Preliminary Geochemistry Assessment of the Proposed Rietvlei Coal Mine May 2014 (DRAFT)

EXECUTIVE SUMMARY

This report presents the results of a preliminary assessment of acid rock drainage risk and potential drainage quality at the proposed Rietvlei opencast coal mine. The approach followed in this preliminary ARD risk assessment is generally consistent with BPG G4 and consisted of a characterisation programme (sampling, laboratory analysis), and geochemical modelling of drainage qualities.

Drilling return from selected geological intervals was sampled during the drilling of groundwater exploration/monitoring boreholes at the site. The two sampled boreholes fall within the proposed pit outlines specified in the mine plan.

The samples were analysed by Waterlab, Pretoria, who conducted acid-base accounting according to the Modified Sobek method. Extraction tests were conducted using distilled water as the extractant solution at a solution:solid ratio of 4:1. The laboratory results are considered suitable for this preliminary geochemistry assessment.

The four samples tested show no short-term acid generation potential. Total sulphur concentrations are less than the concentration that would allow sustained acid generation.

Mine water quality was modelled using the geochemical code PHREEQC coupled with the *minteq.v4.dat* database. General modelling assumptions include:

- The water chemistries used in the modelling are representative of input sources.
- Modelled waters are in full thermodynamic equilibrium.
- The PHREEQC model appropriately simulates chemical reactions and contains the appropriate thermodynamic constants.

A conceptual model was developed to select appropriate boundary conditions for the geochemical modelling. Rainfall percolating into the pit backfill is simulated by the combination of distilled water and sample material under oxidising conditions during the extraction tests. Within the backfill the carbon dioxide partial pressure is higher than atmospheric conditions.

Water content of 10% and 40% was modelled for each of the four samples tested. Parameter concentrations below the laboratory reporting limit were modelled at concentrations one half the reporting limit. This precautionary approach may yield higher concentrations, particularly for the metals of environmental concern. The model allowed geochemically credible mineral phases to precipitate from solution. This yielded eight water quality estimates.

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Both pit water and decant water are modelled to be significantly more saline than natural baseline water quality. However, concentrations of metals of environmental concern[1] will generally be at or below typical laboratory detection limits. Therefore, mining activities at Rietvlei are expected to increase TDS (total dissolved solids), major cation (Na, K, Ca, Mg) and anion (F, Cl, SO_4, alkalinity) concentrations (Table E1). The pH range is expected to be similar to the range of natural baseline water.

Table E1: Range of modelled mine water qualities for the proposed Rietvlei coal mine

Parameter [mg/L] except pH	Pit water		Decant water	
	Upper	Upper	Lower	Lower
pH	6.53	8.19	7.68	5.37
F	4.95	4.84	1.00	1.00
Cl	1237	1236	64	64
SO_4	425	425	7.40	7.40
Alkalinity (as $CaCO_3$)	1625	104	27	41
Na	316	316	9.96	9.97
K	312	312	20	20
Ca	538	237	9.97	9.97
Mg	276	276	9.97	9.97
TDS	4480	2614	150	164

As a result of the limited sampling, the model predictions in this report should be considered indicative of potential mine water quality.

The following recommendations are indicated from the work described in this report:

- Further sampling of Rietvlei lithologies should be conducted during the operational phase of mining when the overburden is exposed in the opencast pit.
- The additional samples should be submitted for ABA testing to confirm the low acid generation potential indicated by the results presented in this report.
- Selected samples should be subjected to extraction tests to confirm the results presented in this report.
- A surface water, groundwater and mine water monitoring programme should be established for the proposed Rietvlei mine. Monitoring should commence prior to mining to extend the current baseline water quality data. Monitoring should continue throughout the operational phase of mining.
- The monitoring data and additional sample testing should be evaluated by an environmental geochemist. The model predictions in this report should be revised based on the data evaluation.
- Field kinetic tests should be established on site. These will provide advance indication of potential post-closure drainage qualities under site environmental conditions. These can be used to inform mine closure planning.

[1] aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, lead, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, thallium, vanadium, and zinc

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APPENDICES

(Included as separate file accompanying this report)

Appendix A Borehole logs

Appendix B Laboratory reports

Appendix C Geochemical model results

GLOSSARY

ARD, AMD	Acid rock drainage/acid mine drainage. Acidic water developed from the natural oxidation of sulphide rock-forming minerals.
ABA	Acid base accounting. An analytical method to determine the potential of a material to generate acid drainage
BPG	Best Practice Guidelines for Water Resources Protection in the South African Mining Industry. A series of documents indicating methodologies to conduct water quality predictions, develop water and salt balances (among others)
DWA	Department of Water Affairs, also previously known as Department of Water Affairs and Forestry (DWAF)
Mine drainage	Water derived from the interaction of rain, groundwater and/or surface water with mining-disturbed rock or mine waste
mg/L	Milligrams per litre. A common unit to indicate the concentration of dissolved chemical species in solution
PHREEQC	PH, Redox, Equilibrium Code. A geochemical modelling code

1 INTRODUCTION

This report presents the results of a preliminary assessment of acid rock drainage risk and potential drainage quality at the proposed Rietvlei opencast coal mine. Solution[H+] conducted the work at the request of WSP Environmental. This assessment is one of several specialist studies conducted to inform the environmental authorisation of the proposed mine.

1.1 Location

The proposed Rietvlei coal mine lies approximately 50 km northeast of Emalahleni (Witbank) and 22 km northeast of Mhluzi (Middelburg) in the Mpumalanga Province (Figure 1). The R555 provincial road links the site to Mhluzi. The site lies within a farming area and private properties border the site on all sides (AEC 2011).

Figure 1: Locality map of the proposed Rietvlei Mine

1.2 Objectives

This preliminary geochemical assessment addresses the following key questions:

- What are the acid rock drainage/metal leaching potentials of the various geological strata and mine wastes that will be exposed, disturbed, or deposited as part of the proposed mining activities?
- Will the mine generate waste material that has a potential to generate acid, neutral or saline drainage?
- How do the geochemical characteristics of the various geological materials and mine wastes vary across the coal resource targeted for mining?
- What mine water qualities can be expected?

This report will provide the following outcomes:

- Forecast the open cast mine water qualities during and after mining operations; and
- Recommend mitigation measures and water management strategies that could reduce long-term surface and groundwater quality impacts.

1.3 Approach

A guideline framework for the assessment of water-related impacts, such as may arise from Acid Rock Drainage (ARD) is provided by the document series “Best Practice Guidelines for Water Resource Protection in the South African Mining Industry” (or “BPG”), developed by the Department of Water Affairs.

Guideline BPG G4 “Impact Prediction” is particularly relevant to the proposed coal mining activities at Rietvlei. BPG G4 documents and defines general strategies, techniques, and tools for predicting water impacts on mine sites.

The approach followed in this preliminary ARD risk assessment is generally consistent with BPG G4 and consisted of a characterisation programme (sampling, laboratory analysis), and geochemical modelling of drainage qualities.

Acid base accounting results were compared to commonly applied local and international guidelines.

