TSHIPI BORWA WASTE ROCK DUMP EXTENSION PROJECT GROUNDWATER STUDY

Tshipi Borwa Manganese Mine

Prepared for: Tshipi e Ntle Manganese Mining (Pty) Ltd

Authority References:
DMR Reference No: NC/30/5/1/2/2/206MR

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EXECUTIVE SUMMARY

Introduction

Tshipi é Ntle Manganese Mining (Tshipi) operates the open pit manganese Tshipi Borwa Mine located on the farms Mamatwan 331 (mining right and surface use areas) and Moab 700 (surface use area), in the John Taolo Gaetsewe District Municipality (JTGDM) and Joe Morolong Local Municipality (JMLM) in the Northern Cape Province.

Tshipi is now proposing the Tshipi Borwa Waste Rock Dump Extension Project (the Project) which includes:

- The extension of the existing East Waste Rock Dump (WRD) to the mining right boundary and towards the Mamatwan WRD and eventually filling the void between these dumps, to provide additional overburden storage capacity;
- The extension of the existing West WRD onto Portion 8 of the farm Mamatwan 331;
- The construction of an 11kV overhead powerline along the Portion 8 boundary onto the existing mining right area. This powerline will be fed by an approved Eskom powerline and associated sub-station; and
- The construction of an overland conveyor system from the existing secondary crushing and screening plant to the existing manganese ore product stockpiles.

SLR Consulting (Africa) (Pty) Ltd (SLR) has been appointed to manage the environmental authorisation processes. This groundwater study supports the environmental authorisation processes and water use licence application process and assesses the proposed project with respect to contamination groundwater impacts. This report complies with the requirements of Regulation 267 promulgated in terms of the National Water Act (NWA) (Act 36 of 1998) and Regulation 326 promulgated in terms of the National Environmental Management Act (NEMA) (Act 107 of 1998, as amended).

Methodology

A desk study was undertaken to collate all pertinent data relating to geology of the project area, hydrogeological characteristics of the project area and the proposed project infrastructure and activities.

This was followed by the development of a three-dimensional groundwater numerical model to simulate flow and mass transport, for operational and post mining scenarios. The model included existing and proposed pollution sources in order to assess potential cumulative impacts for the overall mine. The model additionally considered both the unmitigated scenario in which the waste rock dumps (WRDs) are not lined as is currently the case at Tshipi, as well as the mitigated scenario where the WRDs are lined. The results of the numerical model have been used to assess potential groundwater contamination impacts.

Baseline summary

<u>Groundwater levels</u>
Prior to mining, groundwater flow at the site was from south-east to north-west following the path of the towards the non-perennial Vlermuisleegte river and towards the Ga-Mogara River, located approximately 10 km to the west of the site (WGC, 2009). The groundwater flow is from areas of higher lying ground towards the valleys.

<u>Groundwater aquifer zones</u>
The unsaturated zone is approximately 45 m deep and falls within the Kalahari Formation.

Based on the desktop information review, the following aquifer zones are relevant:

- Shallow aquifer in the Kalahari beds with low hydraulic conductivity of less than 10 metres per day (m/d) (WGC 2009). The Kalahari beds are approximately 70 m thick (SLR 2012). With a water table at 45 m below ground, the shallow aquifer is approximately 25 m thick
- Low permeability Dwyka tillite layer with hydraulic conductivity of less than 0.1 m/d (WGC 2009)
- Deep fractured aquifer with hydraulic conductivity of less than 1 m/d, consisting of Mooidraai Dolomite and Hotazel Formation (manganese ore body) (WGC 2009) (SLR, 2015).

Groundwater quality

Historical information on the groundwater quality in the region was obtained from the National Groundwater Database (NGDB). The results indicated the water in the vicinity was generally elevated in chloride, magnesium, nitrate and to a lesser extent, calcium.

A pre-mining hydrocensus was conducted in 2009 and included groundwater quality testing. These sampling results showed that the groundwater quality in the area ranged from marginal to dangerous for domestic use (DWAF classification of Class 2 and 4). This was mainly due to elevated nitrate levels. In addition, calcium and magnesium exceeded the resource water quality objectives stipulated in the Tshipi Integrated Water Use Licence.

Groundwater and surface water monitoring has been undertaken at the mine on a quarterly basis since 2012. When comparing results against relevant water quality standards, various chemicals of concern were identified, such as chloride (Cl), nitrate (NO_3), aluminium (Al), arsenic (As), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni) and selenium (Se).

Source term

A source term was developed using the acid base and leach test results of water rock material. This source term was used for the groundwater modelling. The acid base results showed that all 23 samples tested had negligible potential to generate acid drainage due to non-detectable sulphur content. The leach test results indicated that a number of metals are leachable at concentrations in excess of relevant water quality standards including aluminium (Al), arsenic (As), barium (Ba), iron (Fe) and manganese (Mn).

The 2016 Waste Assessment study completed by Goloder and Associates indicates that there are no significant parameters of concern with respect to the waste rock material. In addition, the waste rock material was found to be non-hazardous and non-potentially acid generating (non-PAG). In the absence of a parameter of concern from the waste study, chloride was selected for contaminant transport simulation as a conservative parameter which remains in solution and should therefore provide the maximum plume extent. This is consistent with other groundwater and geochemical studies conducted for mining projects in the Northern Cape. Manganese is not typically used in contaminant simulation because the baseline manganese levels are already elevated in groundwater and manganese reacts with other chemical components, therefore simulation using manganese would not result in a conservative and meaningful simulation.

Groundwater Impacts

Key findings of the cumulative pollution modelling exercise include:

- The maximum chloride plume is predicted to extend up to 1,1 km in a western direction at the end of the simulation (year 100) in the unmitigated scenario, and 700 m in the mitigated scenario. Both scenarios result in a plume of low concentration outside of the mining right area.
- There are no known third party boreholes within the predicted pollution plumes in the unmitigated and mitigated scenarios using boreholes for water supply.
- This impact has been rated as having a low significance in both the unmitigated and mitigated scenarios. The relevant mitigation measures are outlined in Section 0.

Based on the above assessment, and assuming that the relevant mitigation measures will be effectively implemented; there are no apparent reasons why the project should not be authorised. In addition, the lining of the waste rock dumps does not significantly reduce the pollution plume or impact significance.

Groundwater Environmental Management Programme

Mitigation Measures

Mitigation measures are provided below. The management actions include any measures outlined in the mine's approved EMPr for both dewatering and pollution impacts for the sake of completeness.

Groundwater Management Plan

No.	Aspect	Management commitment	Action plan		
			Timeframe	Frequency	Compliance indicator
Objective: Prevent quantity impacts to users of groundwater and in nearby surface water systems.					
These commitments apply to construction, operation and decommissioning					
1	Monitoring	Monitor groundwater quality as outlined in Section 11.	Ongoing	As per Section 11	Water monitoring reports
2	Compensation (if required)	If borehole users experience any mine related water contamination or loss of water supply, Tshipi will, in conjunction with other mines in the area that are contributors to the cumulative impact, provide compensation, which could include an alternative water supply of equivalent water quality and quantity.	As required	As required	Investigation report and record of compensation if required
3	Impacts on ground or surface water	In the event that water quality monitoring around any pollution sources (TSF, open pit and WRDs) indicates that these sources are causing pollution, additional management measures will be investigated in consultation with a qualified specialist.	As required	As required	Investigation report and record of corrective action
		Should any off-site contamination be detected, the mine will immediately notify DWS. The mine, in consultation with DWS and an appropriately qualified person, will then notify potentially affected users, identify the source of contamination, identify measures for the prevention of this contamination (in the short term and the long term) and then implement these measures.	As required	As required	Proof of notification of DWS and potentially affected users. Investigation report and record of corrective action
		If monitoring shows that the base flow of the Vlermuisleegte is affected, a specialist team comprising DWS and biodiversity and groundwater experts will be commissioned to investigate the significance of the impacts and the specific management actions that must be implemented by all contributing mines.	As required	As required	Investigation report and record of corrective action
4	Rehabilitation	Should waste rock dumps be removed through backfill of the pit, the footprint area will be rehabilitated by ripping the underlying subsoil, then replacing the topsoil, vegetating, applying fertilizer, and irrigating the new growth for a short period.	Closure	Once off	Rehabilitation reporting

No.	Aspect	Management commitment	Action plan		
			Timeframe	Frequency	Compliance indicator
5	Closure planning	The groundwater model will be re-run periodically during the operation phase to consider potential pollution impacts without the retardation effect of pit dewatering. If necessary, provision will be made by the mine for post closure compensation that may be required for any future negative impacts. This will form part of detailed closure planning	As required	As required	Groundwater model report
6	Emergency	In case of a major discharge incident that may result in the pollution of groundwater resources the Tshipi emergency response procedure will be followed.	As required	As required	Incident investigation report and record of corrective action

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ACRONYMS AND ABBREVIATIONS

Acronym / Abbreviation	Definition
ABA	Acid base accounting
Al	Aluminium
Ca	Calcium
$CaCO_3$	Calcium Carbonate
Cl	Chloride
CO_3	Carbonate
DENC	Department of Environment and Nature Conservation
DMR	Department of Mineral Resources
DWAF	Department of Water Affairs and Forestry (Now the Department of Water and Sanitation)
DWS	Department of Water and Sanitation
EC	Electrical conductivity
EIA	Environmental Impact Assessment
EMPr	Environmental Management Programme
F	Fluoride
Fe	Iron
HCO_3	Bicarbonate
IAP	Interested and Affected Party
JMLM	Joe Morolong Local Municipality
JTGDM	John Taolo Gaetsewe District Municipality
K	Hydraulic conductivity, m/d
mamsl	Metres above mean sea level
MAE	Mean annual evaporation
MAP	Mean annual precipitation
mbgl	Metres below ground level
Mg	Magnesium
mg/ℓ	Milligrams per litre (concentration)
Mn	Manganese
N	Nitrate

Acronym / Abbreviation	Definition
Na	Sodium
NEMA	National Environmental Management Act
NRMSE	Normalised Residual Mean Squared Error
NWA	National Water Act
RMSE	Residual Mean Squared Error
SANS	South African National Standards
SLR	SLR Consulting (Africa) (Pty) Ltd
SO_4	Sulphate
TDS	Total Dissolved Solids
TSF	Tailings Storage Facility
TWQG	Target Water Quality Guideline
UMK	United Manganese of Kalahari (Pty) Ltd
WMA	Water Management Area
WRC	Water Research Commission
WRD	Waste Rock Dump
IWUL	Integrated Water Use Licence

1. INTRODUCTION

Tshipi é Ntle Manganese Mining (Tshipi) operates the open pit manganese Tshipi Borwa Mine located on the farms Mamatwan 331 (mining right and surface use areas) and Moab 700 (surface use area), in the John Taolo Gaetsewe District Municipality (JTGDM) and Joe Morolong Local Municipality (JMLM) in the Northern Cape Province. The mine location is illustrated in Figure 1-1 (regional setting) and Figure 1-2 (local setting).

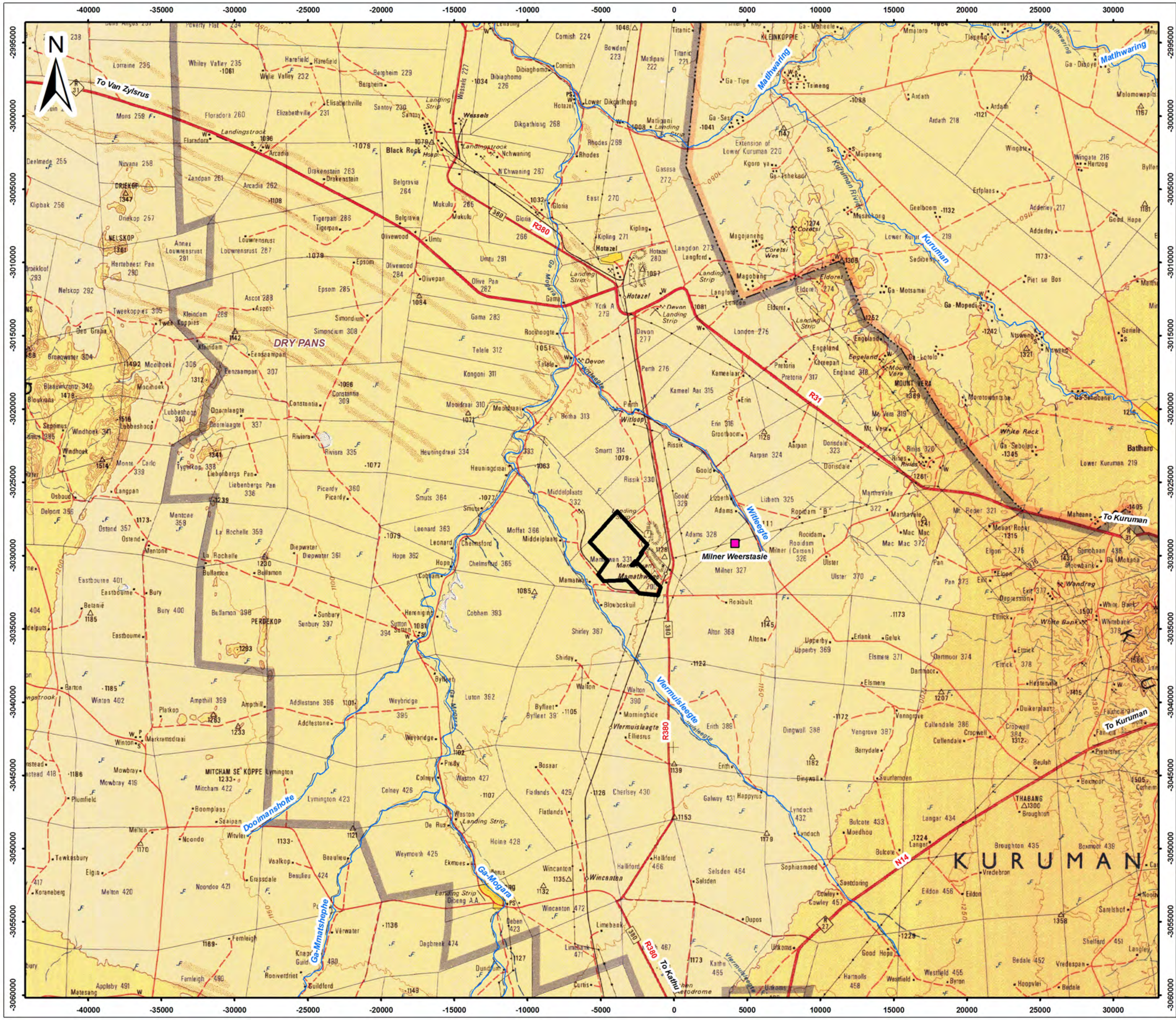
The mine holds a mining right (NC/30/5/1/2/2/0206MR) and an Environmental Management Programme report (EMPr) issued and approved by the Department of Minerals and Energy (currently the Department of Mineral Resources (DMR)), an environmental authorisation (EA) (NC/KGA/KATHU/37/2008) issued by the Department of Tourism, Environment and Conservation (currently the Department of Environment and Nature Conservation (DENC)) and an Integrated Water Use License (IWUL) (10/D41K/AGJ/1735) issued by the Department of Water Affairs and Forestry (DWAF) (currently the Department of Water and Sanitation (DWS)).

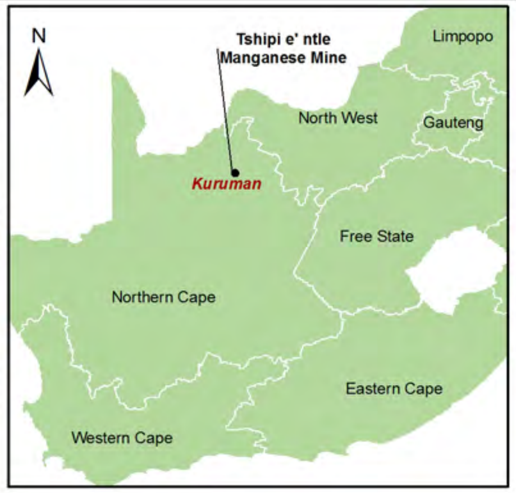
Tshipi is now proposing the Tshipi Borwa Waste Rock Dump Extension Project (the Project) which includes (refer to Figure 6-1):

- The extension of the existing East Waste Rock Dump (WRD) to the mining right boundary and towards the Mamatwan WRD and eventually filling the void between these dumps, to provide additional overburden storage capacity;
- The extension of the existing West WRD onto the remaining extent of Portion 8 of the farm Mamatwan 331;
- The construction of an 11kV overhead powerline along the Portion 8 boundary onto the existing mining right area. This powerline will be fed by an approved Eskom powerline and associated sub-station; and
- The construction of an overland conveyor system from the existing secondary crushing and screening plant to the existing manganese ore product stockpiles.

SLR Consulting (Africa) (Pty) Ltd (SLR), an independent firm of environmental consultants, has been appointed to manage the environmental authorisation processes. This groundwater study supports the environmental authorisation processes and water use licence application process and assesses the proposed project with respect to contamination groundwater impacts. The project does not include dewatering activities, and the dewatering impacts resulting from open pit mining will not be re-assessed in this report.

This report complies with the requirements of Regulation 267 promulgated in terms of the National Water Act (NWA) (Act 36 of 1998) and Regulation 326 promulgated in terms of the National Environmental Management Act (NEMA) (Act 107 of 1998, as amended).





Legend

- Main Roads
- Rivers
- Project Area

0 4 8 Kilometers

Scale: 1:20 000 000 @ A3

Projection: Transverse Mercator
Datum: Hartebeesthoek, Lo 23

Tshipi é Ntle Manganese Mining (Pty) Ltd

Figure 1-1

Regional Setting

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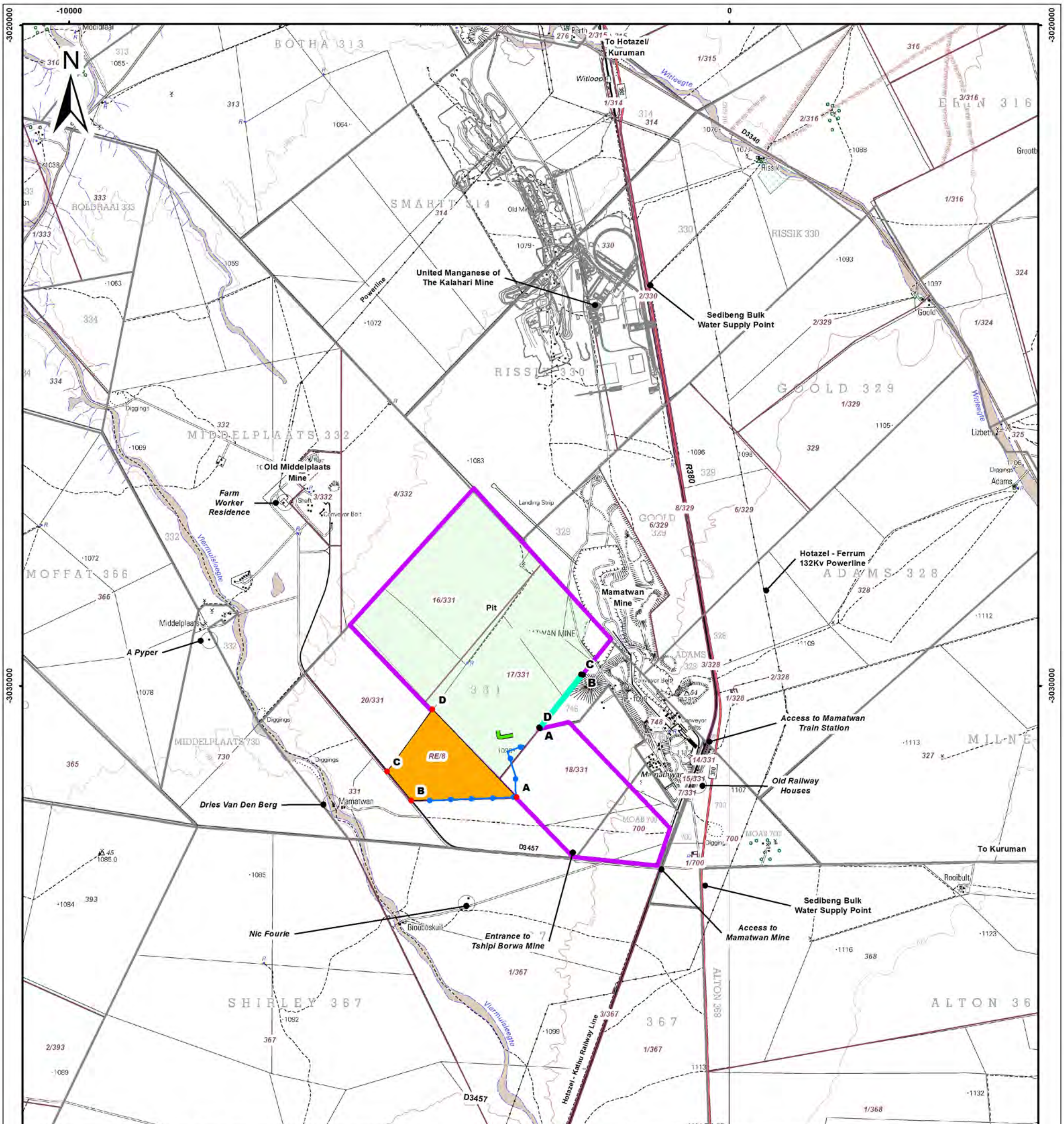

Western Waste Rock Site Coordinates (WGS84)

CID	Latitude	Longitude
A	27° 23' 51.38" S	22° 58' 2.89" E
B	27° 23' 53.05" S	22° 57' 4.68" E
C	27° 23' 38.75" S	22° 56' 51.37" E
D	27° 23' 8.18" S	22° 57' 16.53" E

Eastern Waste Rock Site Coordinates (WGS84)

CID	Latitude	Longitude
A	27° 23' 17.56" S	22° 58' 15.85" E
B	27° 22' 51.19" S	22° 58' 39.44" E
C	27° 22' 51.08" S	22° 58' 38.35" E
D	27° 23' 17.05" S	22° 58' 15.15" E

Legend

- Main Road
- Rivers
- 20m Contours
- Power Lines
- Proposed 11kV Power Line
- Proposed Overland Conveyor System
- Proposed West Waste Rock Dump Extension
- Proposed East Waste Rock Dump Extension
- Approved Mining Right Area
- Surface Use Area
- Farm Boundaries
- Farm Portions

0 1 000 2 000 Meters
Scale: 1:60 000 @ A3
Projection: Transverse Mercator
Datum: WGS1984, Lo23

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Figure 1-2:

Local Setting

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3. DETAILS OF SPECIALIST

Hydrogeologist Mihai Muresan prepared this groundwater report – see Table 3-1 below.

Table 3-1: Details of Report Author

Details	Project Manager, author and reviewer
Name	Mihai Muresan
Tel No.:	011 467 0945
Fax No.:	011 467 0978
E-mail address	Mmuresan@slrconsulting.com
Key qualifications	M.Sc. in Hydrogeology and Engineering Geology
Experience	Over 25 years
Professional registration	South African Council for Natural Scientific Professions: 400105/10

4. DECLARATION

I, Mihai Muresan hereby declare that I am an independent consultant, who has no interest or personal gains in this proposed project whatsoever, except receiving fair payment for rendering an independent professional service.

I am a hydrogeologist with over 25 years' experience conducting hydrogeological assessments for the mining industry. I am a registered professional scientist with the South African Council for Natural Scientific Professions.

My curriculum Vitae is provided in APPENDIX A.

Signature:

5. GEOGRAPHICAL SETTING

5.1 TOPOGRAPHY AND DRAINAGE

The mine falls within the Lower Vaal Water Management Area (WMA) and quaternary catchment D41K. The main rivers in this WMA include the Harts Malopo and Vaal Rivers.

In general the area surrounding the Tshipi Borwa Mine is relatively flat with a gentle slope towards the North West. The elevation varies from 1087 m to 1107 m above mean sea level (mamsl). There are a number of koppies and elongated east-west trending dykes which are post-Mapedi Bostonite dykes. To the west of the mine the local topographic high is formed by outcropping pink and brown quartzite and to the east the ridges and koppies are formed by the Danielskuil formation crocidolite of the Asberge formation. The site has a gradient of 20 m over 5000 m. The ground on site slopes towards the west, where the non-perennial drainage line Ga-Mogara, is located. The Vlermuisleegte River is located approximately two kilometers west from the Tshipi Borwa Mine boundary.

The natural topography of the area surrounding the Tshipi Borwa Mine has been influenced through the presence of mining activities such as the older but operational Mamatwan Mine, the closed Middelplaats Mine and the newer and operational United Manganese of Kalahari Mine. The highest topographical features near the Tshipi Borwa Mine are the Mamatwan waste rock dumps located adjacent to the eastern boundary of the Tshipi Borwa Mine (Figure 1-2).

5.2 CLIMATE

The mine is located in a summer rainfall region in which most of the precipitation occurs from October to April. The closest rainfall station's data available from DWS is from the Olifantshoek meteorological station located 70 km south of the old mine workings. The rainfall data available represents the period between 1960 and 2000.

Based on the data retrieved from the Olifantshoek station the average annual precipitation is 325 mm/annum as shown in Figure 5-1 below.

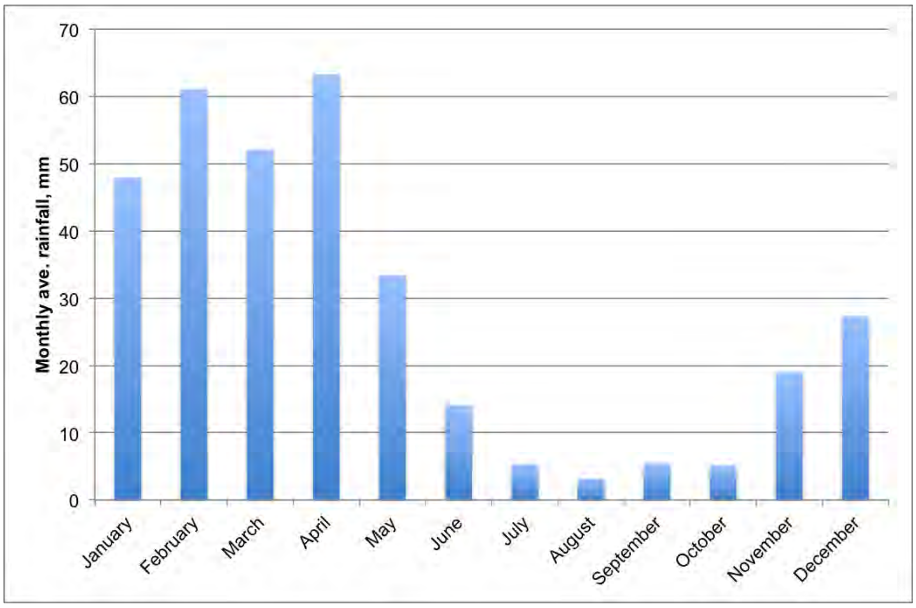


Figure 5-1: Average Monthly Rainfall

The average annual evaporation is 2114 mm/annum. Based on the GRAII dataset the average annual rainfall for quaternary catchment D41K is 344 mm/annum. Furthermore, the expected groundwater recharge in quaternary catchment D41K is 1% (3.25 mm/a) and 3% (9.75 mm/a) of rainfall. High evaporation rates, low rainfall, and the hydraulic characteristics of the underlying geology combined lead to these very small percentages of rainfall infiltrating the soil and rock to recharge the groundwater.

6. SCOPE OF WORK

This groundwater supports the environmental authorisation processes and water use licence application process. This study assesses the project changes to infrastructure and activities with respect to potential contamination groundwater impacts.

The revised surface layout is provided in Figure 6-1. This groundwater study focussed on the mining of the barrier with associated backfilling and changes to waste rock dumps.

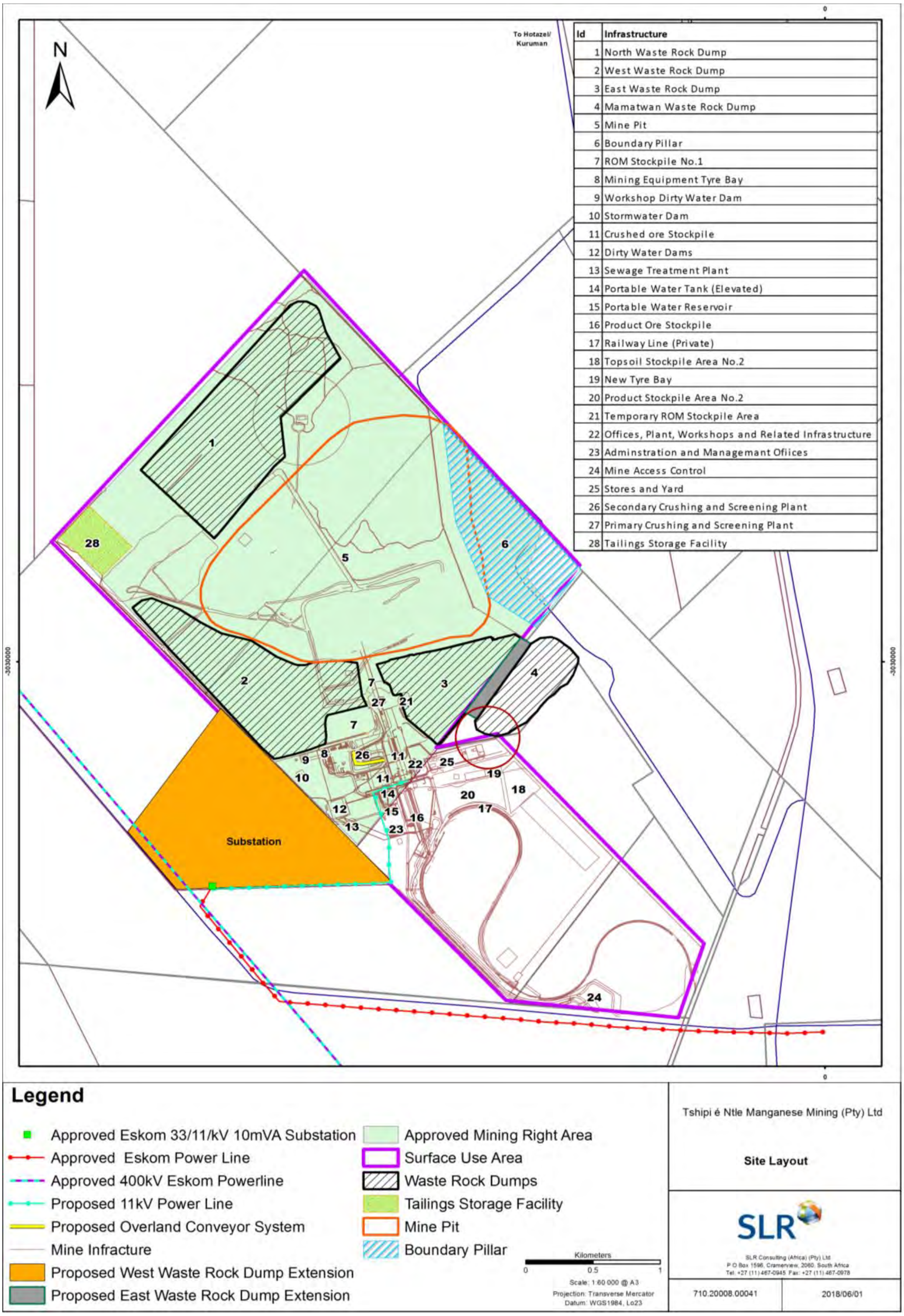


Figure 6-1: Site Layout

7. METHODODLOGY

This section describes the methodology used to conduct this groundwater study.

7.1 DESK STUDY

A desk study was undertaken to collate all pertinent data relating to:

- Geology of the project area
- Hydrogeological characteristics of the project area
- Proposed mining activities.

The available information examined which was applicable to the groundwater study is listed in Table 7-1.

Table 7-1: Sources of Data

Project	Document Title	Author and Reference	Document Date
Hydrocensus	TSHIPI Hydrocensus field report	Metago Environmental Engineers (Pty) Ltd	June 2006
Ntsimbintle Groundwater Assessment	Groundwater investigation for Ntsimbintle mine	U002-01	February 2009
Hydrocensus	Tshipi Borwa Mine: Hydrocensus Study	Water Geosciences Consulting	2012/08/01
Pit Lake Study	Hydrogeological Assessment for Mine Closure Planning - Pit Lake Formation - Site Report and Analytical Model	Ntsimbintle 27/02/09	November 2012
Geochemical Assessment	Geochemical and Groundwater Assessment	Knight Pièsold Consulting	March 2014
Groundwater Risk Assessment	Tshipi Borwa New Waste Rock Dump Groundwater Risk Assessment	RI301-00321/02	April 2015
Waste Type Assessment	Waste classification assessment for Tshipe e Ntle Mine	SLR Consulting (Africa) (Pty) Ltd	February 2016
Environmental Monitoring Report	4th Quarterly Water Monitoring Report and Annual Water Quality Report: 2015-2016.	721.20008.00015	February 2016
Environmental Monitoring Report	Tshipi Borwa Mine: Water Monitoring Report Quarter 2: October 2016	SLR Consulting (Africa) (Pty) Ltd	December 2016
EMP amendment 1	20180105_710.20008.00036_R01_Tshipi_Groundwater	SLR Consulting (Africa) (Pty) Ltd	January 2018

The reports and documents pertinent to the hydrogeological study are briefly overviewed below:

- A hydrocensus was first undertaken by Metago in November 2006 to define the groundwater within a 10 km radius of the mine. Twenty (20) groundwater sites were visited and the groundwater level recorded at nineteen (19) locations and twelve (12) groundwater samples submitted for analysis (Metago, 2006).
- A second hydrocenses was undertaken by Metago in November 2008 to define the groundwater in the region. Seven (7) groundwater levels and seven (7) groundwater samples were collected for analysis as part of a groundwater assessment conducted with Water Geosciences Consulting (WGC). The assessment consisted of a desktop review in terms of structural geology and groundwater reserve and a field investigation including a geophysical survey, drilling of three (3) boreholes and pumping tests on two (2) boreholes. A conceptual site model was developed and used to construct a groundwater numerical model using the MODFLOW software (WGC, 2009).
- Another hydrocenses was concluded by Knight Pièsold in 2012 to determine the overall groundwater levels within the area and the likely impact of the mining activity on the groundwater. A total of 31 boreholes/water points were identified during the hydrocensus. Two sets of water level data were recorded, one set consisting of water levels from the pit area and the other from surrounding boreholes (Knight Pièsold, 2012).
- A hydrogeological assessment was undertaken by SLR (2012) to estimate final pit lake elevations as well as the time to reach the final pit lake level during post-closure phases (SLR, 2012).
- A geochemical assessment was undertaken by SLR in 2014 to geochemically characterise material likely to be used to backfill the open pit at the Tshipi Borwa Mine. Twenty three (23) rock samples were collected and sent to a laboratory for geochemical analysis. Geochemical modelling was also performed using the PHREEQC software (SLR, 2014).
- A groundwater risk assessment was undertaken by SLR (2015) to assess the potential impact of the Eastern WRD at Tshipi Borwa Mine with the aim to update the hydrogeological conceptual model and show the potential spread of a contaminated groundwater plume from the WRD with analytical calculations in Excel (SLR, 2015).
- A waste assessment and classification was undertaken by Golder Associates in February 2016 to determine waste type and liner requirements for the mineral waste from composite samples collected from the three (3) waste rock dumps (Golder Associates, 2016).
- Ongoing groundwater and surface water monitoring has been undertaken on a quarterly basis since 2012. The objective of the monitoring is to identify whether the mining operations, which commenced in 2013, are negatively impacting the surrounding water resources. Seven (7) groundwater and six (6) surface water points were monitored (SLR, 2016).

- A Groundwater Study, including the groundwater numerical model, was undertaken in support of the first EMP amendment (EMP1) (SLR Consulting Africa (PTY) Ltd, 2018).

The mining information was transmitted by the Tshipi Mine and consisted of current and future mining plans, current waste rock dumps, and waste rock survey data from the adjacent Mamatwan Mine (as received).

No new boreholes were drilled for the current study. Instead relevant information was used from the previous studies mentioned above. The following key information components were sourced from these studies:

- Hydrocensus information Aquifer characteristics and recharge
- Groundwater levels and water quality
- Source term for waste rock (sourced from 2015 SLR groundwater report for the Eastern WRD).

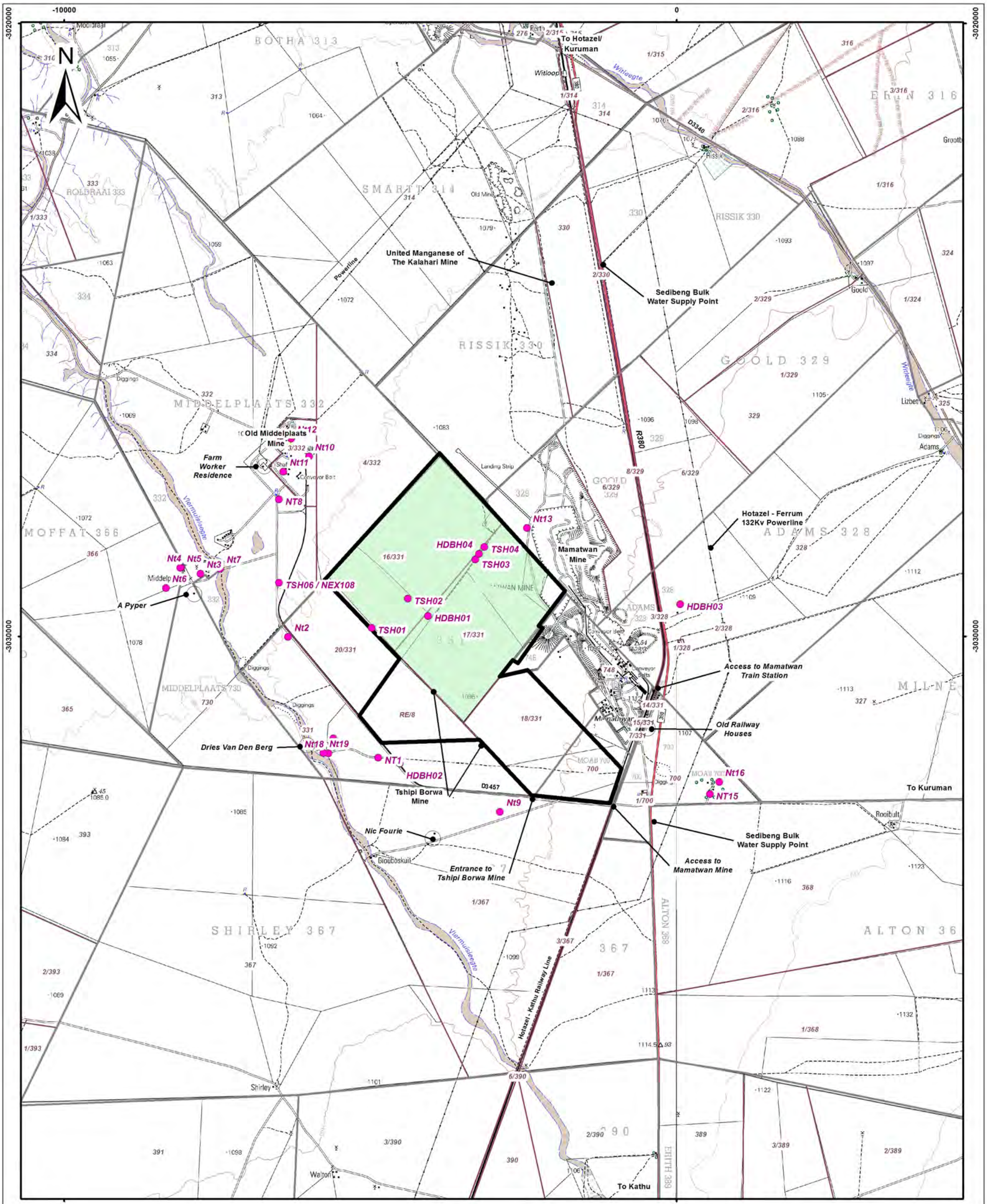
Table 7-2: Summary of Hydrocensus Boreholes (Metago, 2009)

Site name	Farm Name	Water point type	Water use	Longitude	Latitude	Water level (mbgl)
Nt1	Mamatwan 331 RE	Borehole	Livestock watering	27º24´ 01.0˝	22º57´ 02.8˝	N/P - equipped
Nt2		Reservoir	Livestock watering	27º22´ 43.1˝	22º55´ 58.4˝	N/A
Nt3	Middelplaats 730	Borehole	Not in use	27º22´ 22.6˝	22º55´ 24.6˝	dry
Nt4	Middelplaats 730	Borehole	Not in use	27º22´ 20.4˝	22º55´ 17.5˝	23.00
Nt5	Middelplaats 730	Borehole	Not in use	27º22´ 20.5˝	22º55´ 17.2˝	dry
Nt6	Middelplaats 730	Borehole	Livestock watering	27º22´ 28.2˝	22º55´ 11.3˝	N/P - equipped
Nt7	Middelplaats 730	River		27º22´ 21.1˝	22º55´ 32.1˝	N/A
Nt8	Middelplaats RE	Borehole	Domestic use	27º21´ 44.0˝	22º56´ 03.8˝	N/P - equipped
Nt9	Shirley portion 2	Borehole	Livestock watering	27º24´ 46.6˝	22º57´ 32.2˝	N/P - equipped
Nt10	Middelplaats	Borehole	-	27º21´ 30.0˝	22º56´ 20.8˝	28.00
Nt11	Middelplaats	Borehole	-	27º21´ 33.9˝	22º56´ 11.6˝	28.02
Nt12	Middelplaats	Borehole	-	27º21´ 01.9˝	22º56´ 10.6˝	29.46
Nt13	Mamatwan	Borehole	-	27º21´ 44.7˝	22º58´ 05.0˝	dry
Nt14	Alton 368	Borehole	Livestock watering	27º26´ 45.7˝	22º58´ 31.6˝	N/P - equipped
Nt15	Moab 700	Borehole	Livestock watering	27º24´ 20.1˝	23º00´ 19.8˝	± 34 (equipped)
Nt16	Moab 700	Borehole	Not in use	27º24´ 16.8˝	23º00´ 21.2˝	equipped &

Site name	Farm Name	Water point type	Water use	Longitude	Latitude	Water level (mbgl)
						bees
Nt17	Mamatwan 331 RE	Borehole	Livestock watering	27º23´ 52.0˝	22º56´ 32.1˝	21.00
Nt18	Mamatwan 331 RE	Borehole	Livestock watering, watering the garden	27º23´ 57.7˝	22º56´ 28.5˝	N/P - equipped
Nt19	Mamatwan 331 RE	Borehole	Livestock watering, watering the garden.	27º23´ 57.8˝	22º56´ 25.7˝	N/P – equipped
WGC2	Mine site	Borehole	Aquifer testing	27°22’08.8”	22°56’50.5”	-
WGC3	Mine site	Borehole	Aquifer testing	27°23’16.7”	22°57’27.9”	-

N/P = Not possible

N/A = Not applicable



Legend

- Hydrocensus Points
- Project Area
- Approved Mining Right Area
- Main Roads
- Power Line
- Rivers and Streams
- 20m Contour Lines
- Farm Boundaries
- Farm Portions

0 1 000 2 000 Meters

Scale: 1:60 000 @ A3

Projection: Transverse Mercator

Datum: WGS1984, Lo23

Tshipi é Ntle Manganese Mining (Pty) Ltd

Figure 7-1:

2009 Hydrocensus Points

SLR

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710.20008.00041

10/09/2018

7.2 GROUNDWATER MODELLING

A three-dimensional groundwater numerical model was constructed to simulate flow and mass transport, for operational and post mining scenarios. The results of the numerical model have been used for groundwater impact assessment. More information is provided on the groundwater model in Section 0.

8. PREVAILING GROUNDWATER CONDITIONS

8.1 GEOLOGY

8.1.1 Regional Geology

The project is located on the south western outer rim of the **Kalahari Manganese Field (KMF).** The general stratigraphic column of the Kalahari Manganese Field is presented in Figure 8-1.

Table 8-1: General Stratigraphic Column for the Kalahari Manganese Field

<table>
<tr><th colspan="4">Supergroup / Group / Subgroup / Formation</th><th>Geological Description</th></tr>
<tr><td colspan="4">Kalahari Group</td><td>Kalahari sands, calcrete, clays & gravel beds</td></tr>
<tr><td colspan="5">Kalahari unconformity</td></tr>
<tr><td colspan="4">Karoo Supergroup</td><td>Dwyka tillite</td></tr>
<tr><td colspan="5">Dwyka unconformity</td></tr>
<tr><td colspan="3" rowspan="2">Olifantshoek Supergroup</td><td>Lucknow Formation</td><td>White ortho-quartzite</td></tr>
<tr><td>Mapedi Formation</td><td>Green, maroon and black shales and quartzites</td></tr>
<tr><td colspan="5">Olifantshoek unconformity</td></tr>
<tr><td rowspan="9">Transvaal Supergroup</td><td rowspan="9">Postmansburg Group</td><td rowspan="8">Voelwater Subgroup</td><td>Mooidraai Formation</td><td>Dolomite, chert</td></tr>
<tr><td rowspan="7">Hotazel Formation</td><td>Banded ironstone (upper)</td></tr>
<tr><td>Upper Mn Ore Body</td></tr>
<tr><td>Banded ironstone (middle)</td></tr>
<tr><td>Middle manganese body</td></tr>
<tr><td>Banded ironstone (middle)</td></tr>
<tr><td>Lower manganese body</td></tr>
<tr><td>Banded ironstone (lower)</td></tr>
<tr><td colspan="2">Ongeluk Formation</td><td>Andesitic Lava</td></tr>
</table>

Three beds of manganese ore are interbedded with the Banded Iron Formation (BIF) of the Hotazel Formation (Transvaal Supergroup).

The BIF of the **Hotazel Formation** typically consists of repeated thin layers of black iron oxides (magnetite or hematite) alternating with bands of iron-poor shales and cherts.

8.1.2 Local Geology

Tshipi is recovering the manganese from the Hotazel Formation (Transvaal Supergroup) in the KMF (SLR, 2014). The **Hotazel Formation** is underlain by basaltic lava of the **Ongeluk Formation** (Transvaal Supergroup) and

directly overlain by dolomite of the **Mooidraai Formation** (Transvaal Supergroup). The Transvaal Supergroup is overlain unconformably by the **Olifantshoek Supergroup** which consists of arenaceous sediments, typically interbedded shale, quartzite and lavas overlain by coarser quartzite and shale. The different formations present in the project area include the Mapedi and Lucknow units. The whole Supergroup has been deformed into a succession with an east-verging dip (SLR, 2014).
The Olifantshoek Supergroup is overlain by **Dwyka Formation** which forms the basal part of the Karoo Supergroup. At the mine this consists of tillite (diamictite) which is covered by sands, claystone and calcrete of the **Kalahari Group** (SLR, 2014)

The **Hotazel Formation** consists of Banded Iron Formation (BIF). The manganese ore is contained within a 30 to 40 metre thick mineralised zone which occurs along the entire Borwa property and is made up of three manganese rich zones:

- Upper Manganese Ore Body (UMO)
- Middle Manganese Ore Body (MMO)
- Lower Manganese Ore Body (LMO).

The UMO is 10cm to 15cm thick and comprises moderate deposits of manganese. The poorly mineralised MMO is approximately 1m thick and not economically efficient. The LMO is a highly mineralised unit consisting of six important mineralised zones (X, Y, Z, M. C and N). The ore layer dips gradually to the north-west at approximately five degrees (SLR, 2014).

It should be noted that no significant faults, fractures or other lineaments were observed at the Tshipi Borwa Mine (Metago, May 2009).However Tshipi has recently exposed a fault in the open pit.

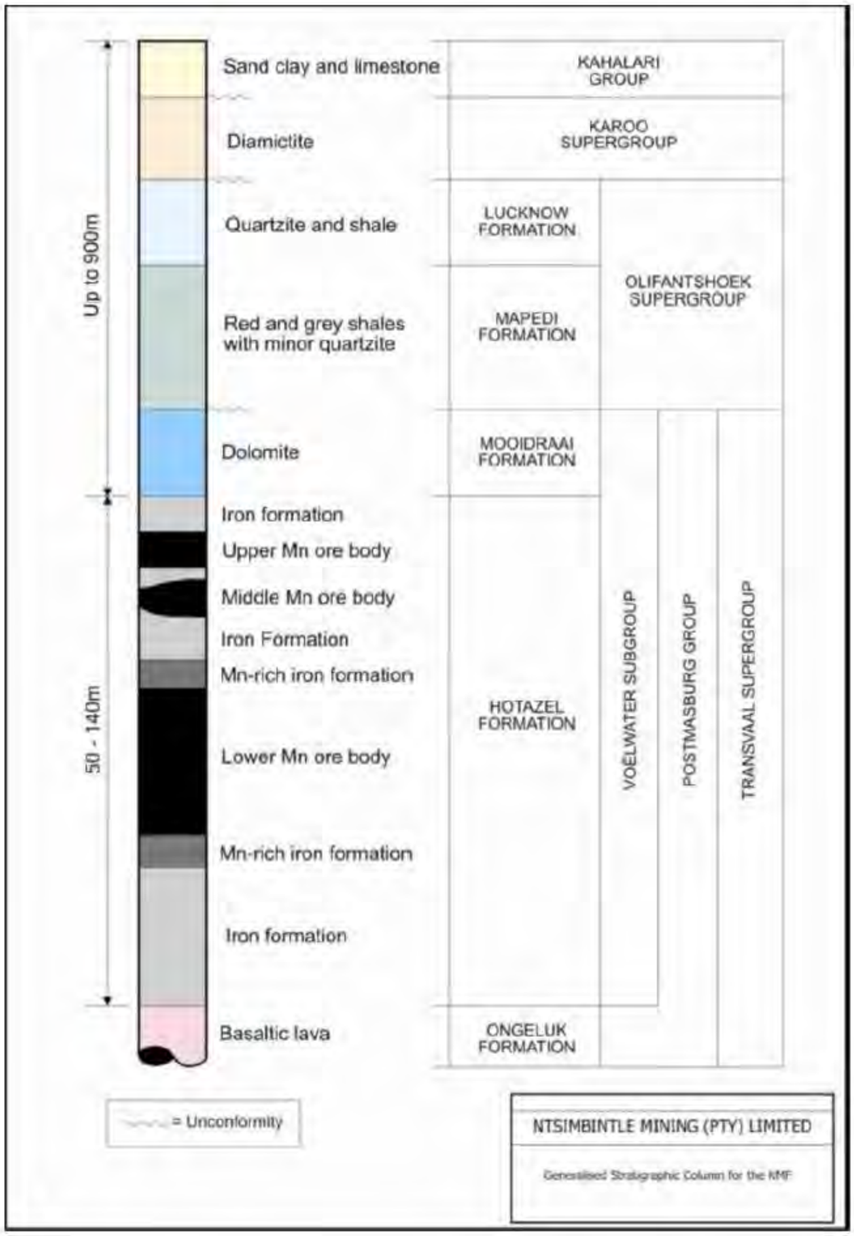

Figure 8-1: Generalized Stratigraphic Column for the KMF (Tshipi Borwa)

8.2 ACID GENERATION CAPACITY

The geochemistry of the waste rock provides an indication of the potential for acid generation. SLR collected 23 samples in 2014 from site which included ore-body material, non-ore body material and a tailings sample generated in the mine laboratory/pilot plant. Samples were submitted to an accredited commercial laboratory for geochemical characterisation tests.

The geochemical test work undertaken as part of the 2014 assessment included static Acid-Base Accounting (ABA), elemental composition, and synthetic precipitation leaching procedure (SPLP) testing.

The ABA results showed that all 23 samples have negligible potential to generate acid drainage due to non-detectable sulphur content (Table 8-2). The SPLP results indicated that a number of metals are leachable at concentrations in excess of relevant water quality standards including aluminium (Al), arsenic (As), barium (Ba), iron (Fe) and manganese (Mn). It is important to note that the table below has been updated with the recent SANS 241 limits for 2015 given that the 2011 limits that the geochemical analysis (SLR, 2014) was based on is no longer applicable.

Synthetic Precipitation Leaching Procedure (SPLP) was used to determine the potential drainage quality from the sampled lithologies at the Tshipi Borwa Mine at neutral (pH7) drainage conditions. In this regard, a total of 23 samples were analysed. The results are provided in Table 7-2 below. The results indicated that a number of metals are leachable at concentrations in excess of relevant water quality standards for waste rock, ore and tailing. These include:

- Aluminium (Al) in terms of the SANS 241 (2105) Operational standards for waste rock
- Arsenic (As) in terms of the WHO standard for Drinking Water (2011) for ore and waste rock
- Barium (Ba) in terms of the WHO standard for Drinking Water (2011) for waste rock
- Cadmium (Cd) in terms of the WHO standard for Drinking Water (2011) for waste rock, ore and tailings
- Iron (Fe) in tems of the SANS 241 (2015) Aesthetic standards for ore
- Manganese (Mn) in tems of the SANS 241 (2015) Aesthetic standards for ore and waste rock
- Lead (Pb) in terms of the WHO standard for Drinking Water (2011) for ore, tailings and waste rock
- pH in terms of IFC Mining Effluent (2007) for waste rock
- Electrical conductivity in terms of SANS 241 (2015) Aesthetic for tailings
- Nitrate (N) in terms of the WHO standard for Drinking Water (2011) for waste rock.

