global environmental solutions

Tshipi Borwa Manganese Mine

# Tshipi Borwa Groundwater Study

SLR Project No.: 710.20008.00036

Report No.: 1

Revision No. 1

July 2017

Tshipi é Ntle Manganese Mining (Pty) Ltd

Tshipi Borwa Manganese Mine

Tshipi Borwa Groundwater Study

SLR Project No.: 710.20008.00036

Report No.: 1

Revision No. 1

July 2017

Tshipi é Ntle Manganese Mining (Pty) Ltd

**DOCUMENT INFORMATION**

| | |
|---|---|
| **Title** | Tshipi Borwa Groundwater Study |
| **Project Manager** | Natasha Smyth |
| **Project Manager e-mail** | nsmyth@slrconsulting.com |
| **Author** | Mihai Muresan; Linda Munro |
| **Reviewer** | Brandon Stobart |
| **Client** | Tshipi é Ntle Manganese Mining (Pty) Ltd |
| **Date last printed** | 2017/08/23 03:22:00 PM |
| **Date last saved** | 2017/08/23 03:22:00 PM |
| **Keywords** | Manganese mine, Northern Cape, open pit, backfilling, groundwater study, contaminant transport |
| **Project Number** | 710.20008.00036 |
| **Report Number** | 1 |
| **Revision Number** | Revision No.1 |
| **Status** | DRAFT |
| **Issue Date** | July 2017 |

# TSHIPI BORWA GROUNDWATER STUDY

## CONTENTS

## LIST OF FIGURES

## LIST OF TABLES



## LIST OF APPENDICES

## ACRONYMS AND ABBREVIATIONS

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

| **Acronyms / Abbreviations** | **Definition** |
|---|---|
| Al | Aluminium |
| Ca | Calcium |
| $CaCO_3$ | Calcium Carbonate |
| Cl | Chloride |
| $CO_3$ | Carbonate |
| DENC | Department of Environment and Nature Conservation |
| DME | Department of Minerals and Energy (Now the Department of Mineral Resources) |
| DMR | Department of Mineral Resources |
| DWA/DWAF | Department of Water Affairs/ 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 |
| HCO3 | Bicarbonate |
| IAP | Interested and Affected Party |
| JMLM | Joe Morolong Local Municipality |
| JTGDM | John Taolo Gaetsewe District Municipality |
| K | Hydraulic conductivity, m/d |
| mamsl | Meters above mean sea level |
| mbgl | Meters below ground level |
| Mg | Magnesium |
| mg/ℓ | Milligrams per litre (concentration) |
| Mn | Manganese |
| N | Nitrate |
| Na | Sodium |
| NEMA | National Environmental Management Act |
| NRMSE | Normalised Residual Mean Squared Error |
| NWA | National Water Act |
| RMSE | Residual Mean Squared Error |
| ROM | Run Of Mine |
| SANS | South African National Standards |
| SLR | SLR Consulting (Africa) (Pty) Ltd |
| SO4 | Sulphate |
| TDS | Total Dissolved Solids |
| 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 |

**NATIONAL ENVIRONMENTAL MANAGEMENT ACT (NEMA) REGULATIONS (2014 as amended) APPENDIX 6: SPECIALIST REPORTING REQUIREMENTS CHECKLIST**

Below is a checklist showing information required by specialists in terms of Appendix 6 of NEMA

| Item | NEMA Regulations (2014): Appendix 6 | Relevant Section in Report |
|---|---|---|
| 1(a)(i) | Details of the specialist who prepared the report | Section 2 |
| 1(a)(ii) | The expertise of that person to compile a specialist report including a curriculum vitae | Appendix A |
| 1(b | A declaration that the person is independent in a form as may be specified by the competent authority | Section 3 |
| 1(c) | An indication of the scope of, and the purpose for which, the report was prepared | Sections 1, 4 and 5 |
| 1(d) | The date and season of the site investigation and the relevance of the season to the outcome of the assessment | Section 6 |
| 1(e) | A description of the methodology adopted in preparing the report or carrying out the specialised process | Section 6 |
| 1(f) | The specific identified sensitivity of the site related to the activity and its associated structures and infrastructure | No specific sensitive areas identified |
| 1(g) | An identification of any areas to be avoided, including buffers | None identified |
| 1(h) | A map superimposing the activity including the associated structures and infrastructure on the environmental sensitivities of the site including areas to be avoided, including buffers; | No specific sensitive areas identified |
| 1(i) | A description of any assumptions made and any uncertainties or gaps in knowledge; | Section 14 |
| 1(j) | A description of the findings and potential implications of such findings on the impact of the proposed activity, including identified alternatives, on the environment | Section 10 |
| 1(k) | Any mitigation measures for inclusion in the EMPr | Section 12 |
| 1(l) | Any conditions for inclusion in the environmental authorisation | None |
| 1(m) | Any monitoring requirements for inclusion in the EMPr or environmental authorisation | Section 11 |
| 1(n)(i) | A reasoned opinion as to whether the proposed activity or portions thereof should be authorised and | Section 16 |
| 1(n)(ii) | If the opinion is that the proposed activity or portions thereof should be authorised, any avoidance, management and mitigation measures that should be included in the EMPr, and where applicable, the closure plan | Section 16 |
| 1(o) | A description of any consultation process that was undertaken during the course of carrying out the study | Section 15 |
| 1(p) | A summary and copies if any comments that were received during any consultation process | Section 15 |
| 1(q) | Any other information requested by the competent authority. | No other information |

# TSHIPI BORWA GROUNDWATER STUDY

## 1 INTRODUCTION

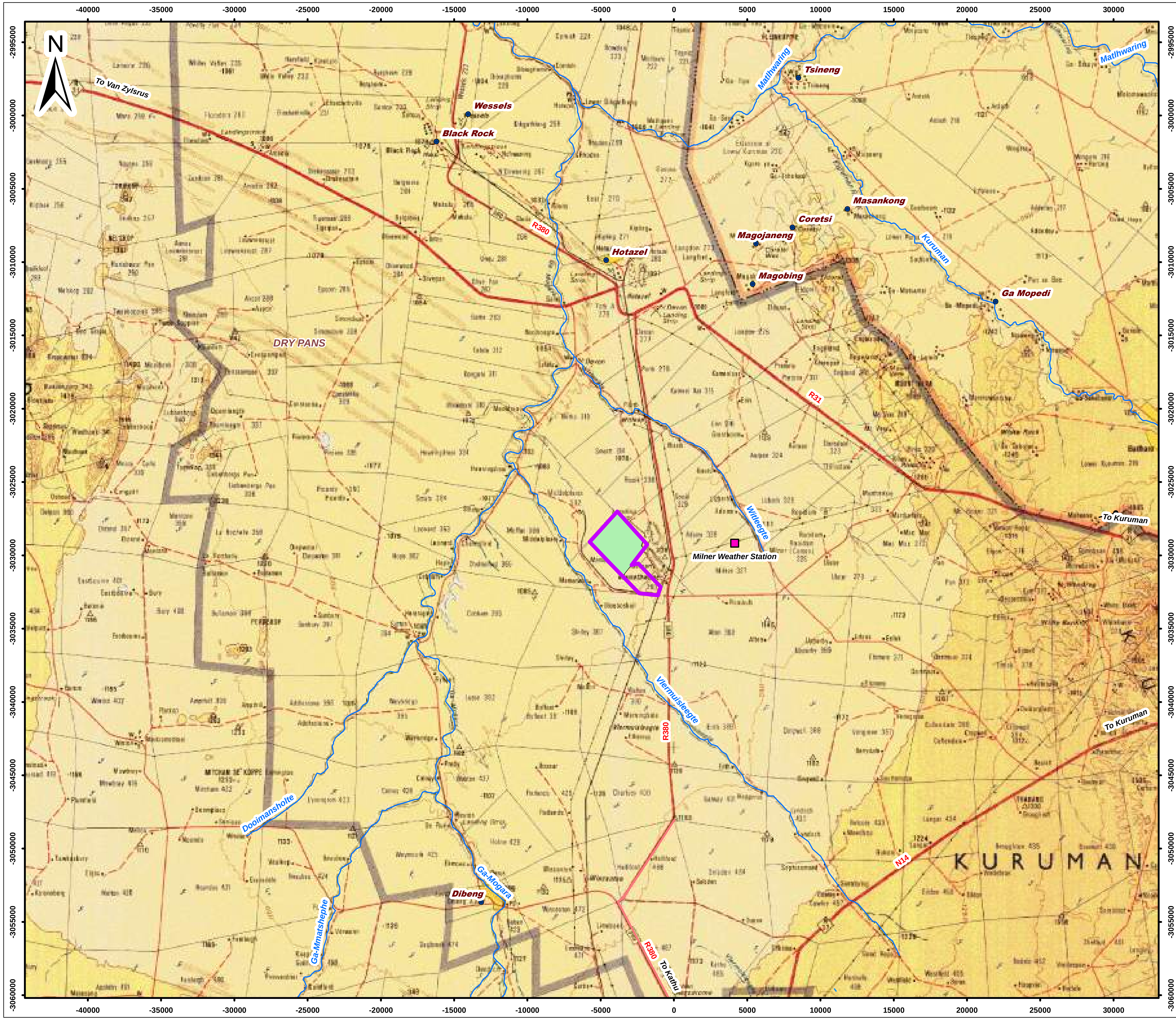
Tshipi é Ntle Manganese Mining (Tshipi) operates the open pit manganese Tshipi Borwa Mine located on the farms Mamatwan 331 (mining right and surface use areas) and Moab 700 (surface use area), in the John Taolo Gaetsewe District Municipality and Joe Morolong Local Municipality in the Northern Cape Province.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

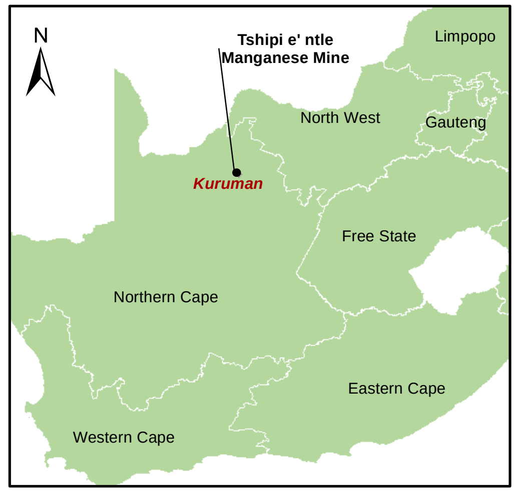
The mine holds a mining right (NC/30/5/1/2/2/0206MR) and an Environmental Management Programme report (EMPr) issued and approved by the Department of Minerals and Energy (currently the Department of Mineral Resources (DMR)), an environmental authorisation (EA) (NC/KGA/KATHU/37/2008) issued by the Department 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's is conducting an EMPr amendment process to approve changes to the mine's infrastructure, which includes the following (refer to Figure 5-1 for the revised site layout):

- An increase in the number, position, volume and layout of waste rock dumps
- Change to the design, capacity and position of the sewage treatment plant
- Change to the stormwater management system, position including additional storage
- Change to the potable water storage facilities capacity and position
- Change to the position of the office, plant and workshop
- Change to the number, position, volume and layout (footprint) of the  ore stockpiles
- Change to the design of the railway line and an increase in length
- The establishment of an additional temporary run-off-mine (ROM) stockpile area
- The establishment of a tyre bays
- The establishment of additional weighbridges
- The establishment of an additional topsoil stockpile area (No. 2)
- Change in the position secondary crushing and screening plant
- The expansion of the approved topsoil stockpile area
- Expansion of topsoil stockpile No.2
- Merging with the adjacent South 32 Mamatwan Mine waste rock dump on the farm Sinterfontein 748
- The change in the position of the approved 78Ml stormwater dam
- Establishment of a clean and dirty water separation system
- Mining of the barrier pillar between the Tshipi Borwa Mine and the adjacent South 32 Mamatwan Mine.

SLR Consulting (Africa) (Pty) Ltd (SLR), an independent firm of environmental consultants, has been appointed to manage the environmental authorisation processes. This groundwater supports the environmental authorisation processes and water use licence application process and assesses the project changes with respect to potential dewatering and 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).




**Legend**

- Approved Mining Right Area
- Surface Use Area
- Main Roads
- Rivers

0 4 8 Kilometers

Scale: 1:20 000 000 @ A3

Projection:Transverse Mercator
Datum: Hartebeeshoek, Lo 23

Tshipi é Ntle Manganese Mining (Pty) Ltd

**Figure 1-1**

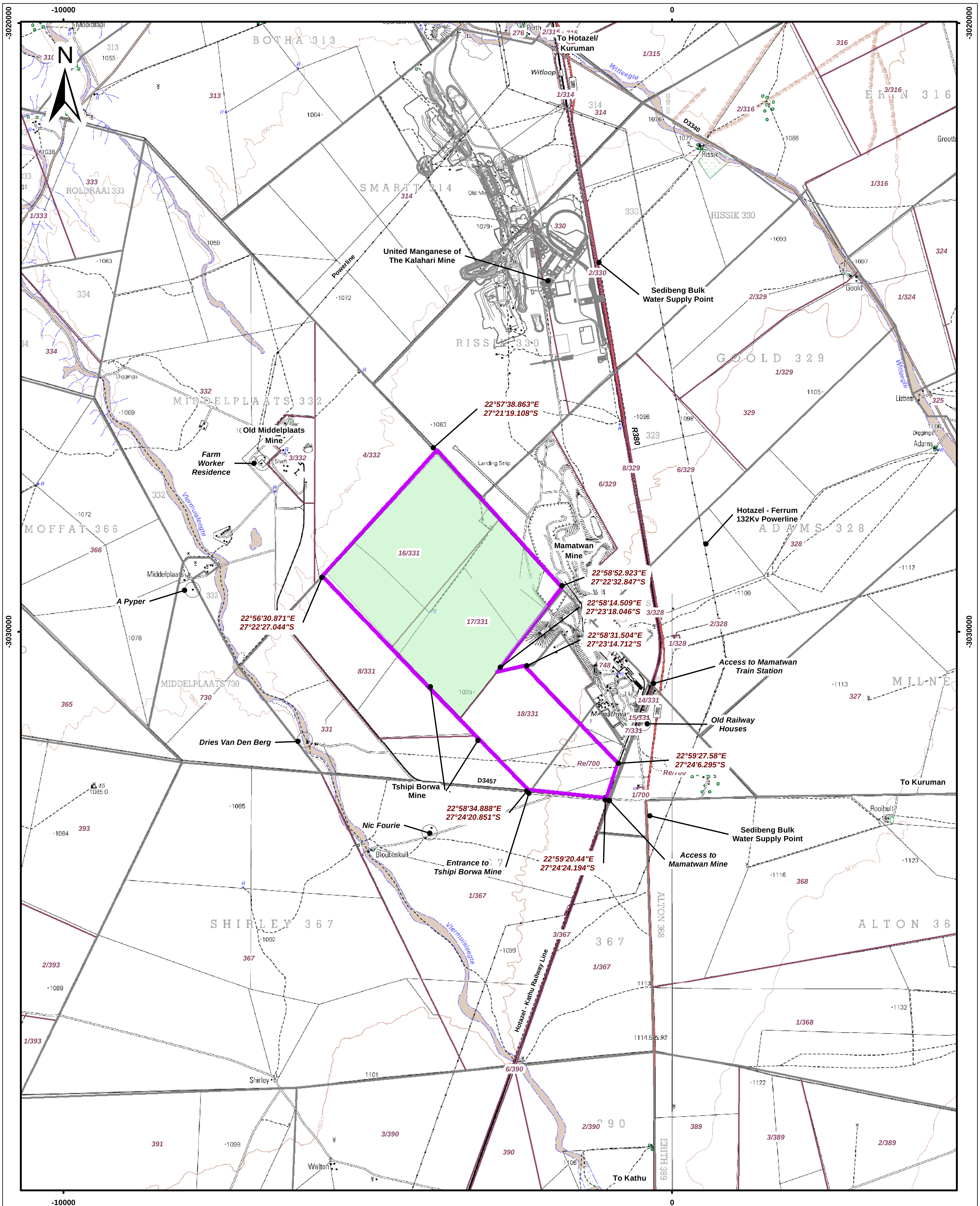
**Regional Setting**

SLR

SLR Consulting (Africa) (Pty) Ltd
P O Box 1596, Cramerview, 2060, South Africa
Tel: +27 (11) 467-0945 Fax: +27 (11) 467-0978

710.21029.00008

2017/07/18




## Legend

- Approved Mining Right Area
- Surface Use 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 1-2**

**Local Setting**

SLR Consulting (Africa) (Pty) Ltd
P O Box 1596, Cramerview, 2060, South Africa
Tel: +27 (11) 467-0945 Fax: +27 (11) 467-0978

710.20029.00008

2017/07/18

# 2 DETAILS OF SPECIALIST

Geohydrologist Mihai Muresan prepared this groundwater report, with assistance from Linda Munro, an environmental assessment practitioner. The details of the report authors are provided in Table 2-1 below.

**TABLE 2-1: DETAILS OF REPORT AUTHORS**

| Details | Project manager, author and reviewer | Co-author |
|---|---|---|
| Name | Mihai muresan | Linda Munro |
| Tel No.: | 011 467 0945 | 011 467 0945 |
| Fax No.: | 011 467 0978 | 011 467 0978 |
| E-mail address | Mmuresan@slrconsulting.com | lmunro@slrconsulting.com |
| Key qualifications | M.Sc. in Hydrogeology and Engineering Geology | M.Sc. in Environmental Science |
| Experience | Over 25 years | Over 15 years |
| Professional registration | South African Council for Natural Scientific Professions: registration number | South African Council for Natural Scientific Professions: registration number |

# 3 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.

# 4 GEOGRAPHICAL SETTING

## 4.1 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 Malopa 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 2 km 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 Mamatwan Mine, the old Middelplaats Mine and the 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).

## 4.2 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 4-1 below.

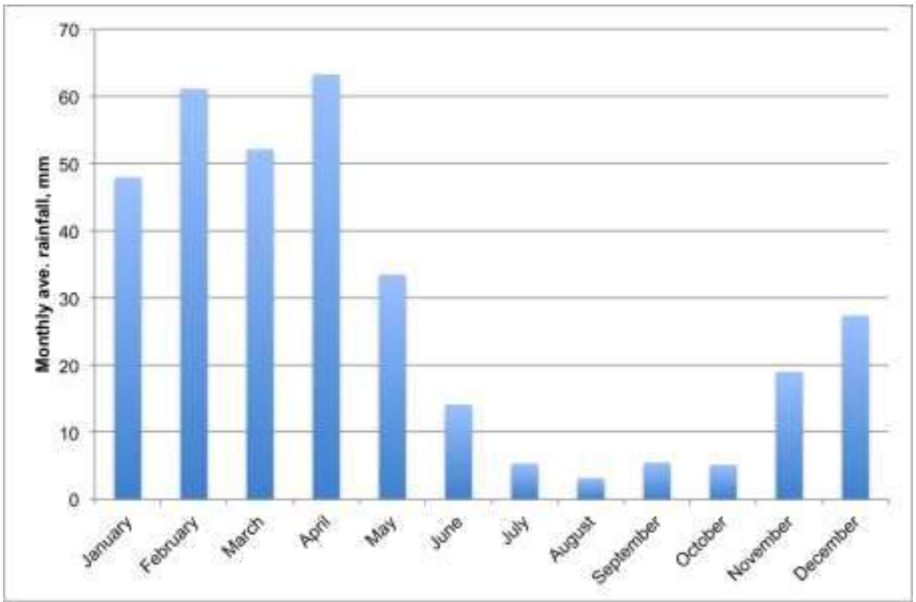



**FIGURE 4-1: AVERAGE ANNUAL RAINFALL**

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.

# 5 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 dewatering and contamination groundwater impacts. The changes to project activities and infrastructure can be grouped into:

1. Relocation of approved surface infrastructure
2. Design changes
3. The establishment of additional facilities and activities.

The relocation of approved surface infrastructure includes:

- The western waste rock dump
- The low grade and fines stockpiles
- The sewage treatment plant
- The dirty water dams
- The 78 Ml stormwater dam
- The plant offices, workshops and related infrastructure.

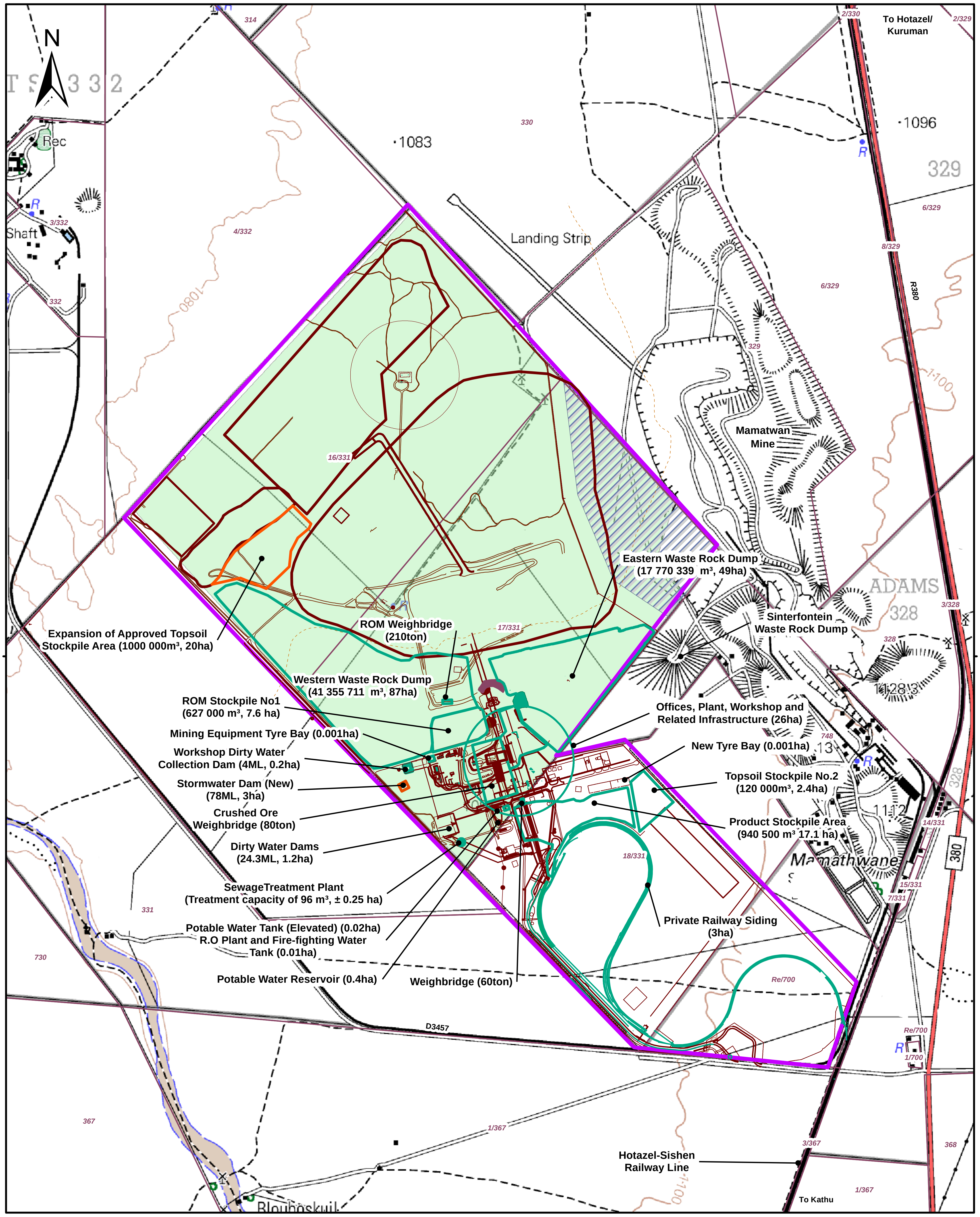
Design changes involve the following infrastructure:

- The dirty water dams
- The railway siding
- The sewage treatment plant
- The potable water storage facilities
- The expansion of approved topsoil stockpile area

The establishment of additional facilities and activities includes:

- The establishment of the eastern waste rock dump
- The waste rock dump merge
- Topsoil stockpile area (No. 2)
- The temporary ROM stockpile area
- The workshop dirty water collection dam
- The clean and dirty water separation
- The tyre bays
- The additional weighbridges
- Mining of the barrier pillar.

The revised surface layout is provided in Figure 5-1. This groundwater study focussed on the mining of the barrier with associated backfilling and changes to waste rock dumps.




## Legend

- Surface Use Area
- Approved Mining Right Area
- Changes to Approved Layout (already implemented)
- Mine Infrastructure (no changes to approved infrastructure layout)
- Proposed Changes to Approved Layout
- Barrier Pillar

0 500 1 000 Meters

Scale: 1:25 000 @ A3

Projection: Transverse Mercator
Datum: WGS1984, Lo23

Tshipi é Ntle Manganese Mining (Pty) Ltd

**Figure 5-1**

**Revised Surface Layout**

SLR Consulting (Africa) (Pty) Ltd
P O Box 1596, Cramerview, 2060, South Africa
Tel: +27 (11) 467-0945 Fax: +27 (11) 467-0978

710.20029.00008

2017/07/18

# 6 METHODOLOGY

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

## 6.1 DESK STUDY

A desk study was undertaken to collate all pertinent data:

- 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 6-1.