Extraction test results were used as a starting point for geochemical modelling of potential drainage quality from pit backfill. Modelling used the PHREEQC code (Parkhurst and Appelo 1999) developed by the United Stated Geological Survey (USGS) and widely applied in environmental geochemistry studies.

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1.4 Background

An Environmental Impact Assessment of an older mine plan was conducted in March 2013. Ownership and the proposed mine plan changed and the EIA needs to be updated. The previous EIA did not include an assessment of the geochemistry of the site, or a prediction of potential mine water quality.

1.4.1 Geology

The following geology description is summarised from the Competent Persons Report on Rietvlei (Botes 2013):

> Coal deposits in Mpumalanga are hosted by the Karoo Supergroup. The basal Stratigraphy of the Karoo Supergroup comprises the Dwyka Group which is a sequence of glacial sediments. This is overlain by the Ecca Group which comprises sandstone, siltstone, mudstone and significant coal seams.
>
> At Rietvlei, the Dwyka Group and the Vryheid Formation of the Ecca Group rest unconformably on an uneven floor of older rocks composed of gabbro and granodiorite associated with the Bushveld Igneous Complex and felsite of the Upper Transvaal Supergroup. The generally flat-lying Vryheid Formation sedimentary rocks consist of sandstone, thinly laminated siltstone, subordinate shale and coal seams. The lithological units are variable in thickness, but are readily identifiable in all boreholes throughout the area.

The sequence includes two coal seams: the No. 1 Seam and the No. 2 seam. The No 1 Seam is subordinate and is less than 2 m thick over most of the area. The No. 2 seam is about 6 m thick and lies at an average depth of 40 mbgl (AEC 2013).

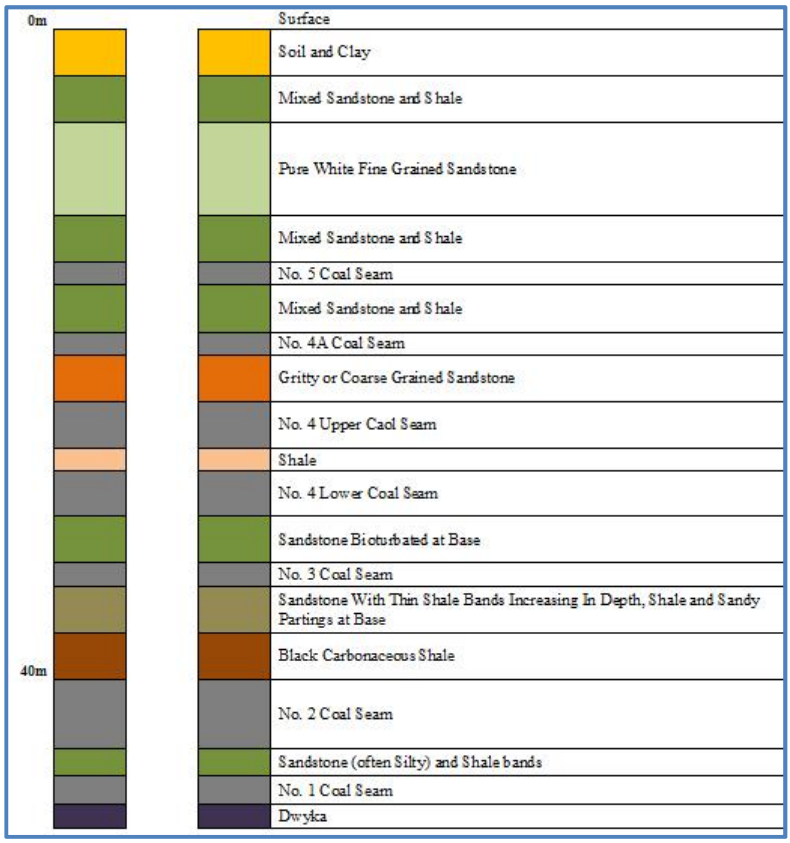

Figure 2: Typical stratigraphy at Rietvlei (from AEC 2013)

1.4.2 Geochemistry

Karoo shales and siltstones are generally non-acid producing and contain silicate and clay minerals such as quartz, illite, smectite, kaolinite and chlorite etc. Many of these minerals contain leachable sodium which may modify the cation concentration of water that comes into contact with these rocks. This is especially the case in the mine setting where broken rock presents a considerably greater surface area for leaching.

Karoo coal and carbonaceous shale are generally associated with the mineral pyrite (Usher et al 2001). Exposure to oxygen from mining activities oxidises the pyrite to form sulphate, iron and acidity which can enter water resources and can significantly influence the mine drainage quality under oxidizing conditions.

Secondary minerals such as calcite ($CaCO_3$), rhodocrocite ($MnCO_3$) and siderite ($FeCO_3$) are known to occur in association with the Karoo rocks in the Rietvlei area. These may modify cation concentrations and offset acidity. However, Fe^{2+} from siderite dissolution will oxidise at surface to release acidity.

2 CHARACTERISATION PROGRAMME

2.1 Sampling

Core from exploration boreholes was not available for geochemical sampling. AquaEarth Consulting (AEC) collected the drilling return from selected geological intervals during the drilling of additional groundwater exploration/monitoring boreholes at the site. The two sampled boreholes fall within the proposed pit outlines specified in Mindset (2013).

AEC collected four samples consisting of several kilogrammes of pulverised rock and submitted them to Waterlab, Pretoria for geochemical analysis (Table 1). Figure 3 shows the location of the sampled boreholes. Appendix A presents geological profiles of the sampled boreholes.

Table 1: Summary of geochemical samples analysed

Borehole	Depth sampled	Sample ID	Lithology
T7D	12-21	T7D (12-21)	White to grey sandstone
T7D	26-50	T7D (26-50)	Coal and carbonaceous shale
T8D	11-21	T8D (11-21)	Carbonaceous shale
T8D	22-50	T8D (22-50)	Coal, carbonaceous shale, sandstone, shale

Figure 3: Locations of boreholes from which geochemical samples were collected

2.2 Analysis

Waterlab, Pretoria, conducted acid-base accounting according to the Modified Sobek method. Total sulphur and neutralisation potential were determined.

Extraction tests were conducted using distilled water as the extractant solution at a solution:solid ratio of 4:1. This is lower than the ratio of 20:1 adopted by the EPA 1312 and DWAF (1998) extraction methods. Price (2009) suggests lower solution:solid ratios to avoid excessively dilute solutions that fail to identify equilibrium mineral solubility limits.

3 CHARACTERISATION RESULTS

3.1 Data validation

For the ABA results relative percent difference between duplicate samples was less than 5% for all parameters. This suggests that the data are reproducible and that systematic errors are within acceptable limits.

Charge balances of the extractions were within 10% for all parameters tested. This suggests the results are internally consistent.

In general, the results are considered suitable for this preliminary geochemistry assessment.

3.2 Analysis

Appendix B presents copies of the laboratory reports.

3.2.1 Acid-base accounting

Table 2 presents the ABA data for the Rietvlei samples.

