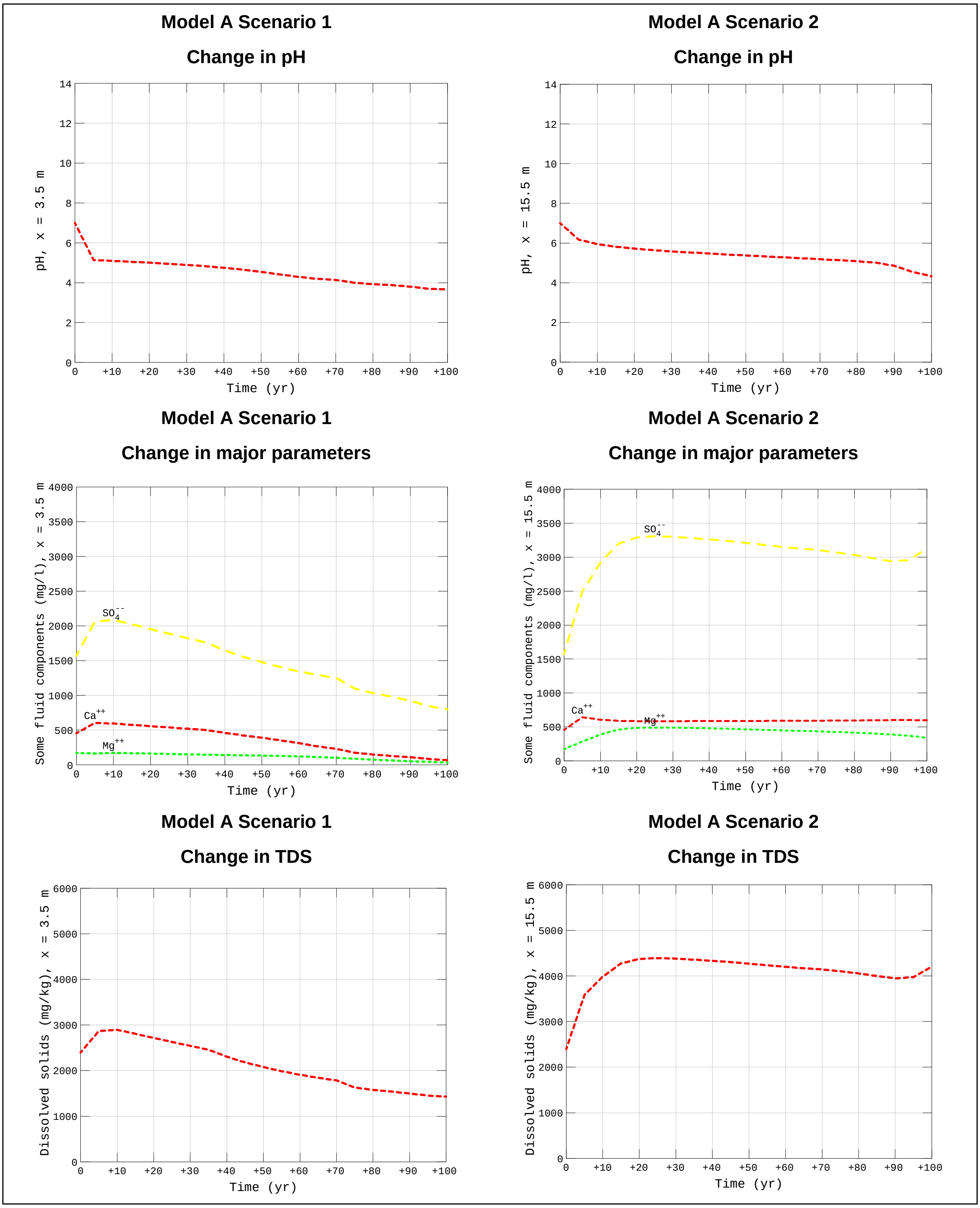

Figure 8 ***Model A Scenario 1 & 2: Changes in pit water quality over model time***

