APPENDIX E: HYDROGEOLOGY ASSESSMENT

GAMSBERG SMELTER PROJECT: HYDROGEOLOGICAL STUDY

Gamsberg Zinc Smelter

Prepared for: Black Mountain Mining (Pty) Ltd

Client Ref: N/A

Authority Ref: NCS 30/5/1/2/2 (518) MR

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BASIS OF REPORT

SPECIALIST DECLARATION OF INDEPENDENCE

I, RAYMOND MINNAAR, declare that -

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

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Signature of Specialist

EXECUTIVE SUMMARY

Introduction

Black Mountain Mining (Pty) Ltd, part of the Vedanta Zinc International, owns and operates the Gamsberg Zinc Mine. The EIA process was completed in 2013 and in 2014 the Gamsberg Zinc Mine received an Environmental Authorisation (Ref: NC/EIA/NAM/KHA/AGG/2012), a Waste Management Licence (Ref: 12/9/11/L955/8); and Water Use Licence (Ref:14/D82C/ABCGI/2654)) for their open pit mining activities and concentrator plant. The Gamsberg Zinc Mine has been in mining operation since June 2016 and is currently mining up to 4 million tonnes per annum (mtpa) and producing up to 250 000 tonnes per annum (tpa) of zinc concentrate for export. Phase 2 will expand the mining capacity to 10 million tons per annum (mtpa). The Gamsberg Zinc Mine is in the Northern Cape Province of South Africa, approximately 14 km east of the town of Aggeneys and 120 km east of Springbok along the N14.

Black Mountain Mining (Pty) Ltd is now proposing to construct a new zinc smelter and associated infrastructure to produce 300 000 tpa special high-grade zinc metal by processing 680 000 tpa of zinc concentrate (Gamsberg Smelter Project). As a by-product 450 000 tpa pure sulphuric acid will be produced for both export and consumption within South Africa.

This Hydrogeological Specialist Report is based on the requirements of both the National Water Act (No. 36 of 1998) (NWA): Regulations Regarding the Procedural Requirements for Water Use Licence Applications and Appeals (GNR 267 of 2017) and the National Environmental Management Act (No. 107 of 1998) (NEMA) EIA Regulations (GNR 326 of 2017), Appendix 6.

Scope of Work

The Hydrogeological Study objective is aimed to support the Environmental specialists to determine whether any groundwater quality impacts may be caused by the Gamsberg Smelter Project.

The scope of work for the Hydrogeological Study included the evaluation of potential changes of groundwater quality during and post operation of the smelter complex and new Jarosite/ Jarofix dumping site. The groundwater specialist study has been conducted by SLR and focuses on the following:

- Review all existing hydrogeological data:
    - this includes monitoring data and baseline hydrogeology (water levels and water quality).
    - review previous studies that were undertaken for the Gamsberg Zinc Mine, including the groundwater model report and all groundwater monitoring data.
    - examine new infrastructure map and determine possible source term sites.
    - extract all pertinent data and compile the Conceptual Hydrogeological Model.
- Groundwater numerical modelling:
    - based on the source term derived from the geochemical study, the existing groundwater numerical model will be updated; and
    - model results will inform the EIA and WULA regarding whether there is any potential for groundwater contamination.
- The groundwater study will include a geochemical and waste assessment to inform the contamination potential of any residues/discards generated by the project. The waste assessment will be undertaken in terms of the National Norms and Standards (Regulation 635 and 656 of 2013).

The potential groundwater impacts were limited to the following activities:

- Proposed new smelter complex (and alternative sites).
- Proposed secured landfill facility (SLF) to dispose of Jarosite (and alternative sites).

This report excludes the following activities or site infrastructure:

- Waste rock dump (WRD).
- Existing tailings storage facility (TSF).
- Open pit mining (groundwater quality and quantity impacts).

Geochemical and Waste Assessment

Samples of the tailings, Jarosite, Jarofix, Jarosite composite (93% tailings mixed with 7% of Jarosite), and Jarofix composite (93% tailings mixed with 7% of Jarofix) were submitted to UIS Laboratory for waste classification analyses. The distilled water tests performed on the samples were in accordance with the classification guidelines of the National Norms and Standards for the Assessment of Waste for Landfill Disposal (DEA, 2013) and were classed against the various thresholds for TC and LC.

The disposal of Jarofix on the SLF was selected as the preferred alternative by the client for the following reasons:

- The Jarosite has leachable concentrations which exceed the LCT3 value preventing disposal without treatment.
- The co-disposal of Jarosite or Jarofix with tailings would require a Class C liner. The existing liner for the tailings does not conform to a Class C (the tailings facility was constructed prior to the enactment of Regulation 635 and Regulation 636).
- Jarosite or Jarofix co-disposed with tailings material may not be stable in the long term due to the potential for acidification of the tailings material. The tailings had total sulphur content of close to 10% which is anticipated to be present largely as sulphide, therefore it has a high potential for ARD in the long term.

The Jarofix material was classified as a Type 1 waste requiring a Class A liner based on the following:

- Lead exceeded the TCT2 guideline values;
- Antimony exceeded the TCT1 guideline values and was within the limits of TCT2;
- Arsenic, barium, cadmium, copper, fluoride, mercury, and zinc exceeded the TCT0 guideline values and were within the limits of TCT1; and
- Sulphate, arsenic, cadmium, nickel, and antimony exceeded the LCT0 and SANS 241-1:2015 guideline values and were within the limits of LCT1.

Groundwater Levels

The average groundwater levels measured during the Golder (2007), SRK (2010), and ERM (2013a) hydrocensus investigations were 31.7 mbgl, 28.1 mbgl, and 29.4 mbgl, respectively.

The Gamsberg groundwater monitoring network consists of privately-owned farm boreholes as well as mine monitoring boreholes that are within the mining rights area (MRA), and monitoring is conducted by environmental consultants, currently GHT Consulting, on behalf of the Gamsberg Mine on a quarterly basis

(GHT, 2019). Regional monitoring boreholes had an average groundwater level of 30.8 mbgl and ranged between 8.6 mbgl and 78.9 mbgl for the April 2019 monitoring round. The mine monitoring boreholes had an average groundwater level of 30.6 mbgl and ranged between 11.6 mbgl and 52.3 mbgl for the April 2019 monitoring round. Groundwater levels of the monitoring network boreholes were quasi-stable and there were no adverse effects due to the pit dewatering affecting mine and regional groundwater levels.

Groundwater Quality

Results from the previous hydrocensus investigations showed pH ranged between 5.81 and 8.67 with an average value of 7.49. The electrical conductivity (EC) ranged between 16 mS/m and 1 626 mS/m with an average value of 161 mS/m. The sulphate concentrations ranged between 14.6 mg/L and 1 706 mg/L with an average concentration of 163.9 mg/L.

Groundwater monitoring results for boreholes within the MRA and on neighbouring farms conducted between November 2017 and April 2019 by GHT Consulting indicated the pH of the groundwater samples ranged between 6.57 and 8.44 with an average value of 7.51. The electrical conductivity ranged between 33 mS/m and 1 141 mS/m with an average value of 229 mS/m. The sulphate concentrations ranged between 28.5 mg/L and 2 324 mg/L with an average concentration of 289.3 mg/L.

The previous hydrocensus investigations conducted before commencement of mining operations and groundwater monitoring results showed several constituents that were elevated above relevant guideline limits. Parameters included EC, total dissolved solids (TDS), sodium (Na), calcium (Ca), magnesium (Mg), chloride (Cl), sulphate (SO_4), fluoride (F), nitrate (as N) (NO_3-N), arsenic (As), lead (Pb), iron (Fe), manganese (Mn), and uranium (U).

Processes of evaporation and long-residence time or the host rock mineralogy (apatite-bearing rocks) may result in elevated fluoride concentrations. Elevated fluoride in groundwater is a characteristic feature of the Northern Cape. SRK (2010) concluded from the Piper diagrams that the chemical composition of the water from the area under investigation has undergone natural base-exchange and precipitation processes. The hydrochemistry of the Gamsberg area was interpreted by SRK (2010) to be indicative of a mature hydrochemical environment with very limited recharge, which generally only takes place in years of exceptionally high precipitation. The piper diagrams for April 2019 of the Gamsberg mine and regional monitoring boreholes confirmed the SRK (2010) findings that the groundwater is indicative of a mature hydrochemical environment with very limited recharge.

GHT Consulting concluded that between November 2017 and April 2019 there was no indication of pollution emanating from the Gamsberg Zinc Mine site that could affect the groundwater quality of the surrounding farm boreholes.

Current Groundwater Conditions

The present groundwater conditions do not indicate any type of impact on the groundwater environment as a result of current mining and processing operations.

Predicted Impacts of Facility

Water seepage and associated contamination to groundwater from the smelter complex is not expected to contribute as potential spillages from water and/or chemical storage facilities is only expected to occur in extreme events.

A deterioration in groundwater quality was the most significant risk associated with the proposed SLF. During the operational phase of the SLF, concentrations of sulphate, sodium, lead, and antimony are expected to increase above current background levels.

The numerical groundwater flow model was setup to predict the potential impact from contaminants of concern identified by the geochemical modelling with various seepage rates. Seepage rates were estimated for operational and closure phases for unconsolidated and consolidated material as well as installation of a Class A liner.

Potential contaminant plumes of sulphate, sodium, lead, and antimony are expected to emanate from the proposed SLF in event of liner failure or leaks. The maximum operational and closure phase plume extent is expected to be maximum ~700 m and ~1 000 m from the SLF, respectively, predominantly in a south-westerly direction. No sensitive receptors' boreholes are located within this potential plume development area.

Water Management Plan

The main mitigation measure during the operational and closure phases consists in the installation of a Class A liner for the SLF. Groundwater monitoring (including recommended additional monitoring boreholes) must be continued, and the update the numerical groundwater model with new data, and geochemical assessment must be done periodically. Additional operational and closure mitigation measures are described in more detail in the report.

Hydrogeological Specialist Recommendation

Based on the findings of the hydrogeological study, no fatal flaws have been identified, which may limit the proposed smelter activities.

It is the opinion of the specialist that the proposed project may proceed on condition that all mitigation measures as outlined and discussed in this report be adhered to.

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APPENDICES

LIST OF TABLES

LIST OF FIGURES

Legislative requirements for Specialist reporting

As required in the National Environmental Management Act (NEMA) Regulations (GNR 326 of 2017) Appendix 6 the following information is required to be included in a Specialist Report. The following Table includes the references for the relevant information within this Report.

No.	NEMA Regulations (2014) (as amended) - Appendix 6	Relevant section in report
a(i)	Details of the specialist who prepared the report	Section 1.2
a(ii)	The expertise of that person to compile a specialist report including a curriculum vitae	Section 1.2 and Appendix A
b)	A declaration that the person is independent in a form as may be specified by the competent authority	Page ii
c)	An indication of the scope of, and the purpose for which, the report was prepared	Section 3
cA)	An indication of the quality and age of base data used for the specialist report	Section 4.1
cB)	A description of existing impacts on the site, cumulative impacts of the proposed development and levels of acceptable change	Section 8.8.1
d)	The duration, date and season of the site investigation and the relevance of the season to the outcome of the assessment	Section 5.5 and Section 5.6
e)	A description of the methodology adopted in preparing the report or carrying out the specialised process inclusive of equipment and modelling used	Section 4
f)	Details of an assessment of the specific identified sensitivity of the site related to the proposed activity or activities and its associated structures and infrastructure inclusive of a site plan identifying site alternative	Section 5.8
g)	An identification of any areas to be avoided, including buffers	Section 5.8
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;	Section 5.8
i)	A description of any assumptions made and any uncertainties or gaps in knowledge	Section 1.3
j)	A description of the findings and potential implications of such findings on the impact of the proposed activity or activities	Section 9
k)	Any mitigation measures for inclusion in the EMPr	Section 9
l)	Any conditions for inclusion in the environmental authorisation	Section 9
m)	Any monitoring requirements for inclusion in the EMPr or environmental authorisation	Section 10
n(i)	A reasoned opinion as to whether the proposed activity or portions thereof should be authorised and regarding the acceptability of the proposed activity or activities	Section 13
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 11

No.	NEMA Regulations (2014) (as amended) - Appendix 6	Relevant section in report
o)	A description of any consultation process that was undertaken during the course of preparing the specialist report	NA
p)	A summary and copies of any comments received during any consultation process and where applicable all responses thereto	Appendix G
q)	Any other information requested by the competent authority.	NA

ACRONYMS AND ABBREVIATIONS

Acronym / Abbreviation	Definition
ABA	Acid-base accounting
AER	Acceptable environmental risk
AP	Acid potential
ARD	Acid rock drainage
BDL	Below detection limit
BDL	Below detection limit
DWS (formerly DWA/ DWAF)	Department of Water and Sanitation (Now Department of Human Settlements, Water and Sanitation)
EC	Electrical conductivity
GQM	Groundwater quality management
MAP	Mean annual precipitation
NAG	Net acid generation
NP	Neutralising potential
SLF	Secured landfill facility
TDS	Total dissolved solids
TSF	Tailings storage facility
WMA	Water management area
WRC	Water research commission of South Africa
WRD	Waste rock dump
WRD	Waste rock dump
XRD	X-ray diffraction
XRF	X-ray fluorescence
K	Hydraulic conductivity (m/d)
T	Transmissivity (m^2/d)
LOM	Life of mine

UNITS OF MEASURE

Unit of measure	Definition
L/s	Litres/second
m	Metre
m/d	Metre/day
m^2/d	Metre^2/day
mamsl	Metres above mean sea level
mbgl	Metres below ground level
Mtpa	Million tonnes per annum
mS/m	Milli-Siemens/metre
tpa	Tonnes per annum

CHEMICAL SYMBOLS

Unit of measure	Definition
Al	Aluminium
As	Arsenic
Ba	Barium
Ca	Calcium
Cd	Cadmium
Cl	Chloride
Cu	Copper
F	Fluoride
Fe	Iron
Hg	Mercury
K	Potassium
Mg	Magnesium
Mn	Manganese
Na	Sodium
NO_3-N / NO_3	Nitrate as N
Pb	Lead
Sb	Antimony

Unit of measure	Definition
Se	Selenium
SO_4	Sulphate
U	Uranium
Zn	Zinc

1 INTRODUCTION

This Hydrogeological Specialist Report is based on the requirements of both the National Water Act (No. 36 of 1998) (NWA): Regulations Regarding the Procedural Requirements for Water Use Licence Applications and Appeals (GNR 267 of 2017) and the National Environmental Management Act (No. 107 of 1998) (NEMA) EIA Regulations (GNR 326 of 2017), Appendix 6.

1.1 PROJECT OVERVIEW

In 1998, Anglo American (Anglo) purchased Goldfield's interest in the Gamsberg Zinc Mine and commenced detailed feasibility studies for the establishment of a large-scale open pit mine with a metal production capacity of 300 kilotons per annum (ktpa). Upon completion of the feasibility study in 1999, Anglo commenced with all environmental and other regulatory approval processes to establish the mine. An old order mining right was granted in terms of the Mineral Act (No. 50 of 1991). Environmental approval was received in 2000 for the proposed mine, associated infrastructure, and waste management facilities in terms of the Environmental Conservation Act (No. 73 of 1989) (ERM, 2013a).

Despite receiving the necessary approvals to proceed with the construction and operation of an open pit mine and associated smelter complex, Anglo did not initiate the full project development for various reasons. Subsequently, Anglo established a small-scale underground mining operation which commenced along the northern section of the Gamsberg inselberg in 2003. These underground mining operations are currently not operational and only open pit mining is taking place.

The feasibility study undertaken during the initial EIA process in 2000 (SRK Consulting) explored various mining options. The study concluded that the viability of a mine at Gamsberg would be dependent on a zinc metal production of 300 000 tpa for at least 25 years. To achieve this zinc metal production, open pit mining was identified to be the only feasible option, as it would have a life span of 33 years, meet the production targets, and recover 95% of the ore reserves. The underground mining option confirmed that the production level could only attain 250 000 tpa, with a life span of less than 25 years as only 65% of ore deposits could be recovered. Based on these findings, Anglo pursued the option of open pit mining to achieve project viability.

The proposed construction of the open pit zinc mine and associated smelter complex was placed on hold until 2007, at which time Anglo commenced a Concept Study to augment the 1999 Feasibility Study. The Concept Study scaled up the proposed metal production from 300 ktpa to 400 ktpa. However, upon completion of this study, the project was placed on hold once again due to insecurity of electricity supply and rising costs of power.

In 2009/2010, Anglo introduced additional project components and initiated a Gap Analysis. The purpose of the Gap Analysis served to identify legislative and technical requirements that were now required, based on the changes in environmental legislation (i.e. EIA regulations) and project components. Upon completion of the Gap Analysis in 2010, Vedanta Resources plc. acquired the Black Mountain Mine (BMM) as well as the Gamsberg Zinc Mine.

Black Mountain Mining (Pty) Ltd, part of the Vedanta Zinc International, owns and operates the Gamsberg Zinc Mine. In 2010 Vedanta Resources acquired Black Mountain Mining (Pty) Ltd from Anglo American as part of the acquisition of the zinc base metal mine take over. Following the acquisition of the Black Mountain Mining properties and rights a feasibility and optimisation of technology for the Gamsberg Zinc Mine was done.

The EIA process was completed in 2013 and in 2014 the Gamsberg Zinc Mine received an Environmental Authorisation (Ref: NC/EIA/NAM/KHA/AGG/2012), a Waste Management Licence (Ref: 12/9/11/L955/8); and Water Use Licence (Ref:14/D82C/ABCGI/2654)) for their open pit mining activities and concentrator plant. The Gamsberg Zinc Mine has been in operation since June 2016 and is currently mining up to 4 million tonnes per annum (mtpa) and producing up to 250 000 tonnes per annum (tpa) of zinc concentrate for export.

The mining activities commenced in June 2016 when overburden stripping for the open pit commenced. The mining plan for Phase 1 consisted of three smaller open pits in the footprint of the 10 million ton per annum footprint. Development of the opencast mine and concentrator plant has been done in phases. The construction of the concentrator plant commenced in 2017 with the official opening in February 2019. Phase 2 will expand the mining capacity to 10 million ton per annum (mtpa) open pit.

Black Mountain Mining (Pty) Ltd is now proposing to construct a new zinc smelter and associated infrastructure to produce 300 000 tpa special high-grade zinc metal by processing 680 000 tpa of zinc concentrate (Gamsberg Smelter Project). As a by-product 450 000 tpa of 98.5% pure sulphuric acid will be produced for both export and consumption within South Africa.

Black Mountain Mining (Pty) Ltd is proposing the following:

- A smelter complex using the Roast-Leach-Electrowinning (R-L-E) with Jarosite precipitation and Jarofix conversion process.
- The development of a secured landfill facility for the disposal of the Jarofix).
- A new water 7 km pipeline from Horseshoe reservoir to the smelter complex.
- A laydown area and business partner camp for the construction phase.
- Associated new roads and transmission line upgrades.

1.2 SPECIALIST DETAILS

Mihai Muresan 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 which include Mine Dewatering (open pit and underground systems) and Environmental Impact Assessment projects (Groundwater Specialist Studies including ground water contaminant flow modelling) for major minerals developments throughout Africa for many of the major mining operators.

Raymond Minnaar is a Hydrogeologist and has 7 years' experience in the mining hydrogeology industry within South Africa, Namibia, Botswana, Mozambique, Lesotho, Zambia, and the DRC. His experience includes mining related hydrogeological investigations: numerical modelling of the impacts on groundwater regimes in terms of flow and contaminant transport (MODFLOW and FEFLOW).

Raymond completed BSc, BSc Honours and MSc degrees in Engineering and Environmental Geology with specialization in Hydrogeology at the University of Pretoria, is a registered Professional Natural Scientist with SACNASP and Professional Member of the Water Institute of Southern Africa.

1.3 PROJECT ASSUMPTIONS, LIMITATIONS AND EXCLUSIONS

The following assumptions and limitations are applicable to this report:

- Information received from the client indicated that open pit mining will not progress below regional groundwater levels outside the inselberg.
- The potential groundwater impacts are limited to the following activities:
    - Proposed new smelter complex (and alternative sites).

  - Proposed secured landfill facility (SLF) to dispose of Jarofix (and alternative sites).
- This report excludes the following activities or site infrastructure:
  - Waste rock dump (WRD).
  - Existing tailings storage facility (TSF).
  - Open pit and underground mining (groundwater quality and quantity impacts).
- Apart from the geophysical survey, no other site visit was conducted by SLR, i.e. no reconnaissance site visit, hydrocensus (incl. groundwater level measurements and quality sampling), etc.
- No intrusive studies were conducted during the SLR study, i.e. no drilling of boreholes.
- No aquifer hydraulic tests were conducted by SLR, i.e. no slug tests and pump tests.
- Site geology was inferred from previous groundwater studies.
- It is assumed that the data and information related to groundwater at the site (both data in the public domain and groundwater level and quality data made available by the client) are reasonably correct.

The proposed Gamsberg Smelter infrastructure and waste facility alternatives are illustrated in Figure 1-1.

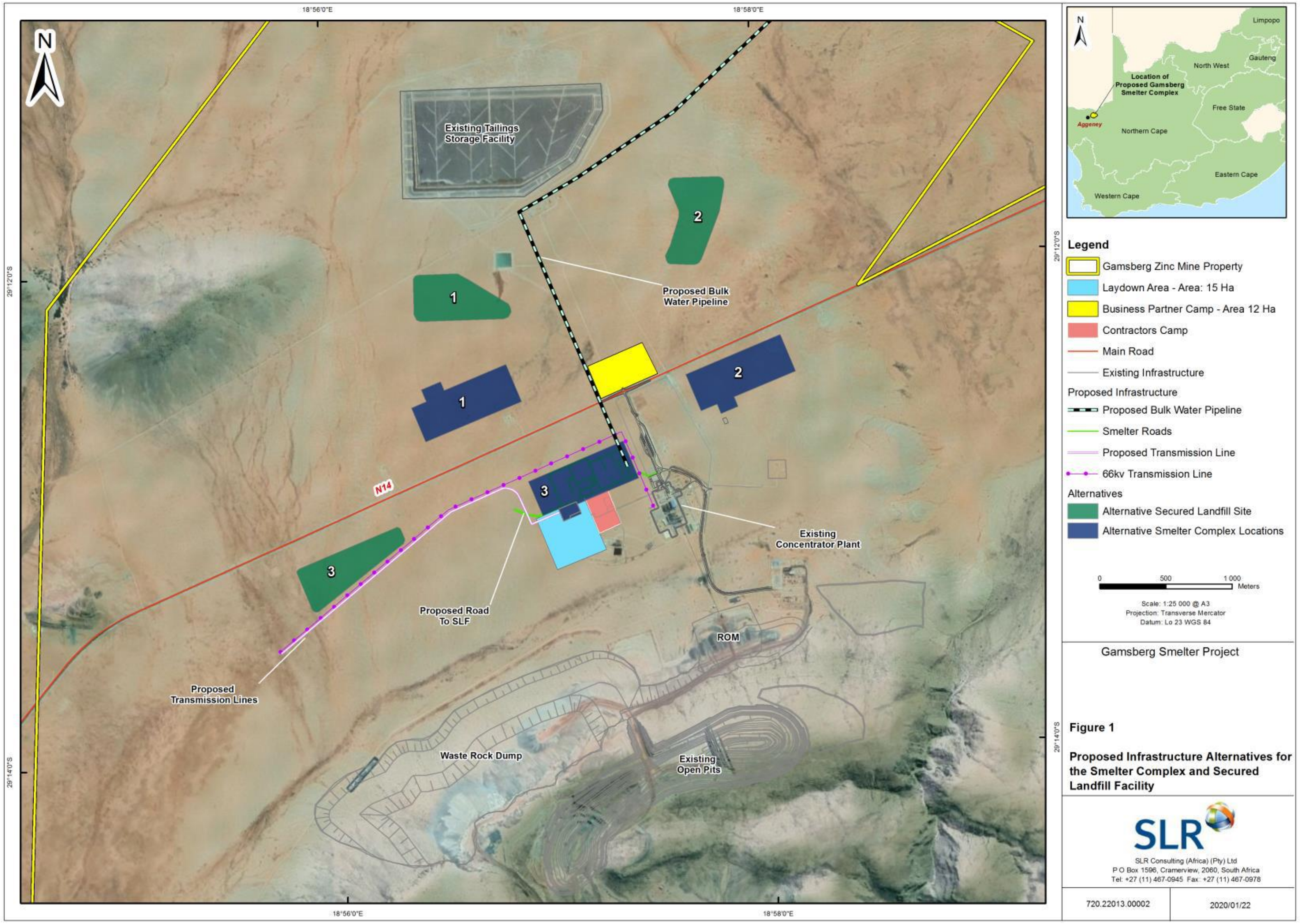


FIGURE 1-1: GAMSBERG SMELTER PROPOSED AND EXISTING INFRASTRUCTURE (INCLUDING PROPOSED ALTERNTIVE SITES).

2 GEOGRAPHICAL SETTING

2.1 CLIMATE

The study area is in a “Hot Desert” region. The area is one of the hottest and driest areas in South Africa with desert and semi-arid conditions. The area experiences extreme climate conditions with temperature maximums exceeding 40°C in the summer months. Rainfall in the summer months is dominated by thunderstorms. Winter temperatures can drop as low as -2°C at night with localised frost and dew from June to August (SRK, 2010).

According to the SRK (2010) study the area receives both summer and winter rainfall with an average of 103 mm/annum, mostly occurring in February. Evaporation rates are high (~3 500 mm/annum) and the area suffers a permanent water deficit, which is highest (over 400 mm) between November and January. Protracted droughts are common in the area.

ERM (2013a) stated that there appeared to be an orographic control on the rainfall distribution with the mountainous areas receiving higher rainfall, as indicated by the modelled distribution of mean annual precipitation which indicates around 110 – 145 mm mean annual precipitation (MAP) on the Gamsberg inselberg.

Rainfall data measured by the South African Weather Service (SAWS) at the Aggeneys Weather Station indicated MAP from 1986 - 2018 ranged between 11.0 mm/a and 219.5 mm/a with an average MAP of 99.1 mm/a (Figure 2-1). However, a 3-year simple moving average (SMA) of MAP indicates that generally rainfall in the region is decreasing. The 3-year SMA in 2007 was 151.7 mm/a and continually dropped to the 2018 3-year SMA of 38.7 mm/a.

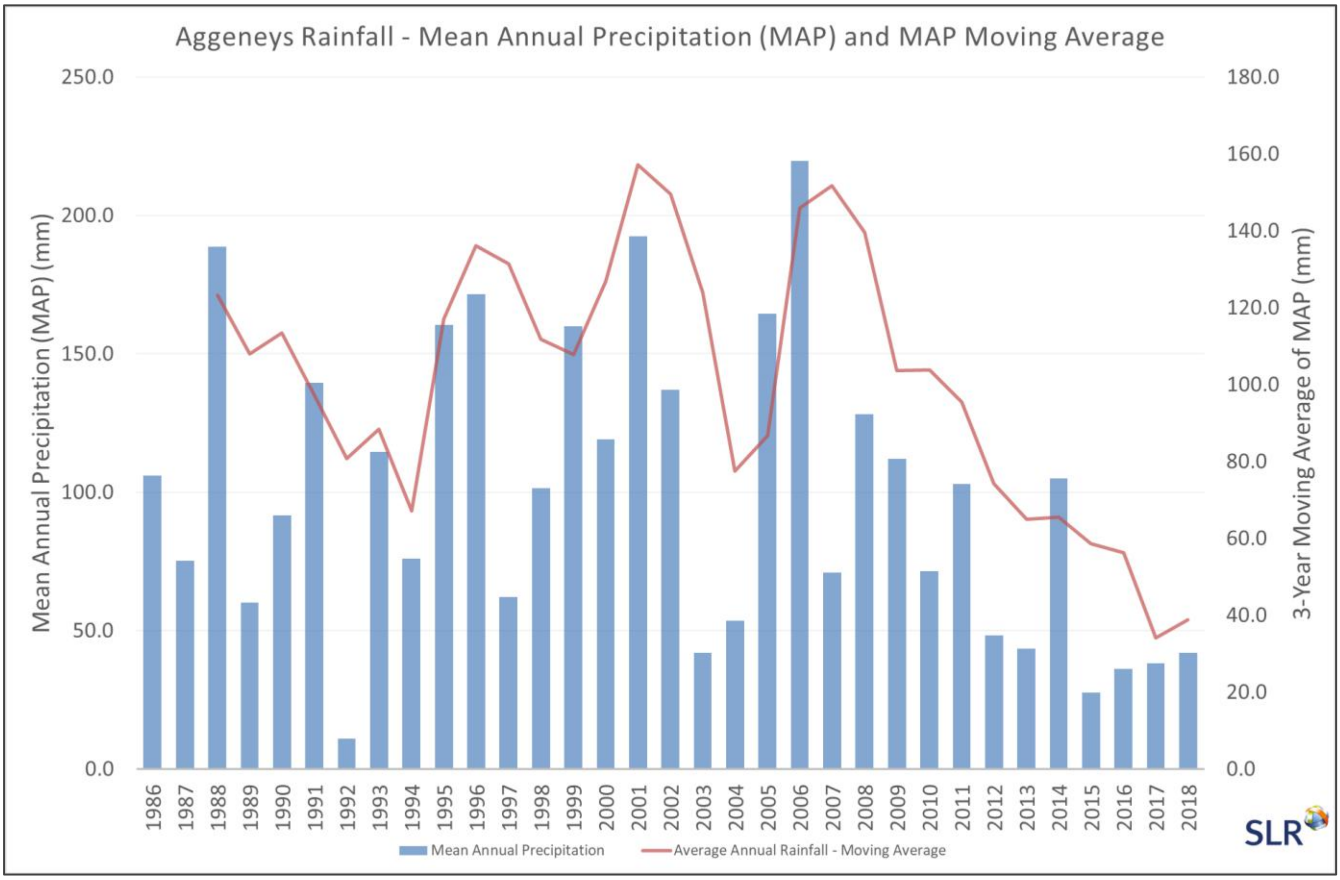


FIGURE 2-1: AGGENEYS RAINFALL – MEAN ANNUAL PRECIPITATION (MAP) AND MAP MOVING AVERAGE 1986 – 2018.

2.2 TOPOGRAPHY AND DRAINAGE

SRK (2010) described the Gamsberg as a steep-sided, oval-shaped inselberg which rises to approximately 250 m above the general level of the surrounding plains. The inselberg extends 7.2 km in an east-west and 4.6 km in a north-south direction. Erosion of the flat-topped inselberg, a relic of an extensive Cretaceous age peneplain, resulted in the formation of an internal basin. At its lowest point, this basin is 60 to 70 m below the rim of the inselberg. The Gamsberg area is surrounded by an extensive peneplain of which the soils are predominantly shallow and stony.

The soils within the inselberg were described by SRK (2010) as shallow lithosol (bouldery or stony scree slope soils) and bare rock on the scarps and crest and shallow gravelly soils in the Gamsberg Basin. Furthermore, the soils on the peneplain generally consist of shallow, reddish sandy topsoil overlying dorbank (duripan) or calcrete. In the northern part of the study area a very shallow (10 cm), red sandy surface layer overlies dorbank or calcrete. Areas of slightly deeper red soils (30 to 60 cm deep) overlying dorbank, cover large areas in the western and southern parts of the study area. Areas of deeper red sandy soils are limited to small dunes and pediment in the south-western portion of the study area.

The study site is situated in the Orange River basin and Orange River water management area (WMA). The study area is located at the watershed between four quaternary catchments, D81G, D82A, D82B and D82C (Figure 2-2). The Gamsberg inselberg itself, excluding the west ridge, is situated within quaternary catchment D81G, which drains in a northerly direction towards the Orange River some 35km from the inselberg. Because of the climate, the drainage features in the region are all ephemeral.

ERM (2013) identified four springs, two were located on privately owned land and two springs were located within the mining right area (MRA) during the hydrocensus investigation. ERM noted that the flow rates of the springs were extremely low.

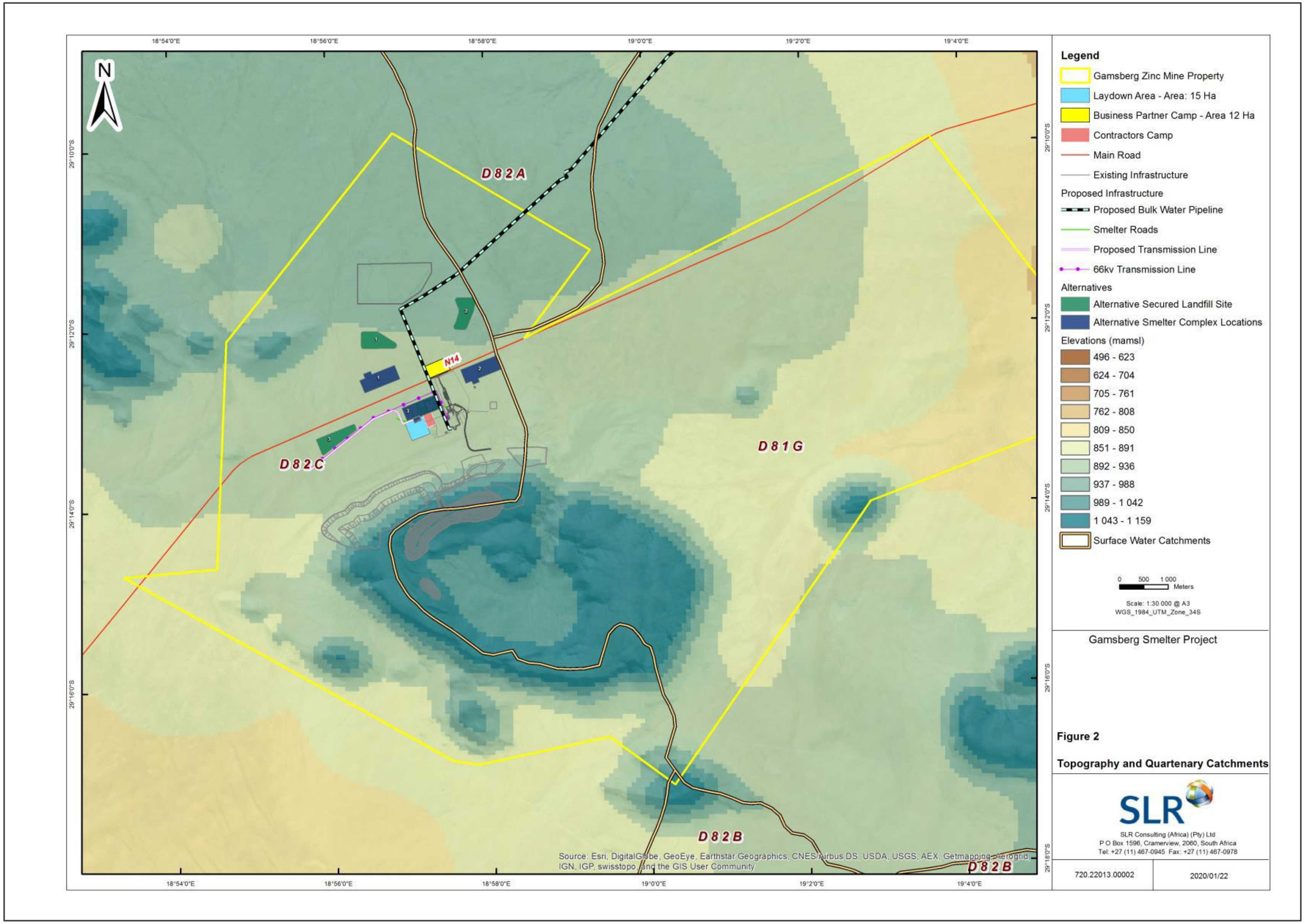


FIGURE 2-2: TOPOGRAPHY AND QUARTERNARY CATCHMENTS OF THE GAMSBERG ZINC MINE AND SURROUNDING AREA.

3 SCOPE OF WORK

The Hydrogeological Study objective is aimed to support the Environmental specialists to determine whether any groundwater quality impacts may be caused by the Gamsberg Smelter Project.

The scope of work for the Hydrogeological Study included the evaluation of potential changes to groundwater quality during and post operation of the smelter complex and associated infrastructure. The groundwater specialist study has been conducted by SLR and focuses on the following:

- Review all existing hydrogeological data:
  - this includes monitoring data and baseline hydrogeology (water levels and water quality).
  - review previous studies that were undertaken for the Gamsberg Zinc Mine, including the groundwater model report and all groundwater monitoring data.
  - examine new infrastructure map and determine possible source term sites.
  - extract all pertinent data and compile the Conceptual Hydrogeological Model.
- Groundwater numerical modelling:
  - based on the source term derived from the geochemical study, the existing groundwater numerical model will be updated.
  - The groundwater numerical model will focus on the new dumping facilities only.
  - model results will inform the EIA and WULA regarding whether there is any potential of groundwater contamination.
- The groundwater study will include a geochemical and waste assessment to inform the contamination potential of any residues/discards generated by the project. The waste assessment will be undertaken in terms of the National Norms and Standards (Regulation 635 and 656 of 2013).

4 METHODOLOGY

4.1 DESK STUDY

The desktop study involved the collation and review of public and site information. The following information and data were made available to the project team or gathered as part of the study:

- 1:250 000 Geology Map of the area (Council for Geoscience).
- 1:500 000 Hydrogeological Map sheet (2916 Springbok, DWS).
- Hydrocensus of the Eastern Lobe of the Gamsberg by Golder Associates in April 2007 (Golder, 2007).
- Gamsberg Zinc Project – Preliminary Geohydrology and Groundwater Quality Baseline Report by SRK Consulting in January 2010 (SRK, 2010).
- Gamsberg Zinc Project ESIA – Geohydrology Specialist Report by ERM in April 2013 (ERM, 2013a).
- Gamsberg Zinc Project ESIA – Geochemical Assessment by ERM in April 2013 (ERM, 2013b).
- Groundwater Monitoring reports by GHT Consulting Scientists:

  - Gamsberg Mine geohydrological report – Construction of new monitoring borehole network for Gamsberg Mine and key farm areas (January 2018).
  - Gamsberg Mine groundwater monitoring report (February 2018).
  - Gamsberg Mine groundwater monitoring report (May 2018).
  - Gamsberg Mine groundwater monitoring report (August 2018).
  - Gamsberg Mine groundwater monitoring report (October 2018).
  - Gamsberg Mine groundwater monitoring report (February 2019).
  - Gamsberg Mine groundwater monitoring report (May 2019).
- Gamsberg Mine and Farm borehole water quality database (December 2000 – July 2019).
- Gamsberg Mine and Farm borehole water level database (May 2015 – May 2019).
- Gamsberg Mine Aeromagnetic survey data.

4.2 HYDROCENSUS

The site has an existing groundwater monitoring network and monitoring is conducted and reported by GHT Consulting Scientists. Previous hydrogeological studies conducted by Golder (2007), SRK (2010), and ERM (2013a) included hydrocensus investigations. Results from the previous hydrogeological studies and GHT Consulting Scientist monitoring reports were used to determine current groundwater conditions. As a result, no hydrocensus was conducted as part of this study. Groundwater quality is discussed in section 5.

4.3 GEOPHYSICAL SURVEY AND RESULTS

A geophysical survey was carried out between the 18th and 21st of September 2019 and consisted of electromagnetic traverses around the planned smelter complex site, SLF and TSF. The geophysical survey results are briefly discussed in section 5.2. The methodology and complete results of the geophysical study are given in the geophysical report attached in Appendix C.

4.4 DRILLING AND SITING OF BOREHOLES

Numerous boreholes were drilled during previous hydrogeological studies. As a result, no new boreholes were required or drilled for this study.

4.5 AQUIFER TESTING

Numerous aquifer tests were completed during previous hydrogeological studies and test results are summarised in section 5.4.3.

4.6 SAMPLING AND CHEMICAL ANALYSIS

The site has an existing groundwater monitoring network and monitoring is conducted and reported by GHT Consulting Scientists. Results from the GHT Consulting Scientist monitoring reports as well as the mine site’s groundwater quality database were used to determine the groundwater quality conditions. As a result, no samples were taken as part of this study. Groundwater quality is discussed in section 5.6.

4.7 GROUNDWATER RECHARGE CALCULATIONS

The main source of groundwater recharge into the aquifer is direct rainfall that infiltrates the aquifer mainly through favourable locations such as the inselberg. According to SRK (2010) the higher recharge on the inselberg is caused by the increased infiltration capacity of the fractured quartzite, with higher permeability and uneven surface reducing the effective evaporation, and due to the potentially higher MAP on the inselberg. A summary of the recharge estimates is provided in section 8.5.

4.8 GROUNDWATER MODELLING

A numerical model is a mathematical approximation of the real word aquifer system and has inherent errors associated with the results due to a lack of data, uncertainty in the data, potential alternative conceptual models in describing the real-world system or the capability of numerical methods to describe natural physical processes. However, numerical groundwater models are considered the best tools available to estimate contaminant fate and transport, and based on the source term derived from the geochemical study, the groundwater numerical model will determine the extent of any potential contaminant plume development and migration. The chosen software code, model set-up, assumptions and results are described in detail in section 7.

4.9 GROUNDWATER AVAILABILITY ASSESSMENT

The Gamsberg Mine is presently receiving water from the Orange River through an intake pump house located at Pella Drift, almost 30 km away to the North East of the plant. A new bulk water pipeline is proposed to replace the existing underground pipeline that was constructed in the 1970's which would connect the Gamsberg Zinc Mine to the existing abstraction point at the Orange River. This pipeline is due for replacement and the necessary environmental and water use permits would be applied for under a separate application. The new underground pipeline would pump water into the existing Horseshoe Reservoir from where it would be gravity fed to the Smelter Complex via an additional 7km section of the new pipeline (Tata, 2019).

No groundwater abstraction is planned to be undertaken as part of this study and site water demands will be met by bulk water supply from the Orange River. Therefore, no groundwater availability assessment was conducted for this study, but current ground water monitoring conducted by the mine is monitoring the effects of the open pit mining on the ground water levels.

5 PREVAILING GROUNDWATER CONDITIONS

5.1 GEOLOGY

5.1.1 Regional Geology

The study area is situated in the Bushmanland terrane, one of the Northern Cape's tectonically bound terrains. The area consists of hard-rock formations; metasedimentary, metavolcanic and intrusive rock units of the Namaqua Metamorphic Province (Vegter, 2006), or Namaqua-Natal Province (SRK, 2010).

Rock types in the area are assigned to a regionally developed sequence of Precambrian-age metamorphic rocks and intrusives collectively termed the Namaqua-Natal Province. This is a tectono-stratigraphic province embracing igneous and metamorphic rocks formed or metamorphosed during the Namaqua Orogeny at ~1 200-1 000 (mega-annum) Ma. The rocks in the Northern Cape (Namaqua Province) are subdivided into several tectonically bound terranes: (1) the Bushmanland Terrane (2) Richtersveld Subprovince (3) Kakamas Terrane (4) Areachap Terrane and (5) Kaaien Terrane. The study area is in the Bushmanland Terrane of which the Hartbees River Thrust forms the eastern boundary, the Groothoek Thrust and Wortel Belt the northern boundaries and is overlain by Karoo-age rocks to the south.

The Bushmanland Terrane is a large supra-crustal block, the volcano-sedimentary rocks of which have been subjected to multiple phases of deformation and medium- to high-grade metamorphism. The Bushmanland Terrane is composed of basement granitic rocks (1 700-2 050 Ma), supracrustal sequences of sedimentary and volcanic origin (1 200, 1 600 & 1 900 Ma) and intrusive charnokite to granitic rocks (950, 1 030-1 060 & 1 200 Ma) (Cornell et al., 2006).

5.1.2 Local Geology

Gamsberg forms part of the Bushmanland Group and according to SRK (2010) comprises basal leucocratic gneiss of the Gladkop Group and is overlain by quartzite and mica-sillimanite schist of the Aggeneys Subgroup. The rocks of the Aggeneys-Gamsberg area are summarised below:

- The basement Gladkop Group is made up of various meta- granodiorite, granite, granitoid and gneissic rocks. These basement rocks are overlain by various depths of surficial, relatively thin cover of wind-blown sand, dunes, scree rubble, sandy soil, and alluvium.
- The basement lithology is unconformably overlain by the Wortel Formation is composed of a basal biotite-sillimanite schist and quartzite, with sporadic magnetite-rich lenses. Lenses of amphibolite and sillimanite occur sporadically throughout. The overlying Witputs Formation is lithologically similar and is therefore grouped together with the Wortel Formation.
- The Skelmpoort Formation comprises dark quartzite grading into graphite- bearing quartz-muscovite schist with fuchsite patches. The Skelmpoort Formation ranges from 47-58 m in thickness. The T'hammaberg Formation, 270 m in thickness, is characterised by quartz-muscovite-sillimanite schist interlayered with quartzite with sporadic fuchsite and graphite (Cornell et al., 2006). The Skelmpoort and T'hammaberg Formations do not occur within the Gamsberg, but outcrop further west and north within the other mineralised deposits.
- The mineralised Hotson Formation comprises quartzite, quartz-feldspar gneiss, and biotite-sillimanite schist. This formation varies from 70 m thick in the west to 500 m thick in the east and the upper 100 m is made up of a mineralised (sulphide) banded iron formation, the Gams Member. The Hotson Formation is unconformably overlain by the Koeris Formation (maximum thickness 634 m) comprising of amphibolite, quartz-feldspar-biotite-muscovite gneiss with sporadic pebbles of meta-conglomerate, quartzite, and quartz-feldspar gneiss (possible meta-rhyolite); and
- The upper contact to the Koeris Formation represents an unconformity, possibly a thrust fault (Cornell et al., 2006).

The stratigraphy is given in Table 5-1 and the geology for the study area is shown in Figure 5-1.

TABLE 5-1: STRATIGRAPHY OF GEOLOGICAL FORMATIONS PRESENT IN THE STUDY AREA.

Eon/ Epoch	Group	Subgroup	Formation	Member	Description
Quaternary	Recent				Alluvium
					Red wind-blown sand and dunes
					Sand, scree, rubble, and sandy soil
Proterozoic/ Mokolian Keisian	Bushmanland	Aggeneys	Koeris		Brown psammitic schists, conglomerate, amphibolite, and quartzite
			Hotson	Gams	Sulphide bearing magnetite-grunerite-garnet-pyroxene rocks, cordierite feldspar, sillimanite schist and quartzite
					Rhythmically layered quartzite, quartz-feldspar-biotite gneiss sillimanite nodules, quartz-biotite-sillimanite gneiss
			T'hammaberg		Upper units – white quartzite, schist, and graphite
					Lower unit – well bedded dark blue quartzite and muscovite-sillimanite schist, graphite, minor iron formation lenses
			Skelmpoort		Muscovite-sillimanite schist grading into rhythmically bedded graphite-fuchsite-quartz-garnet schist and graphite-quartzite, biotite-sillimanite schist with interlayered brown quartzite and minor gossans and garnet-quartz rocks
			Wortel (Witputs)	(Pella quartzite)	Layered sequence of medium to thick bedded with interbedded sillimanite, lenticular quartzite, biotite gneiss and amphibolite/calc-sillicate gneiss
				(Namies schist)	Pelitic schist
	Gladkop		Koeipoort	(Haramoep gneiss)	Pink medium to fine grained biotite-rich, augen Leucogneiss

5.1.3 Structural Geology

The Namaqua Metamorphic Province according to Vegter (2006) is characterised by an intricate pattern of folding and faulting additionally complicated by many granite intrusions. Regional correlation of rock units is furthermore hampered through fragmentary exposures, variable strata successions and complex structure. On structural grounds the Metamorphic Province is divided into four subprovinces: Kheis, Gordonia, Bushmanland and Richtersveld.

The site is located within the Bushmanland Terrane/ subprovince. The Bushmanland Terrane according to SRK (2010) shows polyphase metamorphic and several major tectonic events indicating a complex structural history. In the Aggeneys-Gamsberg area four phases of deformation are recognised. The main deformation events resulted in the large east trending inclined basin-shaped structure of the Gamsberg and the development of the en-echelon folds developed along wrench faults. These en-echelon folds can be followed from east to west with the Aggeneys, Gamsberg, Namies and Samoep synforms.

SRK (2010) noted that groundwater movement in the area will largely be controlled by secondary structural features. The shears, thrust faults, fractures and even regional fabric developed in the jointed hard quartzitic layers will have an influence on the movement of groundwater. Interconnectivity of these features will result in the expansive movement of groundwater over a larger area while discrete, unconnected fractures will result in restricted movement of groundwater along individual structures.

Lineament mapping by SRK (2010), carried out structural mapping in order to identify lineaments that could potentially represent faults, fractures, joints or intrusions which may have an effect by restricting or enhancing groundwater flow paths and direction of groundwater flow. The interpreted structural features were determined to be predominantly oriented in a north to northwest direction with a few lineaments oriented in east to west and southeast directions. Large lineaments occur east and west of the TSF and a small lineament occurs west of the TSF. No lineaments are evident within the proposed infrastructure locations for the smelter complex and SLF. Interpreted lineaments (possibly faults and/or fractures) are shown in Figure 5-1.

SLR Consulting received feedback from the client (email from Pieter David Venter, 14 January 2020) that future mining will not progress below regional groundwater levels and that the geology in the area is such that the mountain aquifer is not connected with the aquifer in the plains/ valley.

5.1.4 Soils/ Overburden

The Gamsberg area is characterised by an extensive peneplain and the soils present in the peneplain are predominantly shallow and stony. The mining is located within an inselberg (isolated hill/ mountain rising from abruptly from the plains), and the soils found within the inselberg are characterised with bouldery and stony scree slope soils. The scarps and crest of the inselberg are characterised with bare rocks, while the Gamsberg Basin itself is characterised with shallow gravelly soils.

The soils present on the peneplain are generally characterised with reddish sandy topsoil that is shallow in nature. However, a 10 cm thick red sandy surface layer is present along the northern section of the proposed site. The western and southern part of the proposed site is characterised with deeper red soils, varying in depth from 30 cm to 60 cm. Along the south western portion of the proposed site, deeper red soils occur. The soils on the plains overlie dorbank (duripan) or calcrete ERM (2013a).

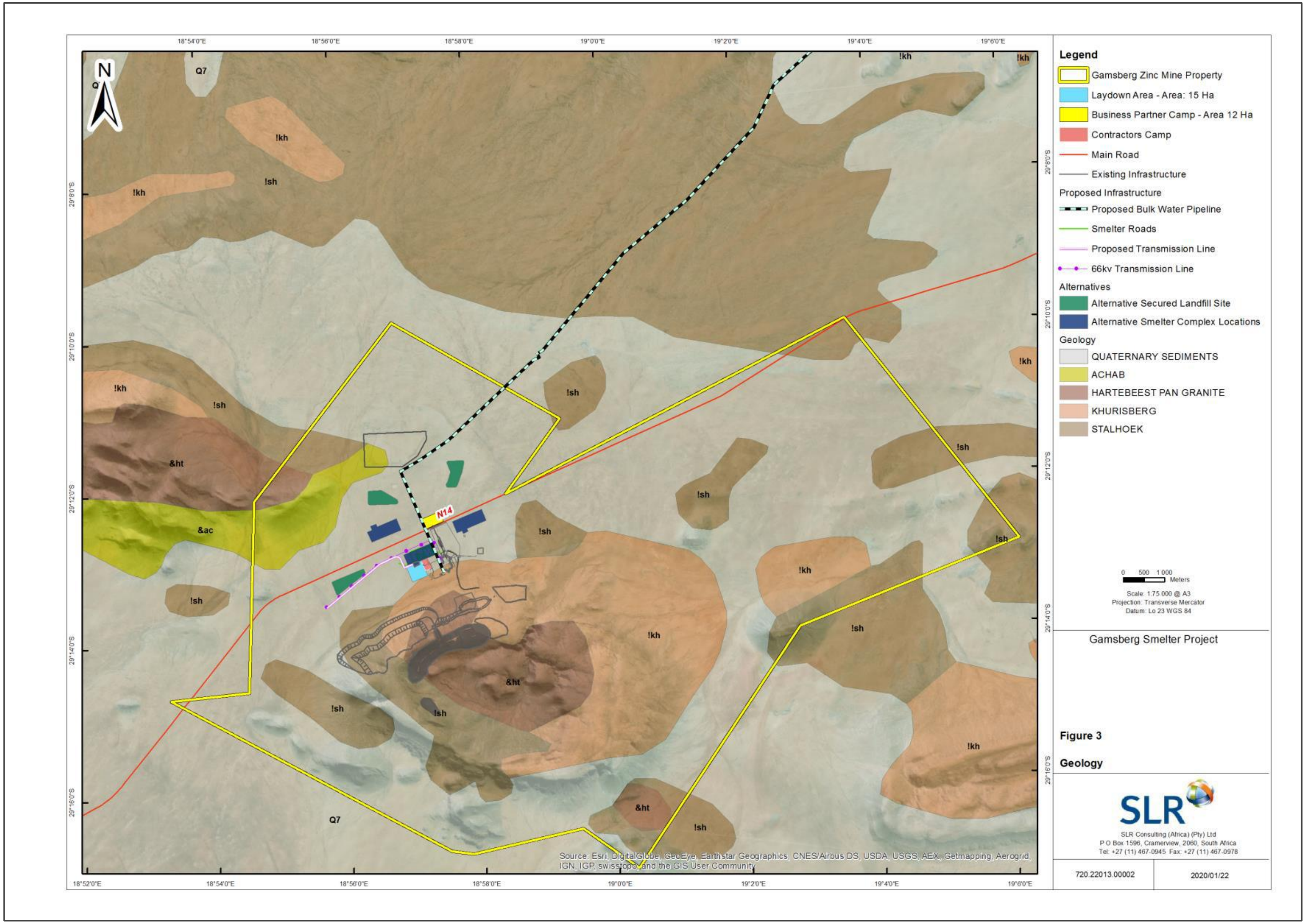


FIGURE 5-1: GEOLOGY AND LINEAMENTS OF THE STUDY AND SURROUNDING AREA.

5.2 GEOPHYSICAL SURVEY

5.2.1 Introduction

The objective of the geophysical survey was to map potential fracture zones in the sub-surface geology for the smelter complex, SLF and TSF sites.

An electromagnetic survey involves transmitting an electromagnetic field into the subsurface and picking up returning signal via a receiver in the same instrument. Data are acquired on a grid covering the area of interest and a contoured plan of the variation in ground conductivity across the site is produced.

The electromagnetic data was acquired by SLR, using the EM-34 instrument. Readings were taken approximately every 20m with a coil separation of 40m where possible, and with 20m depending on the interference from overhead powerlines.

The project area and geophysical traverses are illustrated in Figure 5-2.

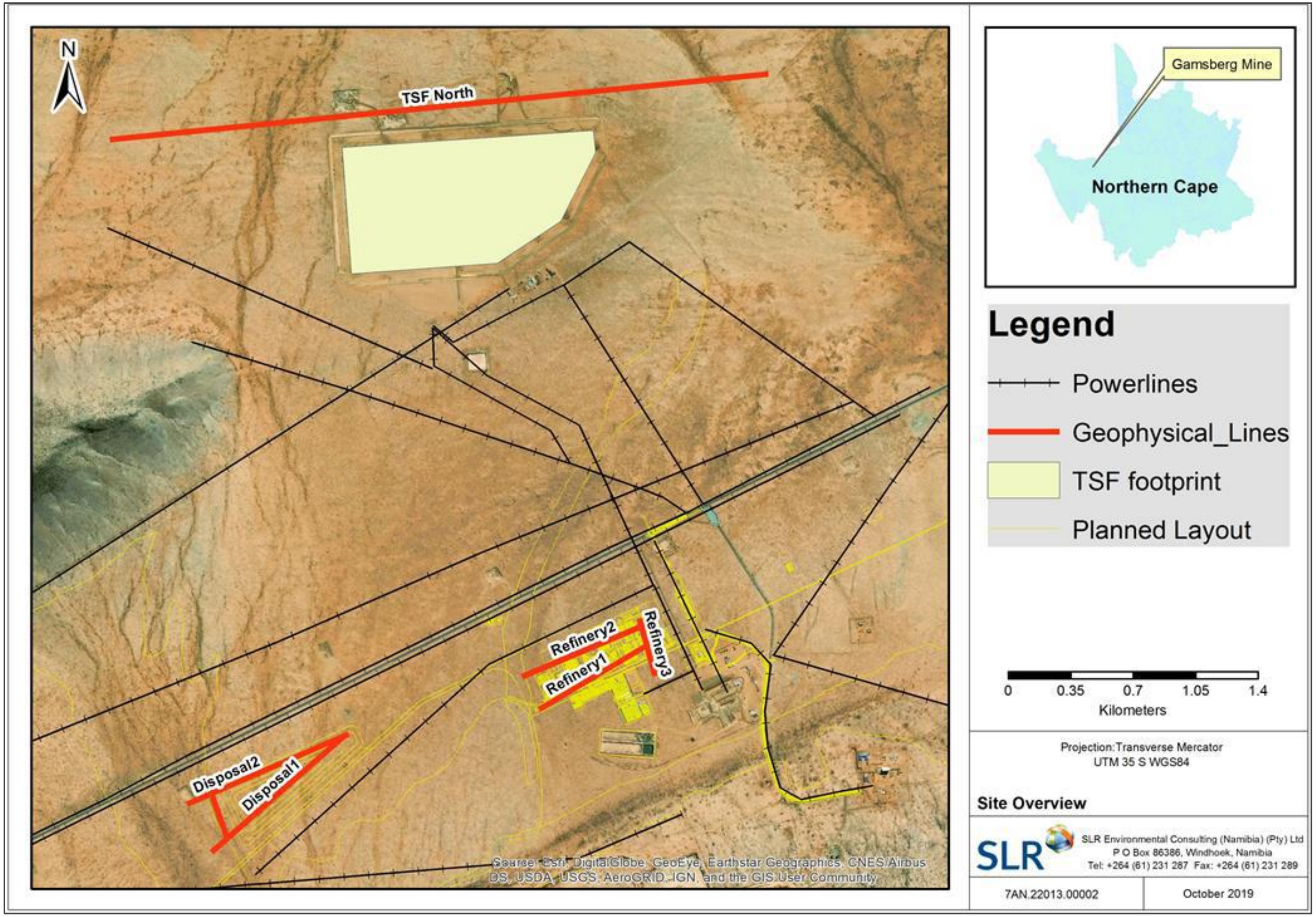


FIGURE 5-2: PROJECT AREA LAYOUT AND GEOPHYSICAL TRAVERSES.