Table 2: Rietvlei ABA results

Sample Number	T7D (12-21)	T7D (26-50)	T8D (11-21)	T8D (22-50)
Paste pH	6.3	6.9	6.9	7.7
Total Sulphur (%) (LECO)	0.05	0.16	0.08	0.22
Acid Potential (AP) (kg/t)	1.56	5.00	2.50	6.88
Neutralization Potential (NP)	-0.97	3.79	0.06	24.04
Nett Neutralization Potential (NNP)	-2.53	-1.22	-2.44	17.17
Neutralising Potential Ratio (NPR) (NP : AP)	0.62	0.76	0.02	3.50

Paste pH is an indicator of short-term acidity. All four samples have neutral paste pH.

If NPR is less than two, a sample is categorised as potentially acid-generating (Price 2009). This criterion is met in three of the four samples.

In general, a sulphur content of less than 0.3% cannot sustain long-term acid generation (Usher et al 2001). All samples fall within this criterion.

3.2.2 Extractions

Table 3 presents a summary of the Rietvlei extraction test data.

Table 3: Summary of the composition of extracts obtained from Rietvlei overburden samples

Sample ID	T7D (12-21)	T7D (26-50)	T8D (11-21)	T8D (22-50)
Lithology	White sandstone	Carbonaceous shale and coal	Carbonaceous shale	Coal, carbonaceous shale, sandstone, clay
pH	5.6	8	7.9	8.1
TDS	24	126	80	96
Alkalinity	<5	64	40	64
Cl	<5	<5	<5	<5

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Sample ID	T7D (12-21)	T7D (26-50)	T8D (11-21)	T8D (22-50)
SO4	<5	31	27	21
F	<0.2	1.7	0.5	1
Ag	<0.025	<0.025	<0.025	<0.025
Al	1.74	<0.100	0.288	0.246
As	<0.010	<0.010	<0.010	<0.010
B	<0.025	0.058	<0.025	<0.025
Ba	0.029	0.306	0.228	0.128
Be	<0.025	<0.025	<0.025	<0.025
Bi	<0.025	<0.025	<0.025	<0.025
Ca	<2	20	12	17
Cd	<0.005	<0.005	<0.005	<0.005
Co	<0.025	<0.025	<0.025	<0.025
Cr	<0.025	<0.025	<0.025	<0.025
Cu	<0.025	<0.025	<0.025	<0.025
Fe	0.28	<0.025	0.044	0.06
K	2	7.9	5.2	7.8
Li	<0.025	<0.025	<0.025	<0.025
Mg	<2	6	7	4
Mn	<0.025	<0.025	0.097	<0.025
Mo	<0.025	0.049	<0.025	<0.025
Na	<2	2	<2	8
Ni	<0.025	<0.025	<0.025	<0.025
P	<0.025	<0.025	<0.025	<0.025
Pb	<0.020	<0.020	<0.020	<0.020
S	0.743	11	10	9.18
Sb	<0.010	<0.010	<0.010	<0.010
Se	<0.020	<0.020	<0.020	<0.020
Si	7.3	3.4	3.4	3.2
Sn	<0.025	<0.025	<0.025	<0.025
Sr	<0.025	0.337	0.141	0.289
Ti	0.088	<0.025	<0.025	<0.025
V	<0.025	<0.025	<0.025	<0.025
W	<0.025	<0.025	<0.025	<0.025
Zn	<0.025	<0.025	<0.025	<0.025
Zr	<0.025	<0.025	<0.025	<0.025

Concentrations of Si, Fe, and Al are higher than expected from thermodynamic considerations and suggest that fine mineral matter suspended in the sample has been included in the analysis of dissolved constituents.

The sandstone extract has the lowest dissolved solids concentration. This is consistent with the poor solubility of quartz and feldspar that dominate sandstone composition. In contrast, the extract from carbonaceous shale and coal has a higher dissolved solids concentration. The extract composition includes higher concentrations of sulphate, calcium, and alkalinity. These parameters could be derived from sulphide oxidation and the dissolution of calcite vein filling in the coal.

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4 DRAINAGE QUALITY ESTIMATION

4.1 Modelling code

This assessment used the geochemical modelling code PHREEQC (Parkhurst and Appelo 1999). The code was developed by the United States Geological Survey (USGS) and is widely applied in environmental geochemistry studies. The USGS posts regular updates to the code.

This study coupled PHREEQC with the *minteq.v4.dat* database. The database includes the "metals of environmental concern" defined by Langmuir et al (2004). These include aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, lead, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, thallium, vanadium, and zinc.

4.2 Modelling limitations

Geochemical modelling to predict water qualities of complex systems demands assumptions since it is generally impossible to determine precisely the physical and geochemical characteristics of the systems. General assumptions include:

- The water chemistries used in the modelling are representative of input sources. It is not possible to model water quality without this essential assumption. Site monitoring and sampling generally provides representative water qualities. The results of a geochemical characterisation programme may indicate other water qualities. Multiple water chemistry results are required to indicate the potential variation in modelled water quality.
- Modelled waters are in full thermodynamic equilibrium. Equilibrium is the computational basis of PHREEQC. Equilibrium is unlikely to be the case for all chemical components throughout all waters. However, geochemical research has shown that assuming equilibrium conditions may usefully describe the composition of natural and mine waters.
- The PHREEQC model appropriately simulates chemical reactions and contains the appropriate thermodynamic constants.

Due to the assumptions and inherent limitations of predictive modelling, the model results presented in this report should be considered as order of magnitude estimates. Therefore, results do not indicate modelled concentrations less than 0.01 mg/L.

4.3 Conceptual model

Figure 4 presents a conceptual model of decant generation from the Rietvlei backfilled opencast pit. This represents the post-closure phase of mining. Rainfall percolating into the pit backfill is simulated by the combination of distilled water and sample material under oxidising conditions during the extraction tests.

Within the backfill the partial pressure of carbon dioxide is expected to be higher than atmospheric conditions due to the oxidation of carbonaceous material. As the water level in the pit rises after mining, the maximum moisture content of the backfill will be limited to the saturated porosity of the backfill. This has been estimated at varying between 10% and 40%. This water content is considerably less than used in the extraction tests. The increase in concentration from lower solution:solid ratios in the backfill will induce precipitation of mineral phases.

The conceptual model was used to select appropriate boundary conditions for the geochemical modelling.