**TABLE 6-1: SOURCES OF DATA**

| Project | Document Title | Author and Reference | Document Date |
|---|---|---|---|
| Hydrocensus | TSHIPI Hydrocensus field report | Metago Environmental Engineers (Pty) Ltd U002-01 | June 2006 |
| Ntsimbintle Groundwater Assessment | Groundwater investigation for Ntsimbintle mine | Water Geosciences Consulting Ntsimbintle 27/02/09 | February 2009 |
| Hydrocensus | Tshipi Borwa Mine: Hydrocensus Study | Knight Pièsold Consulting RI301-00321/02 | 2012/08/01 |
| Pit Lake Study | Hydrogeological Assessment for Mine Closure Planning - Pit Lake Formation - Site Report and Analytical Model | SLR Consulting (Africa) (Pty) Ltd 721.20008.00015 | November 2012 |
| Geochemical Assessment | Geochemical and Groundwater Assessment | SLR Consulting (Africa) (Pty) Ltd 710.20008.00008 | March 2014 |
| Groundwater Risk Assessment | Tshipi Borwa New Waste Rock Dump Groundwater Risk Assessment | SLR Consulting (Africa) (Pty) Ltd 710.20008.00028 | April 2015 |
| Waste Type Assessment | Waste classification assessment for Tshipe e Ntle Mine | Golder Associates Africa (Pty) Ltd 1541973-301423-1 | February 2016 |
| Environmental Monitoring Report | 4th Quarterly Water Monitoring Report and Annual Water Quality Report: 2015-2016. | SLR Consulting (Africa) (Pty) Ltd 755.20029.00005 | February 2016 |
| Environmental Monitoring Report | Tshipi Borwa Mine: Water Monitoring Report Quarter 2: October 2016 | SLR Consulting (Africa) (Pty) Ltd 710.20008.00035 | December 2016 |

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).

The mining information was transmitted by the Tshipi Mine and consisted of current and future mining plans, current waste rock dumps, and the mine plans 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 (refer to Table 6-2 and Figure 6-1)
- Aquifer characteristics and recharge

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

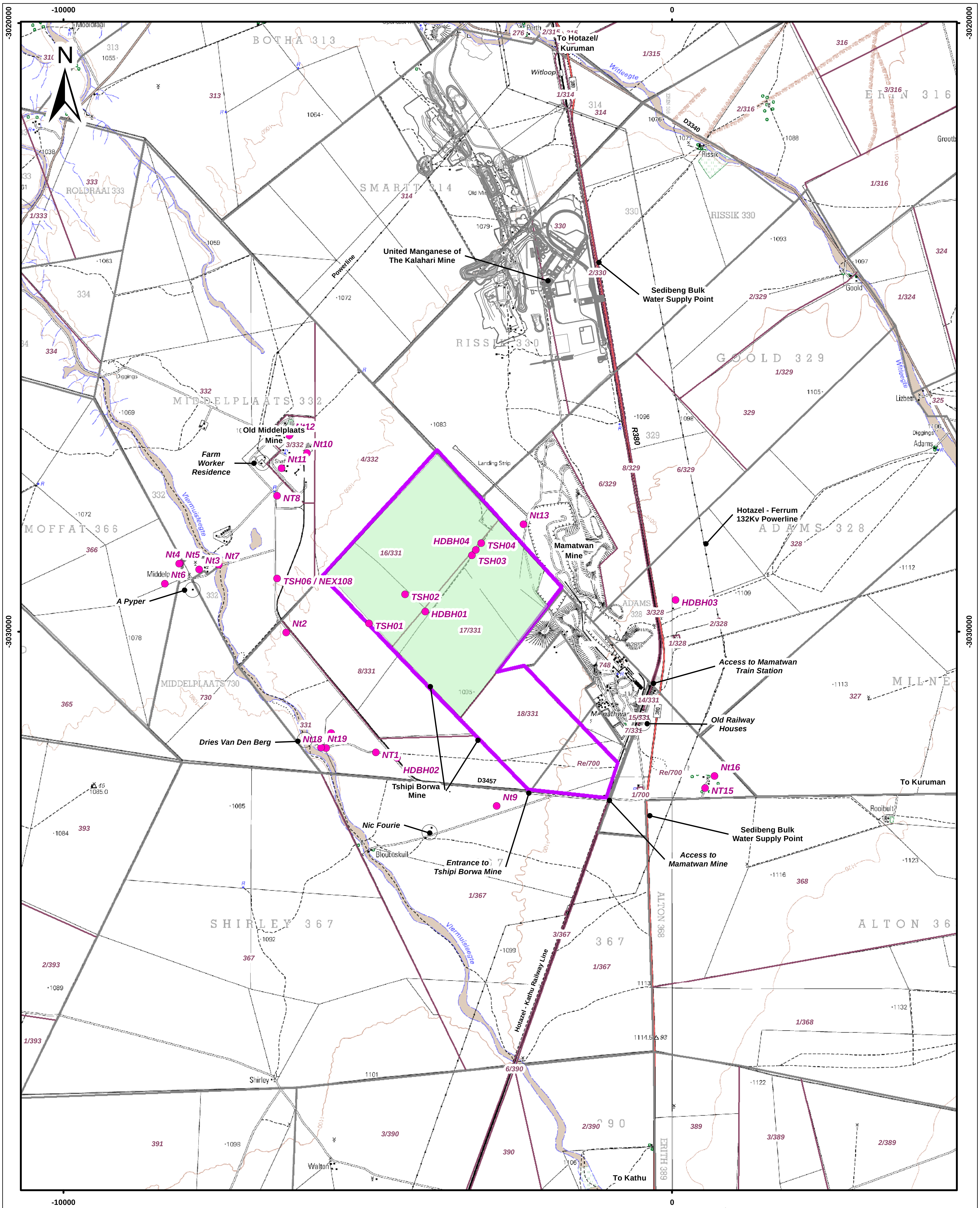
**TABLE 6-2: SUMMARY OF HYDROCENSUS BOREHOLES (METAGO, 2009)**

| 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 & 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" | - |

| Site name | Farm Name | Water point type | Water use | Longitude | Latitude | Water level (mbgl) |
|---|---|---|---|---|---|---|
| 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
- Approved Mining Right Area
- Surface Use 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 6-1**

**2009 Hydrocensus Points**

SLR

SLR Consulting (Africa) (Pty) Ltd
P O Box 1596, Cramerview, 2060, South Africa
Tel: +27 (11) 467-0945 Fax: +27 (11) 467-0978

710.20029.00008

2017/07/18

### 6.2 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 9.

# 7 PREVAILING GROUNDWATER CONDITIONS

## 7.1 GEOLOGY

### 7.1.1 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 Table 7-1.

**TABLE 7-1: 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="10">Transvaal Supergroup</td><td rowspan="10">Postmansburg Group</td><td rowspan="9">Voelwater Subgroup</td><td>Mooidraai Formation</td><td>Dolomite, chert</td></tr>
<tr><td rowspan="8">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.

### 7.1.2 LOCAL GEOLOGY

Tshipi Mining is exploiting 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 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).

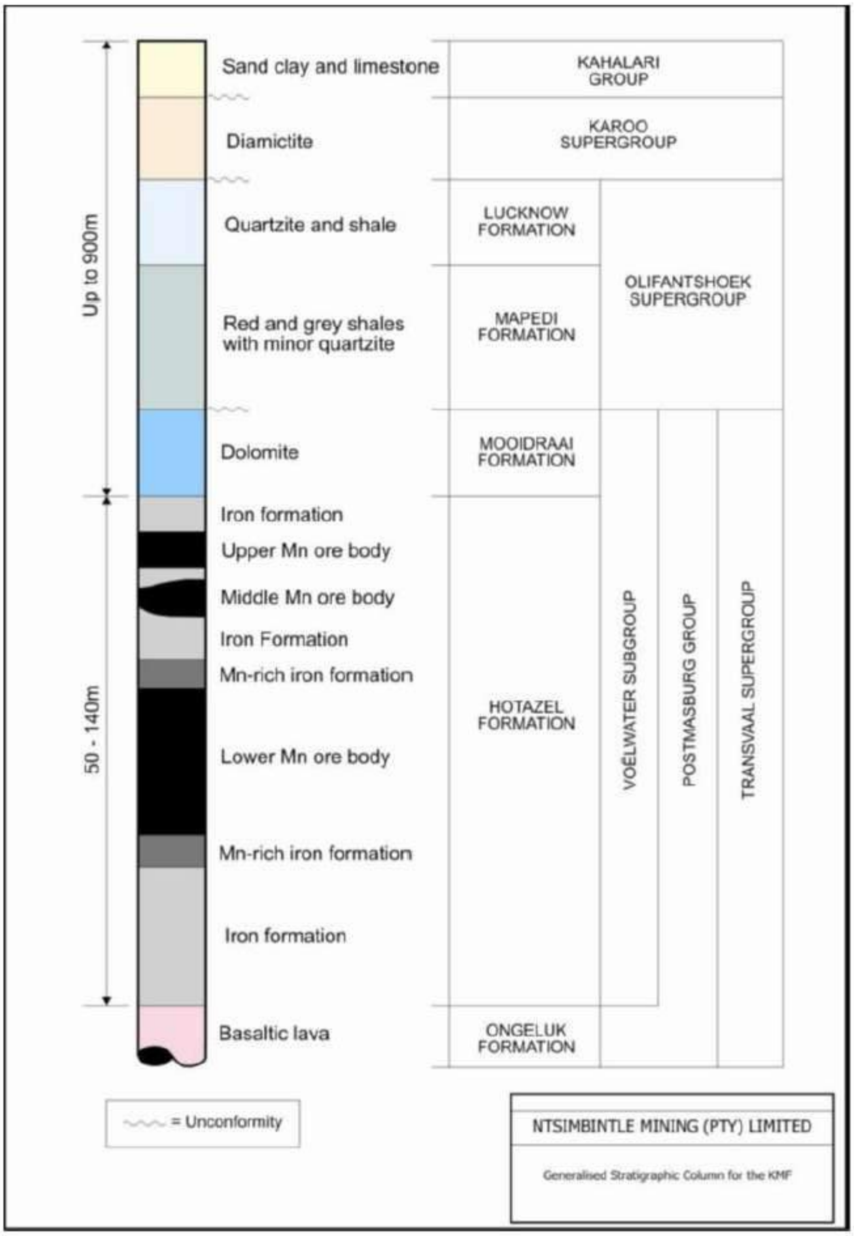



**FIGURE 7-1: GENERALISED STRATIGRAPHIC COLUMN FOR THE KMF (SOURCE: TSHIPI BORWA)**

## 7.2 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 (refer to Table 7-2). 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 twenty three samples were analysed. The results are provided in Table 7-3 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 7-2: 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 7-3: 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 | 0.05 | 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 | <0.025 | <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 | 0.09 | <0.025 | 3 | <0.025 |
| 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 |
| 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 |

## 7.3 HYDROGEOLOGY

### 7.3.1 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.

### 7.3.2 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 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).

### 7.3.3 HYDRAULIC CONDUCTIVITY

Information from the WGC 2015 and SLR 2014 report provide permeability values (K) (Table 7-5). The relevant climatic data on which this permeability was based in provided in Table 7-4. In addition the modelled groundwater pit ingress with associated permeability is provided in Table 7-6, sourced from WGC reports.

**TABLE 7-4: CLIMATIC PARAMETERS USED IN PREVIOUS MODELLING ASSESSMENTS**

| Investigation and reference | MAP (m/a) | 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 |

na: Not available

**TABLE 7-5: HORIZONTAL AND VERTICAL K OF GEOLOGICAL UNITS USED IN PREVIOUS MODELLING ASSESSMENTS IN METERS PER DAY**

| 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 | |
| Pit lake formation (SLR, 2012) | | 7.7 | 0.024 | 0.82 | 0.4 | 10% of K |

na: Not available

**TABLE 7-6: GROUNDWATER INFLOW IN TO 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 |

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 7-7.

**TABLE 7-7: PUMP TEST RESULTS FOR WGC01 AND MMTW BH1 (WGC, 2009)**

| Parameter | WGC01 | MMTW BH1 |
|---|---|---|
| Aquifer | Shallow | Deep fractured aquifer |
| Depth (mbgl) | 48 | 180 |
| Static Water level (mbgl) | 36.15 | 36.43 |
| Porosity (literature values) | 0.2 | $1 \times 10^{-5}$ |
| **RESULTS** | | |
| Transmissivity $m^2$/day | 1 | 9 |
| Storativity | 0.005 – 0.08 | 0.03 – 0.5 |
| Abstraction rate L/s | 0.12 for 30 minutes | 0.9 for 24 hours |

## 7.4 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 6-2 with locations shown in Figure 6-1.

Prior to mining, groundwater flow at the site was from south-east to north-west 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 3-5 km. 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 11-1. A hydrograph is provided in Figure 7-2. The results show that:

- Groundwater levels varied between 35 mbgl in TSH05 to 75 mbgl in TSH01. It follows that since the commencement of the mine, there has been a decrease in the groundwater levels
- Groundwater levels are consistent with previous data
- From the available data, it is difficult to determine groundwater flow direction; however it is likely to follow topography towards the Vlermuisleegte Stream, to the west of the site as indicated by previous studies.

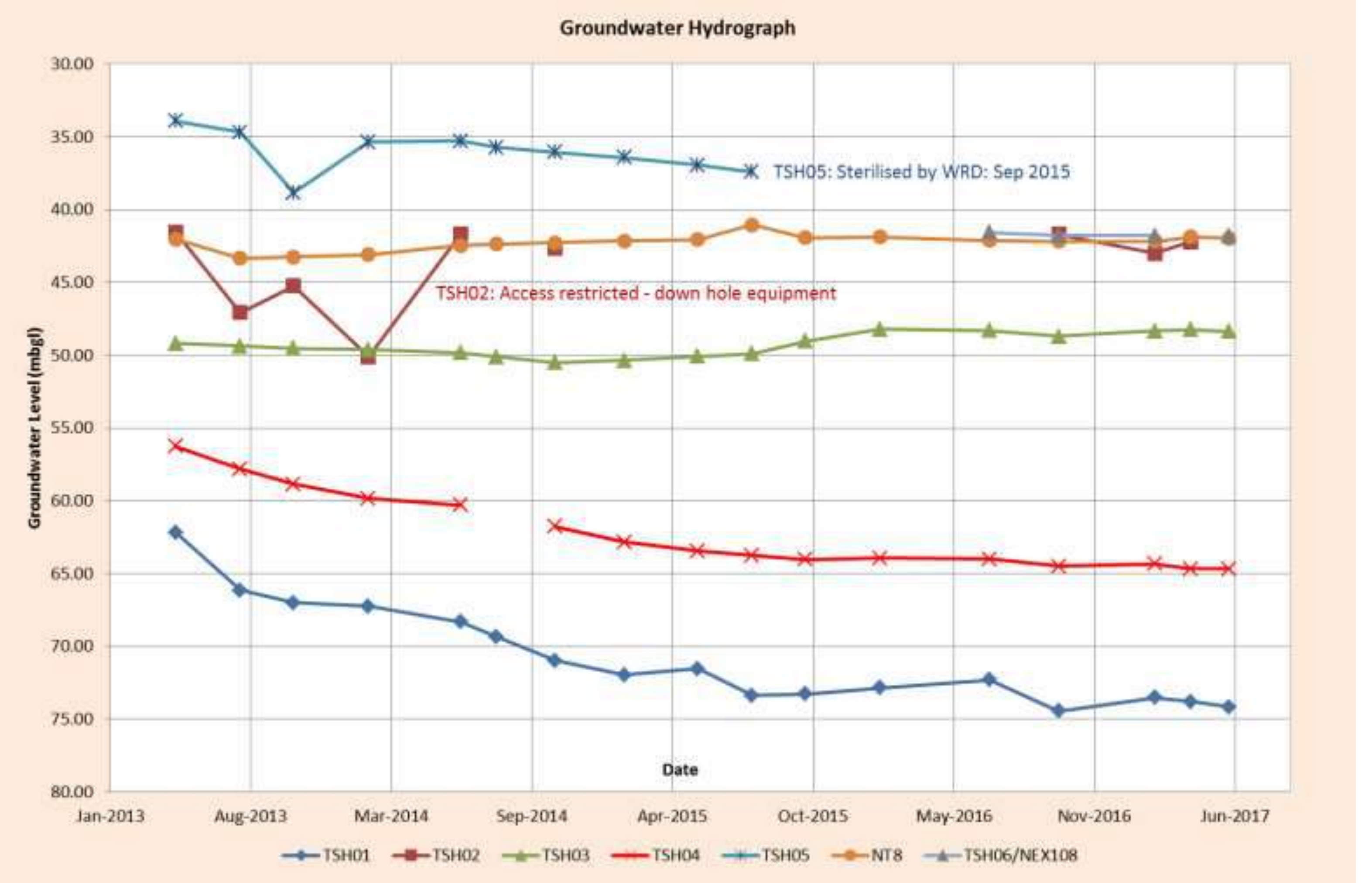



**FIGURE 7-2: GROUNDWATER HYDROGRAPH (mbgl)**

## 7.5 GROUNDWATER QUALITY

Borehole samples collected during the 2009 hydrocebsus were analysed and the results were compared to the South African National Standards (SANS) standard for domestic use (SANS 241:2005). The results were also classified in terms of their suitability for domestic water supplies based on the classification compiled by the Water Research Commission (WRC) together with DWAF and the Department of Health. Table 7-8 shows the various classes defined.

**TABLE 7-8: WATER CLASS GUIDELINE VALUE**

| | |
|---|---|
| Class 0 | Ideal water quality - suitable for lifetime use |
| Class 1 | Good water quality - suitable for use, rare instances of negative effects |
| Class 2 | Marginal water quality - conditionally acceptable. Negative effects may occur in some sensitive groups. |
| Class 3 | Poor water quality - unsuitable for use without treatment. Chronic effects may occur. |
| Class 4 | Dangerous water quality - totally unsuitable for use. Acute effects may occur. |

The sampling results showed that the groundwater quality in the area ranged from marginal to dangerous (DWAF classification of Class 2 and 4). This was mainly due to elevated nitrate levels (refer to Table 7-9). These trends are most probably linked to anthropogenic pollution from farming or mining activities (WGC, 2009).

**TABLE 7-9: SUMMARY OF GROUNDWATER QUALITY (METAGO, 2009)**

| Analyses in mg/l | SANS water quality guidelines for domestic use | | Site Reference | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Class 1 | Class 2 | Nt6 | Nt8 | Nt9 | Nt14 | Nt15 | Nt17 | Nt18 | WGC2 |
| pH Value at 25°C | 5.0 – 9.0 | 4.0 – 10.0 | 7.3 | 7.7 | 7.9 | 7.5 | 7.0 | 7.4 | 7.2 | 8.2 |
| EC in mS/m | <150 | 150 – 370 (7yrs) | 96.6 | 179 | 82.0 | 101 | **396** | 186 | 243 | 95.6 |
| Total Dissolved Solids at 180°C | <1000 | 1000 – 2400 (7 yrs) | 696 | 1208 | 420 | 592 | **2910** | 1340 | 1650 | 622 |
| Total Alkalinity as $CaCO_3$ | N/A | N/A | 392 | 264 | 316 | 380 | 264 | 304 | 292 | 240 |
| Nitrate as N | <10 | 10–20 (7 yrs) | 11 | 0.2 | 14 | 16 | **175** | **111** | **101** | **21** |
| Chloride as Cl | <200 | 200–600(7 yrs) | 50 | 176 | 40 | 56 | **743** | 172 | 304 | 88 |
| Sulphate as $SO_4$ | <400 | 400–600 (7 yrs) | 16 | 481 | 25 | 47 | 51 | 52 | 126 | 45 |
| Fluoride as F | <1.0 | 1 – 1.5 (1 yr) | 0.5 | 0.6 | 0.2 | 0.2 | <0.2 | 0.4 | 0.4 | 0.5 |
| Calcium as Ca | <150 | 150-300 (7 yrs) | 83 | 132 | 48 | 84 | **377** | 141 | 175 | 23 |
| Magnesium as Mg | <70 | 70-100 (7 yrs) | 52 | 59 | 36 | 45 | **184** | **104** | **123** | 48 |
| Sodium as Na | <200 | 200–400(7 yrs) | 46 | 152 | 74 | 45 | 62 | 85 | 88 | 100 |
| Potassium as K | <50 | 50-100 (7 yrs) | 4.4 | 2.6 | 3.0 | 2.8 | 6.0 | 6.6 | 7.0 | 5.7 |
| **Classification of the water (the parameter listed are those responsible for the class of the water)** | | | Nitrate | EC, TDS, SO4 | Nitrate | Nitrate | Nitrate | Nitrate | Nitrate | Nitrate |

Groundwater and surface water monitoring has been undertaken at the mine on a quarterly basis since 2012. When results against relevant water quality standards, the following chemicals of concern were identified:

- Electrical Conductivity (EC)
- Total Dissolved Solids (TDS)
- Chloride (Cl)
- Nitrate ($NO_3$)
- Aluminium (Al)
- Arsenic (As)
- Iron (Fe)
- Manganese (Mn)
- Molybdenum (Mo)
- Nickel (Ni)
- Selenium (Se)

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)** concentrations in boreholes NT15 and TSH05 generally exceed the SANS 241:2015 Aesthetics limit (1700 uS/cm) for most of the monitoring period – refer to Figure 7-3. The baseline EC concentration measured in 2009 (Metago) in NT15 was 3960 uS/cm, which well exceeded the SANS 241:2015 Aesthetics limit. There is a steady increase in the EC of TSH04 and TSH06/NEX108 over the entire monitoring period. TSH04 exceeded the SANS 241:2015 limit for the first time during in February 2017 and this trend continued in the April 2017 (the latest sampling run). Times series plot for EC is presented in Figure 7-3.

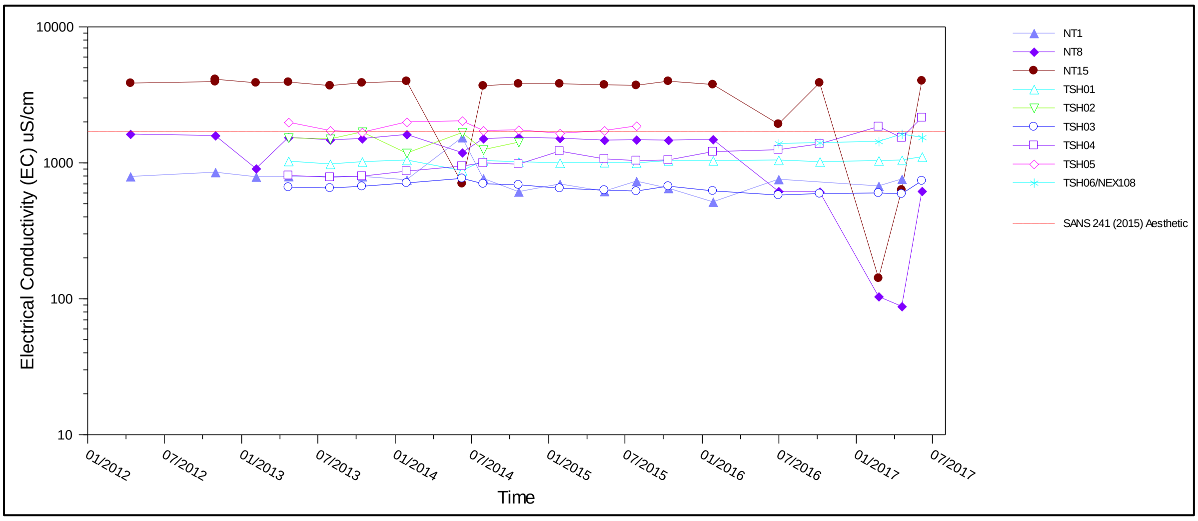



**FIGURE 7-3: ELECTRICAL CONDUCTIVITY TIME SERIES PLOT**

**Total Dissolved Solids (TDS)** concentration in NT15 exceeded the DWAF Target Water Quality Guideline (TWQG) for Livestock Watering (dairy, pigs and poultry – 1000 mg/L) and SANS 241:2015 Aesthetic limit (1200 mg/L) for most of the monitoring period since 2012. The baseline TDS concentration (Metago, 2009) in NT15 was 2910 mg/L which already exceeded both of these limits. TDS in NT8 and TSH05 often exceeded the SANS 241:2015 Aesthetic limit. The baseline TDS concentration (Metago, 2009) in NT8 was 1208 mg/L which slightly exceeded this limit. Since June 2016 TDS concentration in NT8 has decreased to concentrations below 400 mg/L. Similarly TDS concentrations in NT15 also showed a significant decrease in 2017 although this rebounded in the latest sampling run. These trends will continue to be monitored. Time series plot for TDS is presented in Figure 7-4.