Table 8-2: Acid Base Accounting Results for the Tshipi Borwa Mine (SLR, 2014)

Sample ID	Lab ID	Lithology	Elevation (mamsl)	Location	Paste pH	Acid Potential (AP) (kg/t)	Neutralization Potential (NP)	Nett Neutralization Potential (NNP)	Neutralising Potential Ratio (NPR) (NP : AP)	NAG pH: (H_2O_2)	NAG (kg H_2SO_4 / t)	Total Sulphur (%)	Sulphate Sulphur as S (%)	Sulphide Sulphur (%)	Total Carbon (%)	Organic Carbon (%)	Inorganic Carbon (%)
SLR-TB-01	**11220**	Braunie Lutite	1021.922	East Side	8	0.313	280	280	897	8.4	<0.01	<0.01	<0.01	<0.01	5.6	0.172	5.428
SLR-TB-02	**11221**	Upper BIF	1020.801	East Side	8.5	0.313	66	66	213	8.3	<0.01	<0.01	<0.01	<0.01	0.86	0.208	0.652
SLR-TB-03	**11222**	Lower BIF	1018.252	East Side	8.4	0.313	13	13	41	8.8	<0.01	<0.01	<0.01	<0.01	0.148	0.13	0.018
SLR-TB-04	**11223**	Lower BIF - red in colour	1018.919	East Side	8.4	0.313	130	130	417	8.5	<0.01	<0.01	<0.01	<0.01	4.09	0.202	3.888
SLR-TB-05	**11224**	VW Ore Zone	1015.028	East Side	8.6	0.313	167	167	535	8.4	<0.01	<0.01	<0.01	<0.01	6.7	0.17	6.53
SLR-TB-06	**11225**	Top Cut Ore	1013.186	East Side	8.8	0.313	146	145	466	8.4	<0.01	<0.01	<0.01	<0.01	6.91	0.118	6.792
SLR-TB-07	**11226**	Lower Ore body	1010.049	East Side	8.5	0.313	122	121	389	8.4	<0.01	<0.01	<0.01	<0.01	7.33	0.231	7.099
SLR-TB-08	**11227**	Pebble bed in calcareous clay	1026.990	North Side	8.3	0.313	4.26	3.95	14	8.2	<0.01	<0.01	<0.01	<0.01	0.07	0.069	0.001
SLR-TB-09	**11228**	Pebble bed in red calcareous clay	1030.217	North Side	8.5	0.313	323	323	1034	8.3	<0.01	<0.01	<0.01	<0.01	7.8	0.258	7.542
SLR-TB-10	**11229**	Red clay	1031.184	North Side	8.2	0.313	51	51	163	8.8	<0.01	<0.01	<0.01	<0.01	3.34	0.257	3.083
SLR-TB-11	**11230**	Lower BIF	1012.341	North Side	8.7	0.313	100	100	322	8.5	<0.01	<0.01	<0.01	<0.01	3.38	0.119	3.261
SLR-TB-12	**11231**	Red clay	1030.098	South Side	8.2	0.313	74	73	236	8.8	<0.01	<0.01	<0.01	<0.01	1.28	0.247	1.033
SLR-TB-13	**11232**	White Clay	1052.157	South Side	8.1	0.313	5	4.69	16	7.7	<0.01	<0.01	<0.01	<0.01	0.335	0.331	0.004
SLR-TB-14	**11233**	White gravel bed	1054.877	South Side	8.6	0.313	5.75	5.43	18	7.8	<0.01	<0.01	<0.01	<0.01	0.278	0.273	0.005
SLR-TB-15	**11234**	Red Iron Calcareous Sand	1066.225	South Side	8.3	0.313	110	109	351	8.5	<0.01	<0.01	<0.01	<0.01	2.5	0.361	2.139
SLR-TB-16	**11235**	Pebbly Calcrete	1067.984	South Side	8.5	0.313	79	79	254	8.4	<0.01	<0.01	<0.01	<0.01	2.01	0.203	1.807
SLR-TB-17	**11236**	Iron rich Ccalcareous Sands	1067.131	South Side	8.4	0.313	106	106	339	8.5	<0.01	<0.01	<0.01	<0.01	2.76	0.272	2.488
SLR-TB-18	**11237**	Pebbly Calcrete	1072.483	South Side	8.5	0.313	106	105	338	8.5	<0.01	<0.01	<0.01	<0.01	5.41	0.275	5.135
SLR-TB-19	**11238**	Red Kalahari Sands	1088.848	East Side	8.1	0.313	2.73	2.41	8.72	7.7	<0.01	<0.01	<0.01	<0.01	0.26	0.255	0.005
SLR-TB-20	**11239**	Calcrete	1081.302	East Side	8.5	0.313	146	146	467	8.5	<0.01	<0.01	<0.01	<0.01	4.48	0.356	4.124
SLR-TB-21	**11240**	Pebbly Calcrete	1075.395	-	8.7	0.313	113	113	361	8.3	<0.01	<0.01	<0.01	<0.01	3.32	0.314	3.006
SLR-TB-22	**11241**	Tailings Sample	-	-	8.4	0.313	101	100	322	8.4	<0.01	<0.01	<0.01	<0.01	11.5	0.203	11.3
SLR-TB-23	**11242**	Dolomite	998.00	-	8.7	0.313	115	114	367	8.4	<0.01	<0.01	<0.01	<0.01	11.48	0.148	11.33

Table 8-3: Leachate Results for Samples Collected at the Tshipi Borwa Mine (SLR, 2014)

Lithology	Ag	Al	As	B	Ba	Be	Bi	Ca	Cd	Co	Cr	Cu	Fe	K	Li	Mg	Mn	Mo	Na	Ni
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
WHO Standard for Drinking Water (2011)	**N/A**	**N/A**	**0.01**	**2.4**	**0.7**	**N/A**	**N/A**	**N/A**	**0.003**	**N/A**	**0.05**	**2**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**0.07**
IFC Mining Effluent (2007)	**N/A**	**N/A**	**0.1**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**0.005**	**N/A**	**0.1**	**0.3**	**2**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**0.5**
SANS 241 (2015) Operational	**N/A**	**0.3**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
SANS 241 (2015) Aesthetic	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**0.3**	**N/A**	**N/A**	**N/A**	**0.1**	**N/A**	**200**	**N/A**
SANS 241 (2015) Acute Heath	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
SANS 241 (2015) Chronic Health	**N/A**	**N/A**	**0.01**	**2.4**	**0.7**	**N/A**	**N/A**	**N/A**	**0.003**	**0.5**	**0.05**	**2**	**2**	**N/A**	**N/A**	**N/A**	**0.4**	**N/A**	**N/A**	**0.07**
Braunie Lutite	<0.025	<0.100	<0.010	0.04	<0.025	<0.025	<0.025	14	0.005	<0.025	<0.025	<0.025	<0.025	1.1	<0.025	10	<0.025	<0.025	13	<0.025
Upper BIF	<0.025	<0.100	0.01	<0.025	<0.025	<0.025	<0.025	12	0.005	<0.025	<0.025	<0.025	0.031	<1.0	<0.025	6	<0.025	<0.025	3	<0.025
Lower BIF	<0.025	<0.100	<0.010	0.06	0.072	<0.025	<0.025	10	0.005	<0.025	<0.025	<0.025	0.478	<1.0	<0.025	<2	0.128	<0.025	3	<0.025
Lower BIF - red in colour	<0.025	<0.100	<0.010	<0.025	<0.025	<0.025	<0.025	14	0.005	<0.025	<0.025	<0.025	<0.025	<1.0	<0.025	7	<0.025	<0.025	9	<0.025
VW Ore Zone	<0.025	<0.100	<0.010	0.087	0.079	<0.025	<0.025	9	0.005	<0.025	<0.025	<0.025	<0.025	<1.0	<0.025	6	<0.025	<0.025	7	<0.025
Top Cut Ore	<0.025	<0.100	<0.010	0.05	<0.025	<0.025	<0.025	9	0.005	<0.025	<0.025	<0.025	<0.025	<1.0	<0.025	8	0.119	<0.025	<2	<0.025
Lower Ore body	<0.0	<0.1	<0.0	0.10	<0.0	<0.0	<0.0	10	0.0	<0.0	<0.0	<0.0	<0.0	<1.	<0.0	8	0.09	<0.0	3	<0.0

Lithology	Ag	Al	As	B	Ba	Be	Bi	Ca	Cd	Co	Cr	Cu	Fe	K	Li	Mg	Mn	Mo	Na	Ni
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
	25	00	10	2	25	25	25		05	25	25	25	25	0	25			25		25
Pebble bed in calcareous clay	<0.025	<0.100	<0.010	0.082	0.105	<0.025	<0.025	6	0.005	<0.025	<0.025	<0.025	<0.025	1.3	<0.025	4	<0.025	<0.025	10	<0.025
Pebble bed in red calcareous clay	<0.025	<0.100	<0.010	0.074	0.139	<0.025	<0.025	13	0.005	<0.025	<0.025	<0.025	<0.025	1	<0.025	6	<0.025	<0.025	8	<0.025
Red clay	<0.025	<0.100	0.019	0.12	0.134	<0.025	<0.025	10	0.005	<0.025	<0.025	<0.025	<0.025	1.4	<0.025	6	<0.025	<0.025	14	<0.025
Lower BIF	<0.025	<0.100	0.023	0.074	0.096	<0.025	<0.025	10	0.005	<0.025	<0.025	<0.025	<0.025	<1.0	<0.025	8	<0.025	<0.025	2	<0.025
Red clay	<0.025	<0.100	<0.010	0.073	<0.025	<0.025	<0.025	11	0.005	<0.025	<0.025	<0.025	0.041	1.3	<0.025	6	<0.025	<0.025	12	<0.025
White Clay	<0.025	<0.100	<0.010	<0.025	<0.025	<0.025	<0.025	5	0.005	<0.025	<0.025	<0.025	0.045	1.8	<0.025	3	<0.025	<0.025	9	<0.025
White gravel bed	<0.025	<0.100	<0.010	0.064	0.173	<0.025	<0.025	7	0.005	<0.025	<0.025	<0.025	0.037	1.3	<0.025	4	<0.025	<0.025	7	<0.025
Red Iron Calcareous Sand	<0.025	<0.100	<0.010	<0.025	<0.025	<0.025	<0.025	11	0.005	<0.025	<0.025	<0.025	0.038	1.6	<0.025	6	<0.025	<0.025	9	<0.025
Pebbly Calcrete	<0.025	<0.100	<0.010	<0.025	0.042	<0.025	<0.025	12	0.005	<0.025	<0.025	<0.025	0.069	1.8	<0.025	7	<0.025	<0.025	9	<0.025
Iron rich Calcareous Sands	<0.025	<0.100	0.013	0.146	1.21	<0.025	<0.025	12	0.005	<0.025	<0.025	<0.025	<0.025	1.4	<0.025	6	<0.025	<0.025	14	<0.025
Pebbly Calcrete	<0.025	<0.100	0.012	0.107	1.06	<0.025	<0.025	11	0.005	<0.025	<0.025	<0.025	<0.025	1.3	<0.025	7	<0.025	<0.025	13	<0.025
Red Kalahari Sands	<0.025	1.72	0.022	0.053	0.027	<0.025	<0.025	5	0.005	<0.025	<0.025	<0.025	1.51	4.1	<0.025	3	<0.025	<0.025	2	<0.025
Calcrete	<0.025	<0.100	<0.010	<0.025	<0.025	<0.025	<0.025	14	0.005	<0.025	<0.025	<0.025	<0.025	3	<0.025	8	<0.025	<0.025	42	<0.025

Lithology	Ag	Al	As	B	Ba	Be	Bi	Ca	Cd	Co	Cr	Cu	Fe	K	Li	Mg	Mn	Mo	Na	Ni
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Pebbly Calcrete	<0.025	0.147	<0.010	<0.025	0.028	<0.025	<0.025	10	0.005	<0.025	<0.025	<0.025	0.196	1.9	<0.025	5	<0.025	<0.025	19	<0.025
Tailings Sample	<0.025	<0.100	<0.010	0.126	<0.025	<0.025	<0.025	21	0.005	<0.025	<0.025	<0.025	<0.025	1.1	<0.025	14	<0.025	<0.025	10	<0.025
Dolomite	<0.025	<0.100	0.014	0.129	1.07	<0.025	<0.025	10	0.005	<0.025	<0.025	<0.025	<0.025	<1.0	<0.025	17	<0.025	<0.025	4	<0.025

Lithology	P	Pb	Sb	Se	Si	Sn	Sr	Ti	V	W	Zn	Zr	pH Value at 25˚C	Electrical Conductivity	Alkalinity as $CaCO_3$	Chloride as Cl	Sulphate as SO_4	Nitrate as N	Fluoride as F
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	pH Value	mS/m	mg/l	mg/l	mg/l	mg/l	mg/l
WHO Standard for Drinking Water (2011)	**N/A**	**0.01**	**0.02**	**0.04**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**11**	**1.5**
IFC Mining Effluent (2007)	**N/A**	**0.2**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**0.5**	**N/A**	**09-Jun**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
SANS 241 (2015) Operational	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**5 - 9.7**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
SANS 241 (2015) Aesthetic	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**5**	**N/A**	**N/A**	**170**	**N/A**	**300**	**250**	**N/A**	**N/A**
SANS 241 (2015) Acute Heath	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**500**	**11**	**N/A**
SANS 241 (2015) Chronic Health	**N/A**	**0.01**	**0.02**	**0.04**	**N/A**	**N/A**	**N/A**	**N/A**	**0.2**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**1.5**
Braunie Lutite	<0.025	0.02	<0.010	<0.020	6	<0.025	0.029	<0.025	<0.025	<0.025	<0.025	<0.025	10.1	21.1	12	12	7	2	0.3
Upper BIF	<0.025	0.02	<0.010	<0.020	17.2	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	8	11.7	16	<5	<5	<0.2	0.2
Lower BIF	<0.025	0.02	<0.010	<0.020	15.4	<0.025	<0.025	<0.025	<0.025	<0.025	0.098	<0.025	7.9	7.7	12	<5	<5	<0.2	0.2
Lower BIF - red in colour	<0.025	0.02	<0.010	<0.020	6.6	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	8.1	17.1	20	<5	5	1	0.3
VW Ore Zone	<0.025	0.02	<0.010	<0.020	3.1	<0.025	<0.025	<0.025	<0.025	<0.025	0.07	<0.025	8.1	12.7	60	<5	<5	0.3	0.5
Top Cut Ore	<0.025	0.02	<0.010	<0.020	<0.2	<0.025	0.026	<0.025	<0.025	<0.025	<0.025	<0.025	8.2	11.8	64	<5	<5	<0.2	0.2
Lower Ore body	<0.025	0.02	<0.010	<0.020	<0.2	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	8.1	12.5	60	<5	<5	<0.2	0.2
Pebble bed in calcareous clay	<0.025	0.02	<0.010	<0.020	4.7	<0.025	0.042	<0.025	<0.025	<0.025	0.102	<0.025	7.9	11.7	52	<5	<5	<0.2	0.5
Pebble bed in red calcareous clay	<0.025	0.02	<0.010	<0.020	3.6	<0.025	0.06	<0.025	<0.025	<0.025	0.06	<0.025	8.4	14.7	64	<5	<5	0.3	0.5
Red clay	0.072	0.02	<0.010	<0.020	1.3	<0.025	0.065	<0.025	<0.025	<0.025	0.061	<0.025	8.2	16.8	80	<5	6	0.4	0.7
Lower BIF	0.124	0.02	<0.010	<0.020	0.7	<0.025	0.026	<0.025	<0.025	<0.025	0.041	<0.025	8.5	13.6	56	<5	<5	<0.2	0.7
Red clay	<0.025	0.02	<0.010	<0.020	0.7	<0.025	0.061	<0.025	<0.025	<0.025	<0.025	<0.025	8.1	16.7	68	<5	6	0.5	0.9
White Clay	<0.025	0.02	<0.010	<0.020	10.8	<0.025	0.027	<0.025	0.027	<0.025	<0.025	<0.025	7.8	10.9	32	<5	6	1.6	0.8
White gravel bed	<0.025	0.02	<0.010	<0.020	9	<0.025	0.049	0.042	<0.025	<0.025	0.116	<0.025	7.8	11	52	<5	5	1.2	0.3
Red Iron Calcareous Sand	<0.025	0.02	<0.010	<0.020	19.2	<0.025	0.062	<0.025	0.029	<0.025	<0.025	<0.025	9	15.1	64	<5	<5	2.4	0.5
Pebbly Calcrete	<0.025	0.02	<0.010	<0.020	13.9	<0.025	0.076	<0.025	<0.025	<0.025	<0.025	<0.025	8	12.7	68	5	<5	3.4	0.5
Iron rich Calcareous Sands	<0.025	0.02	<0.010	<0.020	19.9	<0.025	0.083	<0.025	<0.025	<0.025	0.211	<0.025	8.2	15.8	72	<5	<5	2.1	0.6
Pebbly Calcrete	<0.025	0.02	<0.010	<0.020	14.8	<0.025	0.081	<0.025	<0.025	<0.025	0.127	<0.025	8.2	16.3	68	<5	<5	2.8	0.5
Red Kalahari Sands	0.207	0.02	<0.010	<0.020	21	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	7.7	6.5	40	<5	11	0.5	0.2
Calcrete	<0.025	0.02	<0.010	<0.020	12.4	<0.025	0.08	<0.025	<0.025	<0.025	<0.025	<0.025	8.1	24.9	60	26	26	18	0.4
Pebbly Calcrete	<0.025	0.02	<0.010	<0.020	11.3	<0.025	0.049	<0.025	<0.025	<0.025	<0.025	<0.025	8.2	24.9	68	6	<5	5.6	0.4
Tailings Sample	<0.025	0.02	<0.010	<0.020	4.1	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	8.3	172	92	<5	33	2	0.4
Dolomite	<0.025	0.02	<0.010	<0.020	<0.2	<0.025	0.03	<0.025	<0.025	<0.025	0.039	<0.025	8.9	0.7	96	<5	<5	<0.2	0.4

8.3 HYDROGEOLOGY

8.3.1 Unsaturated Zone

From the groundwater risk assessment conducted by SLR (2015) it was established that the depth of the unsaturated zone is approximately 45 m. The unsaturated zone falls within the Kalahari Formation and consists of sand, clay and limestone.

8.3.2 Saturated Zone

Based on the desktop information review, the following aquifer zones are relevant:

- Shallow aquifer in the Kalahari beds with hydraulic conductivity of less than 10 metres per day (m/d) (WGC 2009). The Kalahari beds are approximately 70 m thick (SLR 2012). With a water table at 45 m below ground, the shallow aquifer is approximately 25 m thick
- Low permeability Dwyka tillite layer with hydraulic conductivity of less than 0.1 m/d (WGC 2009)
- Deep fractured aquifer with hydraulic conductivity of less than 1 m/d, consisting of Mooidraai Dolomite and Hotazel Formation (manganese ore body) (WGC 2009) (SLR, 2015).

8.3.3 Hydraulic Conductivity

Information from the WGC 2015 and SLR 2014 report provides permeability values (K) (Table 8-6). The relevant climatic data on which this permeability was based in provided in Table 8-4. In addition the modelled groundwater pit ingress with associated permeability is provided in Table 8-6, sourced from WGC reports.

Table 8-4: Climatic Parameters Used in Previous Modelling Assessments

Investigation and reference	Mean annual precipitation-MAP (m/a)	Mean annual evaporation - MAE (m/a)	Runoff	Recharge (m/a)
Groundwater investigation (WGC, 2009)	0.344	2.690	na	0.00683 (GRAII(DWAF))
Pit lake formation (SLR, 2012)	0.356	2.352	40% of MAP	0.0068

Table 8-5: Groundwater Inflow into the Open Pit

Investigation and reference	K value used	Inflow (m^3/day)	Inflow (L/s)
Groundwater investigation (WGC, 2009)	Final K	3842	44.5
	Alternative K	1047	12.1

Table 8-6: Horizontal and Vertical K of Geological Units Used in Previous Assessments (m/d)

Investigation and reference	K value used	Horizontal K (K_H)				Vertical K (K_v)
		Kalahari	Karoo	Mooidraai	Hotazel	All
Groundwater investigation (WGC, 2009)	Initial	1	0.1	8	0.5	10% of K_H
	Final	7.7	0.024	0.82	0.4	
	Alternative	3	0.22	0.054	0.03	

Investigation and reference	K value used	Horizontal K (K_H)				Vertical K (K_v)
		Kalahari	Karoo	Mooidraai	Hotazel	All
Pit lake formation (SLR, 2012)		7.7	0.024	0.82	0.4	10% of K

WGC (2009) conducted pump tests on two boreholes at depths of 180 m (MMTW BH1) and 48 m (WGC01). The results of the pump tests are summarised in Table 8-7.

Table 8-7: Pump Tests Results for WGC01 and MMTW BH1 (WGC, 2009)

Investigation and reference	K value used	Inflow (m^3/day)	Inflow (L/s)
Groundwater investigation (WGC, 2009)	Final K	3842	44.5
	Alternative K	1047	12.1

8.4 GROUNDWATER LEVELS

A hydrocensus within the vicinity of the Mine was undertaken during November 2009 by Metago. Information on these hydrocensus boreholes is provided in Table 7-2 with locations shown in Figure 7-1.

Prior to mining, groundwater flow at the site was from south-east to north-west following the non-perennial Vlermuisleegte River, towards the non-perennial Ga-Mogara River, located approximately 10 km to the west of the site (WGC, 2009). The groundwater flow is from areas of higher lying ground towards the valleys. The potential correlation between the measured head (static water level) and topography (surface elevation) was investigated by cross-plotting the data collected by WGC in 2009. A very good correlation between the measured water levels and surface topography was found (R_2 = 0.97, i.e. approximately 97 % of observed water level variations can be explained by variations in surface elevation) and thus it could be assumed that the water table mimics the surface topography (Knight Pièsold, 2012).

In a hydrocensus conducted by Knight Pièsold in 2012 the water levels were determined from the pit area as well as from the surrounding boreholes covering a radius of three to five kilometers. The average water level found below the then current base of the pit was 5.0 m. The depth of the pit was 30-35 m during the 2012 investigation. The depth of the water in the surrounding boreholes ranged from 25.8 to 55.6 m below ground level.

The groundwater level data collected by WGC in 2009 in the deeper aquifers (tillite, dolomite and banded ironstone formation) did not show any significant correlation with the surface topography. Pre-mining average groundwater levels recorded ranged from 20 m to 45 m below ground level (WGC, 2009). Tshipi continues to monitor groundwater levels. The location of these boreholes are shown in Figure 7-1. A hydrograph is provided in Figure 8-2. The results show that:

- Results show that groundwater levels varied between 19.6 mbgl in borehole TSH09 and 76.5 mbgl in borehole TSH01;
- There has been a slight to medium decrease in the water level of the majority of the boreholes compared to the initial water levels measured;
- A slight increase in the water levels were observed in TSH03, TSH09 and TSH10 compared to the baseline water level;

- A sharp decrease in water level was observed in TSH08. The average water level measured in TSH08 up to the end of 2017 was 36.6 mbgl compared to 76.7 measured during the latest monitoring event. TSH08 is located downstream of the Tshipi open pit. SLR requested Tshipi to confirm the results of this measurement. A measurement was again taken on 3 May 2018. The water level in TSH08 was 73.6 mbgl, which still indicates a decrease in water level of more than 37 m. The decrease in water level is attributed to the current pit expansion, which is moving directly towards TSH08. The numerical groundwater model (SLR 2017) also indicated a development of a cone of drawdown in this particular area.

Table 8-8: Groundwater levels June 2018 (2018-Q2) compared to baseline water levels

Trend compared to baseline						
Borehole ID	Baseline		Latest monitoring event		Level change since initial (m)	Overall trend
	Date measured	Initial groundwater depth (mbgl)	Date measured	Depth (mbgl)		
TSH01	Apr-2013	62.2	Nov-17	76.5	-11.6	decrease
TSH02	Apr-2013	41.5	Nov-17	42.5	-1.0	decrease
TSH03	Apr-2013	49.2	Mar-18	48.5	0.7	increase
TSH04	Apr-2013	56.3	Mar-18	65.9	-9.7	decrease
TSH05	Apr-2013	33.9	Jul-15	Sterilised	-3.5	decrease
NT8	Apr-2013	42.0	Mar-18	43.9	-1.9	decrease
TSH06	Jun-2016	41.6	Mar-18	43.8	-2.3	decrease
TSH07	Jun-2017	36.2	Nov-17	36.7	-0.5	decrease
TSH08	Jun-2017	36.1	Mar-18	73.6	-40.4	decrease
TSH09	Jun-2017	20.5	Mar-18	19.6	0.9	increase
TSH10	Jun-2017	21.6	Mar-18	21.5	0.0	increase

Table 8-9: Groundwater levels June 2018 (2018-Q2) compared to previous month water levels

Trend compared to previous month						
Borehole ID	Previous month		Latest monitoring event		Level change since initial (m)	Monthly trend
	Date measured	Depth (mbgl)	Date measured	Depth (mbgl)		
TSH01	Oct-17	74.0	Nov-17	76.5	-2.5	decrease
TSH02	Oct-17	42.0	Nov-17	42.5	-0.5	decrease
TSH03	Oct-17	48.3	Mar-18	48.5	-0.2	decrease
TSH04	Oct-17	64.6	Mar-18	65.9	-1.3	decrease
TSH05	Jul-15	Sterilised	Jul-15	Sterilised		N/A
NT8	Oct-17	42.1	Mar-18	43.9	-1.8	decrease
TSH06	Oct-17	42.2	Mar-18	43.8	-1.7	decrease

Trend compared to previous month						
TSH07	Oct-17	36.7	Nov-17	36.7	0.0	no change
TSH08	Oct-17	36.8	Mar-18	73.6	-36.8	decrease
TSH09	Oct-17	20.8	Mar-18	19.6	1.2	increase
TSH10	Oct-17	21.8	Mar-18	21.5	0.2	increase

It is noted that water elevations in meters above mean sea level (mamsl) are approximate as the elevations of boreholes are unavailable. Elevations have therefore been estimated using Google Earth® and the groundwater level in mamsl calculated.

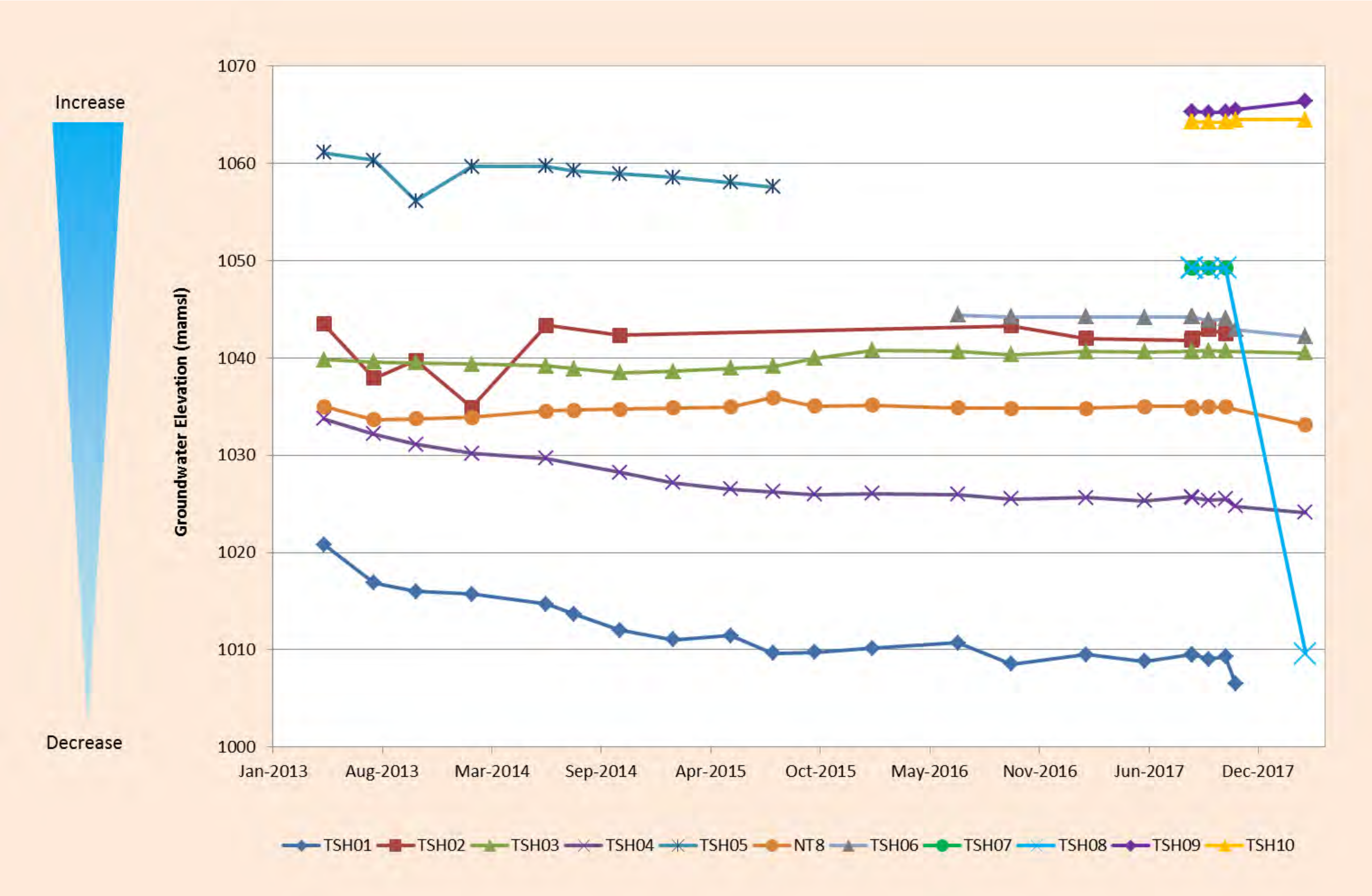

Figure 8-2: Groundwater Hydrographs (mbgl)

8.5 GROUNDWATER QUALITY

8.5.1 Baseline (Pre-mining) Water Quality

Historical information on the groundwater quality in the region was obtained from the National Groundwater Database (NGDB) and previous water monitoring undertaken by Metago in the region over the previous years. A statistical description of the major anions and cations of the points near the Mine was generated. The results indicated the water in the vicinity is generally elevated in chloride, magnesium, nitrate and to a lesser extent, calcium. This is in line with the water quality data from monitoring Metago has undertaken in the region (Metago, 2009).

Metago conducted a hydrocensus around the Tshipi mine in 2009. Chemical data for seven groundwater samples were obtained for the interpretation of the water quality. Figure 8-3 shows the location of the boreholes from which the samples were collected. Trace metal concentrations along with major cations and anions were determined. The data was interpreted by drawing a piper diagram and screening of the concentrations against the legal compliance limits used in the water quality monitoring reports (SLR, 2018).

A piper diagram illustrating the pre-mining major baseline groundwater chemistry is shown in Figure 8-4. Baseline water quality results show that a dominant Mg-Ca-HCO_3 groundwater character is observed, indicating recently recharged and relatively young groundwater. Several samples show a trend to chloride (Cl) anion dominance (Mg-Ca-Cl character) typical of evaporation effects, prior recharge or an older, more evolved water facies in equilibrium with the host rock. Nt8 has a trend towards a SO_4 anion dominated facies (Na-Ca-Mg-SO_4-HCO_3-Cl character) as well as elevated NO_3 concentrations. Therefore elevated concentration of chloride, nitrate and selenium are shown in Table 8-10, with calcium and magnesium exceeding the resource water quality objectives provided in the Integrated Water Use Licence. These trends were believed to be linked to anthropogenic pollution from farming or mining activities (WGC, 2009).

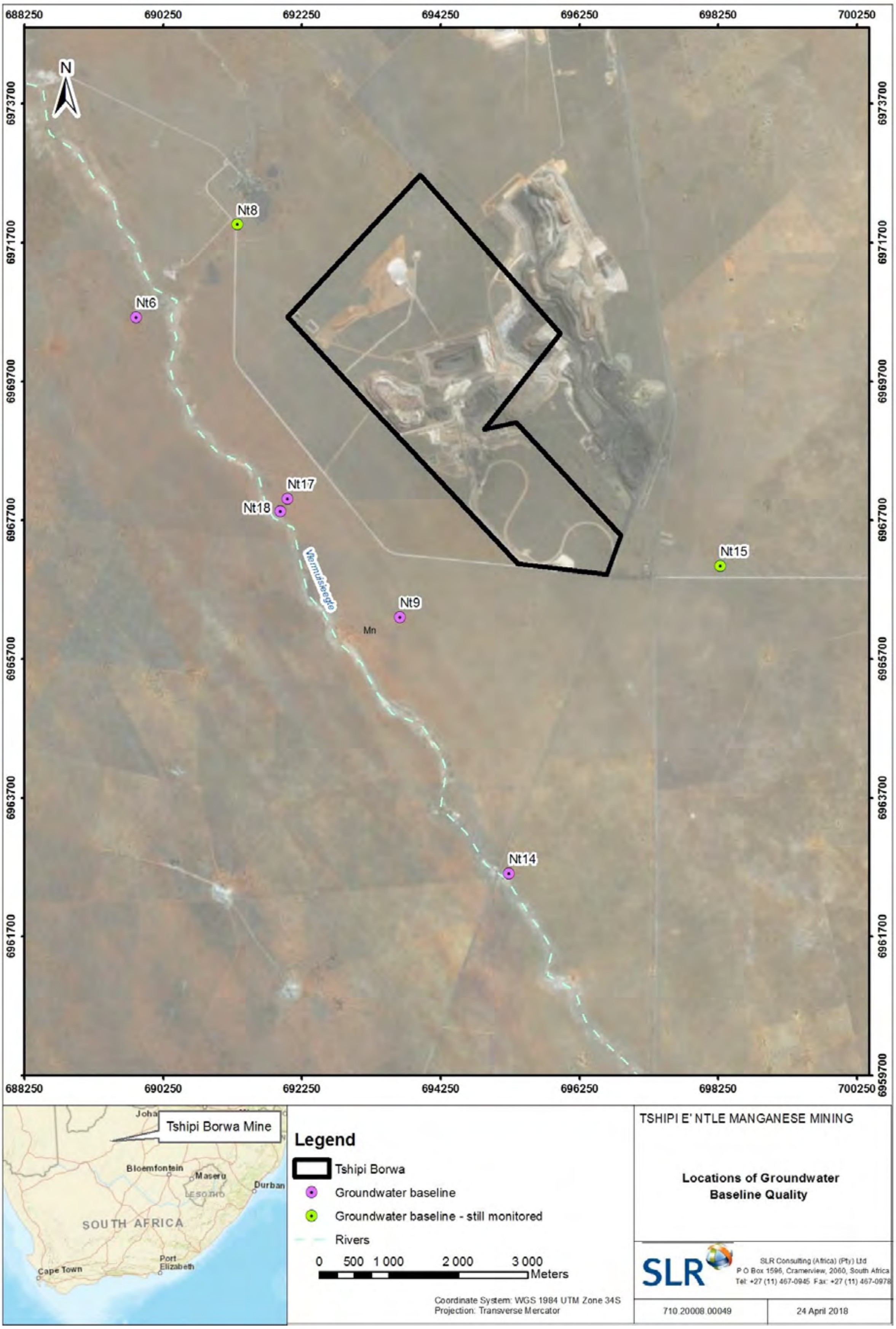

Figure 8-3: Location of groundwater baseline sampling points

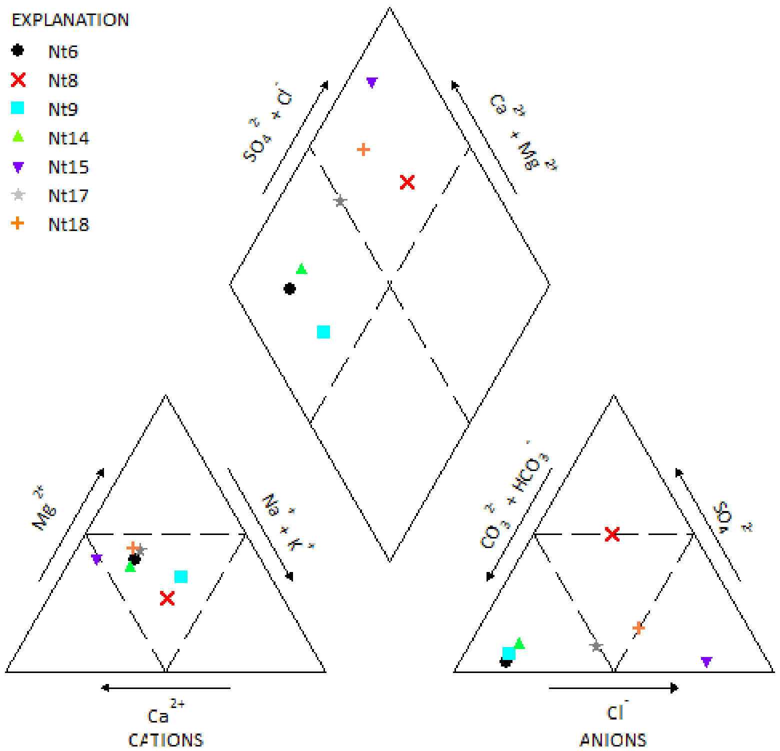

Figure 8-4: Piper diagram illustrating the major baseline groundwater chemistry

Table 8-10: Baseline water quality results (Metago, 2009)

Sample ID	Unit	SANS 241:2015 Operational	SANS 241:2015 Aesthetic	SANS 241:2015 Acute Heath	SANS 241:2015 Chronic Health	DWAF TWQG	IWUL RWQO	Nt6	Nt8	Nt9	Nt14	Nt15	Nt17	Nt18
								November 2008						
pH	pH Unit	5 - 9.7	N/A	N/A	N/A	N/A	5-9.5	7.3	7.7	7.9	7.5	7	7.4	7.2
Electrical Conductivity (EC)	mS/m	N/A	170	N/A	N/A	N/A	150	95.6	179	82	101	396	186	243
Total Dissolved Solids (TDS)	mg/l	N/A	1200	N/A	N/A	1000	1000	696	1 208	420	592	2 910	1 340	1 650
Aluminium (Al)	mg/l	0.3	N/A	N/A	N/A	5	NA	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
Arsenic (As)	mg/l	N/A	N/A	N/A	0.01	1	NA	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Boron (B)	mg/l	N/A	N/A	N/A	2.4	5	NA	0.157	1.700	0.397	0.227	0.099	0.265	0.246
Barium (Ba)	mg/l	N/A	N/A	N/A	0.7	N/A	NA	0.141	<0.025	<0.025	0.064	0.191	0.210	0.174
Beryllium (Be)	mg/l	N/A	N/A	N/A	N/A	N/A	NA	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Bismuth (Bi)	mg/l	N/A	N/A	N/A	N/A	N/A	NA	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Calcium (Ca)	mg/l	N/A	N/A	N/A	N/A	1000	150	83	132	48	84	377	141	175
Cadmium (Cd)	mg/l	N/A	N/A	N/A	0.003	0.01	NA	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Chloride (Cl)	mg/l	N/A	300	N/A	N/A	1500	200	50	176	40	56	743	172	304
Cobalt (Co)	mg/l	N/A	N/A	N/A	N/A	1	NA	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Chromium (Cr)	mg/l	N/A	N/A	N/A	0.05	1	NA	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Copper (Cu)	mg/l	N/A	N/A	N/A	2	0.5	NA	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	0.025
Iron (Fe)	mg/l	N/A	0.3	N/A	2	10	NA	0.208	0.093	<0.025	0.152	<0.025	0.105	0.037
Fluoride (F)	mg/l	N/A	N/A	N/A	1.5	2	1.5	0.5	0.6	0.2	0.2	<0.2	0.4	0.4
Potassium (K)	mg/l	N/A	N/A	N/A	N/A	N/A	NA	4.4	2.6	3	2.8	6	6.6	7
Lithium (Li)	mg/l	N/A	N/A	N/A	N/A	N/A	NA	<0.025	0.05	<0.025	<0.025	<0.025	<0.025	<0.025
Magnesium (Mg)	mg/l	N/A	N/A	N/A	N/A	500	70	52	59	36	45	184	104	123
Manganese (Mn)	mg/l	N/A	0.1	N/A	0.4	10	NA	<0.025	0.261	<0.025	<0.025	<0.025	<0.025	<0.025
Molybdenum (Mo)	mg/l	N/A	N/A	N/A	N/A	0.01	NA	<0.025	0.594	<0.025	<0.025	<0.025	<0.025	<0.025
Sodium (Na)	mg/l	N/A	200	N/A	N/A	2000	200	46	152	74	45	62	85	88
Nickel (Ni)	mg/l	N/A	N/A	N/A	0.07	1	NA	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Nitrate (NO_3)	mg/l	N/A	N/A	11	N/A	22	10	11	0.2	14	16	175	111	101
Phosphorus (P)	mg/l	N/A	N/A	N/A	N/A	N/A	NA	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Lead (Pb)	mg/l	N/A	N/A	N/A	0.01	0.1	NA	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Selenium (Se)	mg/l	N/A	N/A	N/A	0.04	0.05	NA	0.074	0.032	0.042	0.046	0.022	0.062	<0.020
Silicon (Si)	mg/l	N/A	N/A	N/A	N/A	N/A	NA	34	4.47	8.19	27	24	39	33
Tin (Sn)	mg/l	N/A	N/A	N/A	N/A	N/A	NA	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025

Sample ID	Unit	SANS 241:2015 Operational	SANS 241:2015 Aesthetic	SANS 241:2015 Acute Heath	SANS 241:2015 Chronic Health	DWAF TWQG	IWUL RWQO	Nt6	Nt8	Nt9	Nt14	Nt15	Nt17	Nt18
								November 2008						
Strontium (Sr)	mg/l	N/A	N/A	N/A	N/A	N/A	NA	0.492	0.535	0.291	0.44	1.63	1.17	1.39
Sulphate (SO_4)	mg/l	N/A	250	500	N/A	1000	400	16	481	25	47	51	52	126
Titanium (Ti)	mg/l	N/A	N/A	N/A	N/A	N/A	NA	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Alkalinity	mg/l	N/A	N/A	N/A	N/A	N/A	NA	392	264	316	380	264	304	292
Vanadium (V)	mg/l	N/A	N/A	N/A	N/A	1	NA	<0.025	<0.025	<0.025	<0.025	<0.025	0.025	<0.025
Tungsten (W)	mg/l	N/A	N/A	N/A	N/A	N/A	NA	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	0.04
Zinc (Zn)	mg/l	N/A	5	N/A	N/A	20	NA	0.028	0.108	<0.025	0.201	<0.025	0.118	0.109
Zirconium (Zr)	mg/l	N/A	N/A	N/A	N/A	N/A	NA	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025

8.5.2 Water Quality Monitoring

Groundwater and surface water monitoring has been undertaken at the mine on a quarterly basis since 2012. Trace metal and major cations and anion determinant results were compared to the legal guideline requirements used in the current monitoring assessments (SLR, 2018). The results indicated the following:

- Constituents which exceeded the IWUL (DWS, 2015), resource water quality objectives (IWUL RWQO) include Ca, Mg, SO_4, TDS, NO_3, EC and Cl;
- Exceedances of the health guidelines (SANS 241:2015 acute and chronic health and Department of Water and Sanitation Target Water Quality Guidelines (TWQG) for livestock watering (DWS, 1996), include Mo, NO_3, Se and TDS; and
- Exceedances of the aesthetic guideline value (SANS 241:2015) include Cl, EC, Mn, SO_4 and TDS.

Some of these chemicals of concern are discussed below. Reference is made to baseline (pre-mining) conditions to provide context, however only two boreholes have continued to be monitored since the initial hydrocensus (NT15 and NT8).

Electrical Conductivity (EC) of water is proportional to the TDS. Since EC is much easier to measure than TDS it is normally used as an estimate of the TDS concentration. The EC gives an indication of the ability of water to conduct an electrical current because of the presence of ions that carry an electrical charge. These ions can consist of but is not limited to carbonate, bicarbonate, chloride, sulphate, nitrate, sodium, potassium, calcium and magnesium. Figure 8-5 shows a box plot for the EC groundwater monitoring results collected from 2012 to the most current results (March 2018). From the box plot it is clear that EC values recorded for Nt15 does not correlate well with the EC values measured in any of the other monitoring wells. The EC concentrations for the majority of the other boreholes fall below the IWUL RWQO. Values exceeding the IWUL RWQO have been recorded at some point in all the boreholes except TSH01, TSH03 and TSH08. The majority of the concentrations measured in TSH09 exceeded the IWUL RWQO; however, the concentration of EC in TSH09 displays a decreasing trend with concentrations currently below the IWUL RWQO.

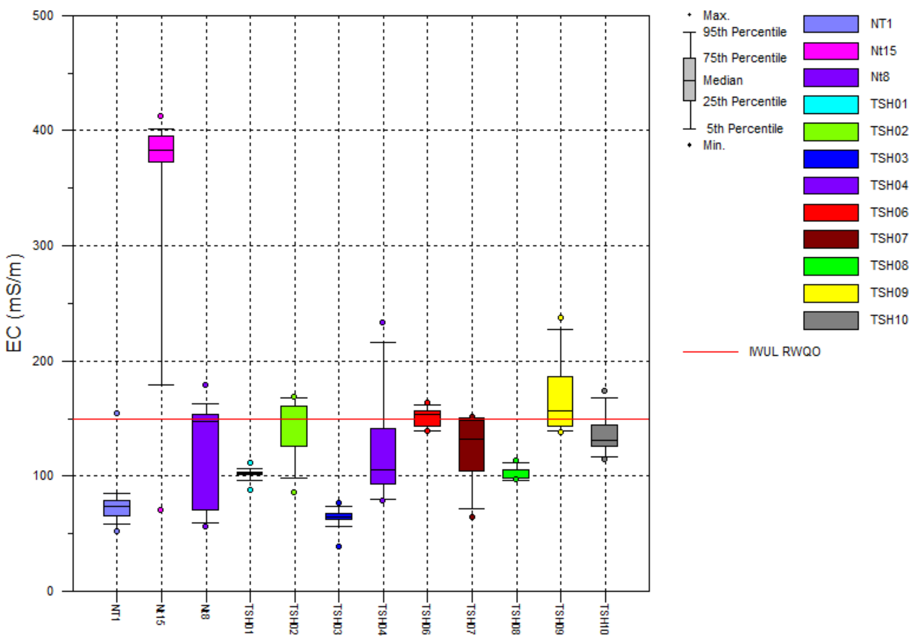

Figure 8-5: Box plot for electrical conductivity in groundwater

Chloride is the anion of the element chlorine. Chlorine does not occur in nature but is only present as chloride. The chlorides of Na, K, Ca and Mg are highly soluble in water. At high concentrations, Cl renders the water unpalatable to most livestock. Figure 8-6 shows a box plot of the chloride concentration measured in groundwater during the entire monitoring period (2012-2018). The Cl values for Nt15 and TSH09 has consistently exceeded the IWUL RWQO. A small range in the Cl concentration is observed in the majority of the boreholes.

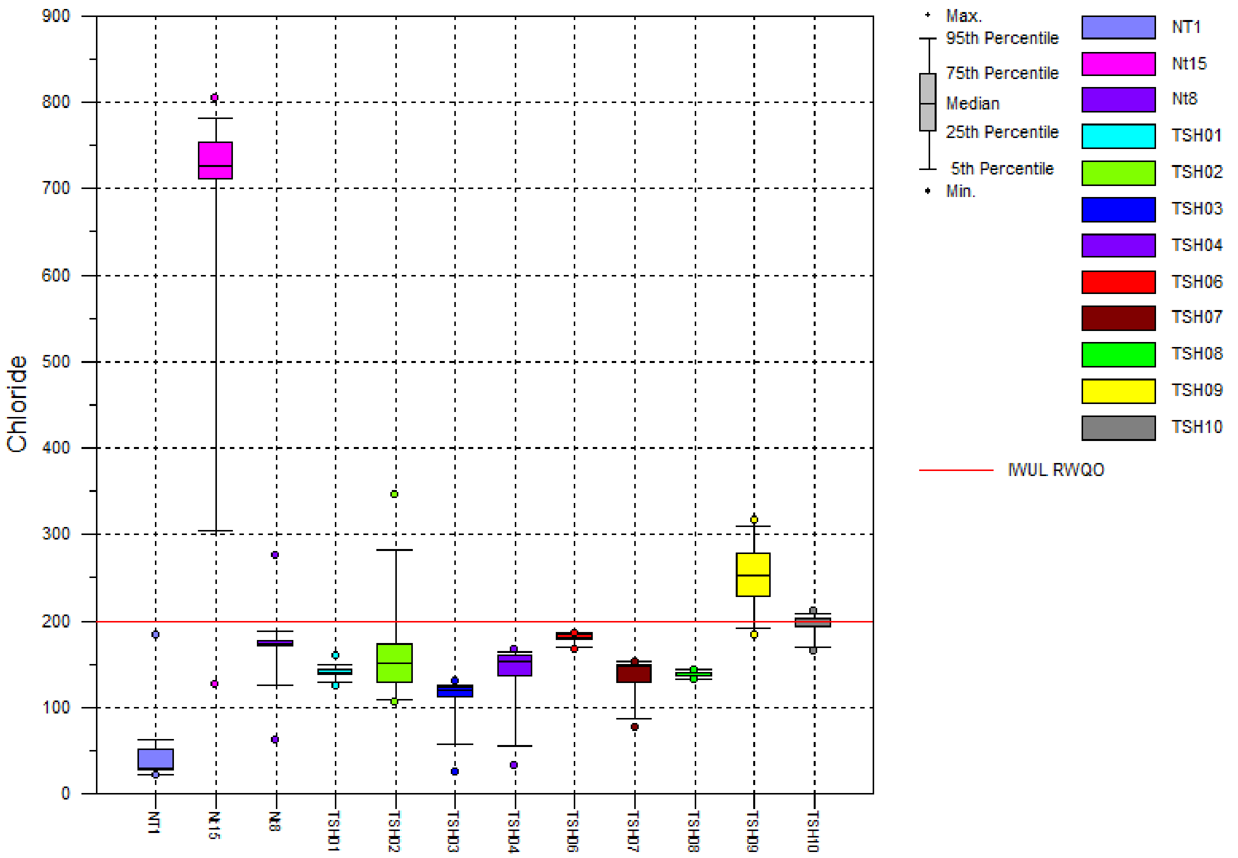

Figure 8-6: Box plot for chloride in groundwater – updated Q1-2018

Nitrate - Figure 8-7 shows a box plot of the NO_3 concentration measured in the groundwater during the 2012 to 2018 monitoring period. A large range of NO_3 concentration is observed in Nt15, TSH02, TSH07, TSH09 and TSH10. The NO_3 concentrations in Nt15 are much higher compared to the concentration in the other monitoring points. The NO_3 concentration in borehole Nt15, TSH02 and TSH09 has consistently exceed the IWUL RWQO with TSH07 exceeding the guidelines in the majority of the sampling events.

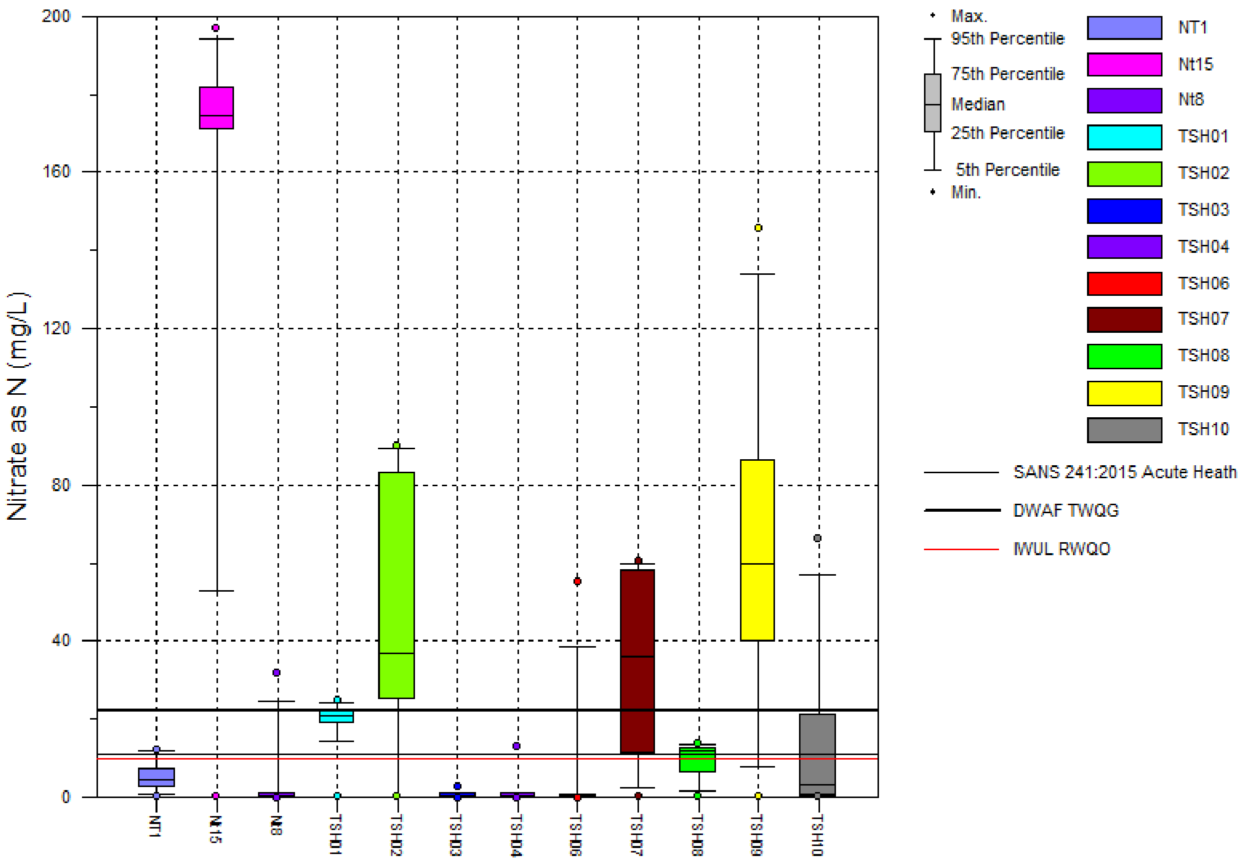

Figure 8-7: Box plot for nitrate in groundwater

Calcium - Figure 8-8 shows the box plot for Ca concentration in the groundwater monitoring points. All the boreholes fall within the same range as Nt8 except for Nt15, which display much higher concentrations, compared to the values measured in the other boreholes. All values measured in Nt15 have exceeded the IWUL RWQO.

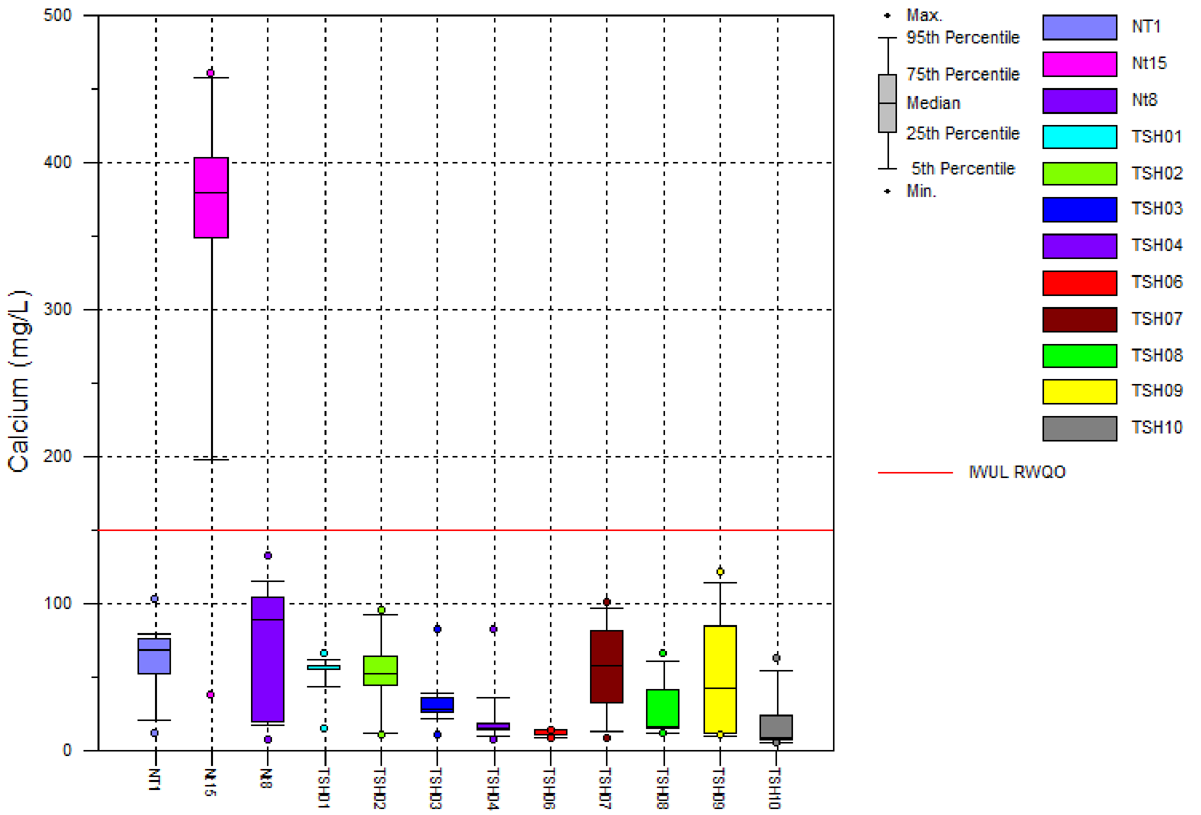

Figure 8-8: Box plot for calcium in groundwater

Magnesium - Figure 8-9 shows the box plots of the Mg concentrations in groundwater for the monitoring period. As with all the above mentioned constituents Nt15 display a higher Mg concentrations comparted to the other monitoring points. The Mg concentration in the majority of the boreholes fall within the range of the concentration measured in downstream borehole, Nt8. As with $NO_{3,}$ the Mg concentrations in TSH02, TSH09 and TSH10 are higher than the concentration in the other boreholes. Concentrations in TSH10 have consistently exceeded the IWUL RWQO.