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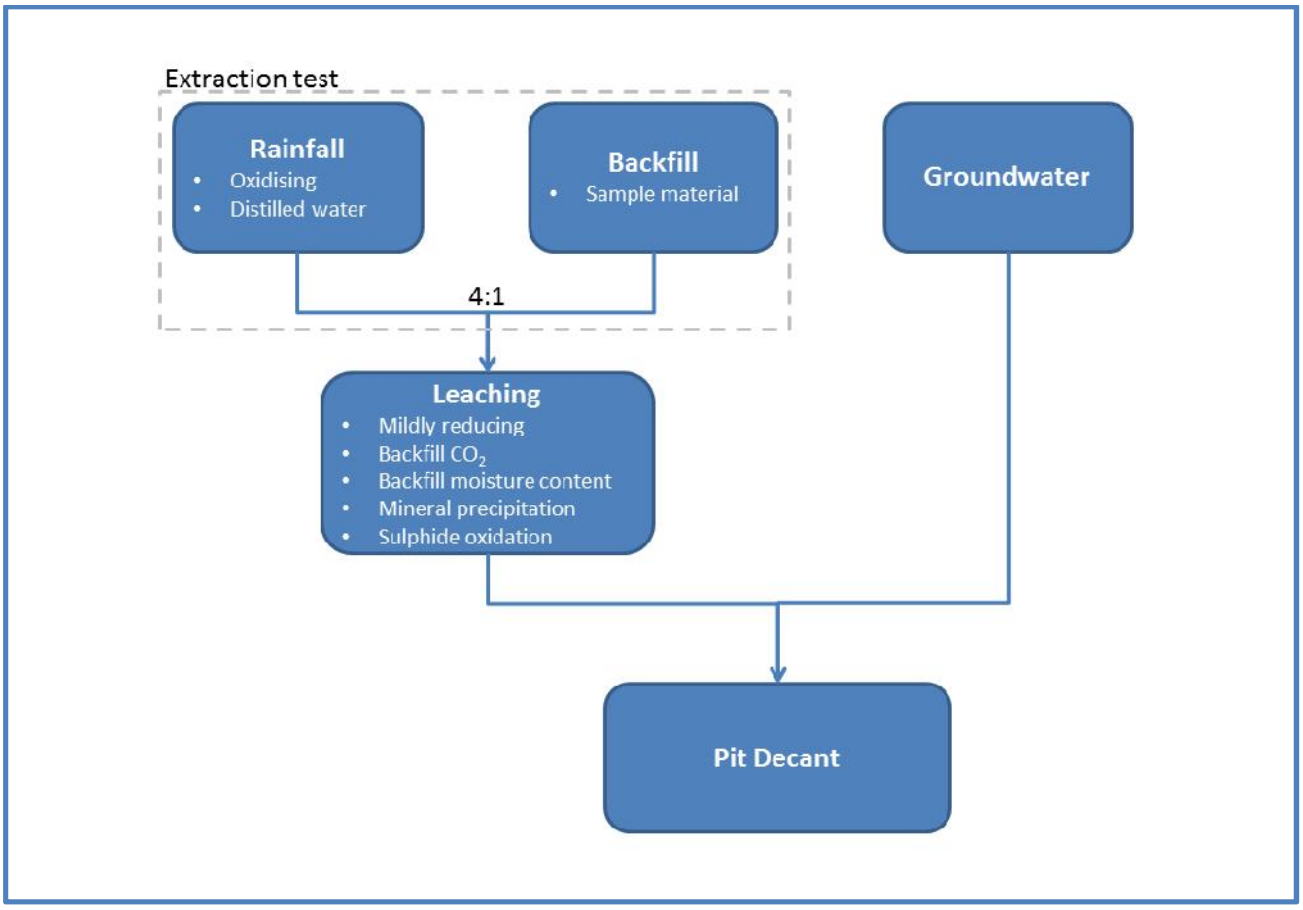

Figure 4: Conceptual model of decant generation after closure and backfilling of the Rietvlei open cast pit

4.4 Model results

Water content of 10% and 40% was modelled for each of the four samples tested. Parameter concentrations below the laboratory reporting limit were modelled at concentrations one half the reporting limit. This precautionary approach may yield higher concentrations, particularly for the metals of environmental concern.

The model allowed geochemically credible mineral phases to precipitate from solution. This yielded eight water quality estimates. Acid generation was not considered as the ABA test results indicated sulphur concentrations too low to significantly impact water quality. Appendix C presents the model results.

4.4.1 Pit water

Table 4 presents the range of the modelled pit water qualities compared to baseline groundwater quality at Rietvlei. Based on the laboratory and modelling results interstitial water in the backfill is generally expected to lie within this quality range. However, site specific conditions may give rise to site water qualities that lie outside this range.

Table 4: Range of modelled pit water quality for the proposed Rietvlei coal mine

Parameter [mg/L] except pH	Pit water		Groundwater baseline*	
	Upper	Lower	Upper	Lower
pH	6.53	5.37	7.98	6.11
F	4.95	1.00	3.5	<0.1
Cl	1237	64	2.7	0.8
SO_4	425	7.40	6.6	2.3
Alkalinity (as $CaCO_3$)	1625	41		
Na	316	9.97	33	2.8
K	312	20	9.3	1.5
Ca	538	9.97	73	9.1
Mg	276	9.97	12	0.6
Ag	0.49	0.12		
Al	0.24	<0.01		
As	0.20	0.05		
Ba	0.29	0.04		
Be	0.49	0.12		
Cd	0.10	0.02		
Co	0.49	0.12		
Cr	0.37	<0.01		
Cu	0.49	0.12		
Fe	10.89	<0.01	2.1	<0.05
Hg	<0.01	<0.01		
Mn	3.83	0.07	0.07	<0.05
Mo	1.93	0.12		
Ni	0.49	0.12		
Pb	0.39	<0.01		
Sb	0.20	0.05		
Se	0.39	0.10		
Sr	13.30	0.12		
Tl	<0.01	<0.01		
V	0.49	0.12		
Zn	0.49	0.12		
TDS	4480	164	149	16

* Preliminary field results provided by AquaEarth Consulting

Table 4 indicates that modelled pit water quality will be more saline than local groundwater by a factor of ten or more. The concentrations of metals of environmental concern will generally be at or below typical laboratory detection limits. However, concentrations of Mo (molybdenum) and Sr (strontium) may be elevated. Both of these metals may be adsorbed by iron and manganese oxyhydroxides which the model indicates will precipitate as the decant reaches surface. Strontium may also co-precipitate in calcium carbonate. Therefore, it is unlikely that the modelled Mo and Sr concentrations will be achieved in the field.

4.4.2 Decant water

When the pit water decants at surface, it will be exposed to atmosphere which will induce chemical changes in the water composition. This was simulated in the numerical model, allowing geochemically credible minerals to precipitate. Table 5 presents the simulation results compared to baseline surface water quality at Rietvlei. Based on the laboratory and modelling results decant water is generally expected to lie

within this quality range. However, site specific conditions may give rise to site water qualities that lie outside this range.

Table 5: Range of modelled decant quality for the proposed Rietvlei coal mine

Parameter [mg/L] except pH	Decant water		Surface water baseline*	
	Upper	Lower	Upper	Lower
pH	8.19	7.68	7.46	7.12
F	4.84	1.00	0.53	0.52
Cl	1236	64	11	6.2
SO_4	425	7.40	8.7	7.9
Alkalinity (as $CaCO_3$)	104	27	40	19
Na	316	9.96	11	9.5
K	312	20	3.5	2.9
Ca	237	9.97	7.6	4.0
Mg	276	9.97	6.1	2.5
Ag	0.49	0.12		
Al	0.24	<0.01	4.3	1.8
As	0.20	0.05		
Ba	0.29	0.03		
Be	0.02	0.01		
Cd	0.10	0.02		
Co	0.49	0.01		
Cr	0.37	<0.01	<0.05	<0.05
Cu	0.02	0.02		
Hg	<0.01	<0.01		
Mn	<0.01	<0.01	<0.05	<0.05
Mo	1.93	0.12		
Ni	0.49	0.12		
Pb	0.13	<0.01		
Sb	0.20	0.05		
Se	0.39	0.10		
Sr	13.29	0.12		
Tl	<0.01	<0.01		
V	0.49	0.12		
Zn	0.49	0.12	<0.05	<0.05
Fe	<0.01	<0.01		
TDS	2614	150	78	68

* Preliminary field results provided by AquaEarth Consulting

Baseline surface water quality contains Al (aluminium) concentrations that are unusually high for natural surface waters (Table 5). This overestimate may be caused by unfiltered colloidal material in the field samples tested in the laboratory.