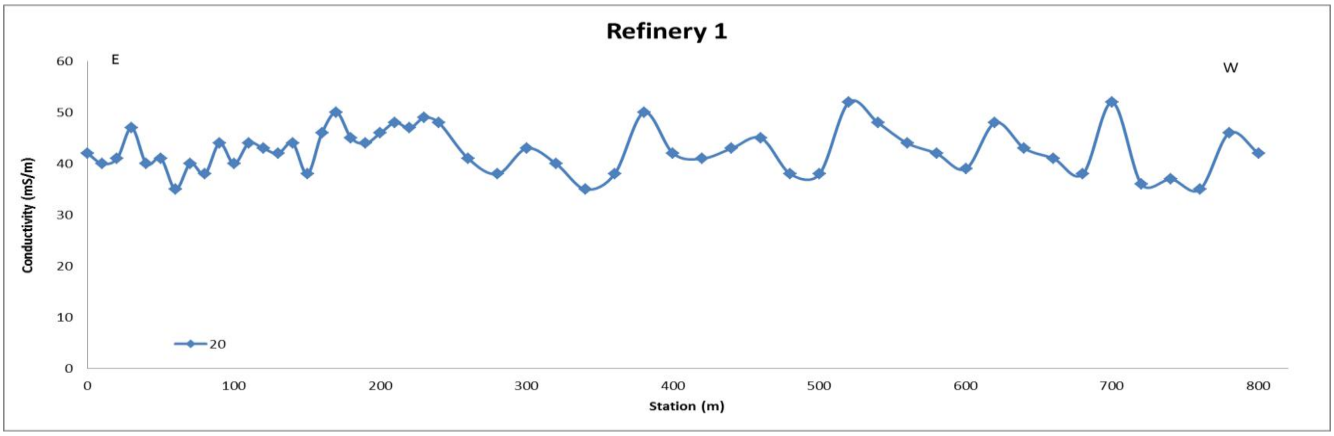
5.2.2 Results

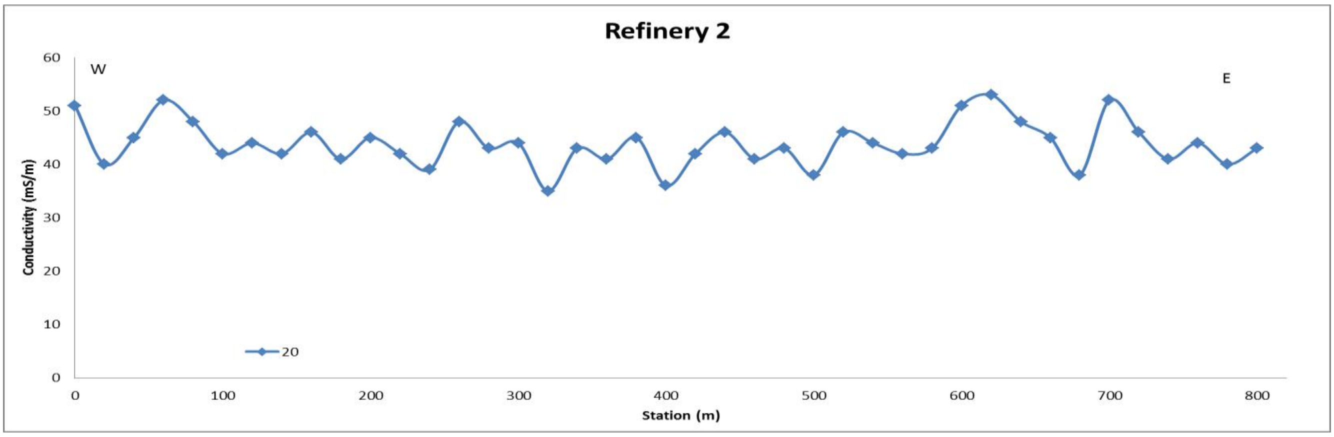
Smelter complex site

The geophysical survey at the smelter complex site consisted of three geophysical traverses, two trending east to west and one north to south, as shown in Figure 5-2.

A high voltage powerline is crossing the site, starting at the mine's sub-station and running northwards to about 100m north of the planned smelter complex before turning 90 degrees in a westerly direction. The high voltage powerline interfered with the electromagnetic reading when trying to infiltrate the sub-surface geology to a deeper level and therefore it was decided to continue with the electromagnetic readings in the area only for the 20m coil separation which does not infiltrate the sub-surface to depth greater than 30m.

The results of all three traverses are illustrated in Figure 5-3 and all showed high conductivities that could potentially indicate a thick layer of overburden colluvium material. The electromagnetic readings did not reach the sub-surface geology and for that reason could not detect any fractures. The readings indicated that a thick layer of overburden is present for the complete planned smelter complex area.





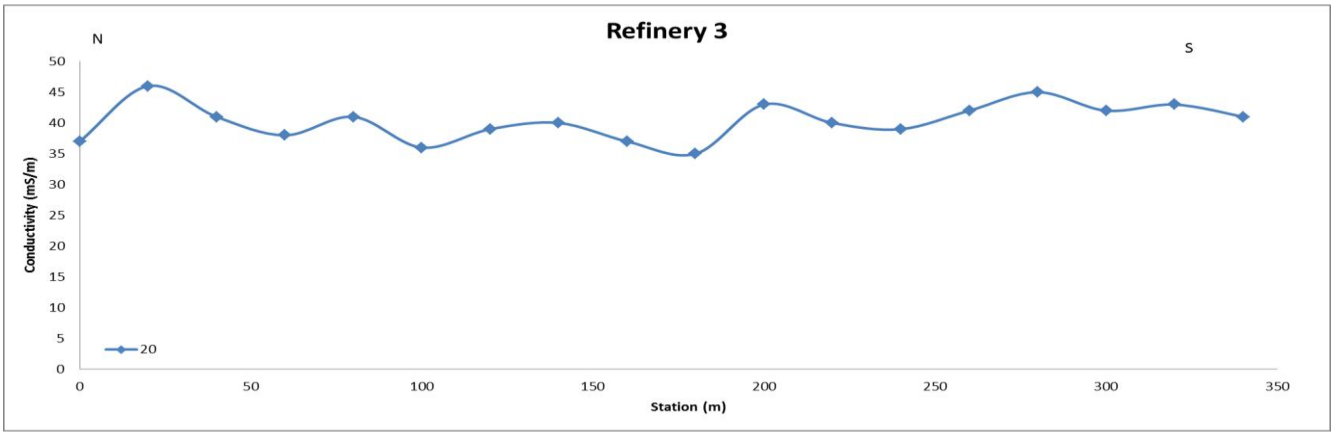
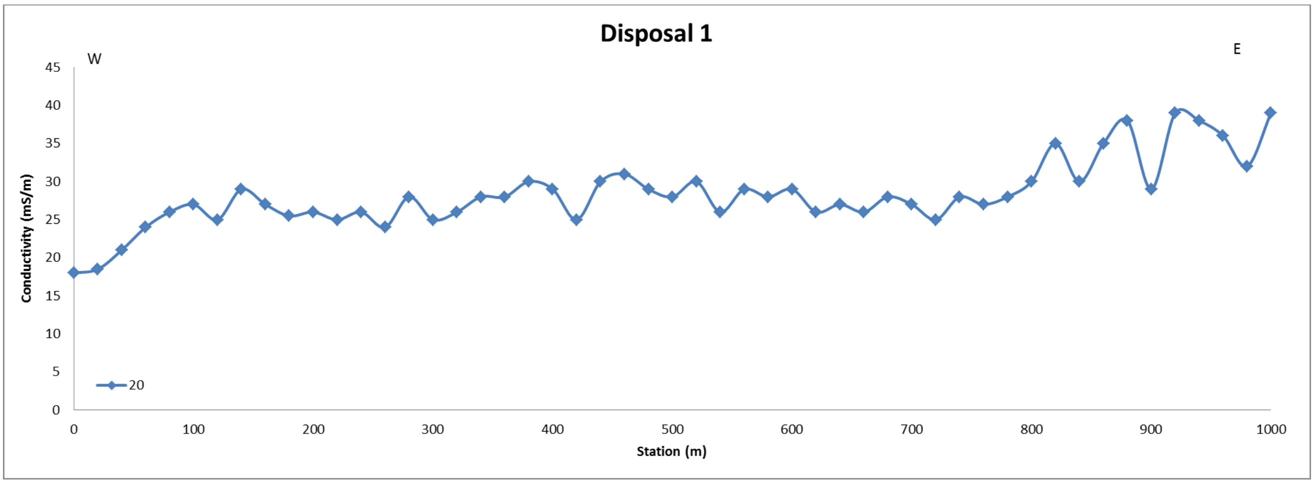


FIGURE 5-3: EM PROFILES FOR THE SMELTER COMPLEX SITE.

SLF site

Another three geophysical traverses were done at the planned disposal site, two stretching north-east to south-west, parallel to the existing powerline and one going north to south. The site has a high voltage powerline to the south of the proposed disposal site and a low voltage powerline to the north. The powerlines interfered with the electromagnetic reading at this site as well and therefore electromagnetic readings in the area could only be done with the 20m coil separation which does not infiltrate the ground to greater depth than 30m.

The three lines had similar results with high conductivities indicating a thick layer of overburden alluvium material (Figure 5-4). The electromagnetic readings did not reach the sub-surface geology and for that reason could not detect any fractures. The readings indicated an increase in conductivity from west to east, therefore the overburden thickness also increases towards the smelter complex site.



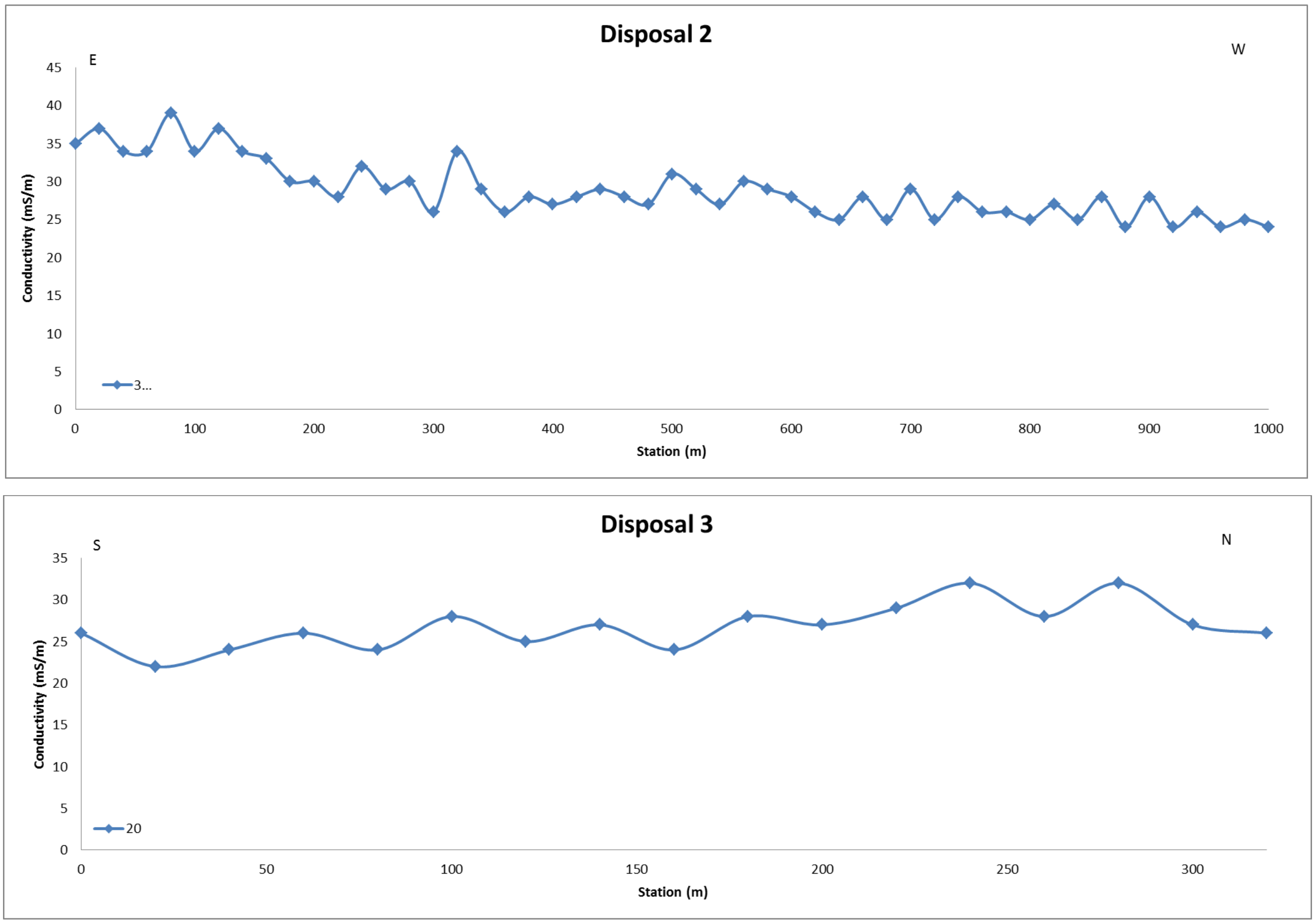


FIGURE 5-4: EM PROFILES FOR SLF.

TSF site

One geophysical traverse was done north of the existing TSF, with the objective to detect possible fractures present in the sub-surface geology. The TSF site was evaluated as one of the Jarosite disposal options available as co-disposal on the existing TSF.

The electromagnetic (EM) response curve showed large variations in electrical conductivity of the subsurface across the traverse length, from ~-5 mS/m to ~15 mS/m. A traverse south of the TSF could not be done due to powerline interferences and therefore fracture strike directions could not be determined. The electromagnetic readings could be done with both the 40m and 20m coil separations. Possible fractures were inferred at four positions north of the TSF (Figure 5-5 and Figure 5-6).

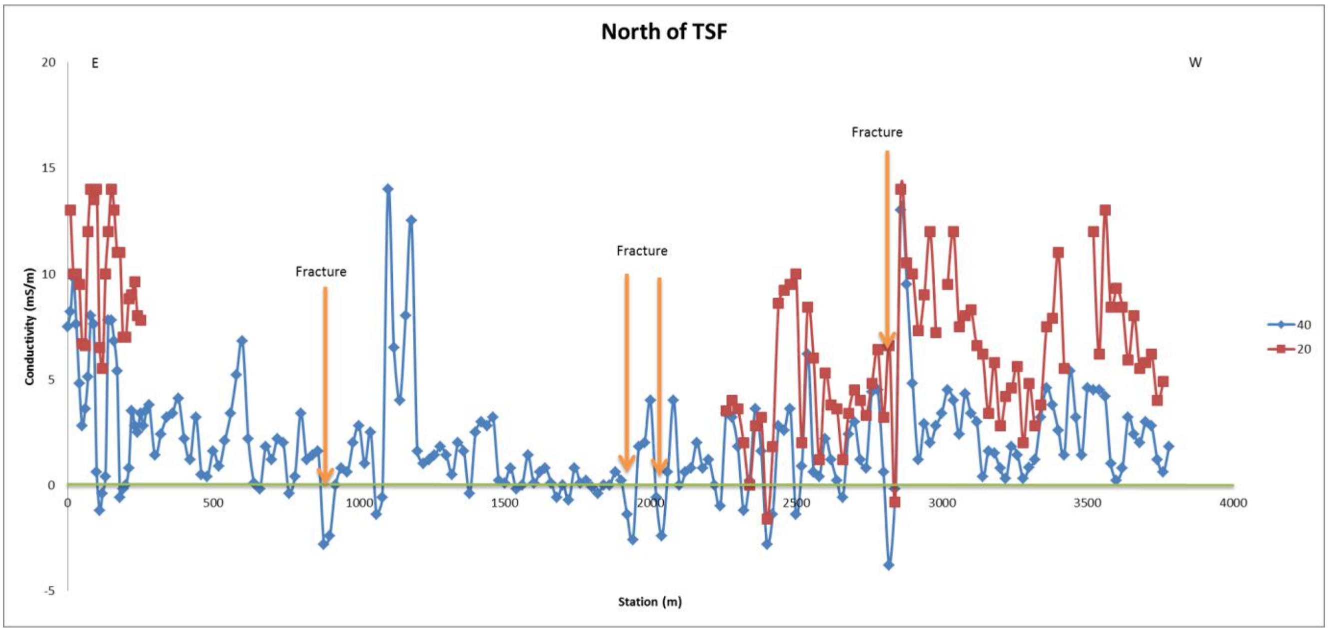


FIGURE 5-5: EM PROFILES NORTH OF THE TSF SITE.

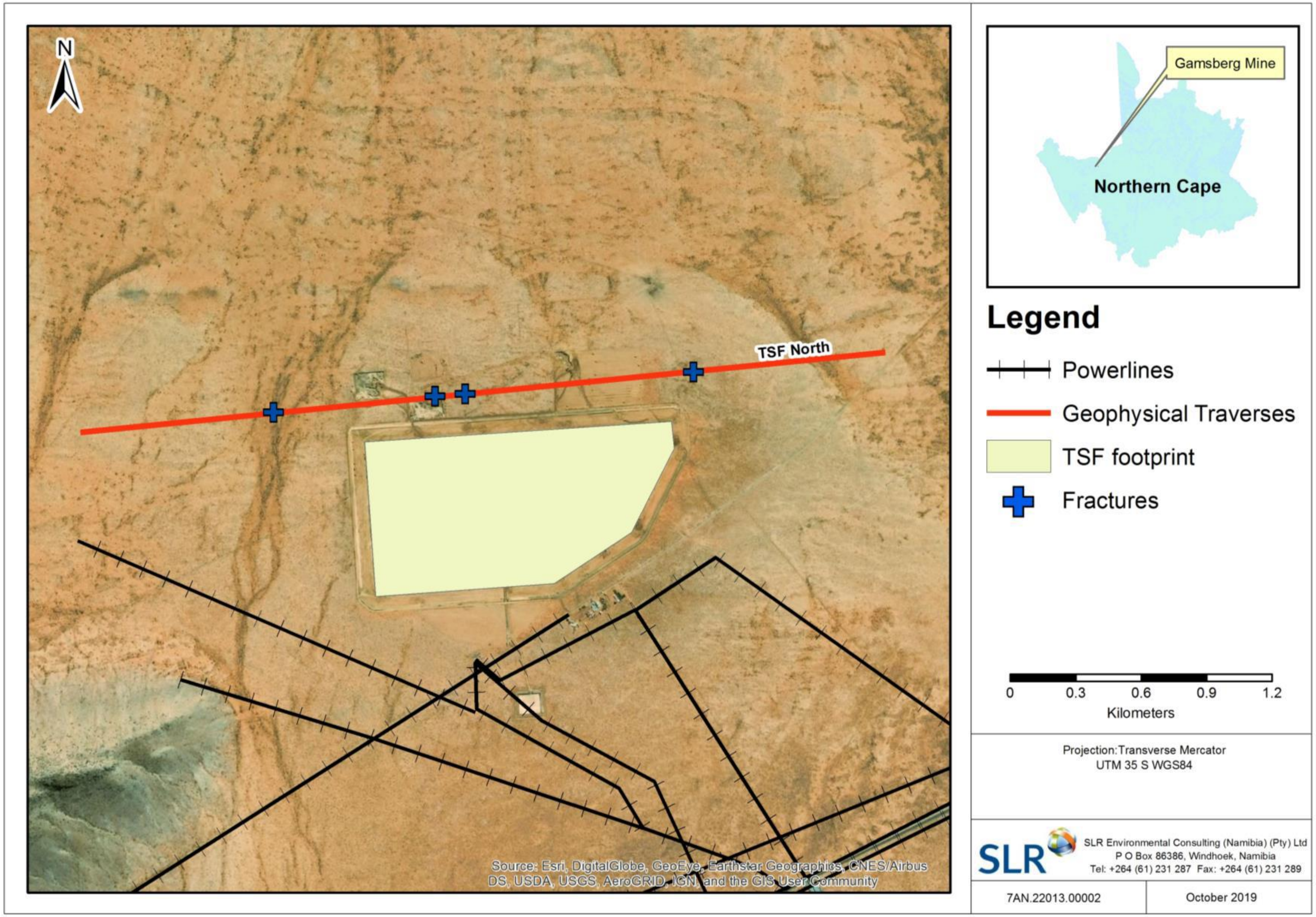


FIGURE 5-6: FRACTURES ALONG THE EM PROFILE NORTH OF THE TSF.

5.2.3 Conclusions

The EM response curves of all smelter complex and disposal/ SLF traverses indicated high conductivity values of the subsurface material, interpreted as a possible thick layer of colluvium material. The EM response curve did not indicate the presence of any geological structures or hydrogeologically significant fractures.

One geophysical traverse was done north of the existing TSF and the EM response curve showed large variations in electrical conductivity of the subsurface across the traverse length, from ~-5 mS/m to ~15 mS/m. Possible fractures were inferred at four positions north of the TSF.

5.3 ACID GENERATION CAPACITY

5.3.1 Previous Geochemical Assessments

ERM (2013b) assessed the potential for the proposed Gamsberg Zinc Project to contaminate water sources through generation of acid rock drainage (ARD) and/or metal leaching. Potential contamination sources assessed in the study included the open pit mine, waste rock dump (WRD), tailings storage facility (TSF) and stockpiles. The geochemical laboratory work included acid-base accounting (ABA), net acid-generation (NAG) and short-term leach tests, as well as determination of mineralogical and whole rock composition (XRD and XRF). Kinetic testing of six samples was done to confirm long term ARD/ leaching potential.

The final tailings contained 23% sulphur as pyrite and pyrrhotite. This translated into a high acid potential (AP) which, combined with low neutralisation potential (NP) resulted in acidic leachate. Sulphate leachate concentrations at the base of the TSF were predicted to steadily increase and stabilise to approximately 12 000 mg/L on closure. ERM (2013b) also determined that metals such as Al, Cd, Cu, Fe, Mn, Pb and Zn could leach from the TSF at concentrations higher than acceptable environmental risk (AER) levels. The mobility of less pH dependent non-metals and metalloids such as NO_3 (from rock reactions and use of ammonium nitrate explosives), F and As were also determined to be potentially elevated in the TSF leachate.

Sulphate leachate concentrations from the WRD were predicted by ERM (2013b) to be relatively constant and ranged between 2 000 to 2 500 mg/L throughout Life of Mine (LOM) and after mine closure. However, the WRD source term is excluded for the purposes of this study (section 1.3).

5.3.2 Jarosite Disposal Geochemical Assessment

Background

The secured landfill facility (SLF) is planned to be approximately 1 km to the west of the smelter complex and would be connected by a paved/ bitumen road for the transportation of the Jarofix and effluent treatment plant (ETP) cake for disposal. The initial design of the SLF would be sized based on the generation of Jarofix for the first 5 years. The total design will accommodate 15 years of disposal in cells with lifespans of about 5 years each such that the first cell can be closed when the advanced Fumer technology becomes viable. There is the potential for contamination due to the disposal of Jarofix on the secured landfill facility.

Mills Water assessed various options for disposal of Jarosite material and to calculate source terms for the preferred disposal option (Mills Water, 2020). This section will briefly summarise the Mills Water (2020) study and main findings. However, additional details, detailed methodology and the regulatory framework are given in the Options Assessment for Jarosite Disposal Gamsberg Zinc Mine report by Mills Water (2020), also attached in Appendix F.

Jarosite will be a waste material generated by a proposed new processing plant which will smelt and refine zinc ore from the Gamsberg Zinc Mine. The geochemical assessment included the following scope of work to assess the potential risks related to the disposal of the Jarosite and to evaluate various co-disposal alternatives:

- Conduct a preliminary ARD and geochemical investigation on the waste material that will be generated as part of the project.
- Undertake a waste type assessment on the waste in terms of GN R.635 (23 August 2013).
- Identify the barrier design required for the waste in terms of GN R.636 (23 August 2013).
- Provide a source term for input into the groundwater contaminant transport model (section 8.7.4) for predictions of water quality impacts.

The disposal options included:

- Disposal of the Jarosite-like residue on a dedicated facility (SLF).
- Co-disposal of Jarosite-like residue on the existing TSF by mixing Jarosite (7%) with tailings (93%).
- Co-disposal of Jarofix (a mixture of Jarosite-like residue, lime, and cement) on the existing TSF by mixing Jarofix (7%) with tailings (93%).
- Disposal of the Jarofix residue on a dedicated facility (SLF).

Assessment of co-disposal alternatives

Samples of the tailings, Jarosite, Jarofix, Jarosite composite (93% tailings mixed with 7% of Jarosite), and Jarofix composite (93% tailings mixed with 7% of Jarofix) were submitted to UIS Laboratory for waste classification analyses. The distilled water tests performed on the samples were in accordance with the classification guidelines and were classed against the various thresholds for total concentrations (TC) and leachable concentrations (LC). Two samples of each material, labelled A and B, were submitted for analysis.

Total concentration threshold

The following classification, also shown in Table 5-2 was made per sample type based on the total concentrations threshold (TCT) classes:

- Tailings A and Tailings B:
    - Hg exceeded the TCT1 guideline values and were within the limits of TCT2.
    - Cd, Cu, F, Mn, Pb, and Zn exceeded the TCT0 guideline values and were within the limits of TCT1.
    - All other elements were below the TCT0 guideline values.
- Jarosite A and Jarosite B:
    - Pb exceeded the TCT2 guideline values.
    - As and Sb exceeded the TCT1 guideline values and were within the limits of TCT2.
    - Ba, Cd, Cu, Hg, and Zn exceeded the TCT0 guideline values and were within the limits of TCT1.
    - All other elements were below the TCT0 guideline values.
- Jarofix A and Jarofix B:

  - Pb exceeded the TCT2 guideline values.
  - Sb exceeded the TCT1 guideline values and were within the limits of TCT2.
  - As, Ba, Cd, Cu, F, Hg, and Zn exceeded the TCT0 guideline values and were within the limits of TCT1.
  - All other elements were below the TCT0 guideline values.
- Comp Tail-Jarosite A and Comp Tail-Jarosite B:
  - Pb exceeded the TCT1 guideline values and were within the limits of TCT2.
  - As, Cd, Cu, F, Hg, Mn, Sb, and Zn exceeded the TCT0 guideline values and were within the limits of TCT1.
  - All other elements were below the TCT0 guideline values.
- Comp Tail-Jarofix A and Comp Tail-Jarofix B:
  - Pb exceeded the TCT1 guideline values and were within the limits of TCT2.
  - As, Ba, Cd, Cu, F, Hg, Mn, Sb, and Zn exceeded the TCT0 guideline values and were within the limits of TCT1.
  - All other elements were below the TCT0 guideline values.

Leachable concentration threshold

The following classification also shown in Table 5-3 was made based on the leachable concentrations threshold (LCT) classes:

- Tailings A and Tailings B:
  - SO_4 and TDS exceeded the LCT0 and SANS 241-1:2015 (Potable Water) guideline values and were within the limits of LCT1.
  - All other elements were below the LCT0 guideline values.
- Jarosite A and Jarosite B:
  - Cd and pH exceeded the LCT3 and SANS 241-1:2015 (Potable Water) guideline values.
  - SO_4, As, Mn, Ni, Pb, Se, and Zn exceeded the LCT0 guideline values and were within the limits of LCT1.
  - All other elements were below the LCT0 guideline values.
- Jarofix A and Jarofix B:
  - SO_4, As, Cd, Ni, and Sb exceeded the LCT0 and SANS 241-1:2015 (Potable Water) guideline values and were within the limits of LCT1.
  - All other elements were below the LCT0 guideline values.
- Comp Tail-Jarosite A and Comp Tail-Jarosite B:

    - SO_4 and TDS exceeded the LCT0 and SANS 241-1:2015 (Potable Water) guideline values and were within the limits of LCT1.
    - All other elements were below the LCT0 guideline values.

- Comp Tail-Jarofix A and Comp Tail-Jarofix B:
    - SO_4 and TDS exceeded the LCT0 and SANS 241-1:2015 (Potable Water) guideline values and were within the limits of LCT1.
    - All other elements were below the LCT0 guideline values.

TABLE 5-2: TOTAL CONCENTRATION THRESHOLD (TCT) RESULTS (ALL SAMPLES).

Parameters	NEMWA Total Concentration Thresholds			Sample ID									
	TCT0	TCT1	TCT2	Tailings A	Tailings B	Jarosite A	Jarosite B	Jarofix A	Jarofix B	Comp Tail-Jarosite A	Comp Tail-Jarosite B	Comp Tail-Jarofix A	Comp Tail-Jarofix B
	mg/kg												
Antimony (Sb)	10	75	300	1	1	240	249	216	220	11	12	11	11
Arsenic (As)	5.8	500	2 000	3	3	765	775	407	398	43	43	26	24
Barium (Ba)	62.5	6 250	25 000	29	30	549	559	1 015	1 034	61	59	82	83
Boron (B)	150	15 000	60 000	48	48	6	6	8	8	45	49	50	54
Cadmium (Cd)	7.5	260	1 040	108	107	168	170	221	226	112	119	123	122
Chromium (Cr)	46 000	800 000	-	1	1	237	236	168	176	15	15	12	12
Cobalt (Co)	50	5 000	20 000	2.1	2.3	2.5	2.6	5.0	5.3	4.0	3.8	4.1	3.9
Copper (Cu)	16	19 500	78 000	29	17	1 090	1 098	761	788	113	116	99	95
Fluoride (F)	100	10 000	40 000	1 591	1 723	69	77	105	131	1 483	1 434	1 414	1 426
Hex Chromium (Cr6)	6.5	500	2 000	0	0	0	0	0	0	0	0	0	0
Lead (Pb)	20	1 900	7 600	728	724	42 743	42 713	30 941	31 312	3 189	3 198	2 538	2 487
Manganese (Mn)	1 000	25 000	100 000	8 255	8 231	211	199	415	410	7 883	7 708	7 638	7 571
Mercury (Hg)	0.93	160	640	195	197	8.2	5.6	3.6	3.4	140	152	155	152
Molybdenum (Mo)	40	1 000	4 000	0	0	13	14	9	9	1.4	1.4	1.2	1.1
Nickel (Ni)	91	10 600	42 400	21	22	5.4	5.5	14	14	21	21	22	22
Selenium (Se)	10	50	200	1	1	1	1	1	1	1	1	1	1
Vanadium (V)	150	2 680	10 720	48	48	88	89	89	89	50	52	53	51
Zinc (Zn)	240	160 000	640 000	33 484	33 774	24 381	24 451	22 051	22 228	31 321	32 349	31 718	31 591

Note – composite values were calculated by weighted averaging. Colours highlighted indicated TC threshold exceeded. Yellow > TCT0, Orange > TCT1, Red > TCT2

TABLE 5-3: LEACHABLE CONCENTRATION THRESHOLD (LCT) RESULTS (ALL SAMPLES).

Parameters	NEMWA Leachable Concentration Thresholds				SANS 241-1:2015	Sample ID									
	LCT0	LCT1	LCT2	LCT3		Tailings A	Tailings B	Jarosite A	Jarosite B	Jarofix A	Jarofix B	Comp Tail-Jarosite A	Comp Tail-Jarosite B	Comp Tail-Jarofix A	Comp Tail-Jarofix B
	mg/L														
Inorganic Anions															
pH	6	6	6	6	5 < pH < 9.7	9.26	9.36	2.42	2.43	8.97	8.94	9.20	9.19	9.19	9.17
Fluoride (F)	1.5	75	150	600	1.5	<0.02	<0.02	0.10	0.09	0.06	0.05	0.26	0.42	0.43	0.45
Nitrate (NO3-N)	11	550	1 100	4 400	11	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Chloride	300	15 000	30 000	120 000	300	33.4	39.0	0.5	0.5	2.3	2.3	39.2	38.6	40.2	39.0
Sulphate	250	12 500	25 000	100 000	500	2 324	2 659	442	447	532	503	2 514	2 571	2 560	2 568
Total dissolved solids	1 000	12 500	25 000	100 000	1 200	2 879	3 379	739	749	725	722	3 301	3 362	3 356	3 363
Metal Ions															
Antimony (Sb)	0.02	1	2	8	0.02	0.001	0.001	0.016	0.015	0.145	0.140	0.001	0.001	0.002	0.002
Arsenic (As)	0.01	0.5	1	4	0.01	0.001	0.001	0.024	0.023	0.024	0.023	<0.001	<0.001	<0.001	<0.001
Barium (Ba)	0.7	35	70	280	0.7	0.008	0.008	0.007	0.008	0.014	0.013	0.004	0.004	0.006	0.006
Boron (B)	0.5	25	50	200	2.4	0.068	0.072	0.019	0.022	0.003	0.003	0.140	0.147	0.138	0.132
Cadmium (Cd)	0.003	0.15	0.3	1.2	0.003	0.001	0.003	5.59	5.59	0.020	0.016	0.001	0.001	0.001	0.001
Cobalt (Co)	0.5	25	50	200	-	0.003	0.003	0.010	0.009	0.003	0.003	0.001	0.001	0.001	<0.001
Copper (Cu)	2	100	200	800	2	0.004	0.007	1.262	1.243	0.011	0.009	<0.001	0.001	0.001	<0.001
Chromium (Cr)	0.1	5	10	40	0.05	0.005	0.006	0.095	0.093	0.001	0.001	0.003	0.003	0.003	0.003
Lead (Pb)	0.01	0.5	1	4	0.01	0.001	0.001	0.163	0.171	0.002	0.002	0.001	0.001	0.001	0.001

Manganese (Mn)	0.5	25	50	200	0.4	0.002	0.003	1.659	1.720	0.023	0.019	<0.001	<0.001	<0.001	<0.001
Mercury (Hg)	0.006	0.3	0.6	2.4	0.006	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002
Molybdenum (Mo)	0.07	3.5	7	28	-	0.002	0.002	<0.0002	<0.0002	0.045	0.047	0.002	0.002	0.003	0.003
Nickel (Ni)	0.07	3.5	7	28	0.07	0.066	0.068	0.097	0.098	0.076	0.080	0.005	0.005	0.006	0.005
Selenium (Se)	0.01	0.5	1	4	0.04	0.004	0.006	0.047	0.044	0.004	0.004	0.001	0.002	0.002	0.002
Vanadium (V)	0.2	10	20	80	-	0.002	0.002	0.009	0.007	0.007	0.007	0.001	0.001	0.001	<0.001
Zinc (Zn)	5	250	500	2 000	5	0.008	0.011	32.13	32.38	<0.001	0.002	0.015	0.016	0.016	0.015

Note – Colours highlighted indicated TC threshold exceeded. Yellow > LCT0, Orange > LCT1, Red > LCT2, Purple > LCT3.

Waste assessment and liner requirements for assessed samples

The resultant waste assessment and required liner types are shown in Table 5-4.

TABLE 5-4: WASTE ASSESSMENT AND LINER REQUIREMENT (ALL SAMPLES).

	Tailings	Jarosite	Jarofix	Comp Tail-Jarosite	Comp Tail-Jarofix
TC Class	TCT 1-2	>TCT2	>TCT2	TCT 1-2	TCT 1-2
LC Class	LCT 0-1	>LCT3	LCT 0-1	LCT 1-2	LCT 1-2
Waste Type	Type 3	Type 0	Type 1	Type 3	Type 3
Liner	Class C	Disposal not allowed	Class A	Class C	Class C

Preferred disposal method

The disposal of Jarofix on the SLF was selected as the preferred alternative by the client for the following reasons:

- The Jarosite has leachable concentrations which exceed the LCT3 value preventing disposal without treatment.
- The co-disposal of Jarosite or Jarofix with tailings would require a Class C liner. The existing liner for the tailings does not conform to a Class C (the tailings facility was constructed prior to the enactment of Regulation 635 and Regulation 636 of the National Environmental Management: Waste Act 2008 (Act No. 59 of 2008), and existing TSF liner was approved by regulators and was legally compliant at the time of construction).
- Jarosite or Jarofix co-disposed with tailings material may not be stable in the long term due to the potential for acidification of the tailings material. The tailings had total sulphur content of close to 10% which is anticipated to be present largely as sulphide, therefore it has a high potential for ARD in the long term.

Detailed analyses of Jarofix

The results of the laboratory analyses on all samples and the preferred disposal method were used to select one Jarofix sample for more detailed analyses. The selected sample was analysed in duplicate for the following:

- Leachate chemistry in a leachate prepared by mixing one-part sample with 20 parts distilled water as per the requirements of GN R635 (23 August 2013).
- Mineralogical analysis by X-ray diffraction (XRD).
- Acid-Base Accounting (ABA) including paste pH, sulphur speciation and measurement of neutralisation potential.
- Net-Acid Generating capacity (NAG).
- Particle size distribution.

The results of the detailed analysis were used to undertake geochemical modelling to calculate a source term for input into the groundwater contaminant transport model (section 8.7.4) for predictions of water quality impacts.

Particle size distribution

A particle size distribution (PSD) was conducted to allow estimation of the reactive surface area of the Jarofix. The PSD also allows high level estimation of the porosity and permeability of the material. The Jarofix is composed of about 35% gravel size particles (greater than 1.7 mm in diameter), 60% of sand-sized particles (0.075 – 1.7 mm in diameter), and approximately 2% silt and clay sized particles.

Mineralogy

Jarofix was found to consist of approximately 60% Jarosite ($KFe_3^{+3}(OH)_6(SO_4)_2$), with 31% gypsum ($CaSO_4.2H_2O$), 8% calcite ($CaCO_3$) and 1% quartz (SiO_2).

Waste classification

The 1:20 measured distilled water leach results are presented in Table 5-5 and the following classification was made:

- SO_4, TDS, Sb, and As exceeded the LCT0 and SANS 241-1:2015 guideline values and were within the limits of LCT1.
- All other elements were below the LCT0 guideline values.

The waste classification remains as Type 1 due to the high lead concentrations from the TCT results even though the leachable concentrations is below the thresholds as per the LCT test .

TABLE 5-5: LEACHABLE CONCENTRATION THRESHOLD (LCT) RESULTS (JAROFIX SAMPLES).

Parameters	NEMWA Leachable Concentration Thresholds				SANS 241-1:2015	Sample ID
	LCT0	LCT1	LCT2	LCT3		Jarofix (n=3)
	mg/L					
Inorganic Anions						
pH	6	6	6	6	5 < pH < 9.7	8.80
Fluoride (F)	1.5	75	150	600	1.5	0.34
Nitrate (NO3-N)	11	550	1 100	4 400	11	<0.1
Chloride	300	15 000	30 000	120 000	300	2.18
Sulphate	250	12 500	25 000	100 000	500	1 759
Total dissolved solids	1 000	12 500	25 000	100 000	1 200	2 659
Metal Ions						
Antimony (Sb)	0.02	1	2	8	0.02	0.193
Arsenic (As)	0.01	0.5	1	4	0.01	0.042
Barium (Ba)	0.7	35	70	280	0.7	0.108
Boron (B)	0.5	25	50	200	2.4	0.040
Cadmium (Cd)	0.003	0.15	0.3	1.2	0.003	0.001
Cobalt (Co)	0.5	25	50	200	-	<0.001
Copper (Cu)	2	100	200	800	2	0.004
Chromium (Cr)	0.1	5	10	40	0.05	<0.001
Lead (Pb)	0.01	0.5	1	4	0.01	<0.001
Manganese (Mn)	0.5	25	50	200	0.4	0.003
Mercury (Hg)	0.006	0.3	0.6	2.4	0.006	<0.0001
Molybdenum (Mo)	0.07	3.5	7	28	-	0.033
Nickel (Ni)	0.07	3.5	7	28	0.07	0.007
Selenium (Se)	0.01	0.5	1	4	0.04	0.009
Vanadium (V)	0.2	10	20	80	-	0.013
Zinc (Zn)	5	250	500	2 000	5	0.004

Note – Colours highlighted indicated TC threshold exceeded. Yellow > LCT0, Orange > LCT1, Red > LCT2, Purple > LCT3.

Potential for acid generation

Development of ARD is typically associated with the oxidation of sulphide minerals, in most cases pyrite (Drever, 1997):

$$FeS_2 + {}^{15}/_{4}\,O_2 + {}^{7}/_{2}\,H_2O \rightarrow Fe(OH)_3 + 2SO_4^{2-} + 4H^+$$

In the absence of sulphide minerals, as is the case here, ARD is unlikely to develop. However, some oxide minerals like Jarosite can store acidity. When Jarosite dissolves, it can release hydrogen ions causing the pH to decrease:

$$KFe_3^{3+}(OH)_6(SO_4)_2 + 3H_2O \rightarrow K^+ + 2SO_4^{2-} + 3Fe(OH)_3 + 3H^+$$

Addition of lime slurry ($Ca(OH)_2$) and cement to the Jarosite to form Jarofix results in a neutralising of the acidity:

$$Ca(OH)_2 + 2H^+ \rightarrow Ca^{2+} + 2H_2O$$

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

$$CaCO_3 + 2H^+ \rightarrow Ca^{2+} + 2H_2CO_3$$

A standard ABA assessment, which assumes that 1 mole of calcite is required to neutralise the acidity generated from 1 mole of sulphur in pyrite, is not appropriate in this case. The AP calculation can be modified for Jarosite based on the stoichiometry of the above reactions i.e. that 0.75 moles of neutralising potential (as $CaCO_3$) can neutralise acidity generated from 1 mole of sulphur. Not all the sulphur present in the Jarofix is due to Jarosite, some is due to gypsum, which is not acid generating. The AP calculation is therefore conducted using only the sulphur that is present in Jarosite. The amount of sulphur present in Jarosite is estimated using two methods:

- Mineralogy (XRD data); and
- Using a normative mineralogy approach with the total chemistry. All carbon is assumed to occur as calcite, which gives an amount of calcite of 4.4 wt%. The remaining calcium is assumed to be present in gypsum, giving an amount of gypsum of 30.5 wt%. Finally, the amount of sulphur remaining is assumed to be present in Jarosite, giving an amount of Jarosite of 35 wt%.

The calculated calcite and gypsum concentrations are similar to XRD results, but the Jarosite amount is far lower. Quantitative XRD provides only order of magnitude estimates of quantities due to preferred orientation and crystallite size effects. In addition, XRD does not readily detect amorphous minerals. Based on the change in colour of Jarosite (yellow) to Jarofix (red) with addition of cement and lime slurry, it seems likely that amorphous iron oxide minerals have formed which are not accounted for in the XRD analysis, and result in overestimation of other mineral quantities. The results from the normative calculation are therefore used to estimate the acid potential of the Jarofix.

The results of the ABA screening are presented in Table 5-6. The amount of sulphur present in Jarosite is sufficient to potentially generate acidity, but this is balanced by the presence of calcite and lime, which can neutralise the acidity. The calculated neutralising potential ratio (NPR) and net neutralising potential (NNP) values are within the ranges for which there is uncertainty as to whether acid will be produced. This is because of how close the AP and NP values are, meaning that the potential for acid generation will depend on the relative rates at which the Jarosite, lime and calcite react. The paste pH and NAG pH do provide some confidence that the initial pH of leachate from Jarofix will be near neutral to slightly alkaline.

TABLE 5-6: MODIFIED ABA SCREENING OF JAROFIX.

Parameter	Units	Screening criteria				Average Jarofix (n=3)
		Type I: High	Type II: Possible/ uncertain	Type III: Low/ uncertain	Type IV: No risk	
Sulphur in Jarosite	Wt%	>0.3	0.2 – 0.3	0.01 – 0.2	<0.1	4.0
Paste pH		<5	<7	>7	>7	8.9
NAG pH		<4.5	<4.5	<4.5	>4.5	7.9
NAG Acidity	kg/t H_2SO_4	>5	<5	<5	0	<0.01
Modified AP from Jarosite S	kg/t H_2SO_4					87.8
NP	kg/t H_2SO_4					92.9
NPR		<1	1 - 2	2 - 4	>4	1.1
NNP		<-20	-20	0 - 20	>20	5.1

Note – Colours highlighted indicated waste type. Green – Type IV No risk, Yellow – Type III Low/ uncertain, Orange Type II Possible/ uncertain, Red Type I High.

5.4 HYDROGEOLOGY

5.4.1 Unsaturated Zone

As per the scope of work received, the groundwater modelling was limited to the simulation of groundwater movement through the saturated zone only and does not consider flow in the unsaturated/ vadose zone.

If unsaturated zone hydrogeological modelling will be required in future, an additional investigation will be required.

5.4.2 Saturated Zone

No regional aquifers are developed in the area and groundwater occurs mainly in secondary fractured-rock aquifers (SRK, 2010). Primary weathered zone aquifers are rare and localised because soils are thinly developed.

Highly permeable scree, talus and intensively weathered bedrock occur to a depth of 20 to 30 m. This zone is, however, thought to be of restricted extent with limited groundwater potential, due to low rainfall and runoff with high evaporation rate resulting in very low and sporadic recharge ERM (2013a).

The highly fractured and weathered hard rock terrain of the white quartzite unit, the schist, and the gneiss, are considered to be water-bearing units, or secondary fractured-rock aquifers. The primary control on permeability is taken as structures and weathering (related to depth from surface), rather than rock type, appreciating that unweathered units at depth can also be water bearing, and that fracturing around major faults will increase hydraulic conductivity. Pump test information interpreted by ERM (2013a) indicated similar ranges of hydraulic conductivities in gneiss, schist, and quartzite lithology, and indicated a broadly confined character in the pump test curves.

5.4.3 Hydraulic Conductivity

Numerous aquifer test results for the site were reviewed and discussed by Golder (2007), SRK (2010), ERM (2013a), and GHT Consulting (2018) and results are summarised below.

Golder (2007)

Pumping tests were conducted on water supply boreholes GAMB1 and GAMB3. A 7-hour constant discharge test was conducted on GAMB1 at a discharge rate of 0.1 L/s. The pumping test for borehole GAMB3 was conducted at a rate of 0.3 L/s. Slug tests were also conducted on boreholes GAMB1, GAMB2, GAMB4 and GAMB5. Borehole locations are given in Figure 5-8.

The transmissivities assessed from the test pumping results and hydraulic conductivities from the slug tests are summarised below in Table 5-7. The aquifer test results indicated that the transmissivity of the fractured-rock aquifers at Gamsberg is predominantly low. Slug tests indicated local and short-term response of the aquifer to changes in water level. According to Golder (2007) the results of the study were consistent with previous studies which indicated that there are no regional aquifers present in the area and that groundwater appears to be present in fractured systems which may be isolated within rocks of generally low permeability.

TABLE 5-7: SUMMARY OF GOLDER (2007) AQUIFER TEST RESULTS.

Borehole	Geology	Transmissivity (m2/day)		Hydraulic Conductivity (m/day)	
		Pumping	Recovery	Falling head	Rising head
GAMB1	Schist	0.05	0.09	0.09	1.0
GAMB2	Schist	-	-	4.8	4.9
GAMB3	Schist	2.4	0.46	-	-
GAMB4	Schist	-	-	4.3	7.2
GAMB5	Schist	-	-	2.7	5.3

SRK (2010)

SRK did not conduct aquifer tests but reviewed data from previous studies, namely AATS (2000) and Golder Associates (2007). The results of the Golder (2007) study have already been discussed above and the results of the AATS (2000) study are summarised below and given in Table 5-8.

During 2000, AATS subjected newly drilled boreholes and several existing boreholes to aquifer testing. Boreholes BH5 and BH29 were subjected to constant rate discharge and recovery tests. The constant rate discharge test rate for boreholes BH5 and BH29 were 2.1 L/s and 2.8 L/s, respectively. All monitoring boreholes drilled at the time (MBH 1, MBH 2, MBH 3, MBH 4, MBH 5 and MBH 6) and existing boreholes PT 6, Gam 122, Gam 123, PT 9 and PT 10 were subjected to falling head tests, where the boreholes were filled with a known amount of water and the subsequent recovery was measured. Boreholes DG 30, PT 3 and PT 4 were subjected to packer testing using the Lugeon Test methodology.

The aquifer test results indicated that the transmissivity of the fractured-rock aquifers at Gamsberg is predominantly low, ranging between 0.8 m^2/d and 1.9 m^2/d. Slug tests indicated very low to low local hydraulic conductivity values for the aquifer units of the Gamsberg area, ranging between 10^{-1} m/d and 10^{-10} m/d.

TABLE 5-8: SUMMARY OF SRK (2010) AQUIFER TEST DATA REVIEW.

Borehole	Geology	Test Type	Transmissivity (m2/day)		Hydraulic Conductivity (m/day)
			Pumping	Recovery	Falling head
BH5	Alluvium & Gneiss	Pumping test	1.9	1.2	-
BH29	Schist	Pumping test	0.8	10^{-2}	-
MBH1	Gneiss	Slug test	-	-	10^{-4}
MBH2	Unspecified	Slug test	-	-	10^{-4}
MBH3	Unspecified	Slug test	-	-	10^{-3}
MBH4	Unspecified	Slug test	-	-	10^{-4}
MBH5	Unspecified	Slug test	-	-	10^{-1}
MBH6	Unspecified	Slug test	-	-	10^{-3}
PT6	Unspecified	Slug test	-	-	10^{-5}
GAM122	Unspecified	Slug test	-	-	10^{-2}
GAM123	Unspecified	Slug test	-	-	10^{-4}
PT9	Unspecified	Slug test	-	-	10^{-10}
PT10	Unspecified	Slug test	-	-	10^{-10}
DG30	Unspecified	Packer test	-	-	10^{-4}
PT3	Unspecified	Packer test	-	-	10^{-4}
PT4	Unspecified	Packer test	-	-	10^{-4}

Aquifer tests were also carried out in boreholes drilled at the TSF to determine parameters of the aquifer unit in this area. Single and double packer tests were conducted to determine the hydraulic conductivity of different horizons. The upper 20 m to 30 m were characterised by low hydraulic conductivity (10^{-3} m/d – 10^{-2} m/d), whereas the strata below 30 m were practically impermeable with very low hydraulic conductivity ($<10^{-5}$ m/d – 10^{-3} m/d).

ERM (2013a)

ERM did not conduct aquifer tests but reviewed data from previous studies, namely AATS (2000) and Golder Associates (2007).

The ERM (2013a) hydraulic test review summarised the hydraulic conductivity values for the Gamsberg aquifer units:

- Hydraulic conductivity results of the gneiss range over one order of magnitude (10^{-4} m/d – 10^{-3} m/d).
- Hydraulic conductivity results of the schist range over three orders of magnitude (10^{-3} m/d – 10^{0} m/d).
- Hydraulic conductivity results of the quartzite range over one order of magnitude (10^{-1} m/d – 10^{0} m/d).

GHT Consulting (2018)

Pumping tests were performed by GHT Consulting on selected farm and mine boreholes to determine aquifer parameters and sustainable yields. Majority of the test holes were in the gneiss aquifer unit and the transmissivity ranged between 10^{-1} m^2/d – 10^{+1} m^2/d.

Summary of hydraulic test results

The results from the studies above indicated that the aquifer units in the Gamsberg area generally have very low to low permeability and increased groundwater occurrence is only associated with secondary structures such as faults and fractures.

The TSF, smelter complex and SLF facilities are all located on basal gneiss of the Gladkop Group and no regional scale lineaments are located within the footprint of these facilities. However, the geophysical survey did indicate the presence of potential fractures within the TSF site area (Section 5.2).

The transmissivity and hydraulic conductivity ranges per aquifer unit are summarised in Figure 5-7.

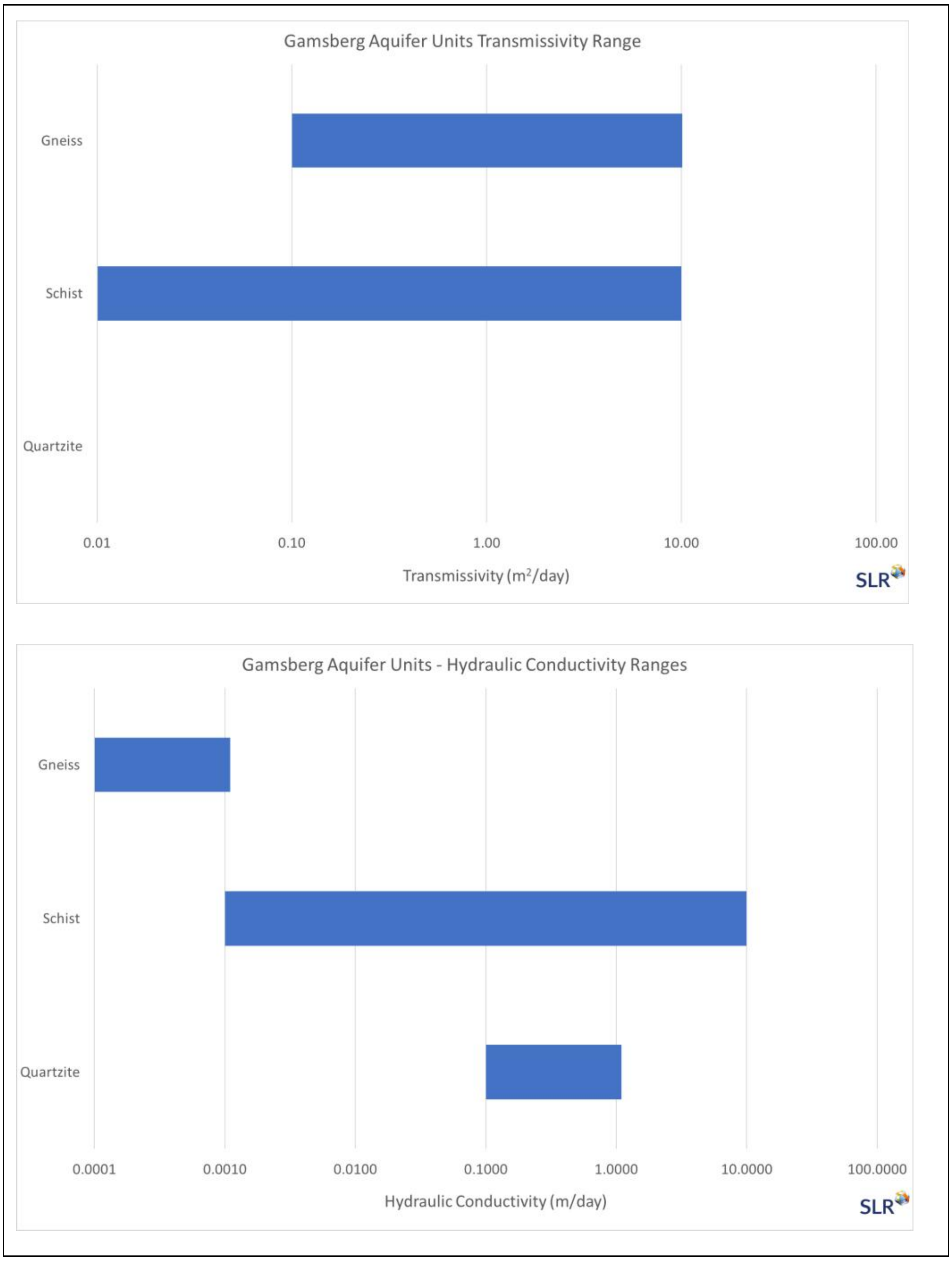


FIGURE 5-7: AQUIFER UNITS – TRANSMISSIVITY AND HYDRAULIC CONDUCTIVITY RANGES.

5.5 GROUNDWATER LEVELS

5.5.1 Previous Studies

Hydrocensus investigations were conducted by Golder (2007), SRK (2010), and ERM (2013a) and groundwater level results are summarised below.

Golder (2007)

Groundwater levels measured in 15 boreholes and a spring during the Golder (2007) hydrocensus ranged from artesian conditions to 179 metres below ground level (mbgl). Apart from a single spring and borehole with a groundwater level of 178.7 mbgl, the hydrocensus boreholes had an average groundwater level of 31.7 mbgl.

The elevation of the spring was measured at 915 mamsl but no flow measurement was recorded. However, Golder (2007) noted from the AATS (2000) study that the only flowing spring had a flow rate of approximately 0.1 m^3/hr – 1.0 m^3/hr.

The results of the hydrocensus indicated that groundwater flow was generally outward from the Gamsberg Inselberg towards the surrounding plains.