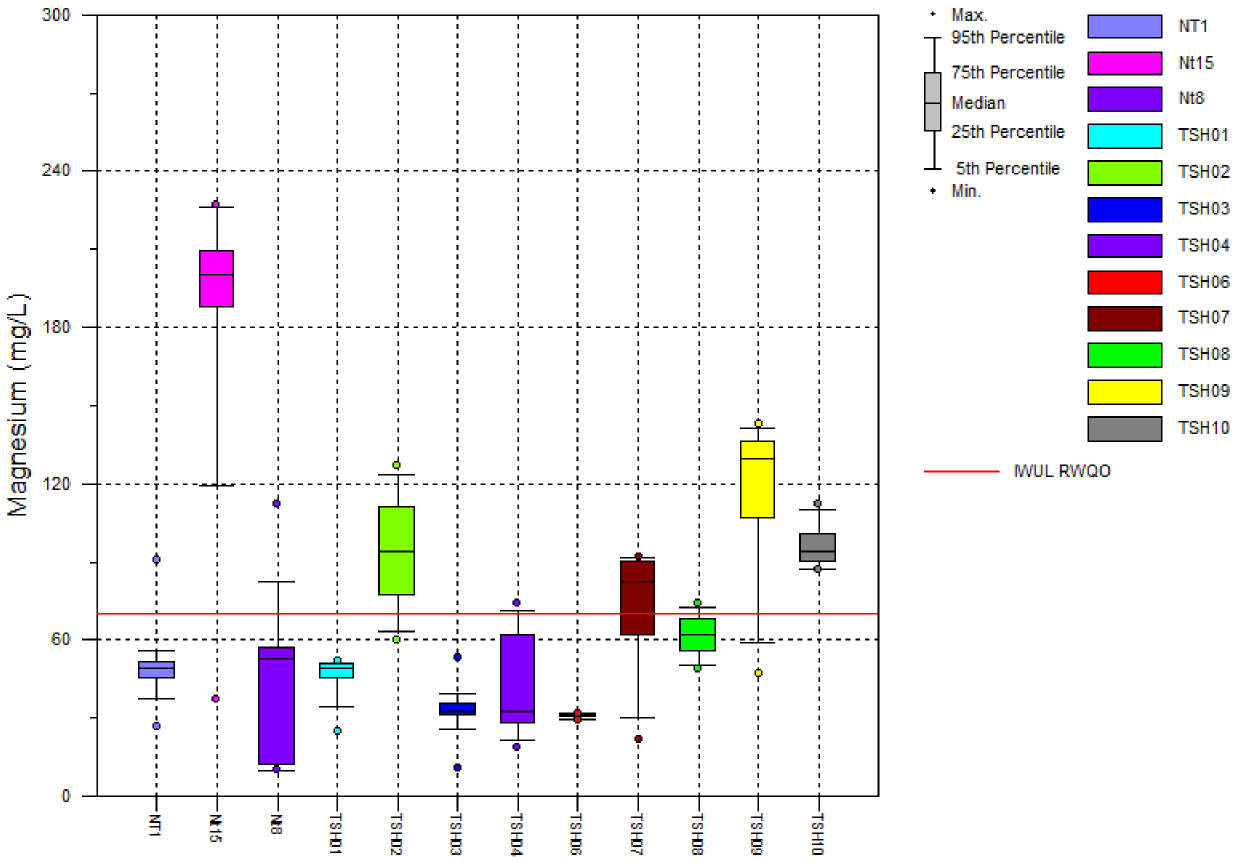

Figure 8-9: Box plot for magnesium in groundwater –

Manganese - Figure 8-10 shows the box plot of the Mn concentration in the boreholes. The Mn concentration in Nt15 plots within the same range as Nt8. TSH04 has a wide range of Mn concentrations with the upper 50^{th} percentile exceeding the SANS 241:2015 chronic health limit.

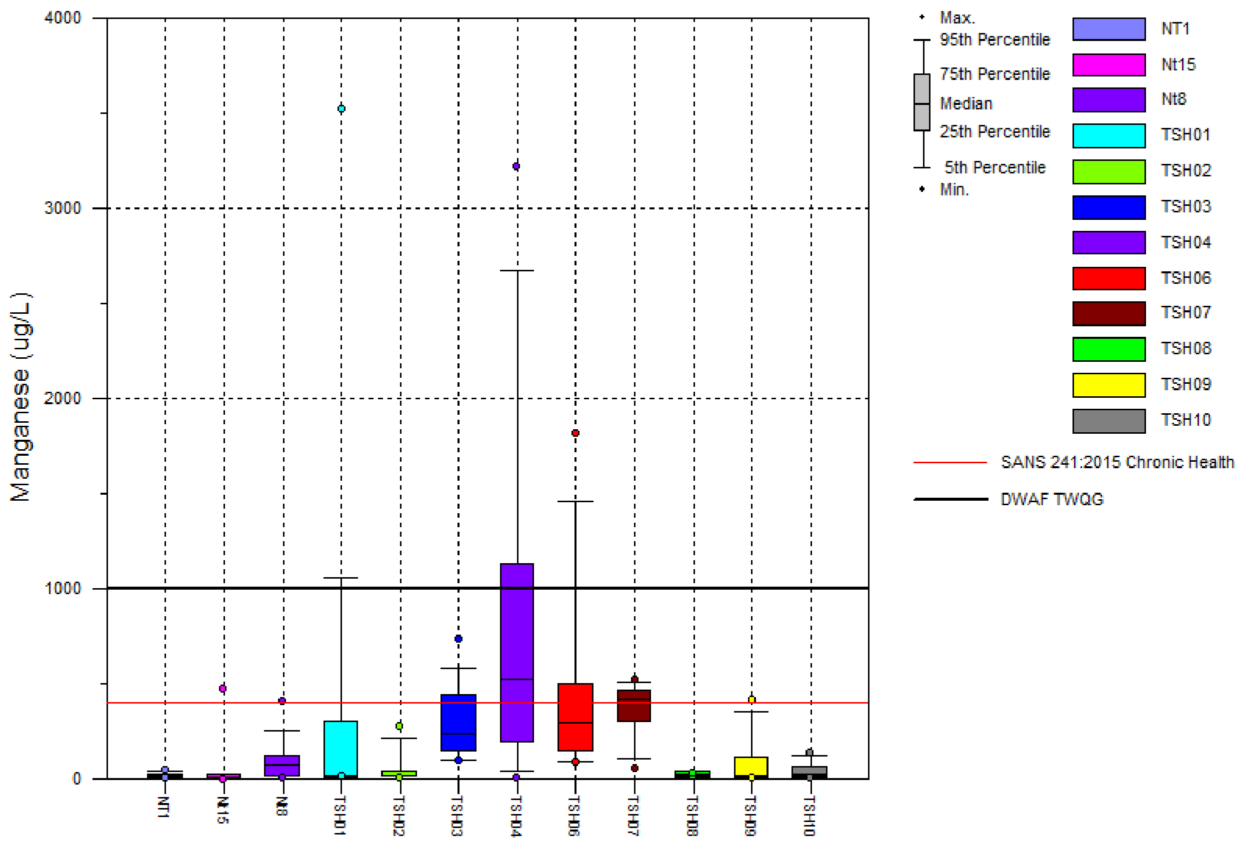

Figure 8-10: Box plot for magnesium in groundwater

Molybdenum - Figure 8-11 shows a box plot of the Mo concentration in the groundwater monitoring points. The Mo concentrations for all the boreholes were mostly below the detection limit. However, there is a large range in the Mo concentration in Nt8 and TSH09 with the majority of the samples being above the DWAF TWQG. The concentration in Nt8 has exceeded the guideline value from the baseline monitoring events.

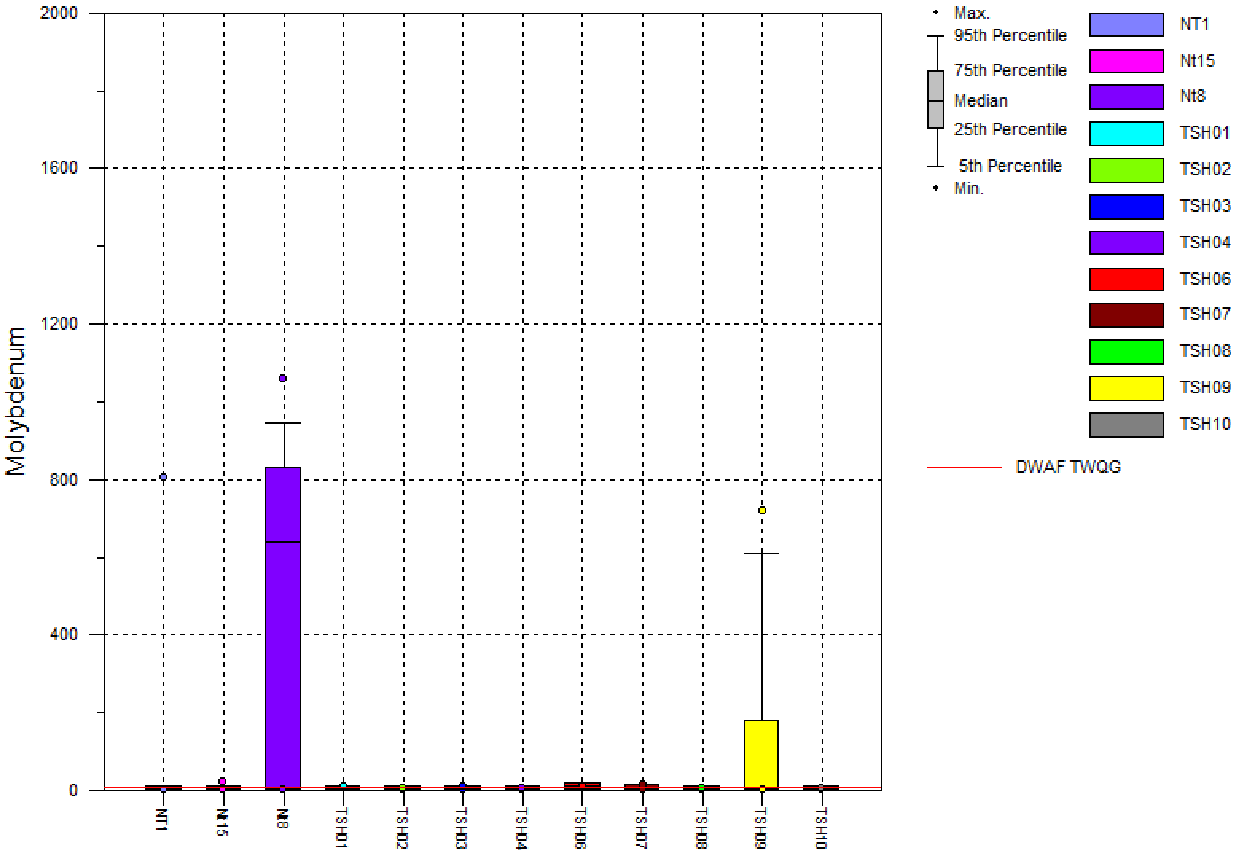

Figure 8-11: Box plot for molybdenum in groundwater Aquifer CHARACTERIZATION

Selenium - Figure 8-12 shows the box plot of the Se concentrations in the groundwater monitoring points. The distributions of Se in most of the boreholes are low and values remain below the health guideline values. In borehole Nt15 just under 50 percent of the results are above the SANS 241:2015 guideline. TSH06 also displays a large range of concentrations with approximately 25 percent of the results exceeding the SANS 241:2015 guideline.

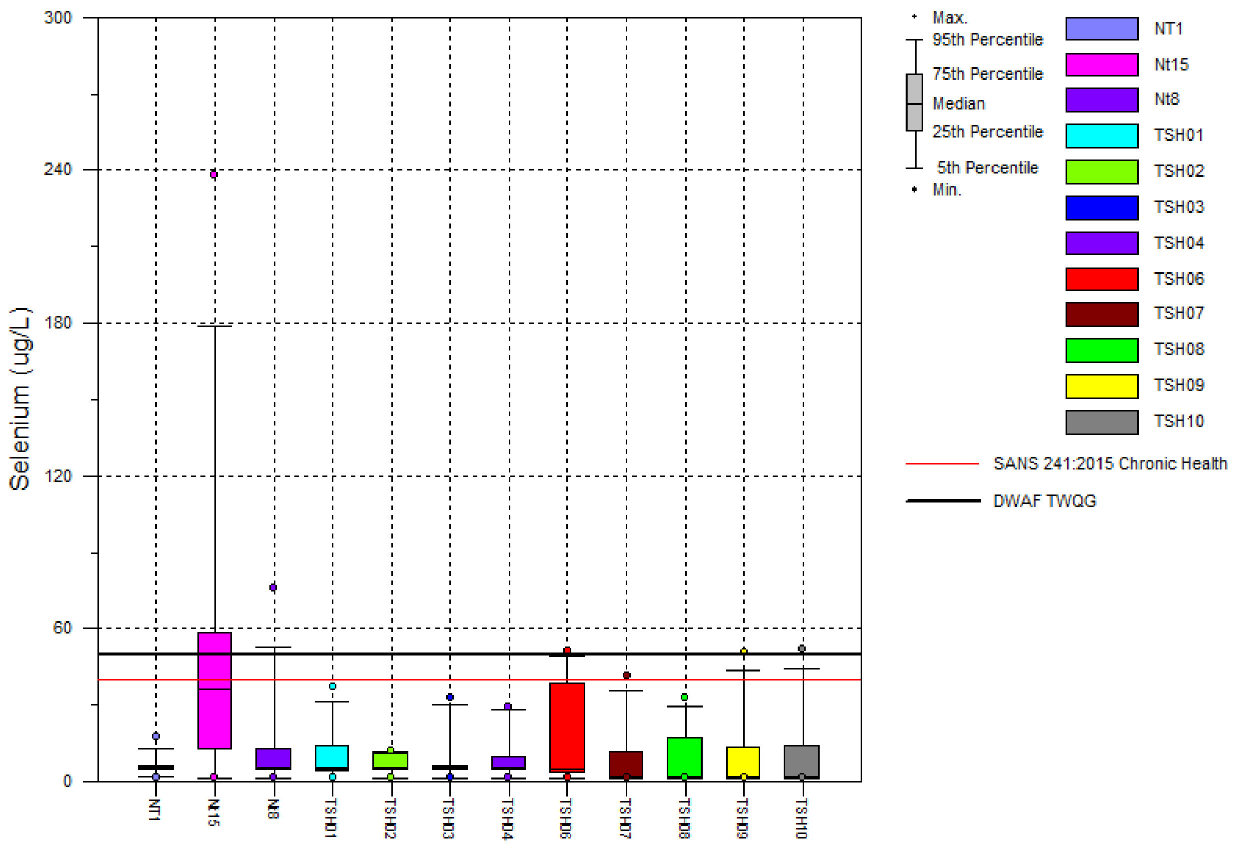

Figure 8-12: Box plot for selenium in groundwater

Arsenic - Figure 8-13 shows the distribution of the As concentrations in the groundwater results. The majority of the boreholes show a small distribution with the exception of Nt15 and Nt8. The majority of the boreholes have As concentrations below the 75^{th} percentile of Nt8.

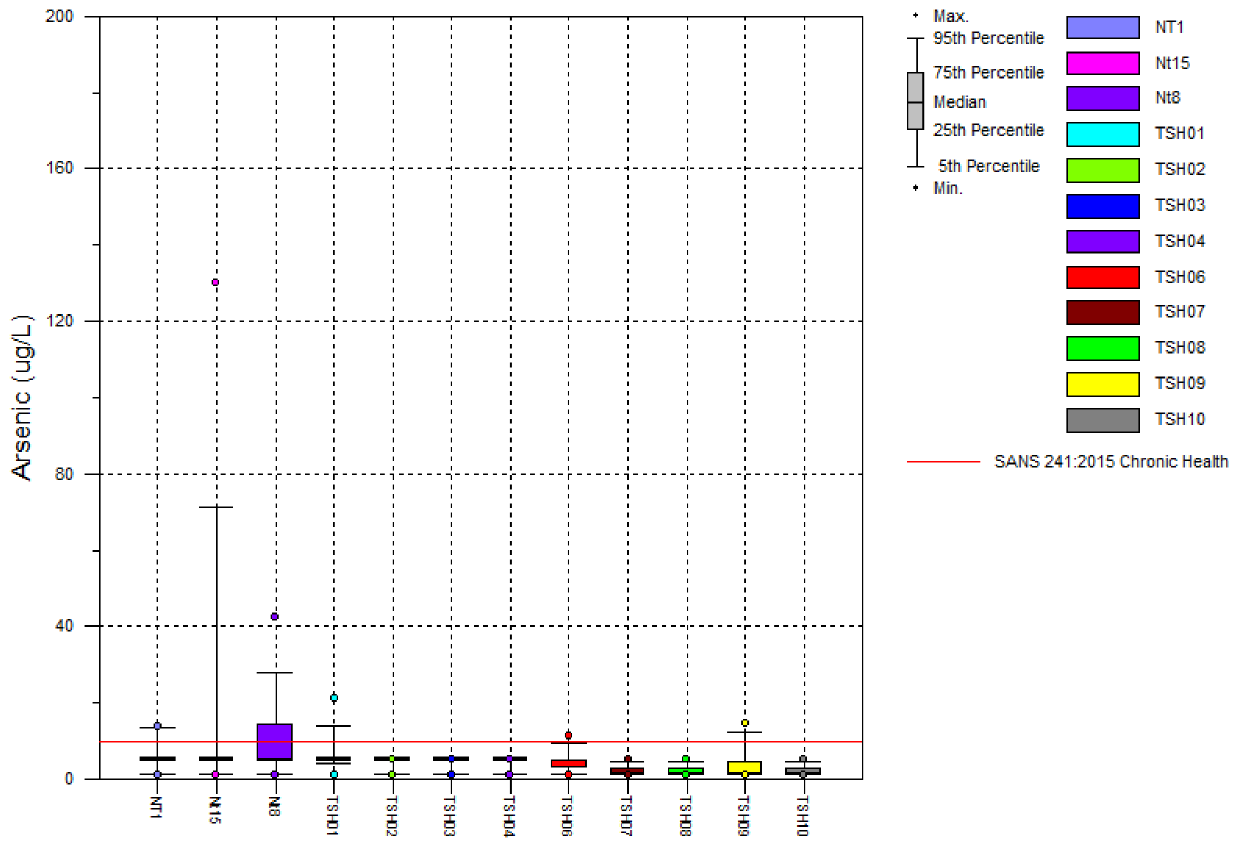

Figure 8-13: Box plot for arsenic in groundwater

Boron - Figure 8-14 shows the box plots of the B concentrations in the groundwater results. Nt8, TSH01 and TSH09 show a relatively high range in B concentrations. Most of the concentrations remain below the SANS guideline except for a few occasions in Nt8.

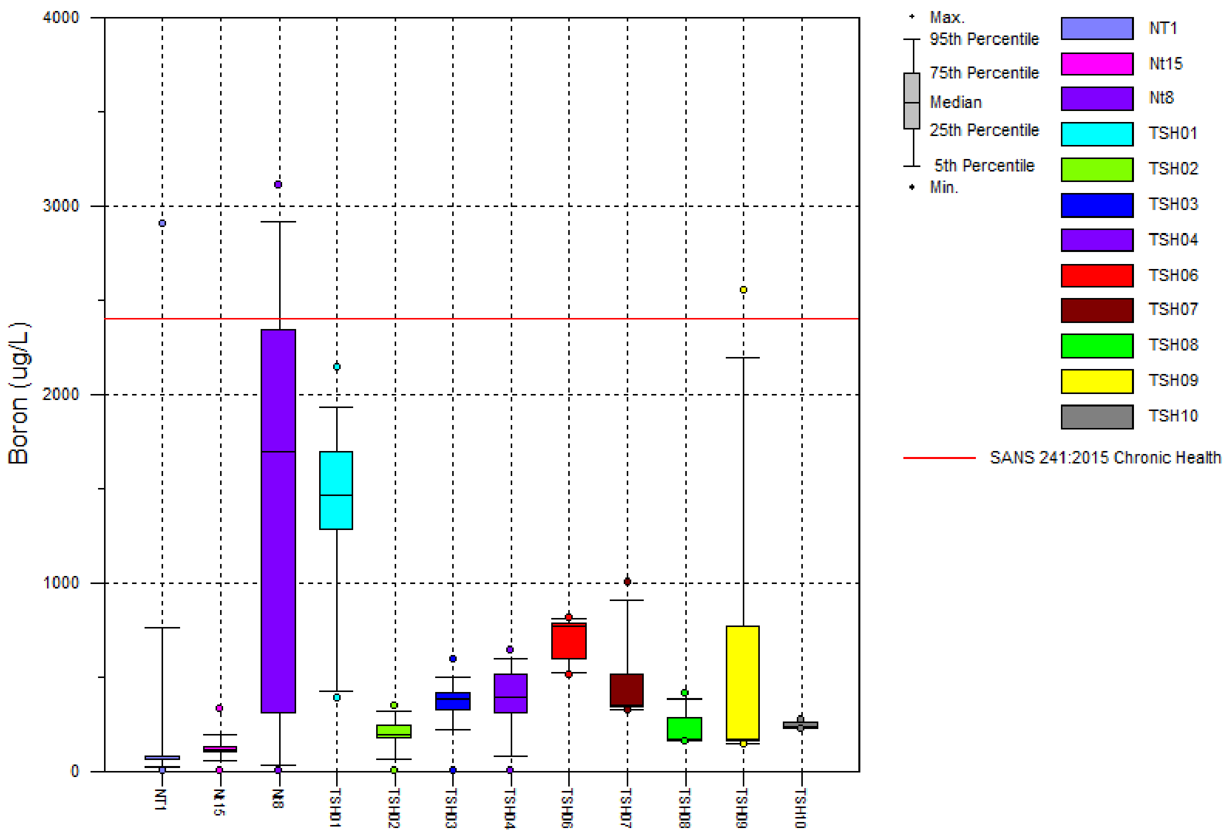

Figure 8-14: Box plot for Boron in groundwater

When considering the groundwater quality data, Tshipi mine is having a moderate impact on the groundwater quality. This impact needs to be assessed with the consideration of neighbouring activities. Water from Nt15, which is upstream from the site, is of poor quality and may contribute to the elevated concentrations of some constituents measured on site.

8.6 GROUNDWATER VULNERABILITY

The Aquifer Vulnerability Map of South Africa (Conrad et al. 1999c) indicates the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer. Based on the map, the Tshipi Borwa area is classified as least to moderately vulnerable which implies the following:

- Least vulnerable: only vulnerable to conservative pollutants in the long term when continuously discharged or leached; and
- Moderately vulnerable: vulnerable to some pollutants, but only when continuously discharged or leached.

The least vulnerable area is restricted to the east and moderately vulnerable to the west of the site.

8.7 AQUIFER CLASSIFICATION

The classification scheme (refer to Table 8-11) was created for strategic purposes as it allows the grouping of aquifer areas into types according to their associated supply potential, water quality and local importance as a resource.

Table 8-11: Aquifer Classification (RSA)

Aquifer System	Defined by Parsons (1995)	Defined by DWAF Min Requirements (1998)
Sole Source Aquifer	An aquifer which is used to supply 50% or more of domestic water for a given area, and for which there are no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.	An aquifer which is used to supply 50% or more of urban domestic water for a given area for which there are no reasonably available alternative sources should this aquifer be impacted upon or depleted.
Major Aquifer	High 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 (<150mSm).	High yielding aquifer (5-20 L/s) of acceptable water quality.
Minor Aquifer	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 those aquifers seldom produce large quantities of water, they are important both for local supplies and in supplying base flow for rivers.	Moderately yielding aquifer (1-5 L/s) of acceptable quality or high yielding aquifer (5-20 L/s) of poor water quality.
Non-Aquifer	These are formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities. Water quality may also be to such that it renders the aquifer as unusable. However, groundwater flow through such rocks, although imperceptible, does take place, and need to be considered when assessing the risk associated persistent pollutants.	Insignificantly yielding aquifer (<1 L/s) of good quality water or moderately yielding aquifer (1-5 L/s) of poor quality or aquifer which will never be utilised for water supply and which will not contaminate other aquifers.
Special Aquifer	An aquifer designated as such by the Minister of Water Affairs, after due process.	An aquifer designated as such by the Minister of Water Affairs, after due process.

In terms of the Aquifer Classification Map of South Africa (Matoti and James, 2012), the Tshipi project area is classified as a poor to minor aquifer region.

In order for the aquifers to be classified, the following information is relevant:

1. The local aquifer, the Banded Ironstone Formation (BIF) is considered to be a minor aquifer because the boreholes drilled previously into the aquifer yielded less than 2L/s during the aquifer tests.
2. The quality of the water is poor, with several elevated parameters (refer to section 8.5).
3. The upper layers of the calcrete are considered to be a non-aquifer which has insignificant yields.

The hydrocensus survey indicates that the two neighbours who farm immediately west of the mine rely entirely on groundwater for their water requirements. The boreholes which are in use are drilled into the Ongeluk Lava and the calcrete of the Kalahari formation, or possibly the dolomite of the Mooidraai formation. The only other available water source locally is the Gamagara Water Scheme. However, there are no boreholes in use in the BIF. The BIF and the calcrete of the Kalahari formation on the site within the study area are therefore classified as minor aquifers.

9. GROUNDWATER MODELLING

Groundwater modelling included all pollution sources in order to assess the groundwater impacts cumulatively. Therefore the existing WRDs and TSF have been included in the modelling.

9.1 MODEL SCENARIOS

An unlined and lined scenario was run for the approved Tshipi infrastructure, as well as with the addition of the proposed WRD extension.

SCENARIO 1: Unlined

This simulates a worst case scenario, being Tshipi's current situation. Currently none of the waste rock dumps on site are lined and the waste rock material is directly situated on top of the topsoil, however the Tailings Storage Facility is considered as lined.

SCENARIO 2: Lined Scenario

In accordance with GN R. 635 and GN R. 636 is classified as Type 1 waste which requires disposal on a facility with a Class A barrier system (Figure 9-1). A Class A liner is designed in such a way to avoid any seepage from the waste facility. A very low hydraulic conductivity is assumed for the areas under the waste rock dumps in this scenario.

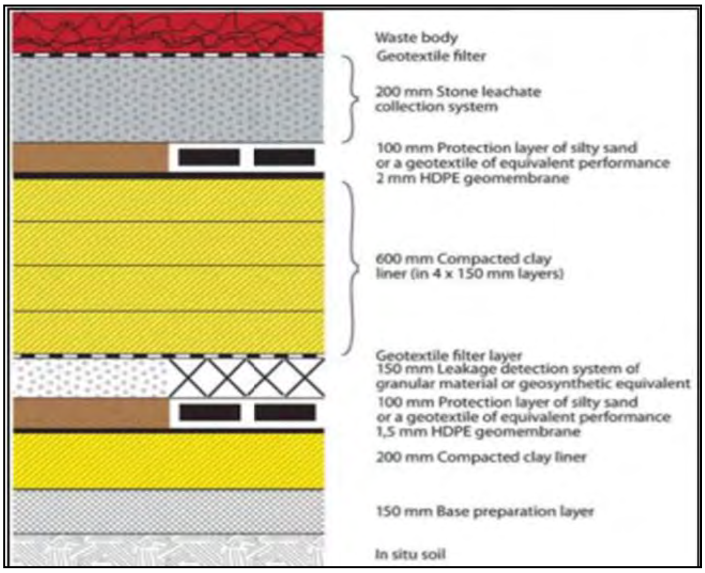

Figure 9-1: Class A Liner System

9.2 MODEL SOFTWARE CHOICE

For successful assessment of the mining and mining related activities impacts on the groundwater environment, Finite Element Flow (*FEFLOW* (DHI-WASY) was selected to simulate groundwater flow and contaminant transport. *FEFLOW* is a finite elements groundwater flow and contaminant transport code appropriate for mining simulations.

9.3 MODEL SET-UP AND BOUNDARIES

The groundwater model domain for Tshipi Mine is shown in Figure 9-2. The model domain was selected based mainly on topography and the sub-catchments identified on the topographic data (RSA topography 50.000 series).

The western model boundary was selected as Specified head boundary, where groundwater flow in- and out- the model domain is allowed during predictive simulations.

The remaining boundaries are declared “no-flow” boundaries and generally represent watershed lines along the higher elevation in the area. The North-Eastern boundary was also included as a “no-flow” boundary as it delineates two sub-catchments, to the north and south, where the mine is situated.

The model domain covers a complex mining area, with several open pit mines being present in close proximity. Mamatwan Mine is situated immediately to the East of Tshipi and UMK Mine is situated approximately two kilometres to the North of Tshipi.

From a groundwater flow point of view, all these mines will have a cumulative effect on groundwater flow and therefore the groundwater model has to take all these into consideration for a reasonable impact assessment.

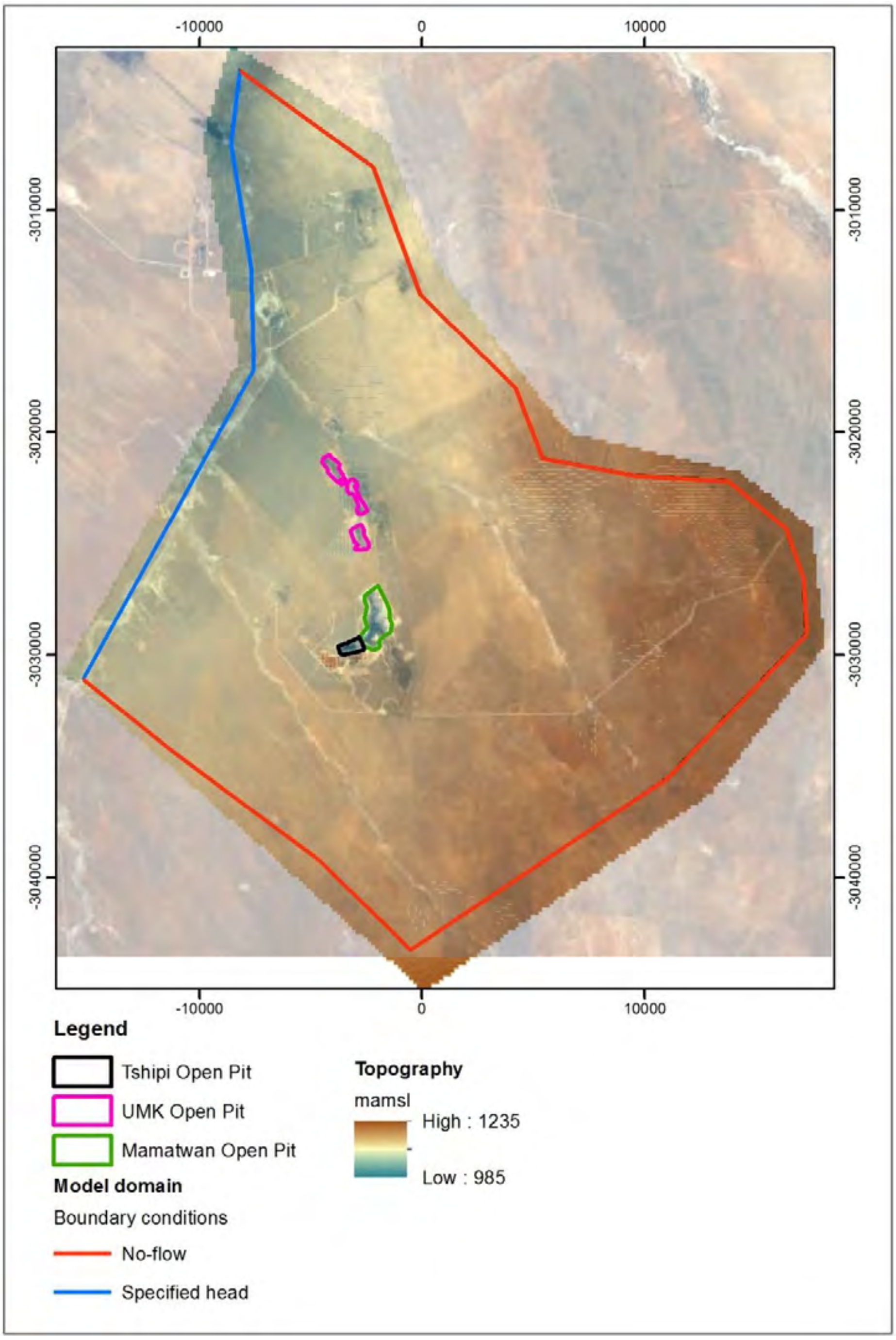

Figure 9-2: Tshipi Model Domain

9.4 GROUNDWATER ELEVATION AND GRADIENT

The groundwater elevation over the whole model domain was interpolated from the existing borehole groundwater measurements and compared with groundwater elevations from previous work in the catchment (AGES, 2007 and SLR, 2014). The initial (pre-mining) groundwater elevations computed for the model domain is shown in Figure 9-3.

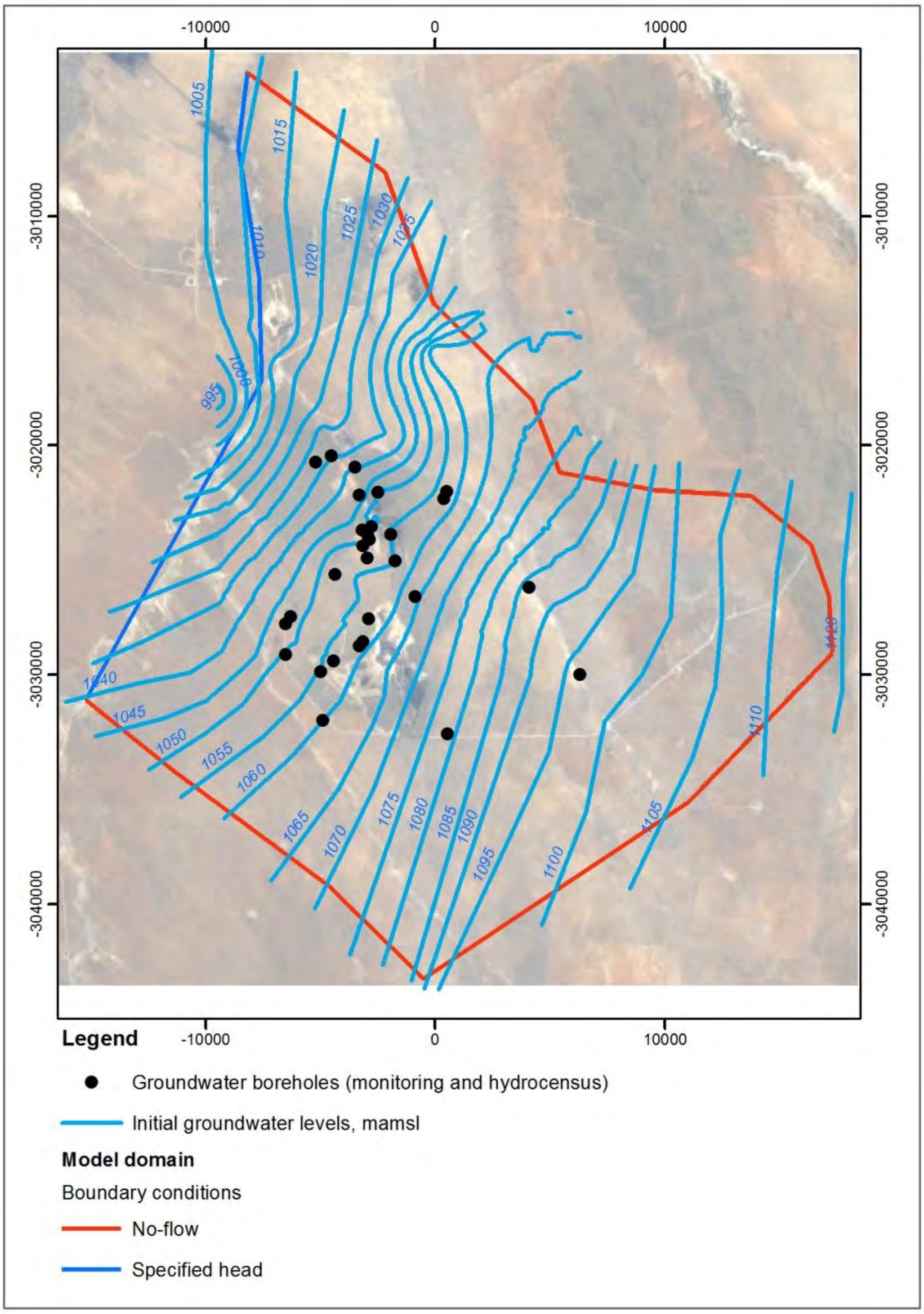

Figure 9-3: Initial Groundwater Levels

The groundwater flow is from South-East to North-West with a calculated gradient is 0.003 towards North-West, which is similar with previous reported gradients (0.004) (AGES, 2007).

9.5 GROUNDWATER SOURCES AND SINKS

Groundwater sources for the Tshipi numerical model are represented mainly by rainfall recharge to the model. The annual recharge considered initially for the numerical model calibration is 2 x 10^{-4} m/d, calculated at 2 % of mean annual precipitation (MAP).

The groundwater sinks are represented by the existing open pits and future open pits. The following sinks are taken into consideration for the Tshipi Numerical Model (Figure 9-4):

- UMK existing open pits
- Mamatwan existing open pit
- Tshipi existing open pit
- Tshipi future open pit.

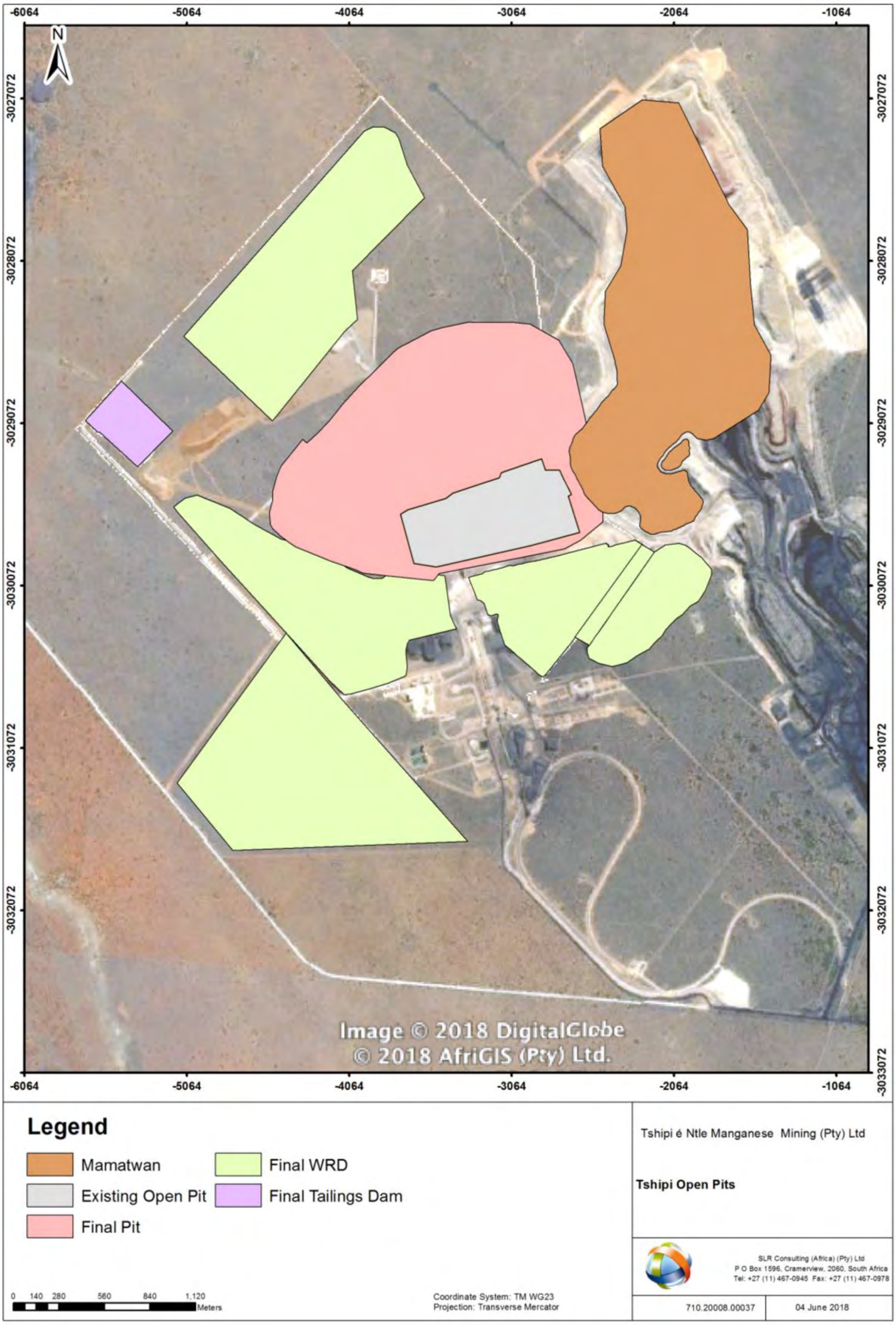

Figure 9-4: Tshipi Open Pits

Note: this figure includes the barrier pillar in the Tshipi open pit to present the maximum pit extent, which was modelled.

9.6 CONCEPTUAL MODEL

Figure 9-5 illustrates the hydrogeological conceptual model which forms the basis of the groundwater numerical model. The conceptual model is a simplification of the real world conditions, but at the same time captures the main elements to be simulated in the numerical model.

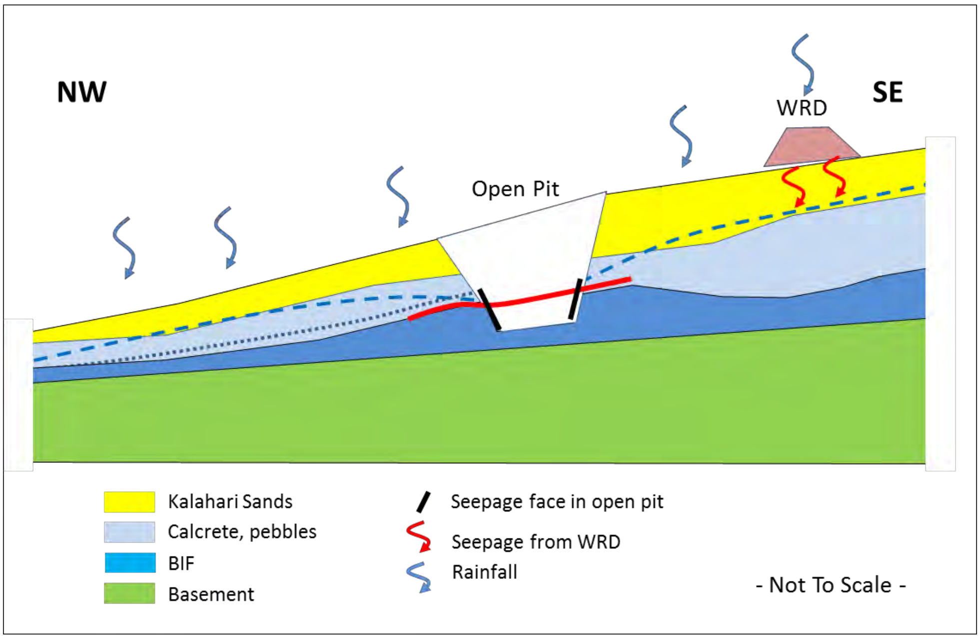

Figure 9-5: Tshipi Hydrogeological Conceptual Model

The Kalahari layer is included across the full extent of the groundwater model as the deposits are surficial and Aeolian. The Kalahari overlies the calcrete layer, which is a minor aquifer in this area. The deeper aquifer is represented by the banded ironstone formation (Hotazel). To avoid numerical non-convergence during the model run, the model was extended to a depth elevation of 500 mamsl, represented by the Basement formations.

9.7 MODEL DISCRETIZATION

The horizontal discretization of the model domain takes into consideration several hydraulic and geochemical stress elements critical for the numerical simulations:

- Existing open pit mines
- Existing waste rock dumps
- Existing tailings dam
- Future mining and waste rock disposal
- Geology
- Surface water bodies.

Figure 9-6 shows the hydraulic and geochemical stress elements incorporated in the model. The resulting horizontal finite elements mesh is showed in Figure 9-7.

The initial vertical discretization was based on the simplified geology described in the area (Table 9-1).

This was further refined considering the mining levels (existing and future).

Table 9-1: Vertical Layers (Ages, 2007)

No	Zone	Hydraulic conductivity (K)	Thick (m)	Trans-missivity (m^2/d)	Head gradient (1)	Darcy flux (m/d)	Recharge (mm/y)	Recharge (m/d)	Seep Vel (m/y)
1	Sand	6.00	5	30	0.005	0.030	344	9.42E-04	110
2	Calcrete	1.50	20	30	0.005	0.008	344	9.42E-04	27
3	BIF	1.00	30	30	0.005	0.005	344	9.42E-04	18
4	Faults	2.40	25	60	0.005	0.012	344	9.42E-04	44

The final vertical layering of the Tshipi groundwater model is shown in Table 9-2.

Table 9-2: Tshipi Groundwater Model - Vertical Discretization

Slice/Layer	Layer Description	Layer elevation	Formation
1	Barrier system	topo + 1.5	Kalahari sands and barrier system where applicable
1	Topo pre-mining	topo	Kalahari sands; liner 1.5m thick
2	Slice1 minus 1m	1080	
3	slice 3 (mining 1060)	1060	
4	slice 4 (mining 1040)	1040	Kalahari calcrete + pebbles
5	bottom Kalahari	1030	Dwyka
6	top_bif1a (mining 1020)	1020	BIF1
7	mining 1000	1000	
8	bottom biff (mining 980)	980	
9	960	960	Hotazel
10	940	940	
11	920	920	
12	900	900	
13	880	880	BIF2
14	860	860	
15	700 mamsl	700	Basement
16	500 mamsl	500	

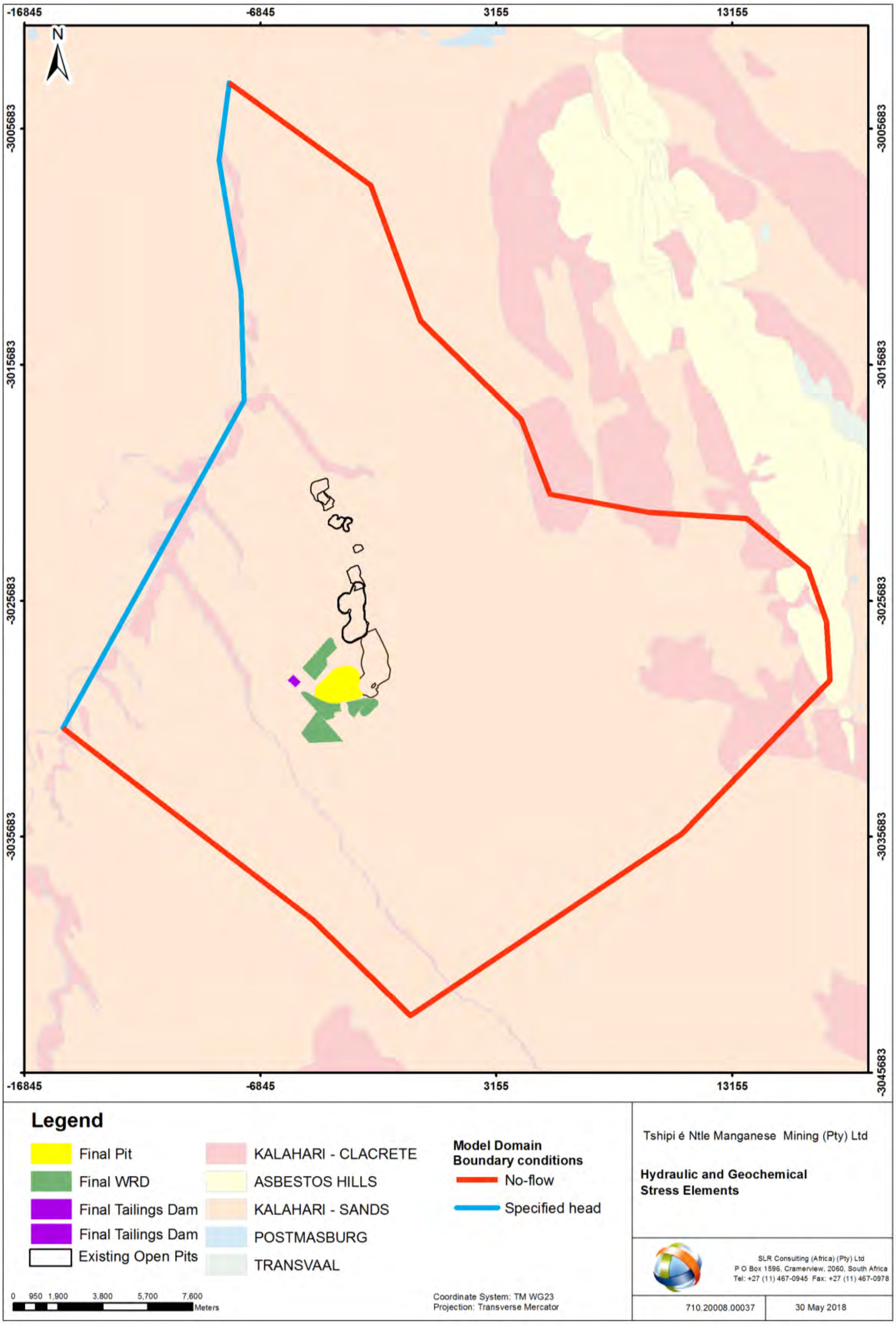

Figure 9-6: Principal Hydraulic and Geochemical Stress Elements

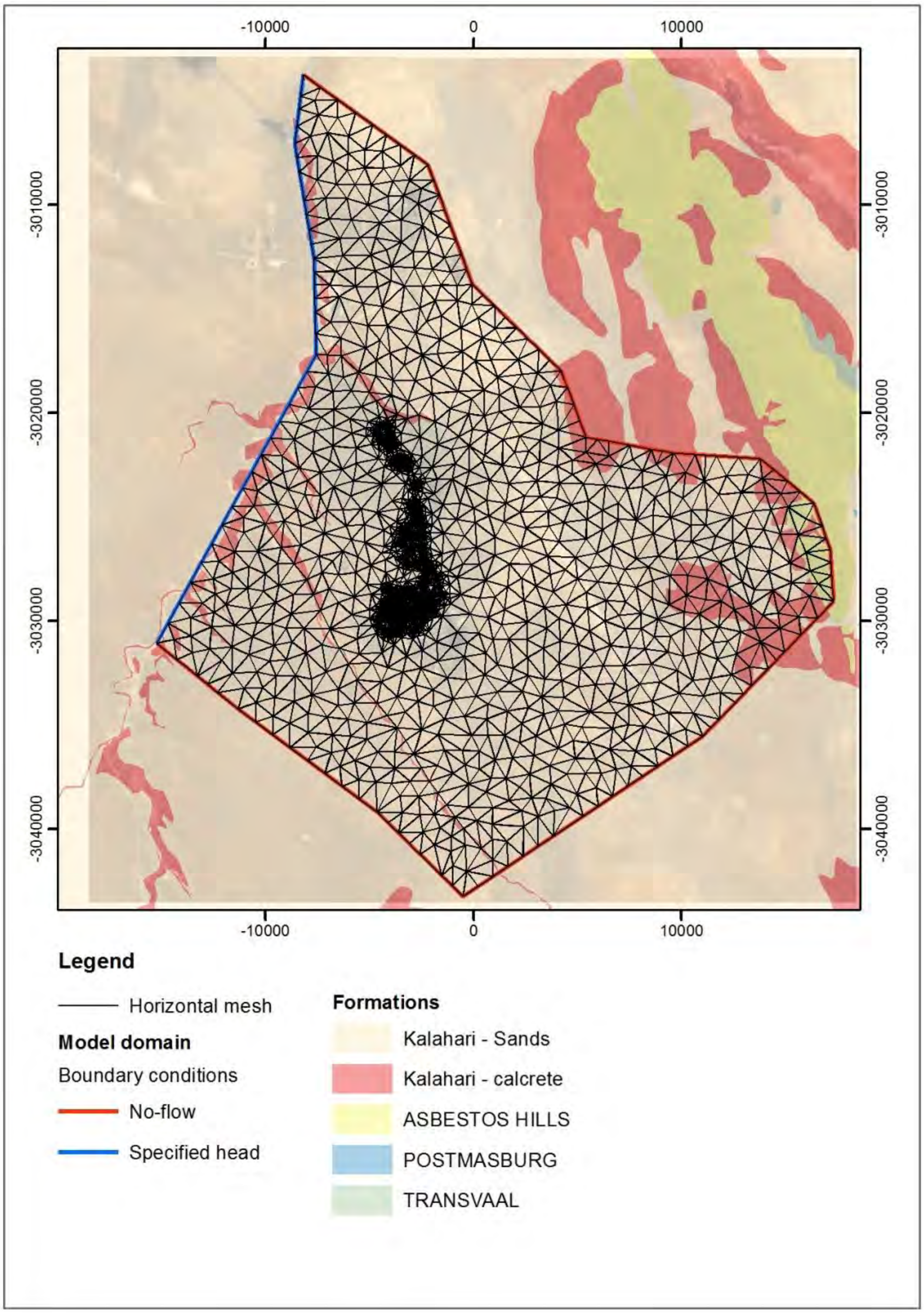

Figure 9-7: Groundwater Model Horizontal Mesh

The resulting three-dimensional numerical model is illustrated in Figure 9-8, and can be summarized as follows:

- Model area: 600 km^2
- Model bottom elevation: 500 mamsl
- Numbers of elements: 276,560
- Number of nodes: 148,036

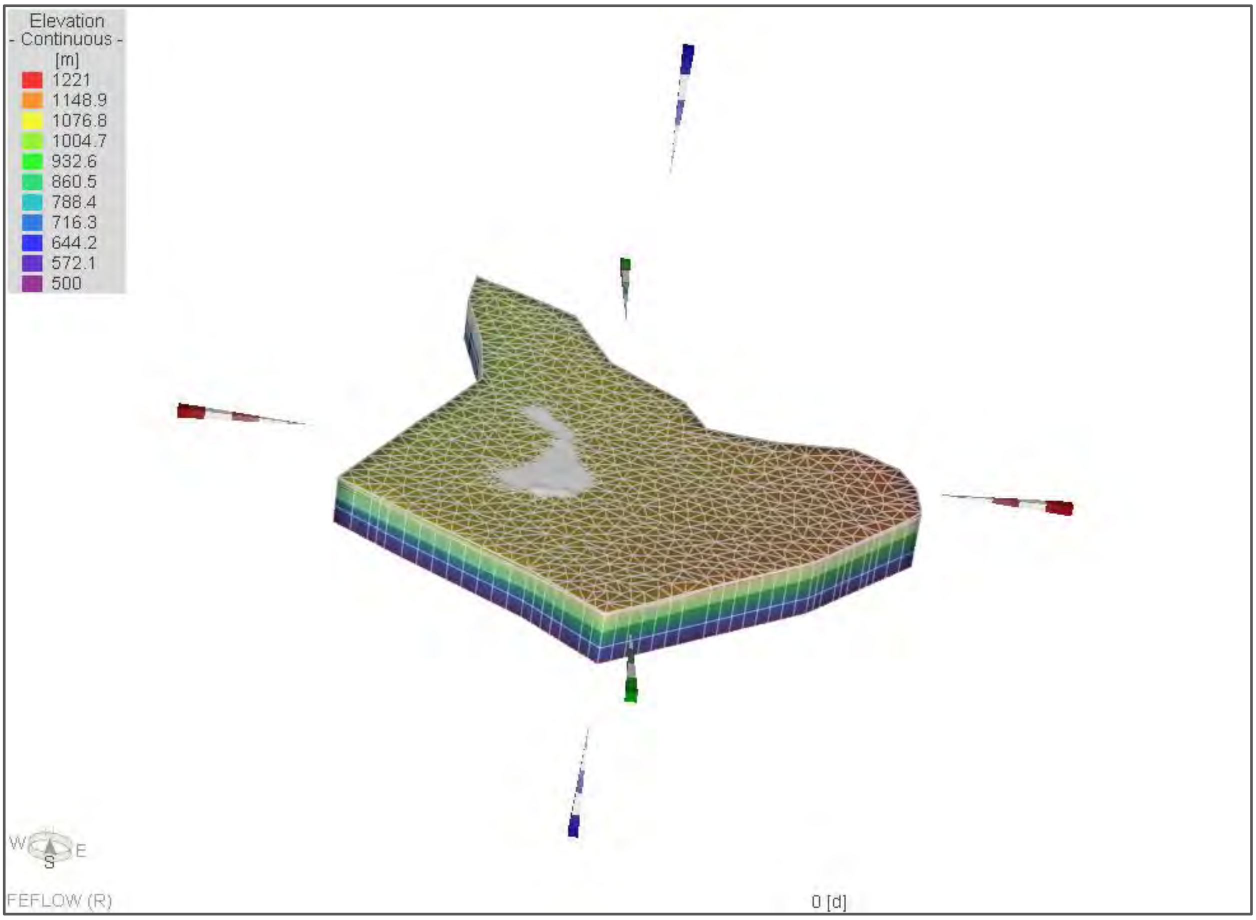

Figure 9-8: Three Dimensional Numerical Model

9.8 NUMERICAL MODEL

9.8.1 Model Initials

Once the three dimensional numerical model is constructed, hydraulic properties are assigned to the model elements. Table 9-3 details the hydraulic properties assigned to the formations represented in the model.