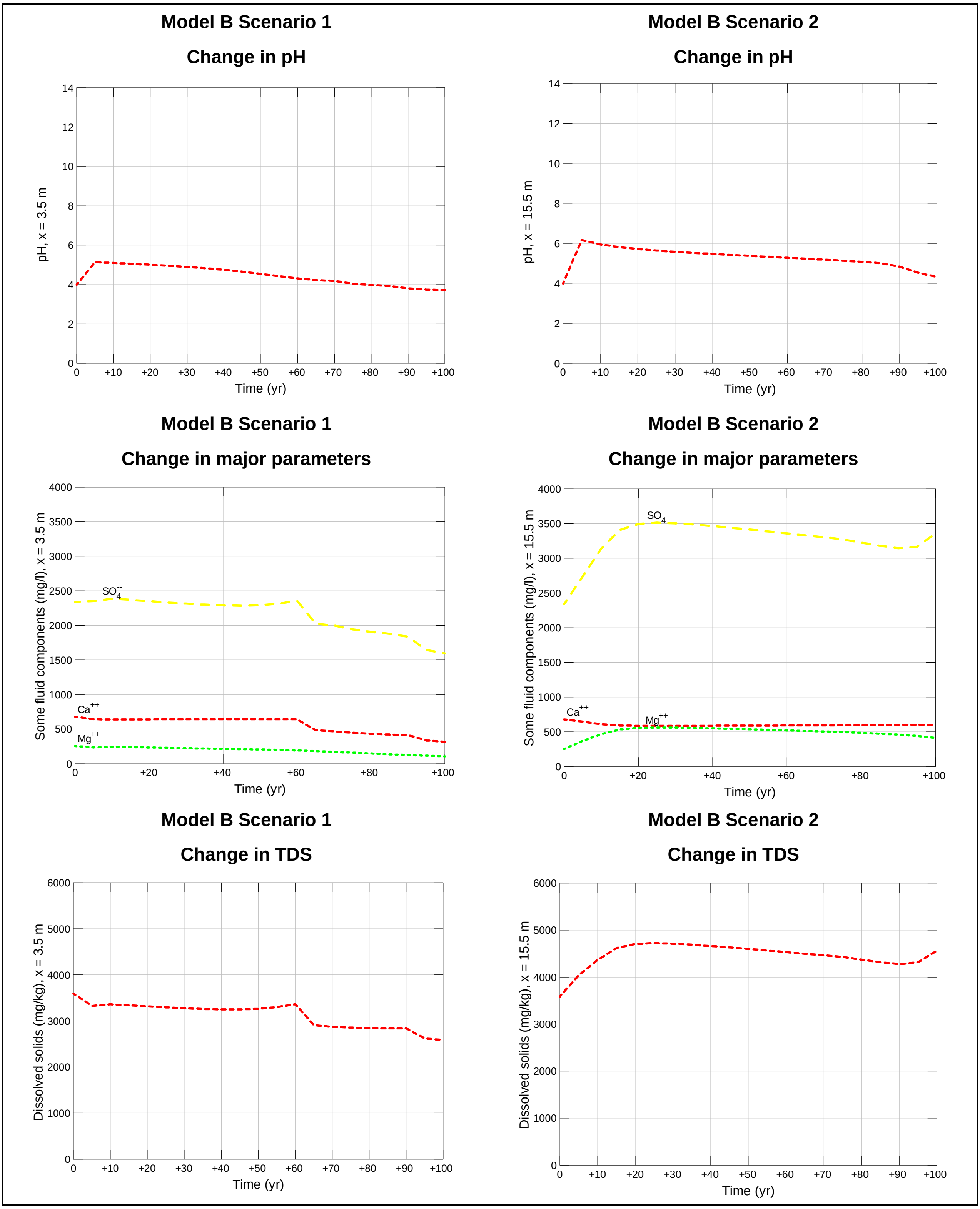

Figure 9 Model B Scenario 1 & 2: Changes in pit water quality over model time

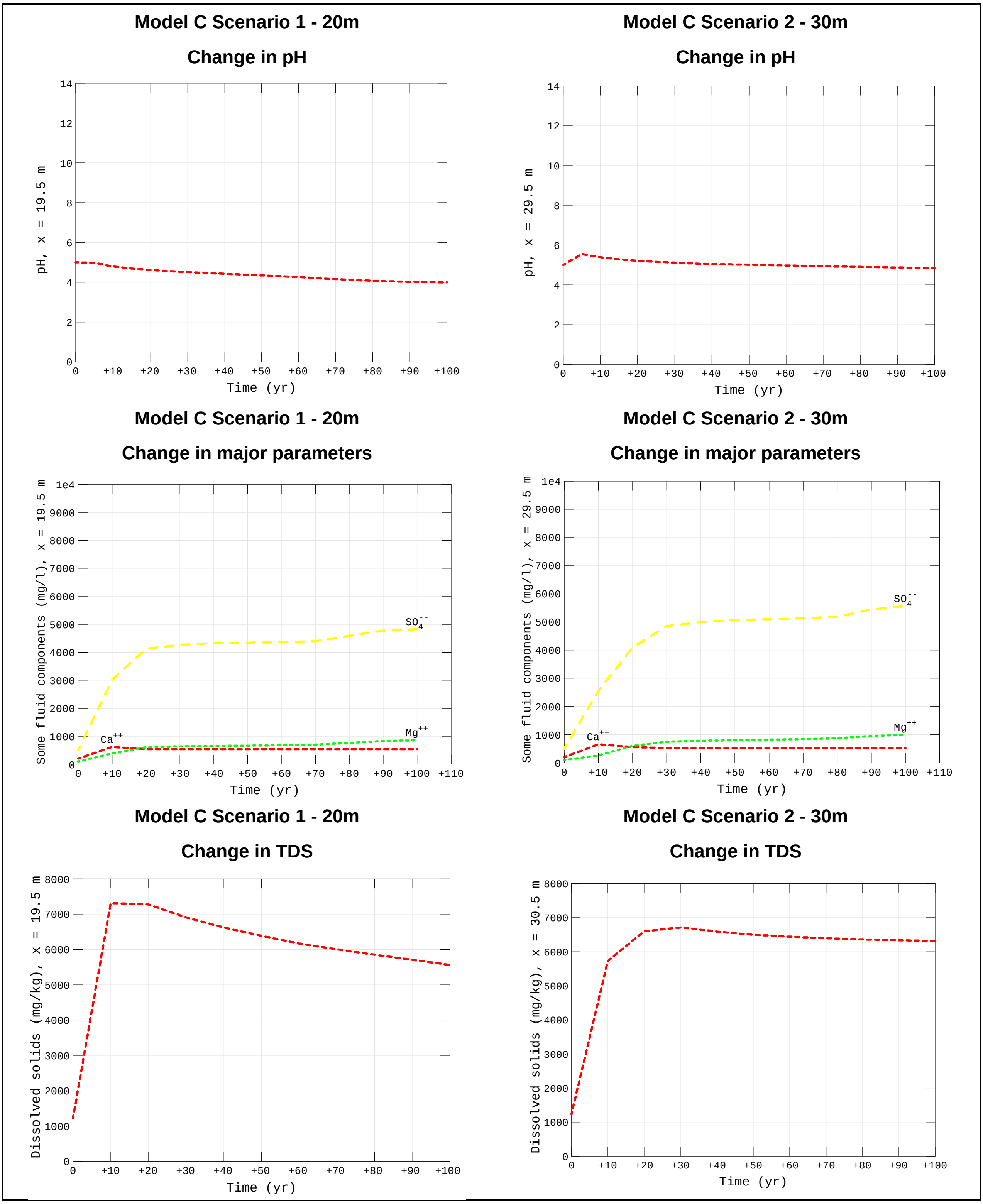

Figure 10 ***Model C Scenario 1 & 2: Changes in discard dump water quality over model time***

5.6. Discussion

The pH and sulphate concentration for the different model scenarios is summarized in Table 26. The evolution in acid-mine drainage with respect to mineralogy and mine water quality is summarized in Table 27. From the model results the following conclusions could be made:

Changes in major ions

Alkalinity is the dominant anion in the infiltrating groundwater into the backfilled opencast and in the rainwater in the discard dump. Within the backfill and the discard, alkalinity in the interstitial water is quickly replaced by sulphate as the dominant anion due to secondary sulphate mineral reactions as well as sulphide oxidation. Sulphate is a conservative (mobile) chemical in the surface and groundwater environment and the first indicator of sulphide oxidation in mine drainage.

Backfilled pit (no discard): At the end of the operational phase, the pit water will have a sulphate concentration of up to 1500mg/L. As the pit water level rises in the next 30 years, the sulphate will increases to between 2200–3300mg/L in the backfill. The pit will have an average unsaturated zone of only 3.5m deep (with limited resultant oxygen infiltration) and the sulphate concentration will improve to below 1000mg/L in the first 100 years after closure (Model A Scenario 1). The maximum unsaturated zone will be 15.5m deep and will generate a sulphate concentration of between 3000mg/L and 3300mg/L (Model A Scenario 2).

Backfilled pit (with discard): With discard backfilling the initial sulphate in the pit water will be at about 2000-2500mg/L (Model A & B Scenario 2). In the average unsaturated zones (3.5m deep) the sulphate concentration will improve to about 1600mg/L over the long-term. In the maximum unsaturated zone, the sulphate will increases to between 3000-3500mg/L over the long-term.

Discard dump: The discard has a high pyrite and sulphate mineral content and seepage from the discard dump will have an average sulphate concentration of between 4500-6000mg/L. However, it is possible that spikes in the sulphate may occur of up to 10 000mg/L.

Initially, Ca and mg is the dominant cations in the drainage due to the initial neutralization reactions of carbonate minerals. The carbonate minerals will, however, become depleted in the backfill and in the discard dump with the result that metals like Al, Fe and Mn will become the majors cations in acidic drainage (as not enough basic cations are present).