SRK (2010)

Groundwater levels were measured in 17 boreholes during the SRK February 2009 hydrocensus. Groundwater levels ranged from artesian conditions at the two springs (ACH1 & GAMS7) and 10 mbgl to 51 mbgl in the plains surrounding the inselberg. Apart from the three springs, the hydrocensus boreholes had an average groundwater level of 28.1 mbgl. The elevation of the springs ACH1, RS5, RS6 were measured at 869 mamsl, 873 mamsl, and 927 mamsl. SRK measured the spring flow rate during the 2009 hydrocensus and noted that flow rates of ~0.1 L/s (0.36 m^3/hr) for springs GAMS7 and GAMS9. The flow rate of spring ACH1, emanating from the Achab se Berge had a flow rate of ~0.5 L/s (1.8 m^3/hr).

SRK (2010) determined that groundwater flow was radially to the northeast and southwest away from the Gamsberg Inselberg. SRK (2010) also found that water levels in the Gamsberg area mimicked surface topography. A good correlation between surface elevation and groundwater elevation was determined by SRK (2010) to indicate possible unconfined aquifer conditions.

ERM (2013a)

The average groundwater level measured during the hydrocensus investigation was 29.41 mbgl, with a range of 4.4 mbgl to a maximum of 178.8 mbgl. ERM (2013a) created a frequency distribution that indicated that most boreholes had groundwater levels ranging from 20 – 50 mbgl for boreholes on the inselberg and up to 60 mbgl for boreholes on the plains.

ERM (2013a) noted that the springs only had small standing water pools and did not have any significant flow to generate a stream. ERM (2013a) did not record any spring flow measurements during the hydrocensus investigation.

ERM (2013a) indicated that topography had a dominant control on the groundwater levels and flow direction, and made the following deductions based on the hydrocensus investigation results:

- Groundwater flowing radially outwards from the inselberg towards the plains with the surface drainage controlling groundwater flow towards the northeast.
- Groundwater flows with higher hydraulic gradient around the inselberg, and significantly lower gradient in the plains.
- Two flow divides exist to the northwest of Gamsberg and to the southeast, due to the influence of the Aggeneys Berg and the Achab se Berge, respectively.

5.5.2 Site Groundwater Level Monitoring

The site has an existing groundwater monitoring network and monitoring is conducted and reported by GHT Consulting Scientists. Results of the groundwater level monitoring are summarised below, and the Gamsberg groundwater monitoring network boreholes are illustrated in Figure 5-8.

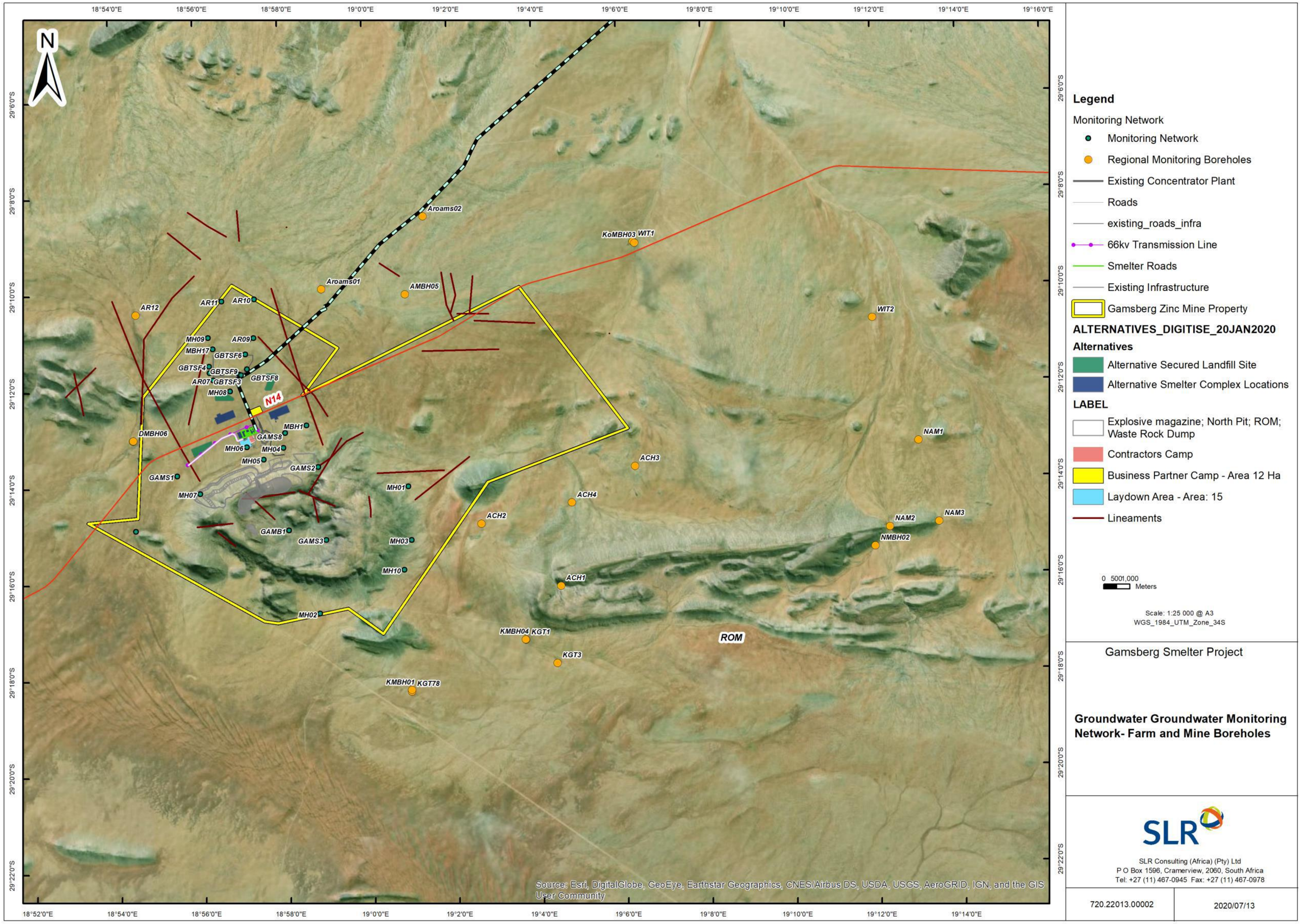


FIGURE 5-8: GAMSBERG GROUNDWATER MONITORING NETWORK – MINE AND FARM BOREHOLES.

Regional Monitoring Boreholes

In general, GHT Consulting (2019) concluded from groundwater monitoring conducted between November 2017 and April 2019 that the boreholes of the regional monitoring network indicated mostly stable groundwater level conditions, with slightly increasing or decreasing static water level elevation trends depending on the specific borehole (Figure 5-9). GHT Consulting indicated that no dewatering effects from the opencast mining are evident based on the groundwater levels of the regional farm boreholes. . Regional boreholes had an average groundwater level of 30.8 mbgl and ranged between 8.6 mbgl and 78.9 mbgl for the April 2019 monitoring round.

Groundwater level logger data installed in certain regional monitoring boreholes by GHT Consulting indicated that water levels varied significantly between October 2017 and April 2019 mostly due to groundwater abstraction from individual farm production wells. It is important to note that no metered groundwater abstraction rates from farm production boreholes were available. The most notable water level ranges for the regional monitoring boreholes included:

- Borehole AMBH05 (32 – 78 mbgl).
- Borehole KGT78 (53 – 90 mbgl).
- Borehole KGT3 (29 – 40 mbgl).
- Borehole KGT1 (24 – 49 mbgl).
- Borehole NAM2 (18.5 – 24 mbgl).

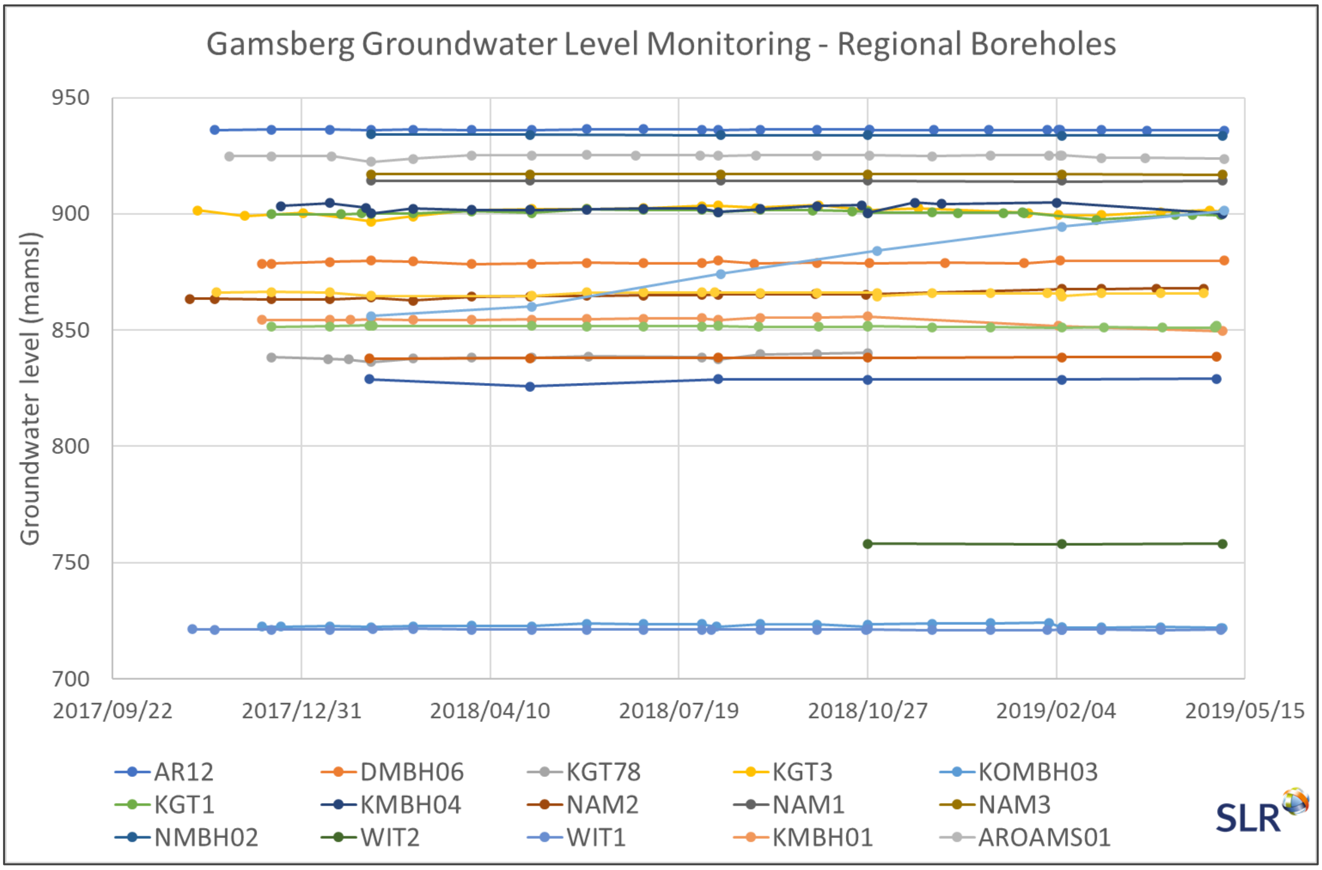


FIGURE 5-9: GAMSBERG GROUNDWATER LEVEL MONITORING – REGIONAL BOREHOLES.

Mine Boreholes

In general, GHT Consulting (2019) concluded from groundwater monitoring conducted between November 2017 and April 2019 that the mine monitoring boreholes indicated stable static groundwater level elevation trends, as illustrated in Figure 5-10. GHT Consulting indicated that no dewatering effects from the opencast mining are evident based on the groundwater levels of the mine boreholes. Mine monitoring boreholes had an average groundwater level of 30.6 mbgl and ranged between 11.6 mbgl and 52.3 mbgl for the April 2019 monitoring round. The average groundwater levels around the existing TSF, smelter complex and SLF areas were 26.89 mbgl and 42.34 mbgl, respectively. Two groundwater level measurements were taken from borehole AD17 on 06 February 2018 and 02 May 2019, indicating an increase in groundwater level from 687.97 mamsl and 773.87 mamsl during this period. This borehole should be continued to be monitored to explain the increase in groundwater level.

Groundwater level logger data installed by GHT Consulting in certain mine monitoring boreholes indicated that water levels were mostly stable between October 2017 and April 2019, apart from one production borehole MH03 (used for water supply) that showed a groundwater level ranging between 23 mbgl and 26 mbgl. It is important to note that no metered groundwater abstraction rates from Borehole MH03, used by the farmer for livestock watering, were available.

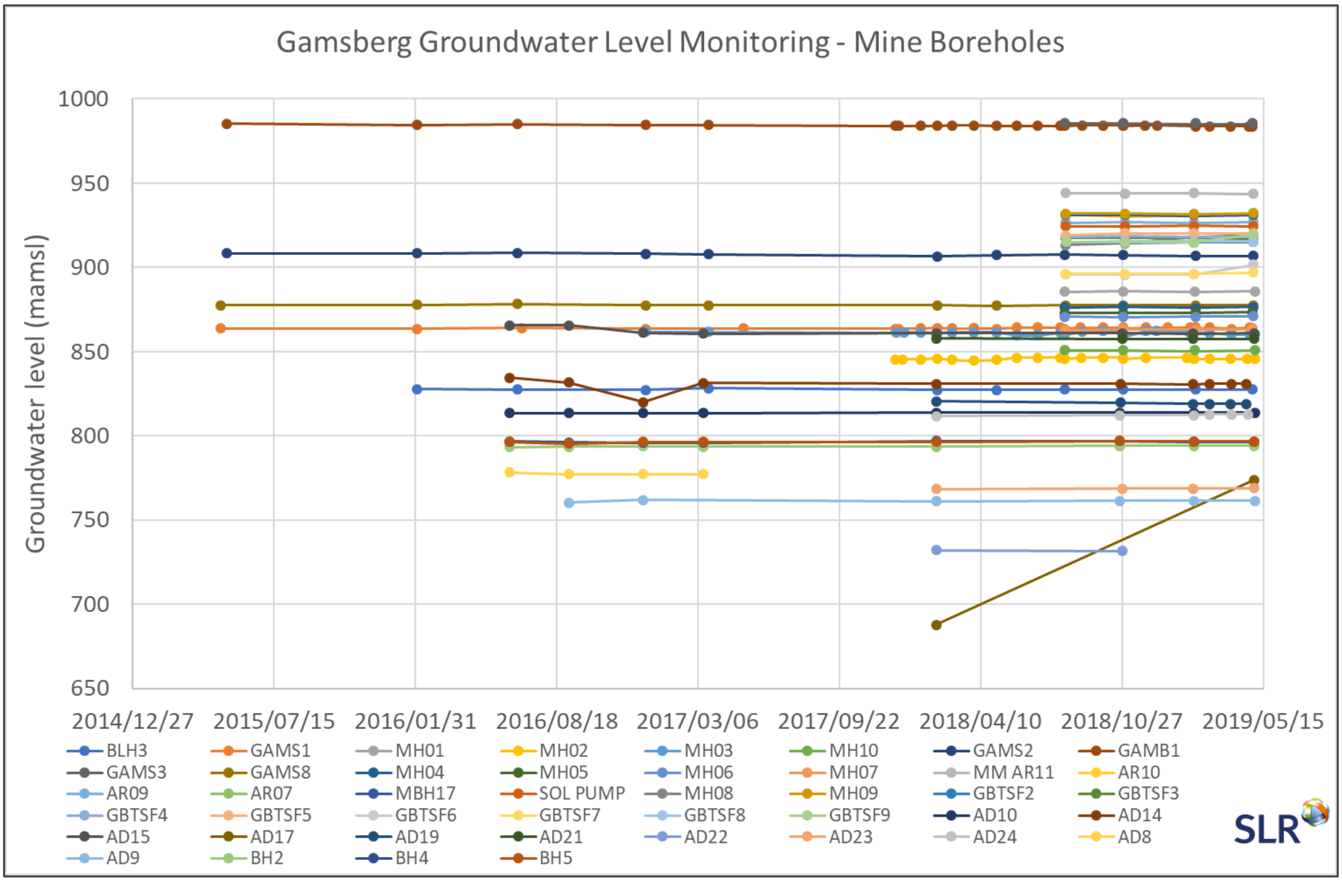


FIGURE 5-10: GAMSBERG GROUNDWATER LEVEL MONITORING – MINE BOREHOLES.

5.5.3 Groundwater Flow Direction

In general, water levels in the Gamsberg area mimic the surface topography, as illustrated in Figure 5-11 (based on April 2019 measured groundwater levels). GHT Consulting observed from the water level elevations of the monitoring data that the farms and mine boreholes had a correlation with the surface elevation (correlation coefficient R > 94 %). This indicated likely unconfined aquifer conditions (SRK, 2010). Figure 5-12 shows an inferred groundwater level contour map of the area and the monitoring boreholes in which groundwater levels were measured. Groundwater levels were contoured to groundwater elevation above mean sea level. The groundwater contour map indicates that groundwater flow is radially to the northeast and southwest away from the Gamsberg Inselberg. This correlates well with the SRK (2010) and ERM (2013a) findings.

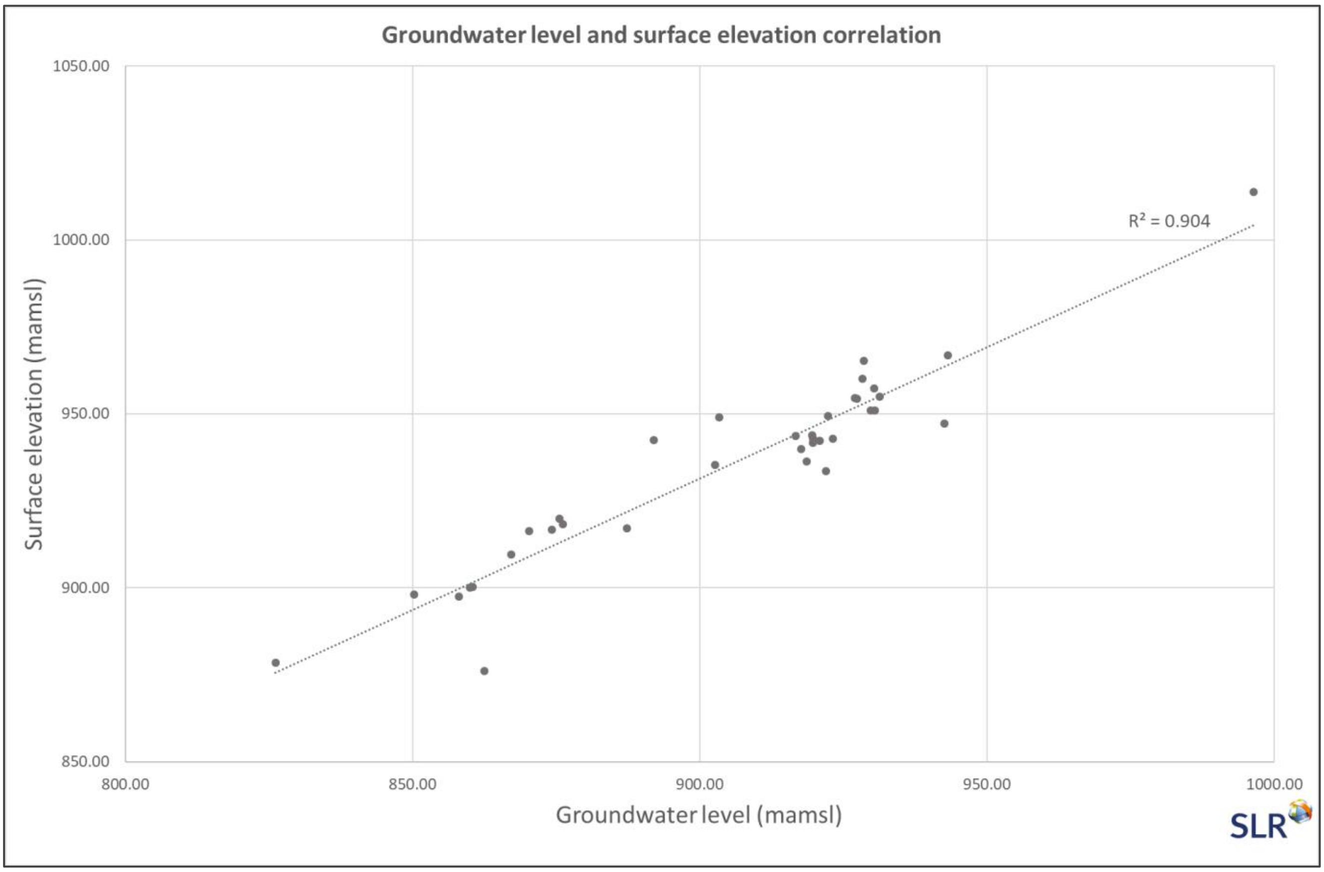


FIGURE 5-11: GROUNDWATER LEVEL AND SURFACE ELEVATION CORRELATION (MAY2019).

5.5.4 Groundwater Level Summary

The average groundwater levels measured during the Golder (2007), SRK (2010), and ERM (2013a) hydrocensus investigations were 31.7 mbgl, 28.1 mbgl, and 29.4 mbgl, respectively. The groundwater levels ranged between artesian conditions and 178.8 mbgl.

Regional monitoring boreholes had an average groundwater level of 30.8 mbgl and ranged between 8.6 mbgl and 78.9 mbgl for the April 2019 monitoring round. The mine monitoring boreholes had an average groundwater level of 30.6 mbgl and ranged between 11.6 mbgl and 52.3 mbgl for the April 2019 monitoring round. Groundwater levels of the monitoring network boreholes were quasi-stable and there were no adverse effects due to the pit dewatering affecting mine and regional groundwater levels.

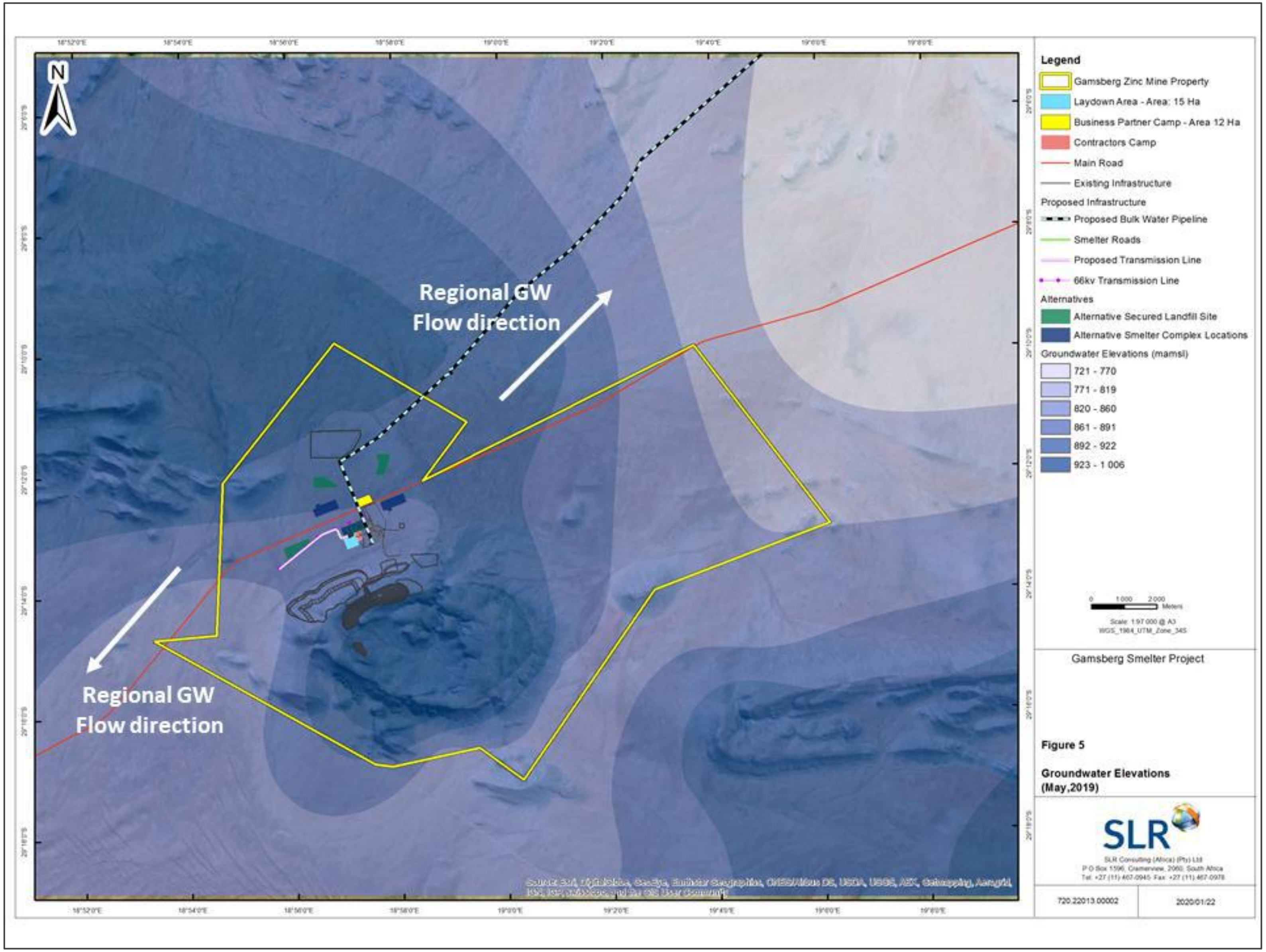


FIGURE 5-12: GAMSBERG GROUNDWATER ELEVATION AND INFERRED GROUNDWATER FLOW DIRECTION.

5.6 GROUNDWATER QUALITY

5.6.1 Previous Studies

Hydrocensus investigations conducted by Golder (2007), SRK (2010), and ERM (2013a) included groundwater sampling and water quality results are summarised below.

Water sample classified according to Classes refer to the classification system described in Quality of Domestic Water Supplies Volume 1: Assessment Guide, Second Edition, (1998) and South African Water Quality Guidelines – Volume 1 Domestic Use (1993 and 1996). For each chemical parameter under analysis, the water is classified as belonging to one of five classes, ranging from ideal to totally unacceptable (Table 5-9).

TABLE 5-9: DESCRIPTION OF WATER QUALITY CLASSES (DWAF, 1998).

Class	Description
Class 0	Ideal water quality
Class 1	Good water quality
Class 2	Marginal water quality
Class 3	Poor water quality
Class 4	Unacceptable water quality

Golder (2007)

Water samples were collected from 3 boreholes and 1 spring during the 2007 hydrocensus investigation. The inorganic analytical results were compared to SANS-241 (2006) drinking water quality guidelines.

The pH of the groundwater samples ranged between 6.92 and 7.39 with an average value of 7.20. The EC ranged between 24 mS/m and 117 mS/m with an average value of 83 mS/m. The SO_4 concentrations ranged between 16.96 mg/L and 70.33 mg/L with an average concentration of 57.73 mg/L.

Apart from elevated fluoride concentration in one sample, the groundwater quality was good with no other constituents elevated above the guideline limits. An elevated fluoride concentration of 1.05 mg/L was noted in sample GAMB1. This concentration was marginally above the Class I guideline of 1 mg/l but is less than the Class II guideline of 1.5 mg/l.

SRK (2010)

During the initial 2009 hydrocensus, five groundwater samples were collected and a further ten samples in May 2009 during completion of the hydrocensus investigation. Ten groundwater samples were also collected during the first groundwater monitoring round in August 2009. The inorganic analytical results were compared to SANS-241 (2006) and World Health Organization 2006 (for uranium and barium) drinking water quality guidelines.

The pH of the groundwater samples ranged between 6.20 and 8.50 with an average value of 7.54. The EC ranged between 16 mS/m and 660 mS/m with an average value of 159 mS/m. The SO_4 concentrations ranged between 14.6 mg/L and 947 mg/L with an average concentration of 170.0 mg/L.

The salinity of all groundwater samples was within Class I or Class II limits, except AR1 (660 mS/m), which had EC well above the guideline limit. Fluoride concentrations ranged between 0.2 and 4.2 mg/L, with a mean value of

2.07 mg/L. Most of the samples showed elevated fluoride concentrations above Class II guideline limits. The boreholes with elevated fluoride concentrations above the guideline limit were predominantly located on the plains surrounding the Gamsberg Inselberg. Nitrate (as N) concentrations varied broadly from below detection limits (<0.3 mg/L) to 43 mg/L (AR1 – dug well). The elevated concentration of nitrate was attributed to point source contamination of the groundwater from the surface, most possibly from a nearby livestock watering point.

The metal concentrations were mostly below detection limits and fell below the Class I acceptable limits. A few samples showed elevated concentrations of metals within the Class II unacceptable quality range. Several samples showed elevated uranium concentration above the WHO (2006) guidelines (0.015 mg/L). Elevated uranium concentrations in groundwater occur naturally in the Northern Cape aquifers (Van Wyk & Coetzee, 2008).

ERM (2013a)

A total of 39 groundwater samples were collected from monitoring boreholes, natural springs, and privately-owned boreholes during the 2013 hydrocensus investigation. Water quality results were compared to the South African Water Quality Guidelines for domestic purposes as well as livestock watering (Department of Water Affairs and Forestry, 1996).

The pH of the groundwater samples ranged between 5.81 and 8.67 with an average value of 7.74. The EC ranged between 24 mS/m and 1 626 mS/m with an average value of 241 mS/m. The SO_4 concentrations ranged between 22.0 mg/L and 1 706 mg/L with an average concentration of 264.0 mg/L.

Electrical conductivities ranged from 24 mS/m to 1 626 mS/m (AR2). Most of the EC values were elevated above the domestic water target of 70 mS/m. The higher EC concentrations were generally from boreholes located in the plains surrounding the Gamsberg inselberg. ERM (2013a) noted that salts concentrating in the soil by evaporation of rainfall can be washed through the soil by rainfall. As limited recharge occurs on the plains, the concentration of salts in recharge was expected to be high.

Groundwater nitrate concentrations ranged from below detection limit (BDL) to 32 mg/L (KGT3). Nitrate concentrations of several samples were elevated above the DWAF target value for domestic water use (6 mg/L). According to ERM (2013a) the elevated concentrations appeared to be located on farms surrounding the inselberg and were possibly related to livestock farming. Fluoride concentrations ranged from BDL to 5.2 mg/L (AR2). Most of the groundwater samples contained concentrations exceeding both the domestic use and livestock watering target values of 1 mg/L and 2 mg/L, respectively.

Elevated concentrations of iron, manganese, lead, and uranium above the guideline values were noticed in several samples. ERM (2013a) concluded that elevated EC, TDS, chloride, sulphate, calcium, magnesium, sodium and zinc were likely to affect the palatability of the groundwater, while nitrate, fluoride, potassium, iron, manganese, lead and uranium presented potential health risks.

5.6.2 Site Groundwater Quality Monitoring

The site has an existing groundwater monitoring network and monitoring is conducted and reported by GHT Consulting Scientists. A total of 14 farms and 22 mine boreholes were sampled by GHT Consulting as part of the site groundwater monitoring programme conducted between November 2017 and April 2019. GHT Consulting compared groundwater quality results to the South African National Standards (SANS241-2015 and SANS241-2006), the South African Water Quality Guidelines, Volume 5 - Agricultural Use: Livestock Watering, and the Gamsberg Mine Water Use License (WUL No.: 14/D82C/ABCGIJ/2654) – Water Resource Quality Objectives. Results of the groundwater quality monitoring results are summarised below.

Regional Monitoring Boreholes

The pH of the groundwater samples ranged between 7.10 and 8.44 with an average value of 7.60. The EC ranged between 33 mS/m and 523 mS/m with an average value of 224 mS/m. The SO_4 concentrations ranged between 28.5 mg/L and 509.6 mg/L with an average concentration of 253.8 mg/L.

The farm production boreholes and associated regional monitoring boreholes had elevated concentrations of As, Fe, Pb, U, EC, TDS, Na, Ca, Mg, Cl, SO_4, F, NO_3-N, and Mn above the relevant guideline limits, as shown in Table 5-10. GHT Consulting found that the background groundwater qualities, of the naturally occurring aquifer waters of the farm areas, in general exceeded drinking water standards.

TABLE 5-10: GAMSBERG – REGIONAL MONITORING BOREHOLES GROUNDWATER QUALITY RESULTS (APRIL 2019).

Date	Station ID	Al (mg/L)	As (mg/L)	Ca (mg/L)	Cd (mg/L)	Cu (mg/L)	Fe (mg/L)	K (mg/L)	Mg (mg/L)	Mn (mg/L)	Na (mg/L)	Pb (mg/L)	U (mg/L)	Zn (mg/L)	pH (Value at 25°C)	Electrical Conductivity in mS/m at 25°C	Total Dissolved Solids at 180°C *	Chloride as Cl	Sulphate as SO_4	Fluoride as F	Nitrate as N
IWUL				**201**					**30**		**463**				**5.6 - 9.5**	**414**		**554**	**202**	**4.8**	**12.1**
SANS 241 (2015) Operational		0.3													5 - 9.7						
SANS 241 (2015) Aesthetic							0.3			0.1	200			5		170	1200	300	250		
SANS 241 (2015) Acute Health																			500		11
SANS 241 (2015) Chronic Health			0.01		0.003	2	2			0.4		0.01	0.03							1.5	
DWAF TWQG (Livestock Watering) TQR		5	1	1000	0.01	[a]0.5	10		500	10	2000	0.1		20			[b]1000	[c]500	1000	[d]2	100
20190504	AR11	< 0.01	< 0.005	137	< 0.002	< 0.01	0.02	25.5	**60.7**	< 0.01	**262**	< 0.01	**0.11**	0.12	7.32	**235**	**1418**	**469**	**258**	**2.02**	2.84
20190504	AR12	< 0.01	< 0.005	68.2	< 0.002	< 0.01	< 0.01	8.6	25.7	< 0.01	51.3	< 0.01	< 0.01	< 0.01	7.9	81.5	458	112	81.2	0.79	3.45
20190503	KGT78	< 0.01	**0.01**	75.8	< 0.002	< 0.01	< 0.01	38.3	**94.7**	< 0.01	**531**	< 0.01	**0.04**	< 0.01	8.44	**353**	**2176**	**714**	**510**	**6.87**	1.8
20190503	KGT3	< 0.01	< 0.005	99.5	< 0.002	< 0.01	0.04	8.85	**38**	< 0.01	132	< 0.01	**0.07**	< 0.01	7.92	144	807	232	104	**2.24**	7.49
20190503	KGT1	< 0.01	**0.01**	**354**	< 0.002	< 0.01	0.03	20	**123**	< 0.01	**545**	**0.01**	**0.04**	< 0.01	7.21	**510**	**3088**	**1365**	**462**	**1.99**	7.51
20190503	NAM3	0.02	< 0.005	107	< 0.002	< 0.01	< 0.01	7.41	27.1	< 0.01	150	< 0.01	< 0.01	< 0.01	7.49	150	866	286	132	**2.39**	12.8
20190503	NAM2	< 0.01	< 0.005	81.8	< 0.002	< 0.01	< 0.01	5.93	21.7	< 0.01	102	< 0.01	0.02	0.04	8.16	111	619	213	93.8	**1.55**	4.58
20190503	NAM1	0.01	**0.01**	**420**	< 0.002	0.05	0.02	18.4	**127**	0.01	**562**	**0.01**	**0.04**	0.02	7.38	**523**	**3287**	**1445**	**502**	**1.64**	25
20190503	WIT1	< 0.01	**0.01**	127	< 0.002	< 0.01	0.09	8.2	**42.7**	0.01	**510**	< 0.01	**0.03**	0.28	7.63	**339**	**1961**	**725**	**388**	**6.47**	6.61
20190504	AROAMS02	< 0.01	< 0.005	68.7	< 0.002	< 0.01	0.02	2.31	17.5	< 0.01	67	< 0.01	< 0.01	< 0.01	7.77	82.3	446	135	45.5	**2.52**	3.19
20190430	ACH2	< 0.01	< 0.005	120	< 0.002	0.06	0.06	31.3	**39.9**	0.02	**248**	< 0.01	0.02	< 0.01	7.53	**200**	**1333**	207	**465**	**4.96**	15.1
20190430	ACH4	< 0.01	< 0.005	78.4	< 0.002	< 0.01	< 0.01	5.59	**39.6**	< 0.01	165	< 0.01	**0.06**	< 0.01	7.11	148	849	204	194	**2.41**	1.48
20190430	ACH3	< 0.01	< 0.005	151	< 0.002	< 0.01	**0.37**	9.97	**52.7**	**0.79**	**228**	< 0.01	0.02	1.59	7.4	**221**	**1326**	**449**	**290**	**2.48**	1.8
20190430	ACH1	< 0.01	< 0.005	13.8	< 0.002	< 0.01	< 0.01	3.16	10.8	< 0.01	29.9	< 0.01	< 0.01	< 0.01	7.1	33.5	178	54.4	28.5	0.25	4.03

Note:

[a] 1500: Monogastric & poultry, 3000: Other livestock; [b]0-0.5: Sheep and calves, 0.5-1: Other livestock; [c] 0 – 2: All other livestock, 0 – 6: Ruminants;[d] 1000: Dairy, pigs & poultry, 2000: Cattle and horses, 3000: Sheep

Highlighted cells indicate which water quality standard has been exceeded

The groundwater of the farm areas boreholes can be described as follow by means of the Piper Diagram (Figure 5-13):

- Stagnant groundwater conditions characterised by Ca/$MgCl_2$ and Ca/$MgSO_4$ groundwater. The groundwater chemistry of the following boreholes can be described as stagnant: AR11, AR12, KGT3, KGT1, NAM3, NAM2, NAM1, AROAMS02, ACH4, ACH3, and ACH1.

- Old or mature groundwater enriched in Na^+ and Cl^-: The groundwater chemistry of the following boreholes can be described as old or mature: KGT78, WIT1, and ACH2.

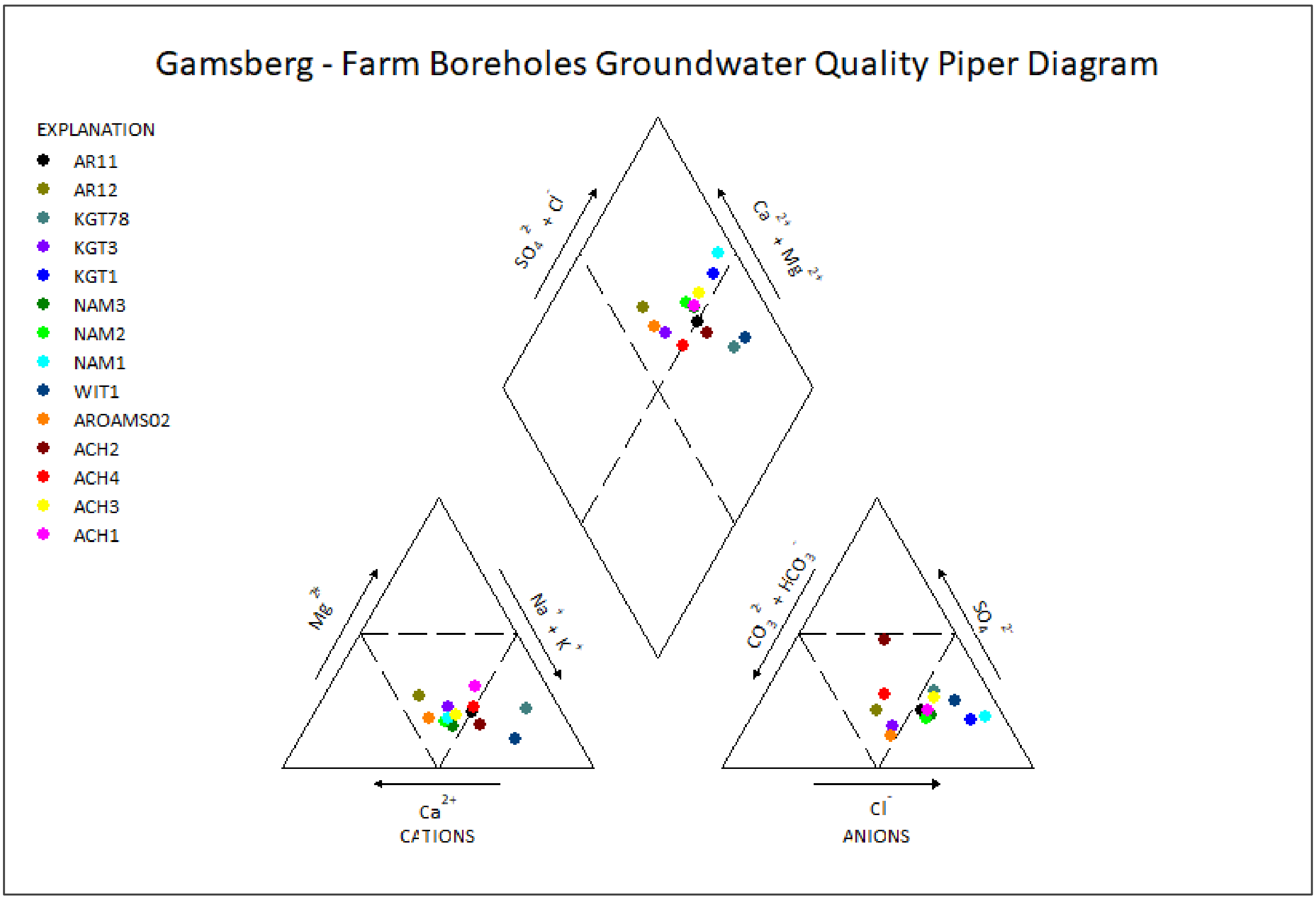


FIGURE 5-13: GAMSBERG – FARM BOREHOLES GROUNDWATER QUALITY PIPER DIAGRAM.

GHT Consulting concluded that between November 2017 and April 2019 there were no indications of pollution plume(s) emanating from the Gamsberg Zinc Mine site that could affect the groundwater quality of the farm water boreholes.

Mine Boreholes

The pH of the groundwater samples ranged between 6.57 and 7.66 with an average value of 7.42. The EC ranged between 37 mS/m and 1 141 mS/m with an average value of 234 mS/m. The SO_4 concentrations ranged between 35.0 mg/L and 2 324.0 mg/L with an average concentration of 324.7 mg/L.

The mine monitoring boreholes had elevated concentrations of EC, TDS, Na, Ca, Mg, Cl, SO_4, F, As, Fe, NO_3-N, Pb, Mn, and U above the relevant guideline limits, as shown in Table 5-11. GHT Consulting concluded that between November 2017 and April 2019 there were no groundwater quality impacts observed in the receiving local aquifer of the Gamsberg Zinc Mine.

The groundwater of the mine boreholes can be described as follow by means of the Piper Diagram (Figure 5-14):

- Stagnant groundwater conditions characterised by Ca/$MgCl_2$ and Ca/$MgSO_4$ groundwater. The groundwater chemistry of the following boreholes can be described as stagnant: MH01, MH02, MH03, MH10, GAMS2, MH06, AR10, AR07, SOL PUMP, MH08, MH09, GBTSF5, and GBTSF6.

- Old or mature groundwater enriched in Na^+ and Cl^-: The groundwater chemistry of the following boreholes can be described as old or mature: GBTSF2, GBTSF3, GBTSF4, GBTSF7, GBTSF8, GBTSF9, AR09, AR11, and MBH17.

The low hydraulic conductivities (section 5.4.3) indicate that locally the geology has slow flowing groundwater with limited recharge (section 8.5.1), which becomes stagnant or mature over time.

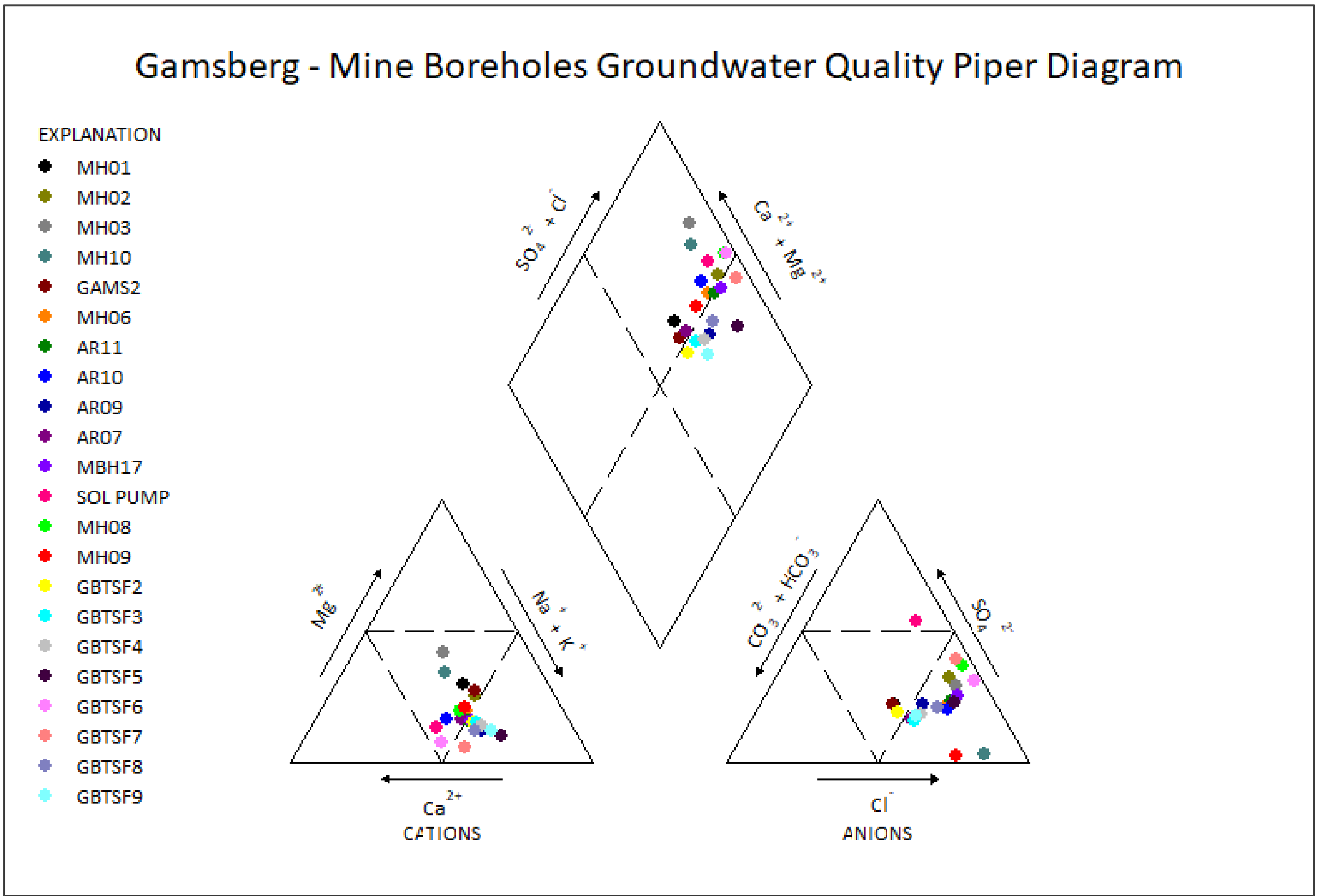


FIGURE 5-14: GAMSBERG – MINE BOREHOLES GROUNDWATER QUALITY PIPER DIAGRAM.

TABLE 5-11: GAMSBERG – MINE MONITORING BOREHOLES GROUNDWATER QUALITY RESULTS (APRIL 2019).

Date	Station ID	Al (mg/L)	As (mg/L)	Ca (mg/L)	Cd (mg/L)	Cu (mg/L)	Fe (mg/L)	K (mg/L)	Mg (mg/L)	Mn (mg/L)	Na (mg/L)	Pb (mg/L)	U (mg/L)	Zn (mg/L)	pH (Value at 25°C)	Electrical Conductivity in mS/m at 25°C	Total Dissolved Solids at 180°C *	Chloride as Cl	Sulphate as SO_4	Fluoride as F	Nitrate as N
IWUL				201					30		463				5.6 - 9.5	414		554	202	4.8	12.1
SANS 241 (2015) Operational		0.3													5 - 9.7						
SANS 241 (2015) Aesthetic							0.3			0.1	200			5		170	1200	300	250		
SANS 241 (2015) Acute Health																			500		11
SANS 241 (2015) Chronic Health			0.01		0.003	2	2			0.4		0.01	0.03							1.5	
DWAF TWQG (Livestock Watering) TQR		5	1	1000	0.01	[a]0.5	10		500	10	2000	0.1		20			[b]1000	[c]500	1000	[d]2	100
20190503	MH01	0.03	< 0.005	22	< 0.002	< 0.01	< 0.01	3.13	14	0.01	36.3	< 0.01	< 0.01	< 0.01	7.73	44.2	225	64.2	43.7	0.66	< 0.35
20190502	MH02	< 0.01	< 0.005	131	< 0.002	< 0.01	< 0.01	22.3	75.2	< 0.01	260	< 0.01	0.02	< 0.01	7.54	246	1491	522	399	2.03	0.56
20190503	MH03	< 0.01	< 0.005	50.9	< 0.002	< 0.01	0.46	13.2	45	0.86	51.4	< 0.01	< 0.01	< 0.01	7.14	95.9	524	204	131	0.15	< 0.35
20190503	MH10	0.01	< 0.005	19.1	< 0.002	< 0.01	< 0.01	4.9	12.5	0.02	20.2	< 0.01	< 0.01	< 0.01	7.36	33.3	166	375	20.7	0.48	0.46
20190501	GAMS2	< 0.01	< 0.005	15.3	< 0.002	< 0.01	0.1	6.15	9.86	1.59	29.5	< 0.01	< 0.01	0.58	6.57	37.3	182	50.3	35	0.72	< 0.35
20190501	MH06	0.12	< 0.005	158	< 0.002	< 0.01	0.13	15.5	60	0.08	268	< 0.01	0.02	< 0.01	7.56	240	1442	556	255	2.02	1.45
20190501	MM AR11	0.13	< 0.005	154	< 0.002	< 0.01	0.3	18	44.3	0.05	259	< 0.01	0.02	< 0.01	7.57	233	1407	521	266	1.82	9.88
20190501	AR10	< 0.01	< 0.005	182	< 0.002	< 0.01	< 0.01	15	45.2	< 0.01	217	< 0.01	0.02	< 0.01	7.49	229	1369	499	221	1.52	17
20190501	AR09	< 0.01	0.01	157	< 0.002	< 0.01	< 0.01	20	36.9	0.01	320	< 0.01	0.03	< 0.01	7.36	255	1514	509	280	1.67	< 0.35
20190501	AR07	< 0.01	< 0.005	110	< 0.002	< 0.01	< 0.01	15.2	31.9	< 0.01	169	< 0.01	0.03	< 0.01	7.48	164	935	300	124	2.16	7.94
20190501	MBH17	< 0.01	0.01	236	< 0.002	0.05	< 0.01	25.2	69.1	< 0.01	420	< 0.01	0.03	< 0.01	7.56	362	2224	814	442	1.72	21
20190501	SOL PUMP	< 0.01	0.01	446	< 0.002	0.07	0.07	57	79	1.63	449	0.01	0.04	0.02	7.22	433	3239	664	1364	1.32	2.76
20190501	MH08	0.02	0.01	850	< 0.002	0.06	0.08	100	301	4.56	1267	0.03	0.09	0.02	7.14	1141	7774	2776	2324	1.34	0.4
20190501	MH09	< 0.01	< 0.005	99	< 0.002	< 0.01	0.16	15.9	39.2	0.24	159	< 0.01	0.01	< 0.01	7.1	164	862	419	19	1.75	< 0.35
20190501	GBTSF2	0.14	< 0.005	95	< 0.002	< 0.01	0.04	22.5	27.3	0.03	169	0.16	0.08	< 0.01	7.53	153	888	253	137	2.3	5.3
20190501	GBTSF3	< 0.01	< 0.005	100	< 0.002	< 0.01	< 0.01	16.6	29.2	< 0.01	189	< 0.01	0.03	< 0.01	7.56	165	955	313	126	2.27	7.15
20190501	GBTSF4	< 0.01	< 0.005	106	< 0.002	< 0.01	0.02	16	31	0.01	225	0.05	0.02	< 0.01	7.53	184	1072	364	161	2.33	4.21
20190501	GBTSF5	< 0.01	0.01	177	< 0.002	< 0.01	0.02	68.1	42.3	0.19	478	0.04	0.03	< 0.01	7.64	333	2040	735	358	2.13	0.61
20190501	GBTSF6	0.01	0.01	474	< 0.002	< 0.01	0.01	49.1	49.5	0.08	523	0.01	0.04	0.02	7.47	537	3164	1217	769	0.96	9.2
20190501	GBTSF7	< 0.01	0.01	377	< 0.002	< 0.01	0.07	63.8	34.09	0.12	572	0.01	0.04	0.02	7.44	468	3129	976	925	1.07	27
20190501	GBTSF8	< 0.01	< 0.005	153	< 0.002	< 0.01	< 0.01	22.1	33.8	0.05	285	< 0.01	0.02	< 0.01	7.63	246	1407	511	247	1.8	2.05
20190501	GBTSF9	< 0.01	< 0.005	95.9	< 0.002	< 0.01	< 0.01	15.5	25.2	< 0.01	229	< 0.01	0.02	< 0.01	7.52	182	1027	335	150	2.25	5.78

Note:

[a] 1500: Monogastric & poultry, 3000: Other livestock; [b]0-0.5: Sheep and calves, 0.5-1: Other livestock; [c] 0 – 2: All other livestock, 0 – 6: Ruminants;[d] 1000: Dairy, pigs & poultry, 2000: Cattle and horses, 3000: Sheep

Highlighted cells indicate which water quality standard has been exceeded

5.6.3 Groundwater Quality Summary

Results from the previous hydrocensus investigations showed pH ranged between 5.81 and 8.67 with an average value of 7.49. The EC ranged between 16 mS/m and 1 626 mS/m with an average value of 161 mS/m. The SO_4 concentrations ranged between 14.6 mg/L and 1 706 mg/L with an average concentration of 163.9 mg/L.

Groundwater monitoring results conducted between November 2017 and April 2019 indicated the pH of the groundwater samples ranged between 6.57 and 8.44 with an average value of 7.51. The EC ranged between 33 mS/m and 1 141 mS/m with an average value of 229 mS/m. The SO_4 concentrations ranged between 28.5 mg/L and 2 324 mg/L with an average concentration of 289.3 mg/L.

The previous hydrocensus investigations and groundwater monitoring results showed several constituents that were elevated above relevant guideline limits. Parameters included EC, TDS, Na, Ca, Mg, Cl, SO_4, F, NO_3-N, As, Pb, Fe, Mn, and U.

Processes of evaporation and long-residence time or the host rock mineralogy (apatite-bearing rocks) may result in elevated fluoride concentrations. Elevated fluoride in groundwater is a characteristic feature of the Northern Cape. SRK (2010) concluded from the Piper diagrams that the chemical composition of the water from the area under investigation has undergone natural base-exchange and precipitation processes. The hydrochemistry of the Gamsberg area was interpreted by SRK (2010) to be indicative of a mature hydrochemical environment with very limited recharge, which generally only takes place in years of exceptionally high precipitation. The piper diagrams for April 2019 of the Gamsberg mine and regional monitoring boreholes confirmed the SRK (2010) findings that the groundwater is indicative of a mature hydrochemical environment with very limited recharge.

GHT Consulting concluded that between November 2017 and April 2019 there was no indication of pollution emanating from the Gamsberg Zinc Mine site that could affect the groundwater quality of the surrounding farm boreholes.

5.7 POTENTIAL GROUNDWATER CONTAMINANTS

There is the potential for contamination due to the operation of the smelter complex and SLF. Contaminants from the project are expected to include construction related consumables, fuels, hydrocarbons, residues, and hazardous wastes. Open pit mining as well as the waste rock dumps are not evaluated in this study.

5.7.1 Secured Landfill Facility (SLF)

The distilled water tests (section 5.3) performed on the Jarofix samples identified the following potential contaminants:

- TCT limits exceeded:
  - Lead exceeded the TCT2 guideline values.
  - Antimony (Sb) exceeded the TCT1 guideline values and were within the limits of TCT2.
  - As, Ba, Cd, Cu, F, Hg, and Zn exceeded the TCT0 guideline values and were within the limits of TCT1.
- LCT limits exceeded:
  - SO_4, As, Cd, Ni, and Sb exceeded the LCT0 and SANS 241-1:2015 guideline values and were within the limits of LCT1.

The geochemical modelling of the SLF, during operational and closure phases, for the main identified potential contaminants are given in Section 7.

5.8 SITE SENSITIVITIES AND APPLICABLE BUFFERS

The primary criterion for assessing the groundwater impacts was based on and the avoidance of privately-owned farm boreholes. The groundwater study will only indicate the movement of potential contaminant plumes in relation to privately owned boreholes. The nearest privately-owned farm boreholes to the SLF and smelter are DMBH06 and AR12, located 2.5 km and 5.0 km towards the northwest. The privately-owned farm boreholes in relation to the possible groundwater contaminant sources are illustrated in Figure 5-15.

The biodiversity sensitivity of the project area has been established over several years of research in the area associated with bioregional planning initiatives and previous EIA applications for mining activities in the Gamsberg inselberg (ERM, 2014). The impact of elevated contaminants of concern in groundwater on irreplaceable and constrained habitats will be assessed by a separate biodiversity study.