Table 9-3: Tshipi Groundwater Model - Hydraulic Properties

Formation	K_h/K_v (m/d)	Storativity
Class A liner	5×10^{-11}	0.0001
Kalahari sands	1.0/1.0	0.01
Kalahari calcrete + pebbles	0.5/0.05	0.001
BIF1	0.05/0.005	0.001
Hotazel	0.001/0.0001	
BIF2	0.01/0.001	0.001
Basement	0.001	0.0001

The initial recharge assigned as in-out flow from top/bottom is 2×10^{-4} m/d, representing 2% of M.A.P.

9.8.2 Model Calibration

The steady state calibration is performed to determine the suitability of hydraulic properties which allow groundwater flow and to compare the simulated hydraulic heads with the measured hydraulic heads in the observation points.

The calibration of the Tshipi groundwater model was run using the initial hydraulic properties assigned together with the hydraulic head values and average annual groundwater recharge computed from the average rainfall data throughout the model domain. Figure 9-9 shows the plot of measured hydraulic heads vs. simulated hydraulic heads.

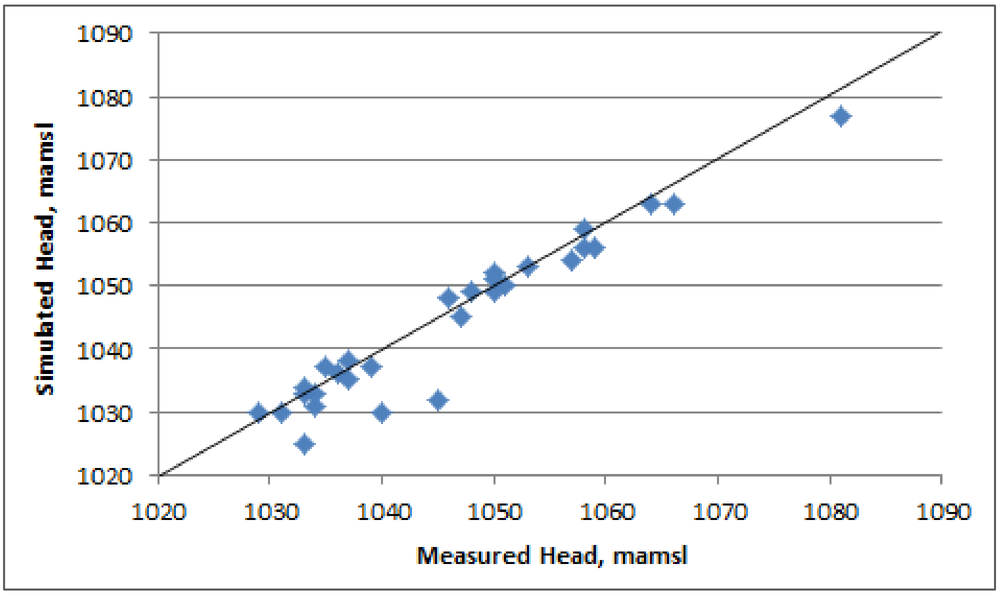

Figure 9-9: Hydraulic Head - Measured vs. Simulated

The differences between the measured hydraulic head and computed hydraulic head are very small, and the calibration was considered satisfactory. The Residual Mean Squared Error (RMSE) and Normalised Residual Mean Squared Error (NRMSE), which represent the quantitative measure of the model calibration are within the prescribed groundwater model calibration guidelines (ASTM Guidelines) –

Table 9-4.

Table 9-4: Tshipi Groundwater Model Calibration

BH	Head	Head_sim	Head_diff	Head diff^2
UMK1	1046	1048	-2	4
UMK2	1064	1063	1	1
UMK3	1058	1056	2	4
UMK4	1066	1063	3	9
UMK5	1081	1077	4	16
JB25	1048	1049	-1	1

BH	Head	Head_sim	Head_diff	Head diff^2
JB9	1031	1030	1	1
JB12	1034	1031	3	9
UMK2017-1	1034	1033	1	1
UMK2017-2	1033	1025	8	64
UMK2017-6	1040	1030	10	100
UMK2017-4	1045	1032	13	169
UMK2017-3	1033	1033	0	0
UMK2017-5	1033	1034	-1	1
BH04	1039	1037	2	4
UMK09	1037	1035	2	4
UMK10	1037	1038	-1	1
NT1	1047	1045	2	4
NT8	1036	1036	0	0
NT15	1058	1059	-1	1
TSH01	1035	1037	-2	4
TSH02	1057	1054	3	9
TSH03	1029	1030	-1	1
TSH04	1059	1056	3	9
TSH06	1050	1049	1	1
			RMSE	3.80
			NRMSE	7%

A Normalised Residual Mean Square Error (NRMSE) value below 10% is considered as an acceptable calibration – in Tshipi's case it is 7% as per Table 9.4 above.

9.8.3 Simulation of Mining

The simulation of mining and backfill was described in detail in the EMP1 Groundwater report (SLR Consulting Africa (PTY) Ltd, 2018). Open pit mining was simulated as follows:

9.8.4 Simulation of Recharge – Transient Mode

In transient mode, the recharge was assigned as cyclic monthly time series, as shown in Figure 9-10, considering 2 % of monthly rainfall averages.

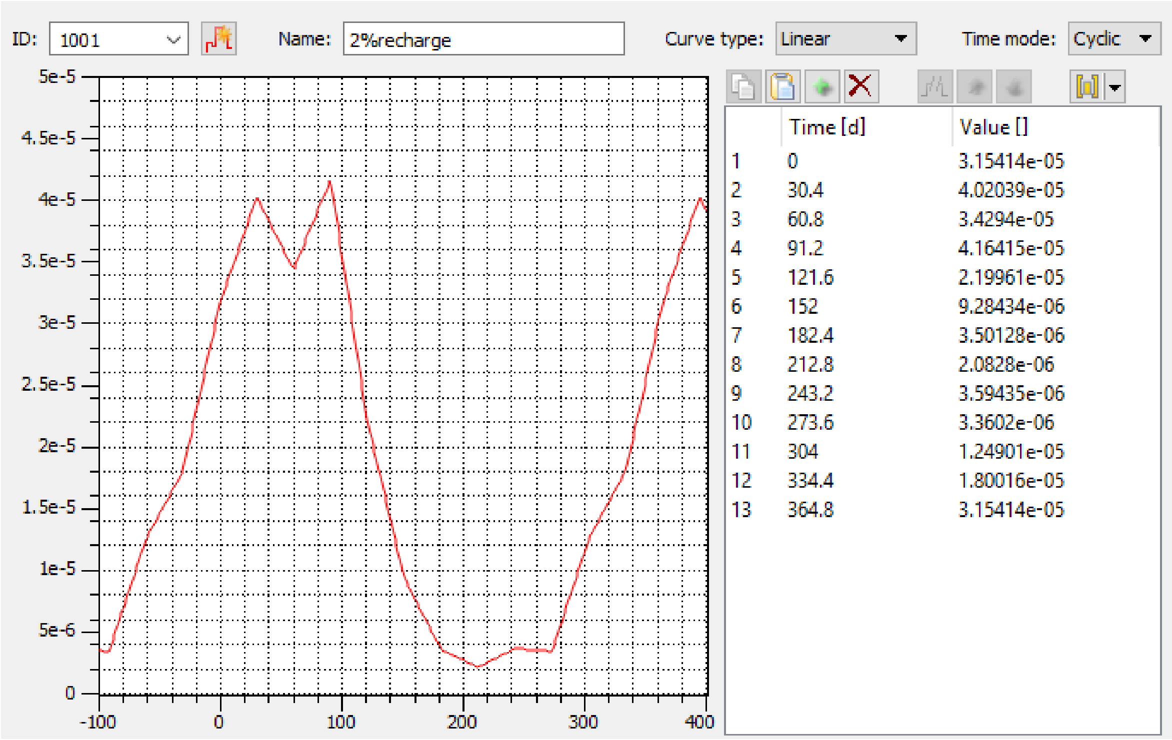

Figure 9-10: Groundwater Model Transient Recharge

9.8.5 Simulation of Source Term

The 2016 Waste Assessment study completed by Goloder and Associates indicates that there are no significant parameters of concern with respect to the waste rock material. In addition, the waste rock material was found to be non-hazardous and non-potentially acid generating (non-PAG). In the absence of a parameter of concern from the waste study, chloride was selected for contaminant transport simulation as a conservative parameter which remains in solution and should therefore provide the maximum plume extent. This is consistent with other groundwater and geochemical studies conducted for mining projects in the Northern Cape. Manganese is not typically used in contaminant simulation because the baseline manganese levels are already elevated in groundwater and manganese reacts with other chemical components, therefore simulation using manganese would not result in a conservative and meaningful simulation

The Source Term has been simulated in transient mode and includes all approved and proposed pollution sources as follows:

- Existing and future Waste Rock Dumps and Tailings Storage Facility: concentrations are simulated as percentage; this can be calculated as soon as Source Term concentrations for elements of concern are determined. Boundary Condition for the whole duration of the simulation
- Open pit backfill: the Concentration Boundary Condition is turned-on at the respective time steps when backfilling occurs in the open pit; the concentration is maintained after that, until the end of the simulation (SLR, 2018).

9.9 MODEL RESULTS

The Tshipi three-dimensional groundwater numerical model was run in transient mode for a period of 100 years. This will cover 25 years of mining and 75 years post-mining. The model results were extracted for the unlined (unmitigated) and lined (mitigated) scenarios at the following time-steps for the approved infrastructure with the proposed WRD extensions.

- Year 25 – End of mining
- Year 50 – Period equal to mining period (post-mining)
- Year 75 – 50 years post-mining
- Year 100 – End of simulation.

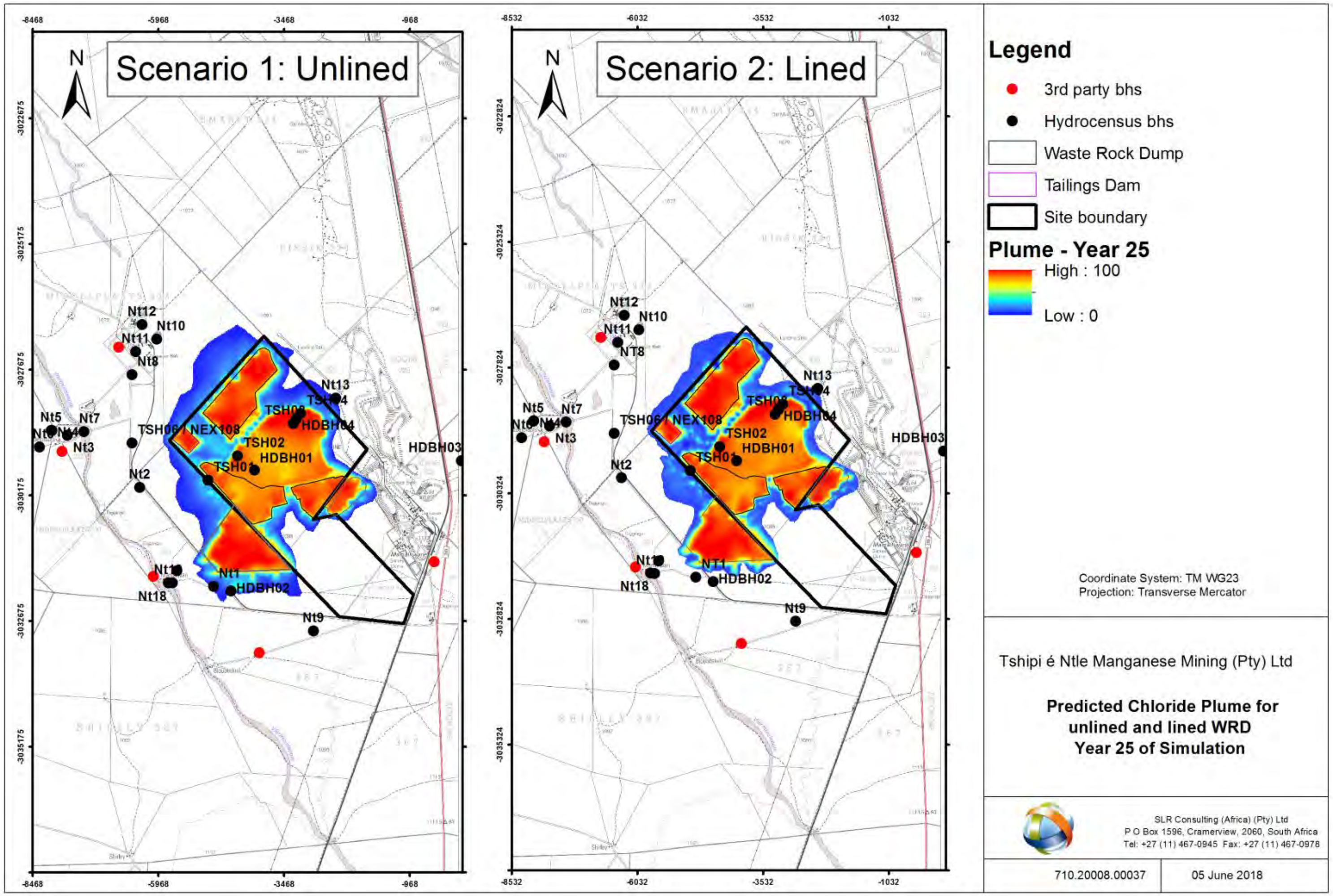

Figure 9-11: Predicted Chloride Plume for Approved Infrastructure and Proposed WRD extensions - Year 25 (End of Mining)

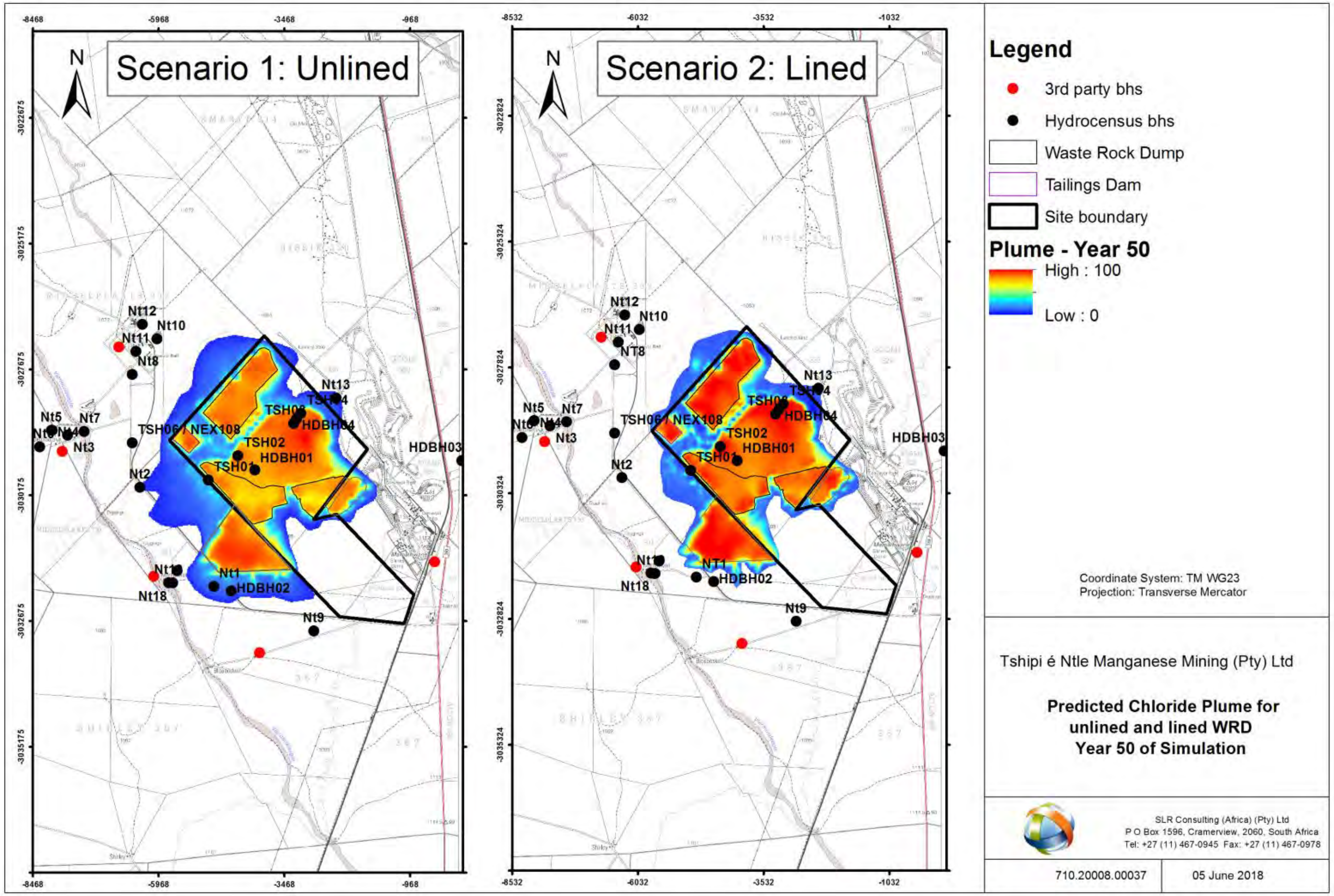

Figure 9-12: Predicted Chloride Plume for Approved Infrastructure and Proposed WRD extensions - Year 50

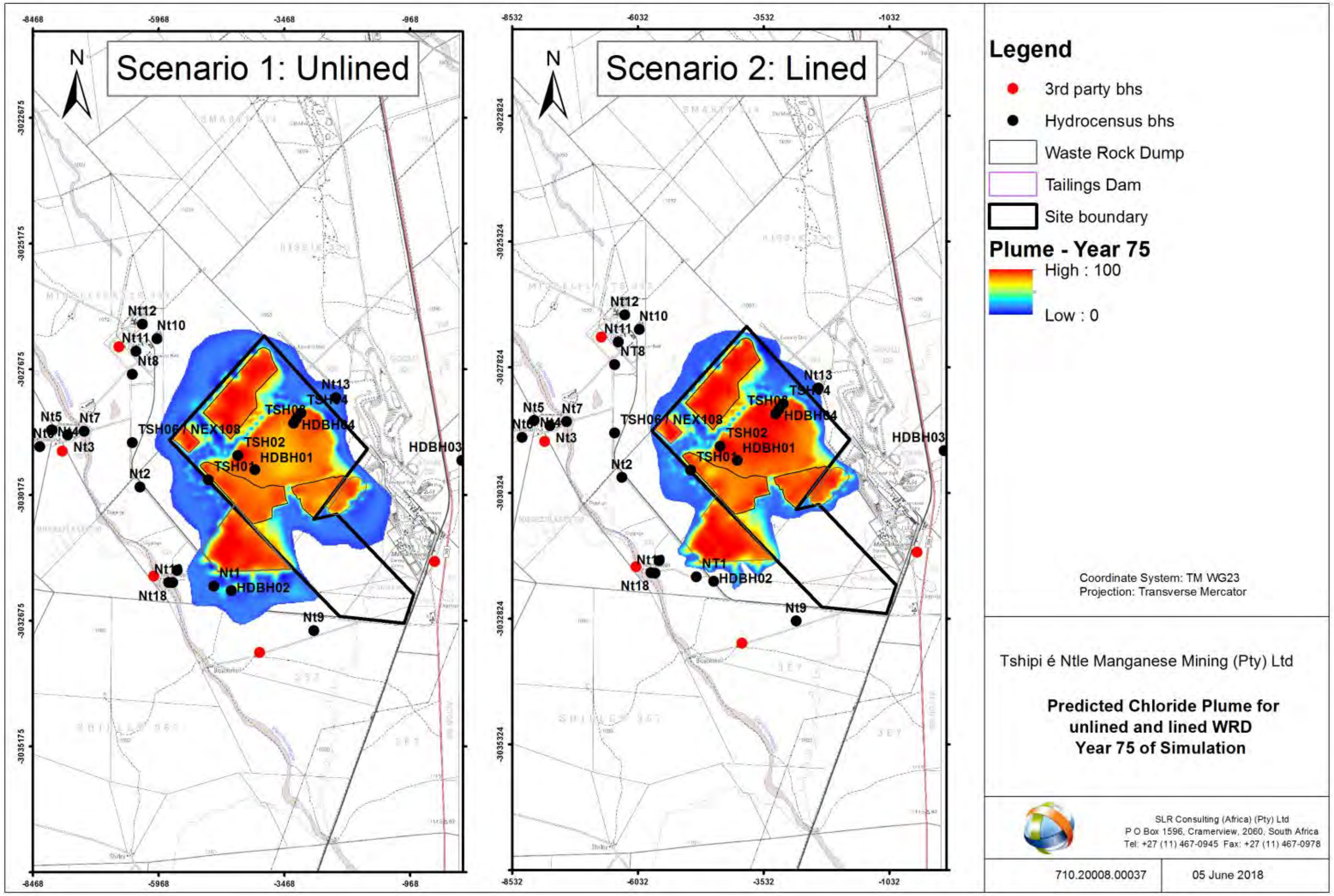

Figure 9-13: Predicted Chloride Plume for Approved Infrastructure and Proposed WRD extensions - Year 75

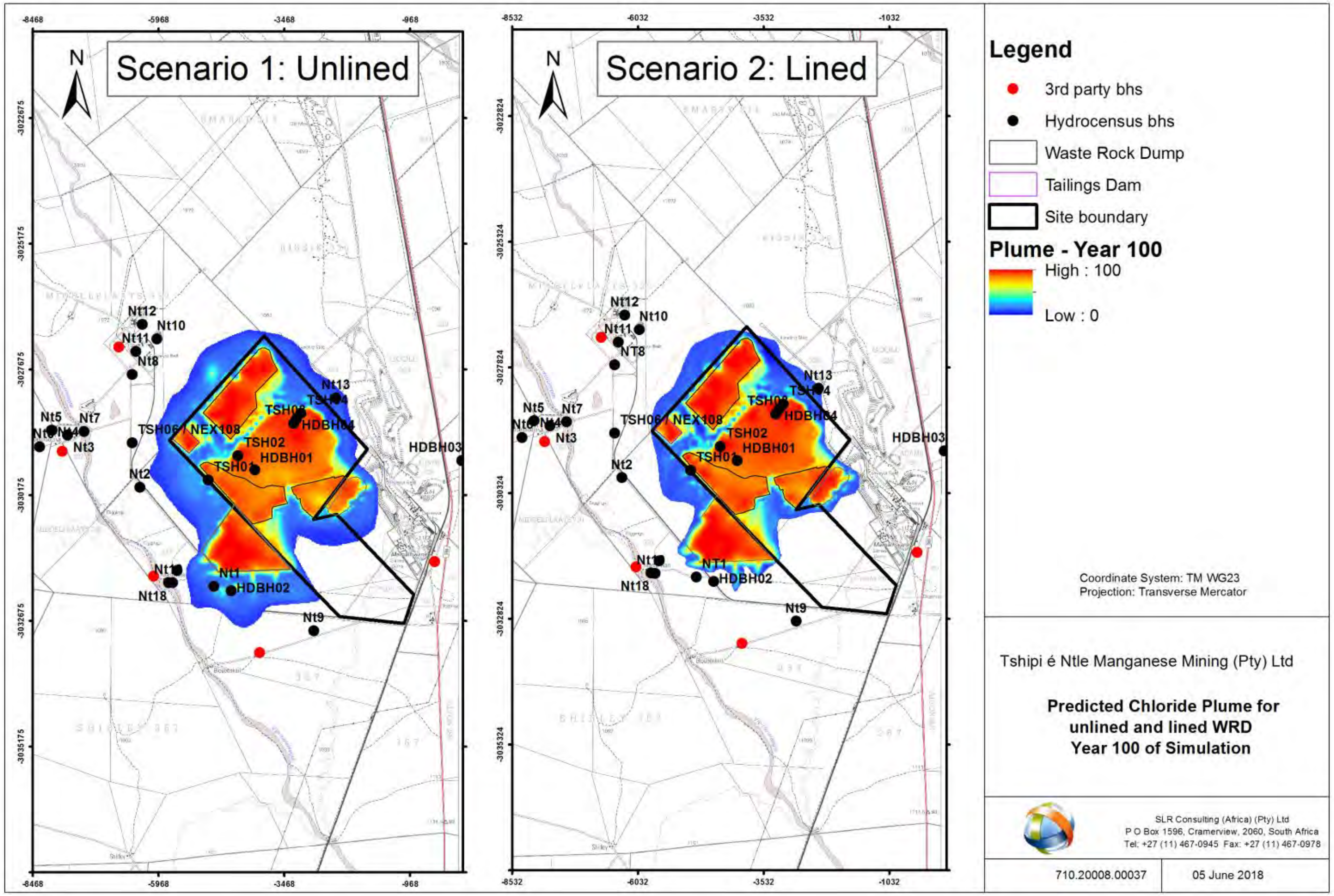

Figure 9-14: Predicted Chloride Plume for Approved Infrastructure and Proposed WRD extensions - Year 100

9.9.1 Conclusions

The mass transport model has been done in a non-reactive mode (conservative). The maximum possible contaminant source (100% of concentration) is assumed to remain in place for the duration of the simulation, on:

- WRDs
- In-pit back filling.
- TSF

This is cumulative assessment of all considered Source Term facilities. Table 9-5 summarises the pollution plume migration.

Table 9-5: Contamination plume migration

		Approved infrastructure and proposed WRD extensions		
Simulated years	**Migration direction**	**Unlined Scenario (worst case) – migration plume**	**Lined scenario (Class A) – migration plume**	**Difference in distance of plume migration**
25 years	North west	730	590	140
	North east	470	430	40
	South east	100	70	30
	South west	840	780	60
50 years	North west	730	620	110
	North east	480	450	30
	South east	170	110	60
	South west	900	840	60
75 years	North west	830	650	180
	North east	480	450	30
	South east	900	120	780
	South west	890	840	50
100 years	North west	980	710	120
	North east	550	470	10
	South east	1300	690	210
	South west	990	840	160

10.GROUNDWATER IMPACTS

Groundwater impacts are discussed under issue headings in this section. Impacts are considered both incrementally and cumulatively in the context of the existing and approved Tshipi mining infrastructure and activities. The potential impacts are rated with the assumption that no management actions are applied and then again with management actions. An indication of the phases in which the impact will occur including the project specific activity associated with each impact is provided below. Management actions identified to prevent, reduce, control or remedy the assessed impacts are provided under the relevant impact discussions sections below. It is important to note that management actions will include any measures outlined in the mine's approved EMPr and any additional management actions identified as part of the project, where relevant. Any additional management actions will be indicated in *italics*.

The proposed project does not include any dewatering activities; therefore, dewatering impacts assessed in the approved EMPr amendment (SLR, 2017d) will remain valid and will not be discussed in this report. This section focusses on the potential groundwater contamination impacts of the proposed project.

The method used to assess potential groundwater impacts is set out in Table 10-1 below. Part A in Table 10-1 below provides a list of criteria that can be selected in order to rank the severity, duration and spatial scale of an impact. The consequence of the impact is determined by combining the selected criteria ratings allocated for severity, spatial scale and duration in part B of Table 10-1. The significance of the impact is determined in Part C of Table 10-1 whereby the consequence determined in part B is combined with the probability of the impact occurring. The interpretation of the impact significance is given in Part D.

Table 10-1: Criteria for Assessing Impacts

PART A: DEFINITION AND CRITERIA*		
Definition of SIGNIFICANCE		**Significance = consequence x probability**
Definition of CONSEQUENCE		**Consequence is a function of severity, spatial extent and duration**
Criteria for ranking of the SEVERITY of environmental impacts	**H**	Substantial deterioration (death, illness or injury). Recommended level will often be violated. Vigorous community action.
	M	Moderate/ measurable deterioration (discomfort). Recommended level will occasionally be violated. Widespread complaints.
	L	Minor deterioration (nuisance or minor deterioration). Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints.
	L+	Minor improvement. Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints.
	M+	Moderate improvement. Will be within or better than the recommended level. No observed reaction.
	H+	Substantial improvement. Will be within or better than the recommended level. Favourable publicity.
Criteria for ranking the DURATION of impacts	**L**	Quickly reversible. Less than the project life. Short term
	M	Reversible over time. Life of the project. Medium term
	H	Permanent. Beyond closure. Long term.
Criteria for ranking the SPATIAL SCALE of impacts	**L**	Localised - Within the site boundary.
	M	Fairly widespread – Beyond the site boundary. Local
	H	Widespread – Far beyond site boundary. Regional/ national

PART B: DETERMINING CONSEQUENCE					
			SEVERITY = L		
DURATION	Long term	**H**	Medium	Medium	Medium
	Medium term	**M**	**Low**	**Low**	Medium
	Short term	**L**	**Low**	**Low**	Medium
			SEVERITY = M		
DURATION	Long term	**H**	Medium	**High**	**High**
	Medium term	**M**	Medium	Medium	**High**
	Short term	**L**	**Low**	Medium	Medium
			SEVERITY = H		
DURATION	Long term	**H**	**High**	**High**	**High**
	Medium term	**M**	**Medium**	Medium	**High**
	Short term	**L**	**Medium**	Medium	**High**
			L	**M**	**H**
			Localised Within site boundary Site	Fairly widespread Beyond site boundary Local	Widespread Far beyond site boundary Regional/ national
			SPATIAL SCALE		

PART C: DETERMINING SIGNIFICANCE					
PROBABILITY (of exposure to impacts)	Definite/ Continuous	**H**	Medium	Medium	**High**
	Possible/ frequent	**M**	Medium	Medium	**High**
	Unlikely/ seldom	**L**	**Low**	**Low**	Medium
			L	**M**	**H**
			CONSEQUENCE		

PART D: INTERPRETATION OF SIGNIFICANCE	
Significance	**Decision guideline**
High	It would influence the decision regardless of any possible management actions.
Medium	It should have an influence on the decision unless it is mitigated.
Low	It will not have an influence on the decision.

***H = high, M= medium and L= low and + denotes a positive impact.**

ISSUE: CONTAMINATION OF GROUNDWATER RESOURCES

Introduction

There are a number of sources in all mine phases that have the potential to pollute groundwater. Some existing sources are permanent (approved tailings dam) and some sources are transient (starting later and at different time-steps) and becoming permanent (pit backfilling). Proposed sources include the WRD extensions which are likely to be permanent sources. Even though some sources are temporary in nature, related potential pollution can be long term. The operational phase will present more long term potential sources (existing WRDs and proposed WRD extensions) and the closure phase will present final land forms, such as the backfilled open pit and the tailings dam that may have the potential to pollute water resources through long term seepage and/or run-off.

Table 10-2: Mine phase and link to project specific activities/infrastructure

Construction	Operational	Decommissioning	Closure
Earthworks	Mineralised waste (existing and proposed sources) Open pit mining (including backfilling)	Mineralised waste (existing and proposed sources) Backfilling of open pit	Final land forms

Rating of impacts

<u>Severity / nature</u>

Groundwater contamination was assessed as part of the original EMPr (Metago, May 2009). The groundwater study supporting the 2009 EMPr found that there would be no significant offsite migration of contaminants and, therefore, the related impact was rated as having a **LOW** significance in the unmitigated and mitigated scenarios. The key contributing factors included:

- Low seepage rates from the TSF and WRDs;
- Limited hydraulic conductivity of the material underlying the TSF and WRDs; and
- The retardation effect of the pit dewatering on parts of the modelled pollution plume.

The approved infrastructure was modelled using two scenarios:

- <u>Unlined Scenario (unmitigated)</u>

  This scenario modelled the current situation where the WRDs on site are not lined; however, the TSF is lined and was modelled as such.
- <u>Lined Scenario (mitigated)</u>

In accordance with GNR 635 and GNR 636 waste rock samples tested for Tshipi were classified as Type 1 waste, which would require disposal on a facility with a Class A barrier system. A Class A barrier is designed in such a way to avoid any seepage from the waste facility. A very low hydraulic conductivity was assumed for the areas under the WRDs in this scenario.

It should however be noted that according to the waste assessment conducted by Golder, there is low risk from leachate from WRDs as all leachate parameters are below the leachable threshold. A Class D barrier was therefore recommended by this study. This corresponds to the unlined scenario, which includes base preparation.

The groundwater model was run to simulate a period of 100 years, which included 25 years of mining and 75 years post-mining, and included approved infrastructure and pollution sources. A chloride source concentration of 2 200 mg/ℓ was simulated for pollution sources. The groundwater model showed a maximum chloride plume would extend up to 990 m from the Mining Right area to the south-west in the unlined scenario, and 840 m in the lined scenario at the end of the simulation (year 100). The assessment found that the changes would not present significantly different contaminants or source types to those previously assessed for all project phases and assessed the cumulative impact as being **low** in the unmitigated scenario because the migration of the pollution plume was expected to be limited and was not expected to impact on third party water users using boreholes for water supply.

The proposed East WRD and West WRD extensions were also modelled using an unlined and lined scenario for a period of 100 years and included all existing and potential pollution sources. The model included all of the approved infrastucture with the addition of the proposed WRD extensions. The maximum chloride plume is predicted to extend a little over 1.1 km from the West WRD extension area in a western direction (refer to Figure 1) at the end of the simulation (year 100) in the unlined scenario. This results in a plume of low concentration outside of the Mining Right area. However, the only third party borehole which falls within the predicted pollution plume is NT13, which is a Mamatwan Mine monitoring borehole and is not used for abstraction for water supply. The lined scenario shows a plume that that does not extend as far out from the West WRD extension area when compared to the unlined scenario. The maximum distance the plume extends is approximately 770 m to the west. There are no known third parties using boreholes for water supply within the predicted plume.

Considering that both scenarios result in a plume of low concentration outside of the Mining Right area and that there are no known third parties using boreholes for water supply within the predicted plumes, there is no significant difference in the impact severity rating in the unlined and lined scenarios.

When adding the East and West WRD extensions, modelling shows that the addition of the pollution sources do not materially change the overall impact of the mine as assessed in the approved EMPr amendment (SLR, 2017), which remains rated at a low severity.

<u>Duration</u>

Groundwater contamination is long-term in nature, occurring for periods longer than the life of mine in both the unmitigated and mitigated scenarios.

<u>Spatial scale / extent</u>

The pollution plume will extend beyond the Mining Right area in both the unmitigated and mitigated scenarios.

Consequence

The consequence is medium in the unmitigated and mitigated scenarios.

Probability

The probability of the impact occurring relies on a causal chain that comprises three main elements:

- Does contamination reach groundwater resources;
- Will people and animals utilise this contaminated water; and
- Is the contamination level harmful?

The first element is that contamination reaches the groundwater resources underneath or adjacent to the mining area. Pollution plume modelling shows that contaminants could reach groundwater resources in the unmitigated and mitigated scenarios. The second element is that third parties and/or livestock use this contaminated water for drinking purposes. There are no known third party boreholes located within the simulated contaminant plume in the unmitigated and mitigated scenarios using boreholes for water supply. The third element is whether contamination is at concentrations which are harmful to users. Based on predicted groundwater modelling, mine related contamination will be at low concentrations outside of the Mining Right area in both the unmitigated and mitigated scenarios. As a combination, the unmitigated and mitigated scenario probability is low.

Cumulative Impact Significance

The unmitigated and mitigated scenario significance is low.

Table 10-3: Unmitigated – summary of the rated cumulative contamination of groundwater impact per phase of the mine

Management	Severity / nature	Duration	Spatial scale / extent	Consequence	Probability of Occurrence	Significance
All phases						
Unmitigated	L	H	M	M	L	L

Table 10-4: Mitigated – summary of the rated cumulative contamination of groundwater impact per phase of the mine

Management	Severity / nature	Duration	Spatial scale / extent	Consequence	Probability of Occurrence	Significance
All phases						
Mitigated	L	H	M	M	L	L

Management objective

The objective is to prevent pollution of groundwater resources and related harm to other water users.

Management actions

Management actions to be implemented include the following:

- Tshipi will continue to monitor groundwater quality (refer to Section 11 for the monitoring programme). *Additional monitoring points have been added to the monitoring programme in order to more effectively monitor potential groundwater contamination impacts. In the event that water quality monitoring around any pollution sources (TSF, open pit and WRDs) indicates that these sources are causing pollution, additional management measures will be investigated in consultation with a qualified specialist.*
- Should any off-site contamination be detected, the mine will immediately notify DWS. The mine, in consultation with DWS and an appropriately qualified person, will then notify potentially affected users, identify the source of contamination, identify measures for the prevention of this contamination (in the short term and the long term) and then implement these measures;
- If third party water users experience any Tshipi related contamination and related loss of water supply, Tshipi will provide compensation, which could include an alternative water supply of equivalent water quality and quantity;
- Prevent pollution through basic infrastructure design; and
- Should any WRDs be removed during decommissioning and closure through backfill into the open pit, the footprints will be rehabilitated by ripping the underlying subsoil, then replacing the topsoil, vegetating, applying fertilizer, and irrigating the new growth for a short period.
- The groundwater model will be re-run periodically during the operational phase to consider potential pollution impacts without the retardation effect of pit dewatering. If necessary, provision will be made by the mine for post closure compensation that may be required for any future negative impacts. This will form part of detailed closure planning.

In case of a major discharge incident that may result in the pollution of groundwater resources the Tshipi emergency response procedure will be followed.

11. GROUNDWATER MONITORING SYSTEM

11.1 GROUNDWATER MONITORING NETWORK

The Tshipi groundwater monitoring programme includes the current monitoring boreholes and also six additional recommended boreholes to address monitoring pollution sources, pollution plume or impact monitoring points and background or upstream points. These points are shown in

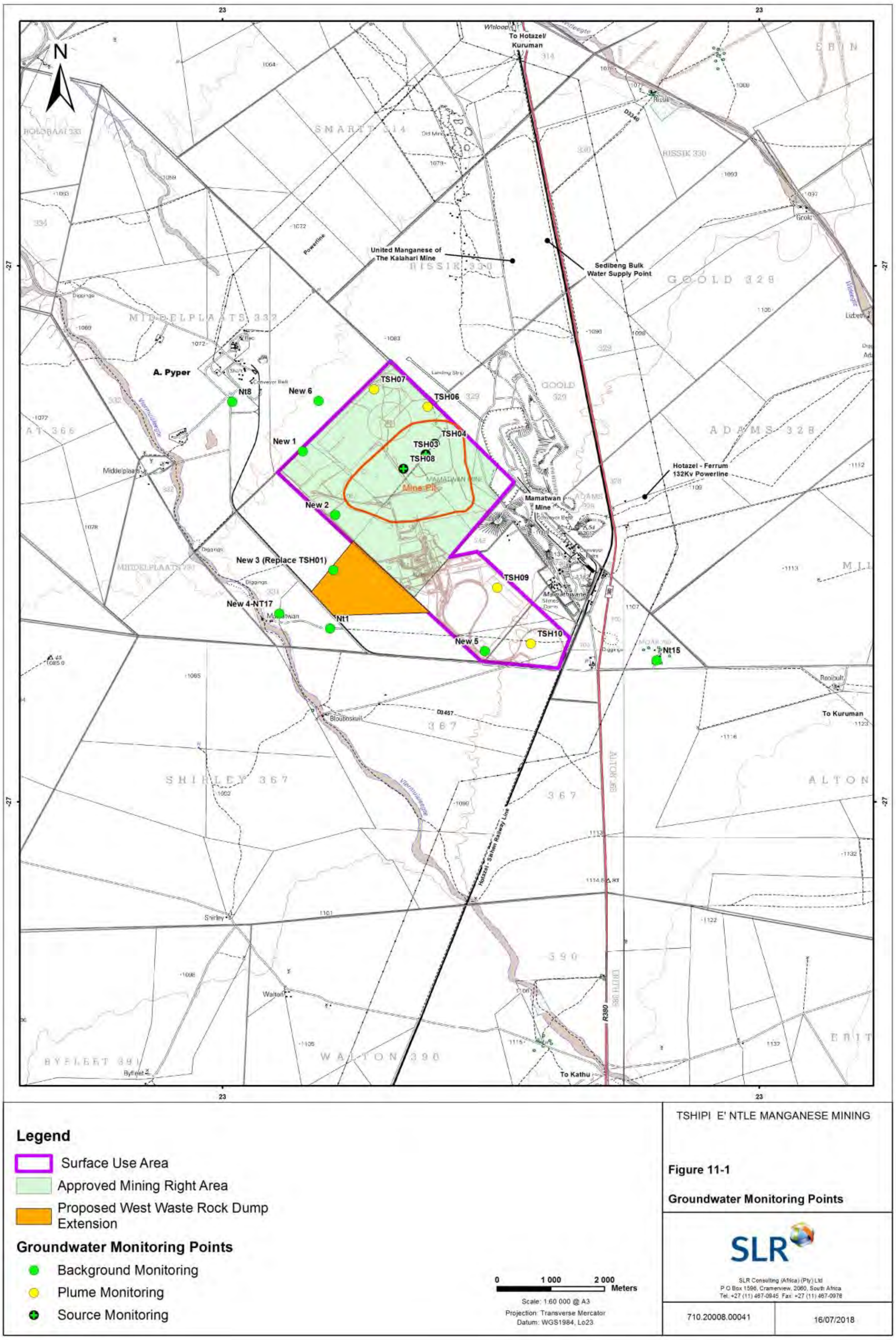

Figure 11-1. Table 11-1 shows the coordinates of the monitoring boreholes.

Table 11-1: Coordinates of monitoring boreholes

Borehole name	Latitude	Longitude
Nt1	27° 24' 1.00" S	22° 57' 2.80" E
Nt8	27° 21' 44.00" S	22° 56' 3.80" E
Nt15	27° 24' 20.10" S	23° 0' 19.80" E
TSH03	27° 22' 15.80" S	22° 58' 0.40" E
TSH04	27° 22' 9.30" S	22° 58' 5.90" E
TSH06	27° 21' 47.16" S	22° 58' 1.70" E
TSH07	27° 21' 36.50" S	22° 57' 29.30" E
TSH10	27° 24' 10.20" S	22° 59' 3.90" E
TSH09	27° 23' 36.20" S	22° 58' 43.60" E
TSH08	27° 22' 24.50" S	22° 57' 47.00" E
New 1	27° 22' 13.92" S	22° 56' 46.24" E
New 2	27° 22' 52.33" S	22° 57' 5.87" E
New 3 (Replaces borehole TSH01 which is no longer usable)	27° 23' 25.69" S	22° 57' 4.74" E
New 4 (hydrocensus point NT17, an existing borehole)	27° 23' 52.01" S	22° 56' 32.10" E
New 5	27° 24' 14.57" S	22° 58' 36.17" E
New 6	27°21'42.993"S	22°56'57.075"E

Note: the final co-ordinates may be adjusted for the new monitoring points once the new boreholes are drilled.

Water quality analyses results should be compared to the Tshipi Water Use Licence requirements. Results should also be classified in terms of the SANS 241 (2015) Water Quality Standards and the DWAF Target Quality Range for Livestock Watering (1996) or whichever is applicable at the time. The monitoring results should be assessed by a suitably-qualified professional registered with the South African Council for Natural Scientific Professional (SACNASP).

11.2 MONITORING FREQUENCY

Groundwater quality monitoring is conducted on a quarterly basis and groundwater levels on a monthly basis.

SLR considers that the monitoring frequency is adequate for groundwater monitoring. However, if contaminants are detected during a monitoring round, a detailed analysis should be performed, and monitoring frequency increased to monthly, for the required monitoring point.

11.3 MONITORING PARAMETERS

The monitoring parameters are as follows:

pH
Conductivity in mS/m at 25 ° c
Total dissolved solids (TDS) at 180 ° c
Alkalinity as $CaCO_3$

Carbonate as CO_3
Bicarbonate as HCO_3
Boron as B
Nitrate as N
Chloride as Cl
Sulphate as SO_4
Fluoride as F
Sodium as Na
Potassium as K
Calcium as Ca
Magnesium as Mg
Manganese as Mn
Full metal scan - Inter Coupled Plasma Scan (ICP) (via Mass Spectrometry (MS)

In the event that the integrated water use licence (IWUL) is amended and changes to the groundwater monitoring programme as outlined in this report are made, the requirements as per the IWUL should be adhered to.

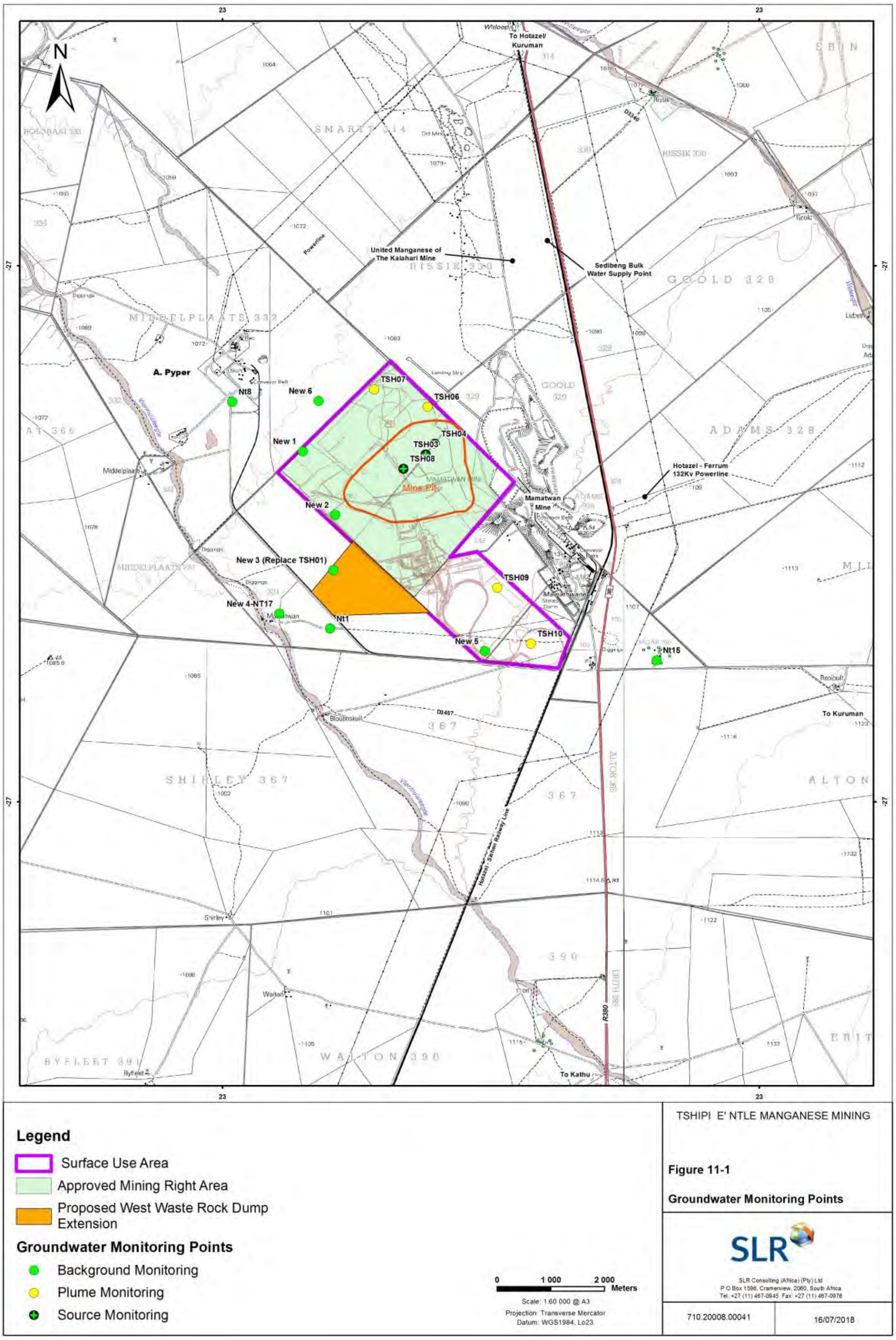

Figure 11-1: Groundwater Monitoring Points

12. GROUNDWATER ENVIRONMENTAL MANAGEMENT PROGRAMME

12.1 CURRENT GROUNDWATER CONDITIONS

The baseline groundwater conditions are described in section 8 of this report.

12.2 PREDICTED IMPACTS OF FACILITY

The results of the simulations are provided in Section 9.9 and the impact assessment is provided in Section 10 of this report.

12.3 MITIGATION MEASURES

Mitigation measures are provided in Table 12-1. The management actions include any measures outlined in the mine's approved EMPr for both dewatering and pollution impacts for the sake of completeness.

Table 12-1: Groundwater Management Plan

No.	Aspect	Management commitment	Action plan		
			Timeframe	Frequency	Compliance indicator
Objective: Prevent quantity impacts to users of groundwater and in nearby surface water systems.					
These commitments apply to construction, operation and decommissioning					
1	Monitoring	Monitor groundwater quality as outlined in Section 11.	Ongoing	As per Section 9	Water monitoring reports
2	Compensation (if required)	If borehole users experience any mine related water contamination or loss of water supply, Tshipi will, in conjunction with other mines in the area that are contributors to the cumulative impact, provide compensation, which could include an alternative water supply of equivalent water quality and quantity.	As required	As required	Investigation report and record of compensation if required
3	Impacts on ground or surface water	In the event that water quality monitoring around any pollution sources (TSF, open pit and WRDs) indicates that these sources are causing pollution, additional management measures will be investigated in consultation with a qualified specialist.	As required	As required	Investigation report and record of corrective action
		Should any off-site contamination be detected, the mine will immediately notify DWS. The mine, in consultation with DWS and an appropriately qualified person, will then notify potentially affected users, identify the source of contamination, identify measures for the prevention of this contamination (in the short term and the long term) and then implement these measures.	As required	As required	Proof of notification of DWS and potentially affected users. Investigation report and record of corrective action
		If monitoring shows that the base flow of the Vlermuisleegte is affected, a specialist team comprising DWS and biodiversity and groundwater experts will be commissioned to investigate the significance of the impacts and the specific management actions that must be implemented by all contributing mines.	As required	As required	Investigation report and record of corrective action
4	Rehabilitation	Should waste rock dumps be removed through backfill to the pit, the footprint area will be rehabilitated by ripping the underlying subsoil, then replacing the topsoil, vegetating, applying fertilizer, and irrigating the new growth for a short period.	Closure	Once off	Rehabilitation reporting

No.	Aspect	Management commitment	Action plan		
			Timeframe	Frequency	Compliance indicator
5	Closure planning	The groundwater model will be re-run periodically during the operational phase to consider potential pollution impacts without the retardation effect of pit dewatering. If necessary, provision will be made by the mine for post closure compensation that may be required for any future negative impacts. This will form part of detailed closure planning	As required	As required	Groundwater model report
6	Emergency	In case of a major discharge incident that may result in the pollution of groundwater resources the Tshipi emergency response procedure will be followed.	As required	As required	Incident investigation report and record of corrective action

13. POST CLOSURE MANAGEMENT PLAN

A preliminary rehabilitation closure plan has been developed for the Tshipi Mine which caters for the following:

- Surface infrastructure will be demolished and removed
- The pit void will be backfilled and the area rehabilitated as far as practically possible
- Areas where infrastructure has been removed will be levelled and restored in terms of soil horizons (as far as practical), vegetation and drainage
- Remaining material stockpiles and waste rock dumps will be profiled and rehabilitated.

Monitoring of groundwater will continue for a time period to be agreed upon with DWS.

14. ASSUMPTIONS AND LIMITATIONS

A numerical groundwater flow and transport model is a representation of some or all characteristics of a real system on an appropriate scale. It is a management tool that is typically used to understand why a system is behaving in a particular observed manner or to predict how it will behave in the future. Its precision depends on chosen simplifications (in a conceptual model) as well as on the completeness and accuracy of input parameters. In particular, data on input parameters like water levels and aquifer properties is often scare and limits the precision and confidence of numerical groundwater models. Impact predictions are based on numerical model results, the precision of which depends obviously on the chosen simplifications as well as the accuracy of input parameters like hydraulic conductivities, porosities or source concentrations.

The groundwater model simulated the UMK and Mamatwan Mines, using their existing pits and does not take into account future mining or backfilling at these mines. An improved groundwater simulation of hydraulic heads (cone of drawdown) and a more realistic contaminant plume could be modelled through information sharing between Tshipi, Mamatwan and UMK.

The source term used for groundwater modelling is considered to be conservative and may overestimate the potential pollution impacts.

It should be noted that no significant faults, fractures or other lineaments were observed at the Tshipi Borwa Mine (Metago, May 2009) and therefore no geological structures have been included in the model. Should such structures be encountered, further hydrogeological work will be needed and the groundwater model will need to be updated. Tshipi has recently exposed a fault in the open pit and will obtain relevant information on this fault to enable it to be included into future groundwater models. This will include drilling and packer testing of the fault.

15. INTERESTED AND AFFECTED PARTY COMMENTS

As part of the environmental impact assessment and environmental management programme process, one interested and affected party (IAP) expressed concern regarding potential impacts of the project on groundwater. This concern has been captured in Table 15-1 below with the response given.

Table 15-1: Groundwater IAP Issue and Comments

Name	Date of comment	Comment received from IAP	Response provided by SLR
Andries van den Berg	14 September 2017 at the public scoping meeting.	In terms of groundwater, I have two boreholes that lie next to the substation and farmhouse on the remainder of the farm Mamatwan 331. The two boreholes have dried up and deliver no water. I would like to know what will happen in future and whether the mine will supply us with water?	The proposed project will not require further dewatering activities. As such the dewatering impacts assessed in the 2017 EMPr remain valid. The dewatering modelling showed that your borehole could experience a drop in water levels of 4 to 7 metres. The Tshipi EMPr includes a commitment to monitor third party boreholes and if borehole users experience any mine related water loss, Tshipi will, in conjunction with other mines in the area that are contributors to the cumulative impact, provide compensation, which could include an alternative water supply of equivalent water quality and quantity as per the approved EMPr. Please approach Tshipi directly to address this issue.