Changes in pH conditions

Backfilled pit (with or without discard backfill): The pit water will acidify as carbonate minerals will become depleted. Initial pH levels of between 5–7 could be expected with long-term pH levels at below <4.5. Most waste rock material has a very low neutralization potential.

Discard dump: The discard has a high pyrite and sulphate mineral content and the discard dump will be in contact with the atmosphere. Seepage from the discard dump will range between pH 3.5–4.5, however, this may be between pH 2-4 for run-off water from the dump.

Metals in seepage/mine water

In neutral pit water Al, Fe and Mn will be present at concentrations of below 10mg/L.

Where acidification occurs, drainage will have Al, Fe and Mn concentrations above 10mg/L even up to 1000mg/L. In acidic drainage, the concentration of trace metals Co and Ni will also become elevated (0.1-2mg/L);

Metal concentrations under acidic conditions can however be expected to be very erratic and will change significantly between each monitoring run.

AMD evolution

The geochemistry of AMD will change over time as summarized in Table 26 and 27. During the first stage of AMD, pyrite oxidation takes place, but enough carbonate minerals are available to neutralise the acid generated. This result in gypsum precipitation as enough Ca is available. Gypsum will precipitate in favour of Al-Fe-sulphates. Metals are generally not elevated during this phase as the pH remains near neutral. The sulphate is generally below about 2500mg/L because of the gypsum precipitation.

During the second AMD stage, pyrite oxidation takes place but carbonate minerals have become depleted. Gypsum does not precipitate anymore as no Ca is generated (from carbonates anymore) and gypsum rather starts to dissolve contributing to the sulphate in solution. Acidic conditions are reached and the sulphate reaches a maximum concentration well above 2500mg/L. Al and Fe become major cations and Al-Fe-sulphates starts to precipitate.

During the third AMD, stage pyrite is depleted in the upper oxidation zone but may still be present deeper in the rock pile. Gypsum is also depleted and sulphate concentrations decrease. Metal concentrations also start to decrease resulting in a change in the secondary Al-Fe-sulphates. Conditions remain acidic as silicate minerals are usually not able to neutralise the long-term acidity.