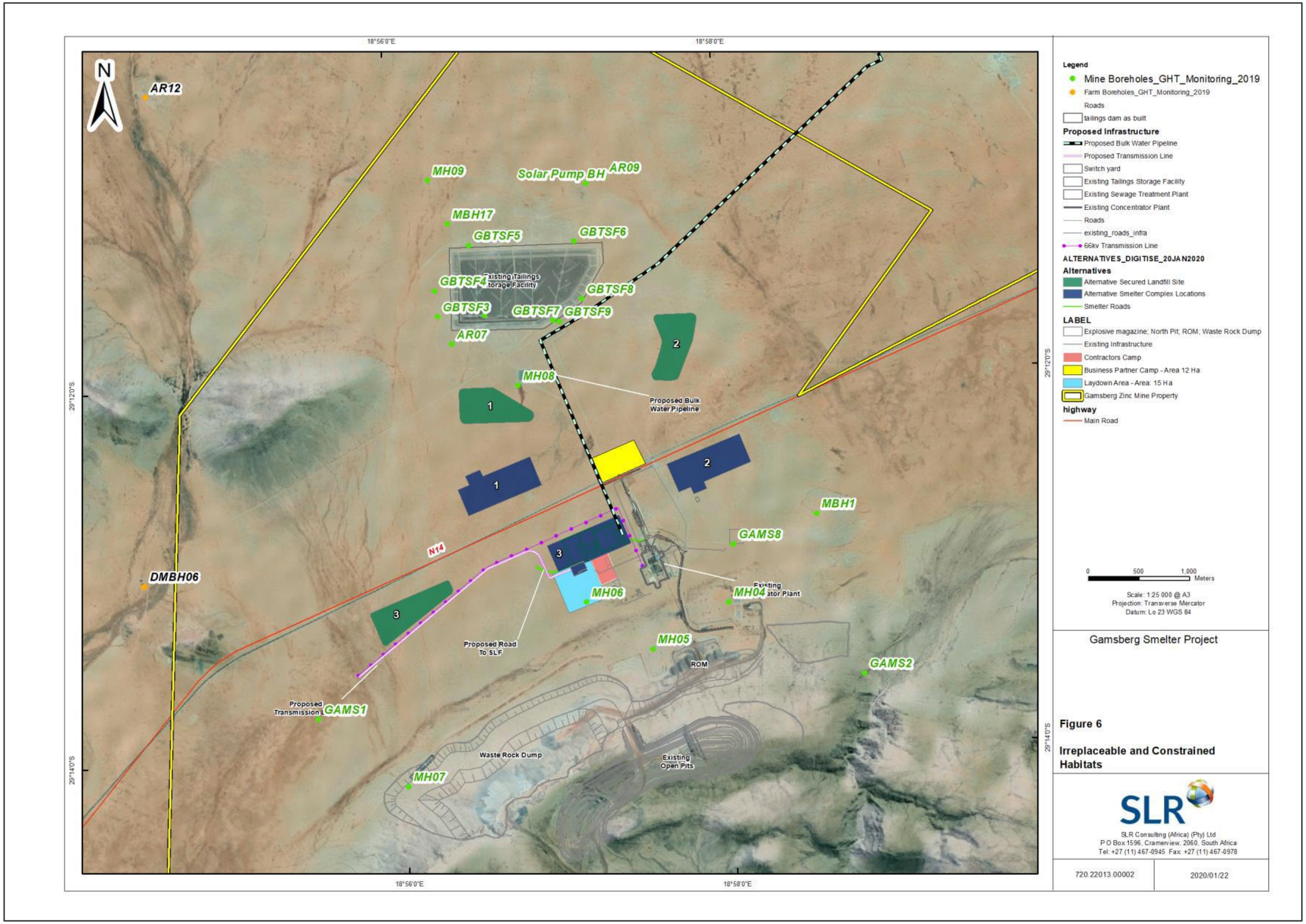


FIGURE 5-15: THE IRREPLACEABLE AND CONSTRAINED HABITATS WITHIN THE PROJECT AREA.

6 AQUIFER CHARACTERISATION

6.1 GROUNDWATER VULNERABILITY

Groundwater vulnerability gives an indication of how susceptible an aquifer is to contamination. Aquifer vulnerability is used to represent the intrinsic characteristics that determine the sensitivity of various parts of an aquifer to being adversely affected by a contaminant load imposed from surface.

The method is based on the DRASTIC method, where vulnerability is determined within hydrogeological settings by evaluating seven parameters denoted by the acronym:

- **D**epth to water table
- **R**echarge (net)
- **A**quifer media
- **S**oil media
- **T**opography
- **I**mpact of the vadose (unsaturated) zone
- **C**onductivity (hydraulic)

Based on the national scale results (Parsons & Conrad, 1998), the aquifer underlying the project area has a low vulnerability rating indicating a low tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some surface location above the uppermost aquifer.

SRK (2010) used the DRASTIC method and determined the local-scale groundwater vulnerability and concluded that approximately 58 % of the study area had a medium-high vulnerability, mostly occurring on the plains surrounding the Gamsberg. The mountainous regions were predominantly of medium low to very low vulnerability. In the south to southeast, in the region of the windblown sand and dune sand, the vulnerability was classified as high. The high vulnerability areas covered approximately 11 % of the study area, while the medium-low to very low areas covered approximately 31 % of the study area. The mine infrastructure was situated in areas of medium high vulnerability.

6.2 AQUIFER CLASSIFICATION

No regional aquifers are developed in the area and groundwater occurs mainly in secondary fractured-rock aquifers (SRK, 2010). Primary weathered zone aquifers are rare and localised because soils are thinly developed. Based on the aquifer classification map (Parsons and Conrad, 1998), the aquifer system underlying the site is regarded mainly as a poor groundwater region. A poor groundwater region consists of a low to negligible yielding aquifer system of moderate to poor water quality.

6.3 AQUIFER PROTECTION CLASSIFICATION

As part of the aquifer classification, a Groundwater Quality Management (GQM) Index is used to define the level of groundwater protection required (Parsons, 1995). The point scoring system and classification of the site-specific study area are presented in Table 6-1.

TABLE 6-1: GROUNDWATER QUALITY MANAGEMENT (GQM) CLASSIFICATION SYSTEM (PARSONS, 1995).

Aquifer System Management Classification		
Class	Points	Project area
Sole source aquifer system	6	0
Major aquifer system	4	
Minor aquifer system	2	
Poor/Non-aquifer system	0	
Special aquifer system	0 – 6	
Aquifer Vulnerability Classification		
Class	Points	Project area
High	3	1
Medium	2	
Low	1	

The recommended level of groundwater protection based on the Groundwater Quality Management Classification is calculated as follows: GQM Index = Aquifer System Management x Aquifer Vulnerability.

A Groundwater Quality Management Index of <1 was estimated for the study area from the ratings for the Aquifer System Management Classification (Table 6-2). According to this estimate, a limited to low-level groundwater protection is required for the aquifer within the study area.

Reasonable groundwater protection measures are recommended to ensure that no cumulative pollution affects the aquifer, even in the long term. DWS water quality management objectives are to protect human health and the environment. Therefore, the significance of this aquifer classification is that if any potential risk exists, measures must be taken to limit the risk to the environment, which in this case is the protection of the underlying aquifer.

TABLE 6-2: GQM INDEX FOR THE PROJECT AREA.

Index	Level of Protection	Project area
<1	Limited	<1
1 – 3	Low level	
3 – 6	Medium level	
6 – 10	High level	
>10	Strictly non-degradation	

6.4 GROUNDWATER RESOURCE RISK – SA MINE WATER ATLAS

6.4.1 Introduction

The Water Research Commission of South Africa (WRC) developed the South African Mine Water Atlas, which maps the un-mitigated threat of mining to water resources across South Africa. The Atlas essentially provides a broad and high-level decision context for the intersection of mining and water resources in South Africa (WRC, 2016).

The Mine Water Atlas is based primarily on a geo-environmental model approach, whereby it is accepted that mineral-deposit geology, along with geochemical and biogeochemical processes, are fundamental controls on the environmental behaviour of mineral deposits. Mineral-deposit geology fundamentally controls the environmental conditions that result from mining. The WRC implemented a geo-environmental model for environmental prediction that also considers the sub-ordinate control of mining method. The mineral deposit risk profiles were then considered against the receiving water resource's vulnerability. The geographic intersection of risk ratings from the geo-environmental model approach and vulnerability ratings of the receiving water resource creates the final mine water threat rating.

Mine water threat is determined using cumulative scores of risk and vulnerability in the geographic intersection of mineral regions (known as mineral provinces) and their respective receiving water resources. Ultimately the threat rating is built from two key aspects:

- Geo-environmental risk, consisting of:
  - Mineralogical risk: Mined materials and host rock geology and mineralogy.
  - Mining Activities: What characterises the dominant in situ mineral extraction process for any "mineral province", those activities typically occurring within the mine lease area (excluding downstream processing or manufacturing).
- Receiving Water Resource vulnerability: the surface and ground water resource, its vulnerability, assimilative capacity, and aspects of consequence for local water resources.

6.4.2 Mineral Risk

The mineral risk reflects the assessed risk of acid production and/or leaching of constituents of concern into the environment. The mineral risk is determined by assessing the following:

- Acid generating potential of a deposit
- Neutralising potential within the deposit geology
- Presence of toxic trace elements at low concentrations within the deposit geology
- Uncertainty – availability of geochemical data

The Gamsberg Zinc Mine and surrounding area falls within two mineral provinces, namely, The Northern Cape Surficial Deposits and the Northern Cape Base Metal provinces. Mineral provinces are mineralised zones that are broadly similar in terms of their host rock geology and mineralogy. Identified main elements of concern in these provinces are uranium and zinc. The mineral risk rating of the study area is high to very high (5/5 score).

6.4.3 Mine Activity Risk

The mine activity risk, for the specific mineral province, assesses the relative risks against the likely dominant mining methods associated with mineral extraction. The mine activity risk for the study area is low (2/5 score).

6.4.4 Groundwater Vulnerability

The groundwater vulnerability model was created using a composite overlay of different hydrogeological criteria, using raster modelling in a Geographic Information System (GIS) and a simple numerical summation algorithm, based on ratings to known associated hydrogeological attributes. Six different hydrogeological criteria are applied based on the groundwater information available nationally in South Africa, consisting of aquifer lithology, hydro-lithological yield, secondary geological structures, borehole yield classes and groundwater quality.

The overall vulnerability rating in the study area varies from ~1.0 to 2 (insignificant to low) due to low yielding, and intergranular and fractured rock aquifer types with brackish to saline background water quality.

6.4.5 Mine Water Threat

Mine water threat is the result of summing the risk and vulnerability ratings of the mineral risk profile, mining activity risk (as explained above in section 6.4.2 – section 6.4.4) and receiving water resource vulnerability:

- mineralogy of each mineral province – very high (5/5).
- the associated or likely mining activities in the same province – moderate low (2/5).
- the intersecting receiving water resource (groundwater vulnerability) – moderate low (2/5).

The mine water threat to groundwater for the study area is moderately low to moderate (9/15).

7 GEOCHEMICAL MODELLING

Mills Water assessed various options for disposal of Jarosite material and to calculate source terms for the preferred disposal option (Mills Water, 2020). This section will briefly summarise the Mills Water (2020) study and main findings. However, additional details, detailed methodology and the regulatory framework are given in the Options Assessment for Jarosite Disposal Gamsberg Zinc Mine report by Mills Water (2020), also attached in Appendix F.

7.1 CONCEPTUAL GEOCHEMICAL SITE MODEL

A conceptual model is required to understand the relationship between the physical and chemical processes occurring within the Jarofix SLF and is used as a basis for geochemical modelling.

Jarofix is dewatered to produce a cake with a moisture content of 50 to 55% which is trucked to the disposal site. The disposal site is currently planned to cover an area of 21 hectares, and to reach a height of 25 m over a life of 15 years. The disposal rate will be 290 000 tons per annum. ETP waste will be co-disposed with the Jarofix at a rate of 24 000 tons per annum. Effluent treatment plant (ETP) waste will be co-disposed with the Jarofix at a rate of 24 000 tons per annum.

Once on the SLF, the Jarofix will be exposed to rainfall and evaporation. The average annual rainfall at Aggeneys between 2004 and 2018 was 99.1 mm, falling mostly between January and April. Between 2015 and 2018 the annual rainfall was less than 50 mm. Monthly rainfall amounts are less than 10 mm more than 70% of the time. Between 2004 and 2018, monthly rainfall of over 50 mm was only recorded on six occasions.

Rain falling on the SLF can either:

- Run off the sides of the SLF as surface runoff.
- Infiltrate into the SLF, flow through the SLF and be captured by the line. This leachate will be directed to a sump from where it will be pumped to the ETP.
- Infiltrate into groundwater.

As the SLF will be lined with a Class A liner with a leachate collection system, the volume of seepage into groundwater is likely to be low and limited by the permeability of the liner. In addition, the presence of cement in the Jarofix is likely to cause it to solidify with time, greatly reducing the potential for infiltration into the SLF.

Surface run-off from the material or water that short-circuits through preferential pathways (e.g. cracks) will likely dissolve salts present on the surface of the disposed material, whereas rainwater that infiltrates the pore spaces in the disposed material will have more time to react, and concentrations in the leachate may reflect equilibrium with the minerals present in the SLF. For the purposes of modelling, only the long residence-time seepage is considered.

Within the SLF, the Jarosite will react with the cement to form Jarofix. Details of these reactions are given in section 7.2. Over time, the Jarofix will age, and become more consolidated, changing the flow conditions of the SLF. Different scenarios are modelled to consider consolidated and unconsolidated material.

The geochemical model used in this assessment is a transport model, which predicts the change in water quality as water flows through a system. The system is set-up as a one-dimensional column divided into 15 cells each 1.5 m long. This column represents a vertical cross-section through the centre of the SLF. The waste is initially saturated with the water that is present at the time of disposal. Water (either rainfall or added water) infiltrates the waste from the top and reacts with the components in the first cell for a specified length of time, and then flows into the next cell, where it reacts before flowing into the following cell etc. Leachate that emerges from the base of the column represents water that has infiltrated from the surface of the waste and undergone reactions with the full thickness of the waste pile. This does not represent all scenarios of interaction of water with the Jarofix, as some water may interact only with surface material and become surface run-off. This procedure is continued for a total amount of time as specified by the modeller, with inflow of water from the top of the column, and outflow of leachate from the bottom. The leachate quality at the base of the column is reported.

The chemistry of a leachate from the SLF will be controlled by four main variables which are discussed in detail below:

- The mineralogy of Jarofix
- The reactive portion of the materials within the SLF
- The flow rate through the SLF
- The composition of the water in the system

The conceptual models for operation and closure are shown in Figure 7-1.

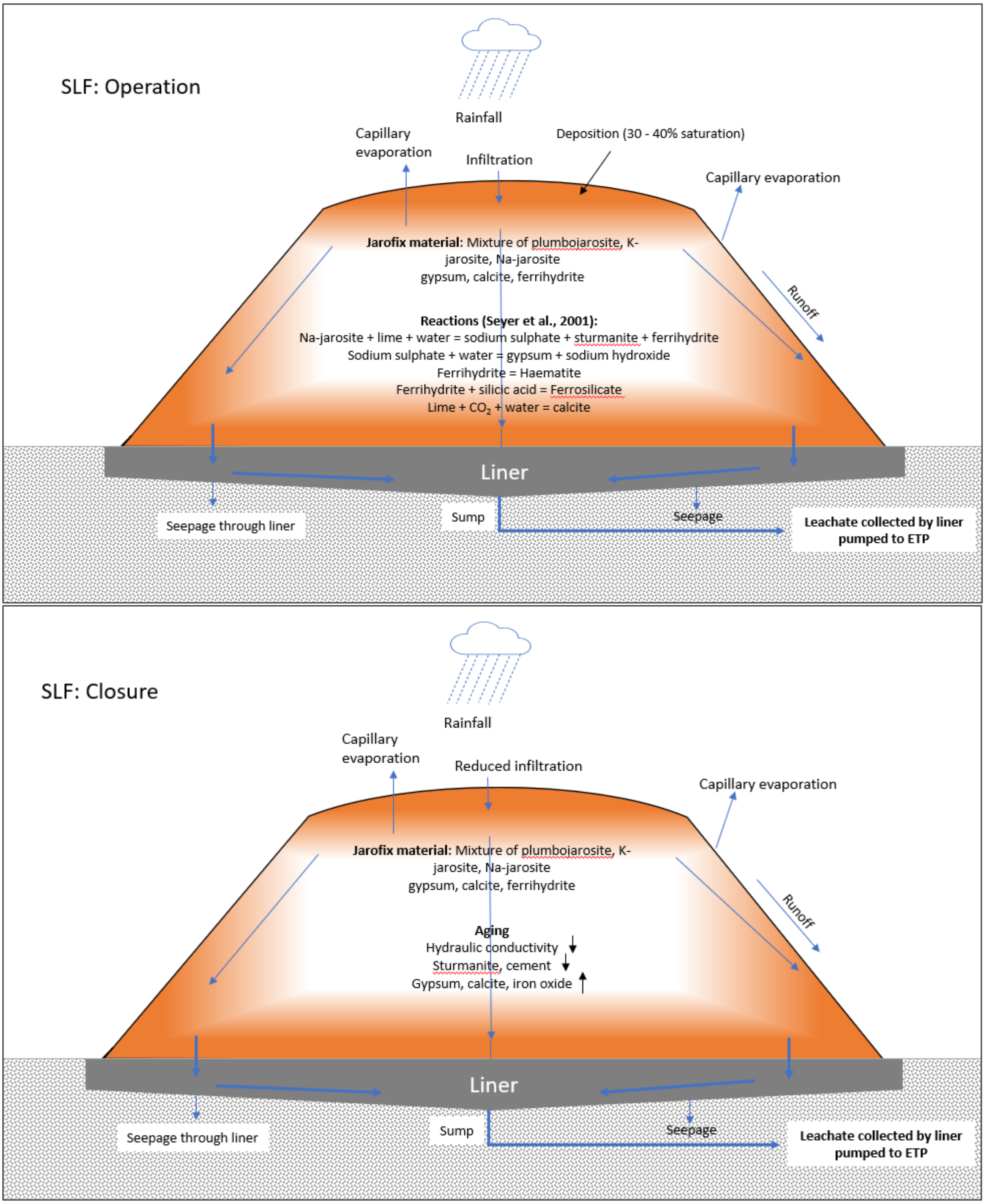


FIGURE 7-1: CONCEPTUAL GEOCHEMICAL SITE MODELS OF THE SLF - OPERATIONAL AND POST CLOSURE.

7.2 JAROFIX MINERALOGY

Jarofix is a chemically and physically stable material formed by mixing Jarosite precipitates with pre-set ratios of Portland cement (10%), hydrated lime (2%) and water. Jarosite reacts with the alkaline constituents of cement, forming stable phases which immobilise zinc and other metals. Jarofix is a preferred disposal option for Jarosite waste in India and Canada, and there have been investigations into its use as a construction material (Sinha, et al., 2019; Shijith, 2015; Seyer et al., 2001).

A Canadian study found that, after three months of curing, the mineralogy of Jarofix is dominated by sodium Jarosite and gypsum, with minor amounts of newly formed minerals forming a matrix which cements together the partially reacted sodium Jarosite. These minerals include Ca-Al-Fe silicate-sulphate-hydrate, sturmanite ($Ca_6Fe_2(SO_4)_3(OH)_{12}.nH_2O$), Ca-Al-Fe oxide, haematite (Fe_2O_3), Ca-Fe sulphate, quartz (SiO_2), ferrihydrite ($Fe(OH)_3$), lime ($Ca(OH)_2$), calcite ($CaCO_3$) and unreacted cement. Ferrihydrite may react further to form complex silicate species. Zinc is immobilised by being structurally incorporated into a Ca-Al-Fe silicate-sulphate-hydrate cement reaction product.

After 6 years, Jarofix is compact, dry, and harder. At this point there is no residual cement and no sturmanite, but greater amounts of gypsum, calcite, and cement reaction products (Ca-Al-Fe silicate-sulphate-hydrate, Ca-Fe sulphate). With time amorphous iron becomes more stable (Seyer et al., 2001).

Given the dominance of Jarosite in Jarofix, an understanding of this mineral is required for modelling purposes. Jarosite is a hydrated iron sulphate mineral. It is well known in ARD environments, where it can accommodate many other elements (Swayze et al., 2008). The standard formula for Jarosite is $KFe_3^{3+}(OH)_6(SO_4)_2$, however, other members of the Jarosite supergroup include:

- Natrojarosite - $NaFe_3^{3+}(OH)_6(SO_4)_2$
- Hydroniumjarosite - $(H_3O)Fe_3^{3+}(OH)_6(SO_4)_2$
- Plumbojarosite - $PbFe_6^{3+}(OH)_{12}(SO_4)_4$
- Alunite - $KAl_3^{3+}(OH)_6(SO_4)_2$

Jarosite is relatively insoluble in water, however, dissolution of Jarosite can release acidity (Blowes et al., 2003; Swayze et al., 2008). According to Sinha et al. (2013), Jarosite in Jarofix takes the form of plumboJarosite. High levels of lead were measured in the Jarofix in this study; therefore, this is likely to be the case.

Based on normative calculations of mineralogy using the total concentrations from this study, the Jarosite in the waste is assumed to consist of a mixture of potassium-Jarosite (16%), sodium-Jarosite (60%) and plumboJarosite (24%). The Jarosite is a complex solid solution containing potassium, sodium, and lead, as well as a range of other trace elements. In the absence of site-specific data, the solubility products used in the model for sodium and potassium Jarosite are the defaults from the minteq.v4 database. Information provided by Forray et al. (2010) suggests that plumbojarosite has a lower solubility product than sodium and potassium Jarosite, and the solubility product from this reference is used. It should be noted that Jarosite solubility is strongly dependent on chemical composition and grain size.

Although not directly identified by XRD, the reddish colour of the Jarofix suggests the presence of ferrihydrite, an amorphous iron hydroxide mineral. Iron hydroxides have a high capacity for adsorbing trace elements from solution. Trace element adsorption onto precipitating iron hydroxides is allowed in the model. This is often the main control on trace element concentrations at neutral pH. Trace elements generally do not form minerals of their own, but often substitute for more common elements within the crystal lattice of other minerals. Trace elements measured in the distilled water leach are likely to have been released from dissolving minerals such as gypsum or Jarosite. Trace elements in solution can adsorb to precipitating iron hydroxide minerals.

Geochemical modelling databases do not incorporate many of the reaction products that form through the reaction of Jarosite and cement, therefore the approach taken was to include the major minerals (Jarosite, gypsum, calcite) as well as known cement reaction products (e.g. ettringite) and potential sinks for sodium, lead, barium, fluoride and sulphate (e.g. mirabilite, $Pb_4(OH)_6SO_4$, fluorite, barite).

The chemistry of leachate is determined by the minerals present and by whether the water reaches equilibrium with the minerals. Calculation of saturation indices for the distilled water leach tests shows that the leach test solutions are in equilibrium with gypsum. Gypsum is therefore used as the equilibrium control on sulphate and calcium concentrations in the model. The degree of saturation of each of the other minerals is controlled by adjusting the saturation indices to be the same as those in the 1:4 distilled water leach test.

7.3 REACTIVE PORTION OF THE MATERIALS IN THE SLF

PHREEQC models are normalised to 1 L of water. Therefore, the amount of mineral reactant used in the model must be scaled to the amount of reactant that would react with 1 L of water. This requires assumptions about the porosity of the rock, the surface area of the minerals and the proportion of the various minerals within the rock that are available to react with water. The finer the grain size of the material, the more exposed surfaces there will be for reaction. It is generally the <2 mm particle size grains that affect drainage chemistry (Price, 2009).

During operation, the waste is assumed to have 30% - 40% moisture content, and the water:rock ratio is therefore controlled by the porosity and the surface area. Post closure, the water:rock ratio is likely to be controlled by the field capacity i.e. the percentage saturation level at which water can drain through the material. Typical values for field capacity in a waste facility are 8-10% (Price, 2009).

A porosity of 30% has been assumed for unconsolidated material based on data for unconsolidated sand and gravel provided by Manger (1963). This means that 1 L of water will be in contact with approximately 3 kg of rock. However, studies of Jarofix have shown that only 30% of the original natrojarosite present reacts (Seyer et al., 2001). A percentage reactivity of 30% is assumed, therefore 1 L of water is assumed to react with 1 kg of rock. Consolidated Jarofix is noted to be very porous (Nova and Arroyo, 2005), therefore a porosity of 20% is assumed. Note that these are arbitrary assumptions but are aimed at providing a conservative estimate of the amount of the material available for reaction. These mineral relationships can only be fully understood by undertaking a mineralogical study. In the absence of a mineralogical study, the geochemical model can be calibrated over time by using field studies and groundwater quality data.

7.4 FLOW RATE THROUGH THE SLF

The rate at which water flows through the materials determines the rate at which new reactants are brought into the system, and the rate at which reaction products are flushed from the system. Where no flow occurs, or where flow is slower than the rate of reaction, reaction products will build up in solution, and the system will reach an equilibrium.

During operation, the waste dump is likely to be saturated due to ongoing deposition of Jarofix with a 30-40% moisture content. The rate of water flow will be governed by the hydraulic properties of the material and the design of the waste facility. Hydraulic conductivity in tailings has been measured at between 1×10^{-4} m/s and 1×10^{-8} m/s, with vertical hydraulic conductivity an order of magnitude lower than horizontal hydraulic conductivity (Price, 2009). Physically, Jarofix hardens with time to a consistency like stiff clay, with hydraulic conductivity similar to silt (Demers and Haile, 2003). The amount of rainfall during operation is unlikely to affect water quality as the volume of rainfall relative to the volume of water deposited in the tailings is likely to be low.

Post-closure, the flow rate is dependent on the amount of rainfall and the degree to which the rainfall infiltrates. For uncovered, unconsolidated waste material, it is assumed that infiltration will be high due to the unevenness of the material surface and the high porosity. If material is consolidated by cement, the infiltration rate will be far lower and most water will run-off.

Four flow-rate scenarios are considered as follows:

- Unconsolidated during operation.
- Consolidated during operation.
- Unconsolidated post-closure.
- Consolidated post-closure.

The input parameters for each of these scenarios are summarised in Figure 7-1.

Please take note that the seepage rates for various capping options of the SLF were not evaluated as part of this study. Additional laboratory analyses and unsaturated flow rate modelling is required to quantify these seepage rates.

TABLE 7-1: INPUT PARAMETERS FOR GEOCHEMICAL MODELLING.

	Units	Operational unconsolidated	Operational consolidated	Closure unconsolidated	Closure consolidated
Hydraulic conductivity	m/s	1×10^{-7}	1×10^{-10}	1×10^{-7}	1×10^{-10}
Porosity	-	0.3	0.2	0.3	0.2
Infiltration	% MAP	50	5	50	5
	m/a	0.05	0.005	0.05	0.005
Flow rate	m/a	11	0.015	0.15	0.004
	m/d	3×10^{-2}	4×10^{-5}	4×10^{-4}	1×10^{-5}
Years/ cell (1.5m)	a	0.14	100	10	410
Reactive portion	%	30	20	30	20
Initial solution		Water in equilibrium with Jarofix at 30% saturation	Water in equilibrium with Jarofix at 30% saturation	Water in equilibrium with Jarofix at 10% saturation	Water in equilibrium with Jarofix at 10% saturation
Leaching solutions		Water in equilibrium with Jarofix	Water in equilibrium with Jarofix	Rain	Rain

7.5 COMPOSITION OF WATER IN THE SYSTEM

The quality of the water in the system can affect the rate and type of reactions occurring within the system.

Water within the SLF during operation will be in equilibrium with the waste material at a saturation level of 30%. This initial water composition is calculated from the 1:4 distilled water leachate results concentrated by a factor of 13.3, and then allowed to equilibrate with selected minerals (calcite, gypsum, ferrihydrite, fluorite, barite, plumbojarosite, K-Jarosite, Na-Jarosite, $Pb_4(OH)_6SO_4$).

Post-closure, when no further water is being added in the waste material, and evaporation and drying of the material has progressed, water within the SLF is assumed to be in equilibrium with the waste material at a saturation level of 10%. This water composition is calculated from the 1:4 distilled water leachate results concentrated by a factor of 40, and then allowed to equilibrate with selected minerals (calcite, gypsum, ferrihydrite, fluorite, barite, plumbojarosite, K-Jarosite, Na-Jarosite, $Pb_4(OH)_6SO_4$). In addition, rainwater is assumed to infiltrate the waste material from the surface and percolate through the waste material. The rainwater is assumed to be pure water equilibrated with oxygen and carbon dioxide at atmospheric partial pressures, resulting in an inflow solution with a pH of approximately 5.7.

7.6 GEOCHEMICAL MODEL RESULTS

7.6.1 Operational Phase

For the unconsolidated scenario, where water flow rates are relatively high, the pH is alkaline and sulphate concentrations increase to more than 18 000 mg/L. Arsenic and antimony are plotted because they exceeded the LCT0 values in the waste assessment. Lead and zinc are included due to their elevated total concentrations. In the predicted leachate from the SLF the concentrations of lead, zinc and arsenic are low (less than LCT0 value) until after about 2 years in the unconsolidated material when lead concentrations increase to between the LCT0 and LCT1 threshold values. The change in concentrations of lead and sulphate after 2 years occurs because the plumbojarosite included in the model is completely dissolved and lead solubility is then controlled by a more soluble lead hydroxysulphate mineral. Antimony concentrations exceed the LCT3 value (8 mg/L) because there does not appear to be a mineral control on antimony solubility, and it does not sorb strongly to ferrihydrite. Antimony should be included in monitoring programme.

For the consolidated scenario, the concentrations remain stable over the operational period. Concentrations of most analytes are lower than the unconsolidated scenario, and arsenic, lead and zinc concentrations are well below leachate thresholds. Antimony concentrations are similar to the unconsolidated scenario. It must be noted that the volume of water that will leach under the consolidated scenario is lower than the unconsolidated scenario, therefore the overall contaminant load is less (Figure 7-2).

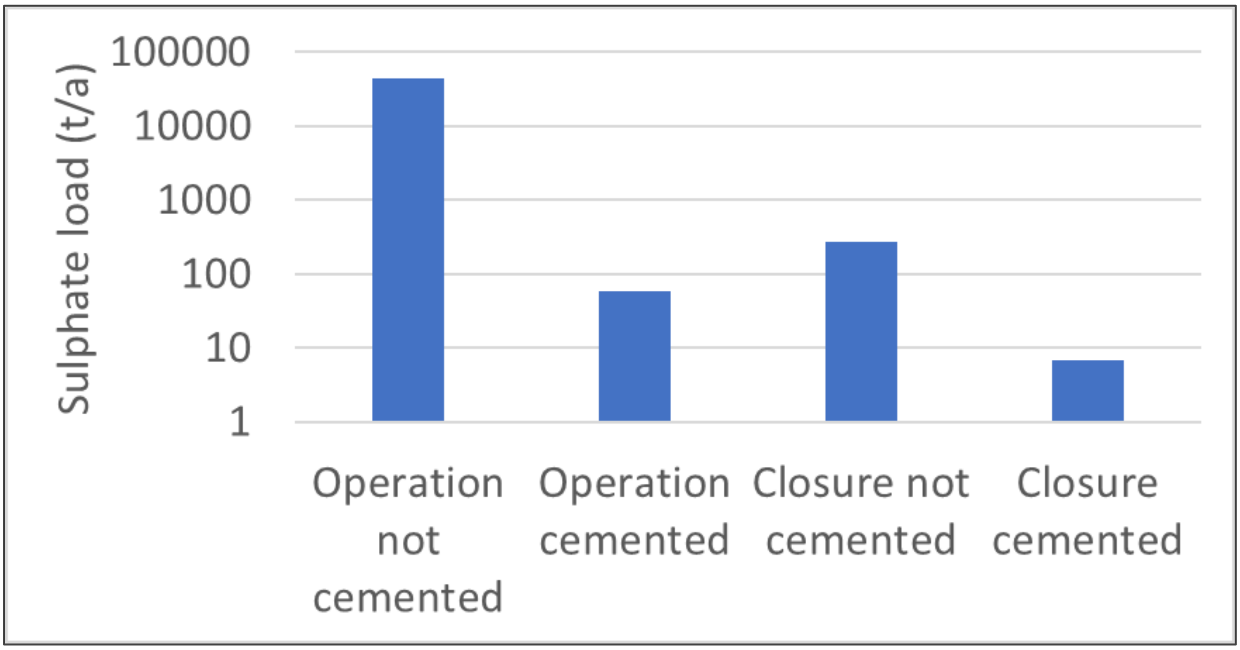


FIGURE 7-2: ESTIMATED ANNUAL SULPHATE LOADS FOR EACH OF THE MODELLED SCENARIOS.

Because the Jarofix will be deposited in an unconsolidated form and will gradually consolidate, at any stage during the growth of the SLF there is likely to be a mixture of unconsolidated and consolidated material on the SLF, therefore the actual leachate quality is likely to be somewhere between the quality of the leachate from the unconsolidated and the consolidated material. Suggested source terms during the operational phase are given in Table 7-2.

TABLE 7-2: SOURCE TERM CONCENTRATIONS FOR OPERATIONAL PHASE.

Parameter	Operational source term concentration
pH	10.0
Sulphate (mg/L)	19 000
Sodium (mg/L)	7 000
Lead (mg/L)	0.6
Antimony (mg/L)	10.0

Selected modelling results for unconsolidated and consolidated material during the operational phase are shown in Figure 7-3.

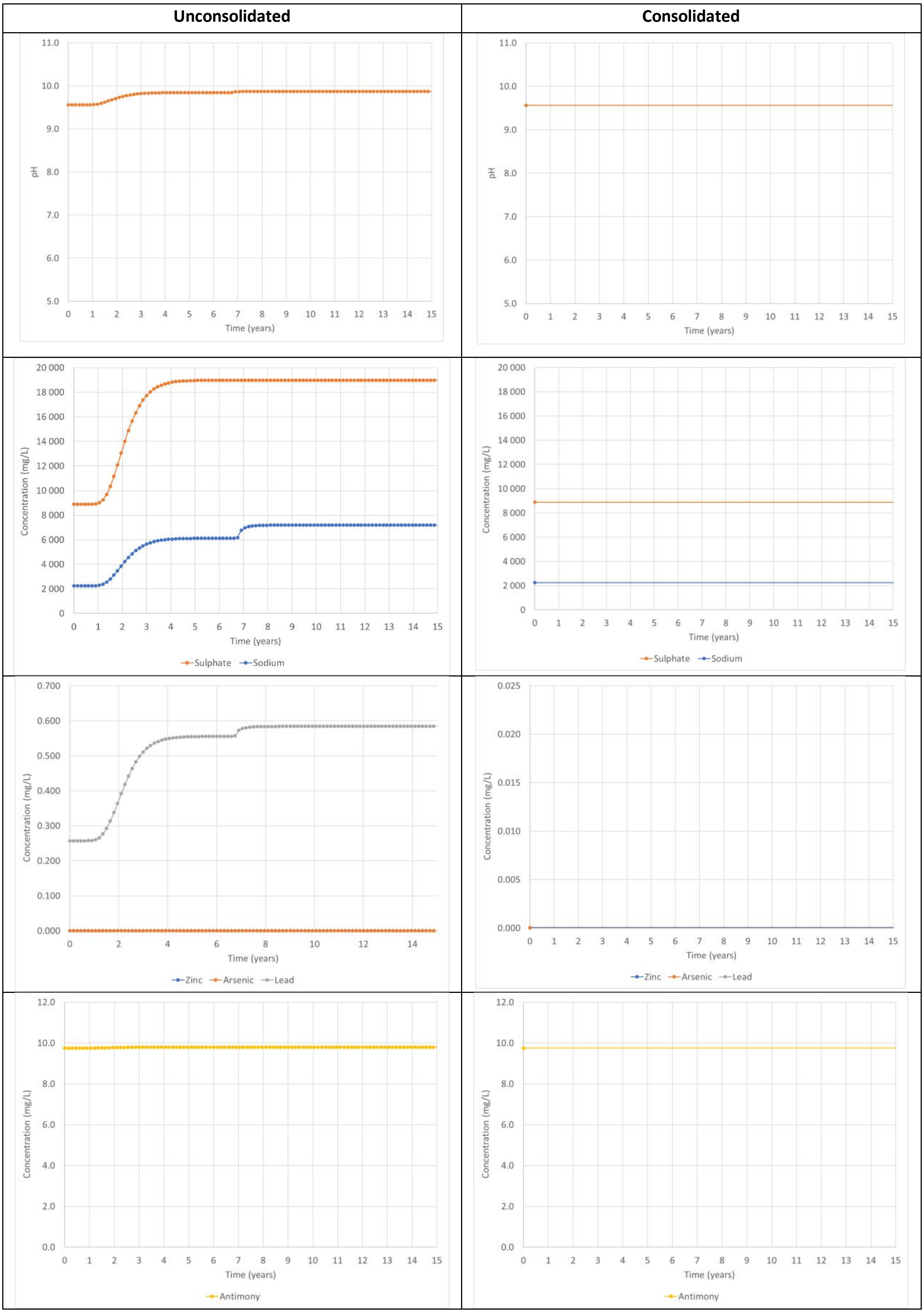


FIGURE 7-3: PREDICTED LEACHATE QUALITY DURING OPERATIONAL PHASE.

7.6.2 Closure Phase

There are two differences between the geochemical model for closure and post-closure:

- The degree of saturation of the material is assumed to be far lower, with the difference between the amount of water at saturation (assumed 30%) and on consolidation (assumed 10%) assumed to be lost by evaporation, with negligible seepage.
- The SLF is now flushed by rainwater only, with no water being added in new material that is deposited.

The suggested single concentration source terms are given in Table 7-3 and predicted post-closure leachate quality results are shown in Figure 7-4.

Flushing by rainwater will gradually remove salts within the waste material, resulting in a reduction in leachate concentrations. However, due to the low volumes of rainfall experienced at the site, this is likely to occur over an extended period, with no observed difference in leachate concentration for hundreds to thousands of years from consolidated material. The estimated annual sulphate loads for the consolidated and unconsolidated scenarios post-closure are shown in Figure 7-2. The sulphate load is higher for the unconsolidated scenario due to the lower assumed seepage rates.

TABLE 7-3: SOURCE TERM CONCENTRATIONS FOR CLOSURE PHASE.

Parameter	Operational source term concentration
pH	9.6
Sulphate (mg/L)	9 000
Sodium (mg/L)	2 000
Lead (mg/L)	0.3
Antimony (mg/L)	10.0

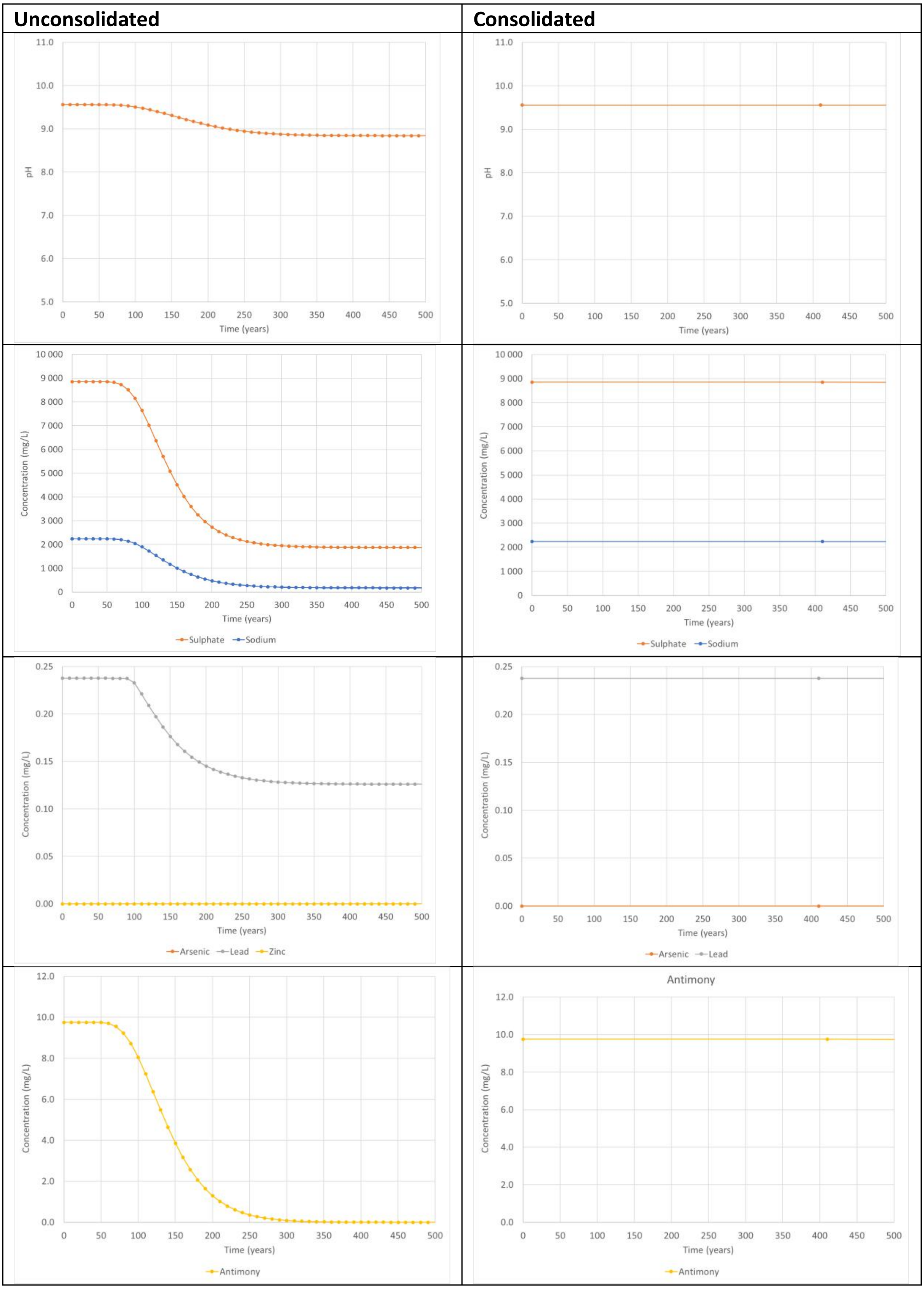


FIGURE 7-4: PREDICTED LEACHATE QUALITY DURING CLOSURE PHASE.

7.7 GEOCHEMICAL ASSESSMENT SUMMARY

The results suggest that the salt concentrations (predominantly sodium and sulphate) in the leachate will be high, but that generally metal concentrations will be low, with the exception of antimony. Initially the volumes of leachate are likely to be controlled by the volumes of water in the Jarofix that is placed on the SLF, but as time progresses and the Jarofix hardens, the volumes of leachate should decrease and the overall load of contaminants in seepage will decrease. The use of a Class A liner which captures seepage for treatment will aid in limiting the risk of groundwater impact during operation, however seepage which may leach through the liner is likely to have high sulphate concentrations. Post-closure, assuming the material hardens and the SLF is covered with a low permeability cap to encourage run-off and prevent infiltration, the risk of groundwater impact will be less but should be assessed through hydrogeological modelling.

Groundwater monitoring up and down-gradient of the SLF should be undertaken to ensure there is no groundwater impact, including sulphate and metal concentrations (especially arsenic, antimony, lead, zinc, and cadmium). Cladding of the SLF sides with unreactive material during operation and capping with compacted, unreactive material post closure should reduce the potential for rainfall interaction with Jarofix.

Although the results indicate that disposal of Jarofix onto the SLF would have minimal geochemical risk, improved confidence in the findings can be obtained by:

- Analysis of Jarofix produced in the local plant as soon as this becomes available.
- Undertaking a detailed geochemical analysis of at least five representative Jarofix disposal samples, including the following static tests:
    - Chemical composition (whole sample and elemental analysis)
    - mineralogical analysis of the material to understand changes in composition as the Jarofix ages
    - acid-base accounting (ABA) and net acid generation (NAG)
    - water extraction tests
- Conducting kinetic leach tests of at least two representative Jarofix disposal samples to confirm how the leachate quality will change with time.
- Update the geochemical model to determine any changes in source term concentrations.
- Undertaking a detailed mineralogical analysis of the material to understand changes in composition as the Jarofix ages.

8 GROUNDWATER MODELLING

8.1 MODEL SOFTWARE CHOICE

The FEFLOW (Finite Element subsurface FLOW and transport system v 7.3.0.18422) modelling code developed by DHI-WASY (Diersch, 2015) was used for the Gamsberg groundwater model. This code is an industry standard groundwater modelling tool widely used in mining and environmental applications. FEFLOW handles a broad variety of physical processes for subsurface flow and transport modelling and simulates groundwater level behaviour indirectly by means of a governing equation that represents the Darcy groundwater flow processes that occur in a groundwater system.

8.1.1 Governing Equation

In the Finite Element (FE) method, the problem domain is subdivided into elements that are defined by nodes. The dependent variable (e.g., head) is defined as a continuous solution within elements in contrast to the Finite Difference (FD) method where head is defined only at the nodes and is considered piecewise constant between nodes. The FE solution is piecewise continuous, as individual elements are joined along edges. The governing flow equation for three-dimensional saturated flow in saturated porous media is:

$$\frac{\partial}{\partial_x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial_y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial_z}\left(K_{zz}\frac{\partial h}{\partial x}\right)\pm W=S_s\frac{\partial h}{\partial t} \qquad \text{Equation 1}$$

where:

Kxx, Kyy, and Kzz are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity (L/T);

- h is the potentiometric head (L).
- W is a volumetric flux per unit volume representing sources and/or sinks of water, with:
    - W < 0.0 for flow out of.
    - W > 0.0 for flow in the groundwater system
- Ss is the specific storage of the porous material (L-1).
- t is time (T).

8.1.2 Solver

FEFLOW offers multiple iterative and two direct equation solvers. By default, FEFLOW uses iterative solvers because they are suited for problems of arbitrary size. Separate iterative solver types can be selected for the symmetric (flow) and unsymmetric (transport) equation systems.

The Gamsberg model solver options were set to preconditioned conjugate-gradient (PCG) solver for flow and a BICGSTABP-type solver for transport. PCG shows fast convergence and have proven efficient for typical problems over a wide range of applications in subsurface flow and transport problems (Diersch, 2015).

8.2 MODEL SET-UP AND BOUNDARIES

Boundary conditions express the way in which the considered domain interacts with its environment. In other words, they express the conditions of known water flux, or known variables, such as the hydraulic head. Different boundary conditions result in different solutions, hence the importance of stating the correct boundary conditions. The boundary conditions are defined at nodes along the boundary or within the model domain. There are four main boundary conditions available in FEFLOW.

- Fixed Head BCs - this boundary prescribes a head in the boundary node.
- The head can be fixed at a prescribed value or assigned to a time series file.
- Flux BCs - this boundary condition describes a constant or time varying flux across the outer boundary of the model. A time varying flux can be specified as a mean step-accumulated discharge (e.g. m^3/d). A positive value implies an inflow to the model cells.

- Well BCs - this boundary condition is applied to nodes and represents a time-constant or time-varying local injection or abstraction of water at a single node or at a group of nodes.
- Zero flux - This is a special flux no-flow boundary, which is the default.

The model boundaries were selected far enough from the area of investigation to not influence the numerical model behaviour in an artificial manner.

No flow boundaries (zero flux) were used on the southern and western part of the model domain at local watershed boundaries. Local streams were represented by hydraulic head boundary conditions with a maximum flow rate constrained to zero. The groundwater level data (section 5.5) indicated that the groundwater flow is radially to the northeast and southwest away from the Gamsberg Inselberg. Groundwater outflow boundary in the northeast was modelled using the hydraulic head (Dirichlet) boundary condition with variable head based on average groundwater levels of approximately 30 mbgl. Groundwater outflow boundary in the southwest was modelled using the hydraulic head (Dirichlet) boundary condition with a variable hydraulic head based on average groundwater levels of approximately 50 mbgl.

Static groundwater levels measured by GHT during the April 2019 monitoring event were used for the model calibration.

The triangular mesh algorithm (Shewchuk, 2005) was selected for finite element meshing owing to its fast speed and its capability to accommodate polygons, lines, and points. The mesh quality was tested by Delaunay criteria for ensuring maximum model stability.

The model boundaries, model mesh and calibration points used in the model are shown in Figure 8-1.

8.3 GROUNDWATER ELEVATION AND GRADIENT

The average groundwater levels measured during the Golder (2007), SRK (2010), and ERM (2013a) hydrocensus investigations were 31.7 mbgl, 28.1 mbgl, and 29.4 mbgl, respectively. The groundwater levels ranged between artesian conditions and 178.8 mbgl.

Regional monitoring boreholes had an average groundwater level of 30.8 mbgl and ranged between 8.6 mbgl and 78.9 mbgl for the April 2019 monitoring round. The mine monitoring boreholes had an average groundwater level of 30.6 mbgl and ranged between 11.6 mbgl and 52.3 mbgl for the April 2019 monitoring round.

ERM (2013a) stated that topography was clearly a dominant control on the groundwater levels and flow direction. Groundwater flow is radially to the northeast and southwest away from the Gamsberg Inselberg. In general, groundwater flows with higher hydraulic gradient around the inselberg and with significantly lower gradient in the plains. Groundwater elevations are discussed in more detail in section 5.5.

8.4 GEOMETRIC STRUCTURE OF THE MODEL

8.4.1 Vertical and Lateral Discretisation

Along the vertical direction, the steady state groundwater model was structured with three aquifer units and five numerical model layers of variable thicknesses as given in Table 8-1. The layer positions were selected based on weathering depth, groundwater levels, and hydrogeological units to allow for accurate horizontal and vertical groundwater flow in the model.

TABLE 8-1: VERTICAL MODEL DISCRETISATION.

Aquifer unit	Layer	Thickness (m)	Depth (mbgl)	Aquifer Unit
1	1	15	15	Weathered zone
	2	15	30	Weathered zone/ Average GW level
2	3	20	50	Fractured aquifer
	4	20	70	Fractured aquifer
3	5	130	200	Solid aquifer

8.4.2 Hydrogeological unit discretisation

The hydrogeological units in the model were based on the available geological information. Model layer 1 and layer 2 represented the weathered aquifer covering the entire modelling area.

For model layers 2-4 available regional geology data were used to discretise the hydrogeological units into the model. Model layer 5 was discretised as the primarily un-weathered and unfractured deep aquifer. Please refer to Figure 8-2 and Figure 8-3 for top view of layer 1 and model cross sections for the Gamsberg model area.

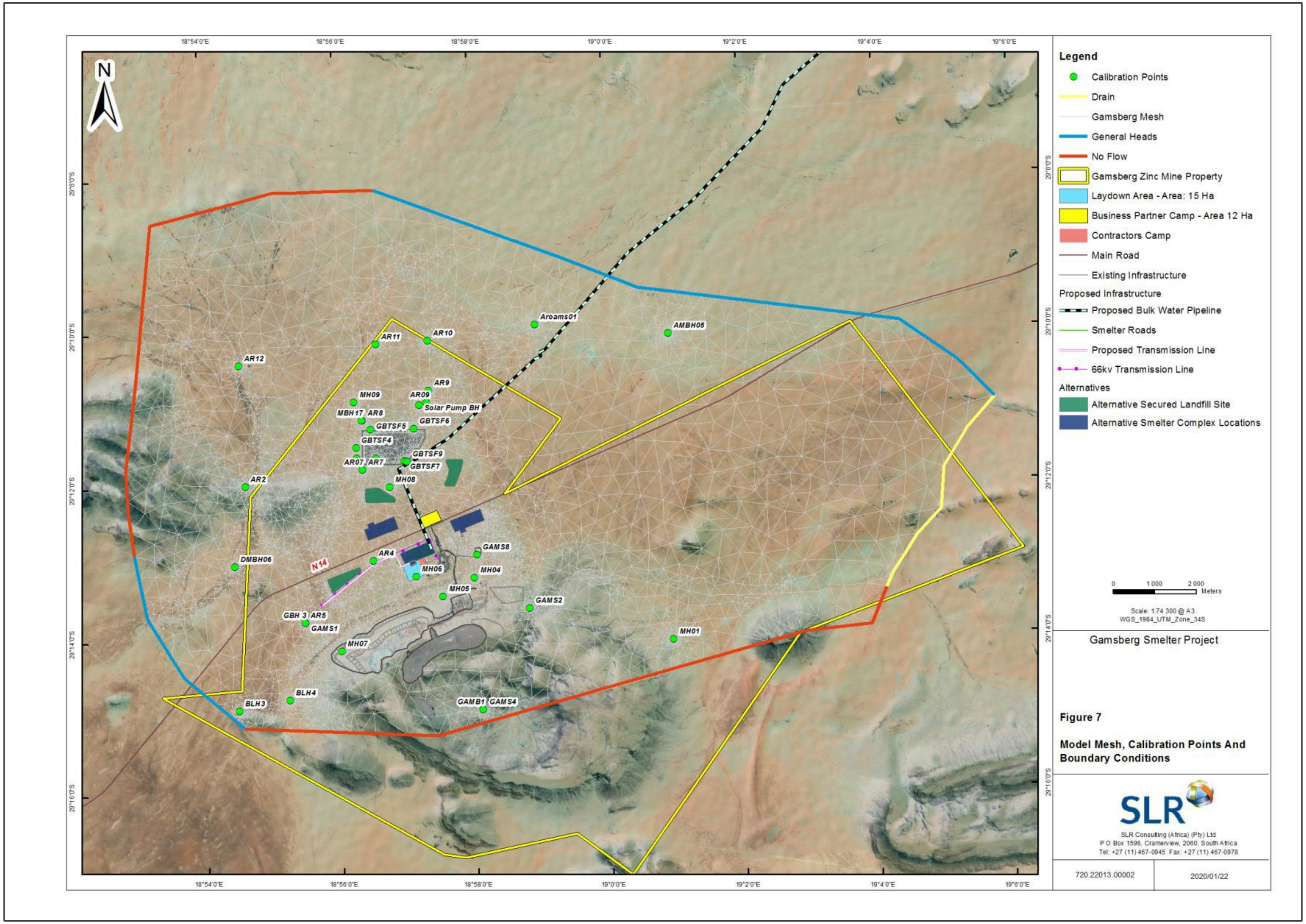


FIGURE 8-1: GAMSBERG MODEL MESH, CALIBRATION POINTS AND BOUNDARY CONDITIONS.

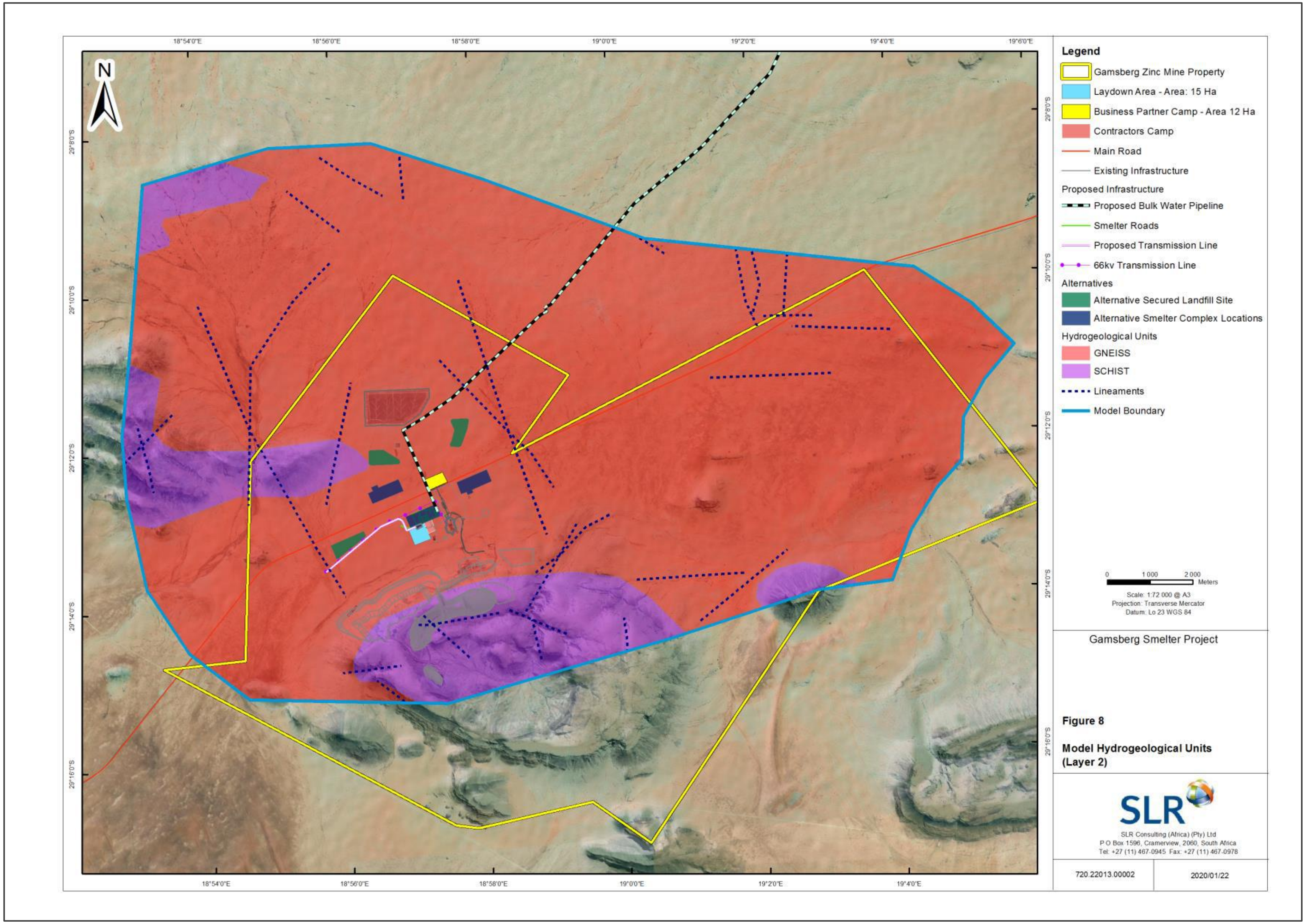


FIGURE 8-2: GAMSBERG MODEL HYDROGEOLOGICAL UNITS (LAYER 1-4).