16.CONCLUSIONS AND RECOMMENDATIONS

A groundwater modelling exercise was conducted to determine potential pollution impacts due to the proposed infrastructure and activities. Key findings of the cumulative pollution modelling exercise include:

- The maximum chloride plume is predicted to extend up to 1,1km in a western direction at the end of the simulation (year 100) in the unmitigated scenario, and 700 m in the mitigated scenario. Both scenarios result in a plume of low concentration for a relatively small area outside of the mining right area.
- There are no known third party boreholes within the predicted pollution plumes in the unmitigated and mitigated scenarios using boreholes for water supply.
- This impact has been rated as having a low significance in both the unmitigated and mitigated scenarios. The relevant mitigation measures are outlined in Section 0.

Based on the above assessment, and assuming that the relevant mitigation measures will be effectively implemented, there are no apparent reasons why the project should not be authorised. In addition, the lining of the waste rock dumps does not significantly reduce the pollution plume or impact significance.

Mihai Muresan	**Linda Munro**	**Brandon Stobart**
(Report Author)	(Project Manager)	(Reviewer)

17. REFERENCES

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APPENDIX A: CURRICULA VITAE

CURRICULUM VITAE

MIHAI MURESAN

TEAM LEAD WATER

Groundwater, South Africa

QUALIFICATIONS

MSc	1988	Hydrogeology and Engineering Geology, Univ. of Bucharest, Romania

EXPERTISE

- Hydrogeology
- Mining Hydrogeology
- Groundwater Numerical Modelling
- Hydrogeology for Unconventional Gas (UCG, CBM, Shale Gas)

Mihai is a Team Leader (Water) with SLR South Africa and is responsible for SLR's Hydrology and Hydrogeology in South Africa. Mihai has over 25 years of experience within Hydrogeology, Mining, Oil and Gas Exploration and Unconventional Gas.

Mihai has managed a wide range of major projects and Mine Dewatering and Environmental Impact Assessment (Groundwater Specialist Studies) projects for major minerals developments throughout Africa for many of the major operators within the minerals industry.

In addition to this he advises clients on a wide range of operational mine dewatering and water supply aspects and hydrogeological operational conditions for development of unconventional gas.

Prior to joining SLR in 2015, he held the position of Mining Hydrogeology Team Leader at Golder Associates Africa, responsible for the dewatering and monitoring network designs and groundwater numerical modelling for mining operations, together with responsibility for the environmental team.

PROJECTS

	Key aspects of Mihai's recent project experience are summarised below.
Sadiola SSP (2016)	Numerical simulations for in-pit tailings disposal
Kamoto Copper, DR Congo (2015)	Project managed mine dewatering for KCC – complex conditions: 1 open pit and 2 underground mines)
Tizerghaf, Mauritania (2015)	Groundwater reserves estimation for SNIM
Technology Options (TOPS) for UCG and CCS (2014)	Hydrogeological conditions for site selection criteria, hydrogeological investigation, groundwater numerical modelling for near-far field of gasifier
Mayoko Iron Ore, Congo (2013)	Project managed mine planning groundwater application and EIA Specialist study (groundwater)
Platreef, South Africa (2013)	Groundwater numerical modelling: estimation of inflows and EIA Specialist study (groundwater)
Large Open Pit (LOP) (2009)	Groundwater numerical modelling for open pit slopes

Orapa and Letlhakne Mines, Botswana (2007)	Groundwater numerical modelling: estimation of inflows and pore pressures distribution for open pit mines
Finch, Venetia (2006)	Estimation of inflows and pore pressures distribution for underground and open pit mines

MEMBERSHIPS

PrSciNat	Member of the South African Council for Natural Scientific Professions

PUBLICATIONS

	Technology Options for Coupled Underground Coal Gasification and CO2 Capture and Storage – Energy Procedia 63 (2014) 5827-5835 (co-author)
	Hydrogeological Numerical Modelling to Simulate UCG Processes – The 2nd Workshop on Underground Coal Gasification, Banff, Canada, 2012
	Importance of Pore Pressure Monitoring in High Walls – The Journal of The South African Institute of Mining and Metallurgy, Vol. 108, November 2008

Appendix B: Geochemical and Groundwater Assessment (Source Term)

SLR. (2014). *Geochemical and Groundwater Assessment.* SLR Consulting (Africa) (Pty) Ltd. Report number: 710.20008.00008, March 2014.

February 2016

TSHIPI E NTLE MINE

Waste Classification Assessment for Tshipi E Ntle Mine

Submitted to:
Tshipi e Ntle Mine
P. O. Box 2098
Kathu
8446

REPORT

Report Number: 1541973-301423-1

Distribution:

1 x electronic copy to Tshipi E Ntle Mine
1 x electronic copy to Golder Associates Africa (Pty) Ltd

Golder Associates

Record of Issue

Company	Client Contact	Version	Date Issued	Method of Delivery
TSHIPI E NTLE MINE	Nthabeleng Paneng	1	07/03/2016	Email
TSHIPI E NTLE MINE	Nthabeleng Paneng	Final Version	02/08/2016	Email

Executive Summary

Golder Associates Africa Pty Ltd (Golder) was appointed by Tshipi é Ntle Manganese Mining (Pty) Ltd's Tshipi Borwa Mine (Tshipi to carry out a waste classification and assessment of materials on three overburden dumps generated during extraction of manganese ore from open pits. The Tshipi Borwa Mine is located in the Kalahari Manganese Field, 40 km north of Kathu, in the Northern Cape Province.

A summary of the Tshipi waste classification and assessment results from this study is presented in the table below:

Tshipi Potential Contaminant Sources	GN R.635	SANS 10234 R.634	Acid Rock Drainage Generation Potential
Northern Dump	Type 1	Non-hazardous	None
Eastern Dump	Type 1		
Western Dump	Type 1		

On the basis of the above findings, it is recommended that whilst the material is Type 1 waste, one of the following ways forward be considered:

1) Given the high manganese content (4 to 7.5%), a resource assessment could be made of the dump with a view to potentially re-mining; or

2) Motivate for no liner requirement for the dumps on the basis that whilst the material is Type 1 waste,

    a. Class A liner is impractical for a waste rock dump on the basis of geotechnical properties: likely liner failure,

    b. The waste material is non-hazardous,

    c. The waste material is non-acid-generating,

    d. The concentration of all constituents of concern in leachate is below LCT0, indicating a low risk from seepage,

    e. The dumps do not contain waste water, so the only seepage through the dumps will be from recharge by the (low) rainfall in this area, and therefore

    f. The dumps do not pose a significant risk to the water resource; or

3) Given that the assessment in this report is based upon three composite samples, a follow-up study could be commissioned to sample individual rock-types and

    a. Derive manganese content per rock-type with a view to considering economic value,

    b. Model the total and leachable concentrations of each whole dump based upon the rock-type specific results and the predicted tonnages of each rock type reporting to the dump, and

    c. This study to be done prior to motivation for no liner requirement.

Note that the barrier designs indicated by GN R. 636 will only apply should new cells or facilities be developed, subject to confirmation with the Department of Water and Sanitation. Current facilities remain legal in terms of transitional arrangements provided that the facilities have already been approved in terms of an EMPR authorised before 2 September 2014.

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APPENDIX A
Sample Location maps, Field Notes and Photos (November 2015 sampling campaign)

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1.0 INTRODUCTION

Tshipi é Ntle Manganese Mining (Pty) Ltd's Tshipi Borwa Mine (Tshipi) is located in the Kalahari Manganese Field, 40 km north of Kathu, and 80 km from Kuruman town in the Northern Cape Province (Figure 1). The mine extracts manganese ore using truck and shovel from open pits. Three dumps of overburden materials stripped during mining exist at the mine. Golder Associates Africa Pty Ltd (Golder) was appointed by Tshipi to carry out a waste classification and assessment of materials on overburden dumps.

This report documents the fieldwork conducted by Golder in 2015, laboratory and waste classification and assessment results for Tshipi overburden materials.

2.0 OBJECTIVES

The specific objectives of the Tshipi waste assessment and classification study are as follows:

- To determine the acid rock drainage (ARD) generation potential of the waste rock material on overburden stockpiles at Tshipi é Ntle Manganese mine;
- To classify waste rock on overburden stockpiles according to SANS 10234 as per Waste Classification and Management Regulations (GN R.634 of 23 August 2013);and
- To assess waste rock on overburden stockpiles as per the National Norms and Standards for the Assessment of Waste for Landfill Disposal (GN R.635 of 23 August 2013).

3.0 APPROACH AND METHODOLOGY

The scope of work is consistent with the following guidance documents and the relevant regulations and National Norms and Standards:

- *Best Practice Guidelines for Water Resource Protection in the South African Mining Industry*[1] - BPG G4 "Impact Prediction"
- Classification of waste according to SANS 10234 as *per Waste Classification and Management Regulations* (GN R.634 of 23 August 2013); and
- Waste Assessment as *per the National Norms and Standards for the Assessment of Waste for Landfill Disposal (*GN R.635 of 23 August 2013).

The approach that was followed is based on the methodology outlined in the BPG G4 Guide and included:

- Step 1: Review available information;
- Step 2: Develop conceptual understanding (models) of key geochemical and flow processes for each mining facility. This step was not conducted as part this study;
- Step 3: Develop a sampling protocol by determining the form and extent of rock and waste units that will occur in each mine component. A strategy for obtaining and testing representative samples of the geological materials and mine wastes should be developed. The strategy should identify sampling requirements (such as the number of samples to be collected, their size/mass, their description and their handling) and should specify the laboratory testing to be undertaken;
- Step 4: Conduct sampling of geological materials and mine wastes;
- Step 5: Conduct laboratory analysis of samples; and
- Step 6: Waste classification and assessment according to GN R.634 and GN R.635 and reporting.

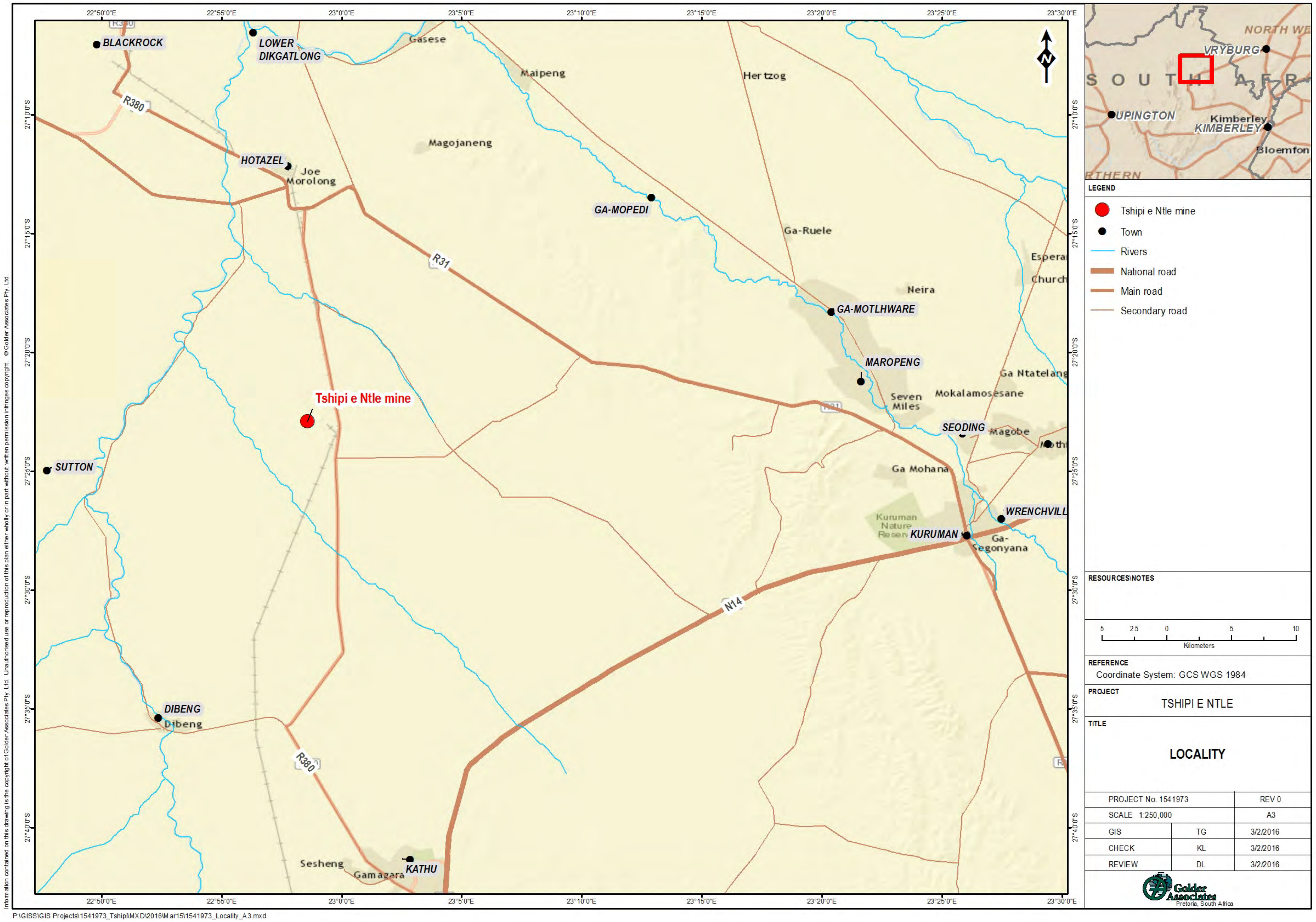

Figure 1: Location map of Tshipi e Ntle Manganese Mine

3.1 Information Review

The following documents were reviewed:

- Turgis Mining Consulting (Pty) Ltd. Feasibility study for Project Kalahari for Ntsimbintle Mining (Pty) Ltd;
- Synergistics Environmental Services. Tshipi Borwa Mine- 2nd quarterly water quality monitoring report August 2015. Report number 755.20029.00005/2015/WQM2; and
- Synergistics Environmental Services. Tshipi Borwa Mine- 3rd Annual water quality report. 4th Quarter of 2014/2015. Report 12. Report number 755.20029.00003/2014/WQM4.

3.1.1 Geology

The Tshipi Borwa mine is located on the south western margin of the Kalahari Manganese Field. A summary of the stratigraphy of the area is shown in Figure 2.

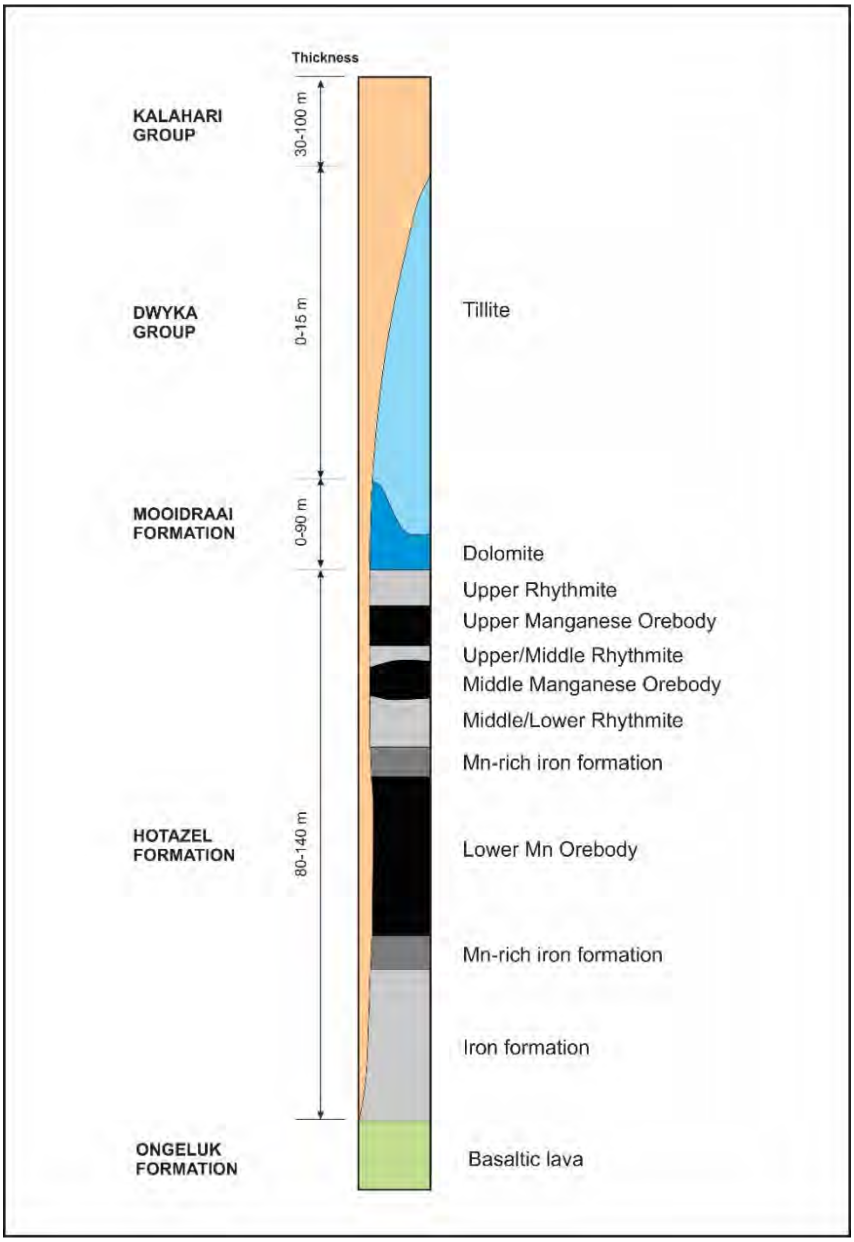

Figure 2: stratigraphic column of study area.

The manganese resource is hosted by the Hotazel Formation and consists of three ore bodies (Lower, Middle and Upper) that are intercalated with BIF and rhythmites. The Lower manganese orebody varies in thickness from 5 to 40 m and contains the highest manganese grades. It is the main ore horizon that is mined. The Middle orebody has a maximum of 2 m thickness, is poorly mineralised and is considered uneconomic. The Upper orebody is moderately mineralised and is stockpiled at the mine for possible future use. The dominant ore minerals are braunite and hausmanite. The ore is carbonate rich and sulphide minerals are rare.

The overburden consists of the 0-84 m thick dolomites of the Mooidraai Formation, which overlies the Hotazel Formation. Above the dolomites is the Dwyka Group, which consists of glacial diamitites/tillites that vary in thickness from 0 m to 90 m. These are covered by 30-100 m thick gravels, clays, calcretes and aeolian sands of the Kalahari Group. The Mooidraai Formation and upper parts of the Hotazel Formation have been eroded in the southern portion of the mine area.

3.1.2 Monitored water quality

Surface and groundwater monitoring is carried out on a quarterly basis at Tshipi Borwa mine. Deep fractured aquifer groundwater is monitored from nine boreholes, five of which are downstream of the mine within the project area (TSH01-TSH05). Surface water monitoring points include two points on the ephemeral Vlermuisleegte Stream and four from the mine water dam. Reviewed data was for the period between April 2012 to January 2015, and the month of July 2015. The water monitoring results show that:

- All the boreholes within the mine area (TSH01-TSH05) were characterised by slightly alkaline to alkaline pH conditions (7.7-9.3) and all boreholes outside of the mine area were characterised by near-neutral to alkaline pH (7.2-8.7) from February 2014 to January 2015, and July 2015;
- The concentrations of trace elements was generally low in groundwater with the exceptions of As and Mo, which were occasionally elevated in some boreholes;
- The concentrations of SO_4^{2-} ranged from <5 to 745 mg/L in groundwater;
- Constituents of concern, which exceeded water quality standards for domestic use and DWAF water quality guidelines for livestock in groundwater on at least one occasion were:
  - EC, TDS, Cl^-, NO_3^-, Mo and As in borehole NT15, which is located to the east of the mine; and As and Mo in borehole NT8, which is located North West of the Mine;
  - EC, TDS, Cl^-, NO_3^-, Fe, Mn, Al and As in at least one of the boreholes that are located within the mine area, downstream of the mine;
- Mine water from the dams was characterised by alkaline pH (8.1-9.1) from February 2014 to January 2015, and July 2015;
- The concentration of SO_4^{2-} was generally low and ranged from <5 to 109 mg/L; and
- Constituents of concern, which exceeded water quality guidelines at least once in the mine water dams were EC, TDS, Cl^-, NO_3^-, Fe, Mn and Al.

The monitoring data classifies groundwater and mine water as neutral mine drainage (Figure 3), rarely bordering on saline.

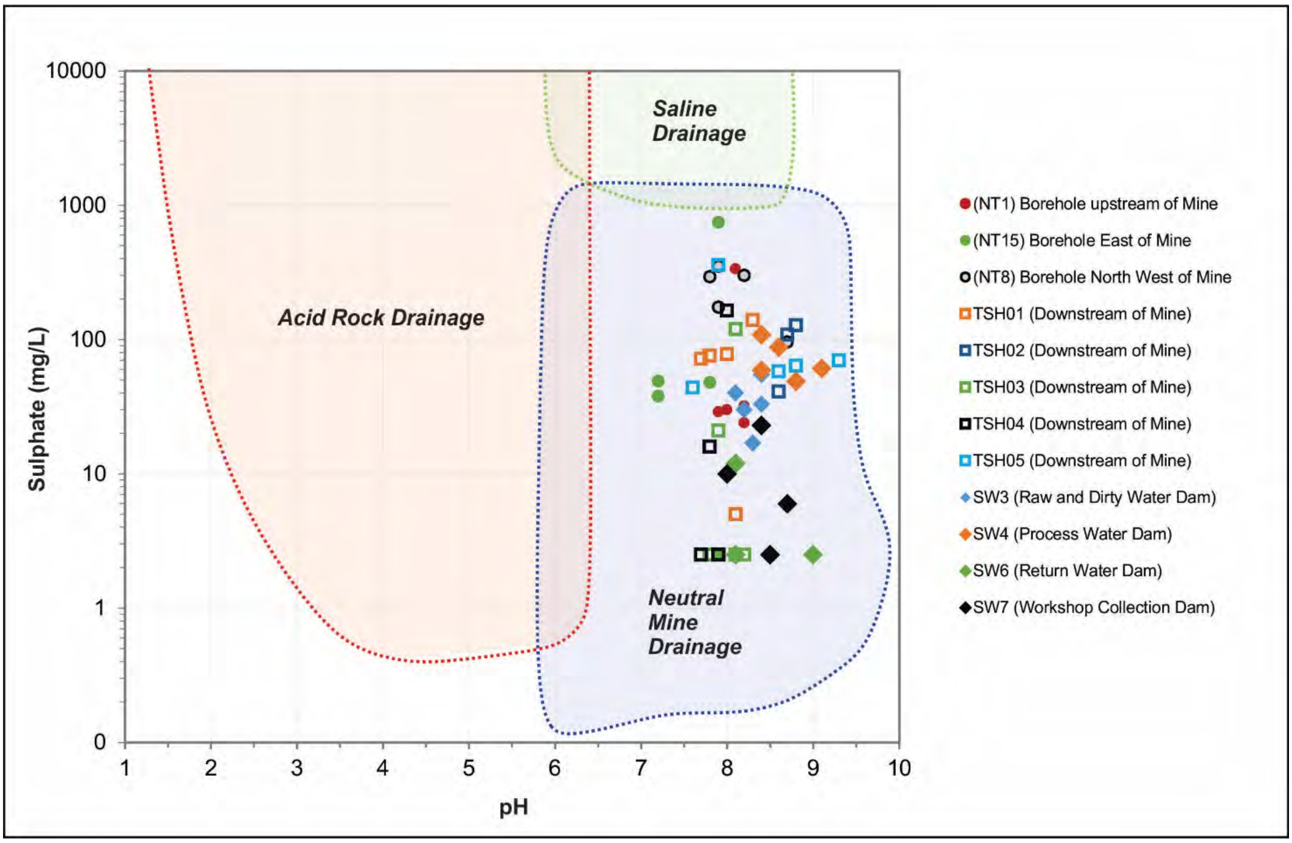

Figure 3: Classification of groundwater and mine water monitoring data based on sulphate and pH (after INAP, 2010)

3.2 Sampling Collection and Handling

The site familiarisation visit and fieldwork at Tshipi was conducted on 26th November 2015.

The sampling for each waste rock dump consisted of:

- Identifying and selecting areas to collect discrete samples;
- Use of a small hand spade by first removing the top 25 – 30 cm surface layers to obtain a discrete sample of the waste material below exposed layers of the targeted potential contaminant source areas/ waste streams;
- Geo-referencing sampling locations and taking photographs of the discrete samples and source area; and
- Compositing the discrete samples to create a composite sample for each waste rock dump. Plastic bags were filled with the composite samples and labelled appropriately.

The composite samples were transported to Johannesburg before shipment to UIS, a SANAS[2] accredited laboratory for analysis.

3.2.1 Sample location and Material types

The potential contamination source areas that were sampled and number of samples collected during the November 2015 sampling event are indicated in Table 1 and Figure 4. The field observations are provided in **Error! Reference source not found.**.

Table 1: Waste material sampled

Source Area	Material/ Rock Type	Number of Discrete Samples	Composite Sample ID
Northern Dump	Kalahari sands, calcrete, reddish brown clay and shale	9	TP_ND
Eastern Dump	Calcrete, reddish brown clay, conglomerate and shale	9	TP_ED
Western Dump	Dark reddish brown clay, black shale, conglomerate, red Kalahari sands and white calcrete	12	TP_WD

It should be noted that sampling was restricted to surface samples from areas near access roads on the top of the dump and around the base of the dumps. The slopes were not accessible due to safety reasons and no samples were collected below surface (>0.3 m) to assess the variation of the overburden materials with depth. Hence, the composite samples collected provide indicative waste characteristics, including ARD potential risk for the different materials on the overburden dumps.

3.3 Laboratory Analyses

The following laboratory analyses were carried out on the composite samples as per National Norms and Standards for the Assessment of Waste for Landfill Disposal No. R.635 gazetted (DEA GN 36784, August 2013):

- Determination of total elemental composition of all waste samples. This included analysis of major elements by XRF and multi-acid digestion followed by analysis of trace elements by ICP-MS; and
- ASLP (deionised 1:20 solid to liquid ratio) extraction, specified for non-putrescible mono disposed waste material, with the leachates analysed for pH, TDS, EC, major cations, major anions and trace elements.

Acid-base accounting (ABA) including paste pH, sulphur speciation (total sulphur, sulphide and sulphate), carbon speciation (total carbon, inorganic carbon and inorganic carbon) and neutralisation potential.

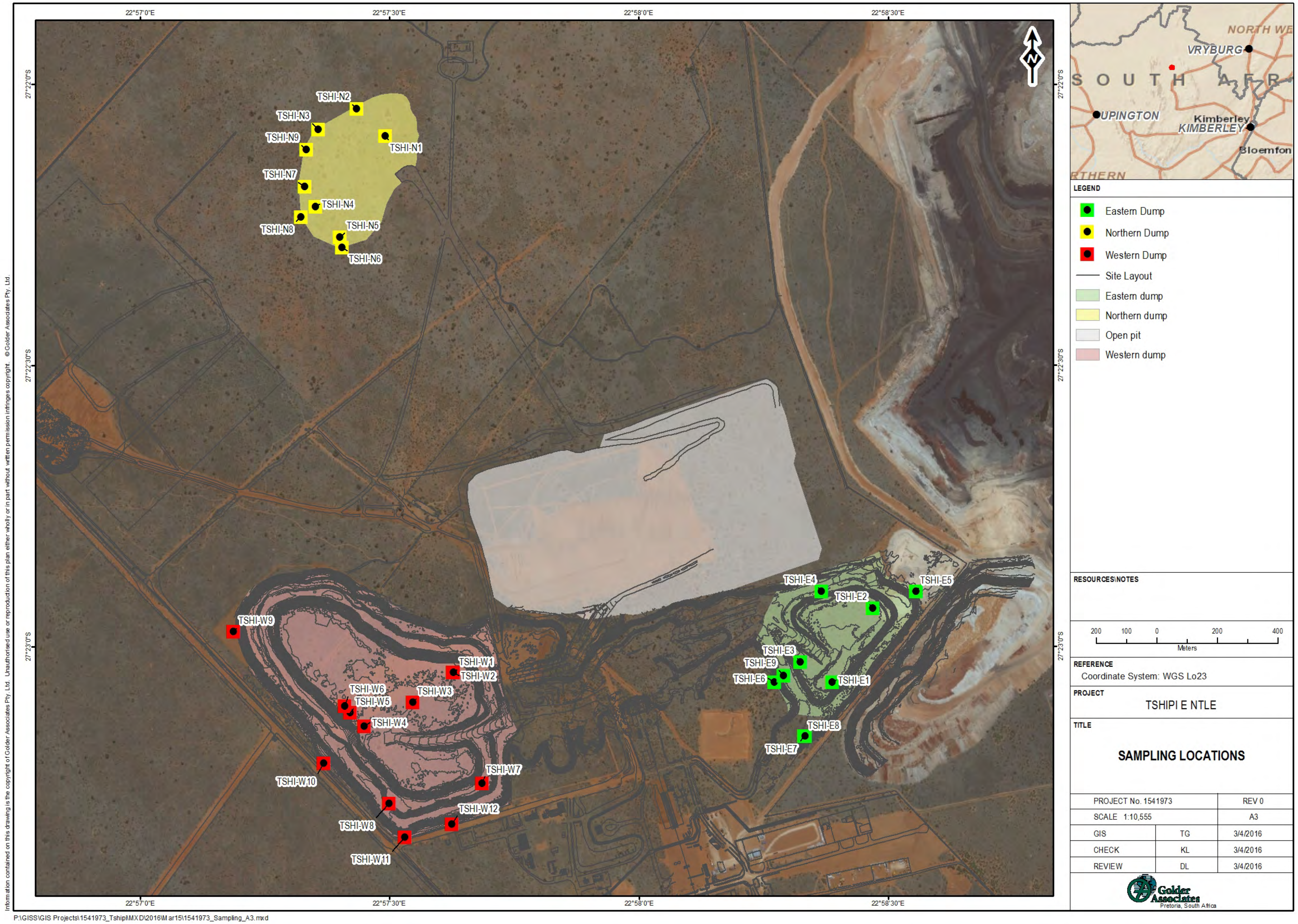

Figure 4: Location map of discrete samples from the waste rock dumps

3.4 Waste Classification and Assessment Methodology

3.4.1 SANS 10234 Classification

According to section 4(2) of GN R.634 of 2013, all waste generators must ensure that their waste is classified in accordance with SANS 10234 within 180 days of generation, except if it is listed in Annexure 1 of the GN R.634. Furthermore, waste must be re-classified every 5 years.

Waste classification according to SANS 10234 (based on the Global Harmonised System) indicates physical, health and environmental hazards. The SANS 10234 covers the harmonised criteria for classification of potentially hazardous substances and mixtures, including wastes, in terms of its intrinsic properties/hazards.

The chemical test results and based here on the intrinsic properties of the waste streams were used for the SANS 10234 classification. Constituents present in concentrations exceeding 1% are used for classification in terms of health hazards, except when the constituent is known to be toxic at lower concentrations (carcinogens etc.) (Table 2).

Environmental hazard is based on toxicity to the aquatic ecosystem and distinguish between acute and chronic toxicity, bioaccumulation and biodegradation.

Table 2: Cut-off values/concentration limits for hazard classes

Hazard class	Cut-off value (concentration limit) %
Acute toxicity	≥ 1.0
Skin corrosion	≥ 1.0
Skin irritation	≥ 1.0
Serious damage to eyes	≥ 1.0
Eye irritation	≥ 1.0
Respiratory sensitisation	≥ 1.0
Skin sensitisation	≥ 1.0
Mutagenicity: Category 1 Category 2	 ≥ 0.1 ≥ 1.0
Carcinogenicity	≥ 0.1
Reproductive toxicity	≥ 0.1
Target organ systemic toxicity	≥ 1.0
Hazardous to the aquatic environment	≥ 1.0

3.4.2 GN R.635 Waste Assessment

National Norms and Standards for the Assessment of Waste for Landfill Disposal No. R. 635 gazetted (DEA GN 36784, 23 August 2013) under the National Environmental Management Waste Act 59 of 2008 (NEMWA) have been used to determine the ZAC material classification type.

According to the Standards, the assessment methodology to determine the specific type of waste for disposal to landfill requirements is that the Total Concentrations (TC) and Leachable Concentration (LC) of the waste material be compared to threshold limits for Total Concentrations Threshold (TCT) and Leachable Concentration Thresholds (LCT) respectively. Exceedances of the threshold limits determine the type of waste (Type 0 to Type 4 Wastes).

The Norms and Standards require that the LC must be determined using Australian Standards (AS4439.1, AS4439.2 and 44396.3) or Toxicity Characteristic Leaching Procedure (TCLP at 1:20 solid: liquid ratio). However, for non-putrescible (non-decomposable) waste that is mono disposed, reagent water extract is required. For the purposes of the slimes, tailings and paste classification deionised water has been used at different solid to liquid ratios to leach the soluble chemical constituents and is hence suitable for use in the classification.

According to the Waste Standards the type of waste destined for disposal is determined as (Figure 5):

- Type 0 Waste: if concentrations above LCT3 or TCT2 limits (LC > LCT3 or TC > TCT2);
- Type 1 Waste: if concentrations are above the LCT2 but below or equal to LCT3 limits, or above the TCT1 but below or equal to TCT2 limits (LCT2 < LC ≤ LCT3 or TCT1 < TC ≤ TCT2);
- Type 2 Waste: if concentrations are above the LCT1 but below or equal to LCT2 and all concentrations below or equal to TCT1 limits (LCT1 < LC ≤ LCT2 and TC ≤ TCT1);
- Type 3 Waste: if concentrations are above the LCT0 but below or equal to LCT1 and all TC concentrations below or equal to TCT1 limits (LCT0 < LC ≤ LCT1 and TC ≤ TCT1); and
- Type 4 Waste: if all concentration levels for metal ions and inorganic anions below or equal to both LCT0 and TCT0 limits (LC ≤ LCT0 and TC ≤ TCT0) and with all chemical substance concentration levels also below the total concentration limits for organics and pesticides.

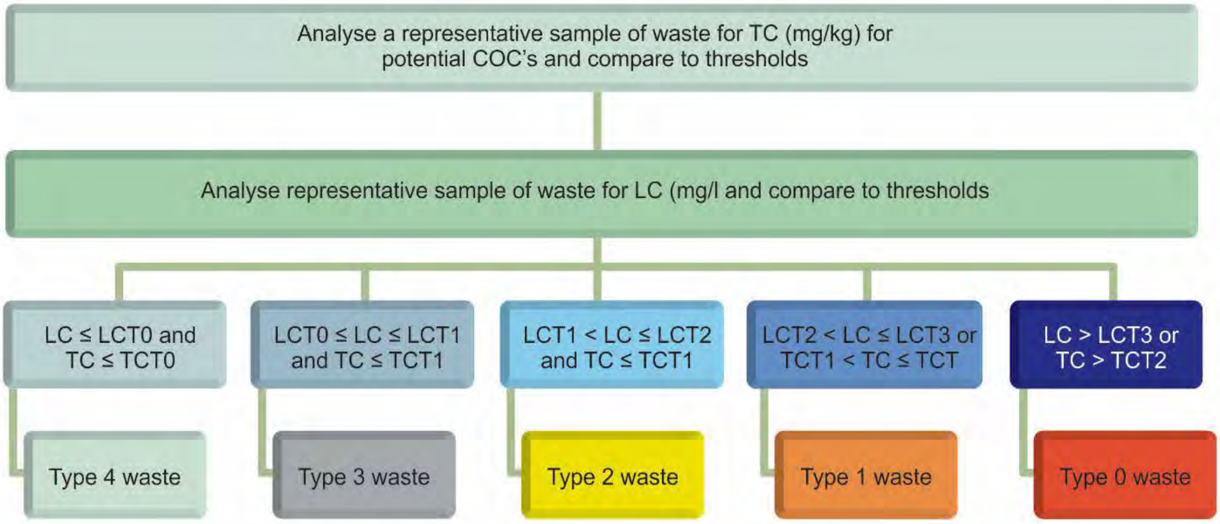

Figure 5: Waste classification based on GN R. 634 of 2013 Waste Standards

3.4.3 Barrier design requirements

The liner requirements/barrier design requirements, based on the type of waste, is detailed in GN R.636 are presented in Table 3.

Table 3: Landfill disposal requirements detailed in the GN R. 636 of 2013

Waste Type	Landfill Disposal Requirements
Type 0 Waste	The disposal of Type 0 waste to landfill is **not allowed**. The waste must be treated and re-assessed in terms of the *Standard for Assessment of Waste for Landfill Disposal*.
Type 1 Waste	Type 1 waste may only be disposed of at a **Class A** landfill designed in accordance with Section 3(1) and 3(2), or, subject to Section 3(4), may be disposed of at a landfill site designed and operated in accordance with the requirements for a **Hh / HH landfill** as specified in the Minimum Requirements for Waste Disposal by Landfill (2nd Ed., DWAF, 1998).
Type 2 Waste	Type 2 waste may only be disposed of at a **Class B** landfill designed in accordance with Section 3(1) and 3(2), or, subject to Section 3(4), may be disposed of at a landfill site designed and operated in accordance with the requirements for a **GLB+ landfill**

Waste Type	Landfill Disposal Requirements
	as specified in the Minimum Requirements for Waste Disposal by Landfill (2nd Ed., DWAF, 1998).
Type 3 Waste	Type 3 waste may only be disposed of at a **Class C** landfill designed in accordance with Section 3(1) and 3(2), or, subject to Section 3(4), may be disposed of at a landfill site designed and operated in accordance with the requirements for a **GLB+ landfill** as specified in the Minimum Requirements for Waste Disposal by Landfill (2nd Ed., DWAF, 1998).
Type 4 Waste	Disposal allowed at a landfill with a **Class D** landfill designed in accordance with Section 3(1) and 3(2), or, subject to Section 3(4), may be disposed of at a landfill site designed and operated in accordance with the requirements for a **GLB- landfill** as specified in the Minimum Requirements for Waste Disposal by Landfill (2nd Ed., DWAF, 1998).

3.4.4 Acid Rock Drainage Assessment

The screening criteria used in this study to assess the acid generation potential of the overburden materials is based on guidelines from Price et al.(1997) in conjunction with Soregaroli and Lawrence (1997), Morin and Hutt (2007) and MEND (2009). These guidelines are summarised in Table 4.

Table 4: Acid Generation Potential Assessment Criteria.

Guidelines from Price et al. (1997) and Soregaroli and Lawrence (1997).			
Sulphide sulphur	**NPR (Bulk NP /AP)**	**Potential for ARD**	**Comments**
<0.3%	----	None	No further ARD testing required provided there are no other metal leaching concerns. *Exceptions:* host rock with no basic minerals, sulphide minerals that are weakly acid soluble.
>0.3%	<1	Likely	Likely to be ARD generating.
	1-2	Possibly	Possibly ARD generating if NP is insufficiently reactive or is depleted at a rate faster than that of sulphides.
	2-4	Low	Not potentially ARD generating unless significant preferential exposure of sulphides occur along fractures or extremely reactive sulphides are present together with insufficiently reactive NP.
	>4	None	No further ARD testing required unless materials are to be used as a source of alkalinity.
Guidelines from Morin and Hutt (2007) and MEND (2009)			
Paste pH	**NPR**	**Potential for ARD**	**Comments**
<6	<1	Acid generating (AG)	Net acid generating, and already acidic.
>6		Potentially acid generating (PAG)	Potentially acid generating unless sulphide minerals are non-reactive. Thus samples are net acid generating, but not yet acidic.
<6 and >6	1 ≤ NPR ≤ 2	Uncertain	Possibly acid generating if NP is insufficiently reactive or is depleted at a rate faster than sulphides.

Guidelines from Price et al. (1997) and Soregaroli and Lawrence (1997).			
>6	>2	Not potentially acid generating (Non-PAG)	Not expected to generate acidity i.e samples are net acid neutralizing.
<6		Theoretically not possible	

4.0 RESULTS OF THE WASTE PROGRAMME

4.1 Waste Classification and Assessment Results

The analytical results on the composite overburden samples from Tshipi are summarised in this section – the full results are in **Error! Reference source not found.**.

4.1.1 Waste Assessment Results

Table 5 and Table 6 provides the comparisons of total elemental results and leachable concentration results to TCT and LCT guideline limits provided in the GN R.635 respectively. Shaded cells indicate exceedances of the respective guideline threshold limits.

The most important factors to note are that Mn exceeds TCT1 threshold (4 to 7.5 wt. % Mn) but all dissolved parameters are below the lowest leachability threshold (LCT0).

Table 5: Comparison of selected Total Concentrations (mg/kg) to TCT limits for Overburden samples

CoC	GNR.635 levels of thresholds for total concentrations			TP_ND	TP_ED	TP_WD
	TCT0	TCT1	TCT2			
As	5.8	500	2000	5.4	4.6	**7.2**
Ba	62.5	6250	25000	**466**	**276**	**560**
Cd	7.5	260	1040	0.38	0.26	0.31
Co	50	5000	20000	35	36	38
Cr	46000	800000	N/A	84.9	39.6	43.8
Cu	16	19500	78000	**25**	**23**	**24**
Hg	0.93	160	640	0.05	0.62	0.001
Mn	1000	25000	100000	70,244	46,407	74,955
Mo	40	1000	4000	5.0	1.5	2.1
Ni	91	10600	42400	27	31	27
Pb	20	1900	7600	9.7	8.2	9.4
Sb	10	75	300	1.6	0.81	0.79
Se	10	50	200	0.53	0.18	0.33
V	150	2680	10720	75	57	76
Zn	240	160000	640000	35	32	40

Notes

Grey: >TCT0; Yellow: >TCT1; Red: >TCT2

COC – Constituent of Concern

Table 6: Comparison of selected Leachable Concentrations (mg/L) to LCT limits for Overburden Material

Australian Standards Leach Procedure (1:20 Solid: Liquid Ratio)							
CoCs	GN R.635 levels of thresholds for leachable concentrations				TP_ND	TP_ED	TP_WD
	LCT0	LCT1	LCT2	LCT3	Northern Dump	Eastern Dump	Western Dump
pH	No guideline				7.9	8.3	7.8
TDS	1000	12500	25000	100000	76	80	80
As	0.01	0.5	1	4	0.002	0.001	0.001
B	0.5	25	50	200	0.041	0.043	0.16
Ba	0.7	35	70	280	0.079	0.082	0.17
Cd	0.003	0.15	0.3	1.2	<0.001	<0.001	<0.001
Co	0.5	25	50	200	0.001	<0.001	<0.001
Cr	0.1	5	10	40	0.004	0.000	0.002
Cu	2	100	200	800	0.004	<0.001	<0.001
Hg	0.006	0.3	0.6	2.4	0.0001	0.0002	0.0002
Mn	0.5	25	50	200	0.027	0.006	0.004
Mo	0.07	3.5	7	28	0.004	0.002	0.003
Ni	0.07	3.5	7	28	0.001	<0.001	<0.001
Pb	0.01	0.5	1	4	0.006	<0.001	<0.001
Sb	0.02	1	2	8	0.002	0.001	0.001
Se	0.01	0.5	1	4	0.001	<0.001	0.002
V	0.2	10	20	80	0.015	0.022	0.010
Zn	5	250	500	2000	0.034	0.002	0.006
Cl	300	15000	30000	120000	0.66	2.03	0.26
SO_4^{2-}	250	12500	25000	100000	4.2	4.14	7.10
NO_3^-	11	550	1100	4400	0.48	1.7	0.25
F^-	1.5	75	150	600	0.27	0.15	0.35
CN (Total)	0.07	3.5	7	28	<0.01	<0.01	<0.01

Notes

Grey: >LCT0; Yellow: >LCT1; Orange: >LCT2; Red: >LCT3

COC – Constituent of Concern

Units-mg/L for all COCs

4.1.1.1 North Dump materials

The total concentrations of barium and copper exceed the TCT0 levels and that of manganese exceeds the TCT1 level. The leachable concentrations of all constituents of concern were less than LCT0 levels in the composite sample. Subsequently the material at the Northern dump is assessed as **Type 1** (LCT2 < LC ≤ LCT3 **or** TCT1 < TC ≤ TCT2).

4.1.1.2 Eastern Dump Materials

The total concentrations of barium and copper exceed the TCT0 levels. Manganese exceeds the TCT1 level. The leachable concentrations of all constituents of concern were less than TCT0 and LCT0 levels in the composite sample. The material at the Eastern dump is therefore assessed as **Type 1** (LCT2 < LC ≤ LCT3 or TCT1 < TC ≤ TCT2).

4.1.1.3 Western Dump Materials

The total concentrations of arsenic, barium and copper exceed the TCT0 levels with manganese exceeding the TCT 1 level. The leachable concentrations of all constituents of concern were less than TCT0 and LCT0 levels in the composite sample. The material at the Western dump is therefore assessed as **Type 1** (LCT2 < LC ≤ LCT3 or TCT1 < TC ≤ TCT2).

4.1.1.4 Barrier Requirements

The material at all three dumps are **Type 1** materials due to total Mn concentrations exceeding the TCT1 level. According to the GN R.636, Type 1 material waste requires a Class A liner (Table 3).

4.1.2 Waste Classification Results

The materials from of the Northern, Eastern and Western dumps are classified as follows in terms of SANS 10234:

- Physical hazards: The materials are not combustible and do not enhance combustion of other substances. Therefore, they are classified as **non-hazardous in terms of physical hazards**;
- Health hazards:
  - The concentration of manganese in the composite samples of all dumps exceeds 1% (4 – 7 %). Chronic exposure to high levels of manganese by inhalation may lead to central nervous system effects (ATSDR, 1997). However, in its current form (solid phase contained in waste rock), the Mn is not considered to be hazardous to human health; and
  - Trace metals such as Cd, Ni, As and Cr (VI) have been recognized as human or animal carcinogens by International Agency for Research on Cancer (IARC). The carcinogenic capability of these metals depends mainly on factors such as oxidation states and chemical structures. The total concentrations of carcinogenic trace metals were <0.1% in all samples. Therefore none of these elements constitute a health risk and the North, Eastern and Western dump material.
  - The waste rock samples collected at Tshipi are considered n**on-hazardous in terms of human health**.

  Environmental hazard: The total Mn content of the waste materials composite samples exceeds the cut-off limit of 1%. The leachable Mn concentrations of these samples are low (< 0.0027 mg/L), as are the leachable concentrations of all other potential CoCs. Mn may be hazardous in the environment, particularly to aquatic organisms (Howe, Malcolm & Dobson, 2005). However, due to the extremely low solubility of the Mn in the waste rock, it is unlikely to impact negatively on the environment and is considered to be **non-hazardous to the environment.**

4.2 Acid Rock Drainage Assessment Results

The acid base results are discussed in this section and laboratory certificates are presented in Appendix D.

The sulphur analysis results indicate that total sulphur, sulphide and sulphate occurred at very low concentrations that were below detection limit (<0.01%). The acid potential (AP) was 0.31 kg CaCO3 eqv t-1 based on half the detection limit of sulphur concentration. This is expected since sulphide minerals are known to be rare in the manganese deposit (Turgis Mining Consulting, 2009).

Bulk neutralisation potential (Bulk NP) was very high in all overburden samples from all the dump (90-187 kg $CaCO_3$ eqv t^{-1}) (Table 7). The CaNP (94-224 kg CaCO3 eqv t-1) was higher than the Bulk NP suggesting that siderite and/or ankerite represented a significant proportion of total carbonates in the overburden samples. However, siderite and ankerite have limited neutralising capacity under oxidising field conditions as ferrous iron is an extra source of acidity due to the strong hydrolysis of the ferrous iron in solution (MEND, 2009).

Table 7: Acid base accounting results for overburden samples

Determinant	Units	Northern Dump	Eastern Dump	Western Dump
		TP-ND	TP-ED	TP-WD
Paste pH	s.u	7.8	8.1	8.2
Total Sulphur	%	<0.001	<0.001	<0.001
Sulphide Sulphur		<0.001	<0.001	<0.001
Sulphur in Sulphate		<0.001	<0.001	<0.001
Total Carbon		1.1	2.5	2.7
Organic Carbon		<0.003	<0.003	<0.003
Bulk NP	kg $CaCO_3$/T	90	187	186
Carbonate NP		94	206	224
Acid Potential		0.2	0.2	0.2
Net Neutralisation Potential		90	187	186
Neutralisation Potential Ratio	none	576	1197	1190
Classification based on NPR		**Non-PAG**	**Non-PAG**	**Non-PAG**

The generally high paste pH (7.8-8.2) indicates excess reactive NP to buffer acidity generated by the initial oxidation of sulphides during the testing procedure. Buffering is expected to be provided by calcite and dolomite which are known to occur in the deposit and in calcrete. There is excess buffering capacity in the overburden materials, with Bulk NP exceeding AP in all the samples.

Classification of acid rock drainage (ARD) potential show that all the samples of overburden materials are not potentially acid generating (Non-PAG) per the guidelines of Morin and Hutt (2007) and MEND (2009). Classification using the guidelines of Price et al. (1997) and Soregaloli and Lawrence (1997) also shows that all samples have no acid generating potential due to very low sulphur content.

Summary of Assessment and Classification Results

Table 8 provides a summary of the Tshipi waste classification and assessment results from this study.

Table 8: Tshipi assessment and classification results samples

Tshipi Potential Contaminant Sources	GN R.635	SANS 10234 R.634	Acid Rock Drainage Generation Potential
Northern Dump	Type 1	Hazardous waste	None
Eastern Dump	Type 1		
Western Dump	Type 1		

5.0 CONCLUSION

Based on the analytical data and information obtained during this investigation, the following are concluded:

- Waste materials: Classifies as non-hazardous waste due to the insolubility of the CoCs;
- Type 1 waste due to total Mn concentrations exceeding TCT1 levels and can be disposed on a facility with Class A liner / barrier. However, due to the insolubility of the CoCs (<LCT0 levels) it is expected to not have a negative impact on the environment; and

- The overburden material is not potentially acid generating.

On the basis of the above findings, it is recommended that whilst the material is Type 1 waste, one of the following ways forward be considered:

1) Given the high manganese content (4 to 7.5%), a resource assessment could be made of the dump with a view to potentially re-mining; or
2) Motivate for no liner requirement for the dumps on the basis that whilst the material is Type 1 waste,
   a. Class A liner is impractical for a waste rock dump on the basis of geotechnical properties: likely liner failure,
   b. The waste material is non-hazardous,
   c. The waste material is non-acid-generating,
   d. The concentration of all constituents of concern in leachate is below LCT0, indicating a low risk from seepage,
   e. The dumps do not contain waste water, so the only seepage through the dumps will be from recharge by the (low) rainfall in this area, and therefore,
   f. The dumps do not pose a significant risk to the water resource; or
3) Given that the assessment in this report is based upon three composite samples, a follow-up study could be commissioned to sample individual rock-types and
   a. Derive manganese content per rock-type with a view to considering economic value,
   b. Model the total and leachable concentrations of each whole dump based upon the rock-type specific results and the predicted tonnages of each rock type reporting to the dump, and
   c. This study to be done prior to motivation for no liner requirement.

Note that the barrier designs indicated by GN R. 636 will only apply should new cells or facilities be developed, subject to confirmation with the Department of Water and Sanitation. Current facilities remain legal in terms of transitional arrangements provided that the facilities have already been approved in terms of an EMPR authorised before 2 September 2014.

6.0 REFERENCES

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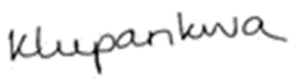

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APPENDIX A

Sample Location maps, Field Notes and Photos (November 2015 sampling campaign)

Table B1: Sample locations

Location of composite	ID	Latitude	Longitude
Eastern Dump	TSHI-E1	-27.3844	22.97313
	TSHI-E2	-27.3822	22.97448
	TSHI-E3	-27.3838	22.97206
	TSHI-E4	-27.3817	22.97276
	TSHI-E5	-27.3817	22.97592
	TSHI-E6	-27.3844	22.97118
	TSHI-E7	-27.386	22.97218
	TSHI-E8	-27.386	22.97222
	TSHI-E9	-27.3842	22.97149
Northern Dump	TSHI-N1	-27.3682	22.95818
	TSHI-N2	-27.3674	22.95722
	TSHI-N3	-27.368	22.95594
	TSHI-N4	-27.3703	22.95586
	TSHI-N5	-27.3712	22.95667
	TSHI-N6	-27.3715	22.95673
	TSHI-N7	-27.3697	22.95549
	TSHI-N8	-27.3706	22.95536
	TSHI-N9	-27.3686	22.95555
Western Dump	TSHI-W1	-27.3841	22.96043
	TSHI-W2	-27.3841	22.96045
	TSHI-W3	-27.385	22.9591
	TSHI-W4	-27.3857	22.95748
	TSHI-W5	-27.3853	22.95701
	TSHI-W6	-27.3851	22.95683
	TSHI-W7	-27.3874	22.96142
	TSHI-W8	-27.388	22.95831
	TSHI-W9	-27.3829	22.95311
	TSHI-W10	-27.3868	22.95611
	TSHI-W11	-27.389	22.95882
	TSHI-W12	-27.3886	22.9604

Figure B1: Different material types on the Western dump. Dark reddish brown clay (left), (middle to right).

Figure B2: Dark reddish brown clay (right), conglomerate and black shale material (centre) and red Kalahari sands (left) on the Western dump

Figure B3: Multiple heaps of material on top of Western dump

Figure B4: Shale heaps on top of Western dump

Figure B5: Side slopes of Western dump, mixture of shale and calcrete

Figure B6: Landscape surrounding Western dump

Figure B7: Side slopes of Western dump, dark reddish brown clay, shale and calcrete, partially mixed, and partially separated along slopes.

Figure B8: Numerous heaps of calcrete, reddish brown clay and shale material at the top of Northern dump

Figure B9: Top of Northern dump

Figure B10: Calcrete heaps (right) at the top of Northern dump

Figure B11: Calcrete heaps at the top of Northern dump

Figure B12: Calcrete heaps mixed with Kalahari sand at the top of Northern dump

Figure B13: Side-slope of Northern dump with varying sections of calcrete (right), dark reddish clay (middle) and Kalahari sands (far left).

Figure B14: Heaps at the top of Eastern dump, calcrete on the left

Figure 15: Side-slope of Eastern dump, portions conglomerate, portions calcrete, and portions reddish brown clay.

Figure B16: Base of Eastern dump, mostly calcrete side slope with reddish brown clay heap also mixed with shale at the base of the dump.