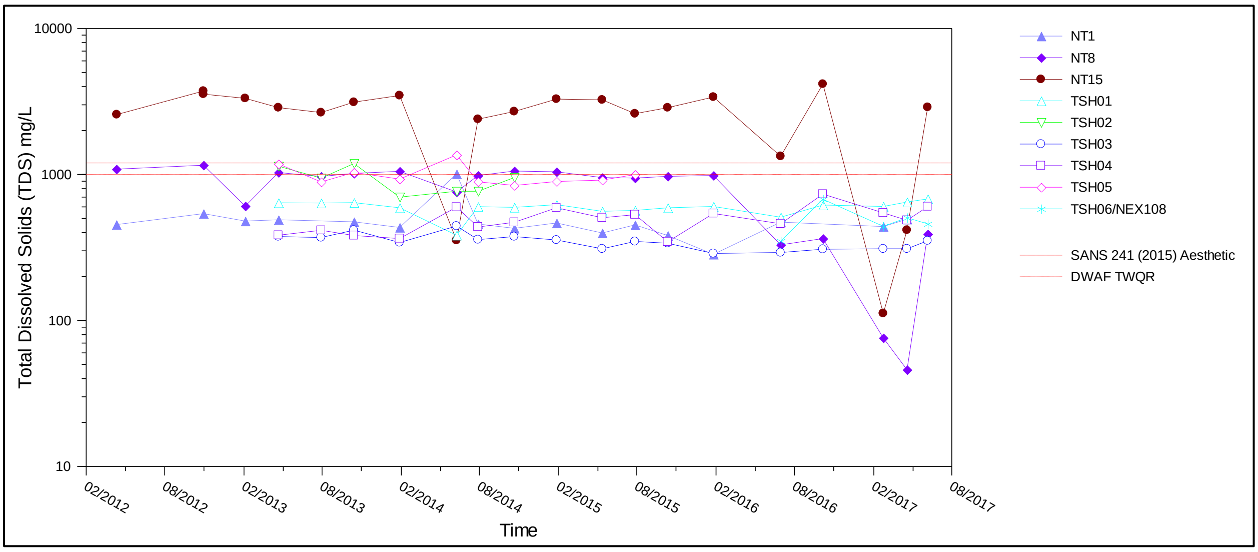



**FIGURE 7-4: TOTAL DISSOLVED SOLIDS CONCENTRATION TIME SERIES PLOT**

**Nitrate ($NO_3$)** concentrations in NT15 exceeded the SANS 241:2015 Acute health (11 mg/L) and NT15 exceeded the SANS and the DWAF TWQG for Livestock Watering (22 mg/L) limits for most of the monitoring period since 2012. The baseline $NO_3$ concentration measured in 2009 (Metago) in NT15 was 175 mg/L which already far exceeded these limits. Nitrate concentrations in TSH01 generally exceeded the DWAF TWQR for Livestock Watering for most of the monitoring period since 2012. Nitrate concentrations in TSH02 and TSH05 exceeded both the SANS 241:2015 Acute health and DWAF TWQR for Livestock Watering at times. The baseline $NO_3$ concentration (Metago, 2009) in NT8 was 0.2 mg/L and has remained below the limits for the entire monitoring period since 2012. Time series plot for $NO_3$ is presented in Figure 7-5.

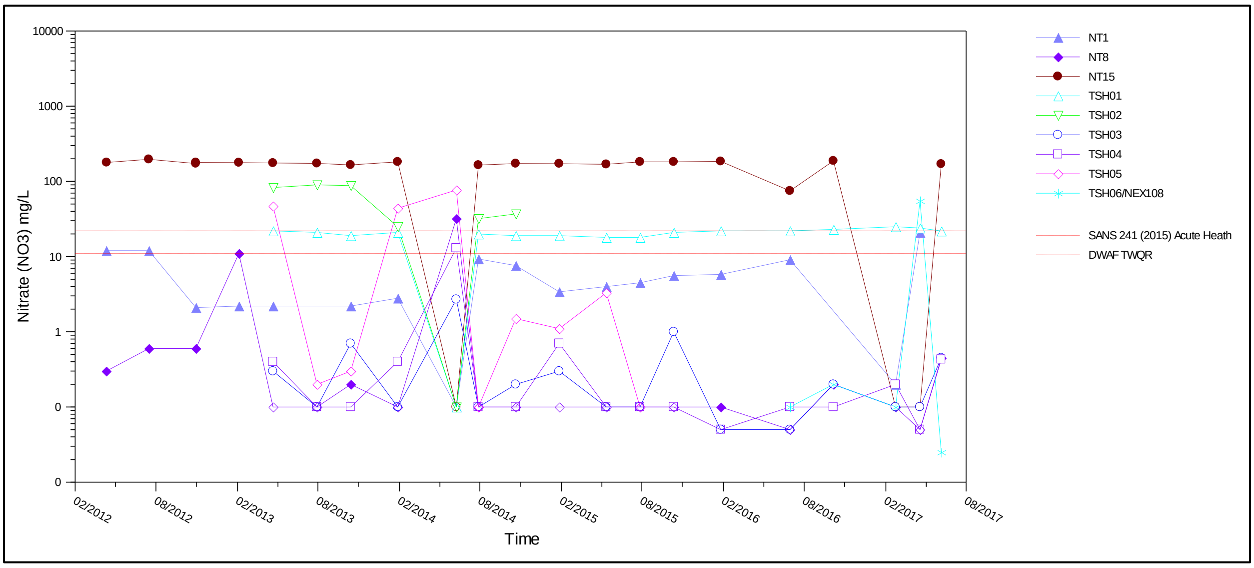



**FIGURE 7-5: NITRATE CONCENTRATION TIME SERIES PLOT**

**Chloride (Cl)** concentrations in exceeded the SANS 241:2015 Aesthetic limit (300 mg/L) for most of the monitoring period since 2012. The baseline Cl concentration measured in 2009 (Metago) in NT15 was 743 mg/L and already significantly exceeded this limit. The baseline Cl concentration (Metago, 2009) in NT8 was 176 mg/L and has remained generally constant. Time series plot for Cl is presented in Figure 7-6.

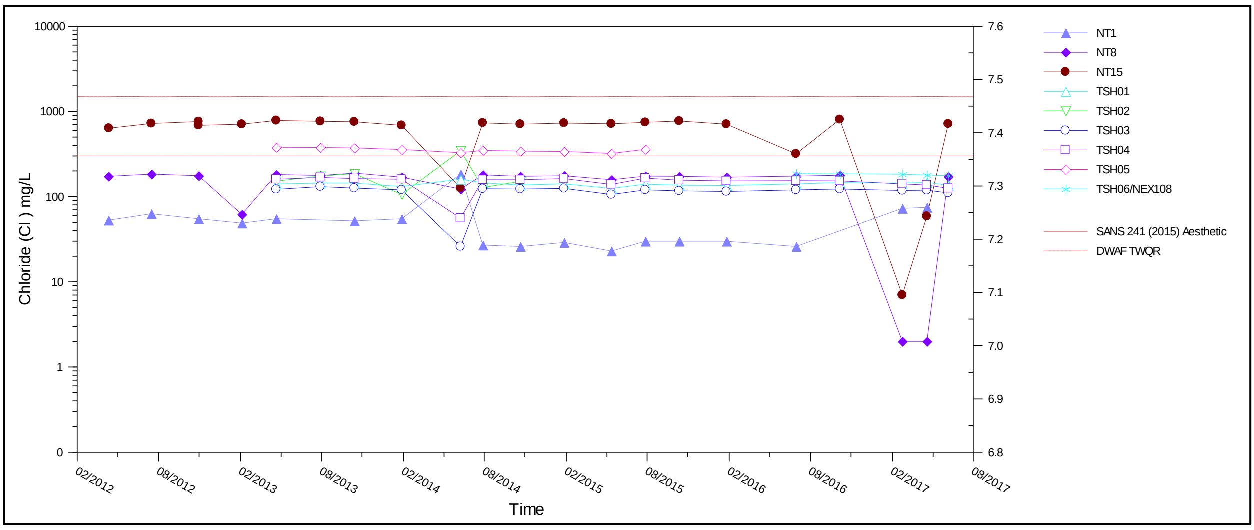



**FIGURE 7-6: CHLORIDE CONCENTRATION TIME SERIES PLOT**

**Manganese (Mn)** concentrations in NT15, NT8, TSH01, TSH02, TSH03, TSH05, TSH06 exceeded the SANS 241:2015 Chronic health limit (0.4 mg/L) for most of the monitoring period since 2012. All boreholes remained below the DWAF TWQG for Livestock Watering (10 mg/L) limit. No baseline Mn data is available. The time series plot for Mn is presented in Figure 7-7.

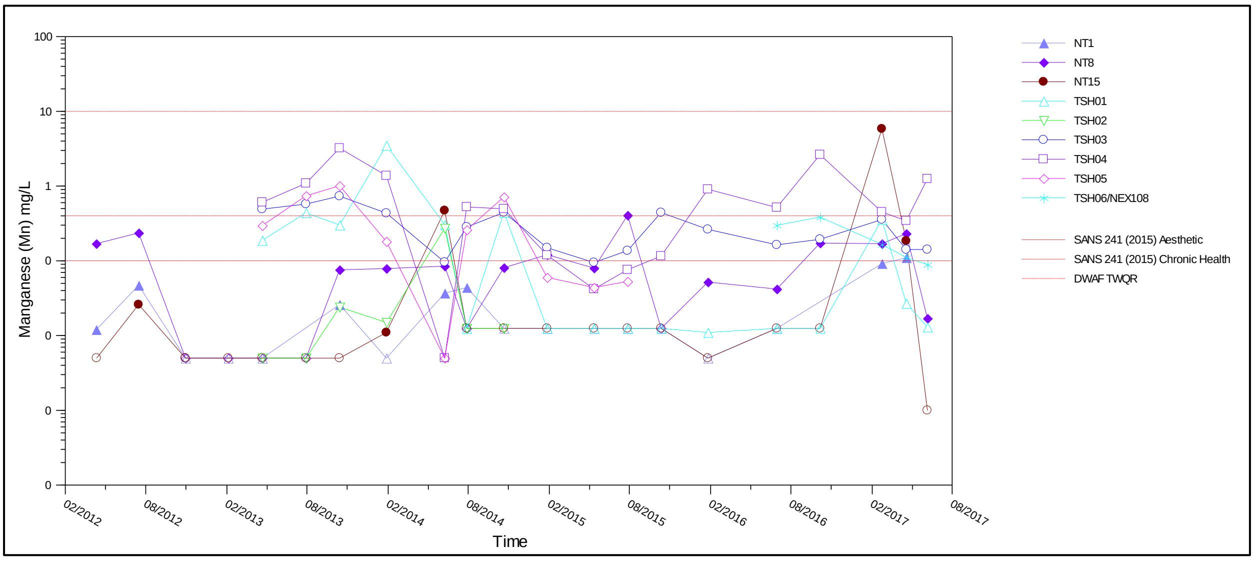



**FIGURE 7-7: MANGANESE CONCENTRATION TIME SERIES PLOT**

**Molybdenum (Mo)** concentrations in NT8 exceeded the SANS 241:2015 Aesthetic limit (10 ug/L) limit for most of the monitoring period since 2012. NT15 and TSH06 also exceeded this limit at times. No baseline Mo information is available. Time series plot for Mo is presented in Figure 7-8.

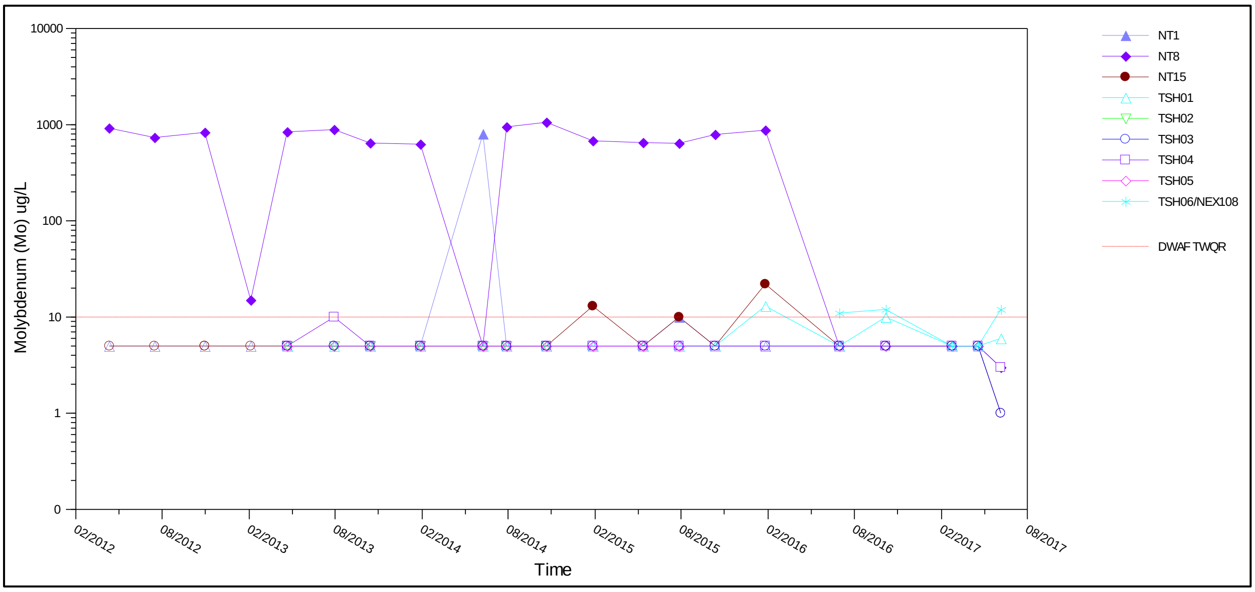



**FIGURE 7-8: MOLYBDENUM CONCENTRATION TIME SERIES PLOT**

**Lead (Pb)** concentrations in TSH03, TSH01 and TSH06 exceeded the SANS 241:2015 Chronic health limit (10 ug/L) at times, while TSH01 also exceeded the DWAF TWQG for Livestock Watering (100 ug/L) limit once. No baseline Pb data is available. Time series plot for Pb is presented in Figure 7-9.

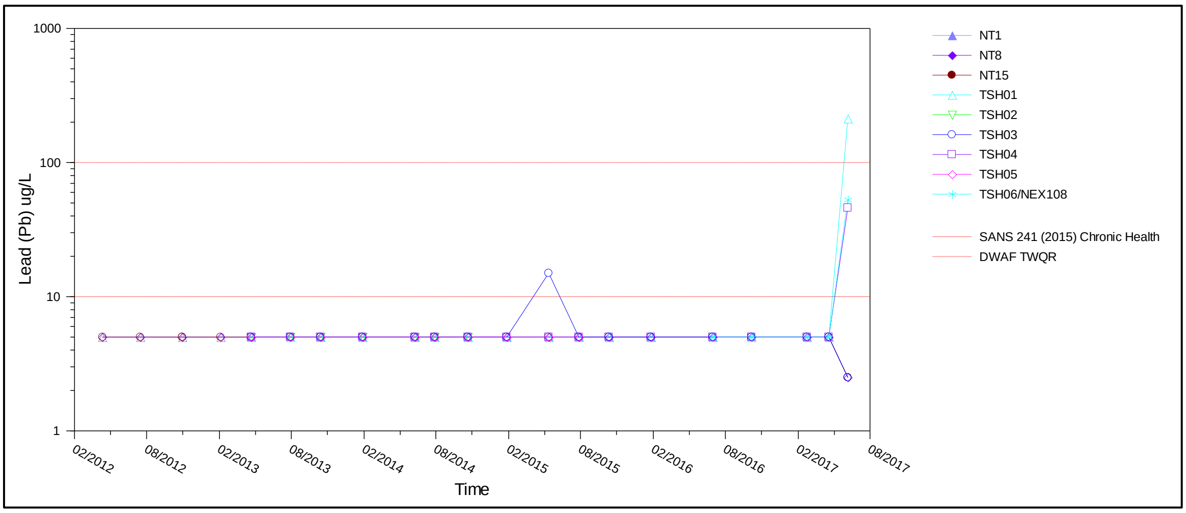



**FIGURE 7-9: LEAD CONCENTRATION TIME SERIES PLOT**

**Other observations:** It was noted that the some trace metals (B, Mo and Sr), Total alkalinity, bicarbonate, $SO_4$, TDS and major cations (Ca, Mg and Na) concentrations in NT8 have significantly decreased since the June 2016 monitoring event. In contrast to these constituents the barium (Ba) the concentration in NT8 has increased by approximately one order of magnitude. These trends will continue to be monitored.

# 8 AQUIFER CHARACTERISATION

## 8.1 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.

## 8.2 AQUIFER CLASSIFICATION

The classification scheme (refer to Table 8-1) 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 8-1: 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 | Moderately yielding aquifer (1-5 L/s) of acceptable quality or high yielding aquifer |

| Aquifer System | Defined by Parsons (1995) | Defined by DWAF Min Requirements (1998) |
|---|---|---|
| | 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. | (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 7.5).
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 adjacent to 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

## 9.1 SOFTWARE MODEL CHOICE

For successful assessment of the mining and mining related activities impacts on the groundwater environment, *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.

## 9.2 MODEL SET-UP AND BOUNDARIES

The groundwater model domain for Tshipi Mine is shown in Figure 9-1. 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 2 km 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.

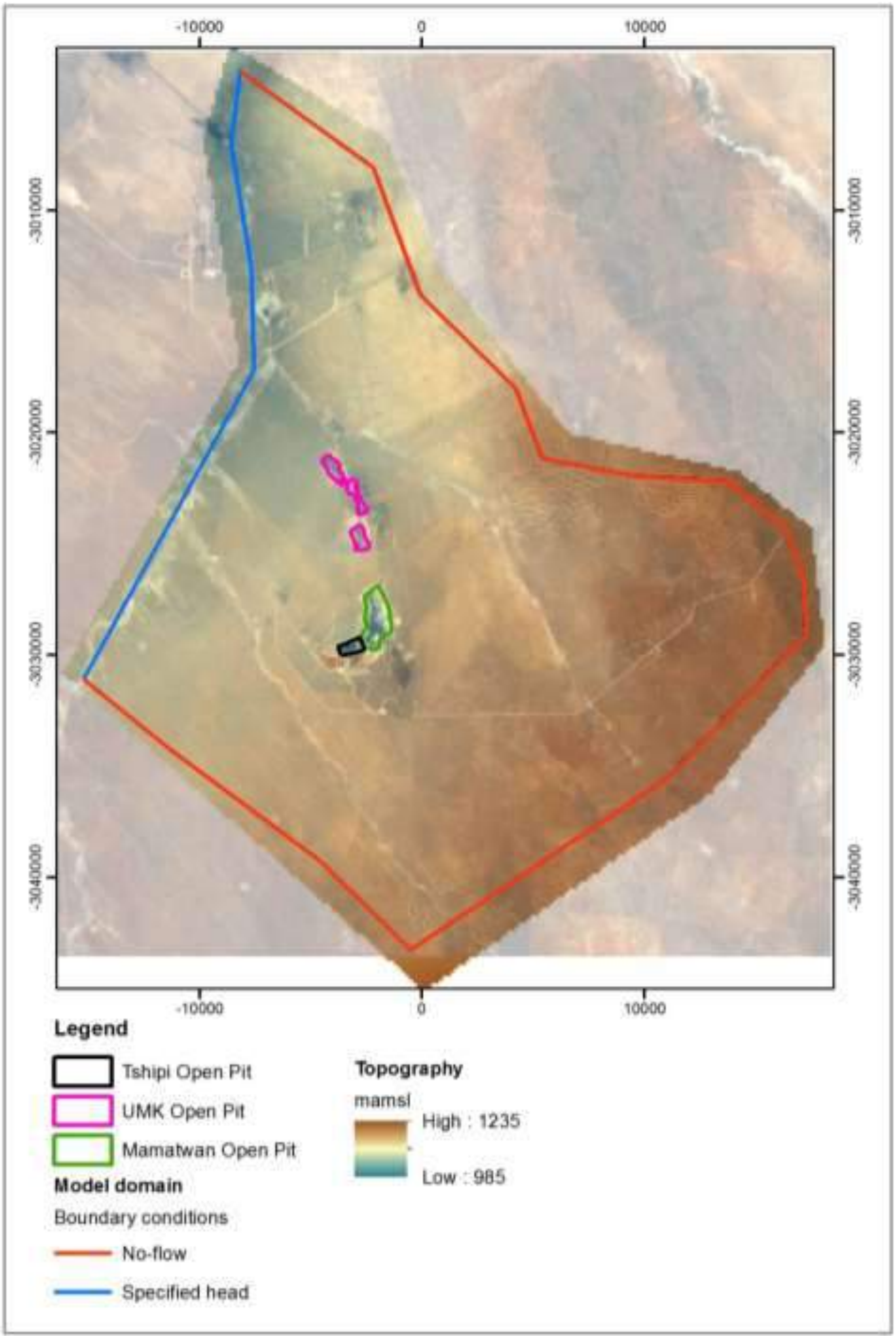



**FIGURE 9-1: TSHIPI MODEL DOMAIN**

## 9.3 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 9-2.

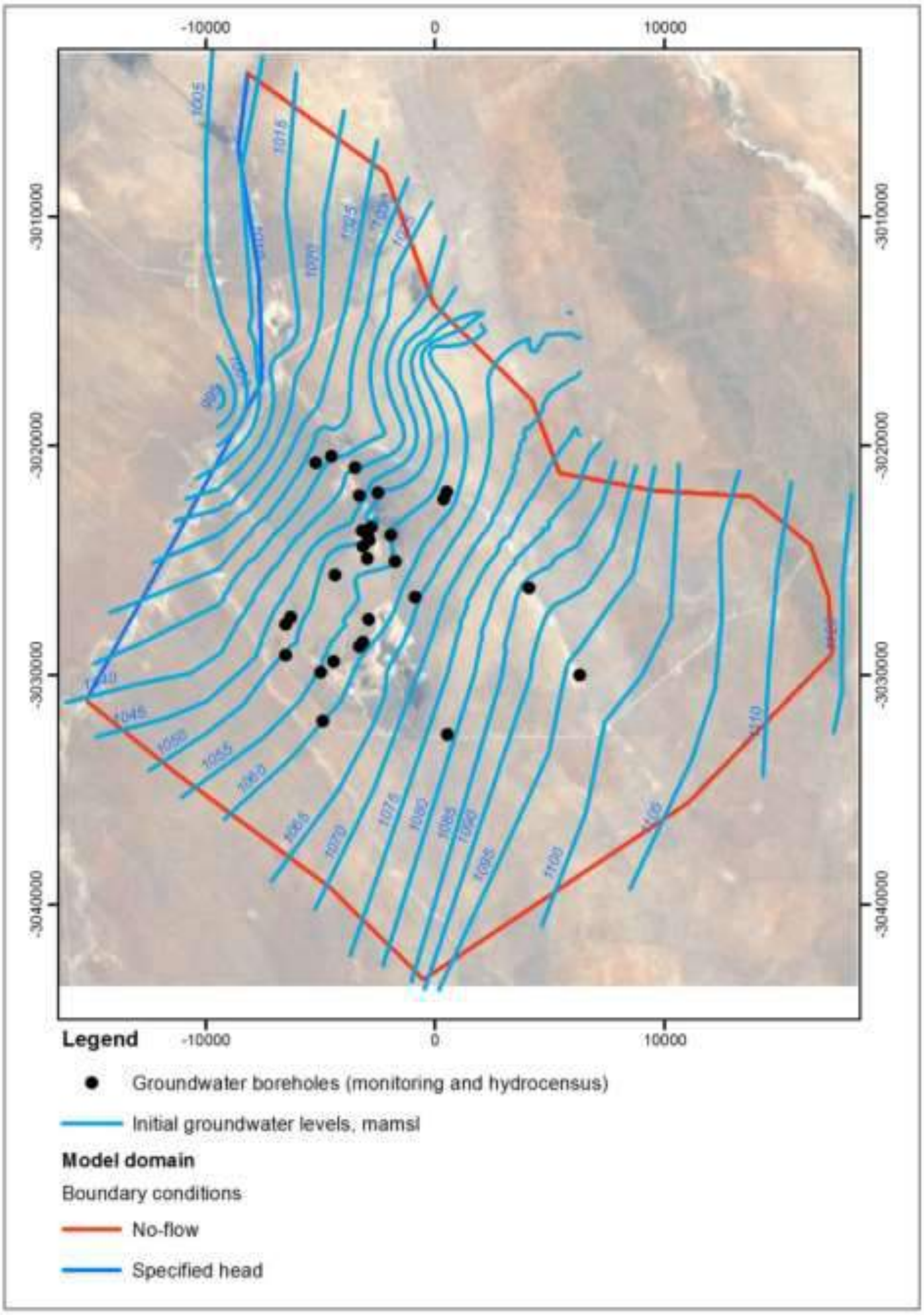



**FIGURE 9-2: INITIAL GROUNDWATER LEVELS**

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).