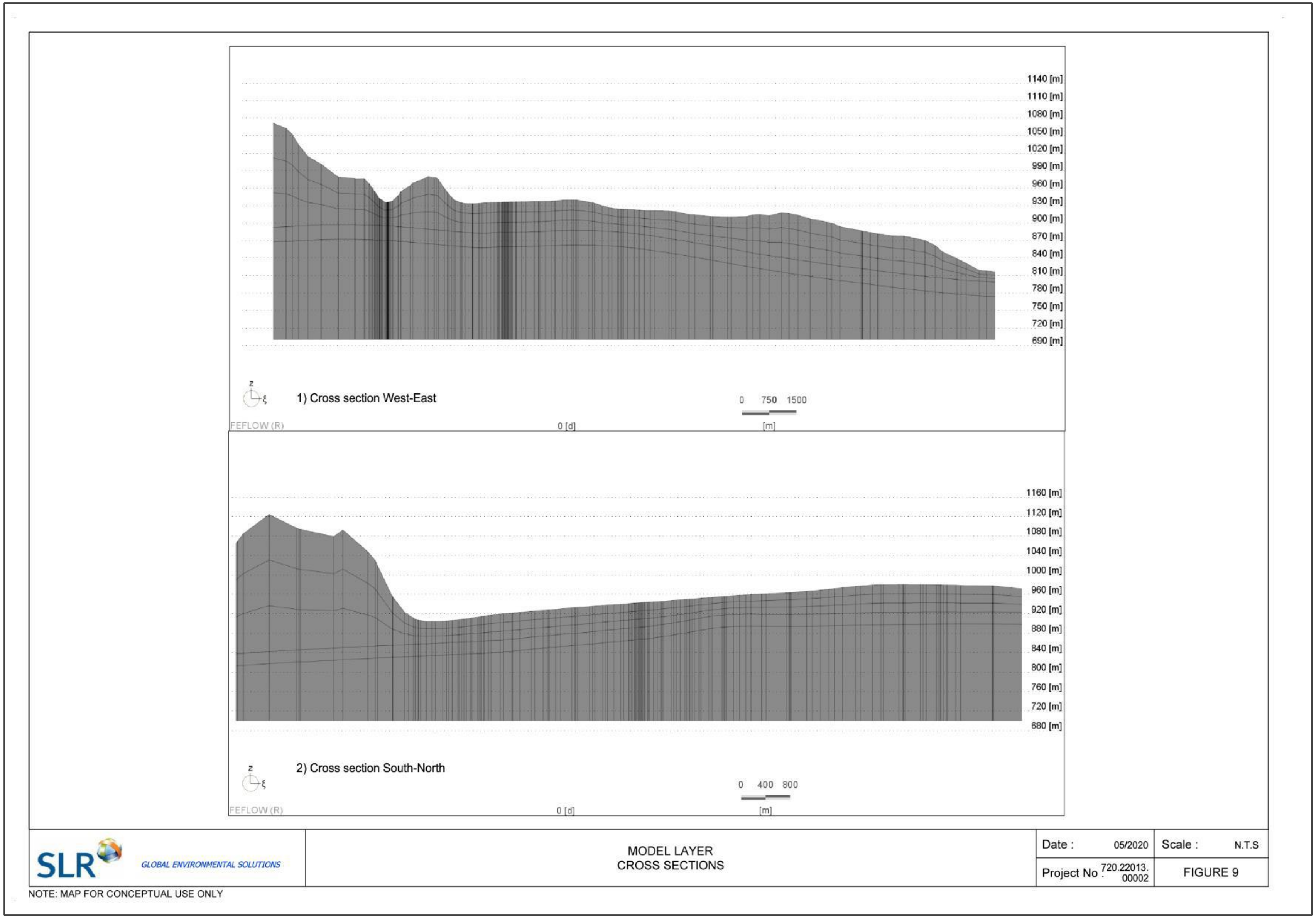


FIGURE 8-3: GAMSBERG MODEL HYDROGEOLOGICAL UNITS - CROSS SECTIONS.

8.5 GROUNDWATER SOURCE AND SINKS

8.5.1 Recharge

Previous Studies

ERM (2013a) noted recharge is generally very low and that recharge is relatively higher on the inselberg compared to the plains. The higher recharge on the inselberg is assumed caused by the increased infiltration capacity of the fractured quartzite, with higher permeability and uneven surface reducing the effective evaporation, and due to the potentially higher MAP on the inselberg. Groundwater levels are in general shallower within the Gamsberg Inselberg than in the surrounding plains, probably due to the higher rainfall/recharge on this feature. ERM (2013a) noted that there was effectively no recharge on the plains.

Perched aquifers were identified by Golder (2007) in the Kloof on the Gamsberg Inselberg which are recharged rapidly by precipitation. It was inferred that recharge only takes place in years of exceptionally high precipitation.

ERM (2013a) provided a summary of estimates for recharge on the Gamsberg, which ranged between 1 mm/a and 2.9 mm/a (1.2 and 2.2% of MAP). The mean annual effective recharge for the study area was estimated by SRK (2010) to be approximately 0.85% of MAP.

Chloride Mass Balance (CMB) Method

There are a wide range of methods estimating recharge to aquifers. One of these methods is the Chloride Balance Method (CMB) which is frequently used in recharge estimations. Beekman et al. (2000) outlined a method to estimate the recharge to groundwater from rainfall using chloride measurements for rainwater and groundwater.

As chloride is a conservative ion, the chloride concentration increases when water is concentrated through evaporation. Knowing the initial chloride concentration of rainwater, the measured chloride in groundwater and making assumptions on dry chloride deposition, one can calculate the percentage of recharge. Since no other sources of chloride in the groundwater other than from the rainfall are expected on-site, the chloride method is considered reliable for the study area. The equation for the chloride method is as follows:

$$R = \frac{(P \times Cl_r + D)}{Cl_{gw}}$$ Equation 2

Where:

R = groundwater recharge (mm/a)

P = mean annual precipitation (mm/a)

Cl_r = chloride concentration in rain (mg/l)

D = dry chloride deposition (mg/m²/a)

Cl_{gw} = chloride concentration in groundwater (mg/l) (harmonic mean is taken if many boreholes are available).

The chloride concentration in rain was estimated from Bredenkamp (1995) to be 0.25 mg/L. The total chloride deposition at surface was taken at 10% of the chloride concentration of groundwater. Chloride concentrations in groundwater ranged between 9.8 mg/L and 18 000 mg/L for the Gamsberg monitoring boreholes with a harmonic mean of 280.07 mg/L. The estimated recharge obtained for the site was estimated to be very low with an average of 0.1 mm/a (~0.1 % of MAP). The low calculated recharge value is consistent with inferences made by SRK (2010) that recharge only takes place in years of exceptionally high precipitation. Furthermore, rainfall data from the Aggeneys Weather Station indicated that generally MAP has been consistently decreasing, with an average MAP of 35.95 mm/a between 2015 – 2018 (section 2.1).

Literature

Vegter (2006) – Hydrogeology of Groundwater Region 26 Bushmanland

Vegter (2006) discussed factors determining groundwater recharge under reigning Bushmanland climatic and geological conditions and concluded that in contrast to areas with thick sand cover, recharge is favoured by shallow sandy soil, calcrete and exposures of fractured rock, due to:

- A thick sand-cover retains and prevents rainwater from entering the underlying formation and thus allows its complete dissipation through evapotranspiration.
- Runoff is promoted by shallow sandy soil, calcrete and rock exposure and accumulates in laagtes and rivers.

Vegter (2006) noted from previous studies in the region that tritium determinations of moisture in the surficial deposit profile at the Vaalputs radioactive disposal site indicated that “young” recharge water only percolates down to about three metres. After 128 mm of rain on four days in December 1985, the infiltration only reached 2.5 m to 3 m, indicating limited infiltration and recharge in the Bushmanland region.

Vegter (2006) noted the national recharge map compiled by DWS as part of the Groundwater Resources Assessment indicated that the mean recharge over Bushmanland varies from west to east from less than 1 mm/a to 5 mm/a.

Vegter (2006) indicated from recharge estimations in the Kenhardt region that during a year of average rainfall (156 mm) recharge in the catchment (about 220 km^2) amounts to 40 000 m^3 i.e. equivalent to about 0.6 mm over the catchment’s area. Furthermore, Vegter (2006) stated that a fixed relationship between MAP and recharge does not exist as recharge is controlled amongst others by the amount, intensity, duration and temporal distribution of individual storms especially whether and to what extent runoff is produced or not.

Summary

Recharge is generally very low in the Gamsberg area, with relatively higher recharge occurring on the Gamsberg inselberg compared to the surrounding plains where practically no recharge occurs and is supported by the findings of SRK (2010) and ERM (2013a).

ERM (2013a) provided a summary of estimates for recharge on the Gamsberg, which ranged between 1 mm/a and 2.9 mm/a (1.2 and 2.2% of MAP). The mean annual effective recharge for the study area was estimated by SRK (2010) to be approximately 0.85% of MAP. The estimated recharge obtained for the site through the CMB method was estimated to be very low. The low calculated recharge value is consistent with inferences made by SRK (2010) that recharge only takes place in years of exceptionally high precipitation.

8.5.2 Seepage from SLF

The total seepage of water moving through the SLF was estimated in section 7.4, and total seepage through the SLF ranged between 50% and 5% of MAP. A portion of this seepage will enter the subsurface as increased groundwater recharge as the base of the SLF. This increased groundwater recharge was estimated to range between 10% and 1% of MAP during the operational phase and between 5.0% and 0.5% of MAP during the closure phase, approximately a fifth of the total seepage moving through the SLF. Previous assumed recharge rates for waste facilities at Gamsberg Mine were up to 20% of MAP (ERM, 2013a).

The saturated numerical groundwater flow and transport model cannot quantify the seepage rate from the SLF which will be under unsaturated conditions. Furthermore, the reduction in seepage due to the aging of the Jarofix and installation of a cap on the SLF cannot be quantified by a saturated numerical groundwater flow and transport model.

As the SLF will be constructed with a Class A liner, the volume of seepage into groundwater is likely to be very low. In addition, the presence of cement in the Jarofix is likely to cause it to solidify with time, significantly reducing the potential for infiltration into the SLF.

The client has indicated that the Class A liner will conform to the norms and standards as per the DWS standard. However, for modelling purposes the final liner specifications, parameters, and design have not been received from the client. The rate of water flow and total seepage will predominantly be governed by the hydraulic properties of the material, the design of the waste facility, and the head of leachate in the SLF. Seepage exiting the SLF and entering the sub-surface as increased groundwater recharge, as proposed by Giroud *et al*. (1992), will depend on:

- Quality of contact between geosynthetic liner and clay/ mineral liner
- Vertical hydraulic gradient
- Head of leachate
- Area of any defects
- Hydraulic conductivity of the liner
- Frequency of defects
- Area of composite liner on base of facility

Calculations made for the operational and closure phase seepage through the liner were made based on the above factors, assuming the most ideal liner installation conditions with very good quality assurance during installation, minimal defects, and permeability and construction of Class A liner as per the Minimum Requirements for Waste Disposal by Landfill (2nd Ed., Department of Water Affairs and Forestry, 1998). Estimated seepage rates through the liner are given in section 8.7.7.

The National Environmental Management: Waste Act, 2008 (Act 59 of 2008), National Norms and Standards for Disposal of Waste to Landfill Regulation 636 (23 August 2013) requires that Type 1 waste may only be disposed of at a Class A landfill designed in accordance with section 3(1) and (2) of these Norms and Standards, or, subject to section 3(4) of these Norms and Standards, may be disposed of at a landfill site designed in accordance with the requirements for a Hh / HH landfill as specified in the Minimum Requirements for Waste Disposal by Landfill (2nd Ed., Department of Water Affairs and Forestry, 1998). The maximum permeability allowed for in the design criteria for a Class A Landfill liner is stated to not exceed 1×10^{-7} cm/s (0.03 m/y or 8×10^{-5} m/d) with a liner thickness of 1.5 metres. The maximum seepage rate to be included into the contaminant transport model will assume the SLF liner design and construction will not exceed the stated maximum seepage rate for a Class A liner as stated above.

To address the uncertainty in seepage rate reaching groundwater from the SLF, the numerical groundwater flow and transport model will run several predictive scenarios accounting for various seepage rates during the operational and closure phases, and accounting for estimated flow through unconsolidated and consolidated material as well as installation of the Class A liner. The scenarios modelled are described in section 8.7.7.

Additional laboratory analyses and unsaturated flow modelling of the SLF is required if quantification of seepage rates reaching groundwater is required that also accounts for the final liner specification and design, as well as the reduction in hydraulic conductivity due to the ageing of the Jarofix.

8.6 CONCEPTUAL GROUNDWATER MODEL

The conceptual model describes the hydrogeological environment and is used to design and construct the numerical model to represent simplified, but relevant conditions of the groundwater system. The conditions should be chosen in view of the specific objective of the modelling and might not be relevant for other modelling objectives. The conceptual model is based on the source-pathway-receptor principle.

8.6.1 Source

The main potential on-site contamination sources for the Gamsberg project, as discussed in section 5.6.3 are:

- Smelter complex; and
- Secured landfill facility

The mining area and waste rock dumps are excluded from this study in terms of groundwater modelling. However, these facilities are evaluated during the cumulative impact assessment.

8.6.2 Pathway

From the reviewed information the conceptual model consists of three hydrostratigraphic units and lineament faults, as illustrated in Figure 8-4:

- Weathered and highly fractured aquifer (gneiss and schist lithology)
- Moderately fractured aquifer (gneiss and schist)
- Competent aquifer
- Potential lineaments

Hydrostratigraphy

No regional aquifers are developed in the area and groundwater occurs mainly in local secondary fractured-rock aquifers (SRK, 2010). Primary weathered zone aquifers are rare and localised because soils are thinly developed. Vegter (2006) states that in the Bushmanland Hydrogeological Region groundwater occurs in fractured rock below the weathered zone and not at the transition between the weathered zone and fresh rock.

Vegter (2006) analysed data from 115 boreholes located in Subdivision 12 of the Bushmanland Hydrogeological Region, comprising the catchment of Pella River/ T'Goob se Laagte. The area is bounded on the northeast by the Mattheusgat Mountains 1 100 mamsl to 1200 mamsl. An east-west range of hills, Poort se Berge, Namies Mountains and Ghaamsberg rising to over 1150 mamsl, lie just within its southern boundary. Where the Pella River joins the Orange River the elevation is about 325 mamsl. Vegter (2006) also determined that 61% of boreholes in the region had yields ranging between 0.1 L/s – 0.49 L/s. It was also found that water strikes with relatively higher yields occurred at depths between 30 mbgl – 70 mbgl, below the transition between the weathered zone and fresh rock. Therefore, the local aquifer in the Gamsberg area is located below the weathered zone and in the fresh fractured rock. Approximately 25% of boreholes struck water at depths greater that 70 mbgl and the deepest water strike in the region was measured at 113 mbgl (Vegter, 2006).

Highly permeable scree, talus and intensively weathered bedrock occur to a depth of 20 to 30 m. This zone is, however, thought to be of restricted extent with limited groundwater potential, due to low rainfall and runoff with high evaporation rate resulting in very low and sporadic recharge ERM (2013a).

The highly fractured and weathered hard rock terrain of the white quartzite unit, the schist, and the gneiss, are considered to be water-bearing units, or secondary fractured-rock aquifers. The primary control on permeability is taken as structures and weathering (related to depth from surface), rather than rock type, appreciating that un-weathered units at depth can also be water bearing, and that fracturing around major faults will increase hydraulic conductivity. Pump test information interpreted by ERM (2013a) indicated similar ranges of hydraulic conductivities in gneiss, schist, and quartzite lithology, and indicated a broadly confined character in the pump test curves.

Aquifer hydraulic properties

The aquifer hydraulic test results from previous studies indicated that the aquifer units in the Gamsberg area generally have very low to low permeability and increased groundwater occurrence is only associated with secondary structures such as faults and fractures. Transmissivity ranged between 10^{-2} m^2/d and 10^{+1} m^2/d for the Gamsberg aquifer units (section 5.4.3).

The TSF, smelter complex and SLF facilities are all located on basal gneiss of the Gladkop Group and no regional scale lineaments are located within the footprint of these facilities. However, the geophysical survey did indicate the presence of potential fractures within the TSF site area (section 5.2).

Groundwater levels

The average groundwater levels measured during the Golder (2007), SRK (2010), and ERM (2013a) hydrocensus investigations were 31.7 mbgl, 28.1 mbgl, and 29.4 mbgl, respectively. The groundwater levels ranged between artesian conditions and 178.8 mbgl. Groundwater levels are discussed in more detail in section 5.5.

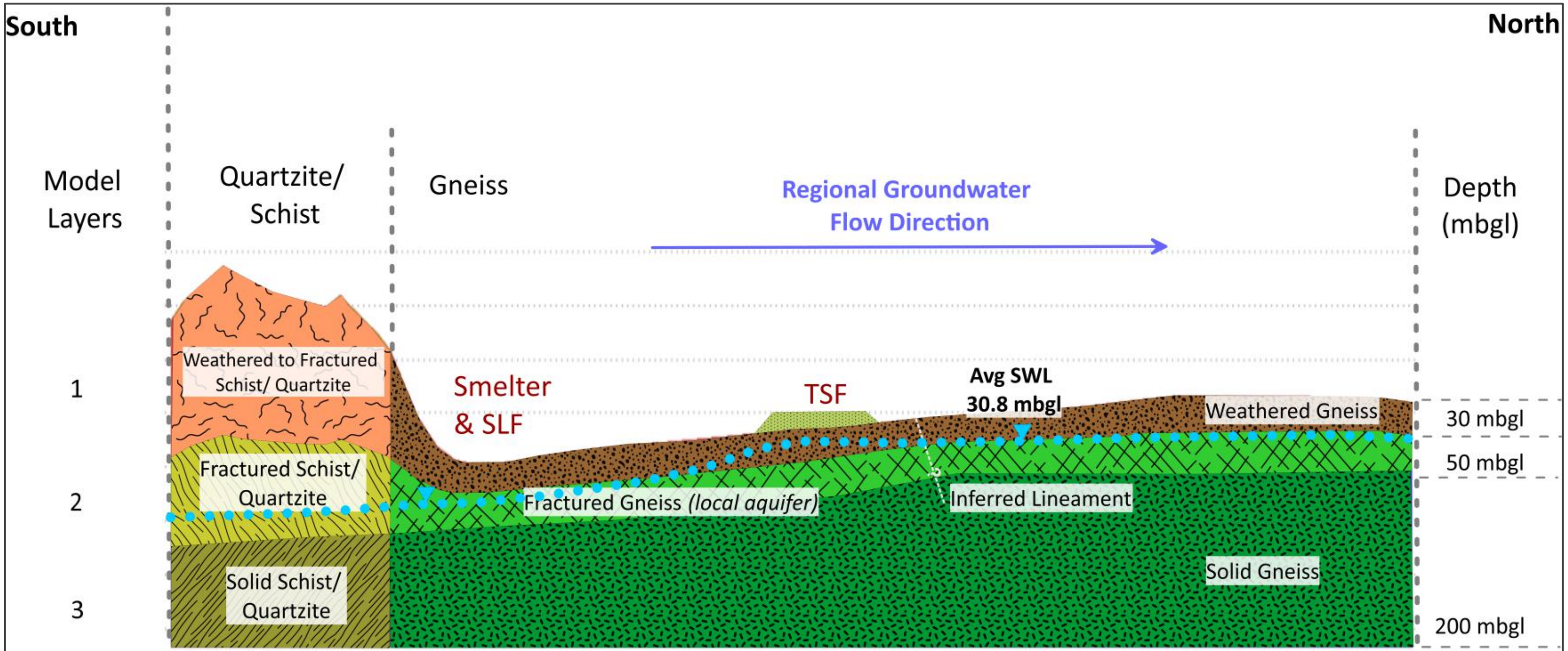
Recharge

ERM (2013a) provided a summary of estimates for recharge on the Gamsberg, which ranged between 1 mm/a and 2.9 mm/a (1.2 and 2.2% of MAP). The mean annual effective recharge for the study area was estimated by SRK (2010) to be approximately 0.85% of MAP. The estimated recharge obtained for the site through the CMB method was estimated to be very low. Recharge is discussed in more detail in section 8.5.1.

8.6.3 Receptors

The receptors under consideration are:

- Groundwater resource.
- Neighbouring groundwater users.



Hydrostratigraphic Units	Hydrogeological Properties	Hydrostratigraphic Units	Hydrogeological Properties
Quartzite/ Schist	T = 0.01 - 10 m^2/d K = 0.001 - 10 m/d Re = 0.10 - 0.50 % MAP	Gneiss	T = 0.10 - 10 m^2/d K = 0.0001 - 10 m/d Re = 0.10 - 0.35 % MAP

FIGURE 8-4: GAMSBERG CONCEPTUAL GROUNDWATER MODEL.

8.7 NUMERICAL MODEL

8.7.1 Model Objectives

The numerical model is to be used to estimate the fate and transport of potential contaminants in groundwater emanating from the SLF. The potential contaminants were identified from the geochemical assessment (section 7). The potential scenarios to be simulated using the Gamsberg model include the following:

- Predict the fate and transport of sulphate, sodium, lead, and antimony emanating from the SLF during operational and closure phases of the Gamsberg project; and
- Predict the potential impact on the irreplaceable and, where possible, constrained habitats (section 5.8).

8.7.2 Model Confidence Level Classification

The level of confidence depended upon the available data for the conceptualisation, design, and construction of the model. Consideration was given to the spatial and temporal coverage of the available datasets to characterise the aquifer.

For the modelling process, the following data was available for the Gamsberg model:

- National surface geology maps for the project area.
- Water level data from previous studies and site monitoring.
- Hydro-geochemical results from previous studies and monitoring data.
- The geochemical study described in this study (section 7).
- Aquifer hydraulic parameters from previous studies.
- Recharge estimations based on this study (section 8.5.1) and previous studies.

Recharge rates and porosity values are important parameters that affect contaminant fate and transport. These parameters were poorly defined in this study, as no site-specific information was available.

The level and type of stresses included in the predictive model are outside the range of those used in the model calibration. Uncertainty in rainfall and recharge rates, together with heterogeneous aquifer properties, results in a degree of uncertainty in the modelled predictions.

The numerical groundwater model is classified as an Australian Guideline Class 1 model as a whole, and was evaluated from a semi-quantitative assessment of the available data on which the model was based, the manner in which the model was calibrated and how the predictions were formulated. A Class 1 model provides insight into the processes of importance in particular settings and conditions, and only provides relatively low confidence associated with any predictions. The level of confidence depended upon the available data for the conceptualisation, design, and construction of the model.

Factors that were considered in establishing the Class 1 model confidence-level classification were:

- Predictive model time frame (Mine operational and closure phase timeframes) far exceeds that of calibration (monitoring data).
- Site geology was inferred from previous groundwater studies.

- Poor quality of digital elevation model to define ground surface elevation – high resolution elevation data were not available for the entire model area.
- Calibration statistics are generally reasonable but may suggest errors in parts of the model domain.
- Mass balance closure error is less than 1% of total.
- Lack of useful time series data that can be used for transient calibration.

The Gamsberg numerical model classified as Class 1 merely provides an initial assessment of the Gamsberg mine and associated impacts and can subsequently be refined and improved to higher confidence level classes as additional data is gathered.

8.7.3 Input Parameters

Model input parameters for this groundwater flow model are divided into two groups:

- hydrogeological parameters; and
- initial conditions.

The initial estimates for hydraulic properties were assigned based on previous study results and literature values (Domenico and Schwartz (1990), Domenico and Mifflin (1965), Freeze and Cherry (1979)). The steady-state initial head conditions were estimated based on average measured groundwater levels for the Gamsberg study area. Recharge rates were applied to different hydrogeological units within the model area as a percentage of MAP which was determined at 99.1 mm/yr. For the steady and transient state models the annual recharge rates as below were used (Table 8-2). The transient calibration and predictive models had recharge values calculated from average monthly rainfall measured between 1986 – 2018 at the Aggeneys Weather Station. Aquifer hydraulic properties are given in section 8.7.5.

TABLE 8-2: ANNUAL RECHARGE VALUES FOR HYDROGEOLOGICAL UNITS.

Hydrogeological Unit	Percentage of MAP	Recharge rate (m/d)
Weathered gneiss (Plains)	0.15 %	4.8E-07
Inselberg (Mountain)	0.50 %	1.6E-06

8.7.4 Transport Parameters

Contaminant movement will mostly take place as a result of advection and to a lesser extent dispersion. Chemical reaction between rocks and elements dissolved in the water was not regarded as significant at this site and was not taken into consideration during simulations. Concentrations at different transport distances in the plume also take dilution from recharge and mixing into account.

Effective porosity was poorly defined in this study, as no site-specific information was available. Effective porosity values were specified for this model as 0.5% for the Gamsberg aquifer units (ERM, 2013a). In the absence of site-specific data, values of dispersivity were inferred from literature values, with a uniform longitudinal dispersion length of 150 m assigned to all aquifer's units and the transversal dispersivity set at 10% of the longitudinal dispersivity (15 m). No site-specific field measurements are available for molecular diffusion either. The molecular diffusion coefficient (D) is generally very small and negligible compared to the mechanical dispersion and is only important when groundwater velocity is very low. A conservative, effective diffusion coefficient of 1 x 10^{-9} m^2/s (9 x 10^{-5} m^2/d) was used in the models (ERM, 2013a).

8.7.5 Calibration and Performance Measures

Steady State Calibration Approach

Calibration is the process of finding a set of boundary conditions, stresses and hydrogeological parameters that produce a result which most closely matches field measurements of hydraulic heads and flows (Kresic, 2007). Model calibration is followed by a sensitivity analysis, to test the robustness of the model to changes in parameters during the calibration period (Barnett et al, 2012). The Gamsberg numerical model calibration was done under steady state conditions.

The initial steady state calibration stages of the Gamsberg model were performed using manual calibration. Steady state calibration of the Gamsberg model area was accomplished by refining the vertical and horizontal hydraulic conductivity relative to average recharge values until a reasonable fit between the measured piezometric levels and the simulated piezometric levels were obtained.

Final steady state model calibration was performed using automated calibration, which is a technique developed to minimise uncertainties associated with the user's subjectivity (Kresic, 2007). According to Anderson and Woessner (1992), automated calibration gives the statistically most appropriate solution for the specified input parameters. Automated calibration coupled with manual calibration is arguably the most appropriate calibration method available (Kresic, 2007).

Automated calibration was undertaken using PEST (a nonlinear parameter estimator), which adjusts model parameters until the fit between model outputs and field observations is optimised in a statistical sense (WNC, 2010). Vertical- and horizontal- hydraulic conductivity and recharge parameters were included for automated calibration for the hydrogeological zones where data was available. The factor by which variables could change was constrained to ten, ensuring that model parameters could not be increased or decreased by a factor of ten from the available site data as discussed in section 5.4.3 and section 8.5.1.

Calibration Performance Measures

Several performance measures have been proposed in the past to indicate when a model fits historical field measurements closely enough to be acceptable for use in future predictions. These may include root mean squared error (RMS) and normalised root mean squared error (NRMS). Predefined performance measures may prevent the best possible calibration from being obtained, based on all available data. This may lead to overfitting, which is the process of increasing model parameters until acceptable low performance measures are obtained. However, overfitting should not be preferred relative to large performance measure values with rational relationships between model parameters (Barnett et al, 2012).

Quantitative performance measurements were closely evaluated, keeping in mind the effect limited geological data (for the entire model area, not just mining lease area) and heterogeneity of the aquifers in the Gamsberg area may have on these performance measurements. Model acceptance was also based on several measures not specifically related to model calibration. This will demonstrate that the Gamsberg model is robust, simulates the water balance as required, and is consistent with the conceptual model.

The following performance measurements were evaluated during the calibration of the Gamsberg model:

- Model convergence: Model convergence was obtained during calibration and a maximum change in heads between iterations was set to 1.0E-10 metres.

- Water Balance: The model demonstrated an accurate water balance during steady state. The water balance error was below one percent. The water balance is presented in Table 8-3.
- Quantitative measures: The steady state calibration was regarded as sufficient at RMS= 14.76m and NRMS= 8.67 %. The graph in Figure 8-5 shows the relation between measured and simulated head at the end of the steady state calibration process. In case of absolute conformity, the points should create a 45-degree straight line (Line of perfect fit). It should be noted that borehole coordinates were derived via GPS and have a ±5 m accuracy and borehole elevations (mamsl) were estimated from the digital elevation model and show a ±20 m accuracy according to SRK (2010). The level of conformity is tolerable especially when the uncertainty in spatial variation of hydraulic properties and topographical elevations are considered.
- Qualitative measures: The steady state water level contours are illustrated in Figure 8-6 and are consistent with the regional drainage features, groundwater levels and expected flow patterns.

TABLE 8-3: MASS BALANCE – STEADY STATE MODEL.

	Flow Out (m^3/day)	**Flow In (m^3/day)**
Sources/ Sinks		
Dirichlet BCs	-234.85	+72.65
Distributed Source (Recharge)	-	+161.97
TOTAL FLOW	-234.85	+234.62
SUMMARY		
	IN – OUT (m^3/day)	**% DIFFERENCE**
TOTAL	-0.23	-0.098%

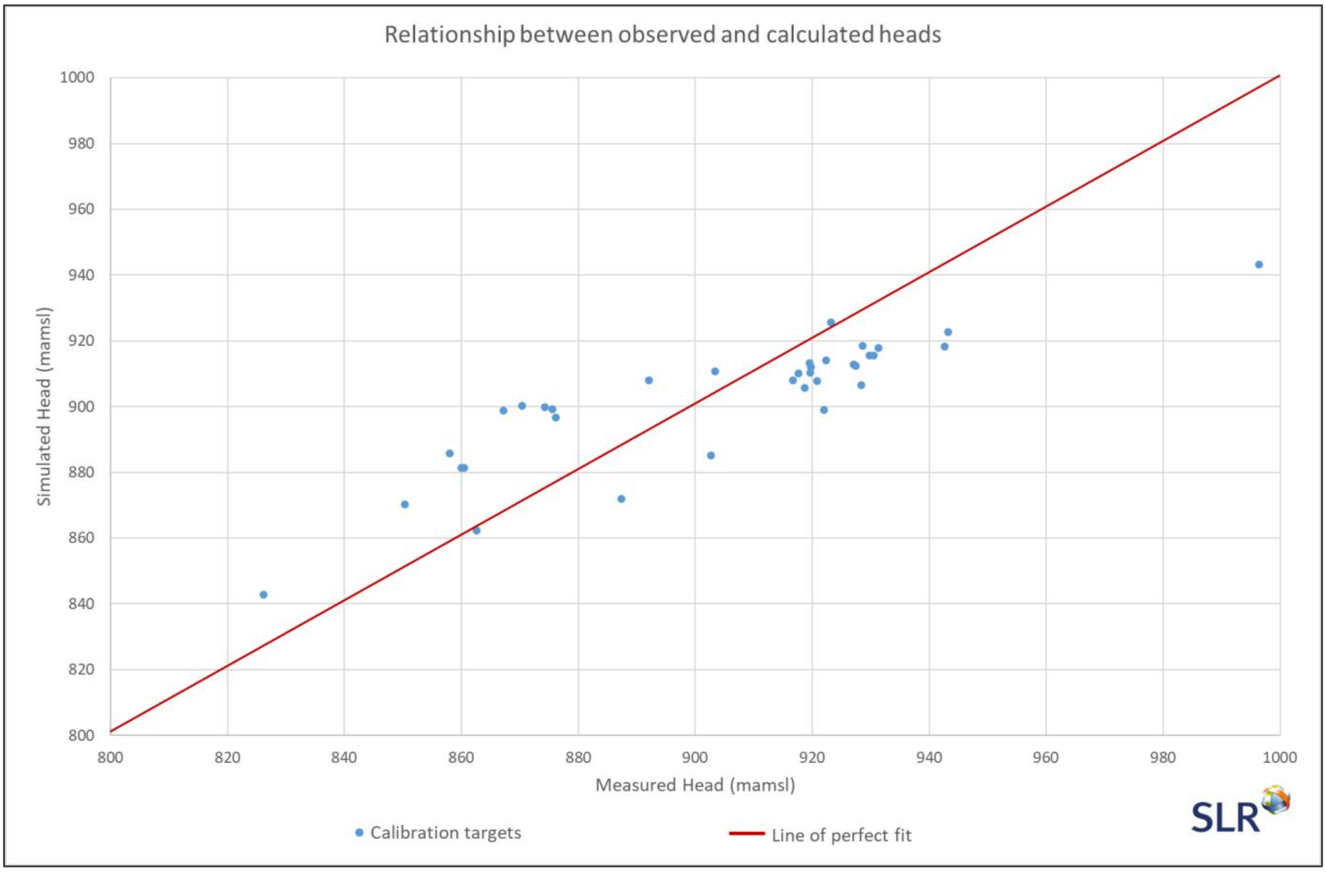


FIGURE 8-5: RELATIONSHIP BETWEEN OBSERVED AND CALCULATED WATER LEVELS.

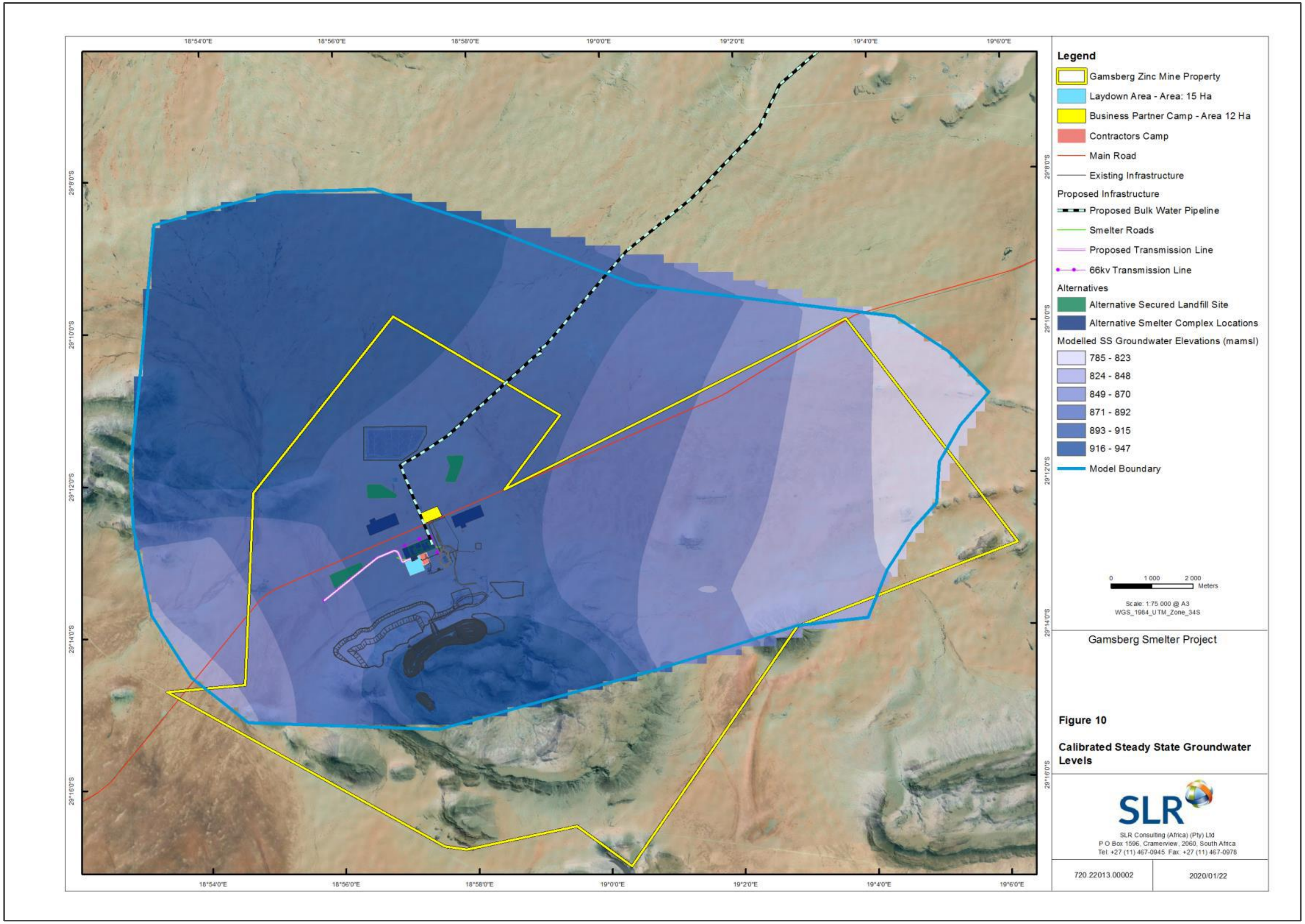


FIGURE 8-6: CALIBRATED STEADY STATE GROUNDWATER LEVELS.

Transient Model Calibration

Understanding the aquifer response to transient stresses is important because groundwater and contaminant movement through the aquifer may be substantially affected by these stresses. To investigate the aquifer response, the transient flow model was calibrated to measured groundwater levels over a 4-year period from the Gamsberg Mine groundwater monitoring network. The transient calibration model covered the period from 1 May 2015 to 2 May 2019. Transient calibration hydrographs were produced for 28 monitoring boreholes and are presented in Appendix E. Calibrated transient groundwater levels generally matched the measured groundwater levels. Groundwater levels of the monitoring network boreholes replicated the quasi-stable aquifer system.

No metered or measured abstraction data were available from pit dewatering or raw water supply boreholes. These volumes should be included into the groundwater management programme for the site and will be vital for future groundwater model updates.

Aquifer Transmissivity

Initial estimates of hydraulic conductivities and transmissivities were obtained from available data from previous studies. These hydraulic conductivity values were assigned to the hydrostratigraphic units in the model area.

The resulting hydraulic transmissivities for each hydrogeological unit are summarised in Table 8-4.

TABLE 8-4: TRANSMISSIVITY VALUES – CALIBRATED MODEL.

Hydrogeological Unit	Transmissivity (m^2/d)
Weathered and fractured gneiss	1.00
Weathered and fractured schist/ quartzite	0.50
Fractured gneiss	0.60
Fractured schist/ quartzite	0.05
Competent gneiss/ basement	0.40
Competent schist/ quartzite	0.005

Other model parameters used in the calibrated model were as follows:

- Vertical anisotropy: 1/10; and
- Specific yield (Sy) and Specific storage (Ss) for the hydrogeological units (Table 8-5):

TABLE 8-5: AQUIFER STORAGE AND POROSITY.

Hydrogeological Unit	Ss (1/m)	Porosity (%)
Weathered and fractured gneiss	1E-04	0.5
Weathered and fractured schist/ quartzite	1E-04	
Fractured gneiss	1E-05	
Fractured schist/ quartzite	1E-05	

Hydrogeological Unit	Ss (1/m)	Porosity (%)
Competent rock mass (basement)	1E-06	

Expected storage values typically ranges between 10^{-4} for the weathered zone and decreases with depth within the fractured aquifer units in the order of 10^{-6}.

Sensitivity Analysis

A sensitivity analysis was carried out on the calibrated model. The purpose of the sensitivity analysis was to quantify the uncertainty in the calibrated model caused by the uncertainty in the estimates of aquifer parameters. During the sensitivity analysis horizontal and vertical hydraulic conductivity and recharge were assessed. The parameter sensitivities can be seen in Figure 8-7 below.

Results of the sensitivity analysis indicate that the water levels in the model are mainly sensitive to changes in recharge in the mountain area and to a lesser extent to the hydraulic conductivity. Time series data of groundwater level from different aquifer units and daily rainfall data will benefit future model updates the most.

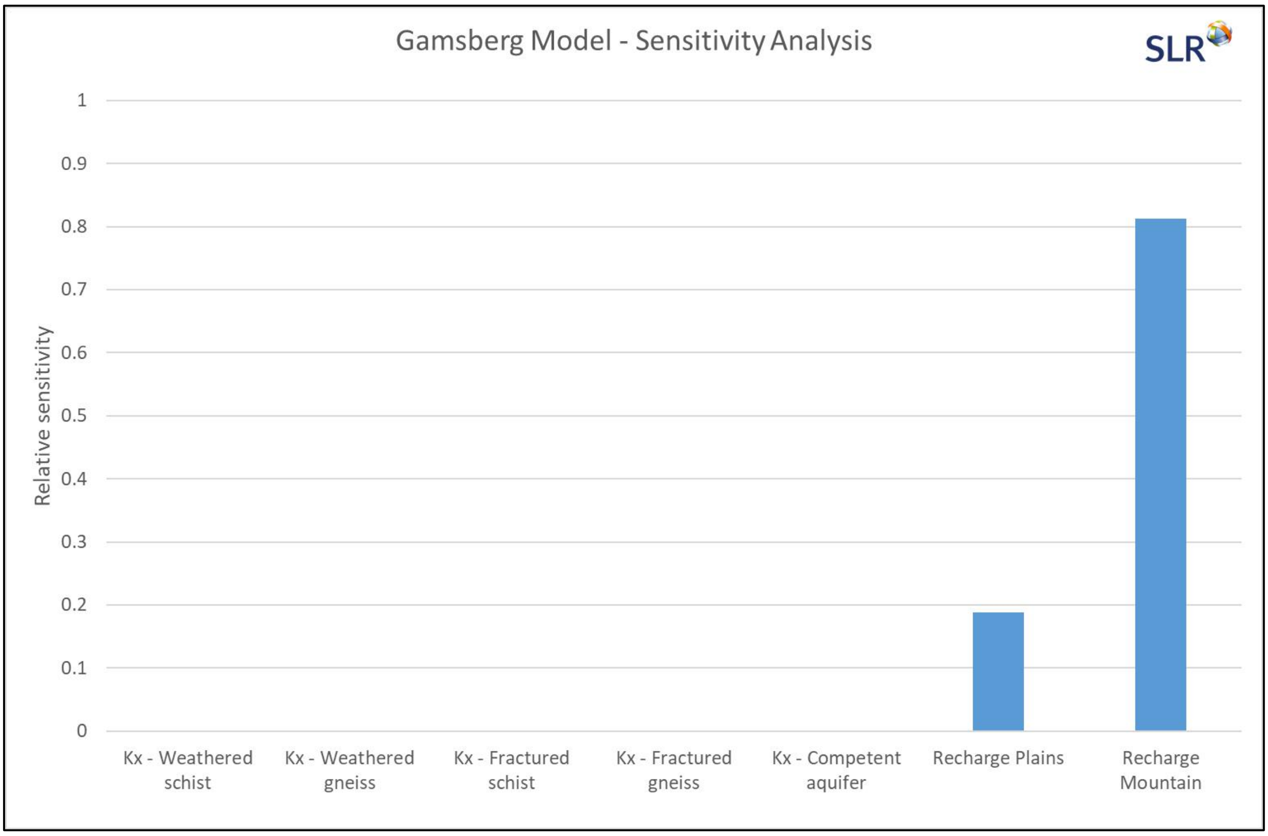


FIGURE 8-7: GAMSBERG MODEL PARAMETER SENSITIVITY ANALYSIS RESULTS.

8.7.6 Time Discretisation

The predictive model was setup in transient state to account for response to changes in seasonal variations in recharge as well as to evaluate the effects of transience on transport of contaminants from the source area during operational and closure phases. The numerical groundwater flow and transport predictive models were set up to account for the different phases of the Gamsberg Zinc Mine operations. These include:

- Operational phase with a total period of 15 years; and
- Post closure phase with a total period of 50 years.

The FEFLOW model was set up with automatic time step control, which provides most flexibility and requires least prior knowledge about the simulation behaviour. The second-order accurate (AB/TR) predictor-corrector scheme was set with an initial time step length set to 0.001 days.

8.7.7 Model Scenarios

The numerical groundwater flow model was setup to predict the potential impact from contaminants of concern identified by the geochemical modelling (section 7.6) with various seepage rates. Seepage rates were estimated for operational and closure phases for unconsolidated and consolidated material as well as installation of a Class A liner. The different scenarios and seepage rates are described in Table 8-6.

TABLE 8-6: MODEL SCENARIO DESCRIPTION AND SEEPAGE RATES.

Phase	Description	Seepage rate as groundwater recharge		Seepage rate as groundwater recharge estimated on
		% MAP	m/d	
Operational	Unconsolidated material	10 %	3.2 E-05	1/5 of total of seepage (50% of MAP) estimated in section 7.4
	Consolidated material	1 %	3.2 E-06	1/5 of total of seepage (5% of MAP) estimated in section 7.4
	Consolidated material with Class A liner	0.44 %	1.4 E-06	Giroud *et al*. (1992), ideal liner installation conditions and Class A liner specifications with head of 0.3 m
Closure	Unconsolidated material	5 %	1.6 E-05	1/5 of total of seepage (50% of MAP) estimated in section 7.4
	Consolidated material	0.5 %	1.6 E-06	1/5 of total of seepage (5% of MAP) estimated in section 7.4
	Consolidated material with Class A liner	0.22 %	7.1 E-07	Giroud *et al*. (1992), ideal liner installation conditions and Class A liner specifications with head of 0.1 m

8.7.8 Model Limitations and Assumptions

The conceptualisation of a complex groundwater flow system into a simplified groundwater management tool, i.e. numerical model, has several uncertainties, assumptions, and limitations. These limitations include, but are not limited to the following list:

- Input data on the types and thickness of hydrogeological units, water levels, and hydraulic properties are estimates of actual values.
- Information received from the client indicated that open pit mining will not progress below regional groundwater levels outside the inselberg therefore.

  - The current model setup does not account for any mining activities (i.e. dewatering and waste rock effects on the regional groundwater levels and gradient, as well as potential contamination emanating from these areas).
  - Mine dewatering (operational phase) and groundwater level rebound (post-closure) may alter the migration of contaminant plumes predicted in this study.
  - Should mining progress below the regional groundwater level, the model should be re-evaluated and updated.
- Water seepage and associated contamination to groundwater from the smelter complex was not modelled as it is expected that potential spillages from water and/or chemical storage facilities will only occur in extreme events. It is assumed that the site will adhere to the following:
  - Refinery infrastructure, will be constructed and operated to comply with the NWA guidelines:
    - Clean water systems are separated from dirty water systems.
    - Clean run-off and rainfall water are diverted around dirty areas and back into the environment.
    - The size of dirty water areas is minimized, and dirty water is contained in systems that allow the reuse and/or recycling of this dirty water.
    - Discharges of dirty water may only occur in accordance with authorisations that are issued in terms of the relevant legislation specifications and they must not result in negative health impacts for downstream surface water users.
  - All hazardous chemicals (new and used), mineralized waste and non-mineralised waste must be handled in a manner that they do not pollute surface water. This will be implemented by means of the following:
    - Pollution prevention through basic infrastructure design.
    - Pollution prevention through maintenance of equipment.
    - Pollution prevention through education and training of workers (permanent and temporary).
    - Pollution prevention through appropriate management of hazardous materials.
    - The required steps to enable containment and remediation of pollution incidents.
  - The design of potentially polluting structures will take account of the requirements for long term surface water pollution prevention.
- A numerical model cannot completely represent all the physical and chemical processes in a catchment.
- The numerical model developed for the proposed Gamsberg Smelter Project cannot be used for any other purpose than the defined model objectives.
- The numerical model is a non-unique solution that can be theoretically calibrated with an unlimited number of acceptable parameters.
- Seepage rates entering the subsurface as increased groundwater recharge from the SLF was estimated from previous groundwater studies and available information:

- increased groundwater recharge was estimated to range between 10% and 1% of MAP during the operational phase and between 5.0% and 0.5% of MAP during the closure phase, approximately a fifth of the total seepage moving through the SLF. Previous assumed recharge rates for waste facilities at Gamsberg Mine were up to 20% of MAP (ERM, 2013a).
- The saturated numerical groundwater flow and transport model cannot quantify the seepage rate from the SLF which will be under unsaturated conditions.
- The reduction in seepage due to the aging of the Jarofix and installation of a cap on the SLF cannot be quantified by a saturated numerical groundwater flow and transport model.
- To address the uncertainty in seepage rate reaching groundwater from the SLF, the numerical groundwater flow and transport model ran several predictive scenarios accounting for various seepage rates during the operational and closure phases, and accounting for estimated flow through unconsolidated and consolidated material as well as installation of the Class A liner. The scenarios modelled are described in section 8.7.7.
- Additional laboratory analyses and unsaturated flow modelling of the SLF is required if quantification of seepage rates reaching groundwater is required that also accounts for the final liner specification and design, the reduction in hydraulic conductivity due to the ageing of the Jarofix, as well as various SLF capping rehabilitation options.

- The numerical model is a simplification of the natural world. The FEFLOW software code was used to develop the numerical groundwater flow and transport model, which represents some or all characteristics of the real system on an appropriate scale. The model is a management tool used to understand why a system is behaving in an 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.

8.8 RESULTS OF THE MODEL

8.8.1 Pre-Facility (SLF and Smelter)

Groundwater Levels

Results from the calibrated steady state model (section 8.7.5) indicate that groundwater levels within the SLF footprint area ranged between 888.9 mamsl and 895.2 mamsl, with a groundwater gradient flowing generally in a south-west direction. Steady state calibrated groundwater levels are illustrated in Figure 8-6.

Additionally, groundwater levels of the mine monitoring network boreholes, monitored between November 2017 and April 2019, were quasi-stable and indicated no adverse effects due to the pit dewatering or any other mining activities affecting mine and regional groundwater levels.

Groundwater Quality

The fate and transport of the potential contaminants, identified during the geochemical assessment (section 5.3 and section 7), emanating from the SLF were included in the numerical groundwater modelling. The potential contaminants include sulphate (SO_4), sodium (Na), lead (Pb), and antimony (Sb).

Monitoring boreholes near the proposed smelter and SLF areas are GAMS1, MH07, MH06, MH05, MH04, and GAMS8. The concentrations of the identified potential contaminants sampled during the April 2019 monitoring round are given in Table 8-7 below. The average concentrations of sulphate and sodium from groundwater samples in the proposed smelter and SLF areas sampled in April 2019 were 143 mg/L and 166 mg/L, respectively. Antimony was not included in the Gamsberg groundwater monitoring analyses, and the previous groundwater studies conducted by ERM (2013a) and SRK (2010) also did not analyse for antimony from groundwater samples collected during the hydrocensus investigations. However, the hydrocensus investigation conducted by Golder (2007) included four samples which were analysed for antimony the concentrations were all below detection limit (<0.001 mg/L). It is recommended that future monitoring include antimony in the groundwater quality analyses.

TABLE 8-7: PRE-FACILITY CONCENTRATIONS OF POTENTIAL CONTAMINANTS (APRIL 2019).

Borehole ID	Sulphate	Sodium	Lead
	mg/L		
GAMS1	220.59	324.23	< 0.01
MH07	105.15	119.00	< 0.01
MH06	255.00	268.00	< 0.01
MH05	124.77	105.00	< 0.01
MH04	106.59	73.30	< 0.01
GAMS8	47.60	111.00	< 0.01
Average concentration	**143.4**	**166.7**	**< 0.01**

8.8.2 Operational phase of Smelter and SLF

Groundwater Levels

No notable change in groundwater levels were observed for the proposed SLF and smelter complex areas for Scenario 1 – Scenario 3, as described in section 8.7.7. As discussed in section 8.5.2, the total seepage emanating from the proposed SLF would be minimal if a Class A liner is installed and thus limiting any significant change in local and regional groundwater levels. This is largely attributed to the Class A liner, which according to the relevant guidelines the liner material cannot exceed a permeability of 1×10^{-7} cm/s (0.03 m/y or 8×10^{-5} m/d). Average groundwater levels around the SLF facility were ~40 mbgl (868 mamsl).

Groundwater Quality

Water seepage and associated contamination to groundwater from the smelter complex was not modelled as it is expected that potential spillages from water and/or chemical storage facilities will only occur in extreme events.

Sulphate, sodium, lead, and antimony were included in the operational phase numerical groundwater contaminant transport models for various seepage rate scenarios described in section 8.7.7. These chemical constituents were identified as from the geochemical assessment as potential contaminants (section 5.3 and section 7). The operational source terms for each of the potential contaminants are given in Table 7-2.

The numerical groundwater contaminant transport models at the end of the operational phase (15 years) resulted in a maximum plume migration of sulphate, sodium, lead, and antimony of ~600 m, ~580 m, ~600 m, and ~700 m respectively with the installation of the liner. Without the liner installation with seepage rates described in Scenario 1, all four contaminant plumes migrate approximately an additional ~100m from the SLF. The migration of the sulphate, sodium, lead, and antimony plumes at the end of the operational phase are illustrated in Figure 8-8, Figure 8-9, Figure 8-10, and Figure 8-11 respectively for both Scenario 1 (worst-case) and Scenario 3 (liner installation) seepage rates. Scenario 2 resulted in similar plume extents than Scenario 3 and is not illustrated in the operational plume maps. The minimum concentration contour for each map has been specified to the SANS 241-1 2015 limits for each potential contaminant. The nearest privately owned farm borehole, DMBH06, is not affected by any of the four plumes and is approximately 1.7 km away from the worst-case Scenario 1 plume extents.

Although the change in seepage rates between Scenario 1 and Scenario 3 did not result in a significant change in the plume extents, the installation of a Class A liner does significantly reduce the contaminant salt load to the aquifer. As indicated in Table 8-8, the installation of the liner results in a decrease of up to 23% in total salt load to the aquifer. Since all contaminants were modelled as conservative tracers, a similar reduction in total mass flux for sodium, lead, and antimony were calculated as that of sulphate.

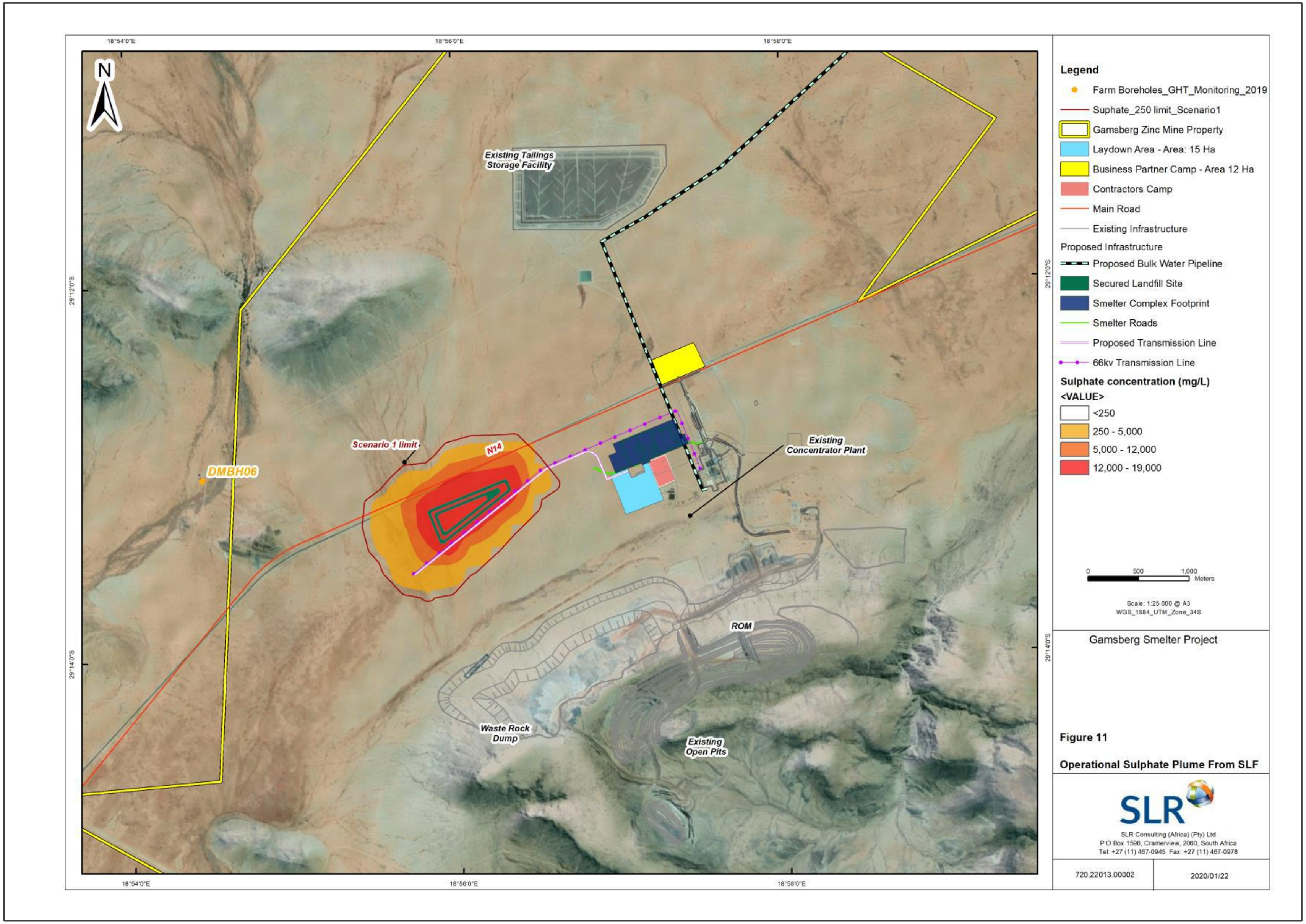


FIGURE 8-8: OPERATIONAL (15 YEARS) SULPHATE PLUME FROM SLF – SCENARIO 1 (WORST CASE) AND SCENARIO 3 (LINER).