APPENDIX B

Waste Assessment Results

Table B1: Classification of individual samples based on total concentrations (Solid sample chemistry data)

CoC	TCT0	TCT1	TCT2	TP_ND	TP_ED	TP_WD
Ag		ng		0.69	0.32	0.41
As	5.8	500	2000	5.42	4.64	7.22
Au		ng		0.01	0.02	0.01
B		ng		55.4	48.1	48.6
Ba	62.5	6250	25000	466	276	560
Be		ng		0.72	0.51	0.69
Bi		ng		0.38	0.23	0.24
Cd	7.5	260	1040	0.38	0.26	0.31
Ce		ng		8.04	7.54	9.66
Co	50.0	5000	20000	34.5	35.9	38.3
Cr	46000	800000	N/A	84.9	39.6	43.8
Cs		ng		1.17	0.88	1.00
Cu	16.0	19500	78000	25	23	24
Ga		ng		34.8	23.1	24.3
Ge		ng		14.5	8.99	13.0
Hf		ng		2.35	1.48	1.42
Hg	0.93	160	640	0.05	0.62	0.001
Ho		ng		0.41	0.13	0.18
Ir		ng		1.30	1.02	0.78
La		ng		10.8	3.27	4.27
Li		ng		8.51	7.47	7.81
Mn	1000	25000	100000	70244	46407	74955
Mo	40	1000	4000	4.97	1.45	2.12
Nb		ng		4.81	4.15	4.27
Nd		ng		10.0	3.48	4.66
Ni	91	10600	42400	26.9	30.6	27.2
Pb	20	1900	7600	9.71	8.23	9.41
Pt		ng		0.01	0.01	0.00
Rb		ng		35.1	32.7	27.4
Sb	10	75	300	1.55	0.81	0.79
Sc		ng		48.5	40.8	28.4
Se	10	50	200	0.53	0.18	0.33
Sn		ng		1.28	1.05	1.05
Sr		ng		300	75.5	197
Ta		ng		0.56	0.42	0.35
Te		ng		1.18	0.75	0.53

CoC	TCT0	TCT1	TCT2	TP_ND	TP_ED	TP_WD
Th	ng			3.01	0.33	0.37
Tl	ng			0.22	0.19	0.17
U	ng			1.32	0.89	1.12
V	150	2680	10720	75.1	56.5	76.1
W	ng			1.24	12.2	0.77
Y	ng			10.8	1.79	2.46
Zn	240	160000	640000	35.0	32.1	40.2
Zr	ng			109	67.9	68.5

Notes:

Grey: >TCT0; Yellow: >TCT1; Red: >TCT2

ng – no guideline

CoC – Constituent of Concern

Table B2: Classification of individual samples based on leachable concentrations (Solid sample leach test (1:20 solid: liquid ratio) chemistry data

CoC	Units	LCT0	LCT1	LCT2	LCT3	TP_ND	TP_ED	TP_WD
Ag	mg/l	ng				0.002	0.001	0.002
Al	mg/l	ng				0.253	0.124	0.016
As	mg/l	0.01	0.5	1	4	0.002	0.001	0.001
Au	mg/l	ng				<0.001	<0.001	<0.001
B	mg/l	0.5	25	50	200	0.041	0.043	0.158
Ba	mg/l	0.7	35	70	280	0.079	0.082	0.167
Be	mg/l	ng				<0.001	<0.001	<0.001
Bi	mg/l	ng				<0.001	<0.001	<0.001
Ca	mg/l	ng				8.114	8.923	8.339
Cd	mg/l	0.003	0.15	0.3	1.2	<0.001	<0.001	<0.001
Ce	mg/l	ng				<0.001	<0.001	<0.001
Co	mg/l	0.5	25	50	200	0.001	<0.001	<0.001
Cr	mg/l	0.1	5	10	40	0.004	0.000	0.002
Cs	mg/l	ng				<0.001	<0.001	<0.001
Cu	mg/l	2	100	200	800	0.004	<0.001	<0.001
Fe	mg/l	ng				0.243	0.140	0.055
Ga	mg/l	ng				<0.001	<0.001	<0.001
Ge	mg/l	ng				<0.001	<0.001	<0.001
Hf	mg/l	ng				<0.001	<0.001	<0.001
Hg	mg/l	0.006	0.3	0.6	2.4	0.0001	0.0002	0.0002
Ho	mg/l	ng				<0.001	<0.001	<0.001
Ir	mg/l	ng				<0.001	<0.001	<0.001
K	mg/l	ng				2.31	2.36	2.64
La	mg/l	ng				<0.001	<0.001	<0.001
Li	mg/l	ng				<0.001	<0.001	<0.001
Mg	mg/l	ng				4.03	4.51	4.45
Mn	mg/l	0.5	25	50	200	0.027	0.006	0.004
Mo	mg/l	0.07	3.5	7	28	0.004	0.002	0.003
Na	mg/l	ng				4.316	4.441	5.018
Nb	mg/l	ng				<0.001	<0.001	<0.001
Nd	mg/l	ng				<0.001	<0.001	<0.001
Ni	mg/l	ng						<0.001
Pb	mg/l	0.01	0.5	1	4	0.006	<0.001	<0.001
Rb	mg/l	ng				0.002	0.001	0.001

CoC	Units	LCT0	LCT1	LCT2	LCT3	TP_ND	TP_ED	TP_WD
Sb	mg/l	0.02	1	2	8	0.002	0.001	0.001
Se	mg/l	0.01	0.5	1	4	0.001	<0.001	0.002
Si	mg/l	ng				6.464	5.835	3.665
Sn	mg/l	ng				0.001	<0.001	<0.001
Sr	mg/l	ng				0.029	0.041	0.033
Ta	mg/l	ng				<0.001	<0.001	<0.001
Te	mg/l	ng				<0.001	<0.001	<0.001
Th	mg/l	ng				<0.0001	<0.0001	<0.0001
Ti	mg/l	ng				0.013	0.011	0.002
Tl	mg/l	ng				<0.001	<0.001	<0.001
U	mg/l	ng				0.0001	0.0001	0.0001
V	mg/l	0.2	10	20	80	0.015	0.022	0.010
W	mg/l	ng				0.002	0.001	0.001
Y	mg/l	ng				<0.001	<0.001	<0.001
Zn	mg/l	5	250	500	2000	0.034	0.002	0.006
Zr	mg/l	ng				<0.001	<0.001	<0.001
pH	su	ng				7.86	8.25	7.84
TDS	mg/l	ng				76	80	80
EC	mS/m	ng				8.10	8.99	8.88
TDS by Sum	mg/l	ng				66	70	62
TDS by EC	mg/l	ng				57	63	62
P Alk.	mg/l CaCO3	ng				<0.6	<0.6	<0.6
M Alk.	mg/l CaCO3	ng				35.5	33.5	37.8
F^-	mg/l	1.5	75	150	600	0.27	0.15	0.35
Cl^-	mg/l	300	15000	30000	120000	0.66	2.03	0.26
NO_2^-	mg/l	ng				<0.2	<0.2	<0.2
NO_3^-	mg/l	ng				2.14	7.33	1.08
NO_3 as N	mg/l	11	550	1100	4400	0.48	1.66	0.25
PO_4^{3-}	mg/l	ng				<0.8	<0.8	<0.8
SO_4^{2-}	mg/l	250	12500	25000	100000	4.23	4.14	7.10
NH_3	mg/l	ng				<0.01	<0.01	<0.01
Acidity to pH8.3	mg/l $CaCO_3$	ng				< 5	< 5	< 5
CN (Total)	mg/l	0.07	3.5	7	28	<0.01	<0.01	<0.01
Cr^{6+}	mg/l	ng				<5	<5	<5

Grey: >LCT0; Yellow: >LCT1; Orange: >LCT2; Red: >LCT3

ng – no guideline *CoC – Constituent of Concern*

ANALYTICAL REPORT: Major Oxides & Total Trace elements

To: **Golder Associates**
Attention: **Keretia Lupankwa**
Project ID: **1541973**
Site Location: TSHIPI
Order No: 12282 / 93114

Date of Request :07.12.2015

UIS Analytical Services
Analytical Chemistry
Laboratories 4, 6
Tel: (012) 665 4291
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Certificate of analysis: 13377

Note: all results in percentage (%) unless specified otherwise

Lims ID	Sample ID	SiO2	Al2O3	Fe(total)	Fe2O3	TiO2	CaO	MgO	Na2O	K2O	MnO	P	Ba	Sr	Cr	V	Zn
	Major Oxides	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
454396	**TP_ND**	58.4	4.18	4.14	5.93	0.388	4.62	1.825	0.156	0.612	8.993	0.014	0.047	0.031	0.010	0.008	0.002
454397	**TP_ED**	52.5	3.64	3.01	4.30	0.364	9.02	3.067	0.147	0.493	6.134	0.002	0.031	0.009	0.004	0.006	0.001
454398	**TP_WD**	40.3	4.31	7.83	11.2	0.370	9.94	3.098	0.234	0.491	9.657	0.028	0.076	0.025	0.004	0.008	0.002
454398 QC	**TP_WD Duplicate**	40.5	4.42	7.91	11.3	0.372	10.1	3.111	0.240	0.499	9.662	0.040	0.078	0.027	0.005	0.008	0.003

Lims ID	Sample ID	C (Total)	C (organic)	C (inorganic)	S (total)	S (pyritic)	S (sulphate)
	Total C & S, LOI	%	%	%	%	%	%
454396	**TP_ND**	1.13	<0.003	1.17	<0.003	<0.01	<0.01
454397	**TP_ED**	2.47	<0.003	2.56	<0.003	<0.01	<0.01
454398	**TP_WD**	2.69	<0.003	2.83	<0.003	<0.01	<0.01
454398 QC	**TP_WD Duplicate**	2.74	<0.003	2.83	<0.003	<0.01	<0.01

Lims ID	Sample ID	Ag	As	Au	B	Ba	Be	Bi	Cd	Ce	Co	Cr	Cs	Cu	Ga	Ge	Hf	Hg	Ho	Ir	La	Li	Mn
	Total trace elements	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
454396	**TP_ND**	0.69	5.42	0.01	55.4	466	0.72	0.38	0.38	8.04	34.5	84.9	1.17	24.9	34.8	14.5	2.35	0.05	0.41	1.30	10.8	8.51	70244
454397	**TP_ED**	0.32	4.64	0.02	48.1	276	0.51	0.23	0.26	7.54	35.9	39.6	0.88	23.2	23.1	8.99	1.48	0.62	0.13	1.02	3.27	7.47	46407
454398	**TP_WD**	0.41	7.22	0.01	48.6	560	0.69	0.24	0.31	9.66	38.3	43.8	1.00	24.1	24.3	13.0	1.42	0.001	0.18	0.78	4.27	7.81	74955
454398 QC	**TP_WD Duplicate**	0.41	7.89	0.01	50.1	570	0.70	0.21	0.32	8.79	41.0	41.4	0.99	25.8	25.4	13.8	1.46	<0.001	0.17	0.70	4.11	8.05	74849

Lims ID	Sample ID	Mo	Nb	Nd	Ni	Pb	Pt	Rb	Sb	Sc	Se	Sn	Sr	Ta	Te	Th	Tl	U	V	W	Y	Zn	Zr
	Total trace elements	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
454396	**TP_ND**	4.97	4.81	10.0	26.9	9.71	0.01	35.1	1.55	48.5	0.53	1.28	300	0.56	1.18	3.01	0.22	1.32	75.1	1.24	10.8	35.0	109
454397	**TP_ED**	1.45	4.15	3.48	30.6	8.23	0.01	32.7	0.81	40.8	0.18	1.05	75.5	0.42	0.75	0.33	0.19	0.89	56.5	12.2	1.79	32.1	67.9
454398	**TP_WD**	2.12	4.27	4.66	27.2	9.41	0.00	27.4	0.79	28.4	0.33	1.05	197	0.35	0.53	0.37	0.17	1.12	76.1	0.77	2.46	40.2	68.5
454398 QC	**TP_WD Duplicate**	2.13	4.30	4.42	27.9	9.45	0.00	27.8	0.73	29.4	0.37	1.14	204	0.31	0.62	0.36	0.19	1.07	76.6	0.72	2.45	44.3	66.8

Chemical elements: Ag, Al, As, Au, Ca, B, Ba, Be, Bi, Cd, Ce, Co, Cr, Cs, Cu, Ga, Ge, Hf, Hg, Ho, Ir, La, Li, Mn, Mo, Nb, Nd, Ni, Pb, Pt, Rb, Sb, Sc, Se, Sn, Sr, Ta, Te, Th, Tl, U, V, W, Y, Zn, Zr
Instrument: ICP-OES, ICP-MS, LECO CS 230
Method: Major oxides in soil by ICP-OES Trace elements in ore/soil by ICP-MS

Date: 26.05.2015
Analysed by: A. Motsepe / S. Nel

Date: 26.05.2015
Authorised : JJ Oberholzer

ANALYTICAL REPORT: Water Leach

No unauthorised copies may be made of this report.

To: Golder Associates
Attention: Keretia Lupankwa
Project ID: 1542613
Site Location: Tati
Order No: 93115

Date of Request : 07.12.2015

UIS Analytical Services
Analytical Chemistry
Laboratories 4, 6

Fax: (012) 665 4294

Certificate of analysis: 13377

Note: all results in parts per million (ppm) unless specified otherwise

Lims ID	Sample ID	Ag	Al	As	Au	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs	Cu	Fe	Ga	Ge	Hf	Hg	Ho	Ir	K	La	Li	Mg	Mn
	WATER LEACH 1:20	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
454399	**TP_ND/WATER/LEACH**	0.002	0.253	0.002	<0.001	0.041	0.079	<0.001	<0.001	8.114	<0.001	<0.001	0.001	0.004	<0.001	0.004	0.243	<0.001	<0.001	<0.001	0.0001	<0.001	<0.001	2.31	<0.001	<0.001	4.03	0.027
454400	**TP_ED/WATER/LEACH**	0.001	0.124	0.001	<0.001	0.043	0.082	<0.001	<0.001	8.923	<0.001	<0.001	<0.001	0.000	<0.001	<0.001	0.140	<0.001	<0.001	<0.001	0.0002	<0.001	<0.001	2.36	<0.001	<0.001	4.51	0.006
454401	**TP_WD/WATER/LEACH**	0.002	0.016	0.001	<0.001	0.158	0.167	<0.001	<0.001	8.339	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	0.055	<0.001	<0.001	<0.001	0.0002	<0.001	<0.001	2.64	<0.001	<0.001	4.45	0.004
454401 QC	**Duplicate**	0.002	0.020	0.001	<0.001	0.165	0.165	<0.001	<0.001	8.178	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	0.034	<0.001	<0.001	<0.001	0.0001	<0.001	<0.001	2.59	<0.001	<0.001	4.36	0.007

Lims ID	Sample ID	pH	pH Temp	TDS	EC	TDS by Sum	TDS by EC	P Alk.	M Alk.	F	Cl	NO2	NO3	NO3 as N	PO4	SO4	Sum of Cations	Sum of Anions	Ion Balance	NH4	NH3	Acidity to pH8.3	CN (free)	CN (Total)	Cr 6+	TSS
	WATER LEACH 1:20		Deg C	mg/l	mS/m	mg/l	mg/l	mg/l CaCO3	mg/l CaCO3	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	me/l	me/l	%	mg/l	mg/l	mg/l CaCO3	mg/l	mg/l	mg/l	mg/l
454399	**TP_ND/WATER/LEACH**	7.86	24.3	76	8.10	66	57	<0.6	35.5	0.27	0.66	<0.2	2.14	0.48	<0.8	4.23	1.03	1.21	-7.97		<0.01	< 5		<0.01	<5	
454400	**TP_ED/WATER/LEACH**	8.25	24.7	80	8.99	70	63	<0.6	33.5	0.15	2.03	<0.2	7.33	1.66	<0.8	4.14	1.10	1.24	-6.30		<0.01	< 5		<0.01	<5	
454401	**TP_WD/WATER/LEACH**	7.84	24.1	80	8.88	62	62	<0.6	37.8	0.35	0.26	<0.2	1.08	0.25	<0.8	7.10	1.09	1.08	0.38		<0.01	< 5		<0.01	<5	
454401 QC	**Duplicate**	7.84	23.7	76	8.93	62	63	<0.6	37.8	0.29	0.23	<0.2	1.46	0.33	<0.8	7.88	1.06	1.09	-1.51		<0.01	< 5		<0.01	<5	

Chemical elements: Ag, Al, As, Au, B, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Fe, Ga, Ge, Hf, Hg, Ho, Ir, K, La, Li, Mg, Mn, Mo, Na, Nb, Nd, Ni, Pb, Pt, Rb, Sb, Sc, Se, Si, Sn, Sr, Ta, Te, Th, Ti, Tl, U, V, W, Y, Zn, Zr — Anions, pH, NH4, Alkalinity, CN, Cr6+

Instrument: ICP-MS Perkin Elmer NexION 300D — Ion Chromatography — Spectrophotometer — Ion Selective Probe

Date: 26/01/2016
Analysed by: UIS Waterlab

Date: 26/01/2016
Authorised : JJ Oberholzer

To: Golder Associates
Attention: Keretia Lupankwa
Project ID: 1542613
Site Location: Tati
Order No: 93115

analytical services

Lims ID	Sample ID	Mo	Na	Nb	Nd	Ni	Pb	Pt	Rb	Sb	Sc	Se	Si	Sn	Sr	Ta	Te	Th	Ti	Tl	U	V	W	Y	Zn	Zr
	WATER LEACH 1:20	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
454399	**TP_ND/WATER/LEACH**	0.004	4.316	<0.001	<0.001	0.001	0.006	<0.001	0.002	0.002	<0.001	0.001	6.464	0.001	0.029	<0.001	<0.001	<0.0001	0.013	<0.001	0.0001	0.015	0.002	<0.001	0.034	<0.001
454400	**TP_ED/WATER/LEACH**	0.002	4.441	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	<0.001	<0.001	5.835	<0.001	0.041	<0.001	<0.001	<0.0001	0.011	<0.001	0.0001	0.022	0.001	<0.001	0.002	<0.001
454401	**TP_WD/WATER/LEACH**	0.003	5.018	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	<0.001	0.002	3.665	<0.001	0.033	<0.001	<0.001	<0.0001	0.002	<0.001	0.0001	0.010	0.001	<0.001	0.006	<0.001
454401 QC	**Duplicate**	0.004	4.654	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	<0.001	0.004	3.534	<0.001	0.034	<0.001	<0.001	<0.0001	0.001	<0.001	0.0001	0.010	0.001	<0.001	0.005	<0.001
	WATER LEACH 1:20																									
454399	**TP_ND/WATER/LEACH**																									
454400	**TP_ED/WATER/LEACH**																									
454401	**TP_WD/WATER/LEACH**																									
454401 QC	**Duplicate**																									

Date: 26/01/2016
Analysed by: UIS Waterlab

APPENDIX C

Acid Base Accounting Results

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CERTIFICATE OF ANALYSES
ACID – BASE ACCOUNTING
EPA-600 MODIFIED SOBEK METHOD

Date received: 2015-12-14 **Date completed: 2016-01-12**
Project number: 184 **Report number: 56559** **Order number:** 13377

Client name: UIS Analytical Services **Contact person:** Japie Oberholzer
Address: P.O. Box 8286, Centurion, 0046 **Email:** japieo@uis-as.co.za
Telephone: 012 665 4291 **Cell:** 072 488 1001

Acid – Base Accounting Modified Sobek (EPA-600)	Sample Identification			
	TP-ND	**TP-ED**	**TP-WD**	**TP-WD**
Sample Number	**24230**	**24231**	**24232**	**24232D**
Paste pH	7.8	8.1	8.2	8.2
Total Sulphur (%) (LECO)	<0.01	<0.01	<0.01	<0.01
Acid Potential (AP) (kg/t)	0.313	0.313	0.313	0.313
Neutralization Potential (NP)	90	187	186	186
Nett Neutralization Potential (NNP)	90	187	186	186
Neutralising Potential Ratio (NPR) (NP : AP)	288	598	597	595
Rock Type	III	III	III	III

*** Negative NP values are obtained when the volume of NaOH (0.1N) titrated (pH: 8.3) is greater than the volume of HCl (1N) to reduce the pH of the sample to 2.0 – 2.5 Any negative NP values are corrected to 0.00.**

Please refer to Appendix (p.2) for a Terminology of terms and guidelines for rock classification

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Geochemistry Project Manager

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Address: P.O. Box 8286, Centurion, 0046 | **Email:** japieo@uis-as.co.za

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APPENDIX: TERMINOLOGY AND ROCK CLASSIFICATION

TERMINOLOGY (SYNONYMS)

- Acid Potential (AP) ; *Synonyms*: Maximum Potential Acidity (MPA)
  Method: Total S(%) (Leco Analyzer) x 31.25
- Neutralization Potential (NP) ; *Synonyms:* Gross Neutralization Potential (GNP) ; *Syn*: Acid Neutralization Capacity (ANC) (The capacity of a sample to consume acid)
  Method: Fizz Test ; Acid-Base Titration (Sobek & Modified Sobek (Lawrence) Methods)
- Nett Neutralization Potential (NNP) ; *Synonyms:* Nett Acid Production Potential (NAPP)
  Calculation: NNP = NP – AP ; NAPP = ANC – MPA
- Neutralising Potential Ratio (NPR)
  Calculation: NPR = NP : AP

CLASSIFICATION ACCORDING TO NETT NEUTRALISING POTENTIAL (NNP)

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

Any sample with NNP < 20 is potentiall acid-generating, and any sample with NNP > -20 might not generate acid (Usher *et al*., 2003)

ROCK CLASSIFICATION

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

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ACID – BASE ACCOUNTING
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Date received: 2015-12-14 **Date completed:** 2016-01-12
Project number: 184 **Report number:** 56559 **Order number:** 13377

Client name: UIS Analytical Services **Contact person:** Japie Oberholzer
Address: P.O. Box 8286, Centurion, 0046 **Email:** japieo@uis-as.co.za
Telephone: 012 665 4291 **Cell:** 072 488 1001

CLASSIFICATION ACCORDING TO NEUTRALISING POTENTIAL RATIO (NPR)

Guidelines for screening criteria based on ABA (Price *et al*., 1997 ; Usher *et al*., 2003)

Potential for ARD	Initial NPR Screening Criteria	Comments
Likely	**< 1:1**	Likely AMD generating
Possibly	**1:1 – 2:1**	Possibly AMD generating if NP is insufficiently reactive or is depleted at a faster rate than sulphides
Low	**2:1 – 4:1**	Not potentially AMD generating unless significant preferential exposure of sulphides along fracture planes, or extremely reactive sulphides in combination with insufficiently reactive NP
None	**>4:1**	No further AMD testing required unless materials are to be used as a source of alkalinity

CLASSIFICATION ACCORDING TO SULPHUR CONTENT (%S) AND NEUTRALISING POTENTIAL RATIO (NPR)

For sustainable long-term acid generation, at least 0.3% Sulphide-S is needed. Values below this can yield acidity but it is likely to be only of short-term significance. From these facts, and using the NPR values, a number of rules can be derived:

1) Samples with less than 0.3% Sulphide-S are regarded as having insufficient oxidisable Sulphide-S to sustain acid generation.
2) NPR ratios of >4:1 are considered to have enough neutralising capacity.
3) NPR ratios of 3:1 to 1:1 are consider inconclusive.
4) NPR ratios below 1:1 with Sulphide-S above 3% are potentially acid-generating. (Soregaroli & Lawrence, 1998 ; Usher *et al*., 2003)

E. Botha
Geochemistry Project Manager

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CERTIFICATE OF ANALYSES
ACID – BASE ACCOUNTING
EPA-600 MODIFIED SOBEK METHOD

Date received: 2015-12-14		**Date completed:** 2016-01-12
Project number: 184	**Report number:** 56559	**Order number:** 13377
Client name: UIS Analytical Services		**Contact person:** Japie Oberholzer
Address: P.O. Box 8286, Centurion, 0046		**Email:** japieo@uis-as.co.za
Telephone: 012 665 4291		**Cell:** 072 488 1001

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E. Botha
Geochemistry Project Manager

APPENDIX D

Document Limitations

DOCUMENT LIMITATIONS

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Golder Associates

TECHNICAL MEMORANDUM

DATE 25 November 2016 **PROJECT No.** 1541973_Mem_002

TO Nthabeleng Paneng
Tshipi é Ntle Manganese Mine

CC Elize Herselman

FROM Keretia Lupankwa and David Love **EMAIL** klupankwa@golder.co.za

MOTIVATION FOR CLASS D BARRIER DESIGN

1.0 INTRODUCTION

In our report (Report Number: 1541973-301423-1) it was determined that the waste rock materials in the three overburden dumps generated during extraction of manganese ore from open pits were assessed as Type 1 waste. This was on the basis of the exceedance of TCT1 levels with respect to total Manganese concentrations exceeding. It should be noted that all leachable parameters, including manganese were below LCT0.

2.0 MOTIVATION FOR CLASS D BARRIER

Whilst the waste rock material is Type 1 waste,

a) A Class A barrier system with liners is impractical for a waste rock dump on the basis of geotechnical properties: likely liner failure,

b) The waste material is non-hazardous,

c) The waste material is non-acid-generating,

d) The concentration of all constituents of concern in leachate is below LCT0, indicating a low risk from seepage,

e) The dumps do not contain waste water, so the only seepage through the dumps will be from recharge by the (low) rainfall in this area, and therefore

f) The dumps do not pose a significant risk to the water resource.

3.0 CONCLUSION

On the basis of the above, the waste rock material, although assessed as type 1 waste, is likely to behave in the environment in a similar fashion as Type 4 waste; there is low risk from leachate as all leachate parameters are below LCT0 as would be the case for Type 4 waste. On this basis a Class D barrier is recommended.

Klupankwa

Keretia Lupankwa
Geochemist

David Love
Technical Lead Geochemistry

KL/DL/ck

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Appendix C: Waste Assessment

global environmental solutions

Tshipi Borwa Mine

Geochemical and Groundwater Assessment

SLR Project No.: 710.20008.00008

Report No.: 1

March 2014

Tshipi Borwa Mine

Geochemical and Groundwater Assessment

SLR Project No.: 710.20008.00008

Report No.: 1

March 2014

Tshipi é Ntle Manganese Mining

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EXECUTIVE SUMMARY

SLR Consulting (Africa) (Pty) Limited ("SLR") has undertaken a geochemical assessment to characterise material likely to be used to backfill the open pit at the Tshipi Borwa Mine near Hotazel in the Northern Cape.

Twenty-three samples were collected from site and included ore-body material, non-ore body material and a tailings sample generated in the mine laboratory/pilot plant. Samples were submitted to an accredited commercial laboratory for geochemical characterisation tests.

The geochemical test work undertaken as part of this assessment included static Acid-Base Accounting (ABA), elemental composition, and SPLP leach testing. The ABA results showed that all 23 samples have negligible potential to generate acid drainage due to non-detectable sulphur content.

The leach tests suggest that the soluble components of the samples result in leachate quality that is generally within relevant water quality standards. However, two elements were noted as potential constituents of concern, including arsenic (As) and barium (Ba). Elevated concentrations of iron (Fe) and manganese (Mn) were recorded in a number of samples.

Drainage quality that could emanate from the backfill lithologies was simulated using the PHREEQC equilibrium geochemical modelling code (Parkhurst and Appelo 1999). The modelled drainage qualities presented in this report are a starting point for determining the quality of water in the backfilled pit. Actual concentrations cannot be determined, as the scheduling and material balance of the backfilled pit have not been determined as yet.

As a preliminary indicator, water in the pit lake may have the following general characteristics:

- Neutral to alkaline pH;
- Saline, with Na, Cl and SO_4 as the dominant ions;
- Low in dissolved iron and manganese (although Fe-Mn colloidal material may be present); and
- Low concentrations of trace elements.

Aquifer characteristics and analytical modelling conducted by SLR indicate that the open pit, if not backfilled) will take of the order of 400 years to reach its equilibrium level. During this time, local groundwater will flow towards the pit and the pit lake water will have no impact on surrounding groundwater quality.

SLR Consulting (Africa) (Pty) Limited

GEOCHEMICAL AND GROUNDWATER ASSESSMENT

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ACRONYMS AND ABBREVIATIONS

Below a list of acronyms and abbreviations used in this report.

Acronyms / Abbreviations	**Definition**
ABA	Acid Base Accounting
AP	Acid Potential
ARD	Acid Rock Drainage
CoC	Chemicals of Concern
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
E.N	Electro Neutrality
IFC	International Financial Corporation
Mamsl	Metres above mean sea level
NAG	Net Acid Generating
NNP	Net Neutralising Potential
NPR	Neutralising Potential Ratio
NP	Neutralising Potential
PAG	Potentially Acid Generating
SANAS	South African National Accreditation System
SANS	South African National Standards
SPLP	Synthetic Precipitation Leaching Procedure
WHO	World Health Organisation
XRF	X-Ray Fluorescence

GEOCHEMICAL AND GROUNDWATER ASSESSMENT

1 INTRODUCTION

SLR Consulting (Africa) (Pty) Limited ("SLR") has been appointed by Tshipi é Ntle Manganese Mining ("Tshipi") to undertake a geochemical assessment to characterise waste material at Tshipi Borwa Mine in the Northern Cape Province, South Africa.

Tshipi Mining currently operate an open pit manganese mine near Hotazel in the Northern Cape Province and plan to backfill the open pit with mine waste as the pit progresses. As part of the amendment to the Environment Impact Assessment (EIA) and Environmental Management Plan (EMP), an assessment to identity the potential impacts on water quality by the backfilling of waste material into the open pit must be undertaken.

1.1 OBJECTIVES

The objectives of this report are:

- To geochemically characterise material likely to be used as backfill material; and
- To provide a preliminary estimate of Pit lake quality / backfill water quality.

Water quality impacts due to pit backfilling cannot be assessed at this stage since the backfilling schedule and composition has not been finalised. However, qualitative water quality impacts have been assessed based on the geochemical characterisation results.

1.2 REPORT STRUCTURE

The report has been divided accordingly:

- Section 2 presents the general site setting determined through a high level desk study;
- Section 3 summarises the geochemical characterisation methodologies;
- Section 4 details the results of the geochemical test work;
- Section 5 details the potential water quality base don geochemical modelling and laboratory results; and
- Section 6 summarises and concludes the report.

2 GEOCHEMICAL BASELINE

A high level desk study has been undertaken reviewing available hydrogeological, geochemical and geological information. The information has been used to develop a Conceptual Site Model (CSM) and is presented in the following sections.

2.1 SITE SETTING

The Tshipi Borwa Mine is located approximately 20km south of Hotazel and approximately 50km north-west of Kuruman in the Northern Cape Province. The site location is presented in Figure 2-1.

The topography of the project area is relatively flat, with a gentle slope towards the North West. The elevation on site varies from 1087m to 1095m above mean sea level (mamsl).

The mine is located in an arid climatic region of South Africa with average annual precipitation of 336.4mm. Rainfall is usually intense, in the form of thunderstorms, and predominantly occurs during the summer months of October to April.

FIGURE 2-1: SITE LOCATION PLAN

2.2 GEOLOGICAL SETTING

The Tshipi Borwa Mine is located on the south western outer rim of the Kalahari Manganese Field (KMF). Tshipi Mining is exploiting the manganese from the Hotazel Formation (Transvaal Supergroup) as presented in Figure 2-2.

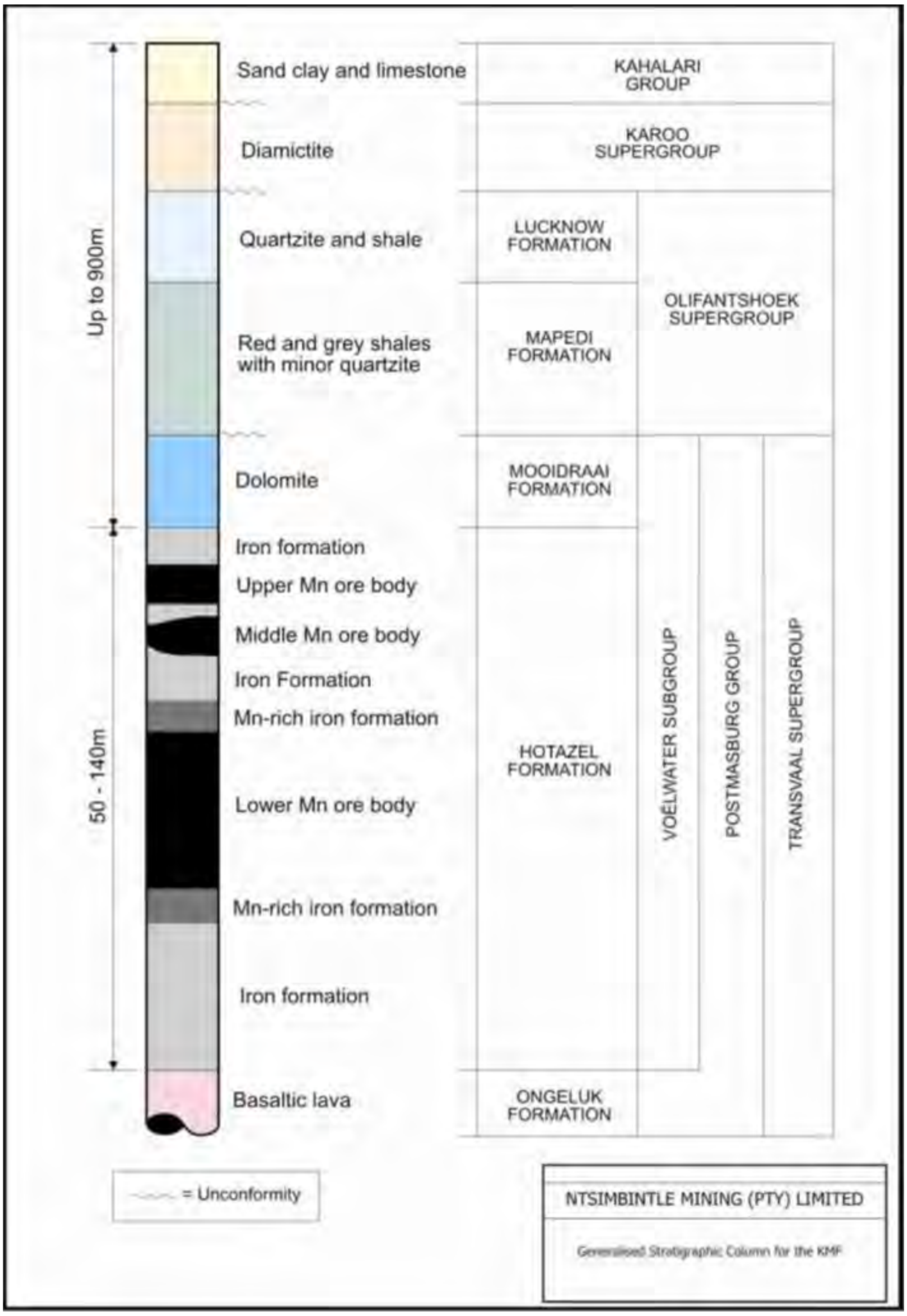

FIGURE 2-2: GENERAL STRATEGIC COLUMN FOR THE KALAHARI MANGANESE FIELD (FIGURE PROVIDED BY TSHIPI BORWA PROJECT TEAM)

The **Hotazel Formation** consists of Banded Iron Formation (BIF). The ore is contained within a 30 to 45 metre thick mineralised zone which occurs along the entire Borwa property (Tshipi, 2012) and is made up of three manganese rich zones; the Upper Manganese Ore Body (UMO), the Middle Manganese Ore Body (MMO) and the Lower Manganese Ore Body (LMO).

The UMO is 10cm to 15cm-thick and comprises moderate deposits of manganese. The poorly mineralised MMO is circa.1m-thick and not economically efficient. The LMO is a highly mineralised unit consisting of six important mineralised zones (X, Y, Z, M. C and N) (Figure 2-3). The ore layer dips gradually to the north-west at approximately five degrees (Tshipi, 2012).

The **Hotazel Formation** is underlain by basaltic lava of the **Ongeluk Formation** (Transvaal Supergroup) and directly overlain by dolomite of the **Moodraai Formation** (Transvaal Supergroup).

The Transvaal Supergroup is overlain unconformably by the **Olifantshoek Supergroup** which consists of arenaceous sediments, typically interbedded shale, quartzite and lavas overlain by coarser quartzite and shale. The different formations present in the project area include the Mapedi and Lucknow units. The whole Supergroup has been deformed into a succession with an east-verging dip (Cornell et al., 1998) (Figure 2-3).

The Olifantshoek Supergroup is overlain by **Dwyka Formation** which forms the basal part of the Karoo Supergroup. At the mine this consists of tillite (diamictite) which is covered by sands, claystone and calcrete of the **Kalahari Group.**

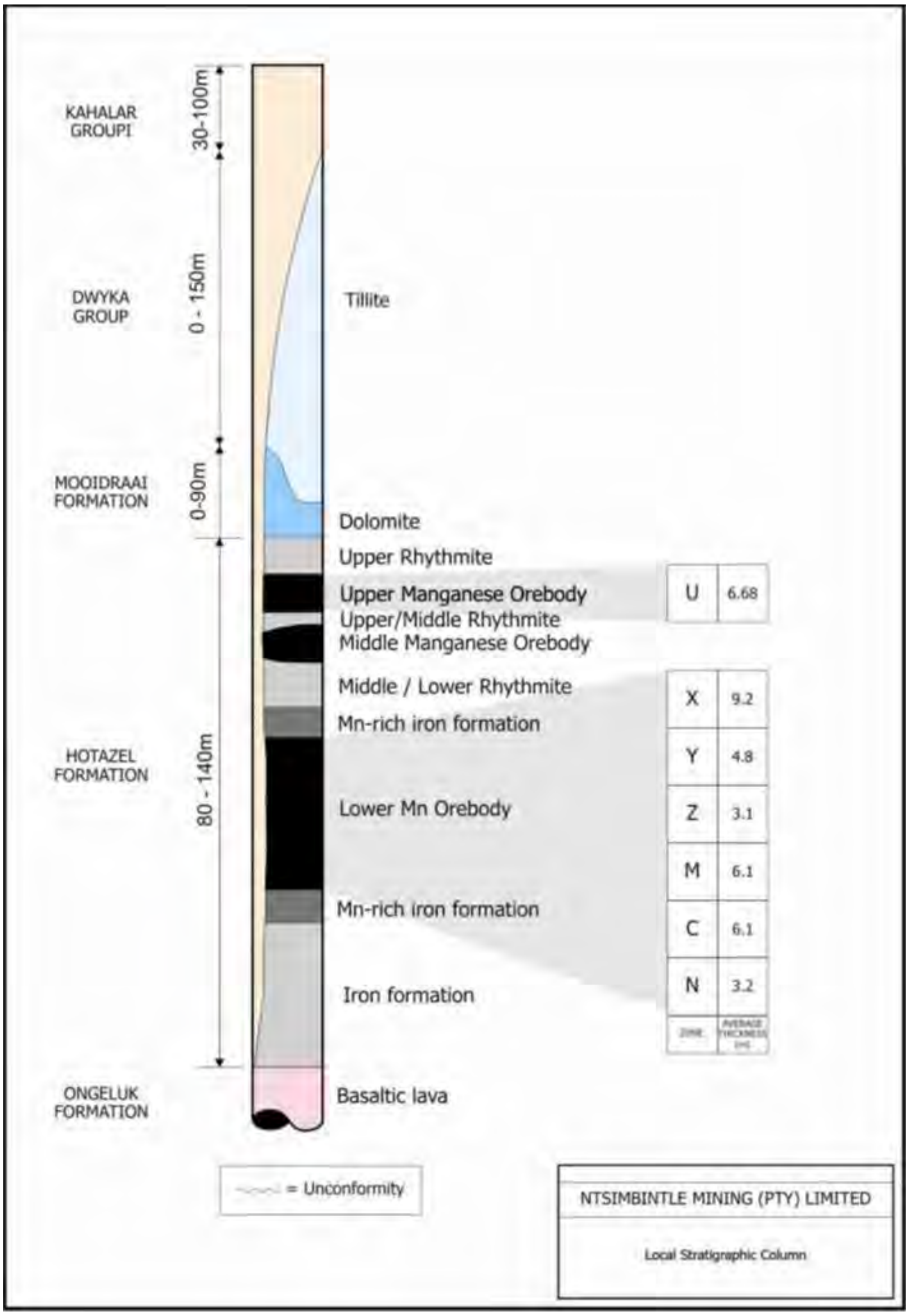

FIGURE 2-3: LOCAL STRATIGRAPHY (FIGURE PROVIDED BY TSHIPI BORWA PROJECT TEAM)

2.3 HYDROGEOLOGICAL SETTING

Two distinct aquifer systems have been observed in a previous investigation at the mine site (Water Geosciences Consulting, 2009):

- A shallow aquifer made of the Kalahari Beds, sand and calcrete; and
- A deep fractured aquifer made of the Dwyka tillite and the Mooidraai Formation dolomite.

The Kalahari sand and the sediment beds with its associated underlying calcrete layer overlie the low permeability Dwyka tillite. The Mooidraai dolomite Formation and Dwyka tillite contact forms the deeper fractured bedrock aquifer.

Pumping tests indicate that the aquifers have poor water yields; average yield for the shallow aquifer system is <1 L/s and for the deep aquifer approximately 0.9 L/s (Water Geosciences Consulting, 2009). The aquifers are classified as a poor to minor aquifers. Although borehole yields in the deeper aquifer are low, structural features such as faults and fractures can produce high yielding boreholes.

A hydrocensus was conducted in August 2012. The average depth of the groundwater table in the larger study area is 45 mbgl (metres below ground level). Groundwater flow is from the southeast towards the north on the mine site. Depth to groundwater water varies between 25.83 and 55.57 m below ground surface (Knight Piésold, 2012).

2.4 Hydrological Setting

The closest watercourses to the project site are:

- Vlermuisleegte River: a non-perennial river located approximately 2km to the southwest;
- Witleegte River: a non-perennial River located approximately 10km to the north-east; and
- Ga-Mogara River: a non-perennial River located approximately 6km to the west.

The Vlermuisleegte and Witleegte are tributaries of the Ga-Mogara River which is a tributary of the Kuruman River, located approximately 40km for the site.

2.5 Mining Plan

The depth of the manganese seam at the start of mining was approximately 70m below ground level (bgl) with the deepest point approximately 330mbgl (Tshipi e Ntle, 2009).

The manganese ore deposits are extracted using conventional open-pit excavation methods encompassing drilling, exploring, blasting, loading and hauling. The extracted material is transported to the plant for processing where material is crushed, screened, conveyed and stockpiled.

Based on information provided by Tshipi, tailings from the ore processing consist of ore particles less than 0.6 mm in size. Lighter particles (presumably consisting of more silica) are separated for pit backfilling, while heavier particles (more manganese and iron) are pumped to the tailings dam.

3 GEOCHEMICAL CHARACTERISATION

The following section describes how samples were selected and collected and the methods undertaken to geochemically characterise the waste material.

3.1 SAMPLE SELECTION AND COLLECTION

A critical success factor for any geochemical characterisation program is the selection of a sample set appropriate for the assessment objectives. The MEND Report suggests that a sampling programme should include good spatial, geologic and geochemical representation because contaminant discharge may be produced by only a portion of the geological material. In the case of Tshipi backfill, it is likely that discharge will be from a mix of different material.

SLR visited the site in June 2013 to conduct sample selection and collection. The SLR hydrogeologist liaised closely with the Chief Geologist to identify the main lithologies that are, or will be, disturbed by mining and would potentially be used as backfill material. Samples were collected directly from the pit walls. At least one sample of each lithology was taken.

A sample of dolomite was taken from a core of an exploratory borehole as it has not yet been exposed in the pit.

A tailings sample generated at the on-site lab was provided to SLR for geochemical testing.

A total of 23 samples were collected from site. Their details are presented in Table 3.1 and the sampling locations are presented in Figure 3.1.

TABLE 3-1: SAMPLE DETAILS

Sample ID	Lab ID	Lithology	Elevation of Sample	Pit Location
SLR-TB-01	11220	Braunie Lutite - Supergene altered Upper body ore	1021.922	East Side
SLR-TB-02	11221	Upper BIF	1020.801	East Side
SLR-TB-03	11222	Lower BIF	1018.252	East Side
SLR-TB-04	11223	Lower BIF - red in colour	1018.919	East Side
SLR-TB-05	11224	VW Ore Zone - Grade too low to be a product	1015.028	East Side
SLR-TB-06	11225	Top Cut Ore - Sample of x zone	1013.186	East Side
SLR-TB-07	11226	Lower Ore body - Composite of z, c, and n zones.	1010.049	East Side
SLR-TB-08	11227	Pebble bed in calcareous clay	1026.990	North Side
SLR-TB-09	11228	Pebble bed in red calcareous clay	1030.217	North Side
SLR-TB-10	11229	Red clay	1031.184	North Side
SLR-TB-11	11230	Lower BIF	1012.341	North Side
SLR-TB-12	11231	Red clay	1030.098	South Side
SLR-TB-13	11232	White Clay	1052.157	South Side
SLR-TB-14	11233	White gravel bed	1054.877	South Side
SLR-TB-15	11234	Red Iron Calcareous Sand	1066.225	South Side
SLR-TB-16	11235	Pebbly Calcrete	1067.984	South Side
SLR-TB-17	11236	Iron rich Calcareous Sands	1067.131	South Side
SLR-TB-18	11237	Pebbly Calcrete	1072.483	South Side
SLR-TB-19	11238	Red Kalahari Sands	1088.848	East Side
SLR-TB-20	11239	Calcrete	1081.302	East Side
SLR-TB-21	11240	Pebbly Calcrete	1075.395	-
SLR-TB-22	11241	Tailings Sample from pilot plant	-	-
SLR-TB-23	11242	Dolomite – core sample as not currently exposed in pit	998.00	-

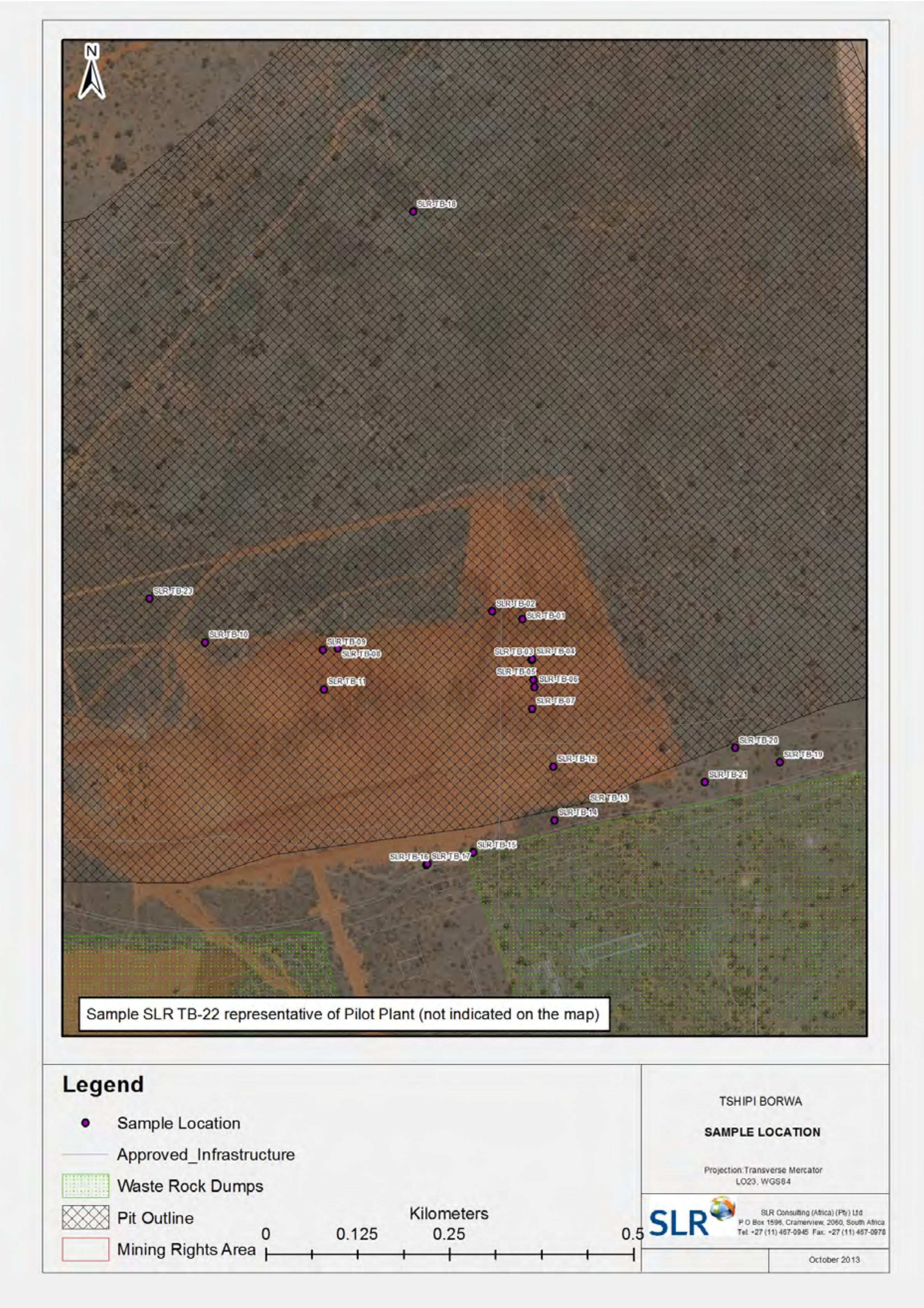

FIGURE 3-1: SAMPLING LOCATION PLAN

3.2 LABORATORY ANALYSIS

All samples were sent to Waterlab (Pty) in Pretoria, South Africa. Waterlab is a SANAS (South African National Accreditation System) accredited laboratory according to ISO/IEC 17025:2005 standards. Waterlab assessed analytical quality control through internal duplication of selected samples.
All samples underwent the following laboratory tests:

- Net Acid Generation (NAG) analysis;
- Acid Base Accounting (ABA);
  - Acid Potential (AP) analysis;
  - Neutralising Potential (NP) analysis; from which may be determined;
    - Net Neutralising Potential (NNP); and
    - Neutralising Potential Ratio (NPR);
  - Paste pH;
  - Sulphur speciation;
- Synthetic Precipitation Leaching Procedure (SPLP) test using distilled water; and
- Whole element analysis by X-ray fluorescence (XRF) on selected sample.

The tests are described in further detail in the following sections.

3.2.1 ACID BASE ACCOUNTING

3.2.1.1 Acid Potential and Neutralising Potential

Acid–Base Accounting (ABA) is an internationally accepted analytical procedure that was developed to screen the acid-producing and acid-neutralizing potential of rocks.

The Acid Generating Potential (AP) is due to the oxidation of sulphide minerals in a rock sample and is calculated as the total sulphide sulphur content in % multiplied by 31.25.

The Acid Neutralising Potential (NP), is a measure of the total acid a material is capable of neutralising and is predominantly a result of neutralising bases, mostly carbonates and exchangeable alkali and alkali earth cations.

3.2.1.2 Net Neutralising Potential (NNP)

The Net Neutralisation Potential (NNP) is calculated by subtracting the Acid Generating Potential (AP) from the Acid Neutralising Potential (NP):

NNP = NP – AP

Results are reported in kg of calcium carbonate per tonne of overburden (or parts per thousand). For a sample:

- Negative NNP indicates potential to generate acid; and
- Positive NNP indicates excess acid-neutralising potential.

3.2.1.3 Neutralising Potential Ratio (NPR)

The Neutralising Potential Ratio is calculated by dividing the Neutralising Potential (NP) by the acid potential (AP):

NPR = NP/AP

In the assessment:

- NPR ratios larger than 2 indicate non-acid generation;
- ratios between 1 and 2 are considered inconclusive / potentially acid generating; and
- NPR ratios below 1 indicate potential acid generation.

3.2.2 NET ACID GENERATION (NAG) TESTS

Net Acid Generation (NAG) tests directly determine the acid generating potential of sulphur minerals in a rock sample by oxidation with hydrogen peroxide (H2O2). The final NAG pH after complete oxidation of the sample is used as a screening criterion for the acid generation potential as follows:

- NAG pH below 4.5 indicates a high risk of acid generation; and
- NAG pH above 4.5 indicates no risk of acid generation.

The supernatant of the test is titrated to a pH of 4.5 and 7.0 and the net acid potential, in the form of kilograms of sulphuric acid produced per tonne of waste rock sample (kg H_2SO_4/t) calculated.

3.2.3 PASTE PH

Paste pH analysis is undertaken in conjunction with the ABA test to determine if acid generation has occurred prior to analysis. The procedure involves the placement of ‘crushed’ sample with distilled water and the pH measured after approximately two minutes.

3.2.4 SULPHUR SPECIATION

Some of the sulphur in a sample may be present in non-acid producing sulphates or native sulphur. If a significant part of the total sulphur occurs as sulphate sulphur instead of potentially acid generating sulphide sulphur, the overall risk of acid generation is reduced. However, significant water quality impacts may result from leaching of sulphate sulphur into local water resources.

3.2.5 INORGANIC CARBON CONTENT

The acid neutralising potential of a sample is characterised by the inorganic carbon content which is assumed to indicate the presence of carbonate minerals.

3.2.6 SYNTHETIC PRECIPITATION LEACHING PROCEDURE (SPLP)

Synthetic Precipitation Leaching Procedure is a laboratory extraction method designed to determine the leachability of both organic and inorganic elements present in liquids, soils, and wastes under certain conditions. The solid phase is extracted over with an extraction fluid, and liquid-to-solid ratio of 4:1 (Price, 2009). Following extraction, the liquid extract is separated from the solid phase by filtration (combined with any potential initial liquid portion) and analysed.

As part of this assessment, SPLP tests were undertaken using distilled water (pH7) to represent neutral drainage conditions. Although the SPLP can determine the leachability of determinants, the liquid-to-solid ratio does not represent actual field conditions; therefore resultant concentrations should not be considered representative of run-off that could emanate from site. The tests are commonly used as a preliminary screening process to identify potential chemicals of concern (CoCs) based on a comparison against relevant water quality and effluent standards. For the purposes of this assessment the following standards were considered:

- World Health Organisation (WHO) Guidelines for drinking-water quality (WHO, 2011);
- International Finance Corporation (IFC) Guidelines for Mining Effluents (IFC, 2007); and
- South African National Standards (SANS) 241 (2011) Drinking Water (SANS 241:2011).

Note that the application of drinking water guidelines does not suggest that leachates and drainage from mine activities will be used for drinking purposes. Use of these guidelines is conducted as an indicator of general environmental risk.

4 RESULTS AND INTERPRETATION

The results of the static testing are presented in the following sections. Copies of laboratory reports are provided in Appendix A.

4.1 DATA VALIDATION

The accuracy of the chemical analysis can be assessed through calculating the electro neutrality for each sample. The electro neutrality (E.N) is calculated using the following equation:

$$E.N.[\%] = \frac{\sum cations\left(\frac{meq}{l}\right) - \sum anions\left(\frac{meq}{l}\right)}{\sum cations\left(\frac{meq}{l}\right) + \sum anions\left(\frac{meq}{l}\right)} * 100\% < 10\%$$

Samples with a calculated E.N value of less that 10% are considered to show an acceptable level of accuracy. Where samples have an error percentage above 10%, results are considered to show an unacceptable level of accuracy and results / interpretation of results should be considered with caution.

The EN calculation was applied to the pH7 leach data. The majority of samples showed an acceptable level of accuracy.

In addition, comparison of the results of the laboratory duplicates indicates that the methods applied show an acceptable level of reproducibility.

4.2 ABA

The ABA Results are presented in Table 4.1.

The Acid Base Accounting (ABA) results show that the total sulphur content and more importantly the sulphide sulphur content of all samples are below the laboratory detection limit of <0.01% which suggests the potential to generated acid is negligible for all samples. In addition, the neutralising potential ratio (NPR) of all samples is above 2, some significantly above 2, which implies all lithologies have sufficient neutralising potential to offset the low acid potential. This is interpreted to be due to carbonate minerals, as suggested by the generally high inorganic carbon in the samples and the carbonate-rich geology (calcretes, dolomites, etc.).

4.3 ELEMENTAL COMPOSITION

The major element composition of the samples has been determined through X-Ray Fluorescence. The relative proportions of the major elements in each analysed lithology are presented in Figure 4-1.