## 9.4 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 (M.A.P).

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 9-3):

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

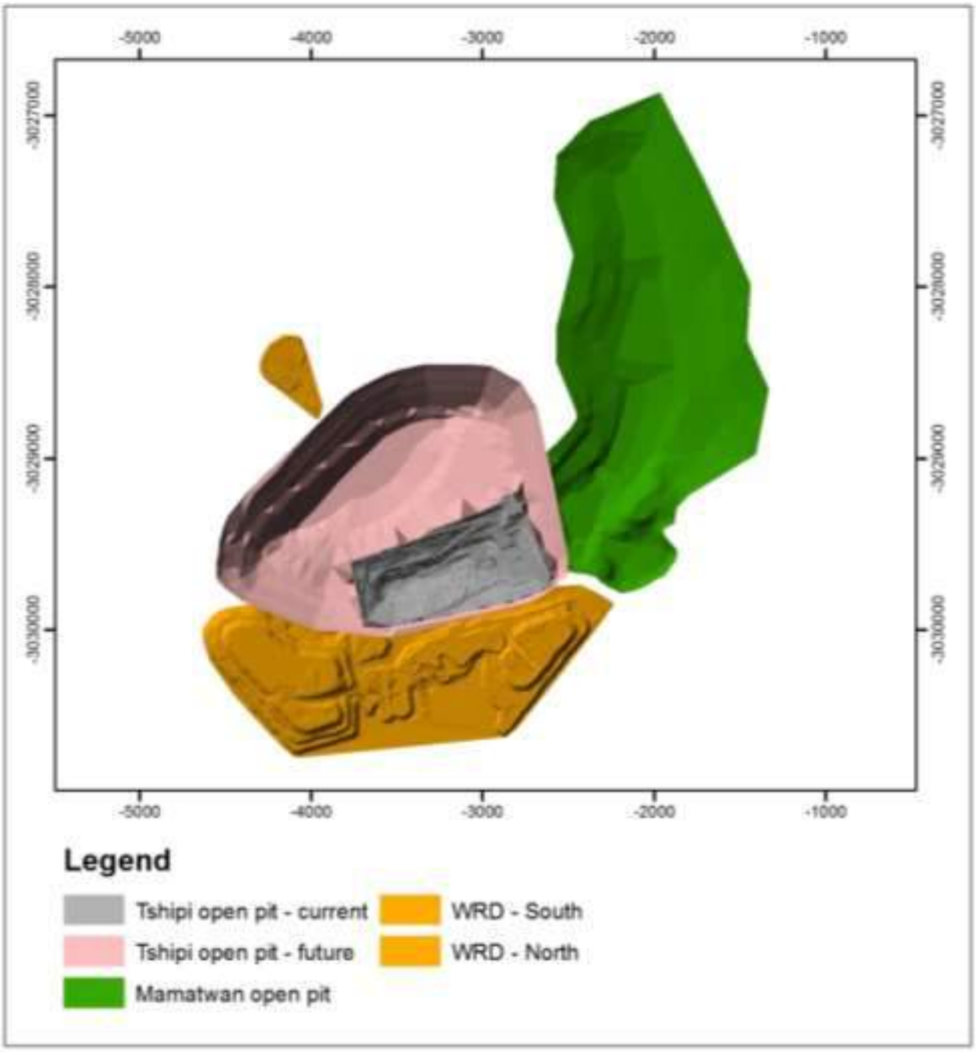



**FIGURE 9-3: TSHIPI OPEN PITS**

## 9.5 CONCEPTUAL MODEL

Figure 9-4 illustrates the hydrogeological conceptual model which forms the basis of the groundwater numerical model. The conceptual model is simplification of the real world conditions, but at the same time captures the main elements to be simulated in the numerical model.

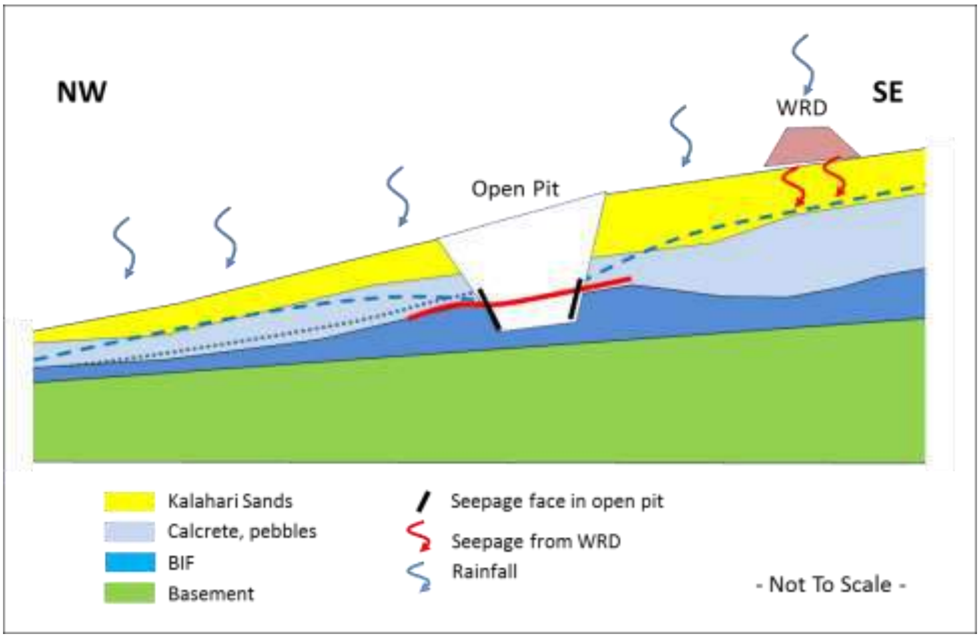



**FIGURE 9-4: TSHIPI HYDROGEOLOGICAL CONCEPTUAL MODEL**

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.

## 9.6 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
- Future mining
- Geology
- Surface water bodies.

Figure 9-5 shows the hydraulic and geochemical stress elements incorporated in the model. The resulting horizontal finite elements mesh is showed in Figure 9-6.

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 | Topo pre-mining | topo | Kalahari sands |
| 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 | |

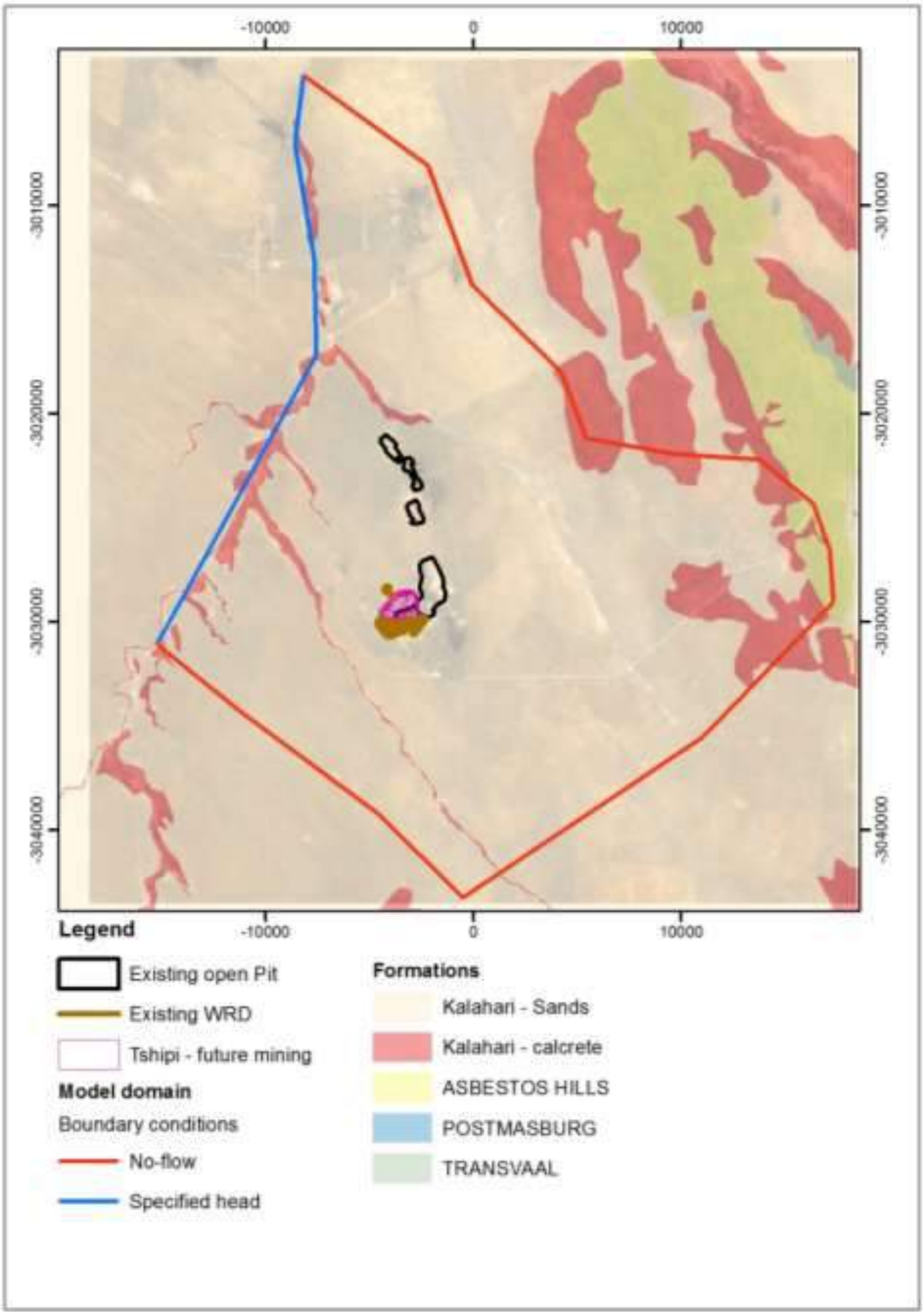



**FIGURE 9-5: PRINCIPAL HYDRAULIC AND GEOCHEMICAL STRESS ELEMENTS**

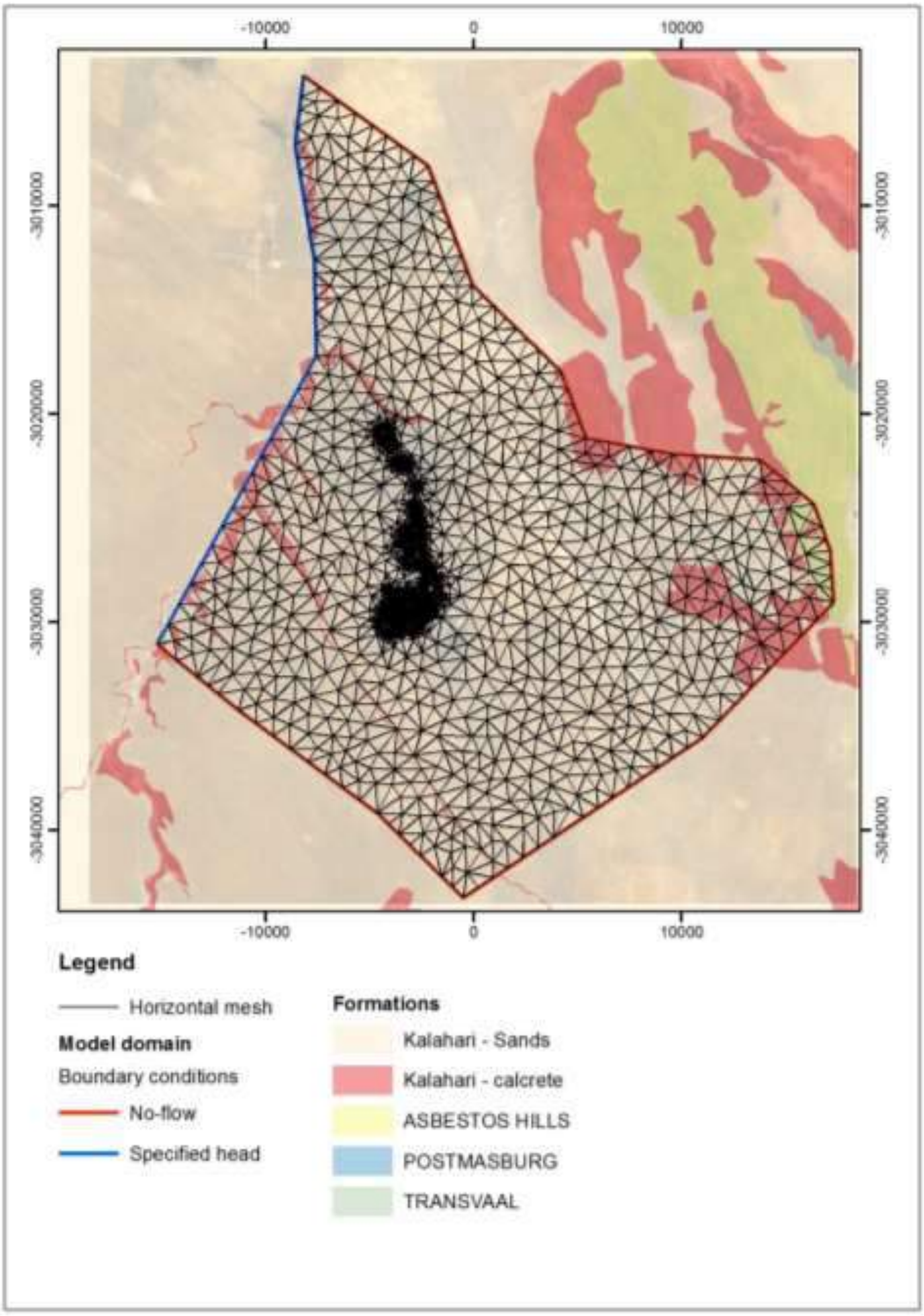



**FIGURE 9-6: GROUNDWATER MODEL HORIZONTAL MESH**

The resulting three-dimensional numerical model is illustrated in Figure 9-7, and can be summarized as follows:

- Model area: 600 km$^2$
- Model bottom elevation: 500 mamsl
- Numbers of elements: 222,075
- Number of nodes: 119,488

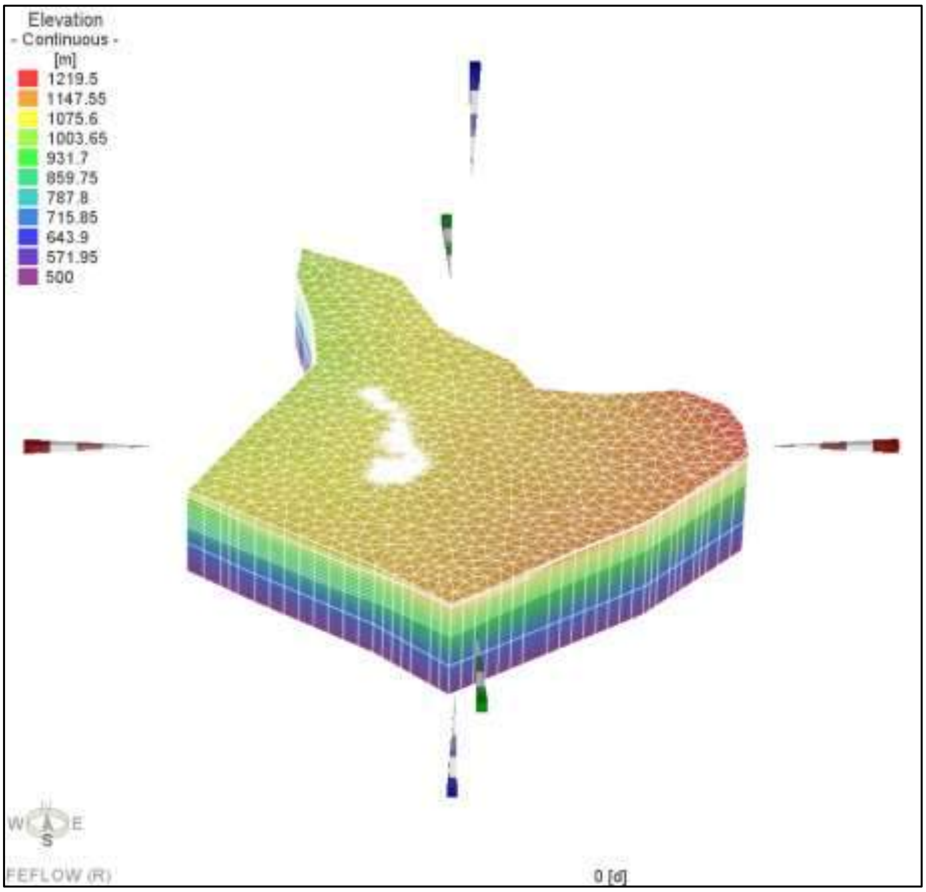



**FIGURE 9-7: THREE DIMENSIONAL NUMERICAL MODEL**

## 9.7 NUMERICAL MODEL

### 9.7.1 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 |
|---|---|---|
| Kalahari sands | 1.0/1.0 | 0.01 |
| Kalahari calcrete + pebbles | 0.5/0.05 | 0.001 |
| BIF1<br>Hotazel | 0.05/0.005<br>0.001/0.0001 | 0.001 |
| 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 x $10^{-4}$ m/d, representing 2% of M.A.P.

### 9.7.2 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 9-8 shows the plot of measured hydraulic heads vs. simulated hydraulic heads.

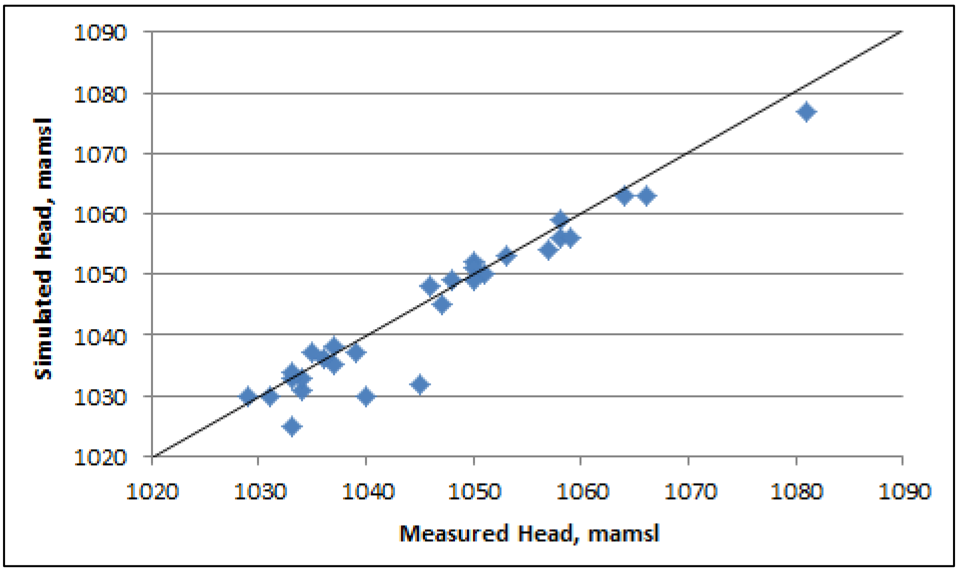



**FIGURE 9-8: HYDRAULIC HEAD – MEASURED VS SIMULATED**

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 |
| JB9 | 1031 | 1030 | 1 | 1 |

| BH | Head | Head_sim | Head_diff | Head diff^2 |
|---|---|---|---|---|
| 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.

#### 9.7.3 SIMULATION OF MINING – TRANSIENT MODE

Open pit mining was simulated as follows:

- Existing open pits, Mamatwan and UMK, were simulated as permanent inactive elements (permanent excavations) with drain (seepage) nodes on the pit faces; the seepage face nodes will only allow negative flow; negative flow constraint is translated by groundwater entering the open pits and pumped out of the system
- Existing Tshipi open pit and future Tshipi open pit were simulated as transient inactive elements with seepage face nodes
- The transient nature of active/inactive elements will allow activation of the element for backfilling; the inactive elements become active as pit backfilling takes place
- The seepage face nodes will remain active on the pits faces for as long as open pit mining take place; these are switched-of as backfilling takes place, allowing groundwater to flow into the backfill volumes, at respective times.

### 9.7.4 SIMULATION OF RECHARGE – TRANSIENT MODE

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

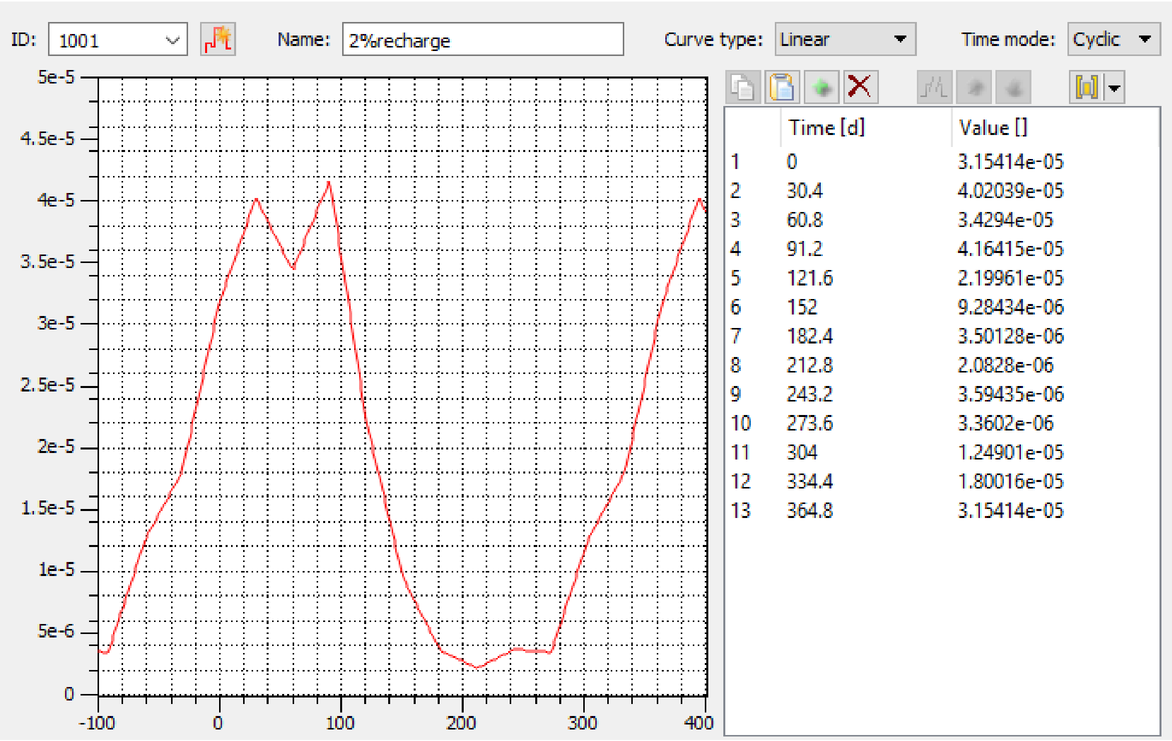



**FIGURE 9-9: GROUNDWATER MODEL TRANSIENT RECHARGE**

### 9.7.5 SIMULATION OF SOURCE TERM – TRANSIENT MODE

The Source Term has been simulated in transient mode as follows:

- Existing Waste Rock Dumps: permanent Chloride Concentration Boundary Condition for the whole duration of the simulation; this can adjusted if Tshipi will decide to remove the existing Waste Rock Dumps
- 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.

Chloride was identified by the Source Term Study (SLR, 2014) as the critical parameter with the highest concentration.

## 9.8 RESULTS OF THE MODEL

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 at the following time-steps:

- 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.

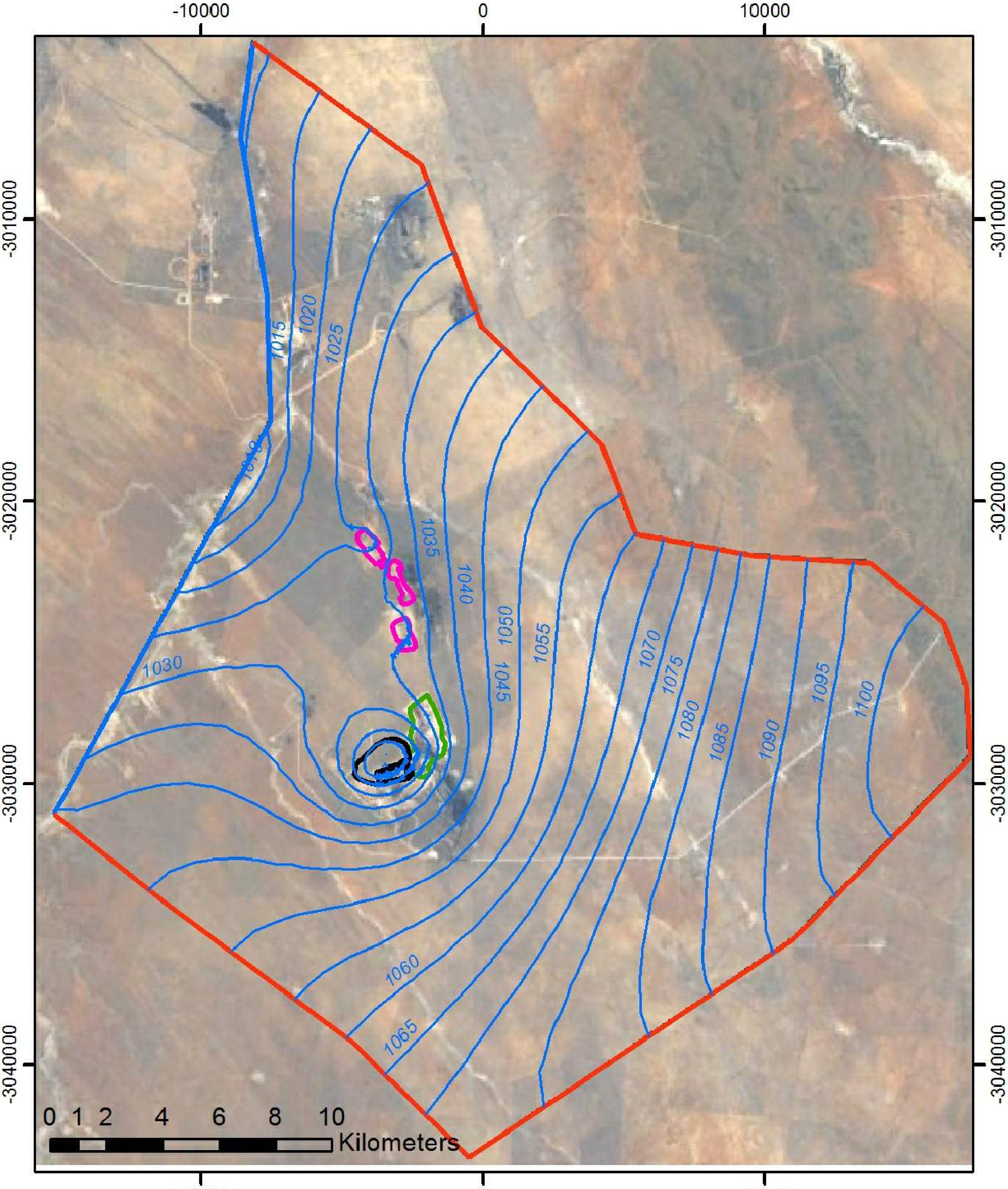
### 9.8.1 DEVELOPMENT OF CONE OF DRAWDOWN

As mining progresses and open pit becomes deeper, it is expected that a cone of drawdown will develop as a result of groundwater passive inflows (ingress) into the open pit excavation.