Table 5 indicates that decant salinity will be about two to forty times more concentrated than baseline surface water quality. The concentrations of metals of environmental concern will generally be at or below typical laboratory detection limits. Field concentrations of Mo (molybdenum) and Sr (strontium) are unlikely to be as high as modelled concentrations due to the considerations outlined above for pit water.

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5 CONCLUSIONS

5.1 Acid drainage

The four samples tested show no short-term acid generation potential. Total sulphur concentrations are less than the concentration that would allow sustained acid generation. Sulphur speciation was not conducted on these samples. However, some of the total sulphur concentration is likely to be due to non-acid generating sulphur organically-bound within the coal. Therefore, the sulphur associated with pyrite is likely to be even lower than suggested by the ABA test results.

The NPR of the samples is not considered to indicate a significant risk of acid generation due to the low sulphur concentration and neutral paste pH measurements.

5.2 Mine water quality

The pit will decant after it has filled with groundwater and infiltrating rain water. This is expected to happen some years after closure[2]. The modelled decant water quality also represents the estimated range of composition of drainage from spoil and runoff within the opencast pit during the operational phase.

Both pit water and decant water are modelled to be significantly more saline than natural baseline water quality. However, concentrations of metals of environmental concern will generally be at or below typical laboratory detection limits. Therefore, mining activities at Rietvlei are expected to increase TDS (total dissolved solids), major cation (Na, K, Ca, Mg) and anion (F, Cl, SO_4, alkalinity) concentrations. The pH range is expected to be similar to the range of natural baseline water.

5.3 Variability

Ninety-seven geological exploration boreholes were drilled, logged and sampled to define the 55 million tonnes of coal that comprise the Rietvlei coal resource (Botes 2013). To access this coal requires the removal of approximately 225 million tonnes of overburden (Mindset 2013). However, two boreholes were sampled to characterise the geochemistry of the overburden.

The four samples tested for this report cannot be considered statistically representative of the significant mass of overburden that will be disturbed by mining. The number of samples is also not sufficient to indicate the potential variability in geochemistry that may exist in the mining-disturbed overburden. Additional sampling and testing is required to confirm the results presented in this report.

As a result of the limited sampling, the model predictions in this report should be considered indicative of potential mine water quality. Site specific monitoring of groundwater, surface water and mine water quality will indicate the validity of the sample characterisation and model results presented in this report.

[2] Refer to the specialist groundwater study by AquaEarth Consulting developed in parallel with this report.

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6 RECOMMENDATIONS

The following recommendations are indicated from the work described in this report:

- Further sampling of Rietvlei lithologies should be conducted during the operational phase of mining when the overburden is exposed in the opencast pit.
- The additional samples should be submitted for ABA testing to confirm the low acid generation potential indicated by the results presented in this report.
- Selected samples should be subjected to extraction tests to confirm the results presented in this report.
- A surface water, groundwater and mine water monitoring programme should be established for the proposed Rietvlei mine. Monitoring should commence prior to mining to extend the current baseline water quality data. Monitoring should continue throughout the operational phase of mining.
- The monitoring data and additional sample testing should be evaluated by an environmental geochemist. The model predictions in this report should be revised based on the data evaluation.
- Field kinetic tests should be established on site. These will provide advance indication of potential post-closure drainage qualities under site environmental conditions. These can be used to inform mine closure planning.

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Terry Harck (Pr.Sci.Nat 400088/95)

Hydrogeochemist

APPENDIX A

BOREHOLE LOGS

water earth life

BOREHOLE LOG

CLIENT:	Butsanani Joint Ventre	BOREHOLE NO : T7D	
PROJECT:	Rietvlei	COORDINATES (WGS84)	
SITE:	Rietvlei Colliery	X : 29.652838	
DRILLER:	Aqua Earth	Y : -25.685354	
DATE DRILLED:	11/2/2014	PLUNGE: Vertical	
LOGGED BY:	Francois Stassen	STATUS: Completed	

BOREHOLE DRILLING AND CONSTRUCTION DETAILS	STRIKES (mbgl)	Water level (m) (m)	Penetration Rate (mbgl)	DEPTH (m)	PROFILE	LITHOLOGICAL DESCRIPTION Rock type, colour, grain size, texture, weathering and fracturing
Drilling / Construction details				0		
Steel casing				0		
Concrete Block		1.7 m	0.1	1		Topsoil: Red
			0.15	2		
			0.2	3		
			0.3	4		
			0.4	6		Sand:Whitish Grey
			0.45	8		
PVC solid casing (125mm)			1.16	9		
			0.28	10		
			0.52	12		
			0.55	14		
			1.21	15		
			0.52	16		Sand:Yellowish White
			1.02	17		
			1.23	18		Sand:Greyish White
	19m		0.42	19		
			1.1	20		
			1.15	21		
Gravel pack			0.42	22		
			1.43	24		
			0.52	25		Carbonaceous Shale: Greyish Black
			0.48	26		
			2.03	27		
			0.44	28		
			1.35	30		Coal: Black
			1.14	32		
			0.34	34		
			1.24	36		
			0.38	38		
			0.28	40		
			0.55	42		
	44m		0.4	44		
			1.09	45		
PVC perforated casing (125mm)			1.25	46		
			1.49	48		
			0.38	49		
			0.56	50		