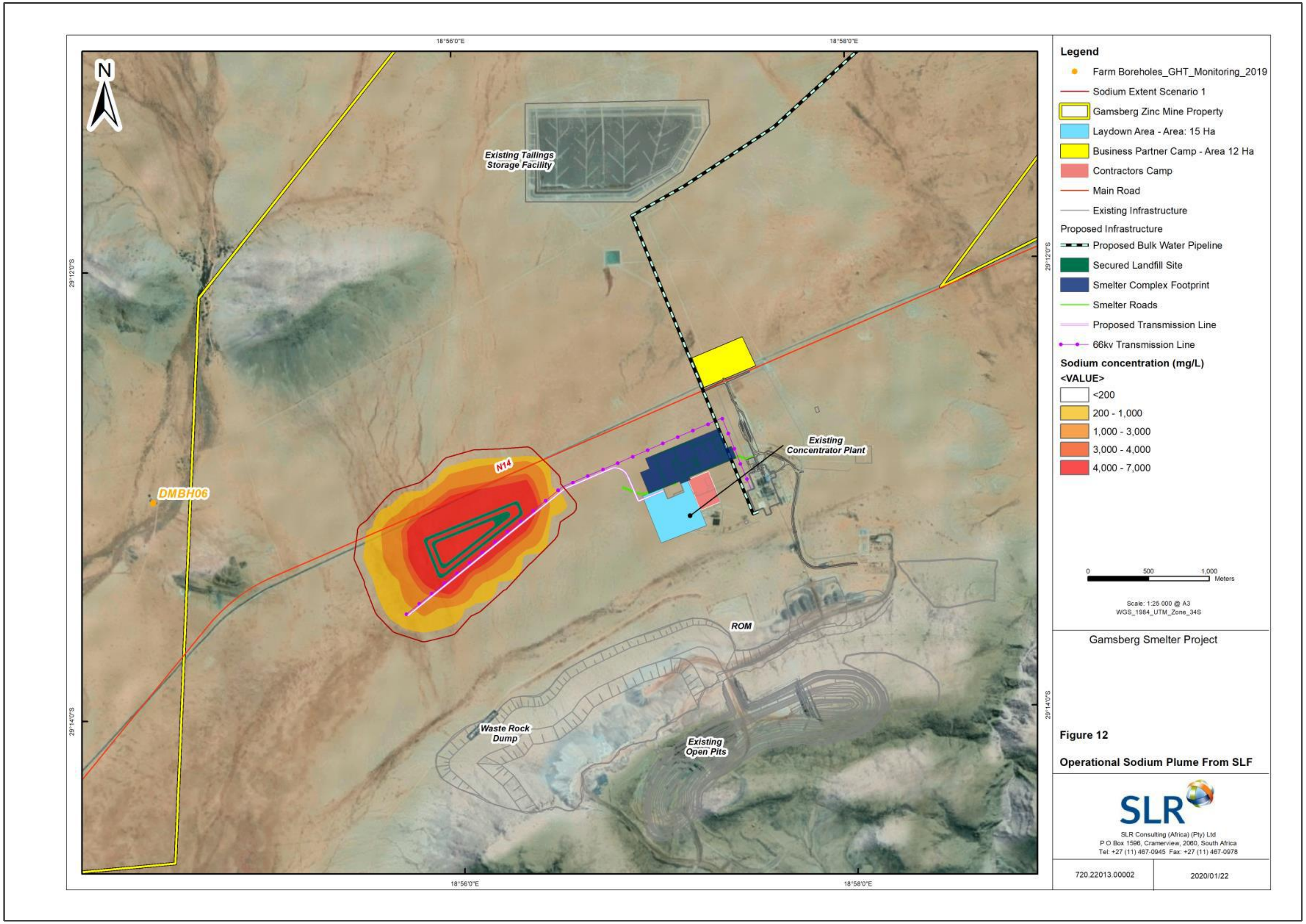


FIGURE 8-9: OPERATIONAL (15 YEARS) SODIUM PLUME FROM SLF – SCENARIO 1 (WORST CASE) AND SCENARIO 3 (LINER).

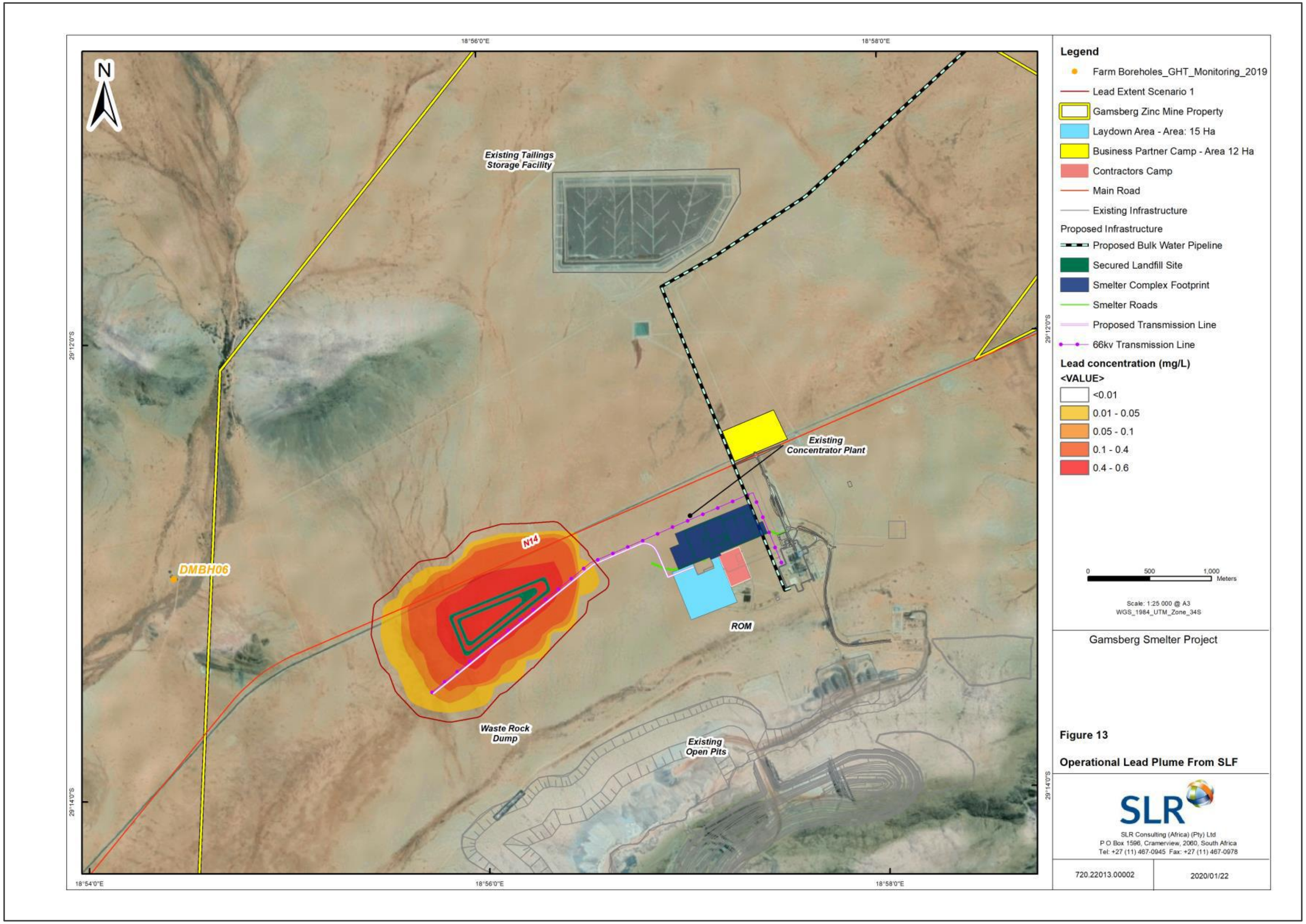


FIGURE 8-10: OPERATIONAL (15 YEARS) LEAD PLUME FROM SLF – SCENARIO 1 (WORST CASE) AND SCENARIO 3 (LINER).

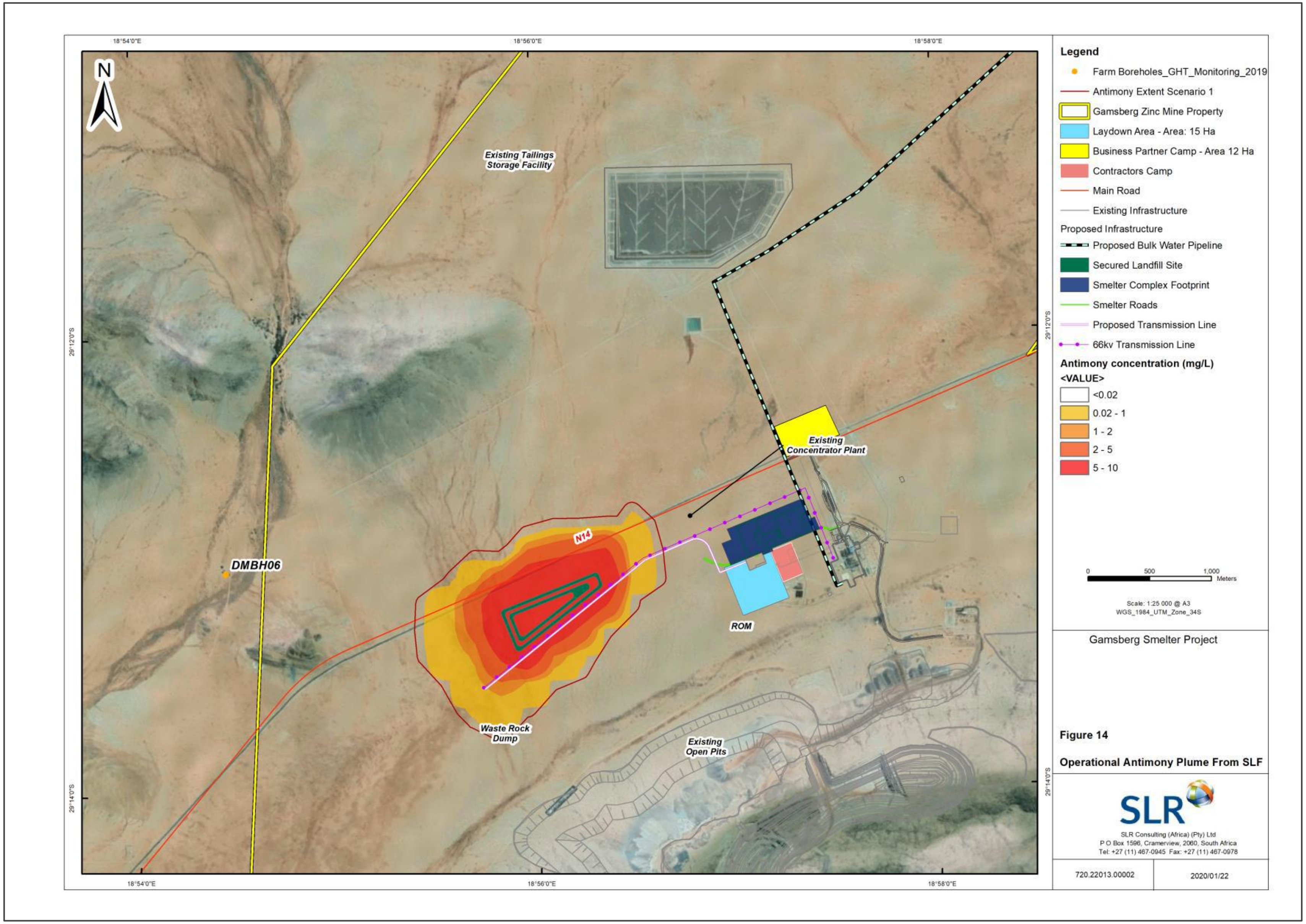


FIGURE 8-11: OPERATIONAL (15 YEARS) ANTIMONY PLUME FROM SLF – SCENARIO 1 (WORST CASE) AND SCENARIO 3 (LINER).

TABLE 8-8: SULPHATE MASS FLUX FOR VARIOUS OPERATIONAL PHASE SCENARIOS.

Scenario	Description	Seepage Rate		Assumption	Area of SLF (km2)	Period (years)	Sulphate Source Term (mg/L)	Sulphate Mass flux		Total mass % change from Base Case
		% MAP	m/d					ton	ton/a	
Scenario 1	Operational unconsolidated - no liner - Base Case	10.00%	3.21E-05	1/5 seepage of SLF	0.21	15	19 000	1120	42	-
Scenario 2	Operational consolidated - no liner	1.00%	3.21E-06	1/5 seepage of SLF				861	24	23%
Scenario 3	Operational - liner	0.44%	1.42E-06	Giroud *et al*. (1992) – 1.5m thick Class A liner				846	23	24%

8.8.3 Post-Closure of Smelter and SLF Facility

Groundwater Levels

No notable change in groundwater levels were observed for the proposed SLF and smelter complex areas for Scenario 4 – Scenario 6, as described in section 8.7.7. As discussed above, the total seepage emanating from the proposed SLF would be minimal if a Class A liner is installed and thus limiting any significant change in local and regional groundwater levels. This is largely attributed to the Class A liner, which according to the relevant guidelines the liner material cannot exceed a permeability of 1×10^{-7} cm/s (0.03 m/y or 8×10^{-5} m/d). Average modelled groundwater levels around the SLF facility were ~44 mbgl (864 mamsl).

Groundwater Quality

Water seepage and associated contamination to groundwater from the smelter complex was not modelled as it is expected that potential spillages from water and/or chemical storage facilities will only occur in extreme events.

Sulphate, sodium, lead, and antimony were included in the closure phase numerical groundwater contaminant transport models for various seepage rate scenarios described in section 8.7.7. These chemical constituents were identified as from the geochemical assessment as potential contaminants (section 5.3 and section 7). The operational source terms for each of the potential contaminants are given in Table 7-2.

The numerical groundwater contaminant transport models at the end of the closure phase (50 years) resulted in a maximum plume migration of sulphate, sodium, lead, and antimony of ~850 m, ~600 m, ~800 m, and ~1 000 m respectively with the installation of the liner. Without the liner installation with seepage rates described in Scenario 6, all four contaminant plumes migrate approximately an additional ~120 m from the SLF. The migration of the sulphate, sodium, lead, and antimony plumes at the end of the closure phase are illustrated in Figure 8-12, Figure 8-13, Figure 8-14, and Figure 8-15 respectively for both Scenario 4 (worst-case) and Scenario 6 (liner installation) seepage rates. Scenario 5 resulted in similar plume extents than Scenario 6 and is not illustrated in the closure plume maps. The nearest privately owned farm borehole, DMBH06, is not affected by any of the four plumes and is approximately 1.3 km away from the worst-case Scenario 1 plume extents.

Although the change in seepage rates between Scenario 4 (worst-case) and Scenario 6 (liner installation) did not result in a significant change in the plume extents, the installation of a Class A liner does significantly reduce the contaminant salt load to the aquifer. As indicated in Table 8-9, the installation of the liner results in a decrease of up to 23% in total salt load to the aquifer. Since all contaminants were modelled as conservative tracers, a similar reduction in total mass flux for sodium, lead, and antimony were calculated as that of sulphate.

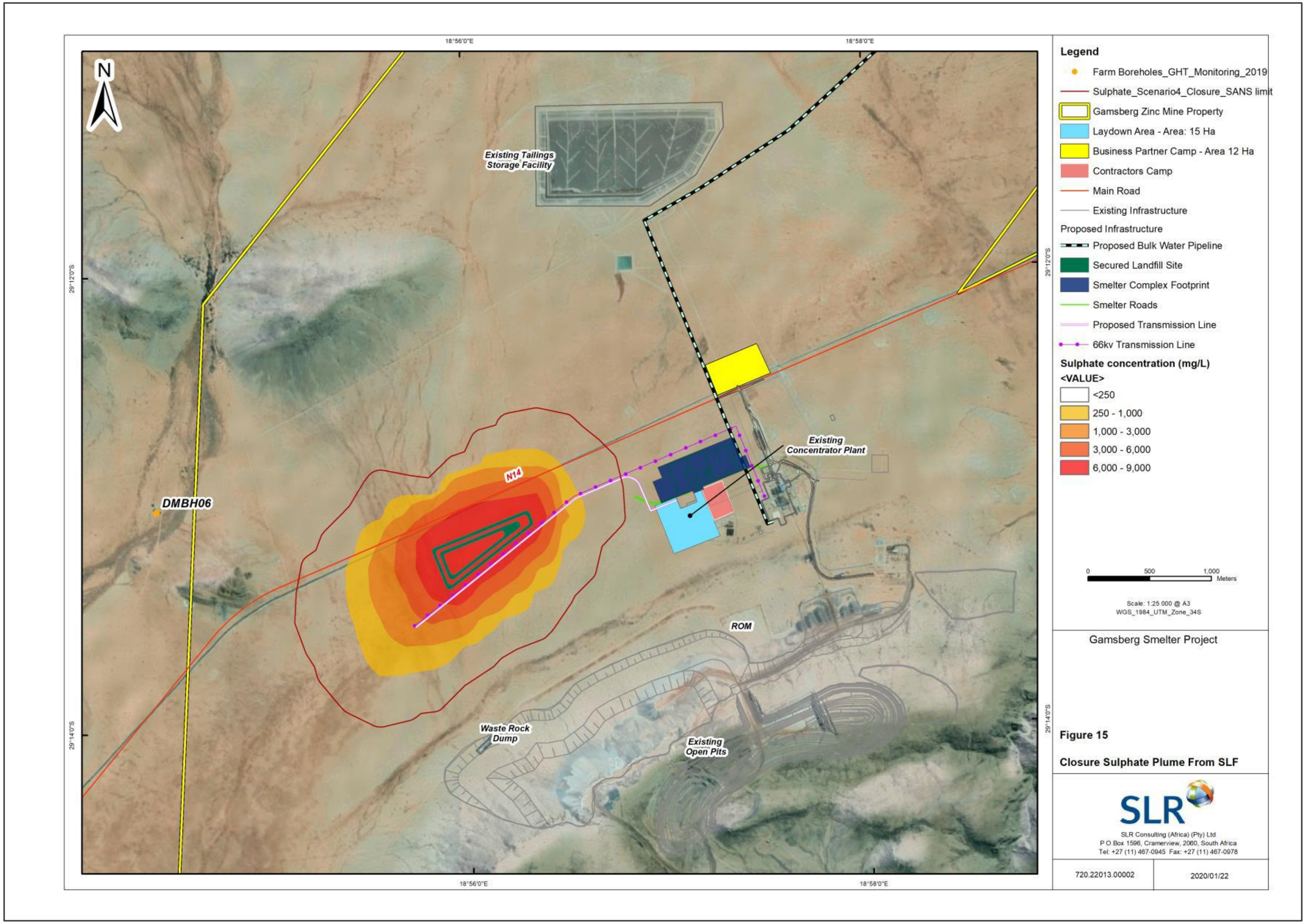


FIGURE 8-12: CLOSURE (50 YEARS) SULPHATE PLUME FROM SLF – SCENARIO 4 (WORST CASE) AND SCENARIO 6 (LINER).

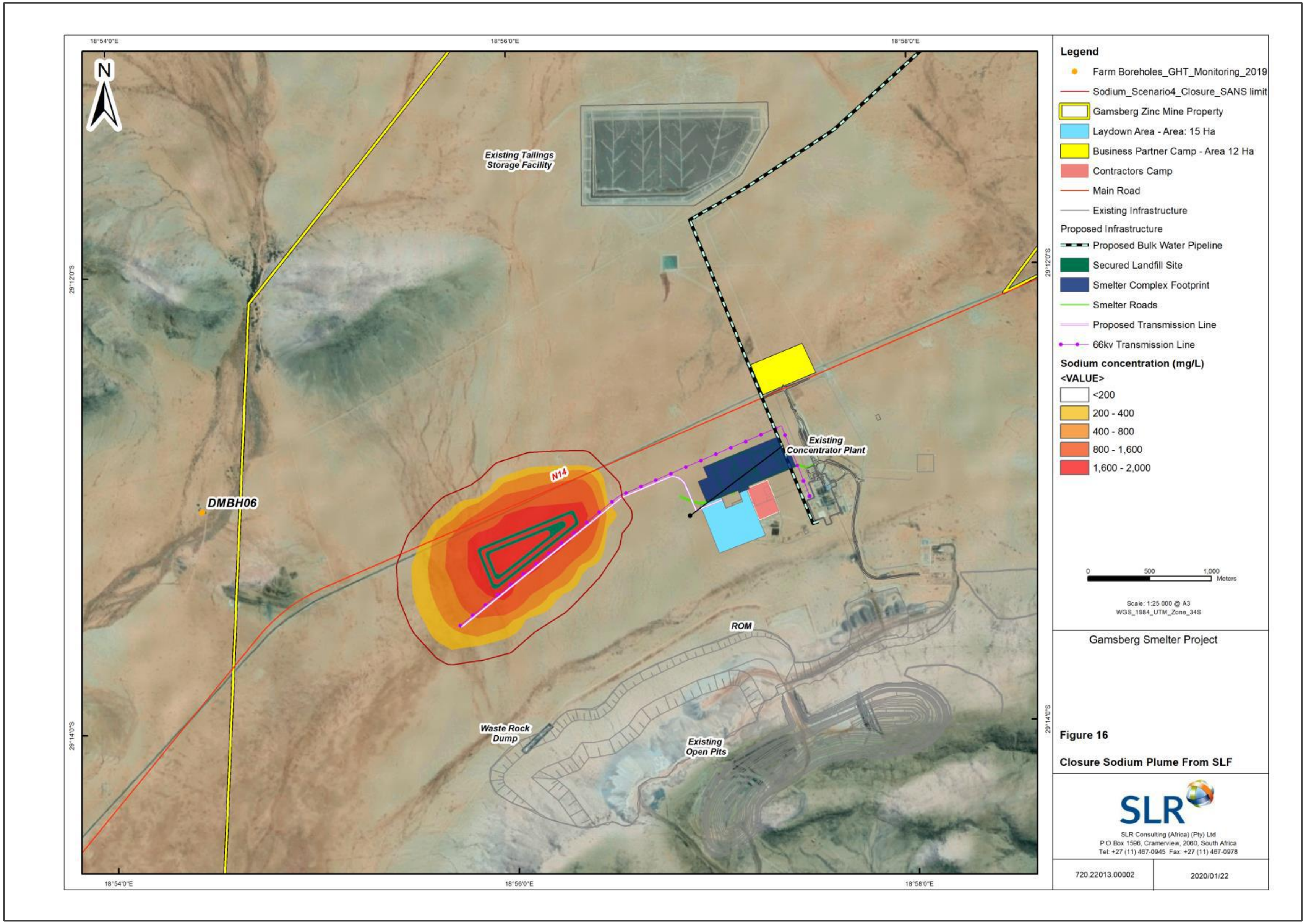


FIGURE 8-13: CLOSURE (50 YEARS) SODIUM PLUME FROM SLF – SCENARIO 4 (WORST CASE) AND SCENARIO 6 (LINER).

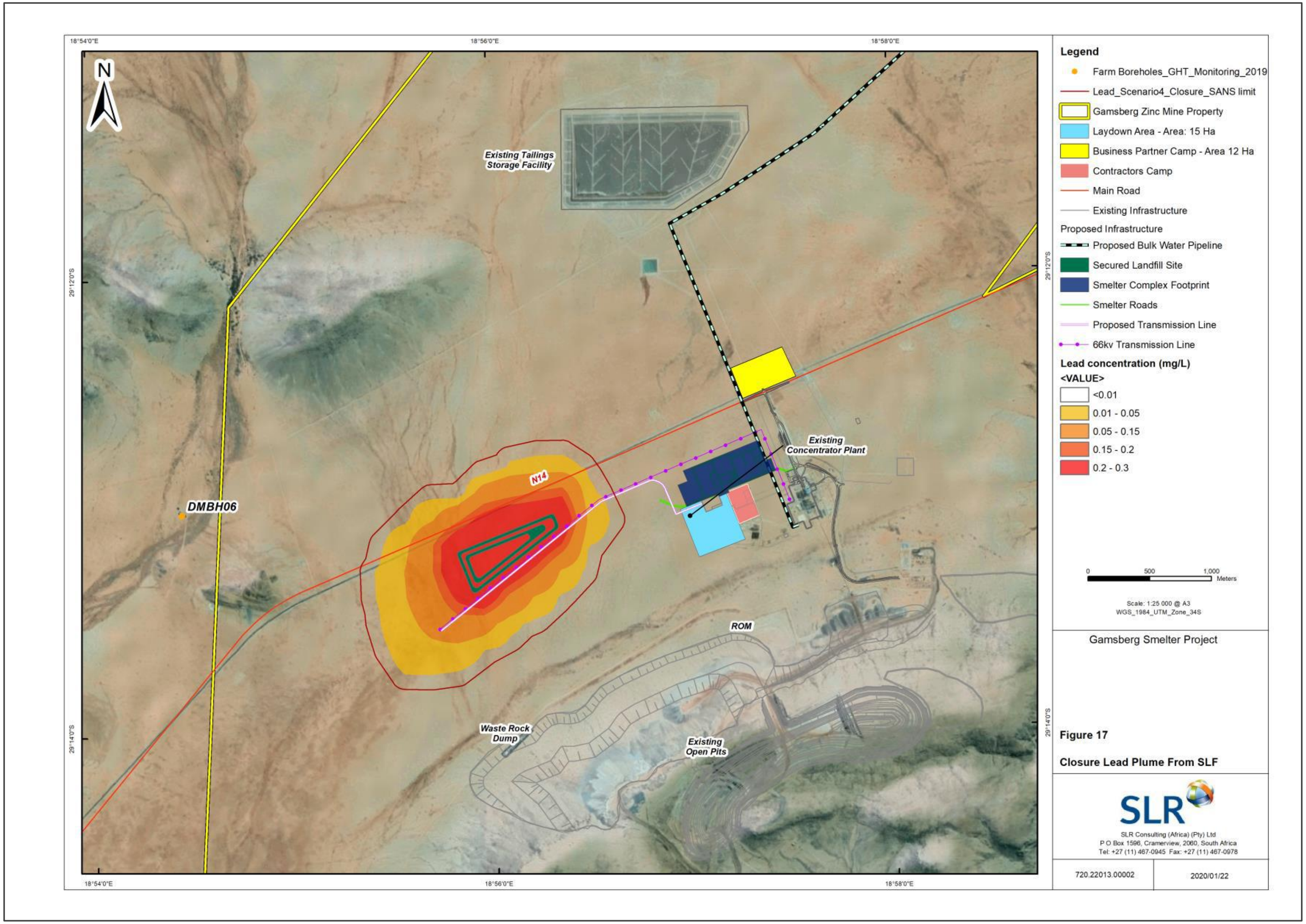


FIGURE 8-14: CLOSURE (50 YEARS) LEAD PLUME FROM SLF – SCENARIO 4 (WORST CASE) AND SCENARIO 6 (LINER).

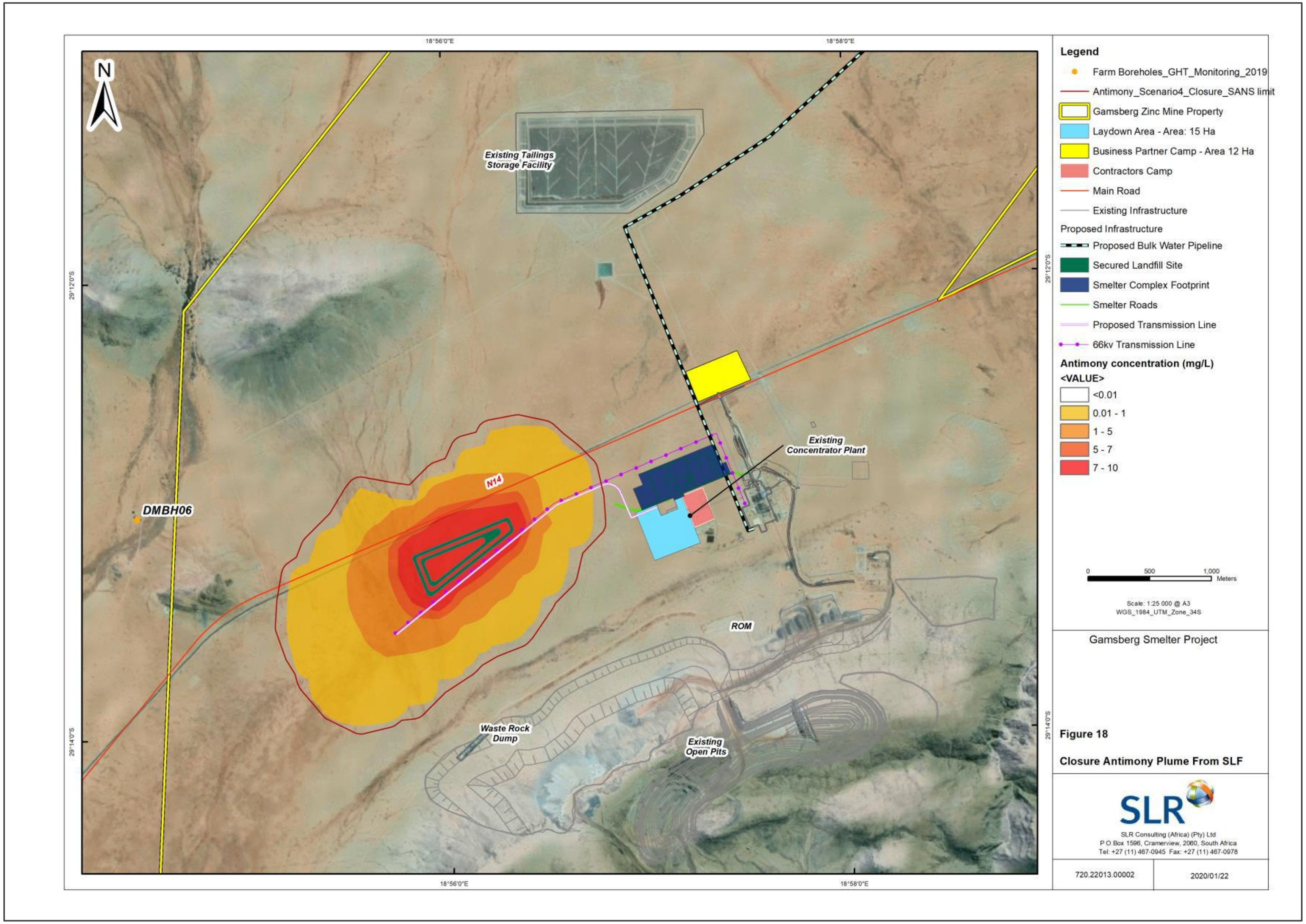


FIGURE 8-15: CLOSURE (50 YEARS) ANTIMONY PLUME FROM SLF – SCENARIO 4 (WORST CASE) AND SCENARIO 6 (LINER).

TABLE 8-9: SULPHATE MASS FLUX FOR VARIOUS CLOSURE PHASE SCENARIOS.

Scenario	Description	Seepage Rate		Assumption	Area of SLF (km2)	Period (years)	Sulphate Source Term (mg/L)	Sulphate Mass flux		Total mass % change from Base Case
		% MAP	m/d					ton	ton/a	
Scenario 4	Closure unconsolidated - no liner - Base Case Closure	5.00%	1.61E-05	Seepage reduced by 50% from operational phase	0.21	50	9000	525	6	-
Scenario 5	Closure consolidated - no liner	0.50%	1.61E-06	Seepage reduced by 50% from operational phase				409	4	22%
Scenario 6	Closure - liner	0.22%	7.08E-07	Giroud *et al*. (1992) – 1.5m thick Class A liner				402	4	23%

9 GEOHYDROLOGICAL IMPACTS

Potential impacts were assessed for the construction, operational and decommissioning/ closure phases of the proposed Gamsberg smelter and SLF. The objective of this section was to rate the significance of the potential impacts pre- and post-mitigation. The impact of the Gamsberg Smelter Project on groundwater levels, flow patterns and contaminant transport were quantified using the numerical groundwater flow and transport model results. Relevant assumptions and limitations are detailed in the specific sections.

The impacts on groundwater have been assessed in terms of possible impacts on existing and/or future groundwater users. In the construction and decommissioning phases some of these potential pollution sources are temporary and diffuse in nature. Even though the sources are temporary in nature, related potential pollution can be long term. The operational and closure phase will present more long-term potential sources, such as the SLF. The project activities and infrastructure that could potentially impact the groundwater resource are listed in Table 9-1.

TABLE 9-1: GAMSBERG PROJECT ACITIVITIES ASSESSED RELEVANT TO GROUNDWATER.

Construction Phase Activities
Site clearing for and construction of the proposed SLF & smelter
Operation Phase Activities
SLF
Smelter
Decommissioning/ Closure Phase Activities
SLF
Smelter

The criteria used to assess impacts as well as the method of determining the significance of impacts is outlined in Appendix B. The assessment methodology enables the assessment of environmental issues including: cumulative impacts, the severity of impacts (including the nature of impacts and the degree to which impacts may cause irreplaceable loss of resources), the extent of the impacts, the duration and reversibility of impacts, the probability of the impact occurring, and the degree to which the impacts can be mitigated. Part A provides the approach for determining impact consequence (combining intensity, extent, and duration). Impact consequence and significance are determined from Part B and C. The consequence rating is considered together with the probability of occurrence to determine the overall significance of each impact. The interpretation of the impact significance is given in Part D. The significance of the impact can be related to the level of risk associated with a specific issue.

9.1 CONSTRUCTION

9.1.1 Issue: Change in Groundwater Levels and Gradient

Description of Impact

The construction phase of the SLF and smelter complex will entail clearing of the footprints, building of roads and other construction related activities. Increased permeability could cause localised altering of the flow and levels of the groundwater in the vadose zone/ shallow aquifer. The groundwater quantity impact during the construction phase is summarised in Table 9-2.

TABLE 9-2: CONSTRUCTION IMPACT SUMMARY – IMPACTS ON GROUNDWATER QUANTITY

Issue: Change in groundwater levels and flow patterns due to SLF and smelter complex construction		
Phases: Construction		
Criteria	Without Mitigation	With Mitigation
Intensity	Minor (Slight) change or disturbance	Minor (Slight) change or disturbance
Duration	Short term	Short term
Extent	Part of site	Part of site
Consequence	Low	Low
Probability	Probable	Conceivable
Significance	Very Low	Very Low
Degree to which impact can be reversed	The impact can be fully reversed once the construction period is completed and management measures are put in place and followed	
Degree to which impact may cause irreplaceable loss of resources	Very low	
Degree to which impact can be mitigated	Low as construction will require clearing of vegetation for infrastructure areas	
Residual impacts	The residual impact is considered to be VERY LOW with only minor impacts on groundwater resources and surrounding receptors.	

9.1.2 Issue: Deterioration of Groundwater Quality

Description of Impact

The construction phase of the SLF and smelter complex and associated infrastructure may result in potential groundwater contamination caused by diffuse pollution sources which includes ad hoc spills and discharges of polluting substances from vehicles, vehicle maintenance, accidents, and fuel storage (e.g. diesel and oil), etc. The groundwater quality impact during the construction phase is summarised in Table 9-3.

TABLE 9-3: CONSTRUCTION IMPACT SUMMARY – IMPACTS ON GROUNDWATER QUALITY.

Issue: Deterioration of groundwater quality due to construction of SLF and smelter complex		
Phases: Construction		
Criteria	Without Mitigation	With Mitigation
Intensity	Minor (Slight) change or disturbance	Minor (Slight) change or disturbance
Duration	Short term	Short term
Extent	Part of site	Part of site
Consequence	Low	Low
Probability	Probable	Conceivable
Significance	Very Low	Very Low
Degree to which impact can be reversed	The impact can be fully reversed once the construction period is completed and management measures are put in place and followed	
Degree to which impact may cause irreplaceable loss of resources	Very low	
Degree to which impact can be mitigated	High – compaction decreases permeability, proper storage, and containment of chemicals	
Residual impacts	The residual impact is considered to be VERY LOW with only minor impacts on groundwater resources and surrounding receptors.	

Groundwater Management

The following management measures should be implemented:

- Continuation of the site and farm groundwater monitoring plan.
- Good housekeeping, and adherence to good health and safety practices on site during construction.
- Supply of chemical toilets and regular maintenance of the toilets at sites where worker/contractor numbers are high.
- Establish good waste management practices on site, to include recycling, separation, and storage of hazardous waste at suitable lined/bunded areas.
- Have available oil spill kits in case of spills of hydrocarbon chemicals.

Monitoring

The following monitoring is recommended (See Monitoring Programme in Section 10):

- The continuation of the groundwater monitoring plan during construction should be focussed on the areas that are likely to be impacted on by construction activities.
    - This will ensure that water quality and water levels are continuously monitored. The collected information should be used as part of an active water management system and act as an early warning system which should be used for the application of mitigation measures - should the data show unacceptable levels of impacts.

The identified impacts during the construction phase are rated very low after mitigation and management measures are applied. These identified construction phase impacts are not likely to negatively affect any decisions on whether the proposed project should proceed.

9.2 OPERATION

9.2.1 Issue: Change in Groundwater Levels and Gradient

Description of Impact

The operation of the SLF may result in an increase in local groundwater levels and a change in groundwater gradient. However, no notable change in groundwater levels were observed for the proposed SLF and smelter areas from the numerical modelling results (section 8.8.2).

No notable change in groundwater levels were observed for the proposed SLF and smelter complex areas for Scenario 1 (worst-case) – Scenario 3 (liner installation), as described in section 8.7.7. As discussed in section 8.5.2, the total seepage emanating from the proposed SLF would be minimal if a Class A liner is installed and thus limiting any significant change in local and regional groundwater levels. This is largely attributed to the Class A liner, which according to the relevant guidelines the liner material cannot exceed a permeability of 1×10^{-7} cm/s (0.03 m/y or 8×10^{-5} m/d).

The groundwater quantity impact during the operational phase for the SLF is summarised in Table 9-4.

TABLE 9-4: OPERATIONAL IMPACT SUMMARY – IMPACTS ON GROUNDWATER QUANTITY FROM SLF.

Issue: Change in groundwater levels and flow patterns due to SLF operation		
Phases: Operational		
Criteria	Without Mitigation	With Mitigation
Intensity	Minor (Slight) change or disturbance	Minor (Slight) change or disturbance
Duration	Long term	Long term
Extent	Part of site	Part of site
Consequence	Low	Low
Probability	Definite	Conceivable
Significance	Low	Very Low
Degree to which impact can be reversed	Low during operational phase.	
Degree to which impact may cause irreplaceable loss of resources	Very low	
Degree to which impact can be mitigated	High – Class A liner will reduce seepage to the aquifer	
Residual impacts	The residual impact is considered to be VERY LOW with only minor impacts on groundwater resources and surrounding receptors.	

Water seepage to groundwater from the smelter complex was not modelled as it is expected that potential spillages from water and/or chemical storage facilities will only occur in extreme events. Therefore, the groundwater impact significance is very low to insignificant.

The groundwater quantity impact during the operational phase for the smelter is summarised in Table 9-5.

TABLE 9-5: OPERATIONAL IMPACT SUMMARY – IMPACTS ON GROUNDWATER QUANTITY FROM SMELTER.

Issue: Change in groundwater levels and flow patterns due to smelter complex operation		
Phases: Operational		
Criteria	Without Mitigation	With Mitigation
Intensity	Negligible	Negligible
Duration	Long term	Long term
Extent	Part of site	Part of site
Consequence	Low	Low
Probability	Possible	Unlikely
Significance	Low	Insignificant
Degree to which impact can be reversed	The impact can be mostly reversed if management measures are put in place and followed	
Degree to which impact may cause irreplaceable loss of resources	Very low	
Degree to which impact can be mitigated	High	
Residual impacts	The residual impact is considered to be VERY LOW with only minor impacts on groundwater resources and surrounding receptors.	

9.2.2 Issue: Deterioration of Groundwater Quality

Description of Impact

The operation of the SLF entails deposition of Jarofix with a moisture content of 30 to 40% which is trucked to the disposal site. ETP cake will also be disposed of in the SLF. The disposal site is currently planned to cover an area of 21 hectares, and to reach a maximum height of 25 m over a life of 15 years.

Contamination to groundwater from the smelter complex was not modelled as it is expected that potential spillages from water and/or chemical storage facilities will only occur in extreme events.

Sulphate, sodium, lead, and antimony were included in the operational phase numerical groundwater contaminant transport models for various seepage rate scenarios described in section 8.7.7. These chemical constituents were identified as from the geochemical assessment as potential contaminants (section 5.3 and section 7). The operational source terms for each of the potential contaminants are given in Table 7-2.

The numerical groundwater contaminant transport models at the end of the operational phase (15 years) resulted in a maximum plume migration of sulphate, sodium, lead, and antimony of ~600 m, ~580 m, ~600 m, and ~700 m respectively with the installation of the liner. Without the liner installation with seepage rates described in Scenario 1, all four contaminant plumes migrate approximately an additional ~100m from the SLF. The nearest privately owned farm borehole, DMBH06, was not affected by any of the four plumes and is approximately 1.7 km away from the worst-case Scenario 1 plume extents.

Although the change in seepage rates between Scenario 1 and Scenario 3 did not result in a significant change in the plume extents, the installation of a Class A liner does significantly reduce the contaminant salt load to the aquifer. As indicated in Table 8-8, the installation of the liner results in a decrease of up to 23% in total salt load to the aquifer. Since all contaminants were modelled as conservative tracers, a similar reduction in total mass flux for sodium, lead, and antimony were calculated as that of sulphate.

These identified operational phase impacts are localised and not likely to negatively affect any private groundwater resources or users. The groundwater quality impact during the operational phase from the SLF is summarised in Table 9-6.

TABLE 9-6: OPERATIONAL IMPACT SUMMARY – IMPACTS ON GROUNDWATER QUALITY

Issue: Deterioration of groundwater quality due to SLF and smelter complex operations		
Phases: Operational		
Criteria	Without Mitigation	With Mitigation
Intensity	Moderate change or disturbance	Minor (Slight) change
Duration	Long term	Long term
Extent	Part of site	Part of site
Consequence	Medium	Low
Probability	Probable	Conceivable
Significance	Medium	Very Low
Degree to which impact can be reversed	The impact cannot be reversed during operational period, but impact can be minimised if management measures are put in place and followed	
Degree to which impact may cause irreplaceable loss of resources	Medium as this impact will affect groundwater quality and the use of the resource during operations (within the site boundary)	
Degree to which impact can be mitigated	High. Liner installation and the mitigation and management measures can reduce the impact and better quantify the source terms	
Residual impacts	The residual impact is considered to be LOW with only localised impacts on groundwater resources, but with no surrounding receptors or groundwater users being affected negatively	

Water seepage and associated contamination to groundwater from the smelter complex was not modelled as it is expected that potential spillages from water and/or chemical storage facilities will only occur in extreme events. Therefore, the groundwater impact significance is very low to insignificant. The groundwater quantity impact during the operational phase for the smelter is summarised in Table 9-8.

TABLE 9-7: OPERATIONAL IMPACT SUMMARY – IMPACTS ON GROUNDWATER QUALITY FROM SMELTER.

Issue: Change in groundwater levels and flow patterns due to smelter complex operation		
Phases: Operational		
Criteria	Without Mitigation	With Mitigation
Intensity	Negligible	Negligible
Duration	Long term	Long term
Extent	Part of site	Part of site
Consequence	Low	Low
Probability	Possible	Unlikely
Significance	Low	Insignificant
Degree to which impact can be reversed	The impact can be mostly reversed if management measures are put in place and followed	
Degree to which impact may cause irreplaceable loss of resources	Very low	
Degree to which impact can be mitigated	High	
Residual impacts	The residual impact is considered to be VERY LOW with only minor impacts on groundwater resources and surrounding receptors.	

Groundwater Management

The following management measures should be implemented:

- Construction of the SLF with a Class A liner.
- Regular inspection of the SLF facility and leak detection measures.
- The site should ensure the water balance of the SLF is updated regularly, this data will benefit future groundwater modelling updates and predictions.
- Drilling of SLF specific monitoring boreholes to detect any potential groundwater plumes from the SLF. If environmentally unacceptable concentrations of constituents of concern are identified during monitoring, an updated hydrogeological study should be initiated to provide updated source term characteristics, aquifer characterisation, and possible plume containment measures (amongst others).
- The installation of lining systems in all surface water holding facilities, such as pollution control dams will minimise any potential seepage of poor water quality to the underlying groundwater systems.
- One of the most effective mitigation measures is the use and update of the existing numerical groundwater model as a management and predictive tool.
    - Long-term monitoring data and optimised groundwater monitoring network will provide valuable information to update and re-run the model at least every two years.
    - Updates to the model developed for the Smelter and SLF in future to include mining plan and processing activities. Regular updates will increase the prediction accuracy as well as providing long term trends and allowing for intervention and timeous prevention measures.

- Improved confidence in the existing geochemical assessment results can be obtained by the continuation of geochemical sampling and analyses during the operational phase, including:
  - Analysis of Jarofix produced in the local plant as soon as this becomes available.
  - Undertaking a detailed geochemical analysis of at least five representative Jarofix and ETP cake disposal samples, including the following static tests:
    - Chemical composition (whole sample and elemental analysis)
    - mineralogical analysis of the material to understand changes in composition as the Jarofix ages
    - acid-base accounting (ABA) and net acid generation (NAG)
    - water extraction tests
  - Conducting kinetic leach tests of at least two representative Jarofix disposal samples to confirm how the leachate quality will change with time.
  - Update the geochemical model to determine any changes in source term concentrations.
  - Undertaking a detailed mineralogical analysis of the material to understand changes in composition as the Jarofix ages.
- Additional laboratory analyses and unsaturated flow modelling to quantify seepage rates due to various closure capping options and the change in hydraulic conductivity as the Jarofix ages.
- Water seepage and associated contamination to groundwater from the smelter complex was not modelled as it is expected that potential spillages from water and/or chemical storage facilities will only occur in extreme events. It is assumed that the site will adhere to the following:
  - Refinery infrastructure, will be constructed and operated so as to comply with the NWA guidelines:
    - Clean water systems are separated from dirty water systems.
    - Clean run-off and rainfall water are diverted around dirty areas and back into the environment.
    - The size of dirty water areas is minimized, and dirty water is contained in systems that allow the reuse and/or recycling of this dirty water.
    - Discharges of dirty water may only occur in accordance with authorisations that are issued in terms of the relevant legislation specifications and they must not result in negative health impacts for downstream surface water users.
  - All hazardous chemicals (new and used), mineralized waste and non-mineralised waste must be handled in a manner that they do not pollute surface water. This will be implemented by means of the following:
    - Pollution prevention through basic infrastructure design.
    - Pollution prevention through maintenance of equipment.
    - Pollution prevention through education and training of workers (permanent and temporary).

    - Pollution prevention through appropriate management of hazardous materials.
    - The required steps to enable containment and remediation of pollution incidents.
  - The design of potentially polluting structures will take account of the requirements for long term surface water pollution prevention.

Monitoring

The following monitoring is recommended (See Monitoring Programme in Section 10):

- Continuation and expansion of the site and regional groundwater monitoring plan.
  - It is recommended to drill at least two additional boreholes around the proposed SLF and at least one additional borehole around the proposed smelter complex site. The monitoring borehole locations are illustrated in Figure 10-1.
  - It is recommended that at least one borehole at the SLF and one borehole at the smelter complex area is equipped with a long-term water level measurement transducer.
  - This will ensure that water quality and water levels are continuously monitored. The collected information should be used as part of an active water management system and act as an early warning system which should be used for the application of mitigation measures - should the data show unacceptable levels of impacts.
- Regular groundwater model updates should provide recommendations to the existing site groundwater monitoring network.

These identified operational phase groundwater quantity and quality impacts are localised to the facilities and is not likely to negatively affect any private/ surrounding groundwater resources or users.

9.3 DECOMMISSIONING AND CLOSURE

9.3.1 Issue: Change in Groundwater Levels and Gradient

Description of Impact

The decommissioning and closure of the SLF may result in a continuation of increased local groundwater levels resulting from the operational phase. No notable change in groundwater levels were observed for the proposed SLF and smelter complex areas from the numerical modelling results (section 8.8.3). Similar to the operational phase, the total seepage emanating from the proposed SLF will be minimal and thus limiting any significant change in local and regional groundwater levels. This is largely attributed to the SLF being required to be constructed with a Class A liner which will limit seepage to groundwater resources by at least one order of magnitude compared to no liner installation. Furthermore, the rehabilitation of the smelter complex area and SLF (cap installation) is expected to further improve the potential impact on local groundwater levels and gradient.

The groundwater quantity impact during the closure phase from the SLF and smelter is summarised in Table 9-8 and Table 9-9 respectively.

TABLE 9-8: DECOMMISSIONING/ CLOSURE IMPACT SUMMARY – IMPACTS ON GROUNDWATER QUANTITY FROM SLF

Issue: Change in groundwater levels and flow patterns due to SLF decommissioning and closure		
Phases: Decommissioning and closure		
Criteria	Without Mitigation	With Mitigation
Intensity	Minor (Slight) change or disturbance	Minor (Slight) change or disturbance
Duration	Long term/ Permanent	Long term/ Permanent
Extent	Part of site	Part of site
Consequence	Low	Low
Probability	Probable	Conceivable
Significance	Low	Very Low
Degree to which impact can be reversed	The impact can be reversed to a large degree once the smelter complex and SLF have been rehabilitated	
Degree to which impact may cause irreplaceable loss of resources	Very low	
Degree to which impact can be mitigated	High	
Residual impacts	The residual impact is considered to be VERY LOW with only minor impacts on groundwater resources and surrounding receptors.	

TABLE 9-9: DECOMMISSIONING/ CLOSURE IMPACT SUMMARY – IMPACTS ON GROUNDWATER QUANTITY FROM SMELTER.

Issue: Change in groundwater levels and flow patterns due to smelter complex decommissioning and closure		
Phases: Decommissioning and closure		
Criteria	Without Mitigation	With Mitigation
Intensity	Negligible	Negligible
Duration	Long term/ Permanent	Long term/ Permanent
Extent	Part of site	Part of site
Consequence	Low	Low
Probability	Possible	Unlikely
Significance	Low	Insignificant
Degree to which impact can be reversed	The impact can be mostly reversed if management measures are put in place and followed	
Degree to which impact may cause irreplaceable loss of resources	Very low	
Degree to which impact can be mitigated	High	
Residual impacts	The residual impact is considered to be VERY LOW with only minor impacts on groundwater resources and surrounding receptors.	

9.3.2 Issue: Deterioration of Groundwater Quality

Description of Impact

The decommissioning and closure of the smelter complex and SLF will involve rehabilitation of the areas and facilities.

Sulphate, sodium, lead, and antimony were included in the closure phase numerical groundwater contaminant transport models for various seepage rate scenarios described in section 8.7.7. These chemical constituents were identified as from the geochemical assessment as potential contaminants (section 5.3 and section 7). The operational source terms for each of the potential contaminants are given in Table 7-2.

The numerical groundwater contaminant transport models at the end of the closure phase (50 years) resulted in a maximum plume migration of sulphate, sodium, lead, and antimony of ~850 m, ~600 m, ~800 m, and ~1 000 m respectively with the installation of the liner. Without the liner installation with seepage rates described in Scenario 6, all four contaminant plumes migrate approximately an additional ~120 m from the SLF. The nearest privately owned farm borehole, DMBH06, is not affected by any of the four plumes and is approximately 1.3 km away from the worst-case Scenario 1 plume extents.

Although the change in seepage rates between Scenario 4 (worst-case) and Scenario 6 (liner installation) did not result in a significant change in the plume extents, the installation of a Class A liner does significantly reduce the contaminant salt load to the aquifer. As indicated in Table 8-9, the installation of the liner results in a decrease of up to 23% in total salt load to the aquifer. Since all contaminants were modelled as conservative tracers, a similar reduction in total mass flux for sodium, lead, and antimony were calculated as that of sulphate.

These identified decommissioning/ closure phase impacts are localised and not likely to negatively affect any private groundwater resources or users. The groundwater quality impact during the construction phase is summarised in Table 9-10.

TABLE 9-10: DECOMMISSIONING/ CLOSURE IMPACT SUMMARY – IMPACTS ON GROUNDWATER QUALITY FROM SLF.

Issue: Deterioration of groundwater quality due to SLF and smelter complex decommissioning and closure		
Phases: Decommissioning and closure		
Criteria	Without Mitigation	With Mitigation
Intensity	Moderate change or disturbance	Minor (Slight) change
Duration	Long term/ Permanent	Long term/ Permanent
Extent	Part of site	Part of site
Consequence	Medium	Low
Probability	Probable	Conceivable
Significance	Medium	Very Low
Degree to which impact can be reversed	The impact cannot be reversed fully but impact can be minimised if management measures and closure/rehabilitation plans are put in place and followed	
Degree to which impact may cause irreplaceable loss of resources	Medium as this impact will affect groundwater quality and the use of the resource after closure (within the site boundary)	
Degree to which impact can be mitigated	Medium as mitigation and management measures can reduce the impact and better quantify the source terms during closure	
Residual impacts	The residual impact is considered to be LOW with only localised impacts on groundwater resources, but with no surrounding receptors or groundwater users being affected negatively	

Water seepage and associated contamination to groundwater from the smelter complex was not modelled as it is expected that potential spillages from water and/or chemical storage facilities will only occur in extreme events. Additionally, once the removal of surface infrastructure and rehabilitation have taken place, this will reduce potential pollution sources from site. Therefore, the groundwater impact significance is very low to insignificant. The groundwater quality impact during the decommissioning/ closure phase for the smelter is summarised in Table 9-11.

TABLE 9-11: DECOMMISSIONING/ CLOSURE IMPACT SUMMARY – IMPACTS ON GROUNDWATER QUALITY FROM SMELTER.

Issue: Change in groundwater levels and flow patterns due to smelter complex operation		
Phases: Decommissioning and closure		
Criteria	Without Mitigation	With Mitigation
Intensity	Negligible	Negligible
Duration	Long term/ Permanent	Long term/ Permanent
Extent	Part of site	Part of site
Consequence	Low	Low
Probability	Possible	Unlikely
Significance	Low	Insignificant
Degree to which impact can be reversed	The impact can be mostly reversed if management measures are put in place and followed	
Degree to which impact may cause irreplaceable loss of resources	Very low	
Degree to which impact can be mitigated	High	
Residual impacts	The residual impact is considered to be VERY LOW with only minor impacts on groundwater resources and surrounding receptors.	

Groundwater Management

The following management measures should be implemented:

- The smelter complex site and SLF should be rehabilitated according to the approved site closure and rehabilitation plan in the line with the contents of National Water Act (Act No 36 of 1998) and National Environmental Management Act (Act 107 of 1998), to avoid subsequent negative environmental impacts that may occur.
- It is recommended that the site conduct a hydrogeological closure assessment.
    - The general closure objective would be to implement an environmental protection strategy to prevent any residual impacts on the environment, restore the land so that it may be suitable for the proposed end land use and obtain expedient closure.
    - All rehabilitation measures should be designed to facilitate a gradual reduction in the potential and identified hydrogeological environmental impacts caused by the entire Gamsberg mining operation.
- Continuation of the site and regional groundwater monitoring plan.

  - Frequency of monitoring and the groundwater closure monitoring network should be determined from a hydrogeological closure assessment.

- One of the most effective mitigation measures is the use of numerical groundwater model as a management and predictive tool.
  - Long-term monitoring data and optimised groundwater monitoring network will provide valuable information to update and re-run the model at least every two years during closure.
  - The updated groundwater model should be used in the closure modelling and closure planning.
  - Updates to the model will have to include mining plan, infrastructure data, and rehabilitation and closure options. Regular updates will increase the prediction accuracy as well as providing long term trends and allowing for intervention and timeous prevention measures.
  - The update of the numerical groundwater model for closure modelling and planning should include an updated geochemical assessment and model to characterise the closure source terms more accurately.