It is important to note that all three stages may eventually be present at a mine as different parts of a dump are subjected to different degrees of oxidation. The upper oxic zone of a dump will reach Stage 3 quicker while deeper saturated parts will remain as Stage 1.

In the backfilled Vlakvarkfontein pit AMD Stage 2 (some depletion of carbonates) will be reached within 30 years. It is interesting to note that alunite (K,Al-sulphate) were identified in some rock samples which indicates that AMD Stage 2 is already present in some of the rock material. All 4 these samples also had a significant pyrite content and almost no neutralisation potential. AMD Stage 2/3 (some depletion of pyrite in unsaturated zone) will be reached within 100 years.

In the discard dump AMD will quickly reach Stage 2 (depletion of carbonates) and at the top few meters of the discard dump Stage 3 will be present (acidification and eventual depletion of pyrite).

Table 26 Estimated range for pH and sulphate concentrations in seepage*

Material	**Average seepage from material over model time**		
Average waste rock backfill. Discard backfill: None.	AMD Stage	Stage 1/Stage 2	Stage 2/Stage3
	Time	0 – 30 years	30 – 100 years
	pH	6 – 4	3.5 – 4.5
	SO_4	1 500 up to 2 200 (average pit) 1 500 up to 3 300 (maximum unsat zone)	2 200 down to 1 000 (average pit) 3 300 down to 3 000 (maximum unsat zone)
Average waste rock backfill. Discard backfilled at least >10 m below decant elevation	AMD Stage	Stage 1/Stage 2	Stage 2/Stage3
	Time	0 – 30 years	30 – 100 years
	pH	6 – 4	3.5 – 4.5
	SO_4	2 500 (average pit) 2 500 up to 3 500 (maximum unsat zone)	2 500 down to 1 600 (average pit) 3 500 - 3 000 (maximum unsat zone)
Discard dump	AMD Stage	Stage 1/Stage 2	Stage 2/Stage3
	Time	0 – 30 years	30 – 100 years
	pH	6 – 4	3.5 – 4.5
	SO_4	500 up to 4 500	4 500 – 5 500 (seepage)

* It was assumed that all discard is backfilled with a neutral pH which may require some addition of calcitic lime.

Table 27 ***Post-closure evolution stages in acid-mine drainage (AMD)***

Component	**AMD Stage 1**	**AMD Stage 2**	**AMD Stage 3**
	Mineralogical reactions and products		
Pyrite	Oxidation of pyrite.	Oxidation of pyrite. SO_4 reaches maximum concentration in interstitial water.	Depleted in upper oxidation zone. Some weakly exposed pyrite still present. SO_4 decrease from maximum.
Calcite and dolomite	Dissolution	Depleted in upper oxidation zone. Some weakly exposed carbonate minerals may however still be present.	Depleted in upper oxidation zone. Some weakly exposed carbonate minerals may however still be present.
Gypsum	Precipitation controls SO_4	Dissolve, contribute to SO_4 in solution.	Depleted in upper oxidation zone.
Al-Fe-sulphates	None	Precipitation	Some dissolute while other keep precipitating.
Metals Al, Fe, Mn	Precipitate/adsorp although there will be a slight increase in concentration below pH 7.	Elevated because these metals become major cations. Not enough base metals to go into solution.	Decrease from maximum.
Trace metals Co, Ni, Pb, Se	More mobile species like Co, and Ni increases.	Elevated	Decrease from maximum.
pH	8 - 5.5 Near neutral	Acidic in seepage from unsaturated zone.	Acidic in seepage from unsaturated zone.
	Water quality changes		
pH	8 - 5.5	3.5 - 5.5 (range)	3.5 - 5.5 (range)
Alkalinity (as $CaCO_3$)	50 – 450	<50	<50
Ca	100 up to 750	750 down to 300	500 - 300 (range)
Mg	50 up to 350	150 - 350 (range)	150 - 350 (range)
Na	50 up to 150	50 - 150 (range)	50 - 150 (range)
K	50 up to 150	50 - 150 (range)	50 - 150 (range)
SO_4	Not above 2 200mg/L See previous table	See previous table	See previous table
Al	< 10	10 - 1000	10 - 1000
Fe	< 10	10 - 1000	10 - 1000
Mn	< 10	10 - 1000	10 - 1000
Ni	< 0.1	0 - 2	0 - 2
Co	< 0.1	0 - 2	0 - 2

5.7. Model validation

Introduction

The Vlakvarkfontein mine is currently operational and it is therefore not possible to directly calibrate the predicted long-term pit water qualities. However, monitoring results from the adjacent historic Arbor mine gives valuable information on the long-term water quality that could be expected for Vlakvarkfontein. The monitoring results available are from boreholes VBH-8S and -8M drilled (by Groundwater Square) to depths of 12m and 30m respectively. The depth to water level in the two boreholes range between 4 – 6mbs. The shallow hole was drilled into the backfill whereas the deeper hole was drilled just outside the historical Arbor pit.

In Figure 11 – 13 monitoring results of the boreholes are presented between July 2013 – November 2016. In Figure 14 the corresponding mineral saturation were calculated for some secondary minerals.