The following figures show the hydraulic head distribution during simulations:

**YEAR 25 – END OF MINING:**

- Figure 9-10
- Year 50 – Period equal to mining period (post-mining): Figure 9-11
- Year 75 – 50 years post-mining: Figure 9-12
- Year 100 – End of simulation: Figure 9-13.



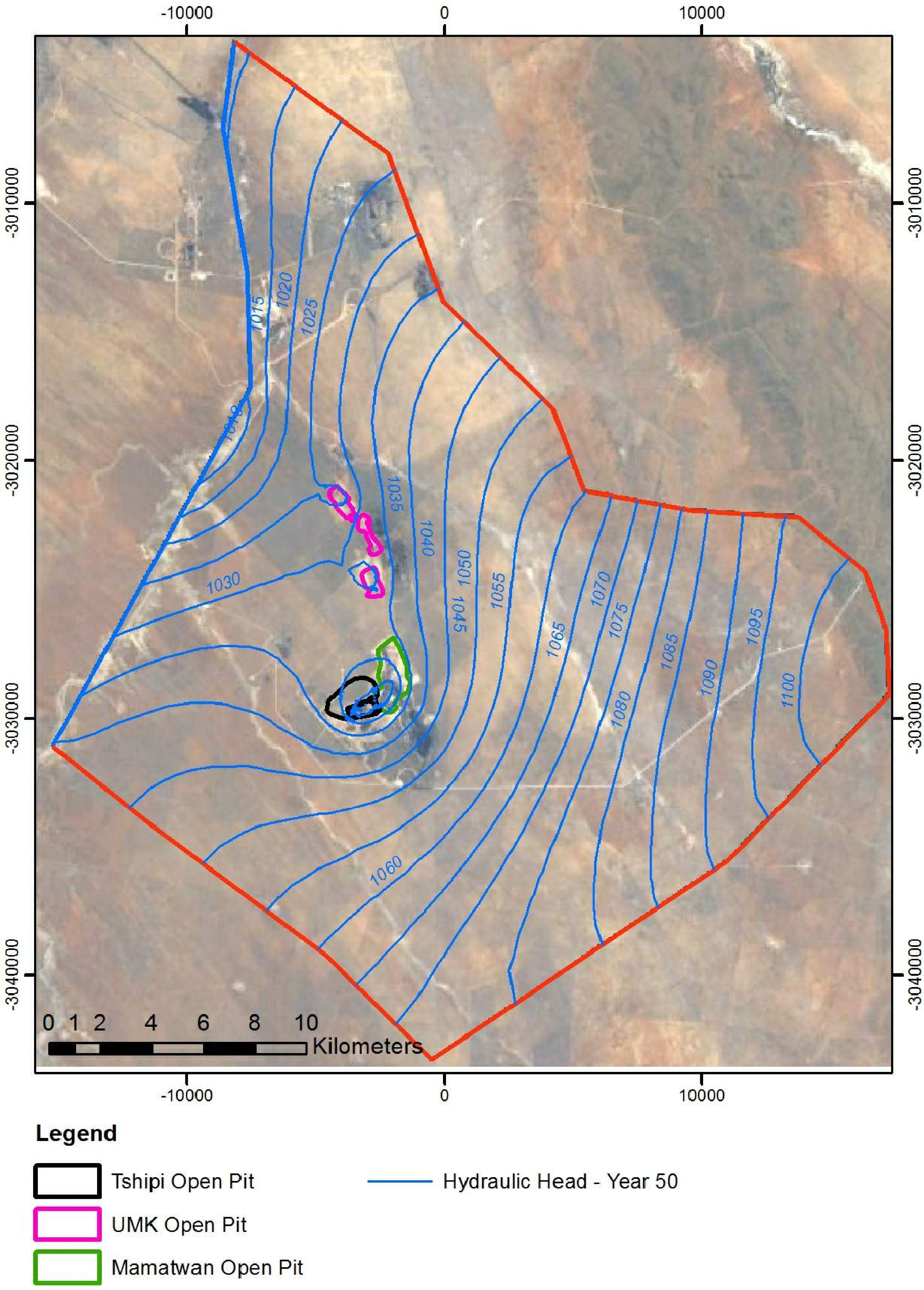

**Legend**

- Tshipi Open Pit
- UMK Open Pit
- Mamatwan Open Pit
- Hydraulic Head - Year 25

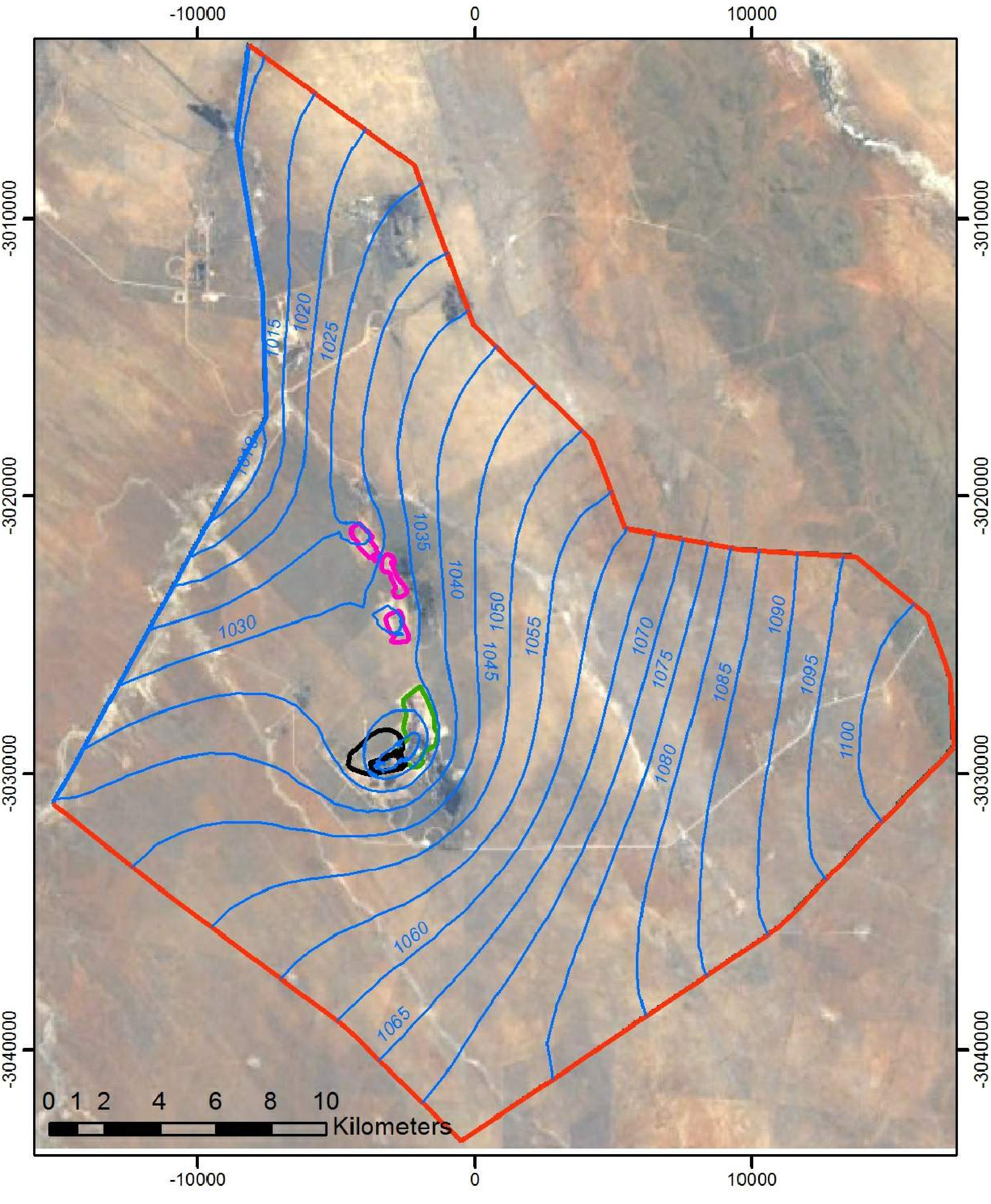
Johannesburg Office
METADO HOUSE
FOURWAYS MANOR OFFICE PARK
CORNER ROOS AND MACBETH STREETS
FOURWAYS
JOHANNESBURG, SOUTH AFRICA
T: +27 (11) 467-0945
F: +27 (11) 467-0978
www.slrconsulting.com

HYDRAULIC HEAD DISTRIBUTION
YEAR 25 (END OF MINING)

| | |
|---|---|
| Date : 07/2017 | Scale : AS SHOWN |
| Project No : 710.20029.00008 | FIGURE 9-10 |




| | | | |
|---|---|---|---|
| SLR Johannesburg Office<br>METAGO HOUSE<br>FOURWAYS MANOR OFFICE PARK<br>CORNER ROOS AND MACBETH STREETS<br>FOURWAYS<br>JOHANNESBURG, SOUTH AFRICA<br>T: +27 (11) 467-0945<br>F: +27 (11) 467-0978<br>www.slrconsulting.com | HYDRAULIC HEAD DISTRIBUTION<br>YEAR 50 OF SIMULATION | Date : 07/2017 | Scale : AS SHOWN |
| | | Project No :<br>710.20029.00008 | FIGURE 9-11 |



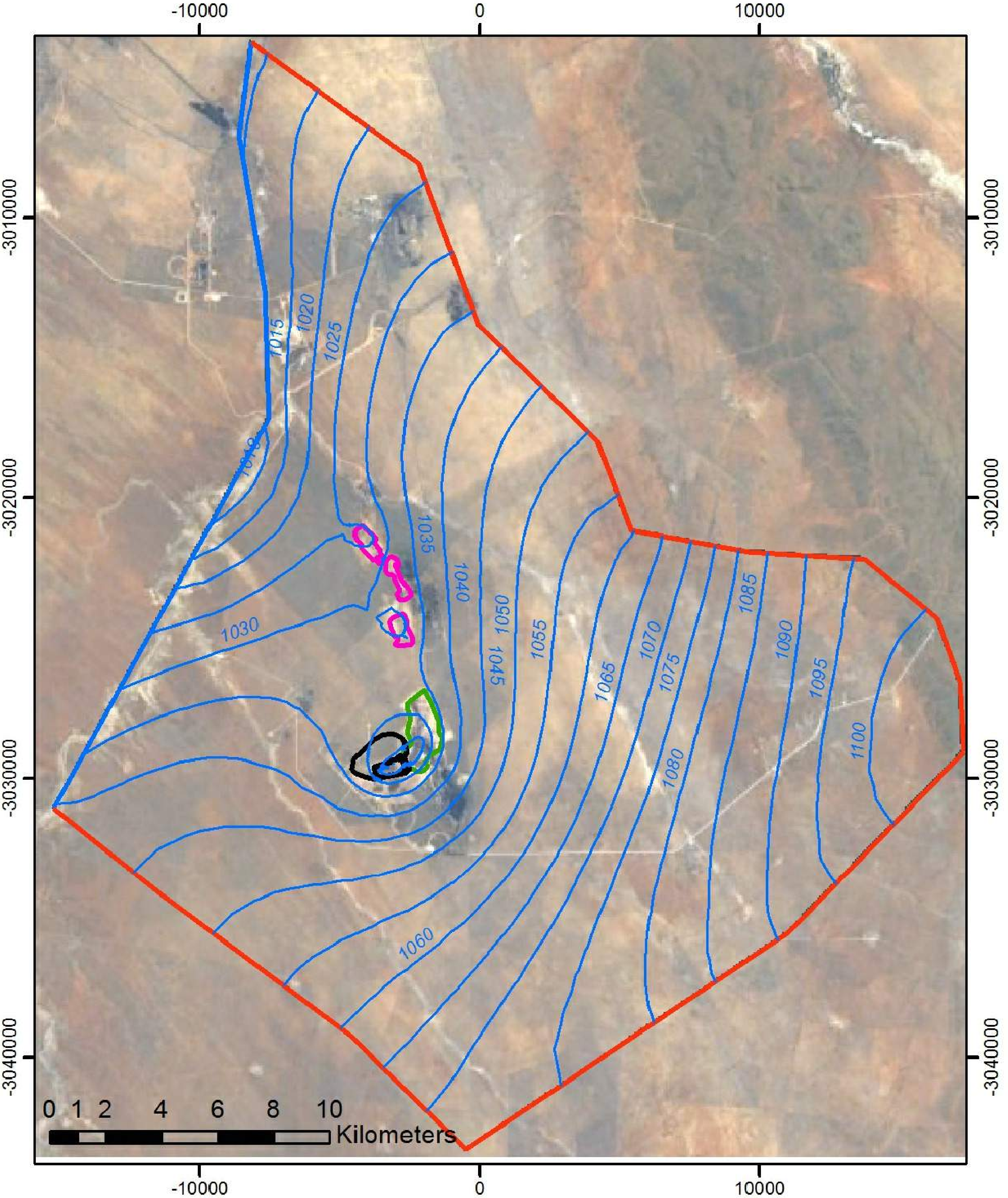

**Legend**

- Tshipi Open Pit
- UMK Open Pit
- Mamatwan Open Pit
- Hydraulic Head - Year 75


Johannesburg Office
METAGO HOUSE
FOURWAYS MANOR OFFICE PARK
CORNER ROOS AND MACBETH STREETS
FOURWAYS
JOHANNESBURG, SOUTH AFRICA
T: +27 (11) 467-0945
F: +27 (11) 467-0978
www.slrconsulting.com


HYDRAULIC HEAD DISTRIBUTION
YEAR 75 OF SIMULATION

| | |
|---|---|
| Date : 07/2017 | Scale : AS SHOWN |
| Project No : 710.20029.00008 | FIGURE 9-12 |




**Legend**

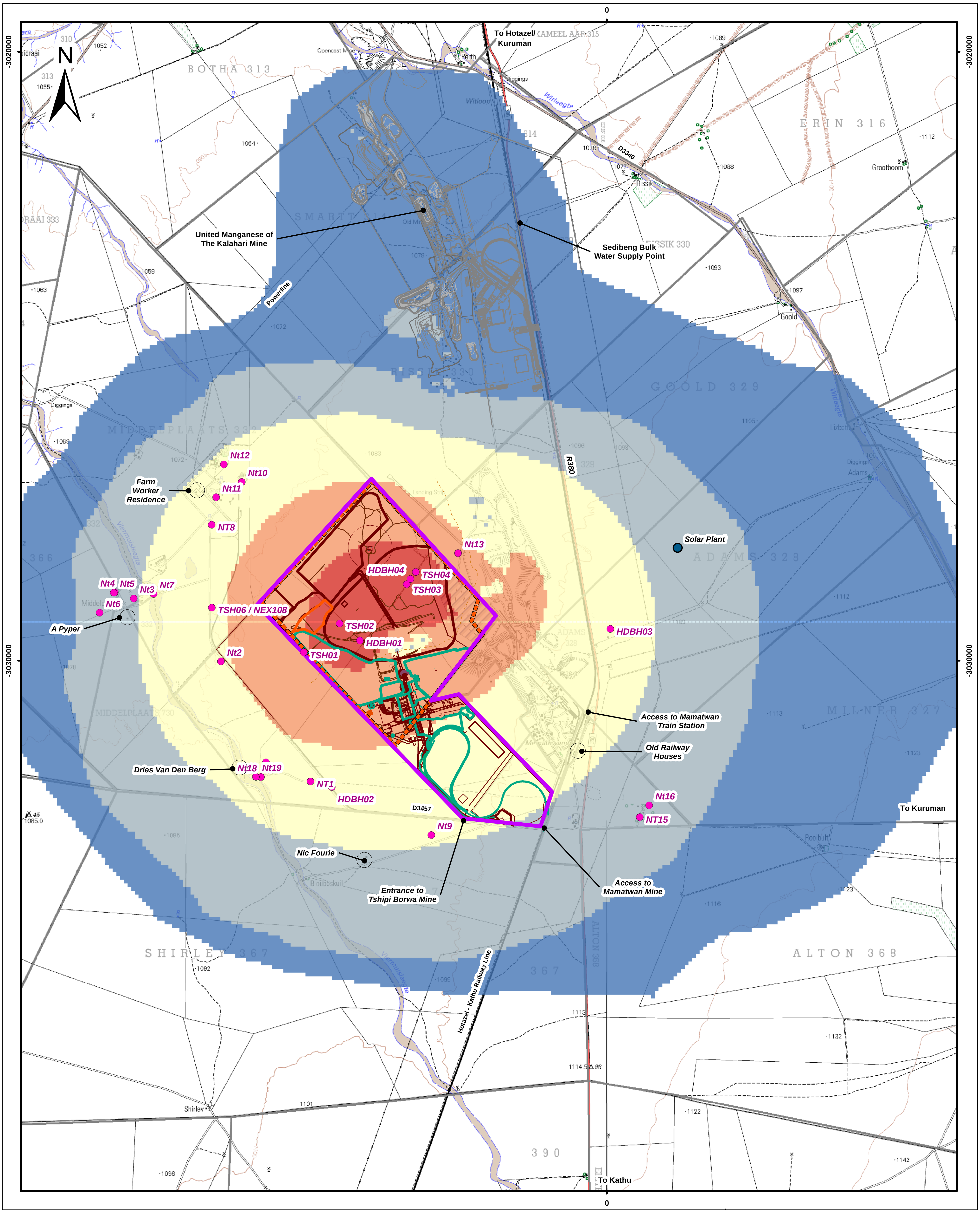
- Tshipi Open Pit
- UMK Open Pit
- Mamatwan Open Pit
- Hydraulic Head - Year 100


SLR
Johannesburg Office
METADO HOUSE
FOURWAYS MANOR OFFICE PARK
CORNER ROOS AND MACBETH STREETS
FOURWAYS
JOHANNESBURG, SOUTH AFRICA
T: +27 (11) 467-0945
F: +27 (11) 467-0978
www.slrconsulting.com


| | | | |
|---|---|---|---|
| HYDRAULIC HEAD DISTRIBUTION YEAR 100 (END OF SIMULATION) | Date : 07/2017 | Scale : AS SHOWN | |
| | Project No : 710.20029.00008 | FIGURE 9-13 | |

The cone of drawdown developed in time associated with the hydraulic heads is shown in the following figures:

- Year 25 – End of mining: Figure 9-14
- Year 50 – Period equal to mining period (post-mining): Figure 9-15
- Year 75 – 50 years post-mining: Figure 9-16
- Year 100 – End of simulation: Figure 9-17.




**Legend**

- Hydrocensus Points
- Surface Use Area
- Approved Mining Right Area
- Changes to Approved Layout (already implemented)
- Proposed Changes to Approved Layout
- Mine Infrastructure (no changes to approved infrastructure layout)
- Barrier Pillar
- Main Roads
- Secondary Roads
- Power Line
- Rivers and Streams

**Cone of drawdown - Year 25**

**mbgl**

- 0 - 2
- 2 - 4
- 4 - 7
- 7 - 12
- 12 - 19

0 1 000 2 000 Meters

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

Tshipi é Ntle Manganese Mining (Pty) Ltd

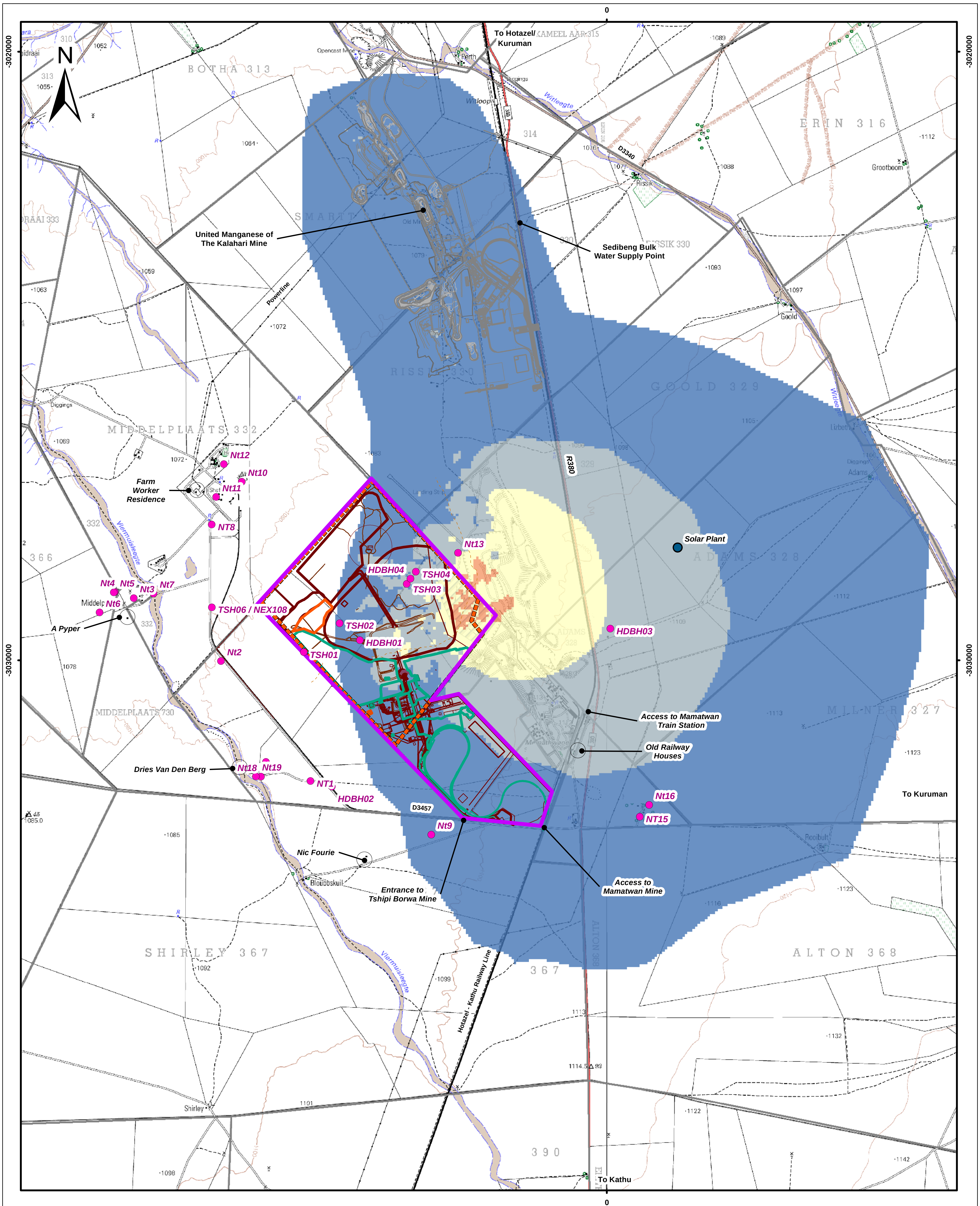
**Figure 9-14**

**Cone of Depression - Year 25 (End of Mining)**

SLR Consulting (Africa) (Pty) Ltd
P O Box 1596, Cramerview, 2060, South Africa
Tel: +27 (11) 467-0945 Fax: +27 (11) 467-0978

710.20029.00008

2017/07/18




## Legend

- Hydrocensus Points
- Surface Use Area
- Approved Mining Right Area
- Changes to Approved Layout (already implemented)
- Proposed Changes to Approved Layout
- Mine Infrastructure (no changes to approved infrastructure layout)
- Barrier Pillar
- Main Roads
- Secondary Roads
- Power Line
- Rivers and Streams