Monitoring

The following monitoring is recommended (See Monitoring Programme in Section 10):

- Continuation of the site and regional groundwater monitoring plan.
  - It is recommended that long-term groundwater level measurement transducers are maintained and operated during closure.
  - This will ensure that water quality and water levels are continuously monitored. The collected information should be used as part of closure water management system and act as an early warning system which should be used for the application of mitigation measures - should the data show unacceptable levels of impacts.
- Regular groundwater model updates should provide recommendations to the existing site groundwater monitoring network and any required changes.

These identified decommissioning and closure phase groundwater quantity and quality impacts are localised to the facilities and is not likely to negatively affect any private/ surrounding groundwater resources or users.

9.4 CUMULATIVE IMPACTS

The approach for assessing cumulative impacts and effects resulting from the project and another activities affecting the same resource/receptor is based on a consideration of the approval/existence status of the 'other' activity and the nature of information available to aid in predicting the magnitude of impact from the other activity.

Cumulative impacts from the entire mining activities within the mining right area are not anticipated. Other sources of groundwater impacts are the open pit mining operations, waste rock dump and tailings storage facility. These areas and facilities were previously investigated by SRK (2010) and ERM (2013a). Impacts predicted included a drawdown cone development around the pit area due to dewatering. The drawdown of groundwater levels around the mine were predicted to capture and prevent the migration of any potential contaminant plume migration beyond the pit and waste rock dump during the operational phase. The impact prediction on groundwater levels during the closure phase made by ERM (2013a) indicated that groundwater levels will not recover around the pit area and will continue to act as a groundwater sink due to high evaporation rates, which will prevent the migration of any potential contaminant plumes away from the pit area. However, SLR Consulting received feedback from the client (email from Pieter David Venter, 14 January 2020) that future mining will not progress below regional groundwater levels and that the geology in the area is such that the mountain aquifer is not connected with the aquifer in the plains/ valley. If this is the case, then no groundwater drawdown in anticipated. SLR was not tasked to conduct hydraulic testing and no hydraulic properties available to confirm these findings. Should future mining plans indicate mining depths below regional groundwater level, then an intrusive groundwater assessment should be conducted (including hydraulic aquifer testing), to prove the two aquifers are not connected and separated by a distinct geological unit acting as a barrier to groundwater flow. Nonetheless, this will change the predictions made by SRK (2010) and ERM (2013a) regarding potential contaminant plumes being captured by the drawdown cone due to mine dewatering.

A seepage analysis was conducted by SRK (2010) for the tailings dam to the northwest using underdrains beneath the underflow material in the wall zone of the tailings dam and cut off trenches, 5 m deep, around the proposed site. The results of the seepage analysis indicate a total flow to the cut off trench of 622 m^3/hour and the total flow not intercepted by the cut off trenches was <1 m^3/annum. Therefore, SRK (2010) predicted that virtually no seepage to the underlying groundwater will occur and the potential of any contaminant movement into the groundwater was insignificant. It is anticipated that impact on groundwater quality from the existing TSF will continue to be insignificant, assuming all factors, assumptions, and limitations made by SRK (2010) remain to be true.

Current site and privately-owned regional borehole monitoring results indicated that between November 2017 and April 2019 there was no indication of pollution emanating from the Gamsberg Zinc Mine site that could affect the groundwater quality of the surrounding farm boreholes.

Groundwater levels of the monitoring network boreholes were quasi-stable and there were no adverse effects due to the pit dewatering affecting mine and regional groundwater levels.

The monitoring results between November 2017 and April 2019 indicated that current mining operations that include the pit areas, waste rock dump and tailings storage facility were not affecting groundwater quality and levels. Since the impacts from the open pit mining, existing TSF and WRD were excluded from this study, limited information and data were available for these facilities to aid in predicting the potential impact from these facilities in the long term.

Future groundwater investigations (including groundwater modelling) should include the cumulative impacts of the entire mining operations, such as the waste rock dumps and open pit mining, as these may impact potential groundwater levels and plume migration, since previous predictions made by SRK (2010) and ERM (2013a) assumed mining below regional groundwater levels, which would result in drawdown cone development during the operational and closure phases and preventing the migration of any potential contaminant plume away from the open pit area.

10 GROUNDWATER MONITORING SYSTEM

10.1 GROUNDWATER MONITORING NETWORK

10.1.1 Source, Plume, Impacts and Background Monitoring

The monitoring network design should comply with the risk-based source-pathway-receptor principle. The source-pathway-receptor model provides a conceptual portrayal of the mode through which contaminants act and the potential harm they may inflict on a receiving water body and/or organism.

The conceptual model and numerical model results are used to develop management action plans and reclamation alternatives that are directed towards mitigating potentially harmful effects caused by the contaminants of concern. Refer to the conceptual site model discussion under section 8.6 for a more detailed discussion on interaction between potential sources of contamination and receptors that could be affected using the source – pathway – receptor methodology.

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

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

Continual monitoring is required:

- To detect the actual and confirm predicted impact on groundwater quality.
- To assess whether the mitigation measures given in section 9 are effective and provide for the update of mitigation measures where necessary.
- Numerical groundwater and geochemical models can be updated and refined based on new information to support adaptive management measures.
    - Model confidence levels can be increased, and groundwater impacts be predicted with more accuracy. With updated and high confidence predictions, Gamsberg mine can act in a pre-emptive manner, thus reducing risks, rather than acting retrospectively when monitoring data reveals a problem.
- To interrogate unknowns identified in this report, in which various field investigations can be carried out to test and improve the conceptual hydrogeological understanding of the aquifer system.
- Allow groundwater monitoring borehole network optimisation.
- Assess compliance with statutory mine and water management licence conditions.

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

The Gamsberg Zinc Mine currently has a groundwater monitoring network consisting of 22 surrounding privately-owned farm areas and 31 mine property boreholes.

The 22 privately-owned farm boreholes serve as background monitoring for groundwater level and quality for the main receiving receptors outside of the mine site boundary. The 31 mine groundwater monitoring boreholes consist of:

- Early warning of pit dewatering/ monitoring boreholes/ background water quality boreholes – 7 boreholes
- Gamsberg mountain aquifer and groundwater level monitoring – 3 boreholes
- Point pollution areas – 5 boreholes
- Tailings dam and holding dam areas – 16 boreholes

10.1.2 Monitoring Frequency

Monitoring frequency on quarterly basis for boreholes is recommended.

10.2 MONITORING PARAMETERS

The existing groundwater level monitoring should continue to be monitored for groundwater levels.

The existing water quality parameters should be continued to be monitored:

- Chemical parameters:
    - Anions and cations (Na, Ca, Mg, Ca, Mg, K, Cl, SO_4, F, nitrate (NO_3-N), Fe, Zn, Pb, Al, Cd, Cu, Mn, and U.
    - Other parameters (pH, EC, TDS, and total alkalinity).

The following parameters, based on findings from this study, are proposed to be included in the water monitoring programme:

- Physical in-field parameter observations:
    - Colour/ clarity, temperature, oxidation-reduction potential (ORP) and odour.
- Anions and cations (Sb, Hg, As, Se, PO_4, Total Cr and Cr (VI), nitrite, and Ba).
- Petroleum hydrocarbons contaminants (where applicable, near workshops and petroleum handling facilities).
- Sewage related contaminants (E.coli, faecal coliforms) in surface water and boreholes in proximity to septic tanks or sewage plants.

The groundwater monitoring network should be reviewed and updated (where necessary) together with any numerical groundwater model update studies.

10.2.1 Monitoring Database

The groundwater-monitoring database (quality and quantity) should be expanded to include the Smelter infrastructure ground water monitoring network. It is recommended that the data continue to be stored in a dedicated database and that quarterly and annual reports continue to be generated for mine management.

10.3 MONITORING BOREHOLES

It is recommended that the status quo surface and groundwater monitoring programme be continued, as given in Table 10-1. Three (3) new monitoring boreholes are recommended to be drilled within the SLF and smelter complex areas. The three new boreholes are described in more detail in Table 10-2 and illustrated in Figure 10-1.

TABLE 10-1: RECOMMENDED GAMSBERG MINE GROUNDWATER MONITORING FREQUENCY AND PARAMETERS.

Monitoring position	Sampling interval	Analysis	Water Quality Standards
Existing Gamsberg Mine monitoring network – Regional Boreholes			
Water Level Monitoring AR12, DMBH06, KGT78, KGT3, KMBH01, KGT1, KMBH04, NAM3, NAM2, NAM1, NMBH02, WIT1, KOMBH03, AROAMS01, AROAMS02, AMBH05, ACH2, ACH4, ACH3, ACH1	Minimum Quarterly: measuring the depth of groundwater levels	N/A	N/A
Water Quality Monitoring AR11, AR12, KGT78, KGT3, KGT1, NAM3, NAM2, NAM1, WIT1, AROAMS01, AROAMS02, ACH2, ACH4, ACH3, ACH1	Quarterly: sampling for cations, anions and ICP metal scan	Full analysis quarterly	- SANS Drinking Water Standards, - South African Water Quality Guidelines: Domestic Use, - DWA Livestock water guidelines 1996, - Site IWUL
Existing Gamsberg Mine monitoring network – Mine Boreholes			
Water Level Monitoring BLH3, GAMS1, MH01, MH02, MH03, MH10, GAMS2, GAMB1, GAMS3, GAMS8, MH04, MH05, MH06, MH07, AR11, AR10, AR09, AR07, MBH17, SOLAR PUMP BH, MH08, MH09, GBTSF2, GBTSF3, GBTSF4, GBTSF5, GBTSF6, GBTSF7, GBTSF8, GBTSF9 2 of above boreholes	Quarterly: measuring the depth of groundwater levels Equipped with automatic water level datalogger for continuous monitoring	N/A	N/A
Water Quality Monitoring BLH3, GAMS1, MH01, MH02, MH03, MH10, GAMS2, GAMB1, GAMS3, GAMS8, MH04, MH05, MH06, MH07, AR11, AR10, AR09, AR07, MBH17, SOLAR PUMP BH, MH08, MH09,	Quarterly: sampling for cations, anions and ICP metal scan	Full analysis quarterly	- SANS Drinking Water Standards,

Monitoring position	Sampling interval	Analysis	Water Quality Standards
GBTSF2, GBTSF3, GBTSF4, GBTSF5, GBTSF6, GBTSF7, GBTSF8, GBTSF9			- South African Water Quality Guidelines: Domestic Use, - DWA Livestock water guidelines 1996, - Site IWUL
New recommended boreholes to be added to mine monitoring network			
Water Level Monitoring GB_SLF_01, GB_SLF_02, GB_SMT_01	Quarterly: measuring the depth of groundwater levels	N/A	N/A
Water Quality Monitoring GB_SLF_01, GB_SLF_02, GB_SMT_01	Quarterly: sampling for cations, anions and ICP metal scan	Full analysis quarterly	- SANS Drinking Water Standards, - South African Water Quality Guidelines: Domestic Use, - DWA Livestock water guidelines 1996, - Site IWUL

TABLE 10-2: RECOMMENDED NEW MONITORING BOREHOLE DETAILS.

Borehole ID	X	Y	BH Purpose
	UTM 34 South (WGS84)		
GB_SLF_01	299770.702	6766218.247	Up gradient of SLF
GB_SLF_02	298642.612	6765493.123	Down gradient of SLF
GB_SMT_01	300986.992	6766712.313	Smelter complex monitoring

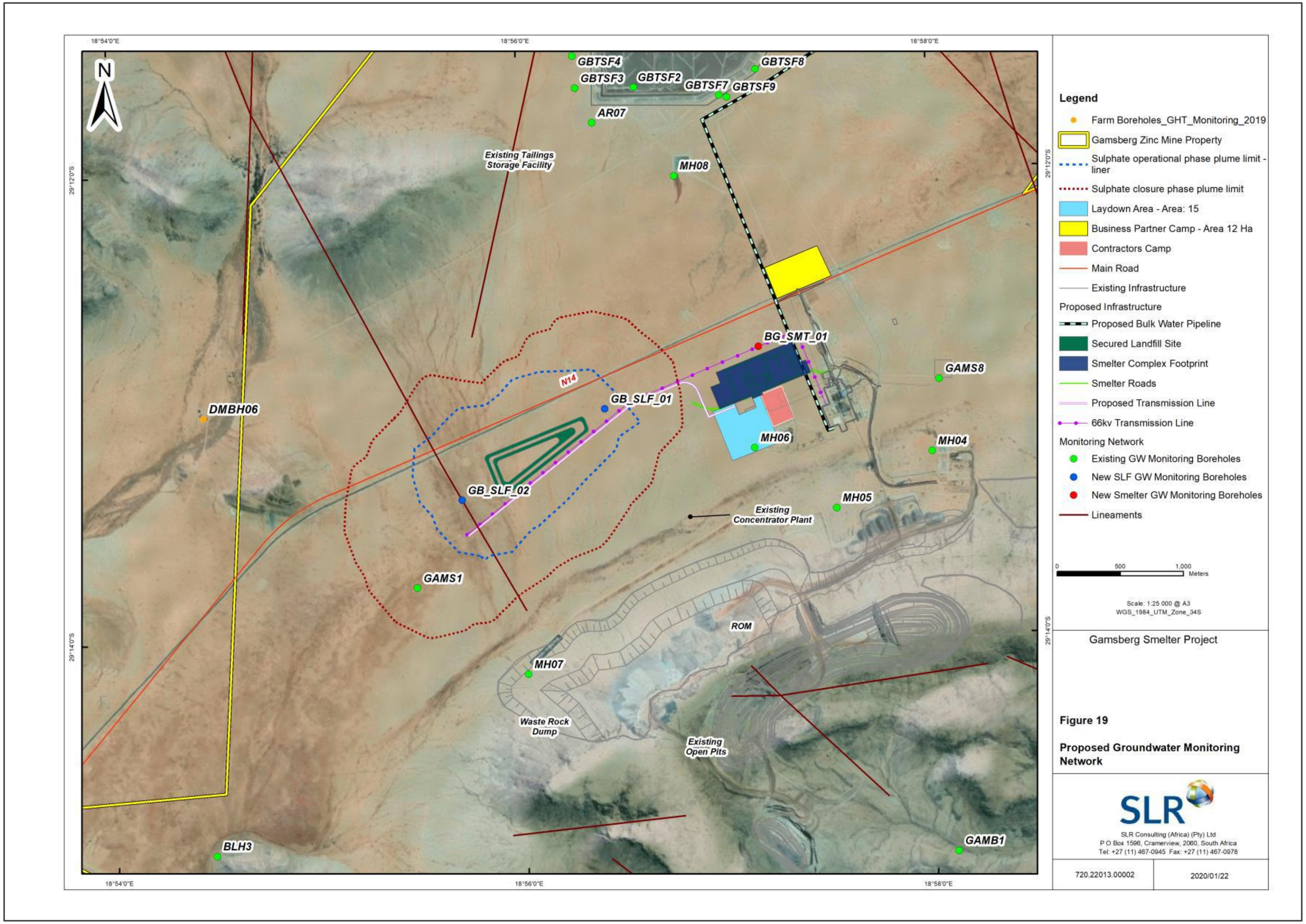


FIGURE 10-1: POSITIONS OF RECOMMENDED ADDITIONAL MONITORING BOREHOLES FOR PROPOSED SLF AND SMELTER COMPLEX.

11 GROUNDWATER ENVIRONMENTAL MANAGEMENT PROGRAMME

11.1 CURRENT GROUNDWATER CONDITIONS

The present groundwater conditions do not indicate any type of impact on the groundwater environment. Refer to the prevailing groundwater conditions (section 5), more specifically the groundwater levels (section 5.5) and groundwater quality (section 5.6) for additional detail on current groundwater conditions on site.

11.2 PREDICTED IMPACTS OF FACILITY

Water seepage and associated contamination to groundwater from the smelter complex is not expected as potential spillages from water and/or chemical storage facilities is only expected to occur in extreme events.

No significant impact on groundwater levels are expected around the smelter area and SLF. The average modelled operational and closure phase groundwater levels were determined to range between 40 mbgl (868 mamsl) and 44 mbgl (864 mamsl), respectively. A deterioration in groundwater quality was the most significant risk associated with the proposed SLF. During the operational phase of the SLF, concentrations of sulphate, sodium, lead, and antimony are expected to increase above current background levels (section 8.8.2). The numerical groundwater flow model was setup to predict the potential impact from contaminants of concern identified by the geochemical modelling (section 7.6) with various seepage rates. Seepage rates were estimated for operational and closure phases for unconsolidated and consolidated material as well as installation of a Class A liner.

11.3 MITIGATION MEASURES

Potential contaminant plumes of sulphate, sodium, lead, and antimony are expected to emanate from the proposed SLF. The maximum operational and closure phase plume extent is expected to be ~700 m and ~1 000 m, respectively. No sensitive receptors' boreholes are located within this potential plume development area.

The main mitigation measures are to install a Class A liner for the SLF and to continue groundwater monitoring, and to update the numerical groundwater model and geochemical assessment periodically. The installation of a Class A liner significantly reduce the potential contaminant salt load to the aquifer, as indicated in section 8.8. Additional operational mitigation measures are given in section 9.2.

12 POST CLOSURE MANAGEMENT PLAN

12.1 REMEDIATION OF PHYSICAL ACTIVITY

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

12.2 REMEDIATION OF STORAGE FACILITIES

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

12.3 REMEDIATION OF WATER RESOURCES IMPACTS

The groundwater monitoring programme as outlined and discussed in this report should be implemented and reviewed regularly and updated if necessary. Monitoring of the groundwater system must be implemented to act as an early warning system, especially in the smelter complex and SLF areas. Should impacts be identified, management and mitigation measures must be implemented to prevent or reduce potential impacts on the groundwater environment as far as possible.

13 CONCLUSION AND RECOMMENDATIONS

13.1 GEOCHEMICAL AND WASTE ASSESSMENT

Samples of the tailings, Jarosite, Jarofix, Jarosite composite (93% tailings mixed with 7% of Jarosite), and Jarofix composite (93% tailings mixed with 7% of Jarofix) were submitted to UIS Laboratory for waste classification analyses. The distilled water tests performed on the samples were in accordance with the classification guidelines and were classed against the various thresholds for TC and LC.

The disposal of Jarofix on the SLF was selected as the preferred alternative by the client for the following reasons:

- The Jarosite has leachable concentrations which exceed the LCT3 value preventing disposal without treatment.
- The co-disposal of Jarosite or Jarofix with tailings would require a Class C liner. The existing liner for the tailings does not conform to a Class C (the tailings facility was constructed prior to the enactment of Regulation 635 and Regulation 636).
- Jarosite or Jarofix co-disposed with tailings material may not be stable in the long term due to the potential for acidification of the tailings material. The tailings had total sulphur content of close to 10% which is anticipated to be present largely as sulphide, therefore it has a high potential for ARD in the long term.

The Jarofix material was classified as a Type 1 waste requiring a Class A liner based on the following:

- Lead exceeded the TCT2 guideline values;
- Antimony exceeded the TCT1 guideline values and was within the limits of TCT2;
- Arsenic, barium, cadmium, copper, fluoride, mercury, and zinc exceeded the TCT0 guideline values and were within the limits of TCT1; and
- Sulphate, arsenic, cadmium, nickel, and antimony exceeded the LCT0 and SANS 241-1:2015 guideline values and were within the limits of LCT1.

13.2 GROUNDWATER LEVELS

The average groundwater levels measured during the Golder (2007), SRK (2010), and ERM (2013a) hydrocensus investigations were 31.7 mbgl, 28.1 mbgl, and 29.4 mbgl, respectively. The groundwater levels ranged between artesian conditions and 178.8 mbgl.

Regional monitoring boreholes had an average groundwater level of 30.8 mbgl and ranged between 8.6 mbgl and 78.9 mbgl for the April 2019 monitoring round. The mine monitoring boreholes had an average groundwater level of 30.6 mbgl and ranged between 11.6 mbgl and 52.3 mbgl for the April 2019 monitoring round. Groundwater levels of the monitoring network boreholes were quasi-stable and there were no adverse effects due to the pit dewatering affecting mine and regional groundwater levels.

13.3 GROUNDWATER QUALITY

Results from the previous hydrocensus investigations showed pH ranged between 5.81 and 8.67 with an average value of 7.49. The electrical conductivity ranged between 16 mS/m and 1 626 mS/m with an average value of 161 mS/m. The sulphate concentrations ranged between 14.6 mg/L and 1 706 mg/L with an average concentration of 163.9 mg/L.

Groundwater monitoring results conducted between November 2017 and April 2019 indicated the pH of the groundwater samples ranged between 6.57 and 8.44 with an average value of 7.51. The electrical conductivity ranged between 33 mS/m and 1 141 mS/m with an average value of 229 mS/m. The sulphate concentrations ranged between 28.5 mg/L and 2 324 mg/L with an average concentration of 289.3 mg/L.

The previous hydrocensus investigations and groundwater monitoring results showed several constituents that were elevated above relevant guideline limits. Parameters included EC, TDS, Na, Ca, Mg, Cl, SO_4, F, NO_3-N, As, Pb, Fe, Mn, and U.

Processes of evaporation and long-residence time or the host rock mineralogy (apatite-bearing rocks) may result in elevated fluoride concentrations. Elevated fluoride in groundwater is a characteristic feature of the Northern Cape. SRK (2010) concluded from the Piper diagrams that the chemical composition of the water from the area under investigation has undergone natural base-exchange and precipitation processes. The hydrochemistry of the Gamsberg area was interpreted by SRK (2010) to be indicative of a mature hydrochemical environment with very limited recharge, which generally only takes place in years of exceptionally high precipitation. The piper diagrams for April 2019 of the Gamsberg mine and regional monitoring boreholes confirmed the SRK (2010) findings that the groundwater is indicative of a mature hydrochemical environment with very limited recharge.

GHT Consulting concluded that between November 2017 and April 2019 there was no indication of pollution emanating from the Gamsberg Zinc Mine site that could affect the groundwater quality of the surrounding farm boreholes.

13.4 CURRENT GROUNDWATER CONDITIONS

The present groundwater conditions do not indicate any type of impact on the groundwater environment.

13.5 PREDICTED IMPACTS OF FACILITY

Water seepage and associated contamination to groundwater from the smelter complex is not expected as potential spillages from water and/or chemical storage facilities is only expected to occur in extreme events.

No significant impact on groundwater levels were determined around the smelter area and SLF. The average modelled operational and closure phase groundwater levels were determined to range between 40 mbgl (868 mamsl) and 44 mbgl (864 mamsl), respectively. A deterioration in groundwater quality was the most significant risk associated with the proposed SLF. During the operational phase of the SLF, concentrations of sulphate, sodium, lead, and antimony are expected to increase above current background levels. The numerical groundwater flow model was setup to predict the potential impact from contaminants of concern identified by the geochemical modelling (section 7.6) with various seepage rates. Seepage rates were estimated for operational and closure phases for unconsolidated and consolidated material as well as installation of a Class A liner.

Potential contaminant plumes of sulphate, sodium, lead, and antimony are expected to emanate from the proposed SLF. The maximum operational and closure phase plume extent is expected to be maximum ~700 m and ~1 000 m from the SLF, respectively, predominantly in a south-westerly direction. No sensitive receptors' boreholes are located within this potential plume development area.

13.6 WATER MANAGEMENT PLAN

The main mitigation measures during the operational and closure phases are to install a Class A liner for the SLF, to continue groundwater monitoring (including recommended additional monitoring boreholes), and to update the numerical groundwater model and geochemical assessment periodically. Additional operational and closure mitigation measures are described in more detail in the report (section 9).

13.7 HYDROGEOLOGICAL SPECIALIST RECOMMENDATION

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

end of report

Raymond Minnaar	Kate Hamilton	Mihai Muresan
(Report Author)	(Project Manager)	(Project Reviewer)

14 REFERENCES

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APPENDICES

APPENDIX A: SPECIALIST CURRICULUM VITAE

CURRICULUM VITAE

RAYMOND MINNAAR

HYDROGEOLOGIST

Hydrogeology, Africa Region

QUALIFICATIONS

MSc	2019	Engineering and Environmental Geology (Hydrogeology), University of Pretoria
BSc (Honours)	2014	Engineering and Environmental Geology (Hydrogeology), University of Pretoria
BSc	2013	Engineering and Environmental Geology, University of Pretoria

EXPERTISE

- Mining hydrogeology
- Groundwater modelling
- Groundwater impact assessments
- Dewatering modelling
- Groundwater management

Raymond Minnaar is a Hydrogeologist and has 6 years' experience in the mining hydrogeology industry within South Africa, Namibia, Botswana, Mozambique, Lesotho, Zambia, and the DRC. His experience includes mining related hydrogeological investigations: numerical modelling of the impacts on groundwater regimes in terms of flow and contaminant transport (MODFLOW and FEFLOW).

Raymond completed BSc, BSc Honours and MSc degrees in Engineering and Environmental Geology with specialization Hydrogeology at the University of Pretoria, is a registered Professional Natural Scientist with SACNASP and Professional Member of the Water Institute of Southern Africa.

PROJECTS

Mine Closure Groundwater Modelling, UMK Mine, Hotazel, Northern Cape, South Africa (2020)	Modelling of mine closure scenarios with updated LOM plans.
Water Quality Monitoring, UMK Mine, Hotazel, Northern Cape, South Africa (2019 - 2020)	Management of IWUL groundwater monitoring project. Compliance of surface water and groundwater to IWUL conditions (organic and inorganic). Annual report review and project management.
Water Quality Monitoring, Tshipi Borwa Mine, Hotazel, Northern Cape, South Africa (2019 – 2020)	Management of IWUL groundwater monitoring project. Compliance of surface water and groundwater to IWUL conditions (organic and inorganic). Annual report review and project management.
Hydrogeological Assessment, Majuba Power Station Ash Disposal, Gemini, Amersfoort, Mpumalanga, South Africa (2019 - 2020)	Hydrogeological opinion assessment to determine the potential impacts due to the expansion of the existing ash disposal facility.

SLR

Hydrogeolgoical Assessment, Tshipi Borwa Mine, Hotazel, Northern Cape, South Africa (2019)	Hydrogeological assessment to determine the cause of water level decreases at the site's monitoring boreholes, review the site's monitoring network, determine the impact from contaminants of concern on site and recommend control measures.
Hydrogeological Specialist Study - Gamsberg Smelter EIA, Vendanta, Pofadder, Northern Cape, South Africa (2019)	Specialist hydrogeological study for the Gamsberg Smelter Project EIA. Work included data review of site monitoring data, interpretation of geophysical survey data, conceptual modelling, numerical groundwater transport modelling to determine the impact from the TSF, landfill & smelter sites.
Hydrogeological Assessment, Tutuka Power Station Ash Disposal, Eskom, Standerton, Mpumalanga, South Africa (2019)	Review of specialist reports and site monitoring data to verify potential groundwater impacts due to ash disposal facility management and planned ash dump extension.
Hydrogeological Assessment, Dorstfontein West Coal Mine, Exxaro, Kriel, Mpumalanga, South Africa (2019)	Update of hydrogeological study to determine impacts due to increased waste disposal facility and updated underground mine plans. Tasks included hydrocensus, groundwater sampling, monitoring and site data review, conceptual model update, numerical groundwater flow and transport model update and AMD treatment plan (conceptual).
Hydrogeological Assessment - Acid Mine Drainage Plan, Dorstfontein East Coal Mine, Exxaro, Kriel, Mpumalanga, South Africa (2019)	Update of hydrogeological study (numerical modelling) to include an AMD treatment plan (conceptual) in order to comply with DWS requirements. Review and determine any impact on hydropedology.
Hydrogeological Assessment, 2Seam Coal Mine, Kriel, Mpumalanga, South Africa (2019)	Model update of previous hydrogeological study to determine groundwater impacts due to new open pit design. Update of groundwater management plan.
IWUL Water Monitoring Assessment, Thabazimbi Mine, ArcelorMittal, Thabazimbi, Limpopo, South Africa (2018 - 2019)	Management of IWUL groundwater monitoring project. Compliance of drinking water, surface water and groundwater to IWUL conditions. Recommendations for amendments to IWUL conditions and monitoring localities.
Hydrogeological Assessment & Packer Testing Programme, Comide Mine, ERG Africa, Kolwezi, DRC (2018 - 2019)	Packer testing of selected inclined diamond core boreholes in order to determine the permeability of selected geological units. Recommend further testing and update of numerical groundwater model for dewatering requirements.
Hydrogeological Assessment, Thabazimbi Mine, ArcelorMittal, Thabazimbi, Limpopo, South Africa (2017 - 2019)	Groundwater model update for the Thabazimbi Mine Closure Assessment and included tasks such as data interpretation, conceptual modelling, numerical flow and transport modelling in order to determine impact due to mine closure.
Groundwater Monitoring Assessment, Thabazimbi Mine, ArcelorMittal, Thabazimbi, Limpopo, South Africa (2018)	Annual report giving the results of the 2018 bi-annual sampling events for the Thabazimbi Mine groundwater monitoring network. Incorporate results to support mine closure objectives and update of numerical model.

SLR

Hydrogeological and Geochemical Assessment, Belfast Mine, Exxaro, Belfast, Mpumalanga, South Africa (2018)	Geochemical sampling of stockpile material in order to determine the geochemical characteristics of the temporary stockpile facility and associated acid generation and groundwater risks. Tasks included geochemical sampling, analyses, data interpretation (XRD, ABA, NAG, & static and kinetic leach testing), and risk determination.
Hydrogeological Assessment ESIA, Comide Mine, ERG Africa, Kolwezi, DRC (2017 - 2018)	Environmental impact assessment focussing on the groundwater impacts of planned future mining several new open pits at the Comide mine. Project involved a hydrogeological baseline assessment and quarterly monitoring of several surface water and groundwater points. Tasked included data interpretation, hydrocensus, groundwater and surface water sampling, spring and stream flow measurements and groundwater flow and contaminant transport modelling. Groundwater impacts were compared to local and international requirements (DRC Mining Code, WHO & IFC guidelines).
Hydrogeological Feasibility Study, Zambeze Coal Project, DRA, Moatize, Tete Province, Mozambique (2018)	Feasibility-level hydrogeological investigation that consisted of data analyses and numerical groundwater modelling. The objective of the numerical groundwater model was to simulate transient groundwater ingress into the opencast pit mine operations, determining pore pressure distribution across the opencast pit walls, simulating the fate and transport of sulphate from the mine waste facilities, and providing input into a water management plan.
Hydrogeological Assessment, Mutoshi TSF facility, Chemaf, Kolwezi, DRC (2018)	Hydrogeological assessment for a planned acid and basic TSF's at feasibility level. Work included site walkover and hydrocensus, conceptual modelling, numerical modelling (flow and contaminant transport), and groundwater risk assessment.
Hydrogeological Assessment, Bwana Mkubwa TSF and plant, FQM, Ndola, Zambia (2018)	Estimation of seepage rate from facility TSF. Study involved sampling of tailings materials and soils, assess phreatic water levels at TSFs by hand auger, aquifer test supervision of selected boreholes, and assistance with seepage rate modelling.
Hydrogeological Assessment EIA, Tharisa Chrome Mine, Tharisa, Marikana, North West, South Africa (2017 - 2018)	Hydrogeological Investigation Scoping Report. Baseline site description, hydrocensus data interpretation, groundwater quality data interpretation, conceptual modelling, and impact risk assessment to groundwater. Hydrogeological component to the Environmental Authorisation (EA) process required for the development and upgrade of three (3) on-site processing plants at the existing Tharisa Mine.
Hydrogeological Assessment, Sese Coal Mine, FQM, Selebi Phikwe, Botswana (2017)	Sese Coal Project Hydrogeological Investigation Report. Hydrocensus, aquifer testing, field reconnaissance, data interpretation, aquifer parameter calculation. This investigation is aimed at verifying the hydrogeological work undertaken in the past, including baseline and risk assessment, and to identify potential gaps and risks in line with international and FQM standards.

Hydrogeological Feasibility Study, Comide Mine, ERG Africa, Kolwezi, DRC (2016 - 2018)	ERG Africa Comide Mine: Feasibility Study – Water Report – Data interpretation, hydrocensus, groundwater and surface water sampling, spring and stream flow measurements and groundwater flow and contaminant transport modelling. The Comide Feasibility Study will include all mine concession areas, existing processing plant, and proposed extension of the existing as well as the newly proposed Tailings Storage Facilities.
Hydrogeological Feasibility Study, Sechaba Coal Project, Shumba Energy, Palapye, Botswana (2016)	Sechaba Project Feasibility Study: Mine Hydrogeology and Environmental Inputs - Data interpretation, falling head aquifer test data interpretation, conceptual aquifer characterisation, groundwater flow and contaminant transport modelling including dewatering scenarios and private water user impact determination, geochemical data interpretation, groundwater management and monitoring plan, report writing.
Hydrogeological Assessment, Moatize Coal Mine, Vale, Moatize, Tete Province, Mozambique (2016-2017)	Moatize River Diversion Reach 1 Detailed Excavatability and Hydrogeological Investigation – Geophysical surveying (electrical resistivity and magnetic), geophysical data interpretation, rotary core drilling supervision, falling head tests, and sub-contractor management. The overall objective of the study was to assess the excavatability along the centreline of the Moatize River Diversion and produce a long section showing the excavation class.
Hydrogeological Assessment, Moatize Coal Mine, Vale, Moatize, Tete Province, Mozambique (2016-2017)	Installation of Aquifer Characterisation and Monitoring Boreholes – The project focus areas were to address groundwater level monitoring for environmental and pit dewatering purposes; piezometer readings in order to monitor and calculate open pit pore pressures; and test boreholes to investigate the boundary effects of the boundary faults and dolerite dykes. The scope of work involved borehole siting with aid of geophysical surveys; drilling and installation of test and monitoring boreholes; pump testing of selected boreholes; packer testing of selected boreholes; installation of vibrating wire piezometers and reporting.
Hydrogeological Assessment, Gautrain, Gauteng Provincial Government, Johannesburg, Gauteng, South Africa (2016)	Details of the project are protected under a non-disclosure agreement.
Hydrogeological Assessment, Mmamabula West Coal Project, Loci Environmental, Gaborone, Botswana (2016)	Baseline hydrocensus including groundwater level measurements and sampling, data interpretation, and report writing.

Hydrogeological Assessment, Tsumeb Smelter, Dundee Precious Metals, Tsumeb, Namibia (2016)	Field work included water level measurements, water sampling, and borehole fluid logging. Compiling of the report included data interpretation, numerical flow and transport model update with updated geological, geochemical and hydrocensus data. The main aim of the project was to determine the operational phase impact on groundwater quality as well as the potential impact of various management scenarios on the fate and transport on the contaminant plume.
Hydrogeological Assessment, Nkomati Mine Onverwacht TSF, Barberton, Mpumalanga, South Africa (2015)	Data interpretation, numerical flow and transport modelling in order to determine the operational and post-closure impact of various tailings storage facility rehabilitation options on groundwater quality.
Hydrogeological Assessment, Leeufontein Coal Washing Plant, REC Services, Kriel, Mpumalanga, South Africa (2015)	Baseline hydrocensus including groundwater and surface water sampling, groundwater level measurements, infiltration tests, and report writing.
Hydrogeological Assessment, Thabazimbi Mine, Kumba Iron Ore (now ArcelorMittal), Thabazimbi, Limpopo, South Africa (2015)	Involved in the groundwater study of the Thabazimbi Mine Closure Assessment and included tasks such as data interpretation, conceptual modelling, numerical flow and transport modelling in order to determine impact due to mine closure.
Hydrogeological Assessment, Thabazimbi Mine, Kumba Iron Ore (now ArcelorMittal), Thabazimbi, Limpopo, South Africa (2015)	Dewatering Assessment. Data interpretation, borehole fluid logging, conceptual modelling, numerical flow modelling in order to determine mine pit inflow rates, develop a proposed dewatering schedule and update groundwater monitoring recommendations.
Hydrogeological Assessment ESIA, Estima (now Chitima) Coal Project, ERG Africa, Tete, Mozambiaque (2015)	ESIA project focused on the groundwater contaminant transport modelling component. Determined the operational and post-closure phase impacts on groundwater resources, groundwater impact study and effectiveness of proposed pit rehabilitation options.
Hydrogeological Assessment, Kamassani and Pumpi Mines, Lamikal, DRC (2015)	Groundwater flow modelling of two mining areas, determining future inflow rates in the mine pits, determining dewatering rates and positions of the dewatering wells for a dewatering plan and determining drawdown extent due to mine dewatering.
Hydrogeological Assessment, Styldrift Platinum Mine, Bafokeng Rasimone, Marikana, North West, South Africa (2014)	The fieldwork component of the study was undertaken and comprised of borehole drilling supervision, aquifer pumping tests, falling head tests, borehole percussion chip logging, water sampling, data collection and interpretation.
Hydrogeological Assessment, Philipi Sand Mine, Consol Glass, Cape Town, Western Cape, South Africa (2014)	Data interpretation, numerical flow and transport modelling in order to determine groundwater impacts due to proposed sand mining.

Hydrogeological Assessment, Thabazimbi Mine, Kumba Iron Ore (now ArcelorMittal), Thabazimbi, Limpopo, South Africa (2014)	Thabazimbi Regional Groundwater Model Update. Review of final regional groundwater model update and final monitoring network determination.
Hydrogeological Assessment, Thabazimbi Mine, Shangoni, Thabazimbi, Limpopo, South Africa (2014)	Infinity Hydrogeological Investigation. Data interpretation, conceptual modelling, determining the impact on groundwater quality and quantity of affected parties by numerical modelling of groundwater flow and contaminant transport and geochemical assessment of waste rock and tailings facilities. The study included environmental impact assessment on groundwater.
Hydrogeological Assessment EIA, Jacomynspan Cu-Ni Project, African Nickel, Kenhardt, Northern Cape, South Africa (2014)	Undertook aquifer test analysis and interpretation, conceptual modelling, hydro-geochemical testing result interpretation, groundwater numerical modelling (flow and contaminant transport) and impact study of the proposed underground mine.

MEMBERSHIPS

SACNASP	Professional Natural Scientist (Earth Science & Water Resource Science) of South African Council for Natural Scientific Professions
WISA	Professional Member (MWISA) of Water Institute of Southern Africa
GWD of GSSA	Member of Ground Water Division of Geological Society of South Africa
IAH	Member of The International Association of Hydrogeologist
IWA	Member of The International Water Association

PUBLICATIONS

SAJG	MINNAAR, R.C. & DIPPENAAR, M.A. (2019). Hydrogeological characterisation of regional faults and dolerite dykes in the Precambrian Basement and Karoo Supergroup (Tete Province, Mozambique). South African Journal of Geology (special edition Southern Africa Hydrostratigraphy). Johannesburg, South Africa.

APPENDIX B: IMPACT ASSESSMENT CRITERIA AND METHODOLOGY

The following impact assessment methodology has been used to assess the significance of the impacts.

PART A: DEFINITIONS AND CRITERIA*		
Definition of SIGNIFICANCE		**Significance = consequence x probability**
Definition of CONSEQUENCE		**Consequence is a function of intensity, spatial extent and duration**
Criteria for ranking of the INTENSITY of environmental impacts	**VH**	Severe change, disturbance or degradation. Associated with severe consequences. May result in severe illness, injury or death. Targets, limits and thresholds of concern continually exceeded. Substantial intervention will be required. Vigorous/widespread community mobilization against project can be expected. May result in legal action if impact occurs.
	H	Prominent change, disturbance or degradation. Associated with real and substantial consequences. May result in illness or injury. Targets, limits and thresholds of concern regularly exceeded. Will definitely require intervention. Threats of community action. Regular complaints can be expected when the impact takes place.
	M	Moderate change, disturbance or discomfort. Associated with real but not substantial consequences. Targets, limits and thresholds of concern may occasionally be exceeded. Likely to require some intervention. Occasional complaints can be expected.
	L	Minor (Slight) change, disturbance or nuisance. Associated with minor consequences or deterioration. Targets, limits and thresholds of concern rarely exceeded. Require only minor interventions or clean-up actions. Sporadic complaints could be expected.
	VL	Negligible change, disturbance or nuisance. Associated with very minor consequences or deterioration. Targets, limits and thresholds of concern never exceeded. No interventions or clean-up actions required. No complaints anticipated.
	VL+	Negligible change or improvement. Almost no benefits. Change not measurable/will remain in the current range.
	L+	Minor change or improvement. Minor benefits. Change not measurable/will remain in the current range. Few people will experience benefits.
	M+	Moderate change or improvement. Real but not substantial benefits. Will be within or marginally better than the current conditions. Small number of people will experience benefits.
	H+	Prominent change or improvement. Real and substantial benefits. Will be better than current conditions. Many people will experience benefits. General community support.
	VH+	Substantial, large-scale change or improvement. Considerable and widespread benefit. Will be much better than the current conditions. Favourable publicity and/or widespread support expected.
Criteria for ranking the DURATION of impacts	**VL**	Very short, always less than a year. Quickly reversible
	L	Short-term, occurs for more than 1 but less than 5 years. Reversible over time.
	M	Medium-term, 5 to 10 years.
	H	Long term, between 10 and 20 years. (Likely to cease at the end of the operational life of the activity)
	VH	Very long, permanent, +20 years (Irreversible. Beyond closure)
Criteria for ranking the EXTENT of impacts	**VL**	A part of the site/property.
	L	Whole site.
	M	Beyond the site boundary, affecting immediate neighbours
	H	Local area, extending far beyond site boundary.
	VH	Regional/National

PART B: DETERMINING CONSEQUENCE							
			EXTENT				
			A part of the site/property	Whole site	Beyond the site, affecting neighbours	Local area, extending far beyond site.	Regional/ National
			VL	**L**	**M**	**H**	**VH**
					INTENSITY = VL		
DURATION	Very long	**VH**	**Low**	**Low**	**Medium**	**Medium**	**High**
	Long term	**H**	**Low**	**Low**	**Low**	**Medium**	**Medium**
	Medium term	**M**	**Very Low**	**Low**	**Low**	**Low**	**Medium**
	Short term	**L**	**Very low**	**Very Low**	**Low**	**Low**	**Low**
	Very short	**VL**	**Very low**	**Very Low**	**Very Low**	**Low**	**Low**
					INTENSITY = L		
DURATION	Very long	**VH**	**Medium**	**Medium**	**Medium**	**High**	**High**
	Long term	**H**	**Low**	**Medium**	**Medium**	**Medium**	**High**
	Medium term	**M**	**Low**	**Low**	**Medium**	**Medium**	**Medium**
	Short term	**L**	**Low**	**Low**	**Low**	**Medium**	**Medium**
	Very short	**VL**	**Very low**	**Low**	**Low**	**Low**	**Medium**
					INTENSITY = M		
DURATION	Very long	**VH**	**Medium**	**High**	**High**	**High**	**Very High**
	Long term	**H**	**Medium**	**Medium**	**Medium**	**High**	**High**
	Medium term	**M**	**Medium**	**Medium**	**Medium**	**High**	**High**
	Short term	**L**	**Low**	**Medium**	**Medium**	**Medium**	**High**
	Very short	**VL**	**Low**	**Low**	**Low**	**Medium**	**Medium**
					INTENSITY = H		
DURATION	Very long	**VH**	**High**	**High**	**High**	**Very High**	**Very High**
	Long term	**H**	**Medium**	**High**	**High**	**High**	**Very High**
	Medium term	**M**	**Medium**	**Medium**	**High**	**High**	**High**
	Short term	**L**	**Medium**	**Medium**	**Medium**	**High**	**High**
	Very short	**VL**	**Low**	**Medium**	**Medium**	**Medium**	**High**
					INTENSITY = VH		
DURATION	Very long	**VH**	**High**	**High**	**Very High**	**Very High**	**Very High**
	Long term	**H**	**High**	**High**	**High**	**Very High**	**Very High**
	Medium term	**M**	**Medium**	**High**	**High**	**High**	**Very High**
	Short term	**L**	**Medium**	**Medium**	**High**	**High**	**High**
	Very short	**VL**	**Low**	**Medium**	**Medium**	**High**	**High**

PART C: DETERMINING SIGNIFICANCE							
PROBABILITY (of exposure to impacts)	Definite/ Continuous	**VH**	**Very Low**	**Low**	**Medium**	**High**	**Very High**
	Probable	**H**	**Very Low**	**Low**	**Medium**	**High**	**Very High**
	Possible/ frequent	**M**	**Very Low**	**Very Low**	**Low**	**Medium**	**High**
	Conceivable	**L**	**Insignificant**	**Very Low**	**Low**	**Medium**	**High**
	Unlikely/ improbable	**VL**	**Insignificant**	**Insignificant**	**Very Low**	**Low**	**Medium**
			VL	**L**	**M**	**H**	**VH**
					CONSEQUENCE		

PART D: INTERPRETATION OF SIGNIFICANCE	
Significance	**Decision guideline**
Very High	Potential fatal flaw unless mitigated to lower significance.
High	It must have an influence on the decision. Substantial mitigation will be required.
Medium	It should have an influence on the decision. Mitigation will be required.
Low	Unlikely that it will have a real influence on the decision. Limited mitigation is likely to be required.
Very Low	It will not have an influence on the decision. Does not require any mitigation
Insignificant	Inconsequential, not requiring any consideration.

APPENDIX C: GEOPHYSICAL SURVEY REPORT

GEOPHYSICAL SURVEY TO INVESTIGATE SUB-SURFACE GEOLOGY

Gamsberg

Prepared for: Vedanta Zinc International

SLR Project No.: 7AN.22013.00002
Report No.: 2019-WG37
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CONTENTS

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

Acronym / Abbreviation	Definition
BMM	Black Mountain Mining Pty. Ltd.
HLEM	Horizontal Loop Electromagnetic
kTPA	Kilo Tons per Annum
LME	
SHG	Special High Grade
TSF	Tailings Storage Facility
4MTPA	Four Million Tons per Annum

1. INTRODUCTION

Black Mountain Mining Pty. Ltd. (BMM), a subsidiary of Vedanta Resources Plc. (Vedanta), has recently commissioned a 4MTPA Zinc Mining and ore beneficiation plant with associated infrastructure at Gamsberg in the Northern Cape Province of the Republic of South Africa.

The concentrator plant will produce zinc concentrate having close to 250 kTPA Zinc (Metal in Concentrate).

BMM is proposing to put up a matching Zinc Smelter/ Refinery as the next step forward. Concentrate for the Refinery will be sourced from the Gamsberg Concentrator and will be producing Special High Grade (SHG) Zinc conforming to LME standards both physically as well as analytically.

This report describes a trial geophysical survey carried out on the 18th to 21st of September 2019. The work was undertaken as part of a geophysical survey by doing electromagentic traverses around the planned refinery site and to complement the TSF geophysical survey.

1.1 SITE DESCRIPTION

Gamsberg is an inselberg in the Northern Cape Province of South Africa and is located next to the national highway N-14 between the towns of Aggeneys and Pofadder. The mining licence area is about 9505 hectares, comprising the oval shaped Inselberg (about 1100 meters above msl) and the surrounding plains.

Three sites for investigation were identified and are described below (Figure 1):

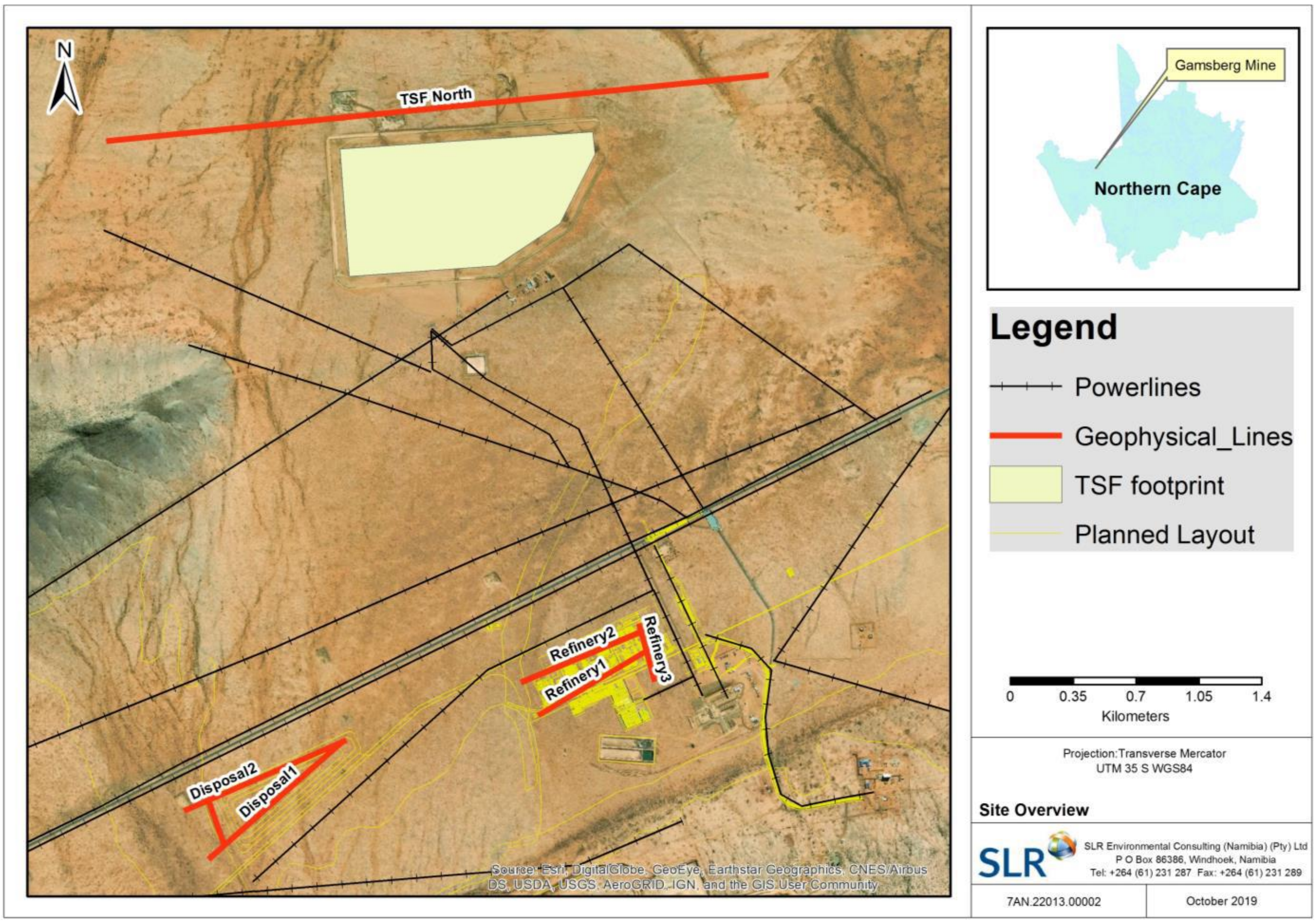

Figure 1: Project area layout and geophysical lines

Site 1: Refinery

The first site was located north of the current contractors camp and west of the processing plant. It comprised of a relatively flat, sand covered and grassy area with no outcrops visible. The survey area was 800m x 300m and includes the planned refinery area (Figure 2).

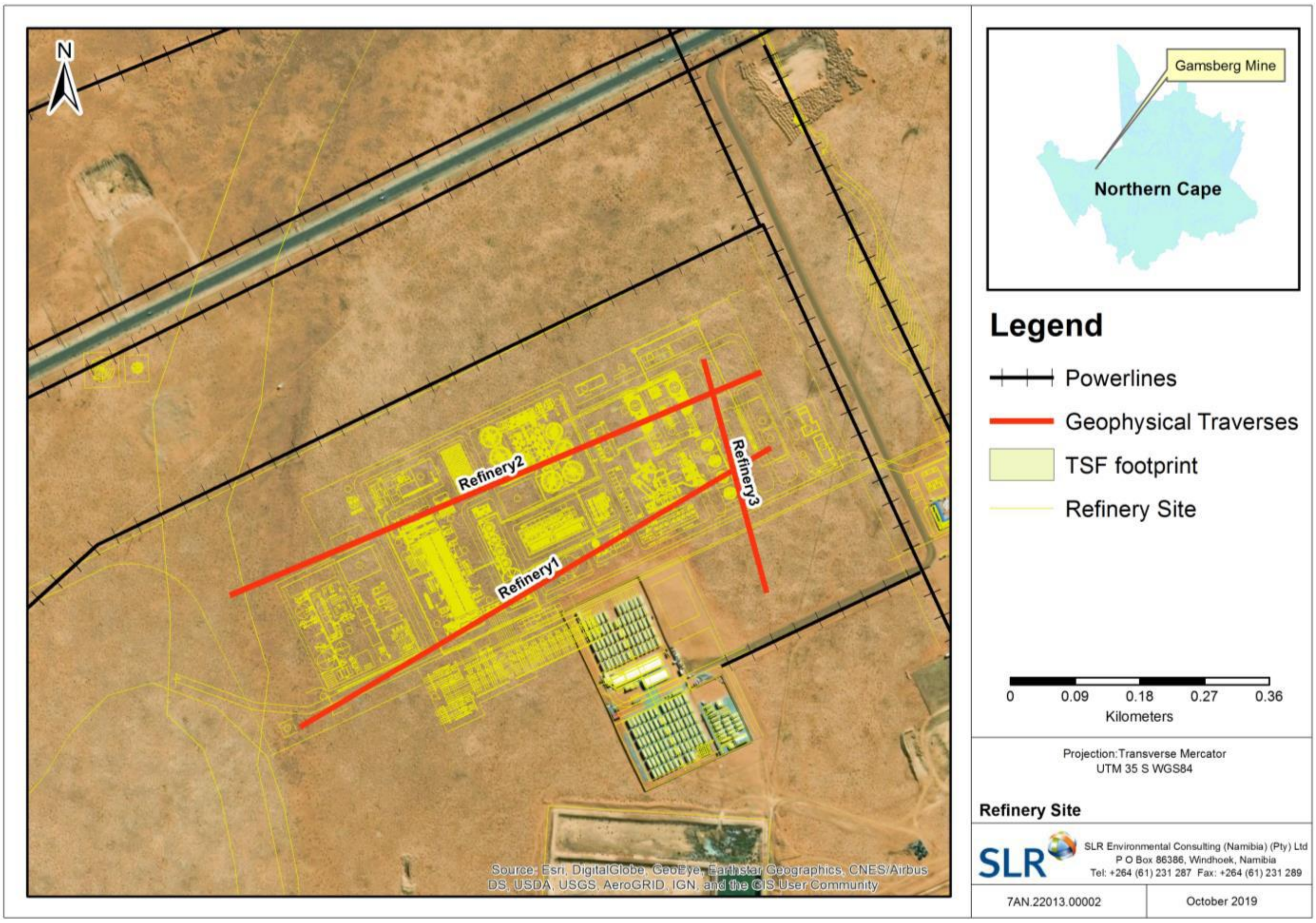

Figure 2: Refinery site with geophysical traverses

Site 2: Disposal Site

The second site was situated approximately 1500m west of site one, the site comprised of similar vegetation with some calcrete outcrops. The surveye area was 1000m x 350m and includes the planned disposal area (Figure 3).

Figure 3: Disposal site with geophysical traverses

Site 3: North of TSF

The third site was approximately 200m north of the current TSF, the site comprised of similar vegetation with some gneissic outcrops. The surveye area was 3600m long in a west to east direction and includes the planned extension area of the current TSF (Figure 4).