Discussion

The Arbor Mine was mined in the 1940's and rehabilitation was performed by the Department of Water Affairs in 2006. Although it could be expected that the Arbor waste rock will be very similar in composition to the Vlakvarkfontein waste rock, the Arbor waste rock dumps (situated on surface before rehabilitation) were exposed to oxidation conditions over a prolonged period. The monitoring results would therefore indicate some worst-case conditions relative to Vlakvarkfontein.

The sulphate in the shallower borehole were between 3500–4300mg/L and in the deeper borehole between 3000-4100mg/L. The pH ranged between 4 – 6 which indicates that although the pit water is acidic, some buffering above pH 4 is still present. This buffering can be from carbonate minerals that are only weakly exposed as well as from some silicate minerals. It is interesting to note that the deeper borehole is less acidic in 2016 than in 2013 which indicate some delayed buffering.

Although the water is acidic, Ca andmg are still present as major cations in the pit water. In the acidic pit water, Al, Fe and Mn are elevated. The presence of elevated Al indicates that some silicates (most likely some clays like kaolinite and smectite) are also contributing to the buffering between pH 4–6. Fe is a product from the pyrite oxidation and Mn could originate from the dissolution of siderite. It is expected that other metals like Co and Ni will also be present in the acidic pit water.

In Figure 14 the calculated mineral saturation is depicted at an assumed Eh of 0.4 V. Eh only affects the saturation of the Fe-minerals (jarosite) in the diagram. It is shown that gypsum is close to saturated in almost all samples. Jarosite is also close to saturation at Eh = 0.4 V and alunite is oversaturated.

Conclusion

The Arbor Mine pit water is acidic (pH 4-6) with elevated sulphate (3000–4500mg/L) and elevated metals (Al, Fe and Mn). The Arbor mine presents a worst-case scenario for Vlakvarkfontein as the waste rock at Arbor were subjected to significant oxidation conditions. The numerical model of the Vlakvarkfontein pit predicts that only in the maximum unsaturated zone will have sulphate concentrations of >3000mg/L. The largest part of the Vlakvarkfontein pit will be flooded with an average unsaturated zone of 3.5m which will limit the degree of oxidation. The average pit will reach sulphate concentrations of up to 2200mg/L decreasing to 1000mg/L over the long-term. If the surface decant level at Vlakvarkfontein is however not reached (e.g. because of diffused seepage into the aquifer), the quality of the pit water will be closer to that predicted for the maximum unsaturated zone (with sulphate concentration of up to 3500mg/L).