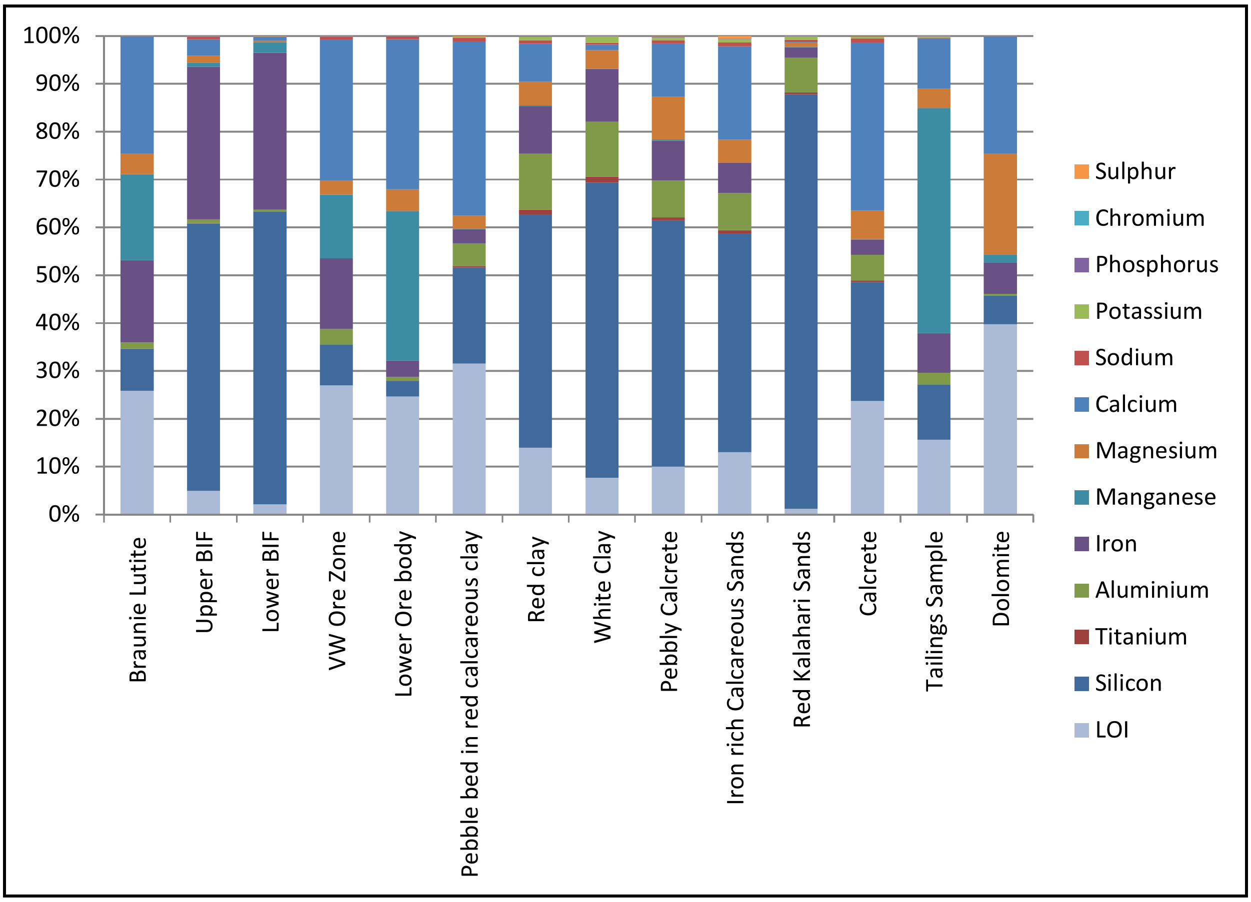

FIGURE 4-1: MAJOR ELEMENT COMPOSITION OF SELECTED TSHIPI BORWA MINE LITHOLOGIES

The elemental compositions are generally consistent with the geology, as summarised below:

- BIF units are dominated by silicon and iron. They have the highest iron content of all the samples tested;
- Manganese ore units appear to contain significant volatiles, as indicated by the high Loss on Ignition (LOI) values. As expected, these samples contain significant manganese. However, calcium and magnesium make up at least 30% of the major element composition;
- The tailings sample contains the highest manganese content of all the samples (almost 50%);
- The clay samples, sand samples and calcrete sample contain significant silicon and aluminium. This is consistent with the presence of clay minerals;
- Many samples, including the braunie lutite, ore zone samples, calcareous clay, calcareous sand and calcrete have similar or greater concentrations of calcium than the dolomite sample. This confirms that the lithologies have excess neutralisation potential. It implies that drainage from these lithologies will form calcium carbonate precipitates; and
- The concentrations of sodium, potassium, phosphorous, chromium and sulphur are of the order of 1% of the major element concentration.

Trace elements at concentrations greater than approximately 10 times the median crustal abundance include cadmium, antimony, and selenium (Figure 4-2). Lead was enriched in the braunie lutite, BIF, pebbly calcrete and one ore sample. Mercury was below the laboratory detection limit in all samples tested.

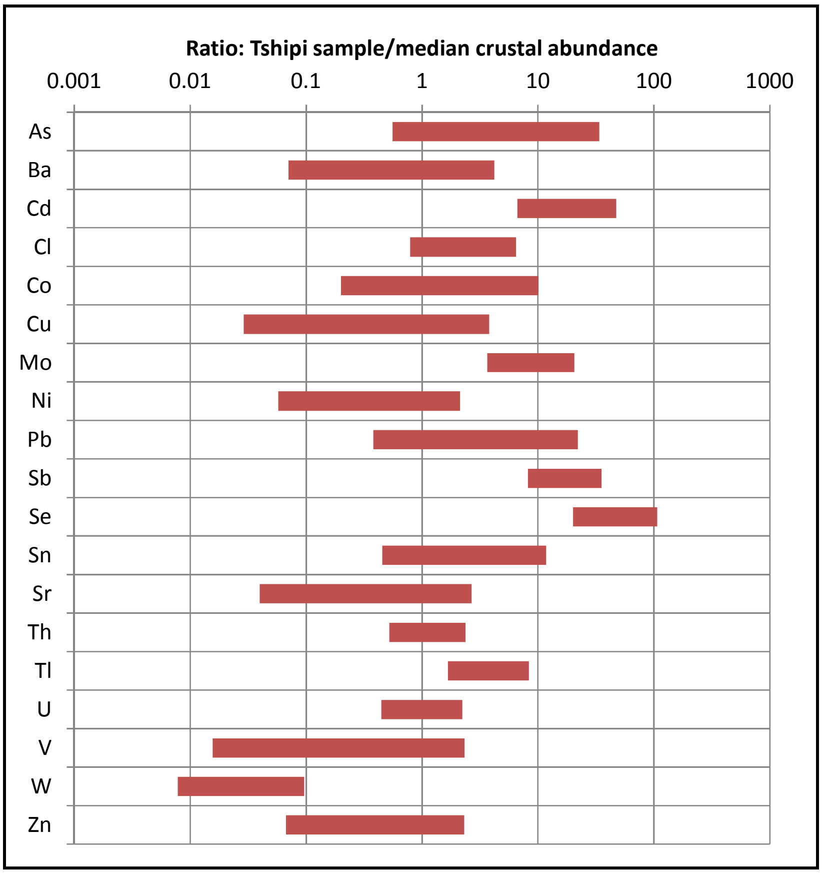

FIGURE 4-2: TRACE ELEMENT RATIOS AGAINST CRUSTAL ABUNDANCE IN TSHIPI SAMPLES

Leachable elements from Tshipi lithologies could lead to environmental risk. This was assessed from leach tests.

4.4 SPLP LEACH TESTS

The SPLP test results are presented in Table 4.1. The final pH of the leachates was generally significantly higher than the initial pH 7. This is consistent with the presence of significant leachable alkalinity in the Tshipi samples.

A number of metals are leachable at concentrations in excess of relevant water quality standards including aluminium (Al), arsenic (As), barium (Ba), iron (Fe) and manganese (Mn).
It is noted that cadmium, antimony, selenium and lead were not detected in the leachates which indicates that these elements are not leachable under the pH conditions of the test.

TABLE 4-1: ACID BASE ACCOUNTING RESULTS FOR SAMPLES COLLECTED FROM TSHIPI BORWA MINE

Sample ID	Lab ID	Lithology	Elevation (mamsl)	Location	Paste pH	Acid Potential (AP) (kg/t)	Neutralization Potential (NP)	Nett Neutralization Potential (NNP)	Neutralising Potential Ratio (NPR) (NP : AP)	NAG pH: (H_2O_2)	NAG (kg H_2SO_4 / t)	Total Sulphur (%)	Sulphate Sulphur as S (%)	Sulphide Sulphur (%)	Total Carbon (%)	Organic Carbon (%)	Inorganic Carbon (%)
SLR-TB-01	**11220**	Braunie Lutite	1021.922	East Side	8	0.313	280	280	897	8.4	<0.01	<0.01	<0.01	<0.01	5.6	0.172	5.428
SLR-TB-02	**11221**	Upper BIF	1020.801	East Side	8.5	0.313	66	66	213	8.3	<0.01	<0.01	<0.01	<0.01	0.86	0.208	0.652
SLR-TB-03	**11222**	Lower BIF	1018.252	East Side	8.4	0.313	13	13	41	8.8	<0.01	<0.01	<0.01	<0.01	0.148	0.13	0.018
SLR-TB-04	**11223**	Lower BIF - red in colour	1018.919	East Side	8.4	0.313	130	130	417	8.5	<0.01	<0.01	<0.01	<0.01	4.09	0.202	3.888
SLR-TB-05	**11224**	VW Ore Zone	1015.028	East Side	8.6	0.313	167	167	535	8.4	<0.01	<0.01	<0.01	<0.01	6.7	0.17	6.53
SLR-TB-06	**11225**	Top Cut Ore	1013.186	East Side	8.8	0.313	146	145	466	8.4	<0.01	<0.01	<0.01	<0.01	6.91	0.118	6.792
SLR-TB-07	**11226**	Lower Ore body	1010.049	East Side	8.5	0.313	122	121	389	8.4	<0.01	<0.01	<0.01	<0.01	7.33	0.231	7.099
SLR-TB-08	**11227**	Pebble bed in calcareous clay	1026.990	North Side	8.3	0.313	4.26	3.95	14	8.2	<0.01	<0.01	<0.01	<0.01	0.07	0.069	0.001
SLR-TB-09	**11228**	Pebble bed in red calcareous clay	1030.217	North Side	8.5	0.313	323	323	1034	8.3	<0.01	<0.01	<0.01	<0.01	7.8	0.258	7.542
SLR-TB-10	**11229**	Red clay	1031.184	North Side	8.2	0.313	51	51	163	8.8	<0.01	<0.01	<0.01	<0.01	3.34	0.257	3.083
SLR-TB-11	**11230**	Lower BIF	1012.341	North Side	8.7	0.313	100	100	322	8.5	<0.01	<0.01	<0.01	<0.01	3.38	0.119	3.261
SLR-TB-12	**11231**	Red clay	1030.098	South Side	8.2	0.313	74	73	236	8.8	<0.01	<0.01	<0.01	<0.01	1.28	0.247	1.033
SLR-TB-13	**11232**	White Clay	1052.157	South Side	8.1	0.313	5	4.69	16	7.7	<0.01	<0.01	<0.01	<0.01	0.335	0.331	0.004
SLR-TB-14	**11233**	White gravel bed	1054.877	South Side	8.6	0.313	5.75	5.43	18	7.8	<0.01	<0.01	<0.01	<0.01	0.278	0.273	0.005
SLR-TB-15	**11234**	Red Iron Calcareous Sand	1066.225	South Side	8.3	0.313	110	109	351	8.5	<0.01	<0.01	<0.01	<0.01	2.5	0.361	2.139
SLR-TB-16	**11235**	Pebbly Calcrete	1067.984	South Side	8.5	0.313	79	79	254	8.4	<0.01	<0.01	<0.01	<0.01	2.01	0.203	1.807
SLR-TB-17	**11236**	Iron rich Ccalcareous Sands	1067.131	South Side	8.4	0.313	106	106	339	8.5	<0.01	<0.01	<0.01	<0.01	2.76	0.272	2.488
SLR-TB-18	**11237**	Pebbly Calcrete	1072.483	South Side	8.5	0.313	106	105	338	8.5	<0.01	<0.01	<0.01	<0.01	5.41	0.275	5.135
SLR-TB-19	**11238**	Red Kalahari Sands	1088.848	East Side	8.1	0.313	2.73	2.41	8.72	7.7	<0.01	<0.01	<0.01	<0.01	0.26	0.255	0.005
SLR-TB-20	**11239**	Calcrete	1081.302	East Side	8.5	0.313	146	146	467	8.5	<0.01	<0.01	<0.01	<0.01	4.48	0.356	4.124
SLR-TB-21	**11240**	Pebbly Calcrete	1075.395	-	8.7	0.313	113	113	361	8.3	<0.01	<0.01	<0.01	<0.01	3.32	0.314	3.006
SLR-TB-22	**11241**	Tailings Sample	-	-	8.4	0.313	101	100	322	8.4	<0.01	<0.01	<0.01	<0.01	11.5	0.203	11.3
SLR-TB-23	**11242**	Dolomite	998.00	-	8.7	0.313	115	114	367	8.4	<0.01	<0.01	<0.01	<0.01	11.48	0.148	11.33

TABLE 4-2: SPLP RESULTS FOR SAMPLES COLLECTED FROM TSHIPI BORWA MINE

Sample ID	Lab ID	Lithology	Ag	Al	As	B	Ba	Be	Bi	Ca	Cd	Co	Cr	Cu	Fe	K	Li	Mg	Mn	Mo	Na	Ni
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
		WHO Standard for Drinking Water (2011)	N/A	N/A	0.01	2.4	0.7	N/A	N/A	N/A	0.003	N/A	0.05	2.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.07
		IFC Mining Effluent (2007)	N/A	N/A	0.1	N/A	N/A	N/A	N/A	N/A	0.05	N/A	0.1	0.3	2	N/A	N/A	N/A	N/A	N/A	N/A	0.5
		SANS 241 (2011) Operational	N/A	0.3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		SANS 241 (2011) Aesthetic	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.3	N/A	N/A	N/A	0.1	N/A	200	N/A
		SANS 241 (2011) Acute Heath	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		SANS 241 (2011) Chronic Health	N/A	N/A	0.01	N/A	N/A	N/A	N/A	N/A	0.003	0.5	0.05	2	2	N/A	N/A	N/A	0.5	N/A	N/A	0.07
SLR-TB-01	11220	Braunie Lutite	<0.025	<0.100	<0.010	0.040	<0.025	<0.025	<0.025	14	<0.005	<0.025	<0.025	<0.025	<0.025	1.1	<0.025	10	<0.025	<0.025	13	<0.025
SLR-TB-02	11221	Upper BIF	<0.025	<0.100	0.010	<0.025	<0.025	<0.025	<0.025	12	<0.005	<0.025	<0.025	<0.025	0.031	<1.0	<0.025	6	<0.025	<0.025	3	<0.025
SLR-TB-03	11222	Lower BIF	<0.025	<0.100	<0.010	0.060	0.072	<0.025	<0.025	10	<0.005	<0.025	<0.025	<0.025	0.478	<1.0	<0.025	<2	0.128	<0.025	3	<0.025
SLR-TB-04	11223	Lower BIF - red in colour	<0.025	<0.100	<0.010	<0.025	<0.025	<0.025	<0.025	14	<0.005	<0.025	<0.025	<0.025	<0.025	<1.0	<0.025	7	<0.025	<0.025	9	<0.025
SLR-TB-05	11224	VW Ore Zone	<0.025	<0.100	<0.010	0.087	0.079	<0.025	<0.025	9	<0.005	<0.025	<0.025	<0.025	<0.025	<1.0	<0.025	6	<0.025	<0.025	7	<0.025
SLR-TB-06	11225	Top Cut Ore	<0.025	<0.100	<0.010	0.050	<0.025	<0.025	<0.025	9	<0.005	<0.025	<0.025	<0.025	<0.025	<1.0	<0.025	8	0.119	<0.025	<2	<0.025
SLR-TB-07	11226	Lower Ore body	<0.025	<0.100	<0.010	0.102	<0.025	<0.025	<0.025	10	<0.005	<0.025	<0.025	<0.025	<0.025	<1.0	<0.025	8	0.090	<0.025	3	<0.025
SLR-TB-08	11227	Pebble bed in calcareous clay	<0.025	<0.100	<0.010	0.082	0.105	<0.025	<0.025	6	<0.005	<0.025	<0.025	<0.025	<0.025	1.3	<0.025	4	<0.025	<0.025	10	<0.025
SLR-TB-09	11228	Pebble bed in red calcareous clay	<0.025	<0.100	<0.010	0.074	0.139	<0.025	<0.025	13	<0.005	<0.025	<0.025	<0.025	<0.025	1.0	<0.025	6	<0.025	<0.025	8	<0.025
SLR-TB-10	11229	Red clay	<0.025	<0.100	0.019	0.120	0.134	<0.025	<0.025	10	<0.005	<0.025	<0.025	<0.025	<0.025	1.4	<0.025	6	<0.025	<0.025	14	<0.025
SLR-TB-11	11230	Lower BIF	<0.025	<0.100	0.023	0.074	0.096	<0.025	<0.025	10	<0.005	<0.025	<0.025	<0.025	<0.025	<1.0	<0.025	8	<0.025	<0.025	2	<0.025
SLR-TB-12	11231	Red clay	<0.025	<0.100	<0.010	0.073	<0.025	<0.025	<0.025	11	<0.005	<0.025	<0.025	<0.025	0.041	1.3	<0.025	6	<0.025	<0.025	12	<0.025
SLR-TB-13	11232	White Clay	<0.025	<0.100	<0.010	<0.025	<0.025	<0.025	<0.025	5	<0.005	<0.025	<0.025	<0.025	0.045	1.8	<0.025	3	<0.025	<0.025	9	<0.025
SLR-TB-14	11233	White gravel bed	<0.025	<0.100	<0.010	0.064	0.173	<0.025	<0.025	7	<0.005	<0.025	<0.025	<0.025	0.037	1.3	<0.025	4	<0.025	<0.025	7	<0.025
SLR-TB-15	11234	Red Iron Calcareous Sand	<0.025	<0.100	<0.010	<0.025	<0.025	<0.025	<0.025	11	<0.005	<0.025	<0.025	<0.025	0.038	1.6	<0.025	6	<0.025	<0.025	9	<0.025
SLR-TB-16	11235	Pebbly Calcrete	<0.025	<0.100	<0.010	<0.025	0.042	<0.025	<0.025	12	<0.005	<0.025	<0.025	<0.025	0.069	1.8	<0.025	7	<0.025	<0.025	9	<0.025
SLR-TB-17	11236	Iron rich Calcareous Sands	<0.025	<0.100	0.013	0.146	1.21	<0.025	<0.025	12	<0.005	<0.025	<0.025	<0.025	<0.025	1.4	<0.025	6	<0.025	<0.025	14	<0.025
SLR-TB-18	11237	Pebbly Calcrete	<0.025	<0.100	0.012	0.107	1.06	<0.025	<0.025	11	<0.005	<0.025	<0.025	<0.025	<0.025	1.3	<0.025	7	<0.025	<0.025	13	<0.025
SLR-TB-19	11238	Red Kalahari Sands	<0.025	1.72	0.022	0.053	0.027	<0.025	<0.025	5	<0.005	<0.025	<0.025	<0.025	1.51	4.1	<0.025	3	<0.025	<0.025	2	<0.025
SLR-TB-20	11239	Calcrete	<0.025	<0.100	<0.010	<0.025	<0.025	<0.025	<0.025	14	<0.005	<0.025	<0.025	<0.025	<0.025	3.0	<0.025	8	<0.025	<0.025	42	<0.025
SLR-TB-21	11240	Pebbly Calcrete	<0.025	0.147	<0.010	<0.025	0.028	<0.025	<0.025	10	<0.005	<0.025	<0.025	<0.025	0.196	1.9	<0.025	5	<0.025	<0.025	19	<0.025
SLR-TB-22	11241	Tailings Sample	<0.025	<0.100	<0.010	0.126	<0.025	<0.025	<0.025	21	<0.005	<0.025	<0.025	<0.025	<0.025	1.1	<0.025	14	<0.025	<0.025	10	<0.025
SLR-TB-23	11242	Dolomite	<0.025	<0.100	0.014	0.129	1.07	<0.025	<0.025	10	<0.005	<0.025	<0.025	<0.025	<0.025	<1.0	<0.025	17	<0.025	<0.025	4	<0.025

Sample ID	Lab ID	Lithology	P	Pb	Sb	Se	Si	Sn	Sr	Ti	V	W	Zn	Zr	pH Value at 25˚C	Electrical Conductivity i	Alkalinity as $CaCO_3$	Chloride as Cl	Sulphate as SO_4	Nitrate as N	Fluoride as F
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	pH Value	mS/m	mg/l	mg/l	mg/l	mg/l	mg/l
		WHO Standard for Drinking Water (2011)	N/A	0.01	0.02	0.04	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	11	1.5
		IFC Mining Effluent (2007)	N/A	0.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.5	N/A	6-9	N/A	N/A	N/A	N/A	N/A	N/A
		SANS 241 (2011) Operational	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5 - 9.7	N/A	N/A	N/A	N/A	N/A	N/A
		SANS 241 (2011) Aesthetic	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5	N/A	N/A	170	N/A	300	250	N/A	N/A
		SANS 241 (2011) Acute Heath	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	500	11	N/A
		SANS 241 (2011) Chronic Health	N/A	0.01	0.02	0.01	N/A	N/A	N/A	N/A	0.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.5
SLR-TB-01	11220	Braunie Lutite	<0.025	<0.020	<0.010	<0.020	6.0	<0.025	0.029	<0.025	<0.025	<0.025	<0.025	<0.025	10.1	21.1	12	12	7	2	0.3
SLR-TB-02	11221	Upper BIF	<0.025	<0.020	<0.010	<0.020	17.2	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	8	11.7	16	<5	<5	<0.2	0.2
SLR-TB-03	11222	Lower BIF	<0.025	<0.020	<0.010	<0.020	15.4	<0.025	<0.025	<0.025	<0.025	<0.025	0.098	<0.025	7.9	7.7	12	<5	<5	<0.2	0.2
SLR-TB-04	11223	Lower BIF - red in colour	<0.025	<0.020	<0.010	<0.020	6.6	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	8.1	17.1	20	<5	5	1	0.3
SLR-TB-05	11224	VW Ore Zone	<0.025	<0.020	<0.010	<0.020	3.1	<0.025	<0.025	<0.025	<0.025	<0.025	0.070	<0.025	8.1	12.7	60	<5	<5	0.3	0.5
SLR-TB-06	11225	Top Cut Ore	<0.025	<0.020	<0.010	<0.020	<0.2	<0.025	0.026	<0.025	<0.025	<0.025	<0.025	<0.025	8.2	11.8	64	<5	<5	<0.2	0.2
SLR-TB-07	11226	Lower Ore body	<0.025	<0.020	<0.010	<0.020	<0.2	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	8.1	12.5	60	<5	<5	<0.2	0.2
SLR-TB-08	11227	Pebble bed in calcareous clay	<0.025	<0.020	<0.010	<0.020	4.7	<0.025	0.042	<0.025	<0.025	<0.025	0.102	<0.025	7.9	11.7	52	<5	<5	<0.2	0.5
SLR-TB-09	11228	Pebble bed in red calcareous clay	<0.025	<0.020	<0.010	<0.020	3.6	<0.025	0.060	<0.025	<0.025	<0.025	0.060	<0.025	8.4	14.7	64	<5	<5	0.3	0.5
SLR-TB-10	11229	Red clay	0.072	<0.020	<0.010	<0.020	1.3	<0.025	0.065	<0.025	<0.025	<0.025	0.061	<0.025	8.2	16.8	80	<5	6	0.4	0.7
SLR-TB-11	11230	Lower BIF	0.124	<0.020	<0.010	<0.020	0.7	<0.025	0.026	<0.025	<0.025	<0.025	0.041	<0.025	8.5	13.6	56	<5	<5	<0.2	0.7
SLR-TB-12	11231	Red clay	<0.025	<0.020	<0.010	<0.020	0.7	<0.025	0.061	<0.025	<0.025	<0.025	<0.025	<0.025	8.1	16.7	68	<5	6	0.5	0.9
SLR-TB-13	11232	White Clay	<0.025	<0.020	<0.010	<0.020	10.8	<0.025	0.027	<0.025	0.027	<0.025	<0.025	<0.025	7.8	10.9	32	<5	6	1.6	0.8
SLR-TB-14	11233	White gravel bed	<0.025	<0.020	<0.010	<0.020	9.0	<0.025	0.049	0.042	<0.025	<0.025	0.116	<0.025	7.8	11	52	<5	5	1.2	0.3
SLR-TB-15	11234	Red Iron Calcareous Sand	<0.025	<0.020	<0.010	<0.020	19.2	<0.025	0.062	<0.025	0.029	<0.025	<0.025	<0.025	9	15.1	64	<5	<5	2.4	0.5
SLR-TB-16	11235	Pebbly Calcrete	<0.025	<0.020	<0.010	<0.020	13.9	<0.025	0.076	<0.025	<0.025	<0.025	<0.025	<0.025	8	12.7	68	5	<5	3.4	0.5
SLR-TB-17	11236	Iron rich Calcareous Sands	<0.025	<0.020	<0.010	<0.020	19.9	<0.025	0.083	<0.025	<0.025	<0.025	0.211	<0.025	8.2	15.8	72	<5	<5	2.1	0.6
SLR-TB-18	11237	Pebbly Calcrete	<0.025	<0.020	<0.010	<0.020	14.8	<0.025	0.081	<0.025	<0.025	<0.025	0.127	<0.025	8.2	16.3	68	<5	<5	2.8	0.5
SLR-TB-19	11238	Red Kalahari Sands	0.207	<0.020	<0.010	<0.020	21	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	7.7	6.5	40	<5	11	0.5	0.2
SLR-TB-20	11239	Calcrete	<0.025	<0.020	<0.010	<0.020	12.4	<0.025	0.080	<0.025	<0.025	<0.025	<0.025	<0.025	8.1	24.9	60	26	26	18	0.4
SLR-TB-21	11240	Pebbly Calcrete	<0.025	<0.020	<0.010	<0.020	11.3	<0.025	0.049	<0.025	<0.025	<0.025	<0.025	<0.025	8.2	24.9	68	6	<5	5.6	0.4
SLR-TB-22	11241	Tailings Sample	<0.025	<0.020	<0.010	<0.020	4.1	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	8.3	172	92	<5	33	2	0.4
SLR-TB-23	11242	Dolomite	<0.025	<0.020	<0.010	<0.020	<0.2	<0.025	0.030	<0.025	<0.025	<0.025	0.039	<0.025	8.9	0.7	96	<5	<5	<0.2	0.4

5 POTENTIAL DRAINAGE AND PIT LAKE QUALITY

This section considers the potential quality of seepage from the mined lithologies at the Tshipi Borwa Mine and the resulting quality of water in the pit lake. Note that the Tshipi mine plan is not clear on the method and scheduling of backfill placement. Therefore, the relative proportions of lithologies making up the backfill are unknown. The backfill material balance has also not been finalised and it also not clear whether or not the Tshipi pit(s) will include a void that may fill with water. This section presents modelled drainage qualities and a general indication of pit lake quality and associated environmental risk.

5.1 MODELLED DRAINAGE QUALITY

Leach tests are an indicator of potential drainage quality from the sampled lithologies. However, the solution to solid ratio in the leach tests is generally higher than field conditions. The moisture content of each material under unsaturated conditions has not been determined. This assessment assumes field moisture content of 10% by weight as an initial estimate for geochemical modelling. This is equivalent to solution: solid ratio of 1:10. The PHREEQC equilibrium geochemical modelling code (Parkhurst and Appelo 1999) was used to simulate the resulting solution composition at this ratio. A full table of results is presented in Appendix B.

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. This includes facilities that do not yet exist, such as the Tshipi Borwa pit backfill. General assumptions include:

- <u>The water chemistries used in the modelling are representative of input sources</u>. It is not possible to model water quality without this essential assumption. Input water qualities are derived from the results of the geochemical characterisation programme. Therefore, the water compositions used in the modelling do not represent actual water samples but “theoretical” compositions;
- <u>Predicting field-scale leaching from lab-scale leach tests is an approximation</u>. Metal leaching at the field scale is variable through time and controlled by factors not fully applied at the lab scale. These factors include temperature, nature of the leaching solution, the solution to solid ratio, solution-solid contact time, particle size of the solid, and so on;
- <u>Modelled waters are in full thermodynamic equilibrium.</u> Equilibrium is the computational basis of PHREEQC. Equilibrium is unlikely to be the case for all chemical components throughout all mine waters. However, geochemical research has shown that assuming equilibrium conditions may usefully describe the composition of natural and mine waters; and
- <u>The PHREEQC model appropriately simulates chemical reactions and contains the appropriate thermodynamic constants</u>.

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

5.2 PIT LAKE QUALITY

The modelled drainage qualities presented in this report are a starting point for determining the quality of water in the backfilled pit. The composition of interstitial water in the backfill will depend on the relative proportion of lithologies making up the backfill. At this stage, it is not clear whether a final void will exist after backfilling. Should a final void develop, the pit lake water quality will depend on the interaction of rainfall on the exposed pit faces, inflowing groundwater and inflowing interstitial water from the backfill.

As a preliminary indicator, pit lake water quality may lie within the range of modelled drainage results presented in this report (Table 5-1). Therefore, water in the pit lake may have the following general characteristics:

- Neutral to alkaline pH;
- Saline, with Na, Cl and SO_4 as the dominant ions;
- Low in dissolved iron and manganese (although Fe-Mn colloidal material may be present); and
- Low concentrations of trace elements.

Specific prediction of water quality under assumed scenarios can be made if a detailed schedule of pit backfill tonnages/volumes and locations is available.

TABLE 5-1: ESTIMATED RANGES DRAINAGE QUALITY

Parameter	Unit	Minimum	Maximum
pH	pH Unit	6.6	9.6
Na	mg/L	78.87	1656.64
K	mg/L	39.43	879.08
Ca	mg/L	3.26	528.07
Mg	mg/L	19.33	552.36
Fe	mg/L	<0.01	<0.01
Mn	mg/L	0.04	5.05
Al	mg/L	0.01	3.95
F	mg/L	3.16	27.61
Cl	mg/L	197.17	2230.53
S(6)	mg/L	163.81	1300.42
Alkalinity	mg/L	89.37	1836.55
Sb	mg/L	0.39	0.39
As	mg/L	0.39	0.91
Ba	mg/L	0.01	0.99

Parameter	Unit	Minimum	Maximum
Be	mg/L	0.04	0.99
Cd	mg/L	0.03	0.20
Cr	mg/L	0.01	0.99
Co	mg/L	0.35	0.99
Cu	mg/L	0.10	0.62
Pb	mg/L	0.08	0.22
Hg	mg/L	<0.01	<0.01
Mo	mg/L	1.18	1.18
Ni	mg/L	0.13	0.99
Se	mg/L	0.79	0.79
Ag	mg/L	0.99	0.99
Sr	mg/L	0.99	3.27
Ti	mg/L	<0.01	<0.01
V	mg/L	1.07	1.18
Zn	mg/L	0.07	3.87

5.3 PIT LAKE ENVIRONMENTAL RISK

SLR developed an analytical water balance model for pit lake formation at the Tshipi Borwa Mine considering the expected pit geometry, estimated groundwater inflow rates and assumed hydrologic input parameters.

It was estimated that the final pit lake elevation at the Tshipi Borwa Mine will reach an equilibrium level at approximately 60 - 70 mbgl after closure. Analytical modelling indicated that it will take more than 400 years for the pit lake water levels to reach this equilibrium elevation *if the pit is not backfilled*. Depending on the extent of backfilling, pit lake levels may reach equilibrium in less time than 400 years. Nevertheless, until equilibrium levels are reached, the Tshipi Borwa Mine pit lake will remain a groundwater sink. Groundwater will flow towards the pit lake from all directions and water in the lake will not recharge the aquifer system.

In addition to the leaching of trace elements indicated by the leach tests presented in this report, the pit lake water will be prone to salinization due to the high rate of evaporation in the Tshipi Borwa area. However, since groundwater flow will be towards the pit, water in the pit is not expected to impact on local groundwater quality.

A detailed pit water balance is required to determine whether evaporation will permanently keep the equilibrium pit lake level lower than the surrounding groundwater level. Should the equilibrium level be similar to or higher than the surrounding groundwater level, saline water from the pit will enter local aquifers and impact on groundwater quality.

6 CONCLUSION

The geochemical assessment undertaken and presented in the report has characterised the material likely to be used to backfill the open pit at the Tshipi Borwa Manganese mine near Hotazel in the Northern Cape.

Samples collected for static analytical tests consisted of all lithologies likely to be mined at the site and included ore-body material, non-ore body material and a tailings sample generated in the mine laboratory / pilot plant.

Acid Base Accounting (ABA) results indicate that the potential to generate acid was negligible in all 23 samples tested.

The elemental composition of the samples is consistent with the lithologies. The tailings sample was shown to comprise almost 50% manganese. Most of the samples contain significant proportions of calcium. Several trace elements of potential environmental concern are elevated above average crustal abundances.

SPLP leach tests indicate two leachable elements that may be of concern in mine drainage: arsenic (As) and barium (Ba). Elevated concentrations of iron (Fe) and manganese (Mn) were recorded in a number of leachates.

Potential water quality that could emanate from the backfill material was simulated using the PHREEQC equilibrium geochemical modelling code (Parkhurst and Appelo 1999). These provide a starting point for the estimation of interstitial water quality in pit backfill and pit lake water quality. Based on these preliminary results, water in the pit lake may have the following general characteristics:

- Neutral to alkaline pH;
- Saline, with Na, Cl and SO_4 as the dominant ions;
- Low in dissolved iron and manganese (although Fe-Mn colloidal material may be present); and
- Low concentrations of trace elements.

However, aquifer characteristics and analytical modelling conducted by SLR indicate that the pit, if not backfilled, will take of the order of 400 years to reach its equilibrium level. During this time, local groundwater will flow towards the pit and pit lake water will have no impact on surrounding groundwater quality.

7 RECOMMENDATIONS

Based on the assessment described in this report, SLR recommends the following:

- Specific prediction of the water quality in the backfill and the pit lake should be undertaken once a detailed schedule of pit backfill tonnages/volumes and locations is available; and
- These projections of water quality in the pit lake should be considered in mine closure planning.

Jenny Ellerton	**Natasha Daly**	**Terry Harck**
(Report Author)	**(Project Manager)**	**(Project Reviewer)**

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APPENDIX A: LABORATORY CERTIFICATES

WATERLAB (PTY) LTD

CERTIFICATE OF ANALYSES

ICP-OES - SCAN

Date received:	2013/07/08	**Date Completed:**	2013/08/12
Project number:	139	**Report number:**	40803

Client name:	SLR Consulting (Africa) (Pty) Ltd	**Contact person:**	Jenny Ellerton
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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
SLR-TB-01	11220	<0.025	<0.100	<0.100	<0.400	<0.010	<0.040
SLR-TB-02	11221	<0.025	<0.100	<0.100	<0.400	0.010	0.040
SLR-TB-03	11222	<0.025	<0.100	<0.100	<0.400	<0.010	<0.040
SLR-TB-04	11223	<0.025	<0.100	<0.100	<0.400	<0.010	<0.040
SLR-TB-05	11224	<0.025	<0.100	<0.100	<0.400	<0.010	<0.040
SLR-TB-06	11225	<0.025	<0.100	<0.100	<0.400	<0.010	<0.040
SLR-TB-07	11226	<0.025	<0.100	<0.100	<0.400	<0.010	<0.040
SLR-TB-08	11227	<0.025	<0.100	<0.100	<0.400	<0.010	<0.040
SLR-TB-09	11228	<0.025	<0.100	<0.100	<0.400	<0.010	<0.040
SLR-TB-10	11229	<0.025	<0.100	<0.100	<0.400	0.019	0.076
SLR-TB-11	11230	<0.025	<0.100	<0.100	<0.400	0.023	0.092
SLR-TB-12	11231	<0.025	<0.100	<0.100	<0.400	<0.010	<0.040
SLR-TB-13	11232	<0.025	<0.100	<0.100	<0.400	<0.010	<0.040
SLR-TB-14	11233	<0.025	<0.100	<0.100	<0.400	<0.010	<0.040
SLR-TB-15	11234	<0.025	<0.100	<0.100	<0.400	<0.010	<0.040
SLR-TB-16	11235	<0.025	<0.100	<0.100	<0.400	<0.010	<0.040
SLR-TB-17	11236	<0.025	<0.100	<0.100	<0.400	0.013	0.052
SLR-TB-18	11237	<0.025	<0.100	<0.100	<0.400	0.012	0.048
SLR-TB-19	11238	<0.025	<0.100	1.72	6.88	0.022	0.088
SLR-TB-20	11239	<0.025	<0.100	<0.100	<0.400	<0.010	<0.040
SLR-TB-21	11240	<0.025	<0.100	0.147	0.588	<0.010	<0.040
SLR-TB-22	11241	<0.025	<0.100	<0.100	<0.400	<0.010	<0.040
SLR-TB-23	11242	<0.025	<0.100	<0.100	<0.400	0.014	0.056

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
SLR-TB-01	11220	0.040	0.160	<0.025	<0.100	<0.025	<0.100
SLR-TB-02	11221	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-03	11222	0.060	0.240	0.072	0.288	<0.025	<0.100
SLR-TB-04	11223	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-05	11224	0.087	0.348	0.079	0.316	<0.025	<0.100
SLR-TB-06	11225	0.050	0.200	<0.025	<0.100	<0.025	<0.100
SLR-TB-07	11226	0.102	0.408	<0.025	<0.100	<0.025	<0.100
SLR-TB-08	11227	0.082	0.328	0.105	0.420	<0.025	<0.100
SLR-TB-09	11228	0.074	0.296	0.139	0.556	<0.025	<0.100
SLR-TB-10	11229	0.120	0.480	0.134	0.536	<0.025	<0.100
SLR-TB-11	11230	0.074	0.296	0.096	0.384	<0.025	<0.100
SLR-TB-12	11231	0.073	0.292	<0.025	<0.100	<0.025	<0.100
SLR-TB-13	11232	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-14	11233	0.064	0.256	0.173	0.692	<0.025	<0.100
SLR-TB-15	11234	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-16	11235	<0.025	<0.100	0.042	0.168	<0.025	<0.100
SLR-TB-17	11236	0.146	0.584	1.21	4.86	<0.025	<0.100
SLR-TB-18	11237	0.107	0.428	1.06	4.25	<0.025	<0.100
SLR-TB-19	11238	0.053	0.212	0.027	0.108	<0.025	<0.100
SLR-TB-20	11239	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-21	11240	<0.025	<0.100	0.028	0.112	<0.025	<0.100
SLR-TB-22	11241	0.126	0.504	<0.025	<0.100	<0.025	<0.100
SLR-TB-23	11242	0.129	0.516	1.07	4.26	<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
SLR-TB-01	11220	<0.025	<0.100	14	56	<0.005	<0.020
SLR-TB-02	11221	<0.025	<0.100	12	48	<0.005	<0.020
SLR-TB-03	11222	<0.025	<0.100	10	40	<0.005	<0.020
SLR-TB-04	11223	<0.025	<0.100	14	56	<0.005	<0.020
SLR-TB-05	11224	<0.025	<0.100	9	36	<0.005	<0.020
SLR-TB-06	11225	<0.025	<0.100	9	36	<0.005	<0.020
SLR-TB-07	11226	<0.025	<0.100	10	40	<0.005	<0.020
SLR-TB-08	11227	<0.025	<0.100	6	24	<0.005	<0.020
SLR-TB-09	11228	<0.025	<0.100	13	52	<0.005	<0.020
SLR-TB-10	11229	<0.025	<0.100	10	40	<0.005	<0.020
SLR-TB-11	11230	<0.025	<0.100	10	40	<0.005	<0.020
SLR-TB-12	11231	<0.025	<0.100	11	44	<0.005	<0.020
SLR-TB-13	11232	<0.025	<0.100	5	20	<0.005	<0.020
SLR-TB-14	11233	<0.025	<0.100	7	28	<0.005	<0.020
SLR-TB-15	11234	<0.025	<0.100	11	44	<0.005	<0.020
SLR-TB-16	11235	<0.025	<0.100	12	48	<0.005	<0.020
SLR-TB-17	11236	<0.025	<0.100	12	48	<0.005	<0.020
SLR-TB-18	11237	<0.025	<0.100	11	44	<0.005	<0.020
SLR-TB-19	11238	<0.025	<0.100	5	20	<0.005	<0.020
SLR-TB-20	11239	<0.025	<0.100	14	56	<0.005	<0.020
SLR-TB-21	11240	<0.025	<0.100	10	40	<0.005	<0.020
SLR-TB-22	11241	<0.025	<0.100	21	84	<0.005	<0.020
SLR-TB-23	11242	<0.025	<0.100	10	40	<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
SLR-TB-01	11220	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-02	11221	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-03	11222	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-04	11223	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-05	11224	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-06	11225	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-07	11226	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-08	11227	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-09	11228	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-10	11229	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100

SLR-TB-11	11230	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-12	11231	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-13	11232	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-14	11233	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-15	11234	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-16	11235	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-17	11236	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-18	11237	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-19	11238	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-20	11239	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-21	11240	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-22	11241	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-23	11242	<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
SLR-TB-01	11220	<0.025	<0.100	1.1	4.3	<0.025	<0.100
SLR-TB-02	11221	0.031	0.124	<1.0	<4.0	<0.025	<0.100
SLR-TB-03	11222	0.478	1.91	<1.0	<4.0	<0.025	<0.100
SLR-TB-04	11223	<0.025	<0.100	<1.0	<4.0	<0.025	<0.100
SLR-TB-05	11224	<0.025	<0.100	<1.0	<4.0	<0.025	<0.100
SLR-TB-06	11225	<0.025	<0.100	<1.0	<4.0	<0.025	<0.100
SLR-TB-07	11226	<0.025	<0.100	<1.0	<4.0	<0.025	<0.100
SLR-TB-08	11227	<0.025	<0.100	1.3	5.1	<0.025	<0.100
SLR-TB-09	11228	<0.025	<0.100	1.0	4.0	<0.025	<0.100
SLR-TB-10	11229	<0.025	<0.100	1.4	5.5	<0.025	<0.100
SLR-TB-11	11230	<0.025	<0.100	<1.0	<4.0	<0.025	<0.100
SLR-TB-12	11231	0.041	0.164	1.3	5.3	<0.025	<0.100
SLR-TB-13	11232	0.045	0.180	1.8	7.0	<0.025	<0.100
SLR-TB-14	11233	0.037	0.148	1.3	5.1	<0.025	<0.100
SLR-TB-15	11234	0.038	0.152	1.6	6.3	<0.025	<0.100
SLR-TB-16	11235	0.069	0.276	1.8	7.1	<0.025	<0.100
SLR-TB-17	11236	<0.025	<0.100	1.4	5.4	<0.025	<0.100
SLR-TB-18	11237	<0.025	<0.100	1.3	5.0	<0.025	<0.100
SLR-TB-19	11238	1.51	6.03	4.1	16.4	<0.025	<0.100
SLR-TB-20	11239	<0.025	<0.100	3.0	11.9	<0.025	<0.100
SLR-TB-21	11240	0.196	0.784	1.9	7.7	<0.025	<0.100
SLR-TB-22	11241	<0.025	<0.100	1.1	4.2	<0.025	<0.100
SLR-TB-23	11242	<0.025	<0.100	<1.0	<4.0	<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
SLR-TB-01	11220	10	40	<0.025	<0.100	<0.025	<0.100
SLR-TB-02	11221	6	24	<0.025	<0.100	<0.025	<0.100
SLR-TB-03	11222	<2	<8	0.128	0.512	<0.025	<0.100
SLR-TB-04	11223	7	28	<0.025	<0.100	<0.025	<0.100
SLR-TB-05	11224	6	24	<0.025	<0.100	<0.025	<0.100
SLR-TB-06	11225	8	32	0.119	0.476	<0.025	<0.100
SLR-TB-07	11226	8	32	0.090	0.360	<0.025	<0.100
SLR-TB-08	11227	4	16	<0.025	<0.100	<0.025	<0.100
SLR-TB-09	11228	6	24	<0.025	<0.100	<0.025	<0.100
SLR-TB-10	11229	6	24	<0.025	<0.100	<0.025	<0.100
SLR-TB-11	11230	8	32	<0.025	<0.100	<0.025	<0.100
SLR-TB-12	11231	6	24	<0.025	<0.100	<0.025	<0.100
SLR-TB-13	11232	3	12	<0.025	<0.100	<0.025	<0.100
SLR-TB-14	11233	4	16	<0.025	<0.100	<0.025	<0.100
SLR-TB-15	11234	6	24	<0.025	<0.100	<0.025	<0.100
SLR-TB-16	11235	7	28	<0.025	<0.100	<0.025	<0.100
SLR-TB-17	11236	6	24	<0.025	<0.100	<0.025	<0.100
SLR-TB-18	11237	7	28	<0.025	<0.100	<0.025	<0.100
SLR-TB-19	11238	3	12	<0.025	<0.100	<0.025	<0.100
SLR-TB-20	11239	8	32	<0.025	<0.100	<0.025	<0.100
SLR-TB-21	11240	5	20	<0.025	<0.100	<0.025	<0.100
SLR-TB-22	11241	14	56	<0.025	<0.100	<0.025	<0.100
SLR-TB-23	11242	17	68	<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
SLR-TB-01	11220	13	52	<0.025	<0.100	<0.025	<0.100
SLR-TB-02	11221	3	12	<0.025	<0.100	<0.025	<0.100
SLR-TB-03	11222	3	12	<0.025	<0.100	<0.025	<0.100
SLR-TB-04	11223	9	36	<0.025	<0.100	<0.025	<0.100
SLR-TB-05	11224	7	28	<0.025	<0.100	<0.025	<0.100
SLR-TB-06	11225	<2	<8	<0.025	<0.100	<0.025	<0.100
SLR-TB-07	11226	3	12	<0.025	<0.100	<0.025	<0.100
SLR-TB-08	11227	10	40	<0.025	<0.100	<0.025	<0.100
SLR-TB-09	11228	8	32	<0.025	<0.100	<0.025	<0.100
SLR-TB-10	11229	14	56	<0.025	<0.100	0.072	0.288
SLR-TB-11	11230	2	8	<0.025	<0.100	0.124	0.496
SLR-TB-12	11231	12	48	<0.025	<0.100	<0.025	<0.100
SLR-TB-13	11232	9	36	<0.025	<0.100	<0.025	<0.100
SLR-TB-14	11233	7	28	<0.025	<0.100	<0.025	<0.100
SLR-TB-15	11234	9	36	<0.025	<0.100	<0.025	<0.100
SLR-TB-16	11235	9	36	<0.025	<0.100	<0.025	<0.100
SLR-TB-17	11236	14	56	<0.025	<0.100	<0.025	<0.100
SLR-TB-18	11237	13	52	<0.025	<0.100	<0.025	<0.100
SLR-TB-19	11238	2	8	<0.025	<0.100	0.207	0.828
SLR-TB-20	11239	42	168	<0.025	<0.100	<0.025	<0.100
SLR-TB-21	11240	19	76	<0.025	<0.100	<0.025	<0.100
SLR-TB-22	11241	10	40	<0.025	<0.100	<0.025	<0.100
SLR-TB-23	11242	4	16	<0.025	<0.100	<0.025	<0.100

Sample Id	Sample number	Pb	Pb	Sb	Sb
		mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.020	<0.080	<0.010	<0.040
SLR-TB-01	11220	<0.020	<0.080	<0.010	<0.040
SLR-TB-02	11221	<0.020	<0.080	<0.010	<0.040
SLR-TB-03	11222	<0.020	<0.080	<0.010	<0.040
SLR-TB-04	11223	<0.020	<0.080	<0.010	<0.040
SLR-TB-05	11224	<0.020	<0.080	<0.010	<0.040
SLR-TB-06	11225	<0.020	<0.080	<0.010	<0.040
SLR-TB-07	11226	<0.020	<0.080	<0.010	<0.040
SLR-TB-08	11227	<0.020	<0.080	<0.010	<0.040

SLR-TB-09	11228	<0.020	<0.080	<0.010	<0.040
SLR-TB-10	11229	<0.020	<0.080	<0.010	<0.040
SLR-TB-11	11230	<0.020	<0.080	<0.010	<0.040
SLR-TB-12	11231	<0.020	<0.080	<0.010	<0.040
SLR-TB-13	11232	<0.020	<0.080	<0.010	<0.040
SLR-TB-14	11233	<0.020	<0.080	<0.010	<0.040
SLR-TB-15	11234	<0.020	<0.080	<0.010	<0.040
SLR-TB-16	11235	<0.020	<0.080	<0.010	<0.040
SLR-TB-17	11236	<0.020	<0.080	<0.010	<0.040
SLR-TB-18	11237	<0.020	<0.080	<0.010	<0.040
SLR-TB-19	11238	<0.020	<0.080	<0.010	<0.040
SLR-TB-20	11239	<0.020	<0.080	<0.010	<0.040
SLR-TB-21	11240	<0.020	<0.080	<0.010	<0.040
SLR-TB-22	11241	<0.020	<0.080	<0.010	<0.040
SLR-TB-23	11242	<0.020	<0.080	<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
SLR-TB-01	11220	<0.020	<0.080	6.0	24	<0.025	<0.100
SLR-TB-02	11221	<0.020	<0.080	17.2	69	<0.025	<0.100
SLR-TB-03	11222	<0.020	<0.080	15.4	61	<0.025	<0.100
SLR-TB-04	11223	<0.020	<0.080	6.6	26	<0.025	<0.100
SLR-TB-05	11224	<0.020	<0.080	3.1	12.5	<0.025	<0.100
SLR-TB-06	11225	<0.020	<0.080	<0.2	<0.8	<0.025	<0.100
SLR-TB-07	11226	<0.020	<0.080	<0.2	<0.8	<0.025	<0.100
SLR-TB-08	11227	<0.020	<0.080	4.7	18.8	<0.025	<0.100
SLR-TB-09	11228	<0.020	<0.080	3.6	14.6	<0.025	<0.100
SLR-TB-10	11229	<0.020	<0.080	1.3	5.2	<0.025	<0.100
SLR-TB-11	11230	<0.020	<0.080	0.7	2.8	<0.025	<0.100
SLR-TB-12	11231	<0.020	<0.080	0.7	3.0	<0.025	<0.100
SLR-TB-13	11232	<0.020	<0.080	10.8	43	<0.025	<0.100
SLR-TB-14	11233	<0.020	<0.080	9.0	36	<0.025	<0.100
SLR-TB-15	11234	<0.020	<0.080	19.2	77	<0.025	<0.100
SLR-TB-16	11235	<0.020	<0.080	13.9	55	<0.025	<0.100
SLR-TB-17	11236	<0.020	<0.080	19.9	79	<0.025	<0.100
SLR-TB-18	11237	<0.020	<0.080	14.8	59	<0.025	<0.100
SLR-TB-19	11238	<0.020	<0.080	21	84	<0.025	<0.100
SLR-TB-20	11239	<0.020	<0.080	12.4	50	<0.025	<0.100
SLR-TB-21	11240	<0.020	<0.080	11.3	45	<0.025	<0.100
SLR-TB-22	11241	<0.020	<0.080	4.1	16.4	<0.025	<0.100
SLR-TB-23	11242	<0.020	<0.080	<0.2	<0.8	<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
SLR-TB-01	11220	0.029	0.116	<0.025	<0.100	<0.025	<0.100
SLR-TB-02	11221	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-03	11222	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-04	11223	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-05	11224	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-06	11225	0.026	0.104	<0.025	<0.100	<0.025	<0.100
SLR-TB-07	11226	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-08	11227	0.042	0.168	<0.025	<0.100	<0.025	<0.100
SLR-TB-09	11228	0.060	0.240	<0.025	<0.100	<0.025	<0.100
SLR-TB-10	11229	0.065	0.260	<0.025	<0.100	<0.025	<0.100
SLR-TB-11	11230	0.026	0.104	<0.025	<0.100	<0.025	<0.100
SLR-TB-12	11231	0.061	0.244	<0.025	<0.100	<0.025	<0.100
SLR-TB-13	11232	0.027	0.108	<0.025	<0.100	0.027	0.108
SLR-TB-14	11233	0.049	0.196	0.042	0.168	<0.025	<0.100
SLR-TB-15	11234	0.062	0.248	<0.025	<0.100	0.029	0.116
SLR-TB-16	11235	0.076	0.304	<0.025	<0.100	<0.025	<0.100
SLR-TB-17	11236	0.083	0.332	<0.025	<0.100	<0.025	<0.100
SLR-TB-18	11237	0.081	0.324	<0.025	<0.100	<0.025	<0.100
SLR-TB-19	11238	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-20	11239	0.080	0.320	<0.025	<0.100	<0.025	<0.100
SLR-TB-21	11240	0.049	0.196	<0.025	<0.100	<0.025	<0.100
SLR-TB-22	11241	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-23	11242	0.030	0.120	<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
SLR-TB-01	11220	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-02	11221	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-03	11222	<0.025	<0.100	0.098	0.392	<0.025	<0.100
SLR-TB-04	11223	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-05	11224	<0.025	<0.100	0.070	0.280	<0.025	<0.100
SLR-TB-06	11225	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-07	11226	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-08	11227	<0.025	<0.100	0.102	0.408	<0.025	<0.100
SLR-TB-09	11228	<0.025	<0.100	0.060	0.240	<0.025	<0.100
SLR-TB-10	11229	<0.025	<0.100	0.061	0.244	<0.025	<0.100
SLR-TB-11	11230	<0.025	<0.100	0.041	0.164	<0.025	<0.100
SLR-TB-12	11231	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-13	11232	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-14	11233	<0.025	<0.100	0.116	0.464	<0.025	<0.100
SLR-TB-15	11234	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-16	11235	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-17	11236	<0.025	<0.100	0.211	0.844	<0.025	<0.100
SLR-TB-18	11237	<0.025	<0.100	0.127	0.508	<0.025	<0.100
SLR-TB-19	11238	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-20	11239	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-21	11240	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-22	11241	<0.025	<0.100	<0.025	<0.100	<0.025	<0.100
SLR-TB-23	11242	<0.025	<0.100	0.039	0.156	<0.025	<0.100

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CERTIFICATE OF ANALYSES
TCLP / ACID RAIN / DISTILLED WATER EXTRACTIONS

Date received: 2013-07-08
Project number: 139
Report number: 40803
Date completed: 2013-08-12
Order number: 5036 Tshipi Borwa

Client name: SLR Consulting (Africa) (Pty) Ltd
Address: PO Box 1596, Cramerview, 2060
Telephone: 011 467 0945
Facsimile: 011 467 0978
Contact person: Jenny Ellerton
Email: jellerton@slrconsulting.com

Analyses	Sample Identification:			
	SLR-TB-01		SLR-TB-02	
Sample number	11220		11221	
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	10.1		8.0	
Electrical Conductivity in mS/m at 25˚C	21.1		11.7	
Units	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Alkalinity as $CaCO_3$	12	48	16	64
Chloride as Cl	12	48	<5	<20
Sulphate as SO_4	7	28	<5	<20
Nitrate as N	2.0	8.0	<0.2	<0.8
Fluoride as F	0.3	1.2	0.2	0.8
ICP-OES Scan	See attached report 40803 ICP DW		See attached report 40803 ICP DW	
Acid Base Accounting	See attached report 40803 ABA		See attached report 40803 ABA	
Net Acid Generation	See attached report 40803 NAG		See attached report 40803 NAG	
Sulphur Speciation	See attached report 40803 SS		See attached report 40803 SS	
Inorganic Carbon [s]	See attached report 40803 Carbon		See attached report 40803 Carbon	
X-ray Fluorescence [s]	See attached report 40803 XRF		See attached report 40803 XRF	

E. Botha
Geochemistry Project Manager

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CERTIFICATE OF ANALYSES
TCLP / ACID RAIN / DISTILLED WATER EXTRACTIONS