**Cone of drawdown - Year 50**

**mbgl**

- 0 - 2
- 2 - 4
- 4 - 7
- 7 - 12
- 12 - 19

0 1 000 2 000 Meters

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

Tshipi é Ntle Manganese Mining (Pty) Ltd

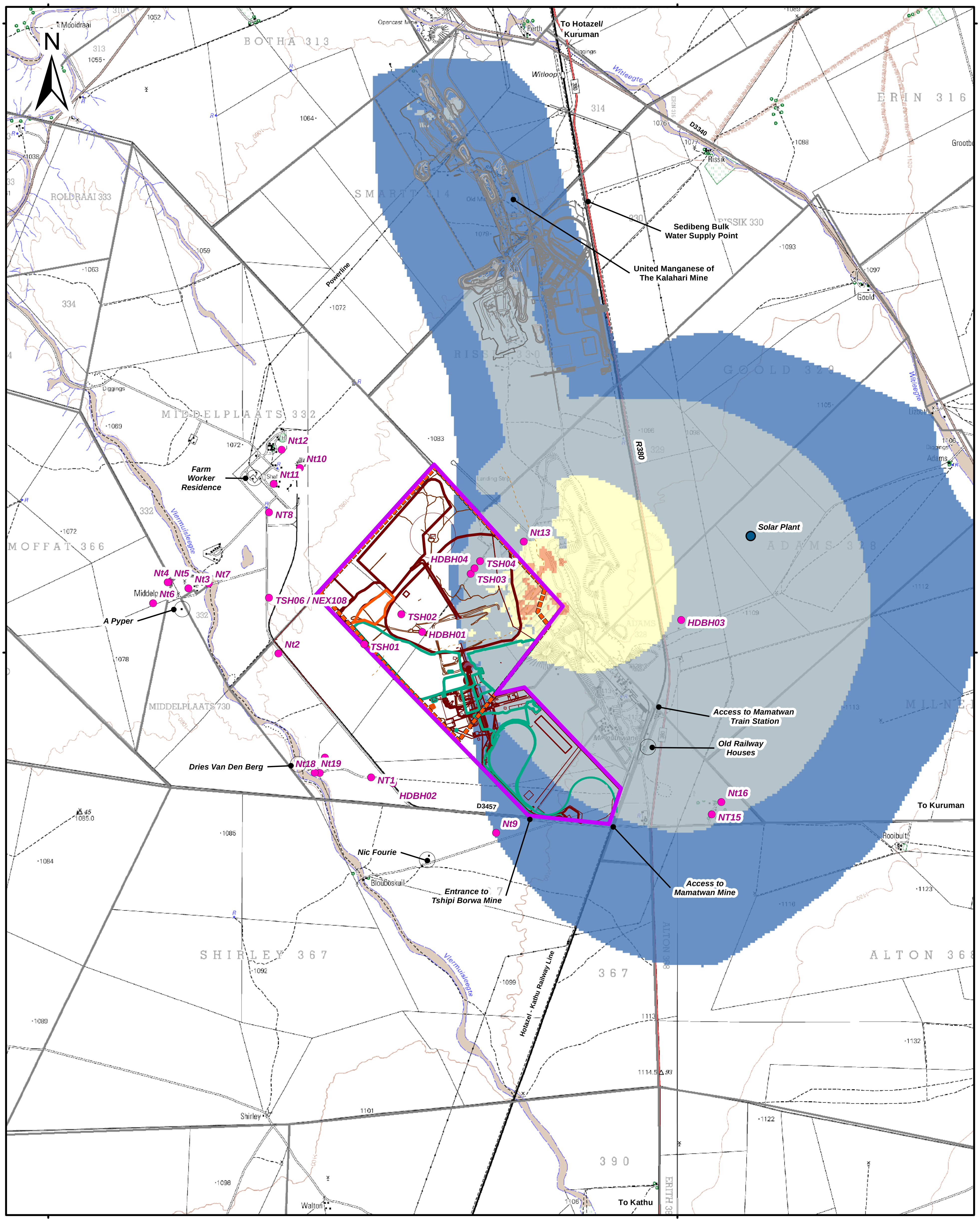
**Figure 9-15**

**Cone of Depression - Year 50 of Simulation**

SLR Consulting (Africa) (Pty) Ltd
P O Box 1596, Cramerview, 2060, South Africa
Tel: +27 (11) 467-0945 Fax: +27 (11) 467-0978

710.20029.00008

2017/07/18




## Legend

- Hydrocensus Points
- Surface Use Area
- Approved Mining Right Area
- Changes to Approved Layout (already implemented)
- Proposed Changes to Approved Layout
- Mine Infrastructure (no changes to approved infrastructure layout)
- Barrier Pillar
- Main Roads
- Secondary Roads
- Power Line
- Rivers and Streams

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

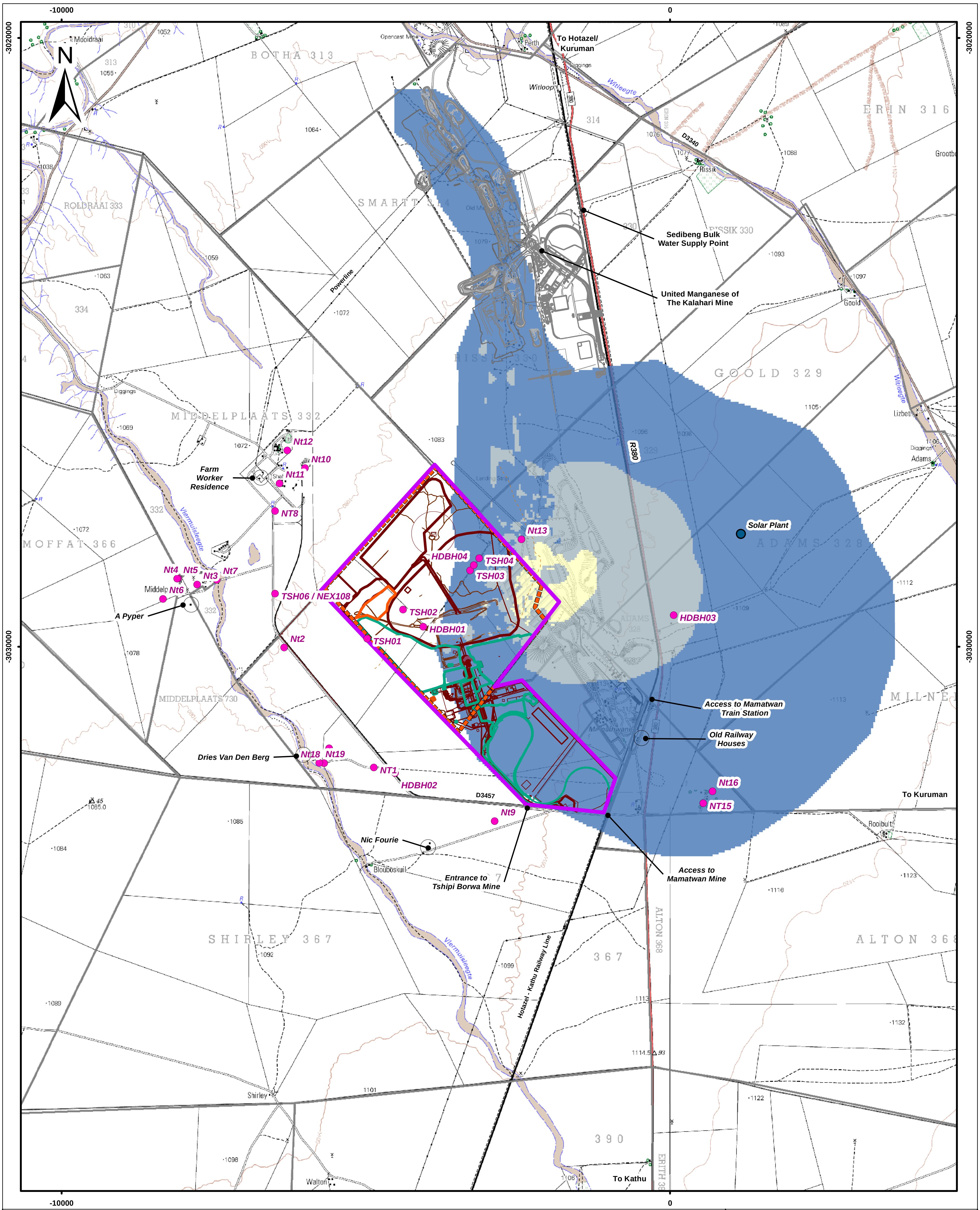
Tshipi é Ntle Manganese Mining (Pty) Ltd

**Figure 9-16**

**Cone of Depression - Year 75 of Simulation**

SLR Consulting (Africa) (Pty) Ltd
P O Box 1596, Cramerview, 2060, South Africa
Tel: +27 (11) 467-0945 Fax: +27 (11) 467-0978

| | |
|---|---|
| 710.20029.00008 | 2017/07/18 |




**Legend**

- Hydrocensus Points
- Surface Use Area
- Approved Mining Right Area
- Changes to Approved Layout (already implemented)
- Proposed Changes to Approved Layout
- Mine Infrastructure (no changes to approved infrastructure layout)
- Barrier Pillar
- Main Roads
- Secondary Roads
- Power Line
- Rivers and Streams

**Cone of drawdown - Year 100**

**mbgl**

- 0 - 2
- 2 - 4
- 4 - 7
- 7 - 12
- 12 - 19

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 9-17**

**Cone of Depression - Year 100 (End of Simulation)**

SLR

SLR Consulting (Africa) (Pty) Ltd
P O Box 1596, Cramerview, 2060, South Africa
Tel: +27 (11) 467-0945 Fax: +27 (11) 467-0978

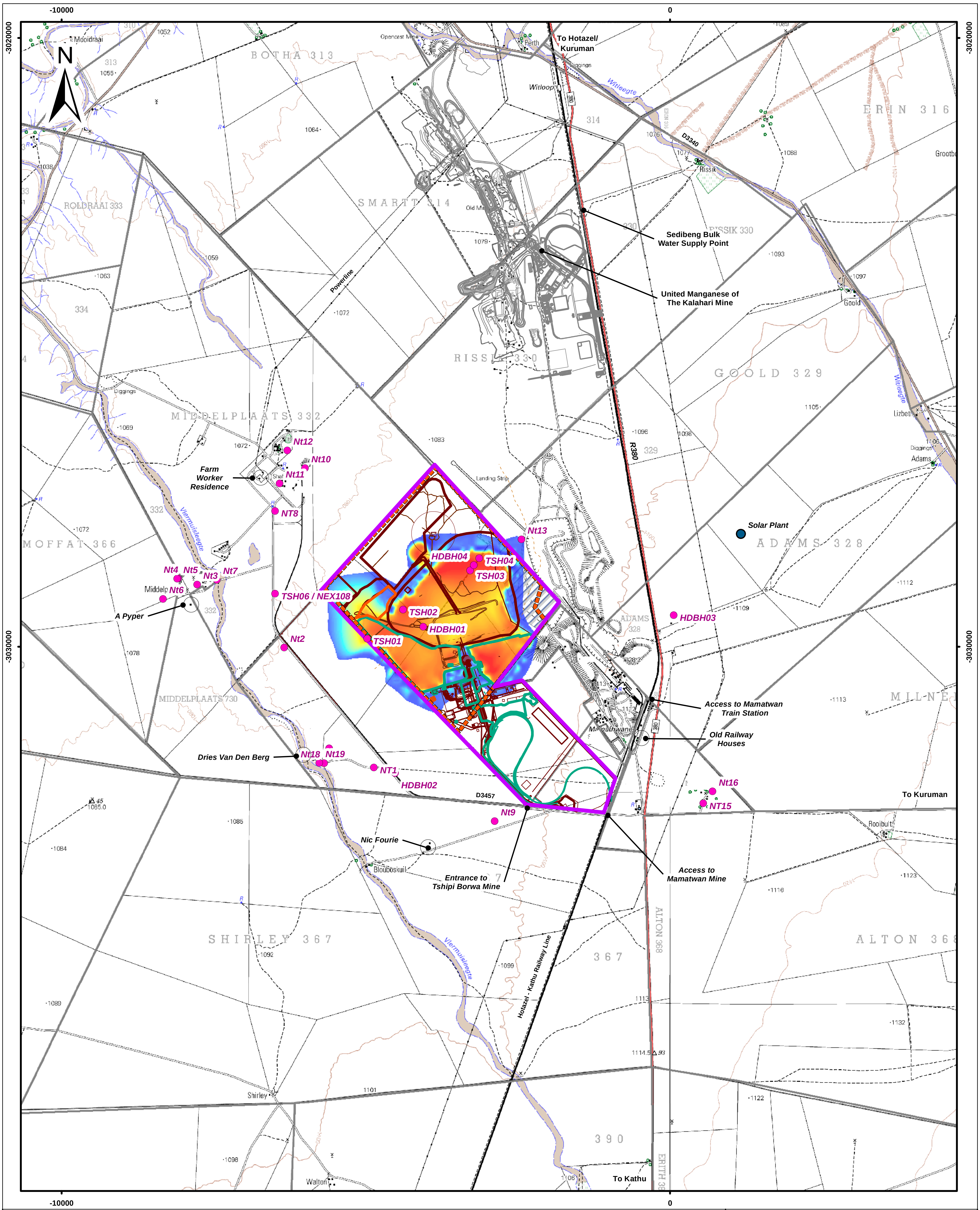
710.20029.00008

2017/07/18

### 9.8.2 Development of Contaminant Plume

The Chloride plume developed from the Waste Rock Dumps and from the in-pit backfilling waste rock is shown in figures:

- Year 25 – End of mining: Figure 9-18
- Year 50 – Period equal to mining period (post-mining): Figure 9-19
- Year 75 – 50 years post-mining: Figure 9-20
- Year 100 – End of simulation: Figure 9-21.




## Legend

- Hydrocensus Points
- Surface Use Area
- Approved Mining Right Area
- Changes to Approved Layout (already implemented)
- Proposed Changes to Approved Layout
- Mine Infrastructure (no changes to approved infrastructure layout)
- Barrier Pillar
- Main Roads
- Secondary Roads
- Power Line
- Rivers and Streams

**Cli Plume - Year 25**

**mg/l**

High : 2200

Low : 0

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 9-18**

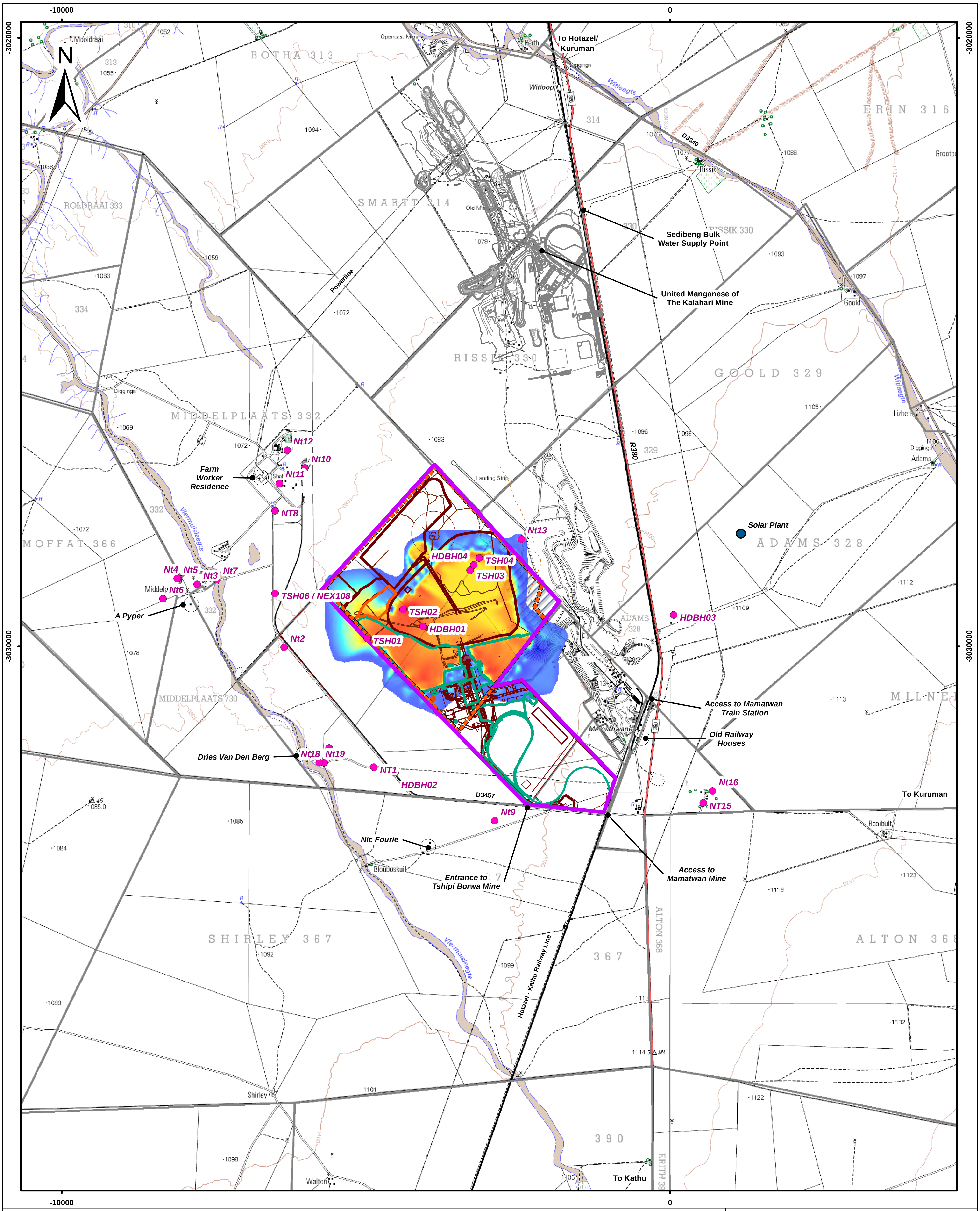
**Predicted Chloride Plume - Year 25 (End of Mining)**

SLR

SLR Consulting (Africa) (Pty) Ltd
P O Box 1596, Cramerview, 2060, South Africa
Tel: +27 (11) 467-0945 Fax: +27 (11) 467-0978

710.20029.00008

2017/07/18




## Legend

- Hydrocensus Points
- Surface Use Area
- Approved Mining Right Area
- Changes to Approved Layout (already implemented)
- Proposed Changes to Approved Layout
- Mine Infrastructure (no changes to approved infrastructure layout)
- Barrier Pillar
- Main Roads
- Secondary Roads
- Power Line
- Rivers and Streams

**Cl Plume - Year 50**

**mg/l**

High : 2200

Low : 0

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 9-19**

**Predicted Chloride Plume - Year 50 of Similation**

SLR

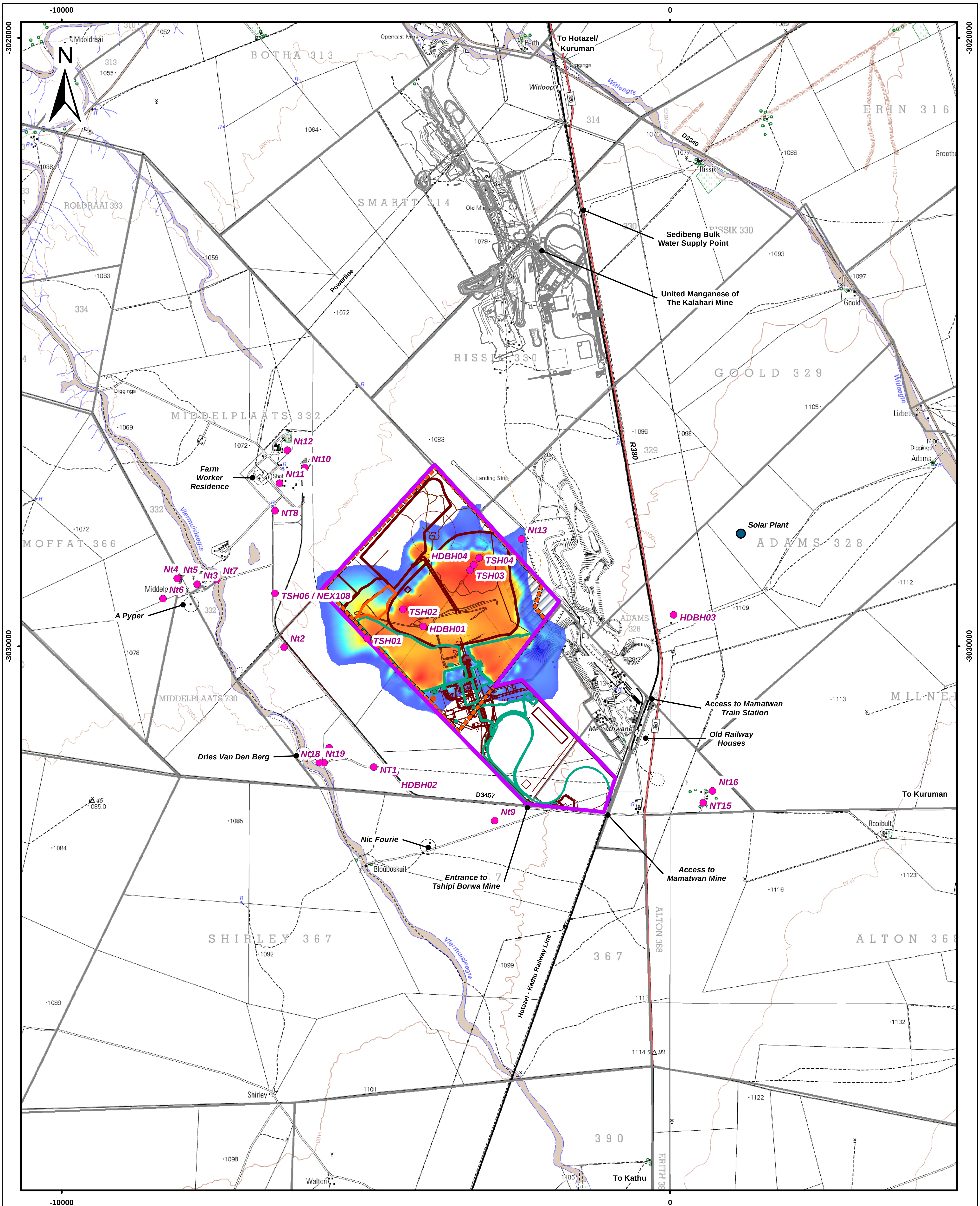
SLR Consulting (Africa) (Pty) Ltd

P O Box 1596, Cramerview, 2060, South Africa

Tel: +27 (11) 467-0945 Fax: +27 (11) 467-0978

710.20029.00008

2017/07/18




## Legend

- Hydrocensus Points
- Surface Use Area
- Approved Mining Right Area
- Changes to Approved Layout (already implemented)
- Proposed Changes to Approved Layout
- Mine Infrastructure (no changes to approved infrastructure layout)
- Barrier Pillar
- Main Roads
- Secondary Roads
- Power Line
- Rivers and Streams

**Cl Plume - Year 75**

**mg/l**

High : 2200

Low : 0

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 9-20**

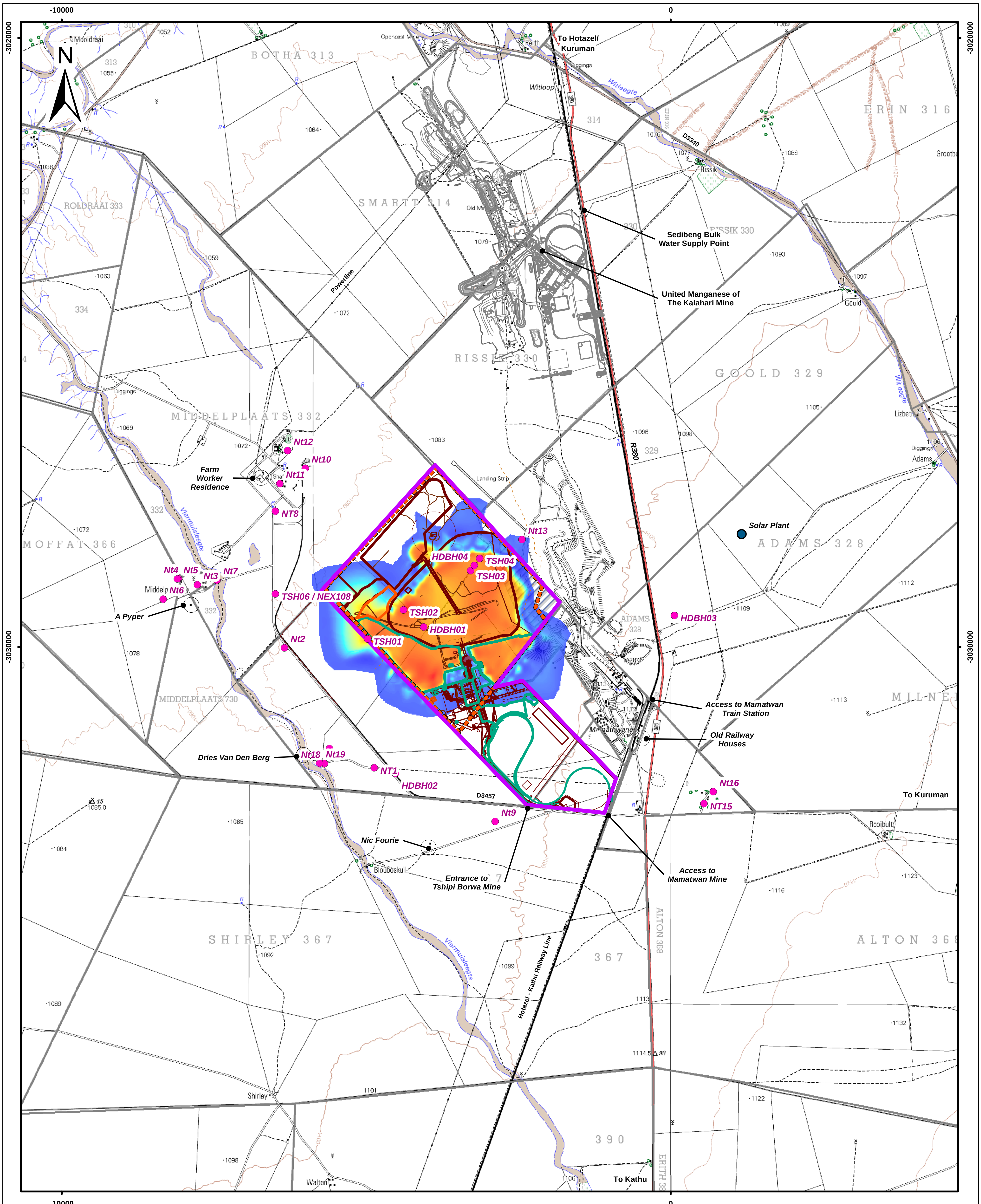
**Predicted Chloride Plume - Year 75 of Similation**

SLR

SLR Consulting (Africa) (Pty) Ltd
P O Box 1596, Cramerview, 2060, South Africa
Tel: +27 (11) 467-0945 Fax: +27 (11) 467-0978

710.20029.00008

2017/07/18




## Legend

- Hydrocensus Points
- Surface Use Area
- Approved Mining Right Area
- Changes to Approved Layout (already implemented)
- Proposed Changes to Approved Layout
- Mine Infrastructure (no changes to approved infrastructure layout)
- Barrier Pillar
- Main Roads
- Secondary Roads
- Power Line
- Rivers and Streams

**Cl Plume - Year 100**

**mg/l**

High : 2200

Low : 0

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 9-21**

**Predicted Chloride Plume - Year 100 (End of Simulation)**


SLR

SLR Consulting (Africa) (Pty) Ltd

P O Box 1596, Cramerview, 2060, South Africa

Tel: +27 (11) 467-0945 Fax: +27 (11) 467-0978


710.20029.00008

2017/07/18

### 9.8.3 CONCLUSIONS

Mining will create a cone of drawdown with a maximum extent of 5.5 km to the East and 8.3 km to the West of Tshipi Mine with a drop in water depth of up to 2 metres at the maximum extent. The cone of drawdown is at maximum extent at the end of mining (Year 25). As mining operations stop and backfilling takes place, the water levels start recovering according to the simulation. The cone of drawdown starting at year 50 until the end of the simulation is located mainly around Mamatwan and UMK Mines, and Tshipi Mine has minimal contribution to the cone of drawdown.