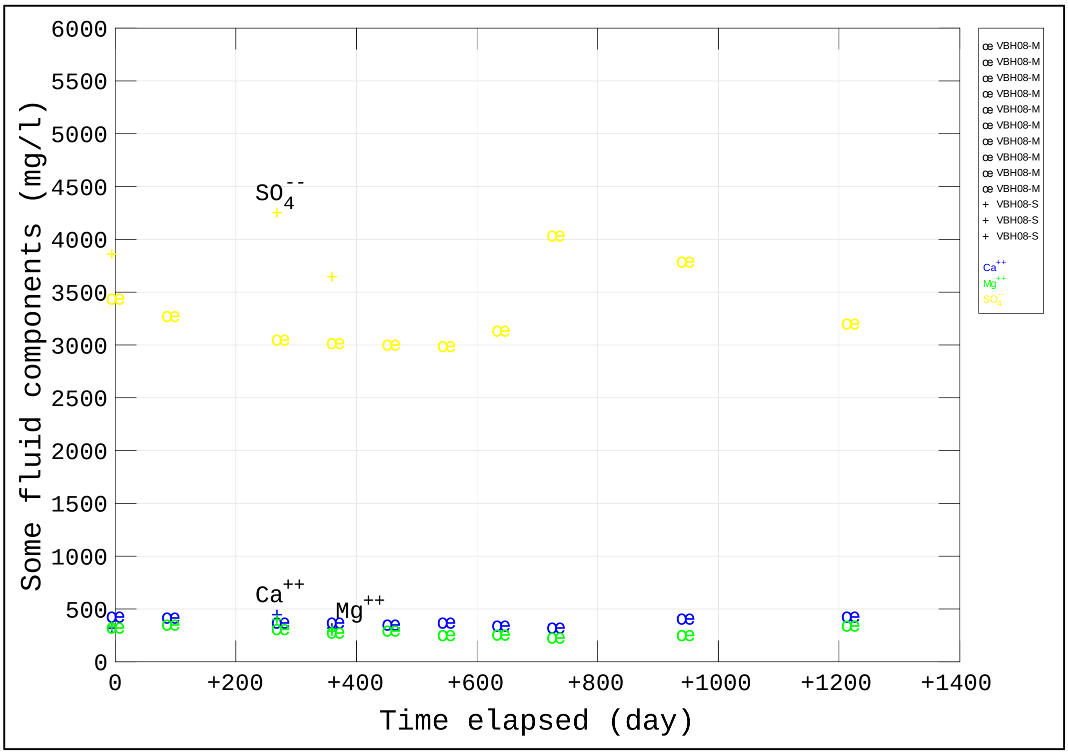

Figure 11 Major parameters in VBH-8S and -8M from July 2013 – November 2016

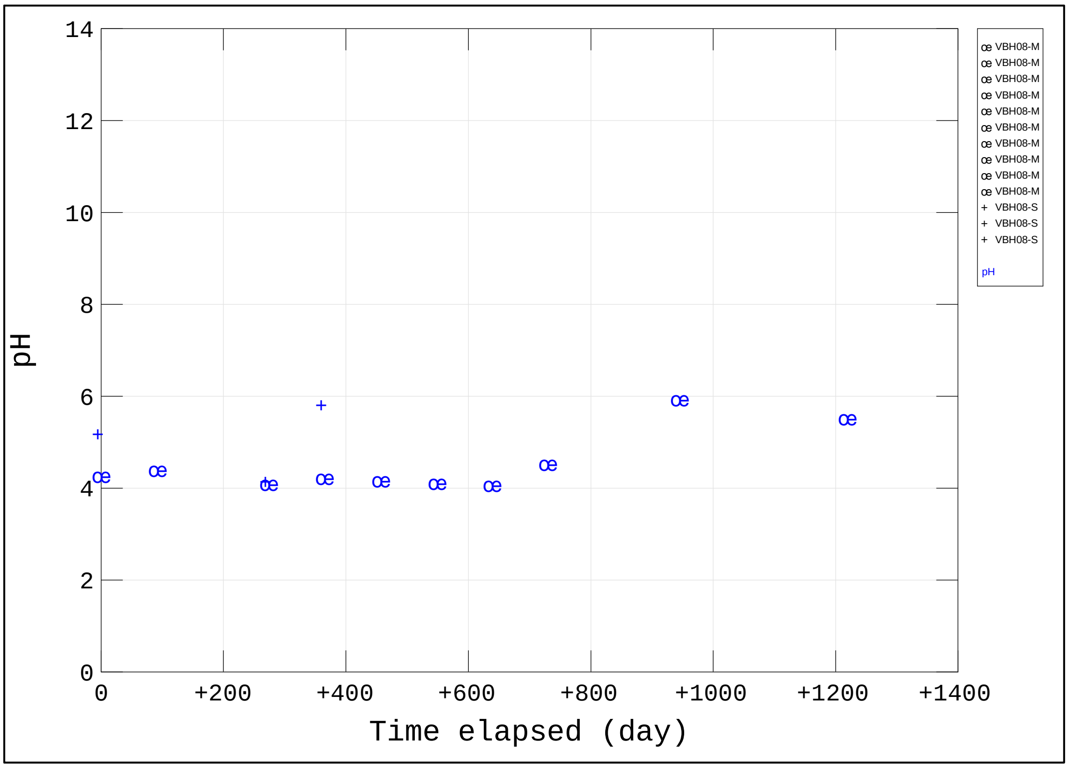

Figure 12 pH in VBH-8S and -8M from July 2013 – November 2016

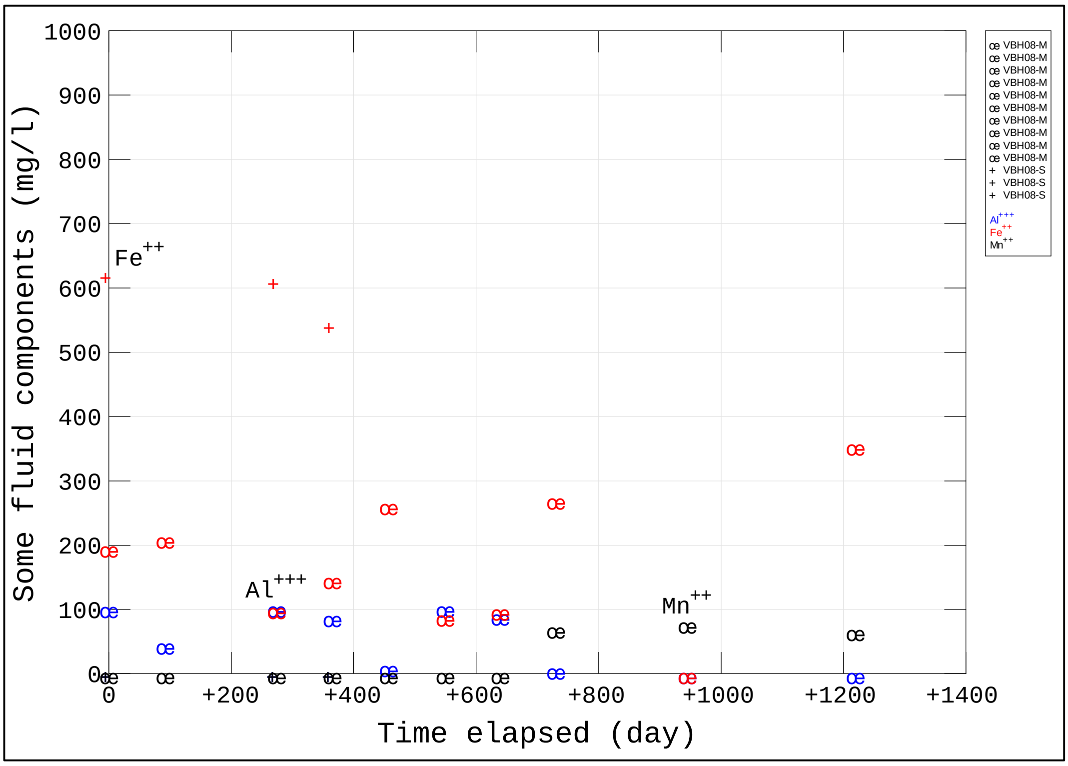

Figure 13 Al, Fe and Mn in VBH-8S and -8M from July 2013 – November 2016

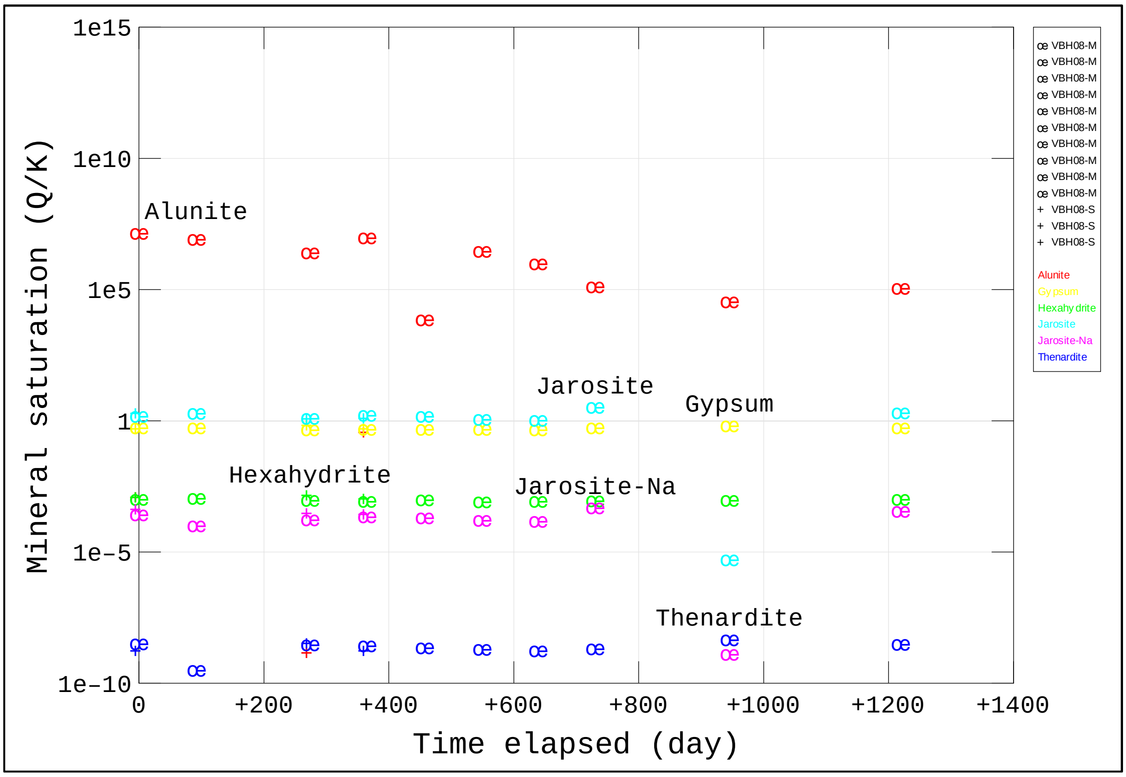

Figure 14 Mineral saturation in VBH-8S and -8M from July 2013 – November 2016 (assuming an Eh = 0.4 V)

5.8. Model limitations

Sample representativeness

The samples collected for this study were assumed to be representative of the future backfill of the pit. Although it is uncertain how representative the samples actually are, very similar results were obtained during the sample runs of 2013 and 2017.

Material heterogeneity and mine water variability

In the backfill of a single opencast mine the mine water quality can vary significantly which is partly due to the heterogeneity of the 1) backfilled rock and 2) variation in unsaturated zone depth. It is not possible to model this heterogeneity. The model only simulates mineralogical reactions based on the typical composition of the material.

Mineral kinetics

The pyrite oxidation rate was determined from the kinetic column test performed. The reaction rate was in good agreement with literature values.

No attempt was made to model any microbial activity. It is assumed that microbial activity could be ignored during near neutral conditions. The modelled concentrations were however in good agreement with mine water measurements at similar mines.

Predicted water quality