Date received: 2013-07-08
Project number: 139
Report number: 40803
Date completed: 2013-08-12
Order number: 5036 Tshipi Borwa

Client name: SLR Consulting (Africa) (Pty) Ltd
Address: PO Box 1596, Cramerview, 2060
Telephone: 011 467 0945
Facsimile: 011 467 0978
Contact person: Jenny Ellerton
Email: jellerton@slrconsulting.com

Analyses	Sample Identification:			
	SLR-TB-03		SLR-TB-04	
Sample number	11222		11223	
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	
Electrical Conductivity in mS/m at 25˚C	7.7		17.1	
Units	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Alkalinity as $CaCO_3$	12	48	20	80
Chloride as Cl	<5	<20	<5	<20
Sulphate as SO_4	<5	<20	5	20
Nitrate as N	<0.2	<0.8	1.0	4.0
Fluoride as F	0.2	0.8	0.3	1.2
ICP-OES Scan	See attached report 40803 ICP DW		See attached report 40803 ICP DW	
Acid Base Accounting	See attached report 40803 ABA		See attached report 40803 ABA	
Net Acid Generation	See attached report 40803 NAG		See attached report 40803 NAG	
Sulphur Speciation	See attached report 40803 SS		See attached report 40803 SS	
Inorganic Carbon [s]	See attached report 40803 Carbon		See attached report 40803 Carbon	
X-ray Fluorescence [s]	See attached report 40803 XRF		---	

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CERTIFICATE OF ANALYSES
TCLP / ACID RAIN / DISTILLED WATER EXTRACTIONS

Date received: 2013-07-08
Project number: 139
Report number: 40803
Date completed: 2013-08-12
Order number: 5036 Tshipi Borwa

Client name: SLR Consulting (Africa) (Pty) Ltd
Address: PO Box 1596, Cramerview, 2060
Telephone: 011 467 0945
Facsimile: 011 467 0978
Contact person: Jenny Ellerton
Email: jellerton@slrconsulting.com

Analyses	Sample Identification:			
	SLR-TB-05		SLR-TB-06	
Sample number	**11224**		**11225**	
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	8.1		8.2	
Electrical Conductivity in mS/m at 25˚C	12.7		11.8	
Units	**mg/ℓ**	**mg/kg**	**mg/ℓ**	**mg/kg**
Alkalinity as $CaCO_3$	60	240	64	256
Chloride as Cl	<5	<20	<5	<20
Sulphate as SO_4	<5	<20	<5	<20
Nitrate as N	0.3	1.2	<0.2	<0.8
Fluoride as F	0.5	2.0	0.2	0.8
ICP-OES Scan	See attached report 40803 ICP DW		See attached report 40803 ICP DW	
Acid Base Accounting	See attached report 40803 ABA		See attached report 40803 ABA	
Net Acid Generation	See attached report 40803 NAG		See attached report 40803 NAG	
Sulphur Speciation	See attached report 40803 SS		See attached report 40803 SS	
Inorganic Carbon [s]	See attached report 40803 Carbon		See attached report 40803 Carbon	
X-ray Fluorescence [s]	See attached report 40803 XRF		---	

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CERTIFICATE OF ANALYSES
TCLP / ACID RAIN / DISTILLED WATER EXTRACTIONS

Date received: 2013-07-08
Project number: 139 **Report number: 40803**
Date completed: 2013-08-12
Order number: 5036 Tshipi Borwa

Client name: SLR Consulting (Africa) (Pty) Ltd
Address: PO Box 1596, Cramerview, 2060
Telephone: 011 467 0945 **Facsimile: 011 467 0978**
Contact person: Jenny Ellerton
Email: jellerton@slrconsulting.com

Analyses	Sample Identification:			
	SLR-TB-07		SLR-TB-08	
Sample number	11226		11227	
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	8.1		7.9	
Electrical Conductivity in mS/m at 25˚C	12.5		11.7	
Units	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Alkalinity as $CaCO_3$	60	240	52	208
Chloride as Cl	<5	<20	<5	<20
Sulphate as SO_4	<5	<20	<5	<20
Nitrate as N	<0.2	<0.8	<0.2	<0.8
Fluoride as F	0.2	0.8	0.5	2.0
ICP-OES Scan	See attached report 40803 ICP DW		See attached report 40803 ICP DW	
Acid Base Accounting	See attached report 40803 ABA		See attached report 40803 ABA	
Net Acid Generation	See attached report 40803 NAG		See attached report 40803 NAG	
Sulphur Speciation	See attached report 40803 SS		See attached report 40803 SS	
Inorganic Carbon [s]	See attached report 40803 Carbon		See attached report 40803 Carbon	
X-ray Fluorescence [s]	See attached report 40803 XRF		---	

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CERTIFICATE OF ANALYSES
TCLP / ACID RAIN / DISTILLED WATER EXTRACTIONS

Date received: 2013-07-08
Project number: 139
Report number: 40803
Date completed: 2013-08-12
Order number: 5036 Tshipi Borwa

Client name: SLR Consulting (Africa) (Pty) Ltd
Address: PO Box 1596, Cramerview, 2060
Telephone: 011 467 0945
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Contact person: Jenny Ellerton
Email: jellerton@slrconsulting.com

Analyses	Sample Identification:			
	SLR-TB-09		SLR-TB-10	
Sample number	11228		11229	
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	8.4		8.2	
Electrical Conductivity in mS/m at 25˚C	14.7		16.8	
Units	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Alkalinity as $CaCO_3$	64	256	80	3.20
Chloride as Cl	<5	<20	<5	<20
Sulphate as SO_4	<5	<20	6	24
Nitrate as N	0.3	1.2	0.4	1.6
Fluoride as F	0.5	2.0	0.7	2.8
ICP-OES Scan	See attached report 40803 ICP DW		See attached report 40803 ICP DW	
Acid Base Accounting	See attached report 40803 ABA		See attached report 40803 ABA	
Net Acid Generation	See attached report 40803 NAG		See attached report 40803 NAG	
Sulphur Speciation	See attached report 40803 SS		See attached report 40803 SS	
Inorganic Carbon [s]	See attached report 40803 Carbon		See attached report 40803 Carbon	
X-ray Fluorescence [s]	See attached report 40803 XRF		See attached report 40803 XRF	

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Analyses	Sample Identification:			
	SLR-TB-11		SLR-TB-12	
Sample number	11230		11231	
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	8.5		8.1	
Electrical Conductivity in mS/m at 25˚C	13.6		16.7	
Units	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Alkalinity as $CaCO_3$	56	224	68	272
Chloride as Cl	<5	<20	<5	<20
Sulphate as SO_4	<5	<20	6	24
Nitrate as N	<0.2	<0.8	0.5	2.0
Fluoride as F	0.7	2.8	0.9	3.6
ICP-OES Scan	See attached report 40803 ICP DW		See attached report 40803 ICP DW	
Acid Base Accounting	See attached report 40803 ABA		See attached report 40803 ABA	
Net Acid Generation	See attached report 40803 NAG		See attached report 40803 NAG	
Sulphur Speciation	See attached report 40803 SS		See attached report 40803 SS	
Inorganic Carbon [s]	See attached report 40803 Carbon		See attached report 40803 Carbon	
X-ray Fluorescence [s]	---		---	

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Analyses	Sample Identification:			
	SLR-TB-13		SLR-TB-14	
Sample number	11232		11233	
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	7.8		7.8	
Electrical Conductivity in mS/m at 25˚C	10.9		11.0	
Units	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Alkalinity as $CaCO_3$	32	128	52	208
Chloride as Cl	<5	<20	<5	<20
Sulphate as SO_4	6	24	5	20
Nitrate as N	1.6	6.4	1.2	4.8
Fluoride as F	0.8	3.2	0.3	1.2
ICP-OES Scan	See attached report 40803 ICP DW		See attached report 40803 ICP DW	
Acid Base Accounting	See attached report 40803 ABA		See attached report 40803 ABA	
Net Acid Generation	See attached report 40803 NAG		See attached report 40803 NAG	
Sulphur Speciation	See attached report 40803 SS		See attached report 40803 SS	
Inorganic Carbon [s]	See attached report 40803 Carbon		See attached report 40803 Carbon	
X-ray Fluorescence [s]	See attached report 40803 XRF		---	

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Analyses	Sample Identification:			
	SLR-TB-15		SLR-TB-16	
Sample number	11234		11235	
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	9.0		8.0	
Electrical Conductivity in mS/m at 25˚C	15.1		12.7	
Units	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Alkalinity as $CaCO_3$	64	256	68	272
Chloride as Cl	<5	<20	5	20
Sulphate as SO_4	<5	<20	<5	<20
Nitrate as N	2.4	9.6	3.4	14
Fluoride as F	0.5	2.0	0.5	2.0
ICP-OES Scan	See attached report 40803 ICP DW		See attached report 40803 ICP DW	
Acid Base Accounting	See attached report 40803 ABA		See attached report 40803 ABA	
Net Acid Generation	See attached report 40803 NAG		See attached report 40803 NAG	
Sulphur Speciation	See attached report 40803 SS		See attached report 40803 SS	
Inorganic Carbon [s]	See attached report 40803 Carbon		See attached report 40803 Carbon	
X-ray Fluorescence [s]	---		See attached report 40803 XRF	

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Analyses	Sample Identification:			
	SLR-TB-17		SLR-TB-18	
Sample number	11236		11237	
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	8.2		8.2	
Electrical Conductivity in mS/m at 25˚C	15.8		16.3	
Units	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Alkalinity as $CaCO_3$	72	288	68	272
Chloride as Cl	<5	<20	<5	<20
Sulphate as SO_4	<5	<20	<5	<20
Nitrate as N	2.1	8.4	2.8	11
Fluoride as F	0.6	2.4	0.5	2.0
ICP-OES Scan	See attached report 40803 ICP DW		See attached report 40803 ICP DW	
Acid Base Accounting	See attached report 40803 ABA		See attached report 40803 ABA	
Net Acid Generation	See attached report 40803 NAG		See attached report 40803 NAG	
Sulphur Speciation	See attached report 40803 SS		See attached report 40803 SS	
Inorganic Carbon [s]	See attached report 40803 Carbon		See attached report 40803 Carbon	
X-ray Fluorescence [s]	See attached report 40803 XRF		---	

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Analyses	Sample Identification:			
	SLR-TB-19		SLR-TB-20	
Sample number	11238		11239	
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	7.7		8.1	
Electrical Conductivity in mS/m at 25˚C	6.5		24.9	
Units	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Alkalinity as $CaCO_3$	40	160	60	240
Chloride as Cl	<5	<20	26	104
Sulphate as SO_4	11	44	26	104
Nitrate as N	0.5	2.0	18	72
Fluoride as F	0.2	2.0	0.4	1.6
ICP-OES Scan	See attached report 40803 ICP DW		See attached report 40803 ICP DW	
Acid Base Accounting	See attached report 40803 ABA		See attached report 40803 ABA	
Net Acid Generation	See attached report 40803 NAG		See attached report 40803 NAG	
Sulphur Speciation	See attached report 40803 SS		See attached report 40803 SS	
Inorganic Carbon [s]	See attached report 40803 Carbon		See attached report 40803 Carbon	
X-ray Fluorescence [s]	See attached report 40803 XRF		See attached report 40803 XRF	

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Analyses	Sample Identification:			
	SLR-TB-21		SLR-TB-22	
Sample number	11240		11241	
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	8.2		8.3	
Electrical Conductivity in mS/m at 25˚C	24.9		172	
Units	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Alkalinity as $CaCO_3$	68	272	92	368
Chloride as Cl	6	24	<5	<20
Sulphate as SO_4	<5	<20	33	132
Nitrate as N	5.6	22.4	2.0	8.0
Fluoride as F	0.4	1.6	0.4	1.6
ICP-OES Scan	See attached report 40803 ICP DW		See attached report 40803 ICP DW	
Acid Base Accounting	See attached report 40803 ABA		See attached report 40803 ABA	
Net Acid Generation	See attached report 40803 NAG		See attached report 40803 NAG	
Sulphur Speciation	See attached report 40803 SS		See attached report 40803 SS	
Inorganic Carbon [s]	See attached report 40803 Carbon		See attached report 40803 Carbon	
X-ray Fluorescence [s]	---		See attached report 40803 XRF	

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Analyses	Sample Identification:	
	SLR-TB-23	
Sample number	11242	
TCLP / Acid Rain / Distilled Water / H_2O_2	Distilled Water	
Dry Mass Used (g)	250	
Volume Used (mℓ)	1000	
pH Value at 25˚C	8.9	
Electrical Conductivity in mS/m at 25˚C	0.7	
Units	mg/ℓ	mg/kg
Alkalinity as $CaCO_3$	96	384
Chloride as Cl	<5	<20
Sulphate as SO_4	<5	<20
Nitrate as N	<0.2	<0.8
Fluoride as F	0.4	1.6
ICP-OES Scan	See attached report 40803 ICP DW	
Acid Base Accounting	See attached report 40803 ABA	
Net Acid Generation	See attached report 40803 NAG	
Sulphur Speciation	See attached report 40803 SS	
Inorganic Carbon [s]	See attached report 40803 Carbon	
X-ray Fluorescence [s]	See attached report 40803 XRF	

Please note: The blank was subtracted from all leach results, except pH and Conductivity.

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CERTIFICATE OF ANALYSES
ACID – BASE ACCOUNTING
EPA-600 MODIFIED SOBEK METHOD

Date received: 2013-07-08
Project number: 139
Report number: 40803
Date completed: 2013-08-20
Order number: 5036 Tshipi Borwa

Client name: SLR Consulting (Africa) (Pty) Ltd
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Acid – Base Accounting Modified Sobek (EPA-600)	Sample Identification:				
	SLR-TB-01	SLR-TB-02	SLR-TB-03	SLR-TB-04	SLR-TB-05
Sample Number	**11220**	**11221**	**11222**	**11223**	**11224**
Paste pH	8.0	8.5	8.4	8.4	8.6
Total Sulphur (%) (LECO)	<0.01	<0.01	<0.01	<0.01	<0.01
Acid Potential (AP) (kg/t)	0.313	0.313	0.313	0.313	0.313
Neutralization Potential (NP)	280	66	13	130	167
Nett Neutralization Potential (NNP)	280	66	13	130	167
Neutralising Potential Ratio (NPR) (NP : AP)	897	213	41	417	535
Rock Type	III	III	III	III	III

Acid – Base Accounting Modified Sobek (EPA-600)	Sample Identification:				
	SLR-TB-06	SLR-TB-07	SLR-TB-08	SLR-TB-09	SLR-TB-09
Sample Number	**11225**	**11226**	**11227**	**11228**	**11228D**
Paste pH	8.8	8.5	8.3	8.5	8.5
Total Sulphur (%) (LECO)	<0.01	<0.01	<0.01	<0.01	<0.01
Acid Potential (AP) (kg/t)	0.313	0.313	0.313	0.313	0.313
Neutralization Potential (NP)	146	122	4.26	323	327
Nett Neutralization Potential (NNP)	145	121	3.95	323	326
Neutralising Potential Ratio (NPR) (NP : AP)	466	389	14	1034	1045
Rock Type	III	III	III	III	III

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Project number: 139 **Report number: 40803** **Order number: 5036 Tshipi Borwa**

Client name: SLR Consulting (Africa) (Pty) Ltd **Contact person: Jenny Ellerton**
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Acid – Base Accounting Modified Sobek (EPA-600)	Sample Identification:				
	SLR-TB-10	SLR-TB-11	SLR-TB-12	SLR-TB-13	SLR-TB-14
Sample Number	11229	11230	11231	11232	11233
Paste pH	8.2	8.7	8.2	8.1	8.6
Total Sulphur (%) (LECO)	<0.01	<0.01	<0.01	<0.01	<0.01
Acid Potential (AP) (kg/t)	0.313	0.313	0.313	0.313	0.313
Neutralization Potential (NP)	51	100	74	5.00	5.75
Nett Neutralization Potential (NNP)	51	100	73	4.69	5.43
Neutralising Potential Ratio (NPR) (NP : AP)	163	322	236	16	18
Rock Type	III	III	III	III	III

Acid – Base Accounting Modified Sobek (EPA-600)	Sample Identification:				
	SLR-TB-15	SLR-TB-16	SLR-TB-17	SLR-TB-18	SLR-TB-18
Sample Number	11234	11235	11236	11237	11237D
Paste pH	8.3	8.5	8.4	8.5	8.6
Total Sulphur (%) (LECO)	<0.01	<0.01	<0.01	<0.01	<0.01
Acid Potential (AP) (kg/t)	0.313	0.313	0.313	0.313	0.313
Neutralization Potential (NP)	110	79	106	106	105
Nett Neutralization Potential (NNP)	109	79	106	105	105
Neutralising Potential Ratio (NPR) (NP : AP)	351	254	339	338	337
Rock Type	III	III	III	III	III

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Acid – Base Accounting Modified Sobek (EPA-600)	Sample Identification:					
	SLR-TB-19	SLR-TB-20	SLR-TB-21	SLR-TB-22	SLR-TB-23	SLR-TB-23
Sample Number	**11238**	**11239**	**11240**	**11241**	**11242**	**11242D**
Paste pH	8.1	8.5	8.7	8.4	8.7	8.9
Total Sulphur (%) (LECO)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Acid Potential (AP) (kg/t)	0.313	0.313	0.313	0.313	0.313	0.313
Neutralization Potential (NP)	2.73	146	113	101	115	114
Nett Neutralization Potential (NNP)	2.41	146	113	100	114	114
Neutralising Potential Ratio (NPR) (NP : AP)	8.72	467	361	322	367	365
Rock Type	III	III	III	III	III	III

***Negative NP values are obtained when the volume of NaOH (0.1N) titrated (pH:8.3) is greater than the volume of HCl (1N) to reduce the pH of the sample to 2.0 – 2.5 Any negative NP values are corrected to 0.00.**

Please refer to Appendix (p.4) for a Terminology of terms and guidelines for rock classification

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APPENDIX : TERMINOLOGY AND ROCK CLASSIFICATION

TERMINOLOGY (SYNONYMS)

- Acid Potential (AP) ; *Synonyms*: Maximum Potential Acidity (MPA)
  Method: Total S(%) (Leco Analyzer) x 31.25
- Neutralization Potential (NP) ; *Synonyms:* Gross Neutralization Potential (GNP) ; *Syn*: Acid Neutralization Capacity (ANC) (The capacity of a sample to consume acid)
  Method: Fizz Test ; Acid-Base Titration (Sobek & Modified Sobek (Lawrence) Methods)
- Nett Neutralization Potential (NNP) ; *Synonyms:* Nett Acid Production Potential (NAPP)
  Calculation: NNP = NP – AP ; NAPP = ANC – MPA
- Neutralising Potential Ratio (NPR)
  Calculation: NPR = NP : AP

CLASSIFICATION ACCORDING TO NETT NEUTRALISING POTENTIAL (NNP)

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

Any sample with NNP < 20 is potentiall acid-generating, and any sample with NNP > -20 might not generate acid (Usher *et al*., 2003)

ROCK CLASSIFICATION

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

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CERTIFICATE OF ANALYSES
ACID – BASE ACCOUNTING
EPA-600 MODIFIED SOBEK METHOD

Date received: 2013-07-08
Project number: 139 **Report number: 40803**
Date completed: 2013-08-20
Order number: 5036 Tshipi Borwa

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CLASSIFICATION ACCORDING TO NEUTRALISING POTENTIAL RATIO (NPR)

Guidelines for screening criteria based on ABA (Price *et al.*, 1997 ; Usher *et al.*, 2003)

Potential for ARD	Initial NPR Screening Criteria	Comments
Likely	**< 1:1**	Likely AMD generating
Possibly	**1:1 – 2:1**	Possibly AMD generating if NP is insufficiently reactive or is depleted at a faster rate than sulphides
Low	**2:1 – 4:1**	Not potentially AMD generating unless significant preferential exposure of sulphides along fracture planes, or extremely reactive sulphides in combination with insufficiently reactive NP
None	**>4:1**	No further AMD testing required unless materials are to be used as a source of alkalinity

CLASSIFICATION ACCORDING TO SULPHUR CONTENT (%S) AND NEUTRALISING POTENTIAL RATIO (NPR)

For sustainable long-term acid generation, at least 0.3% Sulphide-S is needed. Values below this can yield acidity but it is likely to be only of short-term significance. From these facts, and using the NPR values, a number of rules can be derived:

1) Samples with less than 0.3% Sulphide-S are regarded as having insufficient oxidisable Sulphide-S to sustain acid generation.
2) NPR ratios of >4:1 are considered to have enough neutralising capacity.
3) NPR ratios of 3:1 to 1:1 are consider inconclusive.
4) NPR ratios below 1:1 with Sulphide-S above 3% are potentially acid-generating. (Soregaroli & Lawrence, 1998 ; Usher *et al.*, 2003)

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CERTIFICATE OF ANALYSES
NETT ACID GENERATION

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Nett Acid Generation	Sample Identification: pH 4.5 & 7.0				
	SLR-TB-01	SLR-TB-02	SLR-TB-03	SLR-TB-04	SLR-TB-05
Sample Number	11220	11221	11222	11223	11224
NAG pH: (H_2O_2)	8.4	8.3	8.8	8.5	8.4
NAG (kg H_2SO_4 / t)	<0.01	<0.01	<0.01	<0.01	<0.01

Nett Acid Generation	Sample Identification: pH 4.5 & 7.0				
	SLR-TB-06	SLR-TB-07	SLR-TB-08	SLR-TB-08	SLR-TB-09
Sample Number	11225	11226	11227	11227D	11228
NAG pH: (H_2O_2)	8.4	8.4	8.2	8.3	8.9
NAG (kg H_2SO_4 / t)	<0.01	<0.01	<0.01	<0.01	<0.01

Nett Acid Generation	Sample Identification: pH 4.5 & 7.0				
	SLR-TB-10	SLR-TB-11	SLR-TB-12	SLR-TB-13	SLR-TB-14
Sample Number	11229	11230	11231	11232	11233
NAG pH: (H_2O_2)	8.8	8.5	8.8	7.7	7.8
NAG (kg H_2SO_4 / t)	<0.01	<0.01	<0.01	<0.01	<0.01

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Nett Acid Generation	Sample Identification: pH 4.5 & 7.0				
	SLR-TB-15	SLR-TB-16	SLR-TB-17	SLR-TB-17	SLR-TB-18
Sample Number	**11234**	**11235**	**11236**	**11236D**	**11237**
NAG pH: (H_2O_2)	8.5	8.4	8.5	8.5	8.5
NAG (kg H_2SO_4 / t)	<0.01	<0.01	<0.01	<0.01	<0.01

Nett Acid Generation	Sample Identification: pH 4.5 & 7.0					
	SLR-TB-19	SLR-TB-20	SLR-TB-21	SLR-TB-22	SLR-TB-23	SLR-TB-23
Sample Number	**11238**	**11239**	**11240**	**11241**	**11242**	**11242D**
NAG pH: (H_2O_2)	7.7	8.5	8.3	8.4	8.4	8.4
NAG (kg H_2SO_4 / t)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

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CERTIFICATES OF ANALYSES
SULPHUR SPECIATION

Methods from: Prediction Manual For Drainage Chemistry from Sulphidic Geological Materials MEND Report 1.20.1

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Sulphur Speciation*	Sample Identification:				
	SLR-TB-01	SLR-TB-02	SLR-TB-03	SLR-TB-04	SLR-TB-05
Sample Number	11220	11221	11222	11223	11224
Total Sulphur (%) (LECO)	<0.01	<0.01	<0.01	<0.01	<0.01
Sulphate Sulphur as S (%)	<0.01	<0.01	<0.01	<0.01	<0.01
Sulphide Sulphur (%)	<0.01	<0.01	<0.01	<0.01	<0.01

Sulphur Speciation*	Sample Identification:				
	SLR-TB-06	SLR-TB-07	SLR-TB-08	SLR-TB-09	SLR-TB-09
Sample Number	11225	11226	11227	11228	11228D
Total Sulphur (%) (LECO)	<0.01	<0.01	<0.01	<0.01	<0.01
Sulphate Sulphur as S (%)	<0.01	<0.01	<0.01	<0.01	<0.01
Sulphide Sulphur (%)	<0.01	<0.01	<0.01	<0.01	<0.01

Sulphur Speciation*	Sample Identification:				
	SLR-TB-10	SLR-TB-11	SLR-TB-12	SLR-TB-13	SLR-TB-14
Sample Number	11229	11230	11231	11232	11233
Total Sulphur (%) (LECO)	<0.01	<0.01	<0.01	<0.01	<0.01
Sulphate Sulphur as S (%)	<0.01	<0.01	<0.01	<0.01	<0.01
Sulphide Sulphur (%)	<0.01	<0.01	<0.01	<0.01	<0.01

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Sulphur Speciation*	Sample Identification:				
	SLR-TB-15	SLR-TB-16	SLR-TB-17	SLR-TB-18	SLR-TB-18
Sample Number	11234	11235	11236	11237	11237D
Total Sulphur (%) (LECO)	<0.01	<0.01	<0.01	<0.01	<0.01
Sulphate Sulphur as S (%)	<0.01	<0.01	<0.01	<0.01	<0.01
Sulphide Sulphur (%)	<0.01	<0.01	<0.01	<0.01	<0.01

Sulphur Speciation*	Sample Identification:				
	SLR-TB-19	SLR-TB-20	SLR-TB-21	SLR-TB-22	SLR-TB-23
Sample Number	11238	11239	11240	11241	11242
Total Sulphur (%) (LECO)	<0.01	<0.01	<0.01	<0.01	<0.01
Sulphate Sulphur as S (%)	<0.01	<0.01	<0.01	<0.01	<0.01
Sulphide Sulphur (%)	<0.01	<0.01	<0.01	<0.01	<0.01

Notes:
- Samples analysed with Pyrolysis at 550℃ as per Prediction Manual For Drainage Chemistry from Sulphidic Geological Materials MEND Report 1.20.1. Multiply Sulphate Sulphur to calculate SO4 % by 2.996.
- Organic Sulphur are not taken into account.
- Please let me know if results do not correspond to other data.

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CERTIFICATE OF ANALYSES
Organic/ Inorganic Carbon

Date received: 2013-07-08
Project number: 139
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Analysis	Sample Identification:				
	SLR-TB-01	SLR-TB-02	SLR-TB-03	SLR-TB-04	SLR-TB-05
Sample Number	**11220**	**11221**	**11222**	**11223**	**11224**
Total Carbon (%) (LECO)[s]	5.600	0.860	0.148	4.090	6.700
Organic Carbon (%) (LECO) [s]	0.172	0.208	0.130	0.202	0.170
Inorganic Carbon (%) (LECO) [s]	5.428	0.652	0.018	3.888	6.530

Analysis	Sample Identification:				
	SLR-TB-06	SLR-TB-07	SLR-TB-08	SLR-TB-09	SLR-TB-10
Sample Number	**11225**	**11226**	**11227**	**11228**	**11229**
Total Carbon (%) (LECO)[s]	6.910	7.330	0.070	7.800	3.340
Organic Carbon (%) (LECO) [s]	0.118	0.231	0.069	0.258	0.257
Inorganic Carbon (%) (LECO) [s]	6.792	7.099	0.001	7.542	3.083

Analysis	Sample Identification:				
	SLR-TB-11	SLR-TB-12	SLR-TB-13	SLR-TB-14	SLR-TB-15
Sample Number	**11230**	**11231**	**11232**	**11233**	**11234**
Total Carbon (%) (LECO)[s]	3.380	1.280	0.335	0.278	2.500
Organic Carbon (%) (LECO) [s]	0.119	0.247	0.331	0.273	0.361
Inorganic Carbon (%) (LECO) [s]	3.261	1.033	0.004	0.005	2.139

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Analysis	Sample Identification:				
	SLR-TB-16	SLR-TB-17	SLR-TB-18	SLR-TB-19	SLR-TB-20
Sample Number	**11235**	**11236**	**11237**	**11238**	**11239**
Total Carbon (%) (LECO)[s]	2.010	2.760	5.410	0.260	4.480
Organic Carbon (%) (LECO) [s]	0.203	0.272	0.275	0.255	0.356
Inorganic Carbon (%) (LECO) [s]	1.807	2.488	5.135	0.005	4.124

Analysis	Sample Identification:		
	SLR-TB-21	SLR-TB-22	SLR-TB-23
Sample Number	**11240**	**11241**	**11242**
Total Carbon (%) (LECO)[s]	3.320	11.500	11.480
Organic Carbon (%) (LECO) [s]	0.314	0.203	0.148
Inorganic Carbon (%) (LECO) [s]	3.006	11.30	11.33

[s]= Results obtained from subcontracted laboratory

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CERTIFICATE OF ANALYSES
X-RAY FLUORESENCE

Date received: 2013-07-08
Project number: 139
Report number: 40803
Date completed: 2013-08-21
Order number: 5036 Tshipi Borwa

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Major Elements	Major Element Concentration (wt %)[s]						
	SLR-TB-01	SLR-TB-02	SLR-TB-03	SLR-TB-05	SLR-TB-07	SLR-TB-09	SLR-TB-10
	11220	11221	11222	11224	11226	11228	11229
SiO_2	8.74	55.78	61.13	8.48	3.28	20.03	48.64
TiO_2	0.1	0.05	<0.01	0.1	0.04	0.29	1.02
Al_2O_3	1.26	0.82	0.38	3.18	0.75	4.75	11.66
Fe_2O_3	17.19	31.81	32.78	14.8	3.39	2.96	9.91
MnO	17.99	0.86	2.21	13.29	31.34	0.07	0.2
MgO	4.39	1.53	0.31	3	4.59	2.84	4.94
CaO	24.47	3.32	0.78	29.31	31.31	36.24	7.9
Na_2O	0.02	0.58	0.09	0.73	0.65	0.86	0.72
K_2O	<0.01	0.06	0.03	0.08	<0.01	0.11	0.77
P_2O_5	0.07	0.09	<0.01	0.07	0.08	0.1	0.12
Cr_2O_3	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	0.03
SO_3	<0.01	<0.01	0.09	<0.01	<0.01	0.13	0.02
LOI	25.88	4.93	2.09	26.98	24.65	31.5	13.85
Total	100.11	99.83	99.89	100.02	100.1	99.88	99.78
H_2O-	0.53	4.11	0.29	2.12	0.08	3.25	9.99

[s] =Results obtained from sub-contracted laboratory

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Trace Elements	Trace Element Concentration (ppm) [s]						
	SLR-TB-01	SLR-TB-02	SLR-TB-03	SLR-TB-05	SLR-TB-07	SLR-TB-09	SLR-TB-10
	11220	11221	11222	11224	11226	11228	11229
As	<5.00	<5.00	<5.00	<5.00	2.34	<5.00	<5.00
Ba	93	85.2	88.9	226	94	108	252
Bi	<5.00	4.11	2.9	<5.00	<5.00	<5.00	<1.00
Br	<1.00	<5.00	1.1	<5.00	<5.00	<1.00	<1.00
Cd	6.11	<1.00	<1.00	6.27	7.08	6.81	1.87
Ce	91	30.7	27	101	124	101	<5.00
Cl	874	583	134	644	640	624	774
Co	<5.00	253	103	<5.00	<5.00	<5.00	45.1
Cs	1.11	1.63	1.12	1.19	1.8	<5.00	<1.00
Cu	22.7	28.1	44	94	<5.00	54.1	78.9
Ga	<5.00	6.65	<1.00	<5.00	<5.00	2.32	17.5
Ge	26.4	<5.00	<5.00	31.9	<5.00	6.14	4.49
Hf	<5.00	38.6	29.5	<5.00	<5.00	<5.00	6.24
Hg	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
La	<5.00	77.6	77.9	2.43	<5.00	108	116
Lu	<1.00	<5.00	<5.00	<1.00	<1.00	<1.00	<1.00
Mo	19.7	<5.00	<5.00	8.6	12.5	6.81	4.88
Nb	3.3	8.96	7.67	4.95	2.71	4.99	17.3
Nd	240	23.8	31.2	143	120	42.1	35.3
Ni	<5.00	185	151	<5.00	<5.00	19	122
Pb	222	287	308	206	103	6.65	25
Rb	<5.00	117	89	9.3	1.36	20	61
Sb	<5.00	3.79	2.94	7.07	2.31	<5.00	1.76
Sc	126	12.8	17.6	91	142	34.5	12.4
Se	<5.00	5.34	4.2	<5.00	<5.00	<1.00	1.1
Sm	<5.00	<5.00	<5.00	<5.00	<5.00	7.4	2.46
Sn	<5.00	26	9.51	8.1	13.2	5.36	4.9
Sr	991	94.3	114	307	201	154	122
Ta	17.2	5.23	11.4	13	19.1	2.55	4.14
Te	<5.00	4.49	<5.00	<5.00	<5.00	<5.00	27.4
Th	14.2	11.8	12.1	17.8	9.3	7.7	18.5
Tl	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<1.00
U	<5.00	<5.00	<5.00	<5.00	<5.00	1.45	3.15

Results continued on next page

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Telephone: 011 467 0945
Facsimile: 011 467 0978
Contact person: Jenny Ellerton
Email: jellerton@slrconsulting.com

Trace Elements	SLR-TB-01	SLR-TB-02	SLR-TB-03	SLR-TB-05	SLR-TB-07	SLR-TB-09	SLR-TB-10
	11220	11221	11222	11224	11226	11228	11229
V	139	16.4	<5.00	34.6	2.18	84	222
W	1.37	<5.00	<5.00	16.9	<5.00	4.62	3.76
Y	24.4	<5.00	<5.00	10.2	2.97	16.3	27.7
Yb	<5.00	<5.00	<5.00	<5.00	14.3	7.3	7.21
Zn	41.8	131	110	53.9	<5.00	76	173
Zr	3.16	19.7	19.6	31.3	<5.00	51.7	243

[s] =Results obtained from sub-contracted laboratory

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Geochemistry Project Manager

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CERTIFICATE OF ANALYSES
X-RAY FLUORESENCE

Date received: 2013-07-08
Project number: 139
Report number: 40803
Date completed: 2013-08-21
Order number: 5036 Tshipi Borwa

Client name: SLR Consulting (Africa) (Pty) Ltd
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Major Elements	Major Element Concentration (wt %)[s]						
	SLR-TB-13	SLR-TB-16	SLR-TB-17	SLR-TB-19	SLR-TB-20	SLR-TB-22	SLR-TB-23
	11232	11235	11236	11238	11239	11241	11242
SiO_2	61.58	51.32	45.56	86.61	24.78	11.52	5.9
TiO_2	1.2	0.58	0.7	0.39	0.31	0.04	0.03
Al_2O_3	11.49	7.69	7.74	7.18	5.37	2.47	0.47
Fe_2O_3	10.97	8.38	6.3	2.23	3.24	8.26	6.44
MnO	0.08	0.27	0.11	0.03	0.07	47.09	1.66
MgO	3.89	8.91	4.75	0.9	5.92	4.1	21.24
CaO	1.13	11.05	19.48	0.28	35.09	10.51	24.47
Na_2O	0.39	0.64	0.76	0.31	0.87	0.12	<0.01
K_2O	1.36	0.7	0.67	0.8	0.29	0.25	0.02
P_2O_5	0.06	0.14	0.15	0.07	0.11	0.08	0.05
Cr_2O_3	0.02	<0.01	<0.01	<0.01	<0.01	0.03	<0.01
SO_3	0.02	0.11	0.58	<0.01	0.08	<0.01	<0.01
LOI	7.62	9.96	13.01	1.13	23.67	15.56	39.76
Total	99.81	99.75	99.81	99.93	99.8	100.03	100.04
H_2O-	8.92	3.21	3.02	0.86	5.9	2.19	0.09

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Trace Elements	Trace Element Concentration (ppm) [s]						
	SLR-TB-13	SLR-TB-16	SLR-TB-17	SLR-TB-19	SLR-TB-20	SLR-TB-22	SLR-TB-23
	11232	11235	11236	11238	11239	11241	11242
As	<5.00	6.52	<5.00	<5.00	<1.00	<5.00	61
Ba	178	489	264	93.2	148	1943	32.6
Bi	<1.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
Br	<1.00	<1.00	<1.00	1.04	<1.00	1.3	<1.00
Cd	<5.00	1.36	3.71	<5.00	5.99	2.17	5.38
Ce	<5.00	<5.00	<5.00	8.19	88	65.9	45
Cl	638	651	656	508	740	1098	364
Co	24.2	<5.00	<5.00	<5.00	<5.00	<5.00	22.6
Cs	2.79	1.84	<5.00	1.77	<5.00	1.13	<1.00
Cu	103	148	58.8	12.9	243	<5.00	1.85
Ga	16.2	4.84	4.32	<5.00	2.39	<5.00	<5.00
Ge	1.33	6.21	4.6	<5.00	3.97	<5.00	11.3
Hf	12.1	8	5.64	7.95	1.94	<5.00	1.2
Hg	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
La	56.7	30.4	83.1	56.9	116	<5.00	119
Lu	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Mo	5.42	4.69	6.92	4.37	8.9	24.7	5.93
Nb	17.3	7.41	10.4	6.83	5.46	6.77	1.83
Nd	21.4	36.6	31.4	34	43.3	235	13.9
Ni	135	119	65.4	16.8	26.1	<5.00	75
Pb	27.4	172	8.39	5.29	98	146	62
Rb	89.5	39.8	52.2	22.9	34.8	<5.00	5.26
Sb	3.46	1.84	<5.00	1.64	<5.00	4.51	<5.00
Sc	17.3	19.4	28.2	7.45	37.8	151	20.1
Se	<1.00	<1.00	<1.00	<1.00	<5.00	<5.00	<5.00
Sm	4.58	3.15	5.73	10.1	9.5	<5.00	<5.00
Sn	9.5	1.94	4.77	2.75	<1.00	5.41	3.43
Sr	68.8	239	119	19.7	95	551	14.7
Ta	2.57	3.74	3.66	3.88	2.22	39.3	2.13
Te	5.18	17.1	10.3	6.16	<5.00	<5.00	<5.00
Th	20.6	22.7	14.1	13.9	14.3	<5.00	10.5
Tl	1.05	<1.00	<1.00	<1.00	<1.00	<5.00	<5.00
U	2.65	2.13	1.52	2.32	1.97	<5.00	<1.00

Results continued on next page

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Trace Elements	SLR-TB-13	SLR-TB-16	SLR-TB-17	SLR-TB-19	SLR-TB-20	SLR-TB-22	SLR-TB-23
	11232	11235	11236	11238	11239	11241	11242
V	324	160	98	14.5	50.7	13.3	2.85
W	5.22	5.06	5.58	4.67	4.9	<5.00	7.5
Y	24.2	27.6	23.7	6.17	21.3	7.72	5.11
Yb	6.28	7.21	10	15.9	12.4	11.5	4.34
Zn	138	166	81.4	49	38.2	56.7	16
Zr	318	161	365	280	138	14.8	<5.00

[s] =Results obtained from sub-contracted laboratory

E. Botha
Geochemistry Project Manager

APPENDIX B: PHREEQC MODELLING RESULTS

PHREEQC Geochemical Modelling input and output data

INPUT

soln	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	AM
pH	9.59124	7.10234	6.71059	6.55336	6.86777	6.82106	6.78528	6.99474	6.71096	8.1157	6.84536	6.82827	6.97515	6.88794	6.99805	6.74192	6.80441	6.82278	7.0516	6.63761	6.87443	6.5617	6.64387	
Lithology	Braunie Lutite	Upper BIF	Lower BIF	Lower BIF - red in colour	VW Ore Zone	Top Cut Ore	Lower Ore body	Pebble bed in calcareous clay	Pebble bed in red calcareous clay	Red clay	Lower BIF	Red clay	White Clay	White gravel bed	Red Iron Calcareous Sand	Pebbly Calcrete	Iron rich Calcareous Sands	Pebbly Calcrete	Red Kalahari Sands	Calcrete	Pebbly Calcrete	Tailings Sample	Dolomite	
Lithology	6.02493	7.89393	8.37485	8.80754	8.2202	8.19657	8.21903	7.99046	8.4503	7.02775	8.26822	8.36966	8.45422	8.4809	8.70432	8.86082	8.71617	8.7597	8.06856	9.3478	8.8572	8.97562	8.54422	
Na	2.23E-02	5.15E-03	5.15E-03	1.54E-02	1.20E-02	3.43E-03	5.15E-03	1.72E-02	1.37E-02	2.40E-02	3.43E-03	2.06E-02	1.54E-02	1.20E-02	1.54E-02	1.54E-02	2.40E-02	2.23E-02	3.43E-03	7.21E-02	3.26E-02	1.72E-02	6.86E-03	22990
K	1.11E-03	1.01E-03	1.01E-03	1.01E-03	8.59E-03	1.29E-02	6.08E-03	9.18E-03	2.10E-03	1.19E-02	5.84E-03	4.63E-03	5.87E-03	1.47E-02	1.03E-02	1.10E-02	4.54E-03	3.77E-03	1.60E-02	2.25E-02	1.11E-02	6.73E-03	3.41E-03	39098
Ca	1.32E-02	7.07E-03	8.02E-03	9.85E-03	1.13E-03	1.25E-03	1.44E-03	8.47E-04	1.75E-03	8.13E-05	1.34E-03	1.18E-03	1.31E-03	1.14E-03	9.25E-04	1.56E-03	1.24E-03	1.24E-03	1.38E-03	3.58E-03	1.12E-03	2.91E-03	1.19E-04	40078
Mg	1.32E-02	9.74E-03	3.25E-03	1.14E-02	9.74E-03	1.19E-02	1.30E-02	6.49E-03	9.74E-03	7.95E-04	1.30E-02	9.74E-03	4.87E-03	6.49E-03	8.89E-03	1.14E-02	9.74E-03	1.14E-02	4.87E-03	1.30E-02	8.12E-03	2.27E-02	1.79E-02	24305
Fe	2.42E-09	4.23E-09	9.58E-09	1.42E-08	6.91E-09	7.67E-09	8.27E-09	5.25E-09	9.69E-09	8.50E-10	7.24E-09	7.57E-09	5.41E-09	6.60E-09	5.25E-09	9.22E-09	8.01E-09	7.71E-09	4.60E-09	1.23E-08	6.96E-09	1.41E-08	1.14E-08	55847
Mn	1.66E-09	1.79E-05	9.19E-05	1.80E-05	1.10E-05	1.23E-05	1.42E-05	8.14E-06	1.70E-05	7.13E-07	1.30E-05	1.17E-05	1.80E-05	1.11E-05	9.12E-06	1.59E-05	1.25E-05	1.26E-05	1.24E-05	1.79E-05	1.17E-05	1.80E-05	1.80E-05	54938
Al	1.46E-04	7.81E-08	1.62E-07	4.13E-07	9.15E-07	1.55E-05	1.56E-05	6.25E-08	1.87E-07	2.45E-08	6.68E-08	1.00E-07	1.28E-09	7.69E-07	5.30E-07	4.26E-09	2.67E-09	3.18E-09	2.26E-07	1.47E-06	3.74E-09	3.11E-08	4.90E-06	26982
F	6.23E-04	1.96E-04	1.66E-04	2.42E-04	6.01E-04	4.15E-04	4.15E-04	5.89E-04	5.38E-04	1.45E-03	6.38E-04	6.50E-04	4.21E-04	5.35E-04	6.06E-04	6.04E-04	6.41E-04	6.62E-04	4.01E-04	4.99E-04	6.58E-04	6.03E-04	8.31E-04	18998
Cl	6.29E-02	3.25E-02	1.93E-02	4.44E-02	5.56E-03	5.56E-03	5.56E-03	5.56E-03	5.56E-03	5.56E-03	5.56E-03	5.56E-03	5.56E-03	5.56E-03	5.56E-03	5.56E-03	5.56E-03	5.56E-03	5.56E-03	2.89E-02	6.68E-03	5.56E-03	5.56E-03	35453
S(6)	2.88E-03	2.05E-03	2.02E-03	2.05E-03	2.03E-03	2.05E-03	2.05E-03	2.02E-03	2.01E-03	2.43E-03	2.03E-03	2.46E-03	2.46E-03	2.00E-03	2.05E-03	2.04E-03	1.71E-03	1.75E-03	4.51E-03	1.07E-02	2.05E-03	1.35E-02	1.75E-03	96000
Alkalinity	1.79E-03	2.63E-03	5.12E-03	7.72E-03	3.17E-02	3.24E-02	2.98E-02	3.06E-02	2.83E-02	2.48E-02	2.74E-02	3.50E-02	1.86E-02	2.89E-02	2.87E-02	3.30E-02	3.55E-02	3.42E-02	1.56E-02	2.67E-02	3.55E-02	3.67E-02	3.63E-02	50000
Sb	3.24E-06	3.24E-06	3.24E-06	3.24E-06	3.24E-06	3.24E-06	3.24E-06	3.24E-06	3.24E-06	3.24E-06	3.24E-06	3.24E-06	3.24E-06	3.24E-06	3.24E-06	3.24E-06	3.24E-06	3.24E-06	3.24E-06	3.24E-06	3.24E-06	3.24E-06	3.24E-06	121757
As	5.27E-06	5.26E-06	5.26E-06	5.27E-06	5.27E-06	5.27E-06	5.27E-06	5.27E-06	5.27E-06	1.00E-05	1.21E-05	5.27E-06	5.27E-06	5.27E-06	5.26E-06	5.27E-06	6.85E-06	6.32E-06	1.16E-05	5.26E-06	5.27E-06	5.27E-06	7.37E-06	74922
Ba	7.18E-06	4.33E-07	3.44E-07	5.51E-07	3.96E-07	4.17E-07	4.16E-07	3.58E-07	3.89E-07	2.38E-07	4.08E-07	3.43E-07	2.55E-07	3.71E-07	3.97E-07	4.60E-07	5.18E-07	5.27E-07	1.34E-07	1.48E-07	4.68E-07	9.27E-08	5.57E-07	137327
Be	9.08E-07	1.08E-05	3.80E-05	7.37E-05	7.39E-05	4.99E-05	5.39E-05	5.30E-05	1.09E-04	4.53E-06	1.09E-04	1.09E-04	3.85E-05	6.61E-05	4.97E-05	1.09E-04	1.09E-04	1.09E-04	2.82E-05	1.09E-04	1.09E-04	1.09E-04	1.09E-04	9012
Cd	1.76E-06	1.75E-06	1.75E-06	1.75E-06	3.75E-07	4.11E-07	4.78E-07	2.87E-07	5.78E-07	5.29E-08	4.49E-07	3.85E-07	4.62E-07	3.83E-07	3.16E-07	5.08E-07	4.02E-07	4.06E-07	4.89E-07	1.75E-06	3.80E-07	9.51E-07	5.64E-07	112411
Cr	1.90E-05	2.52E-08	6.04E-08	1.90E-05	4.25E-08	4.73E-08	5.16E-08	3.02E-08	6.39E-08	7.81E-07	4.48E-08	5.01E-08	6.26E-08	5.41E-08	2.92E-07	1.08E-07	8.42E-08	1.05E-07	2.94E-08	7.03E-07	2.54E-07	1.42E-07	8.17E-08	51996
Co	1.67E-05	1.67E-05	1.67E-05	1.67E-05	1.67E-05	1.67E-05	1.67E-05	1.67E-05	1.67E-05	5.97E-06	1.67E-05	1.67E-05	1.67E-05	1.67E-05	1.67E-05	1.67E-05	1.67E-05	1.67E-05	1.67E-05	1.67E-05	1.67E-05	1.67E-05	1.67E-05	58933
Cu	3.90E-08	1.63E-06	3.72E-06	5.71E-06	6.04E-06	6.44E-06	6.45E-06	5.15E-06	6.95E-06	2.05E-06	5.73E-06	6.67E-06	4.09E-06	5.66E-06	4.95E-06	7.20E-06	6.92E-06	6.62E-06	3.43E-06	7.83E-06	6.41E-06	9.79E-06	8.50E-06	63546
Pb	2.61E-09	6.28E-07	7.72E-07	1.07E-06	4.72E-07	4.98E-07	5.19E-07	4.16E-07	5.68E-07	4.38E-07	4.84E-07	4.96E-07	4.26E-07	4.62E-07	4.20E-07	5.58E-07	5.12E-07	5.04E-07	4.04E-07	7.86E-07	4.85E-07	7.72E-07	6.27E-07	207200
Hg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	200590
Mo	1.23E-05	1.23E-05	1.23E-05	1.23E-05	1.23E-05	1.23E-05	1.23E-05	1.23E-05	1.23E-05	1.23E-05	1.23E-05	1.23E-05	1.23E-05	1.23E-05	1.23E-05	1.23E-05	1.23E-05	1.23E-05	1.23E-05	1.23E-05	1.23E-05	1.23E-05	1.23E-05	95940
Ni	2.21E-06	1.68E-05	1.68E-05	1.68E-05	1.68E-05	1.68E-05	1.68E-05	1.68E-05	1.68E-05	1.68E-05	1.68E-05	1.68E-05	1.68E-05	1.68E-05	1.68E-05	1.68E-05	1.68E-05	1.68E-05	1.68E-05	1.68E-05	1.68E-05	1.68E-05	1.68E-05	58693
Se	9.99E-06	9.99E-06	9.99E-06	9.99E-06	9.99E-06	9.99E-06	9.99E-06	9.99E-06	9.99E-06	9.99E-06	9.99E-06	9.99E-06	9.99E-06	9.99E-06	9.99E-06	9.99E-06	9.99E-06	9.99E-06	9.99E-06	9.99E-06	9.99E-06	9.99E-06	9.99E-06	78960
Ag	9.14E-06	9.14E-06	9.14E-06	9.14E-06	9.14E-06	9.14E-06	9.14E-06	9.14E-06	9.14E-06	9.14E-06	9.14E-06	9.14E-06	9.14E-06	9.14E-06	9.14E-06	9.14E-06	9.14E-06	9.14E-06	9.14E-06	9.14E-06	9.14E-06	9.14E-06	9.14E-06	107868
Sr	1.31E-05	1.13E-05	1.13E-05	1.13E-05	1.13E-05	1.17E-05	1.13E-05	1.89E-05	2.70E-05	1.22E-05	1.17E-05	2.75E-05	1.22E-05	2.21E-05	2.79E-05	3.42E-05	3.74E-05	3.65E-05	1.13E-05	3.60E-05	2.21E-05	1.13E-05	1.35E-05	87620
Tl	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	204383
V	2.32E-05	2.32E-05	2.32E-05	2.32E-05	2.32E-05	2.32E-05	2.32E-05	2.32E-05	2.32E-05	2.32E-05	2.32E-05	2.32E-05	2.09E-05	2.32E-05	2.25E-05	2.32E-05	2.32E-05	2.32E-05	2.32E-05	2.32E-05	2.32E-05	2.32E-05	2.32E-05	50942
Zn	1.05E-06	1.51E-05	5.91E-05	1.51E-05	4.22E-05	1.51E-05	1.51E-05	3.54E-05	3.62E-05	8.52E-06	2.47E-05	1.51E-05	1.51E-05	4.55E-05	1.51E-05	1.51E-05	4.98E-05	4.96E-05	1.51E-05	1.51E-05	1.51E-05	1.51E-05	2.35E-05	65390

OUTPUT

soln	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
pH	9.6	7.1	6.7	6.6	6.9	6.8	6.8	7.0	6.7	8.1	6.8	6.8	7.0	6.9	7.0	6.7	6.8	6.8	7.1	6.6	6.9	6.6	6.6
Lithology	Braunie Lutite	Upper BIF	Lower BIF	Lower BIF - red in colour	VW Ore Zone	Top Cut Ore	Lower Ore body	Pebble bed in calcareous clay	Pebble bed in red calcareous clay	Red clay	Lower BIF	Red clay	White Clay	White gravel bed	Red Iron Calcareous Sand	Pebbly Calcrete	Iron rich Calcareous Sands	Pebbly Calcrete	Red Kalahari Sands	Calcrete	Pebbly Calcrete	Tailings Sample	Dolomite
Lithology	6.02493	7.89393	8.37485	8.80754	8.2202	8.19657	8.21903	7.99046	8.4503	7.02775	8.26822	8.36966	8.45422	8.4809	8.70432	8.86082	8.71617	8.7597	8.06856	9.3478	8.8572	8.97562	8.54422
Na	513	118	118	355	276	79	118	395	316	552	79	473	355	276	355	355	552	513	79	1657	750	395	158
K	43	39	39	39	336	503	238	359	82	465	229	181	230	574	404	432	177	148	627	879	436	263	133
Ca	528	283	322	395	45	50	58	34	70	3.3	54	47	53	46	37	63	50	50	55	143	45	117	4.8
Mg	320	237	79	276	237	290	316	158	237	19	316	237	118	158	216	276	237	276	118	316	197	552	434
Fe	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mn	<0.01	0.99	5.05	0.99	0.61	0.68	0.78	0.45	0.93	0.04	0.72	0.64	0.99	0.61	0.50	0.88	0.69	0.69	0.68	0.99	0.64	0.99	0.99
Al	3.95	<0.01	<0.01	0.01	0.02	0.42	0.42	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.01	<0.01	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	0.13
F	11.84	3.73	3.16	4.59	11.42	7.89	7.89	11.19	10.22	27.61	12.11	12.34	7.99	10.15	11.52	11.47	12.17	12.57	7.61	9.47	12.50	11.46	15.78
Cl	2231	1153	686	1574	197	197	197	197	197	197	197	197	197	197	197	197	197	197	197	1026	237	197	197
S(6)	276	196	194	196	195	196	196	194	193	233	195	236	236	192	196	196	164	168	433	1024	196	1300	168
Alkalinity	89	132	256	386	1584	1618	1491	1531	1417	1238	1372	1750	929	1446	1436	1650	1777	1712	780	1336	1774	1837	1815
Sb	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
As	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.75	0.91	0.39	0.39	0.39	0.39	0.39	0.51	0.47	0.87	0.39	0.39	0.39	0.55
Ba	0.99	0.06	0.05	0.08	0.05	0.06	0.06	0.05	0.05	0.03	0.06	0.05	0.04	0.05	0.05	0.06	0.07	0.07	0.02	0.02	0.06	0.01	0.08
Be	<0.01	0.10	0.34	0.66	0.67	0.45	0.49	0.48	0.99	0.04	0.99	0.99	0.35	0.60	0.45	0.99	0.99	0.99	0.25	0.99	0.99	0.99	0.99
Cd	0.20	0.20	0.20	0.20	0.04	0.05	0.05	0.03	0.06	<0.01	0.05	0.04	0.05	0.04	0.04	0.06	0.05	0.05	0.05	0.20	0.04	0.11	0.06
Cr	0.99	<0.01	<0.01	0.99	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.04	0.01	<0.01	<0.01
Co	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.35	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Cu	<0.01	0.10	0.24	0.36	0.38	0.41	0.41	0.33	0.44	0.13	0.36	0.42	0.26	0.36	0.31	0.46	0.44	0.42	0.22	0.50	0.41	0.62	0.54
Pb	<0.01	0.13	0.16	0.22	0.10	0.10	0.11	0.09	0.12	0.09	0.10	0.10	0.09	0.10	0.09	0.12	0.11	0.10	0.08	0.16	0.10	0.16	0.13
Hg	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mo	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18
Ni	0.13	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Se	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79
Ag	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Sr	1.14	0.99	0.99	0.99	0.99	1.03	0.99	1.66	2.37	1.07	1.03	2.41	1.07	1.93	2.45	3.00	3.27	3.20	0.99	3.16	1.93	0.99	1.18
Tl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
V	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.07	1.18	1.14	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18
Zn	0.07	0.99	3.87	0.99	2.76	0.99	0.99	2.31	2.37	0.56	1.62	0.99	0.99	2.97	0.99	0.99	3.25	3.25	0.99	0.99	0.99	0.99	1.54

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