The mass transport model has been done in a non-reactive mode (conservative). The maximum possible chloride source (2200 mg/ℓ, SLR 2015) is assumed to remain in place for the duration of the simulation, on:

- Existing WRDs
- In-pit back filling.

The maximum chloride plume developed from the sources extends up to 1.1 km in a western direction from the Tshipi Mine, at the end of the simulation (year 100). However, this does not influence any third party users.

# 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 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*.

For the purpose of this assessment discussion project changes have been grouped. In this regard reference will only be made to the relocation of approved surface infrastructure, design changes and the establishment of additional facilities and activities as opposed to making specific reference to each project change, unless otherwise stated. When referencing the relocation of approved surface infrastructure this specifically caters for:

- The western waste rock dump
- The low grade and fines stockpiles
- The sewage treatment plant
- The dirty water dams
- The 78 Ml stormwater dam
- The plant offices, workshops and related infrastructure.

When referencing the design changes this specifically caters for:

- The dirty water dams
- The railway siding
- The sewage treatment plant
- The potable water storage facilities
- The expansion of approved topsoil stockpile area

When referencing the establishment of additional facilities and activities this specifically caters for:

- The establishment of the eastern waste rock dump
- The waste rock dump merge
- Topsoil stockpile area (No. 2)

- The temporary ROM stockpile area
- The workshop dirty water collection dam
- The clean and dirty water separation
- The tyre bays
- The additional weighbridges
- Mining of the barrier pillar.

The method used to assess potential groundwater impacts is set out in the 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<br>Within site boundary<br>Site | Fairly widespread<br>Beyond site boundary<br>Local | Widespread<br>Far beyond site boundary<br>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 sources are permanent (existing WRDs) and some sources are transient (starting later and at different time-steps) and becoming permanent (pit backfilling). 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 (waste rock dumps) and the closure phase will present final land forms, such as the backfilled open pit and residual waste rock dumps (where applicable) that may have the potential to pollute water resources through long term seepage and/or run-off.

### *Mine phase and link to project specific activities/infrastructure*

| Construction | Operational | Decommissioning | Closure |
|---|---|---|---|
| | | | |
| Earthworks *(topsoil expansion)*<br>Mineralised waste *(waste rock dump merge)*<br>Water use and management *(clean and dirty water separation and 78Ml* | Mineralised waste<br>Non-mineralised waste<br>Water use and management<br>Support services<br>Transportation system<br>Continued use of approved facilities and services | Mineralised waste<br>Non-mineralised waste<br>Water use and management<br>Support services<br>Transportation system<br>Continued use of approved facilities and services | Final land forms |

| Construction | Operational | Decommissioning | Closure |
|---|---|---|---|
| *stormwater dam)* | Open pit mining and backfilling | Backfilling of open pit | |

**Rating of impacts**

Severity / nature

The impact associated with groundwater contamination was assessed as part of the approved EMPr (Metago, May 2009). The groundwater study supporting the approved EMPr modelled the migration of contaminants from the TSF, Northern and Western WRDs using a worst case scenario (WGC, 2009). This scenario assumed maximum expected seepage rates and maximum concentrations for total dissolved solids (TDS) (4000 mg/ℓ) and Manganese (30 mg/ℓ). This study found that there would be no significant off-site 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 waste rock dumps
- Limited hydraulic conductivity of the material underlying the TSF and waste rock dumps
- The retardation effect of the pit dewatering on parts of the modelled pollution plume.

The relocation of surface infrastructure and design changes will not present significantly different contaminants or source types to those previously assessed for all project phases. In this regard no material changes to the TSF and Northern WRD are included in this project and therefore the above assessment remains valid with respect to these facilities. However the establishment of additional facilities will contribute additional pollution sources during the operational, closure and post-closure phases. This relates to the Eastern and Western WRDs as well as mining of the barrier. The groundwater study to support the current EIA process therefore focussed on these facilities.

A chloride source concentration of 2200 mg/ℓ was simulated for mining the barrier and WRDs. The maximum chloride plume is predicted to extend up to 1.1 km in a western direction (refer to Figure 9-21) at the end of the simulation (year 100). This results in a plume of low concentration for a small area outside of the mining right area. However, there are no known third party boreholes within the predicted pollution plume. When considered incrementally this has a low severity in the unmitigated and mitigated scenarios.

The cumulative severity rating assessing the impact of the changes to the operation within the context of the approved mining operations is also low in the unmitigated scenario because the migration of the pollution plume is not expected to impact on third party water users.

Duration

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

Spatial scale / extent

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

Consequence

The consequence is moderate 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?
- 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.

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 contaminant plume.

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 for a small area outside of the mining right area.

As a combination, the unmitigated and mitigated probability is low.

Significance

The unmitigated and mitigated scenario significance is low.

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 |

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). The existing monitoring network is considered sufficient to detect any pollution related to the revised site layout. 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 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.
- Prior to closure, the groundwater model will be re-run 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.

**ISSUE: LOWERING OF GROUNDWATER LEVELS AND REDUCING AVAILABILITY**

**Introduction**

Dewatering of the extended open pit has the potential to lower groundwater levels in the operational phase. Lowering of groundwater levels through dewatering may cause a loss in water supply to surrounding borehole users if they are in the impact zone.

***Mine phase and link to project specific activities/infrastructure***

| Construction | Operational | Decommissioning | Closure |
|---|---|---|---|
| N/A | | N/A | N/A |
| | Pit dewatering | Recovery of groundwater levels | Recovery of groundwater levels |

**Rating of impact**

Severity / nature

The impact of lowering of groundwater levels was assessed as part of the approved EMPr (Metago, May 2009). In this regard, the modelled cone of depression indicated a drop in the order of 22 m and that this drop in water levels would reduce with distance from the mine up to a limit of approximately 8.3 km towards the east and between 2 and 5 km in the other directions. This model also presented the possibility that pit dewatering and the surrounding mining operations could both lower the water level in some third party boreholes around the site and reduce the contribution of groundwater to the sub surface flow of the Vlermuisleegte. Prior to mining the depth of the water in surrounding boreholes ranged from 25 to 55 m below ground level. 2016 groundwater level monitoring data shows water depths ranging from 41 to 75 m below ground level. This shows a drop in water levels similar to that predicted by the 2009 simulations. The impact was rated as high in the unmitigated scenario and low in the mitigated scenario in the 2009 EMPr.

The relocation of surface infrastructure and design changes will not influence the lowering of groundwater levels and related reduction in availability. However the extension of the open pit to mine the barrier with Mamatwan mine could result in further dewatering impacts. In addition, the presence of several mines in close proximity will have a combined effect on the cone of drawdown. The groundwater model therefore considered cumulative effects taking into account the neighbouring Mamatwan and UMK Mines.

Mining at Tshipi has been simulated to create a cone of drawdown with a maximum extent of 5.5 km to the east and 8.3 km to the west of Tshipi Mine at the end of mining (Year 25) (refer to Figure 9-14). Third parties within the simulated cone of depression may therefore experience a drop in water levels of two to seven metres. The simulation shows that as mining operations stop and backfilling takes place, the water levels start recovering and allow the water levels to recover by the end of life of mine. The cone of drawdown at year 50 (25 years after mining and dewatering has ceased at Tshipi) until the end of the simulation (year 100) (refer to Figure 9-17) is located mainly around Mamatwan and UMK Mines, and Tshipi Mine has no significant contribution to the cone of drawdown. It remains a possibility that dewatering at Tshipi and the surrounding mining operations could reduce the contribution of groundwater to the sub surface flow of the Vlermuisleegte during the operational phase, until groundwater levels recover after mining ceases.

When considered incrementally this has a medium severity in the unmitigated scenario reducing to low with mitigation. The cumulative severity rating assessing the impact of the changes to the operation within the context of the approved mining operations is medium in the unmitigated scenario. In the mitigated scenario the severity reduces to low.

Duration

The duration of the impacts is linked to the duration of the dewatering and the recharge time thereafter. Based on groundwater model predictions, the groundwater level will recover by the end of life of mine. It follows that in both the unmitigated and mitigated scenarios the duration is the life of the mine.

Spatial scale / extent

The spatial scale of the predicted dewatering cone extends beyond the mining area in both the mitigated and unmitigated scenarios.

Consequence

The consequence is moderate in the unmitigated and mitigated scenarios.

Probability

The probability of impacting on third party water users is high given that there are third party boreholes identified within the simulated impact zone.

Significance

The impact significance is medium in the unmitigated scenario and low in the mitigated scenario.

Unmitigated – summary of the rated cumulative initial dewatering impact per phase of the mine

| Management | Severity / nature | Duration | Spatial scale / extent | Consequence | Probability of Occurrence | Significance |
|---|---|---|---|---|---|---|
| Operation | | | | | | |
| Unmitigated | M | M | M | M | H | M |

Mitigated – summary of the rated cumulative initial dewatering impact per phase of the mine

| Management | Severity / nature | Duration | Spatial scale / extent | Consequence | Probability of Occurrence | Significance |
|---|---|---|---|---|---|---|
| Operation | | | | | | |
| Mitigated | L | M | M | M | L | L |

**Management objective**

The objective is to prevent water losses to third party water users.

**Management actions**

Management actions to be implemented include the following:

- Tshipi will continue to mmonitor groundwater levels (refer to Section 11 for the monitoring programme). The existing monitoring network is considered sufficient to detect changes in water levels due to the revised site layout.

- 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.
- 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.

# 11 GROUNDWATER MONITORING SYSTEM

## 11.1 GROUNDWATER MONITORING NETWORK

The Tshipi groundwater monitoring programme includes boreholes for monitoring pollution sources, pollution plume or impact monitoring points and background or upstream points. These points are shown in Figure 11-1. Water quality analyses results should 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

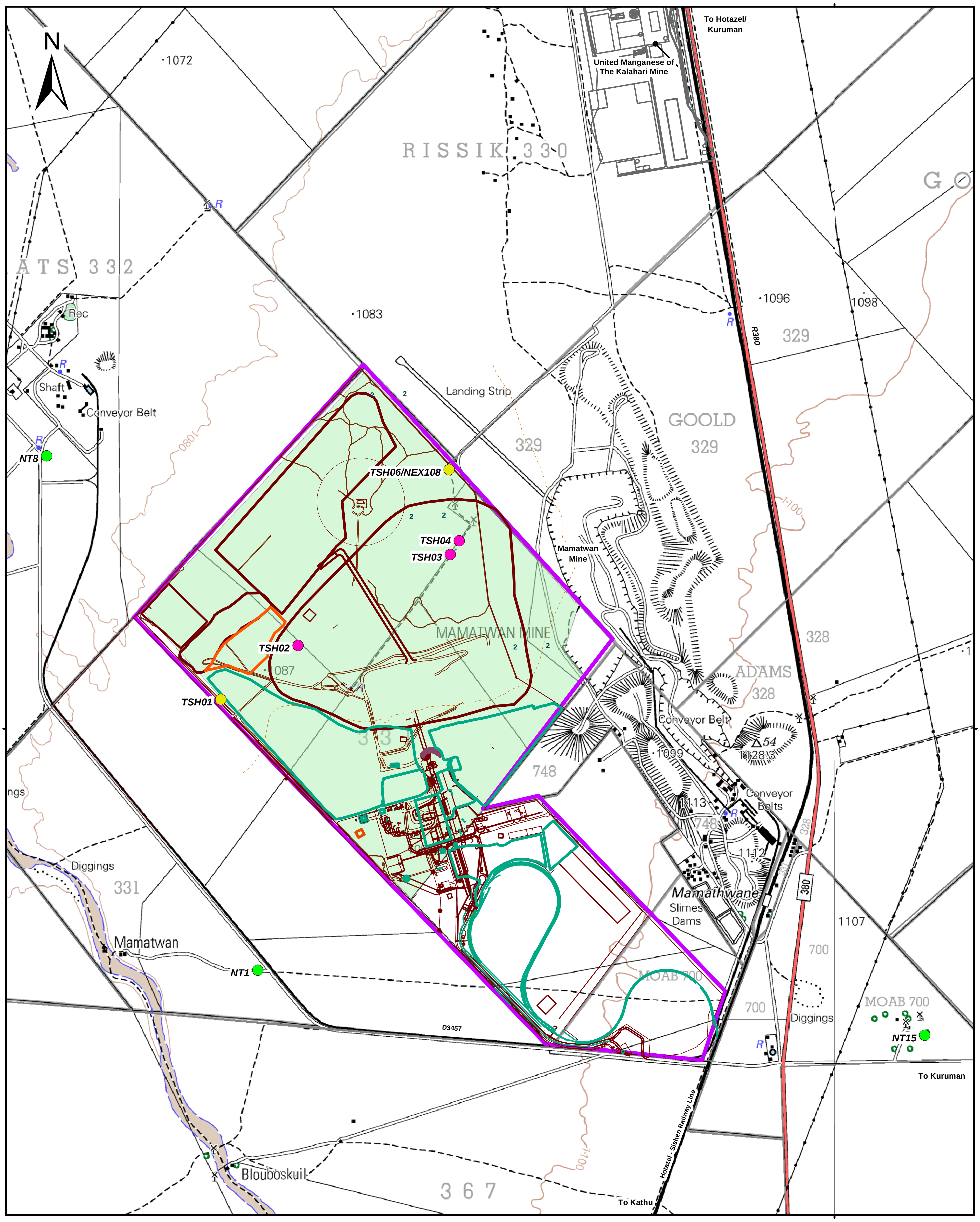
Groundwater quality monitoring is conducted on a quarterly basis and groundwater levels on a monthly basis.

## 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.*




## Legend

- Surface Use
- Approved Mining Right
- Farm Boundaries
- Mine Infrastructure (no changes to approved infrastructure layout)
- Changes to Approved Layout (already implemented)
- Proposed Changes to Approved Layout

**Groundwater Monitoring Points**

- Background Monitoring
- Plume Monitoring
- Source Monitoring

0 500 1 000 Meters

Scale: 1:31 000 @ A3
Projection: Transverse Mercator
Datum: WGS1984, Lo23

TSHIPI E' NTLE MANGANESE MINING

**Figure 11-1**

**Groundwater Monitoring Points**

SLR Consulting (Africa) (Pty) Ltd
P O Box 1596, Cramerview, 2060, South Africa
Tel: +27 (11) 467-0945 Fax: +27 (11) 467-0978

710.23031.00002

2017/07/18

# 12 GROUNDWATER ENVIRONMENTAL MANAGEMENT PROGRAMME

## 12.1 CURRENT GROUNDWATER CONDITIONS

The baseline groundwater conditions are described in section 7 of this report.

## 12.2 PREDICTED IMPACTS OF FACILITY

The results of the simulations are provided in section 9.8 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 and any additional management actions identified as part of the project, where relevant are indicated in *italics*.

**TABLE 12-1: GROUNDWATER MANAGEMENT PLAN**

| No. | Aspect | Management commitment | Action plan | | |
|---|---|---|---|---|---|
| | | | **Timeframe** | **Frequency** | **Compliance indicator** |
| **Objective: Prevent quantity and quality 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 WRD indicates that the waste rock dumps are causing pollution, catchment paddocks and soak-always will be provided to minimise the risk of exposure to wildlife, livestock and humans.* | 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* | *The footprint of temporary waste rock dumps 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* |
| 5 | Closure planning | Prior to closure, the groundwater model will be re-run 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 completely backfilled and the area rehabilitated
- 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.

# 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 RESPONSE**

| Name | Date of comment | Comment received from IAP | Response provided by SLR |
|---|---|---|---|
| Andrew Pyper | 30 July 2013 at the general public meeting | The availability and quality of water is very important to us. Approximately 10 years ago, one of our cows died as a result of poor groundwater quality. We no longer use this specific borehole. We do still make use of another groundwater borehole on the farm Moab 700. The quality of this borehole water is poor however it is not poor enough to result in the death of our cattle. We also use water from the Vaal Ga-Magara pipeline.<br><br>We therefore emphasise that a lot of attention needs to be given to both groundwater and surface water quality and quantity particularly with regard to backfilling the open pit with a combination of tailings, waste rock, gravel and sand. | As part of the approved EMPr (Metago, May 2009), and prior to the establishment of the Tshipi Borwa Mine the water quality had been influenced by anthropogenic pollution from farming and surrounding mining activities. Current groundwater quality data indicates that elevated levels of TDS, EC, Chloride and nitrate are consistent with baseline conditions.<br><br>It is important to note that the EMPr amendment process commenced in early 2013. Since the commencement of the project, the use of a combination of tailings, waste rock, gravel and sand to back fill the open pit will no longer take place and has been excluded from the project scope.<br><br>Further to the above where Tshipi's operations are directly responsible for a loss in third party water supply, appropriate compensation will be provided. |

# 16 CONCLUSION AND RECOMMENDATIONS

A groundwater modelling exercise was conducted to determine potential dewatering and contaminant impacts due to the changes in project infrastructure and activities. The study focussed on mining of the barrier with Mamatwan Mine and the East and West WRDs. Key findings of the modelling exercise include:

- Potential pollution impacts: 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). This results in a plume of low concentration for a small area outside of the mining right area. However, there are no known third party boreholes within the predicted pollution plume. 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 12.
- Potential dewatering impacts: A cone of drawdown with a maximum extent of 5.5 km to the east and 8.3 km to the west of Tshipi Mine is predicted at the end of mining (Year 25). Third parties within the simulated cone of depression may therefore experience a drop in water levels. The simulation shows that as mining operations stop and backfilling takes place, the water levels start recovering and allow the water levels to recover by the end of life of mine. The cone of drawdown at year 50 (25 years after mining and dewatering has ceased at Tshipi) until the end of the simulation (year 100) is located mainly around Mamatwan and UMK Mines, and Tshipi Mine has no significant contribution to the cone of drawdown. It remains a possibility that dewatering at Tshipi and the surrounding mining operations could reduce the contribution of groundwater to the sub surface flow of the Vlermuisleegte during the operational phase, until groundwater levels recover after mining ceases. This impact has been rated as having a moderate significance in the unmitigated scenario, reducing to low with mitigation. The relevant mitigation measures are outlined in Section 12.

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.

| | | |
|---|---|---|
| **Mihai Muresan** | **Natasha Smyth** | **Mihai Muresan** |
| **(Report Author)** | **(Project Manager)** | **(Project Reviewer)** |

# 17 REFERENCES

Golder Associates. (2016). *Waste classification assessment for Tshipe e Ntle Mine.* Golder Associates Africa (Pty) Ltd. Report number: 1541973-301423-1.

Knight Pièsold. (2012). *Tshipi Borwa Mine: Hydrocensus Study.* Knight Pièsold Consulting. Report number: RI301-00321/02.

Metago. (2006). *UMK Hydrocensus field report.* Metago Environmental Engineers (Pty) Ltd. Report number: U002-01, June 2006.

SLR. (2012). *Hydrogeological Assessment for Mine Closure Planning - Pit Lake Formation - Site Report and Analytical Model.* SLR Consulting (Africa) (Pty) Ltd. Report Number: 721.20008.00015, November 2012.

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

SLR. (2015). *Tshipi Borwa New Waste Rock Dump Groundwater Risk Assessment.* SLR Consulting (Africa) (Pty) Ltd. Report number: 710.20008.00028, April 2014.

SLR. (2016). *Tshipi Borwa Mine: Water Monitoring Report Quarter 2: October 2016.* SLR Consulting (Africa) (Pty) Ltd. Report number: 710.20008.00035, December 2016.

WGC. (2009). *Groundwater investigation for Ntsimbintle mine.* Water Geosciences Consulting. Report number: Ntsimbintle 27/02/09.

Metago. (2009). *Environmental Impact Assessment and Environmental Management Programme for the proposed Ntsimbintle Manganese Project.* Metago Environmental Engineers (Pty) Ltd. Report number: N001-03/02, May 2009.

Matoti A, Conrad J, and Jones S. (1999). *Aquifer Classification of South Africa*. Map recompiled 2012. Published by CSIR and Department of Water Affairs, 22 March 1999

AGES. (2007). *United Manganese of Kalahari: Specialist Geohydrological Study.* Africa Geo-Environmental Services. Report number: AG-R-2007-03-22.

**APPENDIX A: CURRICULA VITAE**

**Mihai Muresan**
Team Lead Water (South Africa)

**Curriculum Vitae**

## Qualifications

| | | |
|---|---|---|
| PrSciNat | Since 2010 | Member of the South African Council for Natural Scientific Professions |
| MSc | 1988 | Hydrogeology and Engineering Geology, Univ. of Bucharest, Romania |

## Key Areas of Expertise

Key areas of Mihai's expertise are summarised below.

| | |
|---|---|
| Hydrogeology | Drilling and testing design, hydrogeological parameters interpretation, monitoring, sampling, numerical modelling |
| Mining Hydrogeology | Design of dewatering works, predictive simulations of (residual) passive inflows and pore pressures distribution for slope optimization |
| Groundwater Numerical Modelling | Feflow (DHI-Wasy), MineDW (Itasca) |
| Hydrogeology for Unconventional Gas (UCG, CBM, Shale Gas) | Majuba (Eskom), Theunissen (African Carbon Energy), Zonderwater (Exxaro), TOPS (Imperial College, European Commission for Technology), San Juan (San Juan), Prediction of fractures development (Golder Research) |

## Summary of Experience and Capability

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.