The model predicted long-term pit water qualities for the Vlakvarkfontein pit. The results of the maximum unsaturated zone correlate with the pit water qualities of the historic Arbor Mine. However, monitoring data for the Arbor Mine was limited. It is recommended that the Vlakvarkfontein Mine actively monitor the Arbor Mine pit water quality as well as its own operational pit water quality. Validation of the model should take place over the life of the mine with cognizance of the Arbor Mine monitoring data. Calibration and validation of the model results will help the mine to construct an effective closure plan.

6. FINAL DISCUSSION AND CONCLUSIONS

Based on the results of the geochemical assessment, the following conclusions could be made:

Mineralogical composition

Sandstone: Quartz is the dominant mineral in the sandstone with the result that SiO_2 is the dominant oxide in the rock. Microcline and kaolinite are present as major minerals in one sample with the result that Al_2O_3 and K_2O are slightly higher relative to the other samples (where these two minerals are mostly present as minor minerals). Other minor and accessory minerals in the sandstone include calcite, dolomite, pyrite and siderite.

Carbonaceous shale: Most of the carbonaceous shale samples contains more than 10% carbon. The mineralogy of the shale samples is dominated by kaolinite with some major quartz, with the result that Al_2O_3 and SiO_2 are the dominant oxides in the rock. Other minor and accessory minerals in the shale include microcline, muscovite, calcite, dolomite, pyrite and siderite. Slightly elevated traces in the shale include Cu and Cr.