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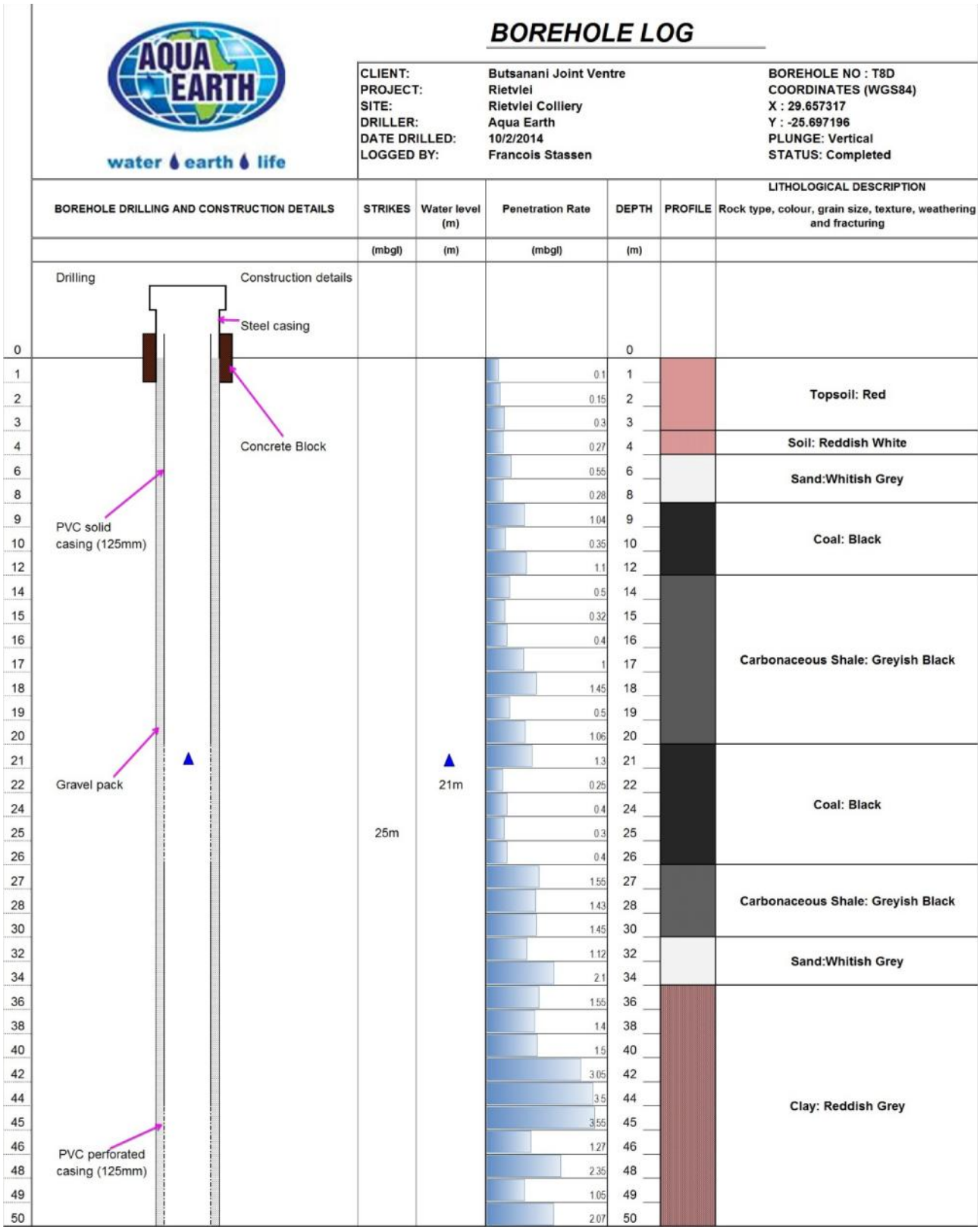
BOREHOLE LOG
AQUA EARTH
water earth life
CLIENT: Butsanani Joint Ventre
PROJECT: Rietvlei
SITE: Rietvlei Colliery
DRILLER: Aqua Earth
DATE DRILLED: 10/2/2014
LOGGED BY: Francois Stassen
BOREHOLE NO : T8D
COORDINATES (WGS84)
X : 29.657317
Y : -25.697196
PLUNGE: Vertical
STATUS: Completed
BOREHOLE DRILLING AND CONSTRUCTION DETAILS
STRIKES
Water level (m)
Penetration Rate
DEPTH
PROFILE
LITHOLOGICAL DESCRIPTION
Rock type, colour, grain size, texture, weathering and fracturing
(mbgl)
(m)
(mbgl)
(m)
Drilling
Construction details
Steel casing
Concrete Block
PVC solid casing (125mm)
Gravel pack
PVC perforated casing (125mm)
25m
21m
Topsoil: Red
Soil: Reddish White
Sand:Whitish Grey
Coal: Black
Carbonaceous Shale: Greyish Black
Coal: Black
Carbonaceous Shale: Greyish Black
Sand:Whitish Grey
Clay: Reddish Grey

APPENDIX B

LABORATORY REPORTS

WATERLAB

WATERLAB (PTY) LTD

Building D, The Woods,
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CERTIFICATE OF ANALYSES
TCLP / ACID RAIN / DISTILLED WATER EXTRACTIONS

Date received: 2014-02-14 **Date completed: 2014-03-10**
Project number: 221 **Report number: 44357** **Order number:**

Client name: Aqua Earth Consulting **Contact person: Pacome Ahokpossi**
Address: 72_5th Avenue, Fountainbleau, Randberg **E-mail: pacome@aquaearth.co.za**
Tel: 011 791 3490 **Facsimile: 011 507 6612**

Analyses	Sample Identification Rietvlei			
	T7D (12-21)		T7D (26-50)	
Sample number	30890		30891	
TCLP / Acid Rain / Distilled Water / H_2O_2	Distilled Water		Distilled Water	
Dry Mass Used (g)	250		250	
Volume Used (mℓ)	1000		1000	
pH Value at 25°C	5.6		8.0	
Units	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Total Dissolved Solids	24	96	126	504
Alkalinity as $CaCO_3$	<5	<20	64	256
Chloride as Cl	<5	<20	<5	<20
Sulphate as SO_4	<5	<20	31	124
Fluoride as F	<0.2	<0.8	1.7	6.8
ICP-OES Scan	See attached report 44357 DW		See attached report 44357 DW	
Acid Base Accounting	See attached report 44357 ABA		See attached report 44357 ABA	

E. Botha
Geochemistry Project Manager

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WATERLAB

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CERTIFICATE OF ANALYSES
TCLP / ACID RAIN / DISTILLED WATER EXTRACTIONS

Date received: 2014-02-14 **Date completed: 2014-03-10**
Project number: 221 **Report number: 44357** **Order number:**

Client name: Aqua Earth Consulting **Contact person: Pacome Ahokpossi**
Address: 72_5th Avenue, Fountainbleau, Randberg **E-mail: pacome@aquaearth.co.za**
Tel: 011 791 3490 **Facsimile: 011 507 6612**

Analyses	Sample Identification Rietvlei			
	T8D (11-21)		T8D (22-50)	
Sample number	30892		30893	
TCLP / Acid Rain / Distilled Water / H_2O_2	Distilled Water		Distilled Water	
Dry Mass Used (g)	250		250	
Volume Used (mℓ)	1000		1000	
pH Value at 25°C	7.9		8.1	
Units	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Total Dissolved Solids	80	320	96	384
Alkalinity as $CaCO_3$	40	160	64	256
Chloride as Cl	<5	<20	<5	<20
Sulphate as SO_4	27	108	21	84
Fluoride as F	0.5	2.0	1.0	4.0
ICP-OES Scan	See attached report 44357 DW		See attached report 44357 DW	
Acid Base Accounting	See attached report 44357 ABA		See attached report 44357 ABA	

E. Botha
Geochemistry Project Manager

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WATERLAB (PTY) LTD

CERTIFICATE OF ANALYSES

ICP-OES - SCAN

Date received:	14/02/2014	Date Completed:	10/03/2014
Project number:	221	Report number:	44357

Client name:	Aqua Earth Consulting	Contact person:	Pacome Ahokpossi
Adress:	72_5th Avenue, Fountainbleau, Randberg	Email:	pacome@aquaearth.co.za