## Recent Project Experience

Key aspects of Mihai's recent project experience are summarised below.

| Project | Date | Mihai's Role |
|---|---|---|
| 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 |
| Finsch, Venetia | 2006 | Estimation of inflows and pore pressures distribution for underground and open pit mines |

## 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 2$^{nd}$ 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.

global environmental solutions

Tshipi Borwa Mine

Geochemical and Groundwater Assessment

SLR Project No.: 710.20008.00008

Report No.: 1

March 2014

Tshipi é Ntle

Manganese Mining

Tshipi Borwa Mine

Geochemical and Groundwater Assessment

SLR Project No.: 710.20008.00008

Report No.: 1

March 2014

Tshipi é Ntle Manganese Mining

**DOCUMENT INFORMATION**

| | |
|---|---|
| **Title** | Geochemical and Groundwater Assessment |
| **Project Manager** | Natasha Daly |
| **Project Manager e-mail** | ndaly@slrconsulting.com |
| **Author** | Jenny Ellerton |
| **Reviewer** | Terry Harck |
| **Client** | Tshipi é Ntle Manganese Mining |
| **Date last saved** | 2014/03/20 09:59:00 AM |
| **Keywords** | Manganese ore, geochemical assessment |
| **Project Number** | 710.20008.00008 |
| **Report Number** | 1 |
| **Status** | FINAL |
| **Issue Date** | March 2014 |

## 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.

# GEOCHEMICAL AND GROUNDWATER ASSESSMENT

## CONTENTS



## LIST OF FIGURES

## LIST OF TABLES



## LIST OF APPENDICES

# 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.

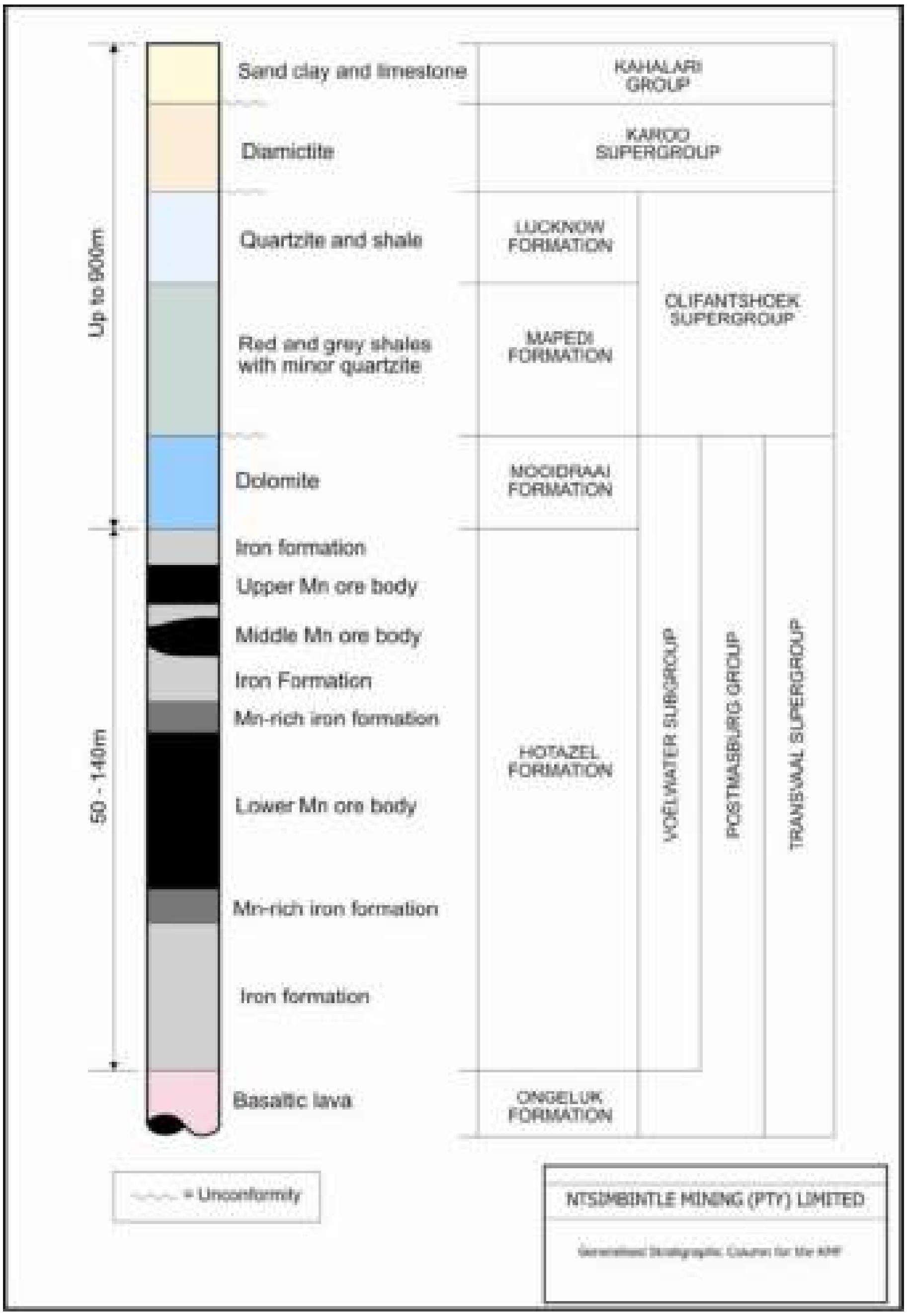



**FIGURE 2-2: GENERAL STRATEGIC COLUMN FOR THE KALAHARI MANGANESE FIELD (FIGURE PROVIDED BY TSHIPI BORWA PROJECT TEAM)**

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.**

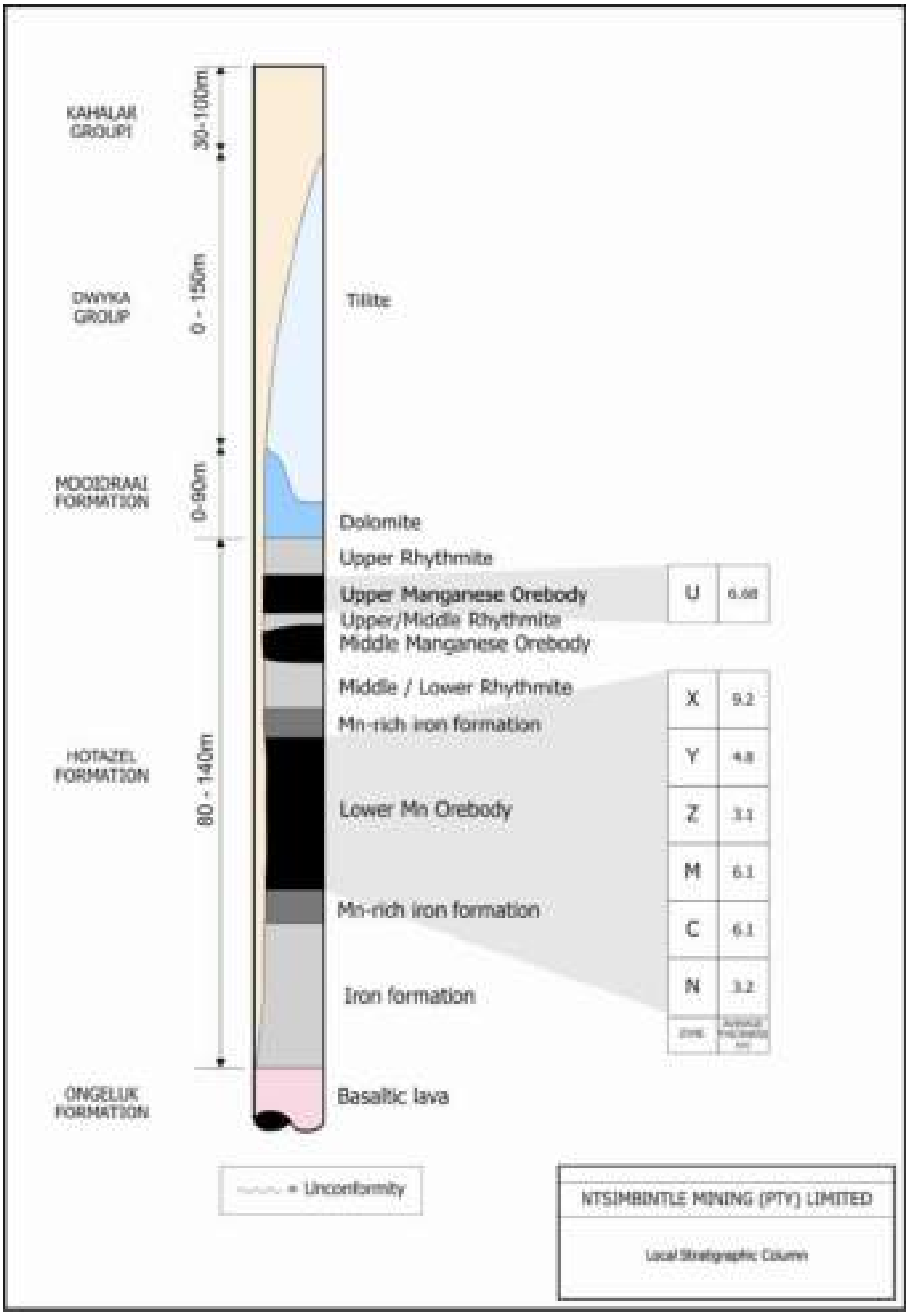



**FIGURE 2-3: LOCAL STRATIGRAPHY (FIGURE PROVIDED BY TSHIPI BORWA PROJECT TEAM)**

## 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 | - |

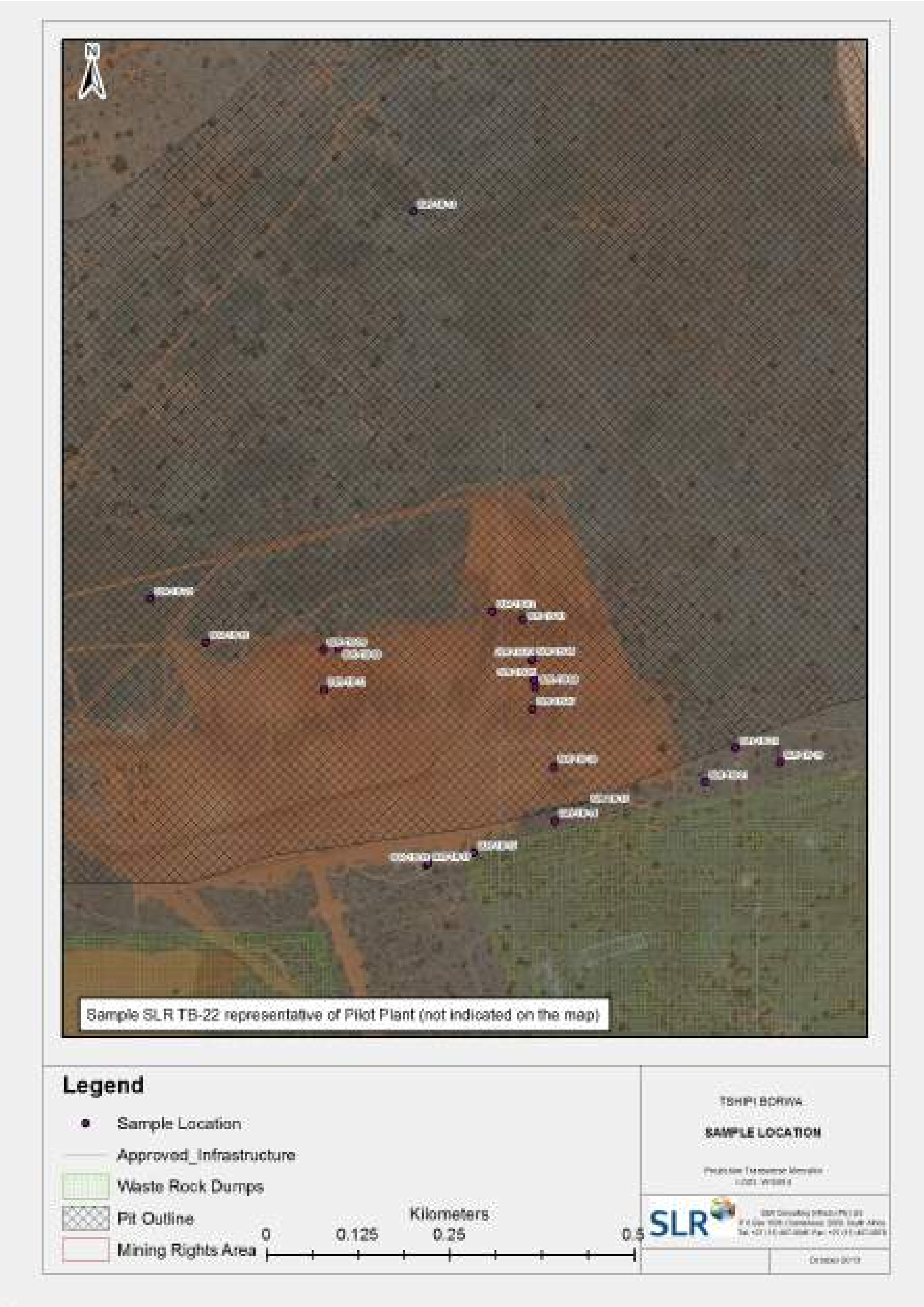



**FIGURE 3-1: SAMPLING LOCATION PLAN**

## 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):

$$\mathbf{NNP = NP - AP}$$

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):

$$\mathbf{NPR = NP/AP}$$

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.

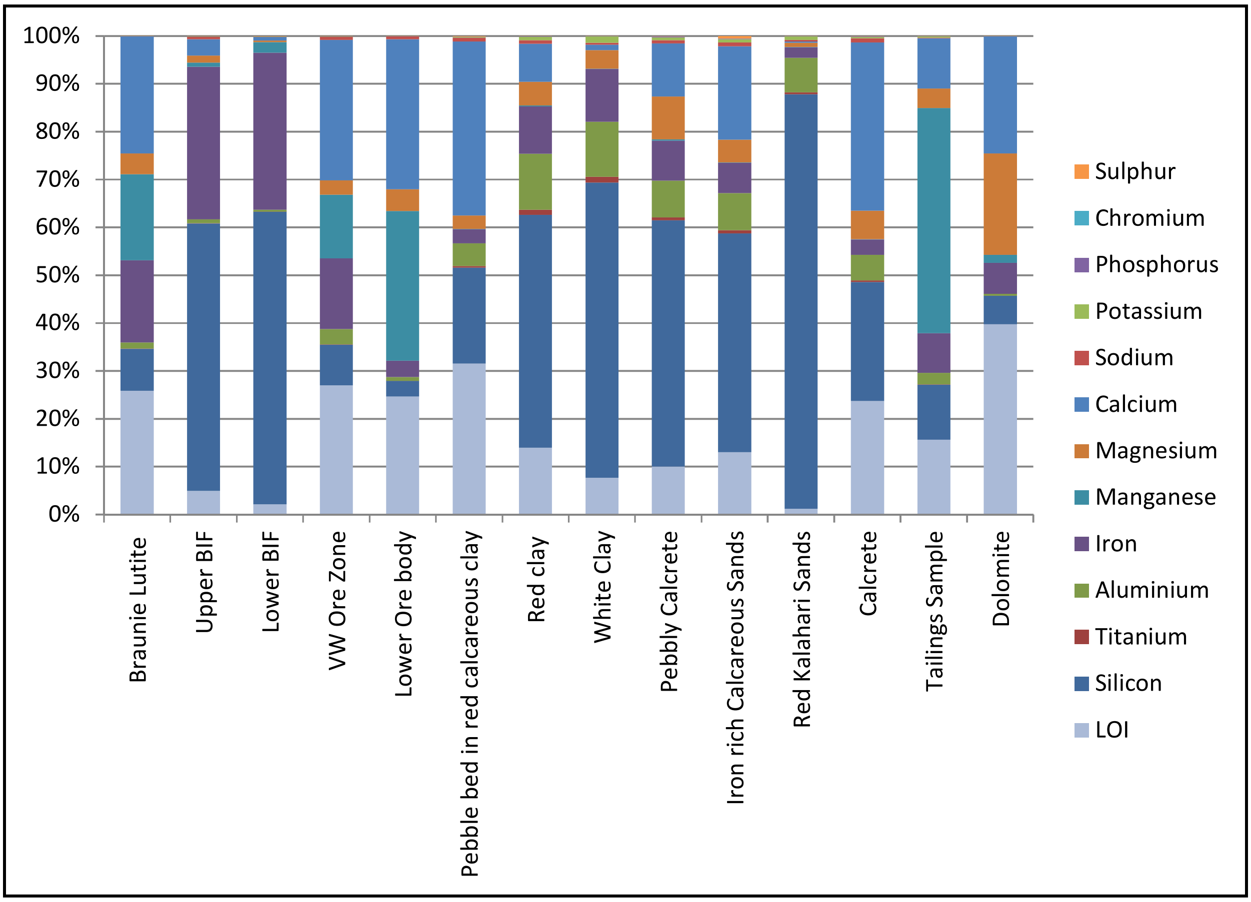



**FIGURE 4-1: MAJOR ELEMENT COMPOSITION OF SELECTED TSHIPI BORWA MINE LITHOLOGIES**

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.

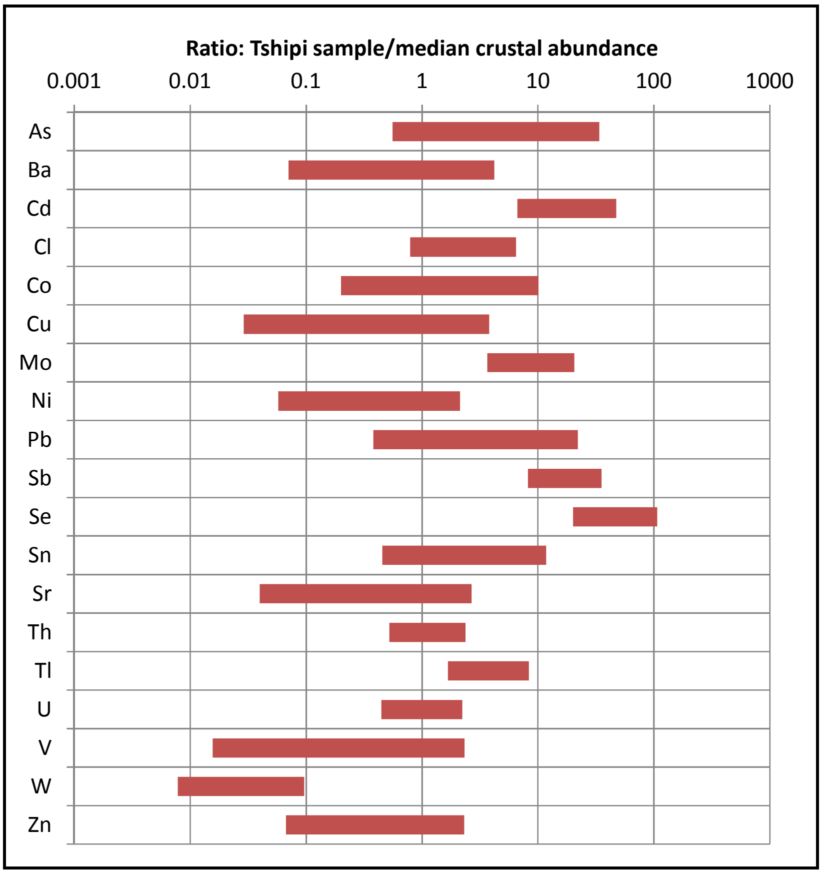



**FIGURE 4-2: TRACE ELEMENT RATIOS AGAINST CRUSTAL ABUNDANCE IN TSHIPI SAMPLES**

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 | 8 | <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 | 0.470 | <1.0 | <0.025 | <2 | 0.120 | <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 | 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)** |

# REFERENCES

Cornell, D.H., Armstrong, R.A. and Walraven, F. (1998). Geochronology of the Hartley Formation, South Africa: constraints on the Kheis tectogenesis and the Kaapvaal Craton's earliest Wilson Cycle. J. Afr. Erath. Sci., 6, 39-27.

Knights Piésold Consulting (2012) Tshipi Borwa Mine –Hydrocensus Study. Project No. RI301-00321/02. Draft Report

Metago Environmental Engineers. (2009). Ntsimbintle mining feasibility study environmental input. Johannesburg: Metago.

Metago Environmental Engineers (2009) Environmental Impact Assessment and Environmental Management Programme for the Proposed Ntsimbintle Manganese Mining Project. Project Reference: N001-03 Report No.2

Parkhurst DL and Appelo CAJ (1999) *User's Guide to PHREEQC (Version 2) – A Computer Program for Speciation, Batch-Reaction, One-dimensional Transport, and Inverse Geochemical Calculations*. United States Geological Survey (USGS) Water-Resources Investigations Report 99-4259.

Tshipi e Ntle. (2009). Environmental management procedures: EIA & EMP. Johannesburg: Tshipi e Ntle

Water Geosciences Consulting (2009) Groundwater Investigation for Ntsimbintle Mine. Report Number 27/02/09

**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 |
| Address: | PO Box 1596, Cramerview, 2060 | Email: | jellerton@slrconsulting.com |
| Telephone: | 011 467 0945 | | |

| 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 |

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

## 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

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## 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 | | --- | |

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## 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 | | --- | |

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## 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 | | --- | |

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## 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-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 | |

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## 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-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] | --- | | --- | |

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## 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-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 | | --- | |

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## 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-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 | |

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## 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-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 | | --- | |

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

## CERTIFICATE OF ANALYSES
## TCLP / ACID RAIN / DISTILLED WATER EXTRACTIONS

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

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

| 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 | |

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## 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-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 | |

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## 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-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.

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## 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**
**Address: PO Box 1596, Cramerview, 2060**
**Telephone: 011 467 0945** **Facsimile: 011 467 0978**
**Contact person: Jenny Ellerton**
**Email: jellerton@slrconsulting.com**

| 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 |

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## 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**
**Address: PO Box 1596, Cramerview, 2060**
**Telephone: 011 467 0945**
**Facsimile: 011 467 0978**
**Contact person: Jenny Ellerton**
**Email: jellerton@slrconsulting.com**

| 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 |

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


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

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

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

| 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

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

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

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

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

### 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 |

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

WATERLAB

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


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

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

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

**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

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


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

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

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

**REFERENCES**


LAWRENCE, R.W. & WANG, Y. 1997**. Determination of Neutralization Potential in the Prediction of Acid Rock Drainage**. Proc. 4th International Conference on Acid Rock Drainage. Vancouver. BC. pp. 449 – 464.

PRICE, W.A., MORIN, K. & HUTT, N. 1997. **Guidelines for the prediction of Acid Rock Drainage and Metal leaching for mines in British Columbia** : Part 11. Recommended procedures for static and kinetic testing. In: Proceedings of the Fourth International Conference on Acid Rock Drainage. Vol 1. May 31 – June 6. Vancouver, BC., pp. 15 – 30.

SOBEK, A.A., SCHULLER, W.A., FREEMAN, J.R. & SMITH, R.M. 1978. **Field and laboratory methods applicable to overburdens and minesoils**. EPA-600/2-78-054. USEPA. Cincinnati. Ohio.

SOREGAROLI, B.A. & LAWRENCE, R.W. 1998. Update on waste Characterisation Studies. Proc. Mine Design, Operations and Closure Conference. Polson, Montana.

USHER, B.H., CRUYWAGEN, L-M., DE NECKER, E. & HODGSON, F.D.I. 2003. **Acid-Base : Accounting, Techniques and Evaluation (ABATE): Recommended Methods for Conducting and Interpreting Analytical Geochemical Assessments at Opencast Collieries in South Africa.** Water Research Commission Report No 1055/2/03. Pretoria.

ENVIRONMENT AUSTRALIA. 1997. **Managing Sulphidic Mine Wastes and Acid Drainage**.


E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

## CERTIFICATE OF ANALYSES
## NETT ACID GENERATION

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

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

| 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 |

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## CERTIFICATE OF ANALYSES
## NETT ACID GENERATION

**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**
**Address: PO Box 1596, Cramerview, 2060**
**Telephone: 011 467 0945**
**Facsimile: 011 467 0978**
**Contact person: Jenny Ellerton**
**Email: jellerton@slrconsulting.com**

| 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 |

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## CERTIFICATES OF ANALYSES
## SULPHUR SPECIATION

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

**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**
**Address: PO Box 1596, Cramerview, 2060**
**Telephone: 011 467 0945**
**Facsimile: 011 467 0978**
**Contact person: Jenny Ellerton**
**Email: jellerton@slrconsulting.com**

| 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 |

E. Botha___________________
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## CERTIFICATES OF ANALYSES
## SULPHUR SPECIATION

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

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

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

| 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.

E. Botha__________________
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

## CERTIFICATE OF ANALYSES
### Organic/ Inorganic Carbon

**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**
**Address: PO Box 1596, Cramerview, 2060**
**Telephone: 011 467 0945**
**Facsimile: 011 467 0978**
**Contact person: Jenny Ellerton**
**Email: jellerton@slrconsulting.com**

| 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 |

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## CERTIFICATE OF ANALYSES
### Organic/ Inorganic Carbon

**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**
**Address: PO Box 1596, Cramerview, 2060**
**Telephone: 011 467 0945**
**Facsimile: 011 467 0978**
**Contact person: Jenny Ellerton**
**Email: jellerton@slrconsulting.com**

| 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**

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## 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**
**Address: PO Box 1596, Cramerview, 2060**
**Telephone: 011 467 0945**
**Facsimile: 011 467 0978**
**Contact person: Jenny Ellerton**
**Email: jellerton@slrconsulting.com**

| 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**

E. Botha
Geochemistry Project Manager

WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za

# CERTIFICATE OF ANALYSES
## X-RAY FLUORESENCE

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

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

| 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**

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## 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**
**Address: PO Box 1596, Cramerview, 2060**
**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**

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## 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**
**Address: PO Box 1596, Cramerview, 2060**
**Telephone: 011 467 0945**
**Facsimile: 011 467 0978**
**Contact person: Jenny Ellerton**
**Email: jellerton@slrconsulting.com**

| 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 |

**[s] =Results obtained from sub-contracted laboratory**

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## 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**
**Address: PO Box 1596, Cramerview, 2060**
**Telephone: 011 467 0945**
**Facsimile: 011 467 0978**
**Contact person: Jenny Ellerton**
**Email: jellerton@slrconsulting.com**

| 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 | | | | | | | |

E. Botha
Geochemistry Project Manager

# WATERLAB (PTY) LTD

Building D, The Woods,
Persequor Techno Park,
Meiring Naudé Road, Pretoria
P.O. Box 283, 0020

Telephone: +2712 – 349 – 1066
Facsimile: +2712 – 349 – 2064
Email: accounts@waterlab.co.za


## 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**
**Address: PO Box 1596, Cramerview, 2060**
**Telephone: 011 467 0945**
**Facsimile: 011 467 0978**
**Contact person: Jenny Ellerton**
**Email: jellerton@slrconsulting.com**

| 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 |

SLR Consulting (Africa) (Pty) Ltd

## RECORD OF REPORT DISTRIBUTION

| | |
|---|---|
| **SLR Reference:** | 710.20008.00036 |
| **Title:** | Tshipi Borwa Groundwater Study |
| **Site name:** | Tshipi Borwa Manganese Mine |
| **Report Number:** | 1 |
| **Client:** | Tshipi é Ntle Manganese Mining (Pty) Ltd |

| Name | Entity | No. of copes | Date issued | Issuer |
|---|---|---|---|---|
| Jeff Leader | Tshipi é Ntle Manganese Mining (Pty) Ltd | 1 | July 2017 | M. Muresan |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

global environmental solutions


**JOHANNESBURG**

**Fourways Office**
P O Box 1596, Cramerview, 2060,
SOUTH AFRICA

Unit 7, Fourways Manor Office Park,
1 Macbeth Ave (On the corner with Roos Street), Fourways, Johannesburg,
SOUTH AFRICA

**T: +27 (0)11 467 0945**