Coal: The coal samples are dominated by a high carbon content (>50%), and also contain major kaolinite and quartz, and accessory microcline, muscovite, calcite, dolomite, pyrite. P2O5 and Cr are slightly elevated in the coal. The coal has a much higher pyrite content (average total S% >0.9% from ABA test results) than the associated waste rock.

Alunite is present in 4 samples of one borehole as a secondary mineral. This indicates that these rocks were subjected to acidic drainage. All 4 these samples also had a significant pyrite content and almost no neutralisation potential.

Acid-base testing (ABA)

The majority of the clastic waste rocks samples (roughly about 64.5% of all waste rock) have a very low sulphide content and will not generate acidic drainage. 35.5% of the clastic waste rocks have a moderate sulphide content and have a low to medium potential to generate acidic drainage. The backfill will, therefore, be a heterogeneous mixture of low potential acid generation and non-acid generation rocks. The neutralisation potential of the non-acid generating rock is however not sufficient to prevent significant acidification of the backfill situated within the oxic zone.

All coal samples had a high sulphide content and will generate acidic drainage in the long term.

Kinetic leach tests

Kinetic leach testing was performed to indicate what metals may leach from the material under especially acidic conditions. The initial acidic leachate with elevated sulphate is due to the leaching of secondary sulphate minerals from the sandstone. The columns test of the coal samples had initial circumneutral leachate which became acidic after a few weeks.

The following metals and metalloids leached at slightly elevated concentrations during the acidic leaches: Al, Mn, Fe, Cu, Co, Ni, Pb and Se. Ni and Mn leached persistently from the columns over longer leaching periods.

Potential impact on drainage quality

Backfilled pit (no discard at the end of the operational phase, the pit water will have a sulphate concentration of up to 1500mg/L. As the pit water level rises in the next 30 years, the sulphate will increases to between 2200–3300mg/L in the backfill. The pit will have an average unsaturated zone of only 3.5m deep (with limited resultant oxygen infiltration) and the sulphate concentration will improve to below 1000mg/L in the first 100 years after closure. The maximum unsaturated zone will be 15.5m deep and will generate a sulphate concentration of between 3000mg/L and 3300mg/L.

Backfilled pit (with discard): With discard backfilling the initial sulphate in the pit water will be at about 2000-2500mg/L. In the average unsaturated zones (3.5m deep) the sulphate concentration will improve to about 1600mg/L over the long-term. In the maximum unsaturated zone, the sulphate will increases to between 3000-3500mg/L over the long-term. It is however important that the discard is backfilled only in the deepest parts of the pit at least 10m below the decant elevation.

Discard Dump: The discard has a high pyrite and sulphate mineral content and seepage from the discard dump will have an average sulphate concentration of between 4500-6000mg/L. However, it is possible that spikes in the sulphate may occur of up to 10000mg/L.

In neutral pit water metals (e.g. Al, Fe and Mn) will be present at concentrations of below 1mg/L. Where acidification occurs in the discard dump, seepage will have Al, Fe and Mn concentrations above 10mg/L, even up to 1000mg/L. In acidic seepage, the concentration of trace metals Co and Ni will also become elevated (0.1-2mg/L).

Recommendations

- Coal material in contact with the atmosphere will result in oxidization of the pyrite and eventual acidification of drainage. It is therefore recommended that the coal material is not subjected to atmospheric conditions as far as possible as this will limit the contamination of water seepage from the material. A permanent discard dump on the surface will result in acidification of its seepage water while previous studies have shown that the correct backfilling of discard may result in less water being contaminated;
- Discard backfilled in the pit should be flooded as soon as possible and should be situated several meters below the final pit water level (>10m below the decant elevation) to ensure that limited oxidation takes place;
- The discard must have a neutral (paste) pH when backfilled else it would immediately acidify interstitial water before being covered with water. In this case, it is recommended that calcitic lime is added to the discard. However, the amount of lime required will depend on the degree of oxidation before backfilling and should be determined during the operational phase;
- As much as possible coal should be removed from the opencast mine during the operational phase. Carbonaceous rocks (including interburden and discard) should be placed in the deepest part of the pit and the mined-out section of the pits must be backfilled, compacted and rehabilitated as soon as possible;
- An important management measures relates to the monitoring of the mine waste and surrounding groundwater quality. The following parameters should be measured in surface water on a monthly basis and in groundwater on a quarterly basis:
  - System parameters: pH, TDS, EC, Total alkalinity;
  - Major cations: Ca,mg, Na, K;
  - Anions and compounds: SO_4, Cl, PO_4, NO_3, NH_3;
  - Minor metals: Al, Fe, Mn;
  - Trace metals (only in acidic water): Co, Cu, Ni, Se, Pb.
- The paste pH as well as the acid-base properties of the discard should be monitored throughout the life of the mine. If discard are placed in the pit, piezometers should be installed to monitor both the shallow and deeper pit water level and quality;
- It is recommended that the Vlakvarkfontein Mine actively monitor the Arbor Mine pit water quality as well as its own operational pit water quality. Validation of the geochemical model should take place over the life of the mine with cognizance of the Arbor Mine monitoring data. Calibration and validation of the model results will help the mine to construct an effective closure plan.

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