Extract	Sample Dry Mass	Volume	Mass (g/l)	Factor
Distilled Water	250	1000	250	4

Sample Id	Sample number	Ag	Ag	Al	Al	As	As
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.025	<0.100	<0.100	<0.400	<0.010	<0.040
T7D (12-21)	30890	<0.025	<0.100	1.74	6.94	<0.010	<0.040
T7D (26-50)	30891	<0.025	<0.100	<0.100	<0.400	<0.010	<0.040
T8D (11-21)	30892	<0.025	<0.100	0.288	1.15	<0.010	<0.040
T8D (22-50)	30893	<0.025	<0.100	0.246	0.984	<0.010	<0.040

Sample Id	Sample number	B	B	Ba	Ba	Be	Be
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
T7D (12-21)	30890	<0.025	<0.100	0.029	0.116	<0.025	<0.100
T7D (26-50)	30891	0.058	0.232	0.306	1.22	<0.025	<0.100
T8D (11-21)	30892	<0.025	<0.100	0.228	0.912	<0.025	<0.100
T8D (22-50)	30893	<0.025	<0.100	0.128	0.512	<0.025	<0.100

Sample Id	Sample number	Bi	Bi	Ca	Ca	Cd	Cd
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.025	<0.100	<2	<8	<0.005	<0.020
T7D (12-21)	30890	<0.025	<0.100	<2	<8	<0.005	<0.020
T7D (26-50)	30891	<0.025	<0.100	20	80	<0.005	<0.020
T8D (11-21)	30892	<0.025	<0.100	12	48	<0.005	<0.020
T8D (22-50)	30893	<0.025	<0.100	17	68	<0.005	<0.020

Sample Id	Sample number	Co	Co	Cr	Cr	Cu	Cu
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
T7D (12-21)	30890	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
T7D (26-50)	30891	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
T8D (11-21)	30892	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
T8D (22-50)	30893	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100

Sample Id	Sample number	Fe	Fe	K	K	Li	Li
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.025	<0.100	<1.0	<4.0	<0.025	<0.100
T7D (12-21)	30890	0.280	1.12	2.0	7.9	<0.025	<0.100
T7D (26-50)	30891	<0.025	<0.100	7.9	31	<0.025	<0.100
T8D (11-21)	30892	0.044	0.176	5.2	21	<0.025	<0.100
T8D (22-50)	30893	0.060	0.240	7.8	31	<0.025	<0.100

Sample Id	Sample number	Mg	Mg	Mn	Mn	Mo	Mo
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<2	<8	<0.025	<0.100	<0.025	<0.100
T7D (12-21)	30890	<2	<8	<0.025	<0.100	<0.025	<0.100
T7D (26-50)	30891	6	24	<0.025	<0.100	0.049	0.196
T8D (11-21)	30892	7	28	0.097	0.388	<0.025	<0.100
T8D (22-50)	30893	4	16	<0.025	<0.100	<0.025	<0.100

Sample Id	Sample number	Na	Na	Ni	Ni	P	P
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<2	<8	<0.025	<0.100	<0.025	<0.100
T7D (12-21)	30890	<2	<8	<0.025	<0.100	<0.025	<0.100
T7D (26-50)	30891	2	9	<0.025	<0.100	<0.025	<0.100
T8D (11-21)	30892	<2	<8	<0.025	<0.100	<0.025	<0.100
T8D (22-50)	30893	8	32	<0.025	<0.100	<0.025	<0.100

Sample Id	Sample number	Pb	Pb	S	S	Sb	Sb
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.020	<0.080	<0.100	<0.400	<0.010	<0.040
T7D (12-21)	30890	<0.020	<0.080	0.743	2.97	<0.010	<0.040

T7D (26-50)	30891	<0.020	<0.080	11	44	<0.010	<0.040
T8D (11-21)	30892	<0.020	<0.080	10	40	<0.010	<0.040
T8D (22-50)	30893	<0.020	<0.080	9.18	37	<0.010	<0.040

Sample Id	Sample number	Se	Se	Si	Si	Sn	Sn
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.020	<0.080	<0.2	<0.8	<0.025	<0.100
T7D (12-21)	30890	<0.020	<0.080	7.3	29	<0.025	<0.100
T7D (26-50)	30891	<0.020	<0.080	3.4	13.5	<0.025	<0.100
T8D (11-21)	30892	<0.020	<0.080	3.4	13.6	<0.025	<0.100
T8D (22-50)	30893	<0.020	<0.080	3.2	12.7	<0.025	<0.100

Sample Id	Sample number	Sr	Sr	Ti	Ti	V	V
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
T7D (12-21)	30890	<0.025	<0.100	0.088	0.352	<0.025	<0.100
T7D (26-50)	30891	0.337	1.35	<0.025	<0.100	<0.025	<0.100
T8D (11-21)	30892	0.141	0.564	<0.025	<0.100	<0.025	<0.100
T8D (22-50)	30893	0.289	1.16	<0.025	<0.100	<0.025	<0.100

Sample Id	Sample number	W	W	Zn	Zn	Zr	Zr
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
T7D (12-21)	30890	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
T7D (26-50)	30891	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
T8D (11-21)	30892	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
T8D (22-50)	30893	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100

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APPENDIX C

GEOCHEMICAL MODELLING RESULTS

DECANT	TD7(12-21)	TD7(12-21)	TD7(26-50)	TD7(26-50)	TD8(11-21)	TD8(11-21)	TD8(22-50)	TD8(22-50)	MAX	MIN
	10%	40%	10%	40%	10%	40%	10%	40%		
pH	8.19	7.68	7.90	8.08	7.95	8.11	7.98	8.13	8.19	7.68
pe	12.41	12.91	12.69	12.52	12.65	12.49	12.62	12.47	12.91	12.41
F	3.95	1.00	4.00	3.33	4.35	4.84	4.03	3.39	4.84	1.00
Cl	254.37	64.29	1182.14	298.80	1070.04	270.44	1236.14	312.45	1236	64
S(6)	28.59	7.40	425.19	107.50	387.96	98.08	358.36	90.61	425	7.40
Alkalinity	103.91	26.97	62.19	72.91	66.24	80.70	68.64	80.33	104	27
Na	39.45	9.97	78.89	19.94	39.42	9.96	315.56	79.76	316	9.96
K	78.90	19.94	311.62	78.77	205.14	51.85	307.68	77.77	312	20
Ca	39.45	9.97	236.54	73.67	185.39	63.03	165.99	57.12	237	9.97
Mg	39.45	9.97	236.68	59.82	276.13	69.79	157.78	39.88	276	9.97
Ag	0.49	0.12	0.49	0.12	0.49	0.12	0.49	0.12	0.49	0.12
Al	0.00	0.00	0.14	0.02	0.09	0.24	0.13	0.03	0.24	0.00
As	0.20	0.05	0.20	0.05	0.20	0.05	0.20	0.05	0.20	0.05
Ba	0.14	0.29	0.03	0.05	0.03	0.05	0.03	0.05	0.29	0.03
Be	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01
Cd	0.05	0.02	0.10	0.02	0.10	0.02	0.10	0.02	0.10	0.02
Co	0.01	0.11	0.10	0.03	0.08	0.12	0.49	0.02	0.49	0.01
Cr	0.37	0.12	0.03	0.00	0.02	0.01	0.02	0.01	0.37	0.00
Cu	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Hg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mo	0.49	0.12	1.93	0.49	0.49	0.12	0.49	0.12	1.93	0.12
Ni	0.49	0.12	0.49	0.12	0.49	0.12	0.49	0.12	0.49	0.12
Pb	0.00	0.01	0.13	0.00	0.11	0.02	0.11	0.07	0.13	0.00
Sb	0.20	0.05	0.20	0.05	0.20	0.05	0.20	0.05	0.20	0.05
Se	0.39	0.10	0.39	0.10	0.39	0.10	0.39	0.10	0.39	0.10
Sr	0.49	0.12	13.29	3.36	5.56	1.41	11.40	2.88	13.29	0.12
Tl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V	0.49	0.12	0.49	0.12	0.49	0.12	0.49	0.12	0.49	0.12
Zn	0.49	0.12	0.49	0.12	0.49	0.12	0.49	0.12	0.49	0.12
Fe	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TDS	588	150	2537	715	2235	649	2614	741	2614	150
Precipitate	Barite		Barite	Barite	Barite	Barite	Barite	Barite		
	Be(OH)2	Be(OH)2	Be(OH)2	Be(OH)2	Be(OH)2	Be(OH)2	Be(OH)2	Be(OH)2		
	Calcite		Calcite	Calcite	Calcite	Calcite	Calcite	Calcite		
			Cerrusite		Cerrusite			Cerrusite		
			CoCO3				CoCO3			
	Co(OH)3	Co(OH)3	Co(OH)3	Co(OH)3	Co(OH)3			Co(OH)3		
	Ferrihydrite	Ferrihydrite	Ferrihydrite	Ferrihydrite	Ferrihydrite	Ferrihydrite	Ferrihydrite	Ferrihydrite		
			Fluorite	Fluorite	Fluorite	Fluorite	Fluorite	Fluorite		
			Magnesite	Magnesite						
	Malachite	Malachite	Malachite	Malachite	Malachite	Malachite	Malachite	Malachite		
	Manganite	Manganite	Manganite	Manganite	Manganite	Manganite	Manganite	Manganite		
	Otavite		Otavite	Otavite	Otavite					
			Strontianite	Strontianite	Strontianite					

BACKFILL	TD7(12-21)	TD7(12-21)	TD7(26-50)	TD7(26-50)	TD8(11-21)	TD8(11-21)	TD8(22-50)	TD8(22-50)	MAX	MIN
	10%	40%	10%	40%	10%	40%	10%	40%		
pH	5.37	5.40	6.14	6.53	6.22	6.29	6.17	6.50	6.53	5.37
pe	4.07	4.39	5.47	5.25	5.33	5.37	5.52	5.35	5.52	4.07
F	3.95	1.00	4.14	3.33	4.35	4.95	4.04	3.40	4.95	1.00
Cl	254.43	64.29	1182.71	298.83	1070.43	270.46	1236.71	312.48	1237	64
S(6)	28.60	7.40	425.40	107.52	388.12	98.10	358.54	90.63	425	7.40
Alkalinity	161.31	41.01	1578.10	632.58	1445.40	367.83	1624.70	609.14	1625	41
Na	39.46	9.97	78.93	19.94	39.44	9.97	315.70	79.77	316	9.97
K	78.92	19.94	311.77	78.77	205.22	51.85	307.83	77.78	312	20
Ca	39.46	9.97	537.61	185.06	456.29	119.37	474.92	162.31	538	9.97
Mg	39.46	9.97	236.79	59.83	276.25	69.80	157.85	39.88	276	9.97
Ag	0.49	0.12	0.49	0.12	0.49	0.12	0.49	0.12	0.49	0.12
Al	0.00	0.00	0.14	0.02	0.09	0.24	0.13	0.03	0.24	0.00
As	0.20	0.05	0.20	0.05	0.20	0.05	0.20	0.05	0.20	0.05
Ba	0.15	0.29	0.04	0.06	0.04	0.06	0.04	0.07	0.29	0.04
Be	0.49	0.12	0.49	0.12	0.47	0.12	0.49	0.12	0.49	0.12
Cd	0.10	0.02	0.10	0.02	0.10	0.02	0.10	0.02	0.10	0.02
Co	0.49	0.12	0.49	0.12	0.49	0.12	0.49	0.12	0.49	0.12
Cr	0.37	0.12	0.03	0.00	0.02	0.01	0.02	0.01	0.37	0.00
Cu	0.49	0.12	0.49	0.12	0.49	0.12	0.49	0.12	0.49	0.12
Hg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mn	0.49	0.12	0.07	0.12	3.83	0.97	0.49	0.12	3.83	0.07
Mo	0.49	0.12	1.93	0.49	0.49	0.12	0.49	0.12	1.93	0.12
Ni	0.49	0.12	0.49	0.12	0.49	0.12	0.49	0.12	0.49	0.12
Pb	0.00	0.01	0.39	0.00	0.33	0.02	0.36	0.10	0.39	0.00
Sb	0.20	0.05	0.20	0.05	0.20	0.05	0.20	0.05	0.20	0.05
Se	0.39	0.10	0.39	0.10	0.39	0.10	0.39	0.10	0.39	0.10
Sr	0.49	0.12	13.30	3.36	5.56	1.41	11.41	2.88	13.30	0.12
Tl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V	0.49	0.12	0.49	0.12	0.49	0.12	0.49	0.12	0.49	0.12
Zn	0.49	0.12	0.49	0.12	0.49	0.12	0.49	0.12	0.49	0.12
Fe	10.89	2.79	0.01	0.00	0.01	0.00	0.01	0.00	10.89	0.00
TDS	646	164	4355	1386	3885	992	4480	1375	4480	164
Precipitate	Barite		Barite	Barite	Barite	Barite	Barite	Barite		
					Be(OH)2	Be(OH)2				
			Calcite		Calcite		Calcite			
					Cerrusite		Cerrusite			
	Cr(OH)3		Cr(OH)3	Cr(OH)3	Cr(OH)3	Cr(OH)3	Cr(OH)3	Cr(OH)3		
	Ferrihydrite	Ferrihydrite	Ferrihydrite	Ferrihydrite	Ferrihydrite	Ferrihydrite	Ferrihydrite	Ferrihydrite		
			Fluorite	Fluorite	Fluorite		Fluorite	Fluorite		
			Gibbsite	Gibbsite	Gibbsite	Gibbsite	Gibbsite	Gibbsite		
	Sn(OH)4	Sn(OH)4		Sn(OH)4	Sn(OH)4	Sn(OH)4	Sn(OH)4	Sn(OH)4		
					FCO3Apatite	FCO3Apatite	FCO3Apatite	FCO3Apatite		
	Pyromorphite	Pyromorphite		Pyromorphite		Pyromorphite				
			MnHPO4			MnHPO4				