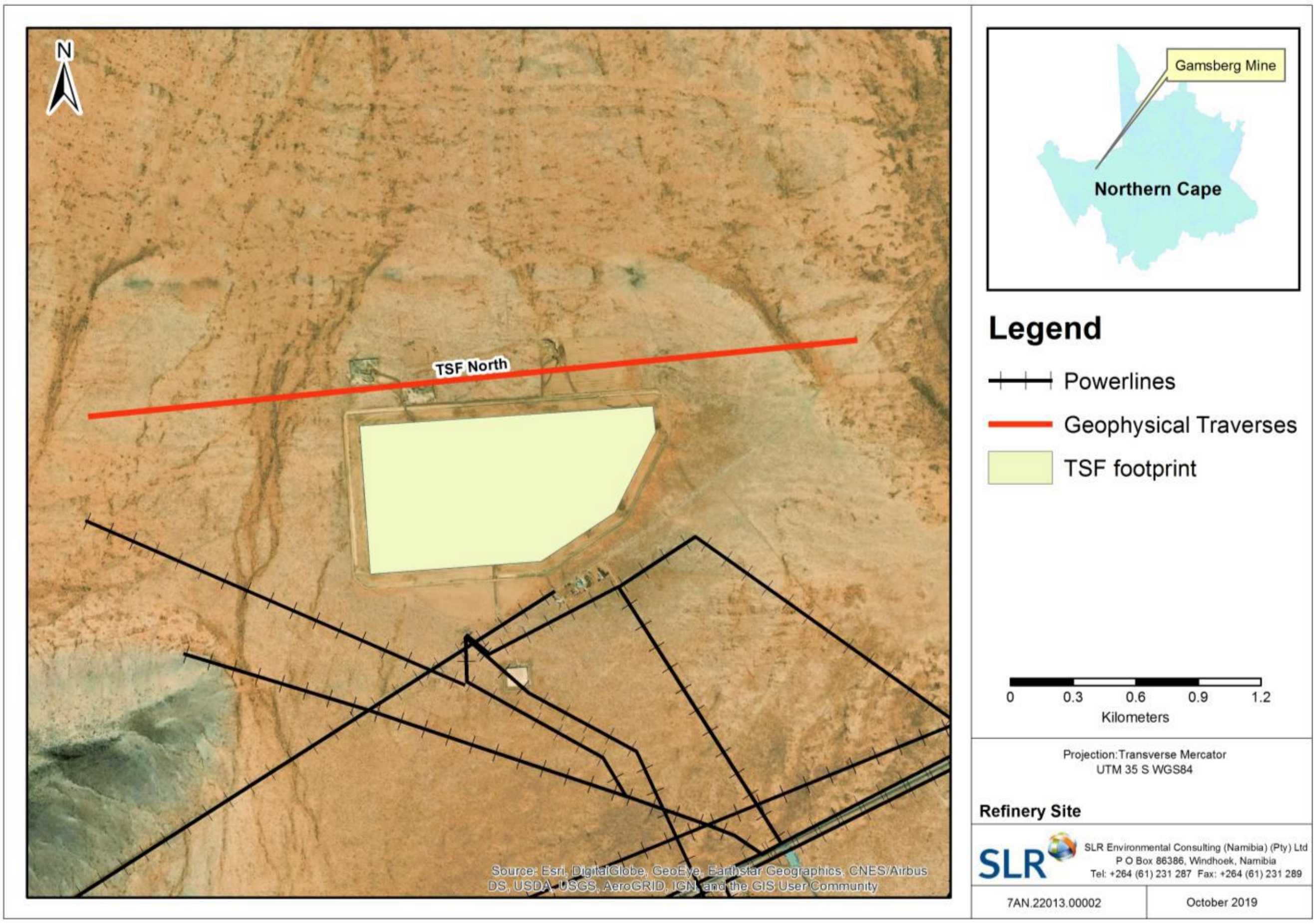

Figure 4: TSF site with geophysical traverses

1.2 SURVEY OBJECTIVES

The initial objective of the geophysical survey was to map fracture zones in the sub-surface geology in the areas of intersest. Fracture zones can play an important role as groundwater conduits and generally in hydrogeological and environmental geological practice. In most cases fracture zones are considered hydraulic conductors, but they may sometimes also act as hydraulic barriers preventing flow across them (Committee on Fracture Characterization and Fluid Flow et al. 1996). The porosity of the fractures is called secondary porosity. Rock material can contain smaller fissures, e.g. by contraction while cooling, or larger fractures by tectonic movements along fault zones. Fissured rocks have similar petrophysical properties as primary-porous material, so in principle the same geophysical techniques as for the exploration of water reservoirs in primary-porosity material can be applied. In addition, fracture zones are a special target for geophysical and hydrogeological exploration, because in general, hydraulic and petrophysical properties of fracture zones and host material are strongly different. Although extending over large distances, the width of fracture zones is mostly narrow.

Fracture zones can often be detected as lineation structures in satellite imagery or on air photos. However, for a successful groundwater exploration this remote mapping must be backed by airborne or ground geophysical surveys.

1.3 METHODOLOGY

The FDEM (Frequency Domain Electromagnetic Method, after SAGA, 2002)

Fracture zones are frequently associated with tectonic faults, and that is why the geophysical location of fracture zone aquifers is frequently confined to the location of faults. Moreover and different from seismic measurements, faults can in many cases be more easily found by low-expense electrical methods. Hence, geoelectrical techniques for the evaluation of fracture zone aquifers may be applied.

Frequently, faults and steeply dipping conductive fracture zones are studied more rapidly and more economically by electromagnetic induction measurements than by galvanic resistivity surveys. The most common methods are the Slingram (or dipole induction) method. Without connecting the ground, electromagnetic coupling enables even continuously moving digital data acquisition.

Originally, transmitter and receiver coils with horizontal orientations are used for exploration purposes leading to the name Horizontal Loop Electromagnetic (HLEM) systems or the Swedish name Slingram. Both coils are operated at a fixed distance during the survey. Depth penetration can be controlled by the frequency or the coil separation, both are often coupled. Operation is also possible with vertical coils.

Unlike geoelectrical methods, no galvanic contact to the ground is required; therefore measurements on sealed terrains are possible. Normally, the magnetic component of the superposition of primary and secondary field is measured. The measured field is split into the inphase and outphase (=quadrature, 90º phase shift) component with respect to the primary field. Both components are recorded. A typical response of the inphase and quadrature signal to a steeply dipping and highly conducting fracture zone is shown in Figure 5 and Figure 6.

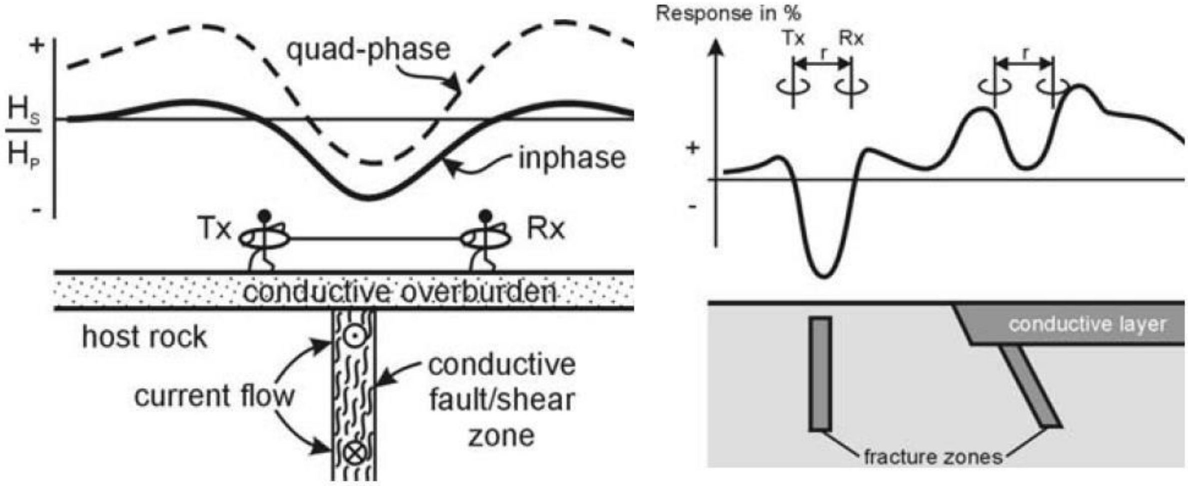

Figure 5: left: Slingram response over a highly conductive fracture zone, right: influence of a good conductive layer on the Slingram response (SAGA, 2002).

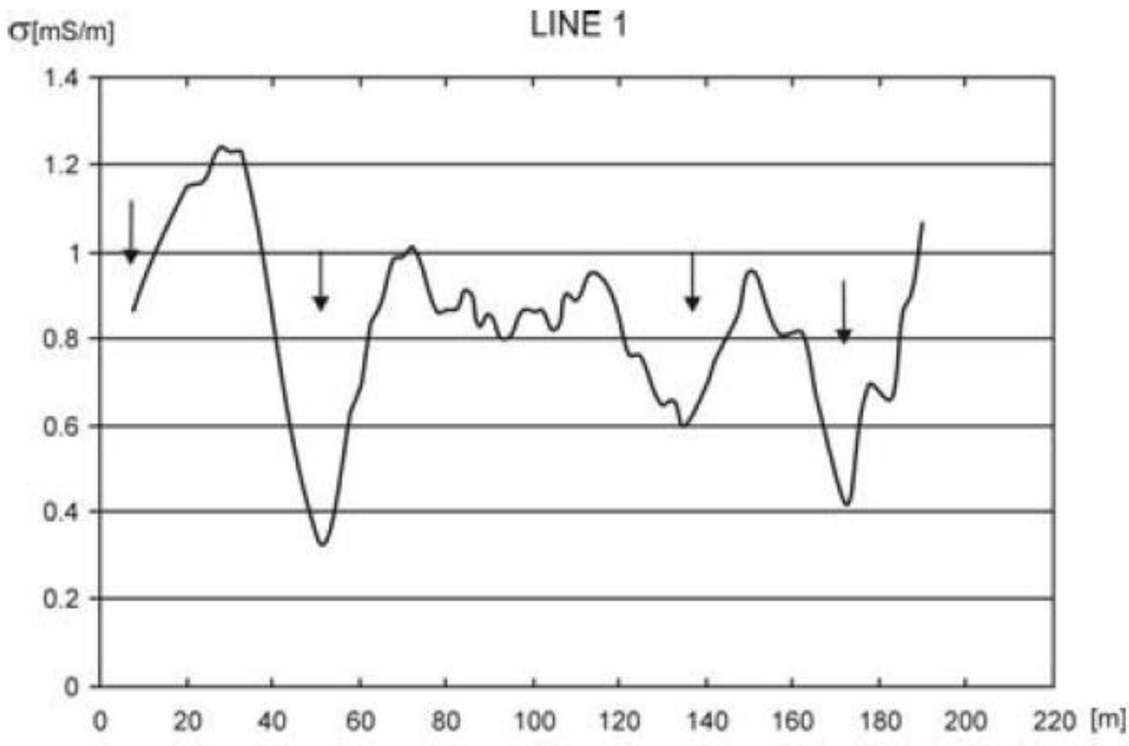

Figure 6: Typical EM34 response to fracture zones (arrows). The shift from the zero line is an overburden effect (Kirsch, 2006).

1.4 QUALITY CONTROL

The geophysical data were collected in line with normal operating procedures as outlined by the instrument manufacturer and SLR Consulting company policy. On completion of the survey, the data were recorded on to a computer and backed-up appropriately. The acquired dataset was initially checked for errors that may have been caused by instrument noise; low batteries, positional discrepancies etc. and any field notes were either written up or incorporated in the initial data processing stage. The dataset was processed using the standard processing routines and once completed, the resulting were subject to peer review to ensure the integrity of the interpretation.

2. RESULTS

2.1 ELECTROMAGNETIC SURVEY FIELD ACTIVITY

An electromagnetic survey involves transmitting an electromagnetic field into the subsurface and picking up returning signal via a receiver in the same instrument. Data are acquired on a grid covering the area of interest and a contoured plan of the variation in ground conductivity across the site is produced. The electromagnetic data were acquired by two people carrying the EM-34 along the traverses. Readings were taken approximately every 20m with a coil separation of 40m were possible and with 20m depending on the interference from overhead powerlines.

2.2 GROUND CONDUCTIVITY FOR SURVEYED LINES

Site 1: Refinery

Three geophysical traverses was done at the refinery site, two stretching east to west and one going north to sourh. The site has a high voltage powerline starting at the mines sub-station and running northwards to about 100m north of planned refinery before turning perpendicular in an westerly direction. The high voltage powerline interfered with the electromagnetic reading when trying to infiltrate the sub-surface geology to a deeper level and therefore it was decided to continue with the electromagnetic readings in the area only for the 20m coil separation which does not infiltrate the ground to greater depth than 30m.

The three lines had similar results with high conductivities indicating a thick layer of overburden alluvium material (Figure 7). The electromagnetic readings did not reach the sub-surface geology and for that reason could not detect any fractures. The readings indicated that a thick layer of overburden is present for the complete planned refinery area.

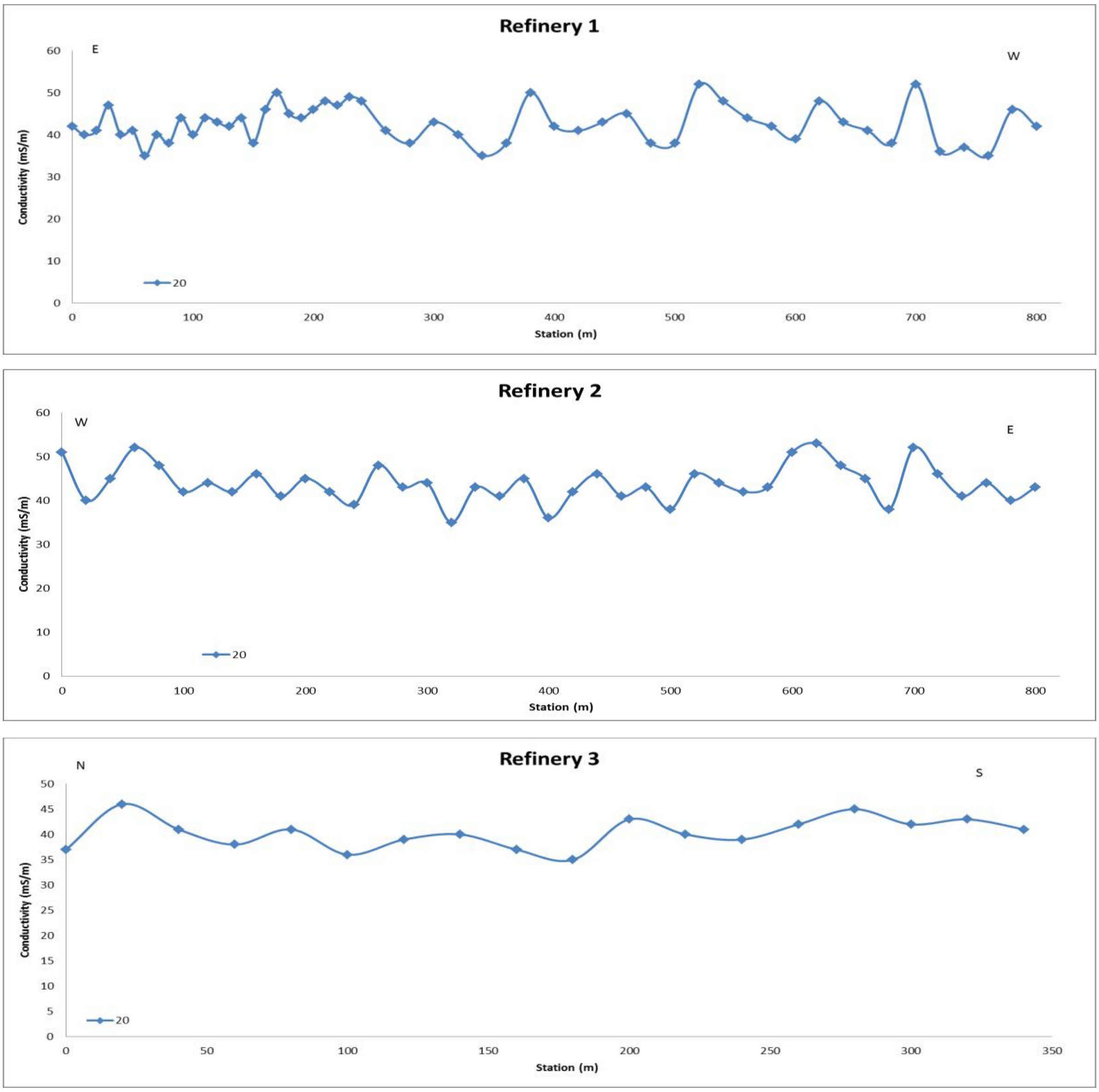

Figure 7: EM profiles for the refinery site

Site 2: Disposal

Another three geophysical traverses was done at the planned disposal site, two stretching north-east to south-west, parallel to existing powerline and one going north to sourh. The site has a high voltage powerline to the south of the proposed disposal and a low voltage powerline to the north. The powerlines interfered with the electromagnetic reading at this site as well and therefore electromagnetic readings in the area could only be done with the 20m coil separation which does not infiltrate the ground to greater depth than 30m.

The three lines had similar results with high conductivities indicating a thick layer of overburden alluvium material (Figure 8). The electromagnetic readings did not reach the sub-surface geology and for that reason could not detect any fractures. The readings indicated an increase in conductivity from west to east, therefore the overburden thickness also increase towards the refinery site.

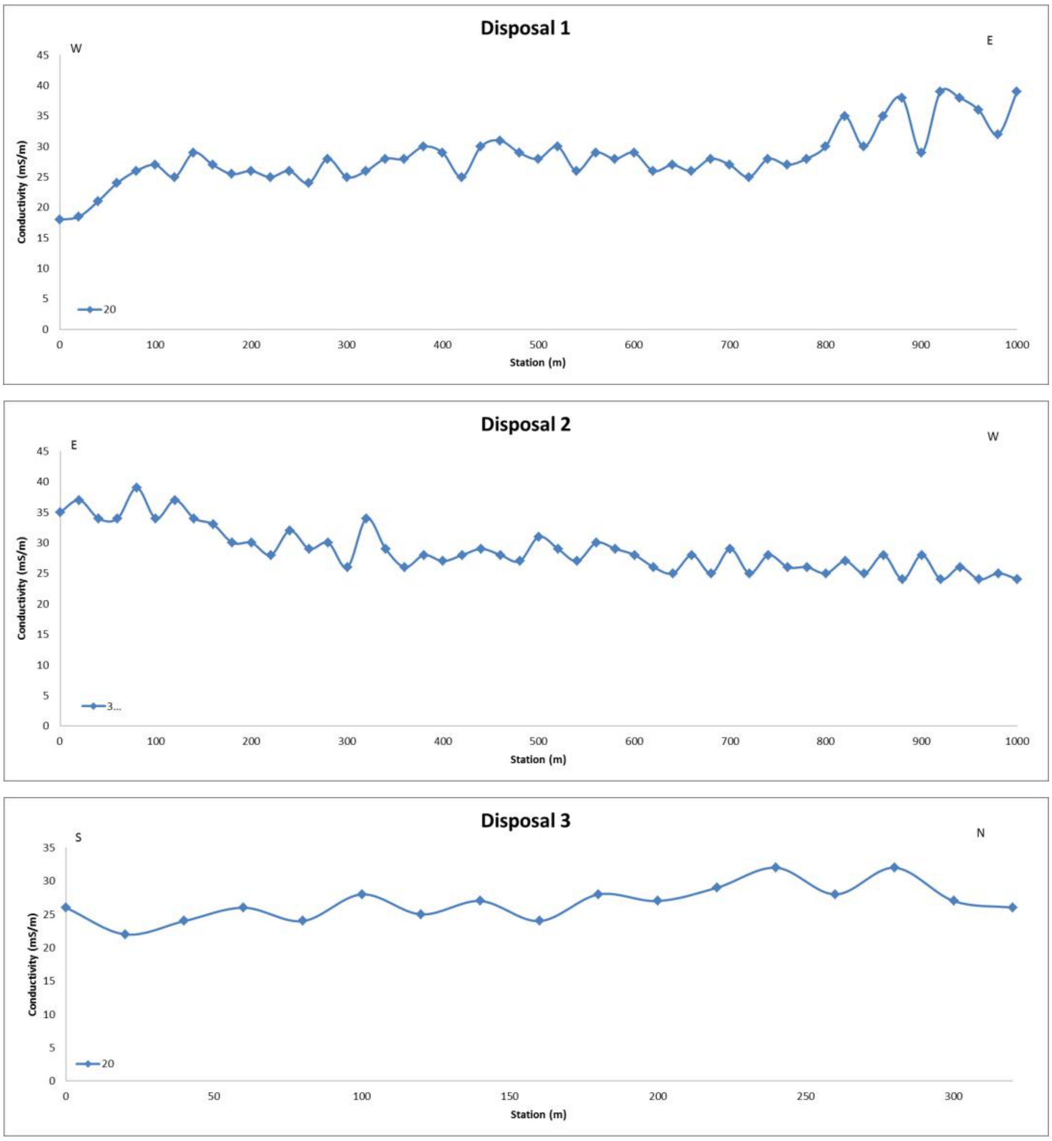

Figure 8: EM profiles for the disposal site

Site 3: North of TSF

One geophysical traverses was done north of the current TSFto detect fractures in the sub-surface geology. Fractures could be detected north of the TSF but a traverse south of the TSF could not be done due to powerline interferences and therefore fracture strike directions could not be determined.

The electromagnetic readings could be done with both the 40m and 20m coil separations. Four fractures could be detected in this traverse as indicated in Figure 9 and Figure 10. The interpreted fractures are potential conduits for pollutants emanating from the TSF and are recommended as monitoring drill sites in case additional monitoring sites are considered in the TSF area.

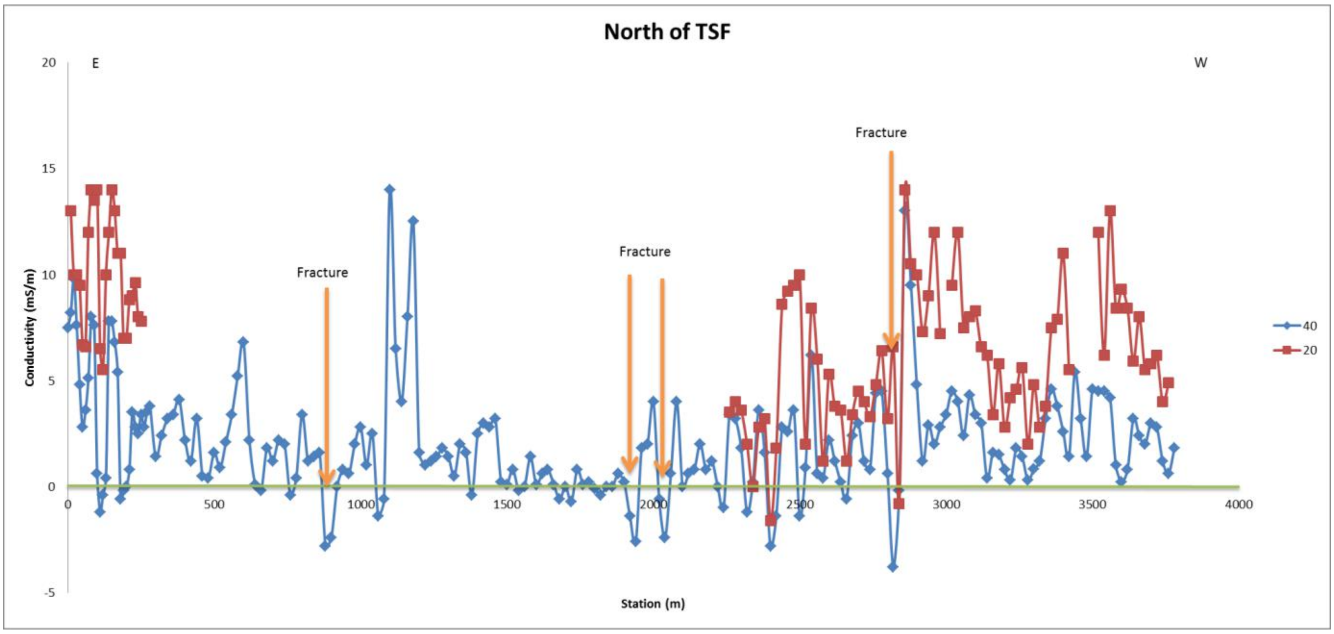

Figure 9: EM profiles north of the TSF site

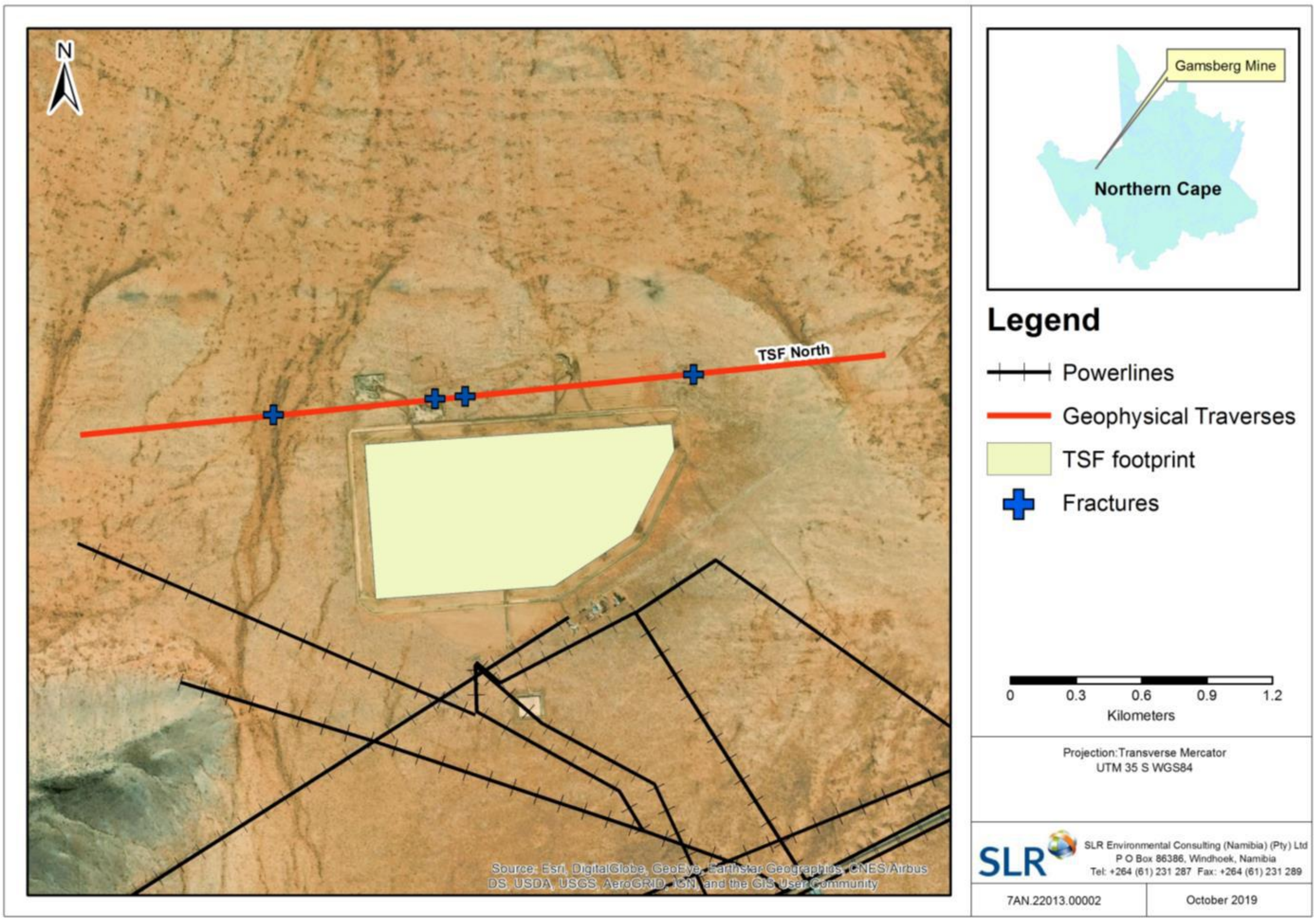

Figure 10: Fractures along the EM profile north of the TSF

3. CONCLUSION AND RECOMMENDATIONS

It is concluded that:

1. Both the refinery and disposal sites are covered by a thick layer of overburden alluvium material with overburden increasing in thickness from west to east;
2. The calcrete and clay-rich layers of the semi-consolidated Tertiary overburden in the proposed refinery and disposal site can act as a hydraulic barriers for possible pollution plumes, preventing deeper percolation ;
3. Four fractures within the underlying gneissic basement were detected with the east-west profile north of the TSF;
4. Powerline interference resulted in a lack of penetration with the electromagnetic meter and therefore alternative measures should be taken to determine the depth and fractured areas south of the N14 road.

It is recommended that:

1. Shallow exploration boreholes should be drilled in the area of the planned refinery and disposal site to determine the thickness and oermeability of the overburden and unsaturated zone as potential protection zone for the deeper lying bedrock aquifer;
2. Deep exploration boreholes, reaching the gneissic basement, should be drilled in the area of the planned refinery and disposal site to determine the depth of the groundwater table and to establish groundwater monitoring boreholes to be sampled on a regular basis;
3. If monitoring boreholes are planned north of the TSF they should be drilled into the identified fractures as indicated in Figure 9 andFigure 10.

Gerhard Jacobs	**Mihai Muresan**	**Arnold Bittner**
(Report Author)	(Project Manager)	(Reviewer)

4. REFERENCES

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TATA Consulting Engineers Limited, 2019,. Pre-feasibility study report, 250kTPA Zinc Smelter Refinery with Infrastructure at Gamsberg, South Africa

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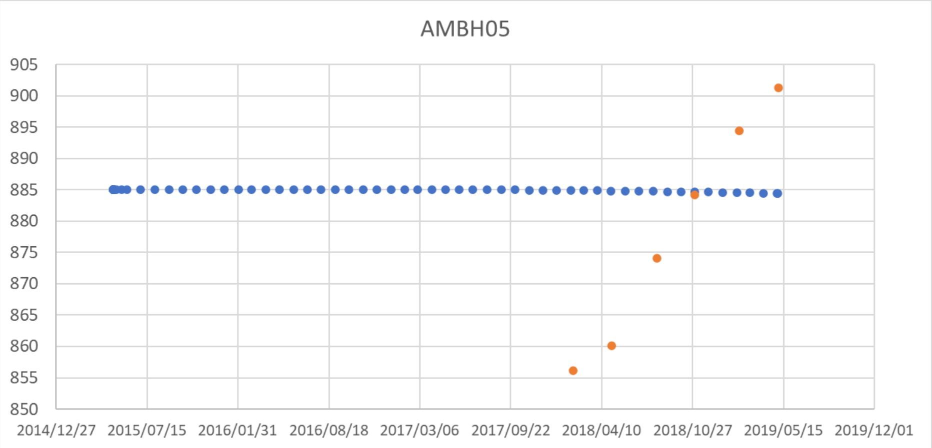
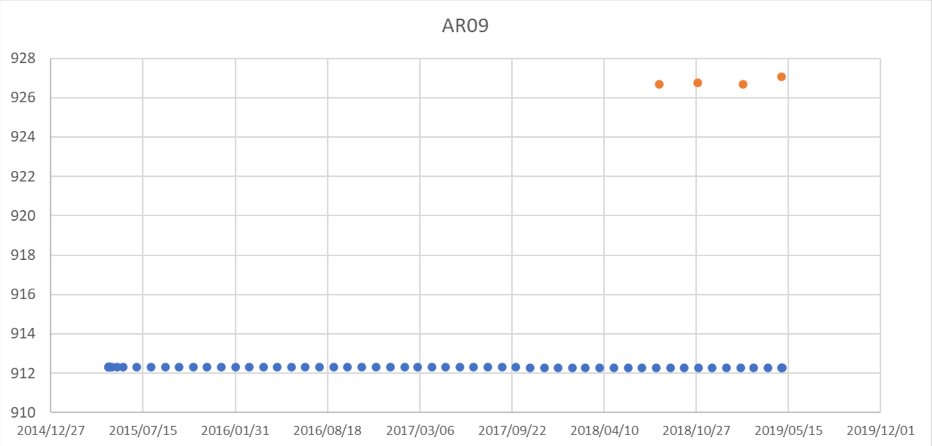
APPENDIX D: STEADY STATE CALIBRATION TARGETS

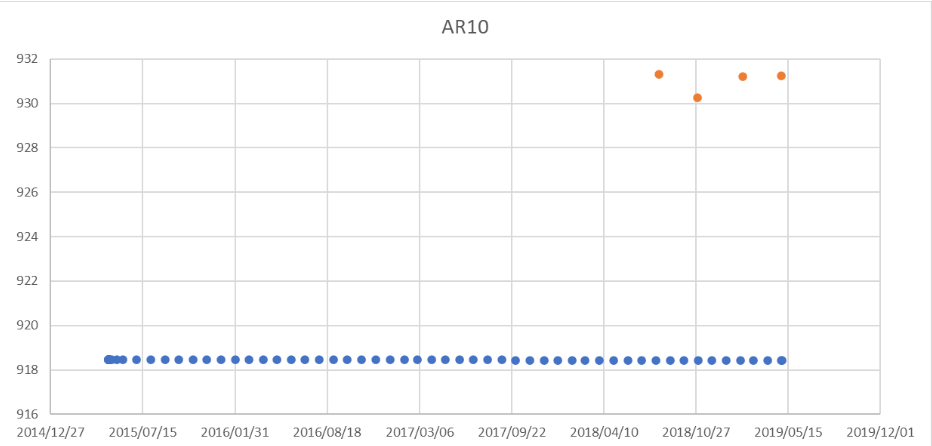
X	Y	BH ID	SWL
307007.4	6771785	AMBH05	902.622
299667.4	6768481	AR07	917.655
301201.5	6770104	AR09	927.429
301225.2	6771593	AR10	928.551
299975.4	6771506	AR11	943.22
296685.3	6770969	AR12	923.158
296843.1	6768063	AR2	942.654
299923.8	6766289	AR4	876.173
298288	6764796	AR5	859.466
299667.4	6768481	AR7	917.655
299652.5	6769663	AR8	930.479
301249.9	6770394	AR9	930.423
303800	6771977	Aroams01	928.366
296704.9	6762675	BLH3	826.174
297929.1	6762933	BLH4	850.291
296597.1	6766138	DMBH06	887.371
302576.5	6762724	GAMB1	996.375
298289.3	6764799	GAMS1	860.475
303691.2	6765164	GAMS2	922.013
302576.5	6762724	GAMS4	998.435
302419.5	6766451	GAMS8	875.531
298290.9	6764795	GBH 3	860
299997.1	6768763	GBTSF2	919.665
299531.3	6768755	GBTSF3	919.721
299508.3	6769010	GBTSF4	919.569
299848.8	6769454	GBTSF5	922.315
300894.2	6769476	GBTSF6	903.395
300671.4	6768701	GBTSF7	892.038
300960.6	6768909	GBTSF8	916.65
300733.9	6768687	GBTSF9	920.864
299644.6	6769668	MBH17	929.813
307154.4	6764414	MH01	862.546
302363.1	6765889	MH04	874.239
301607.6	6765437	MH05	870.323
300958.4	6765912	MH06	867.175
299168.4	6764118	MH07	858.019
300315.8	6768063	MH08	918.661
299457	6770103	MH09	931.318
301019.5	6770047	Solar Pump BH	927.058

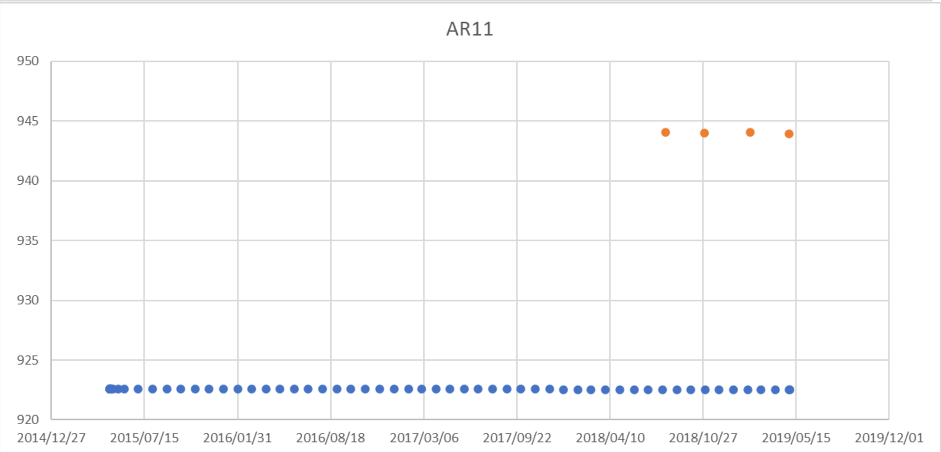
APPENDIX E: TRANSIENT CALIBRATION HYDROGRAPHS

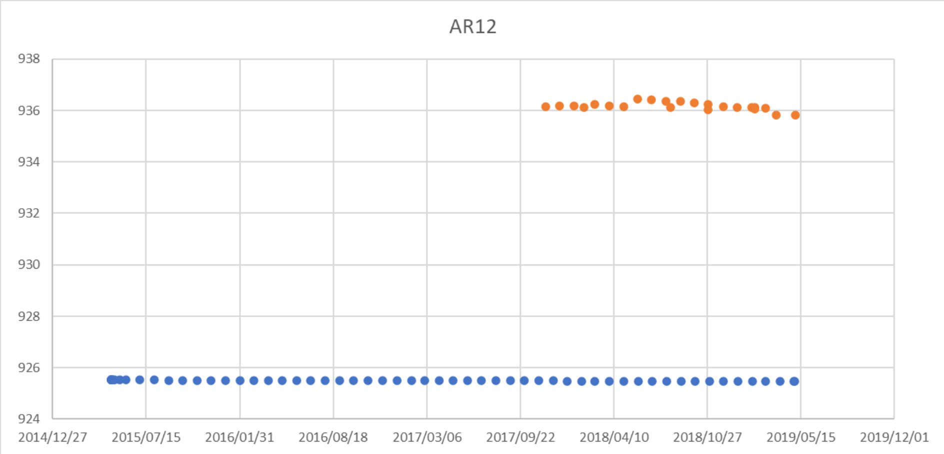
Orange – observed; Blue - simulated










AR12
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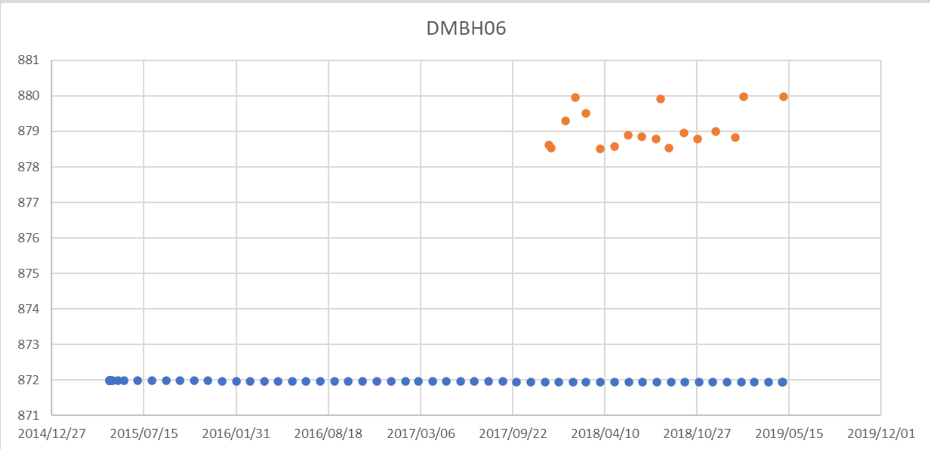
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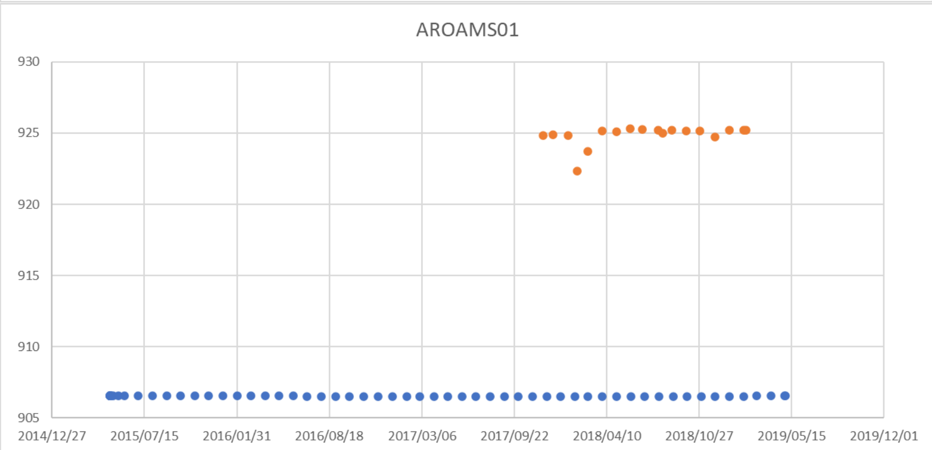
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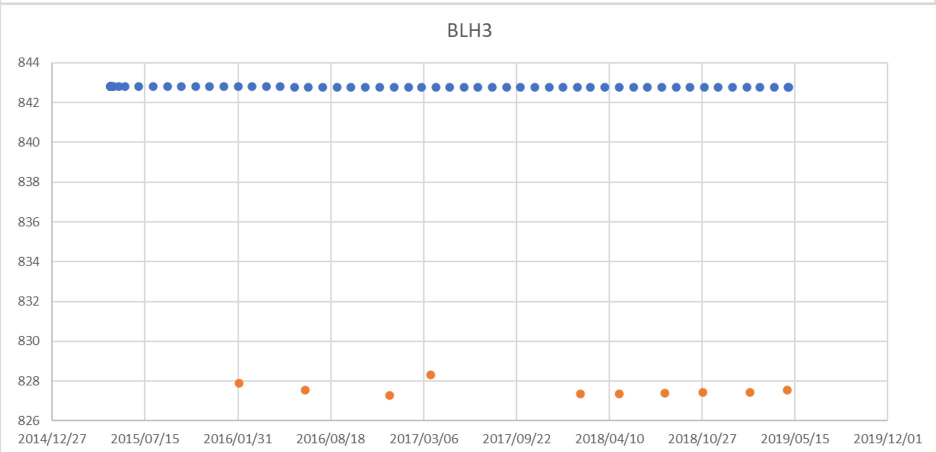
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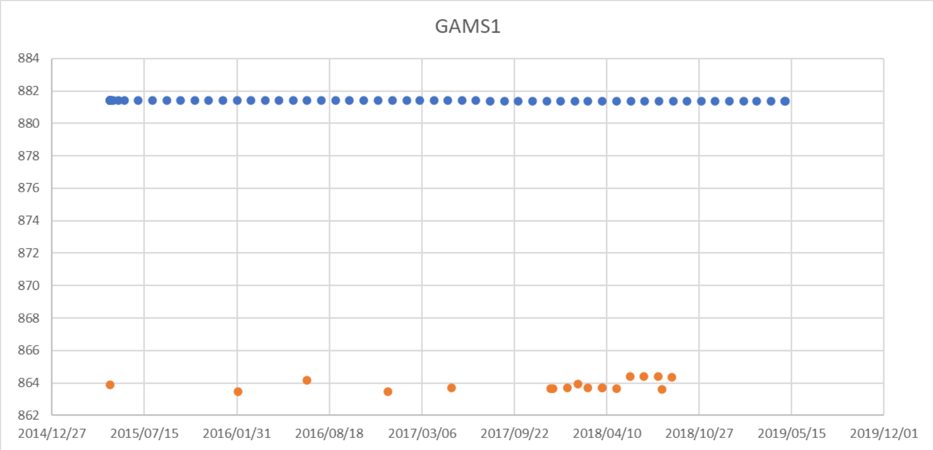
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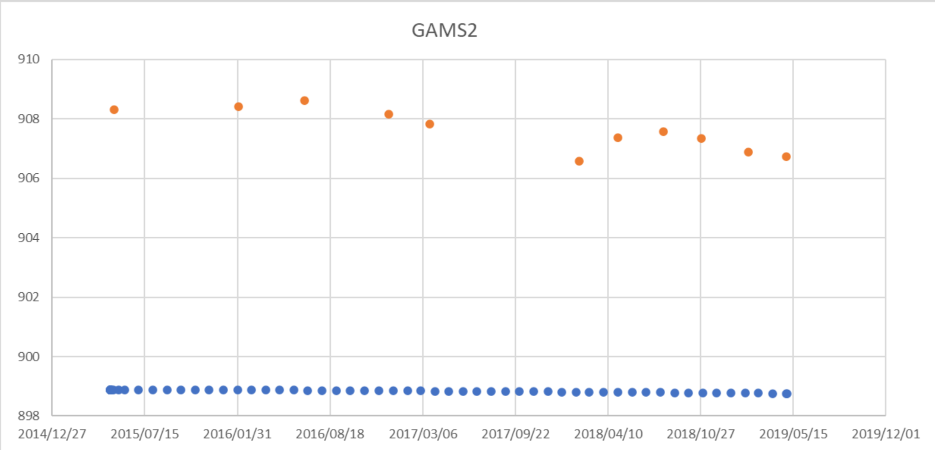
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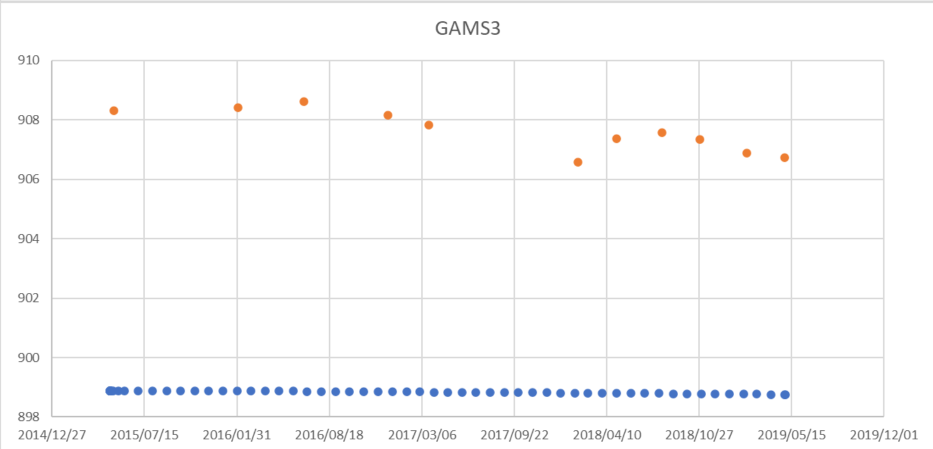
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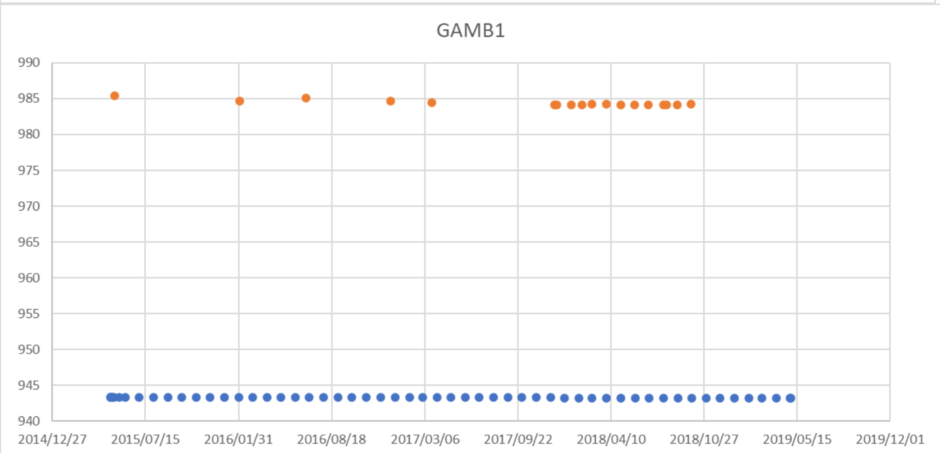
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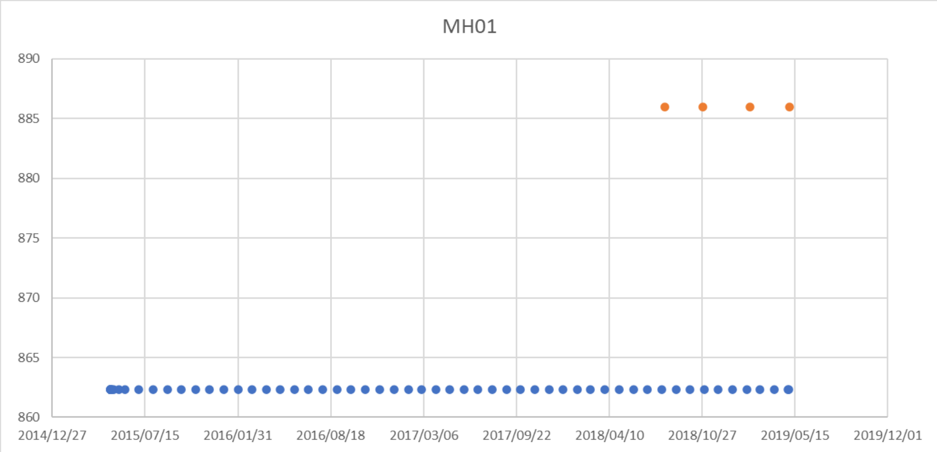
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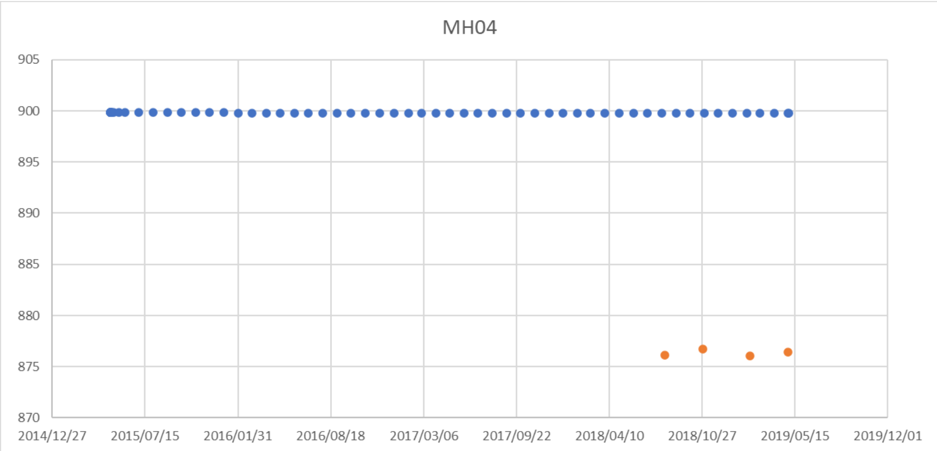
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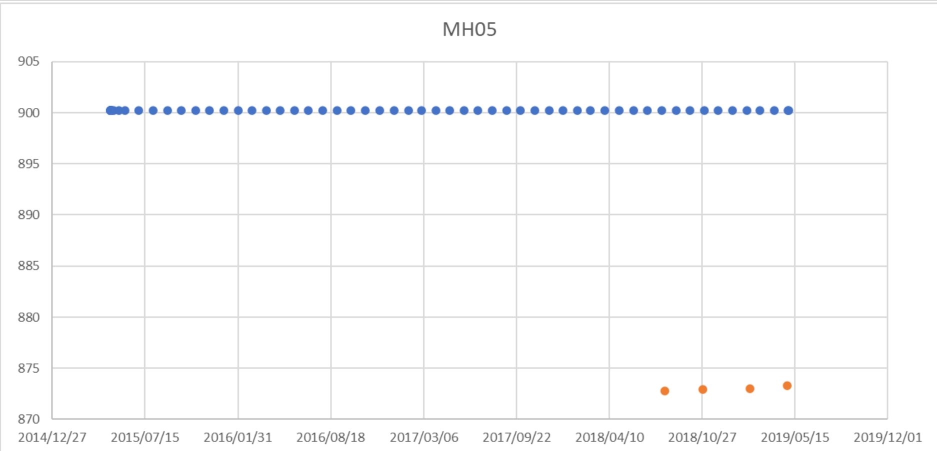
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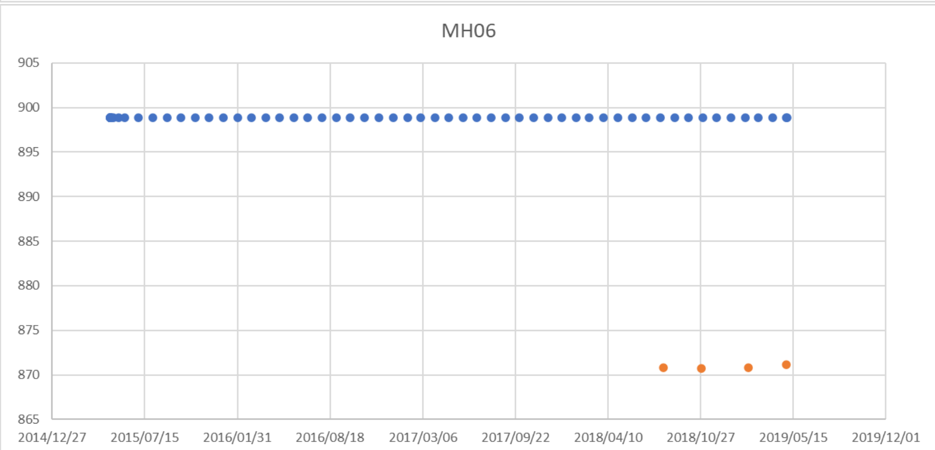
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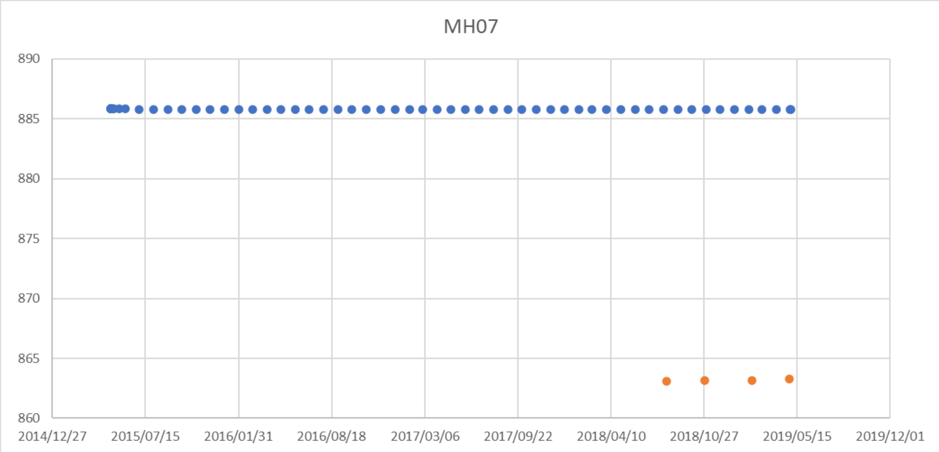
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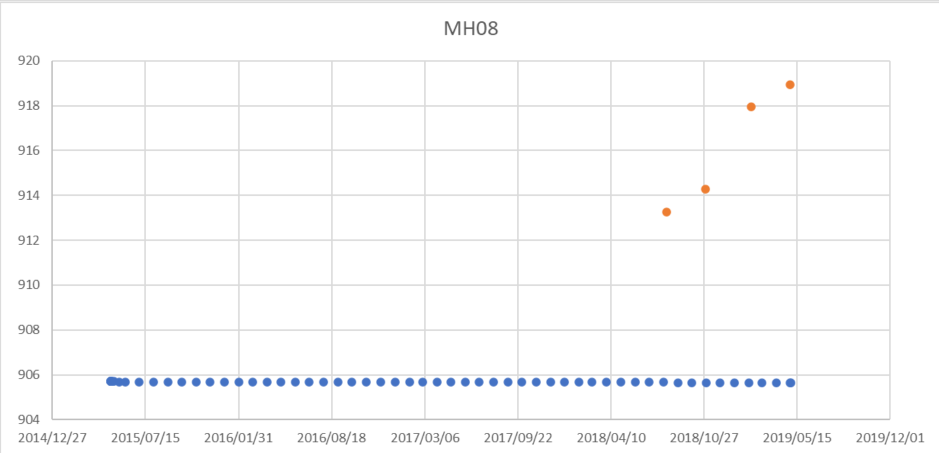
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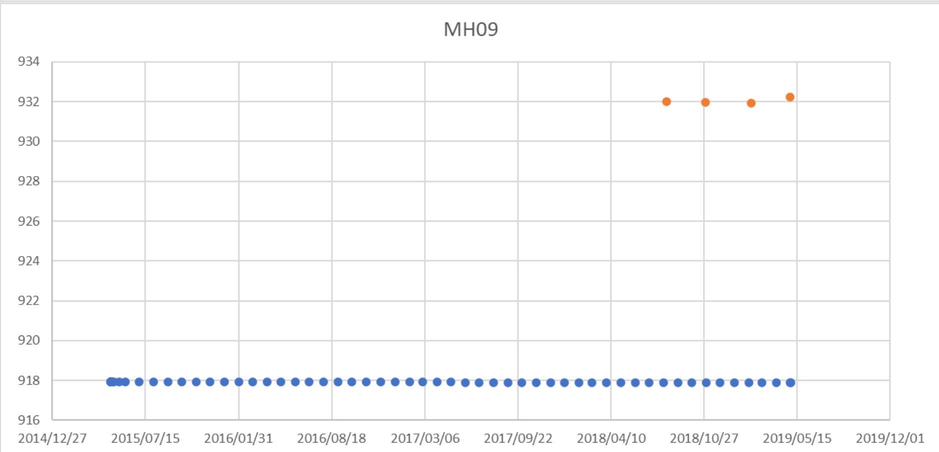
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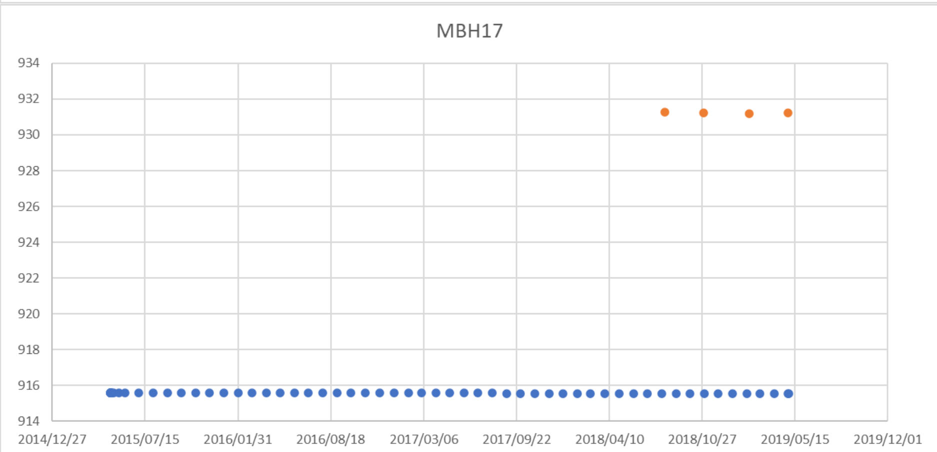
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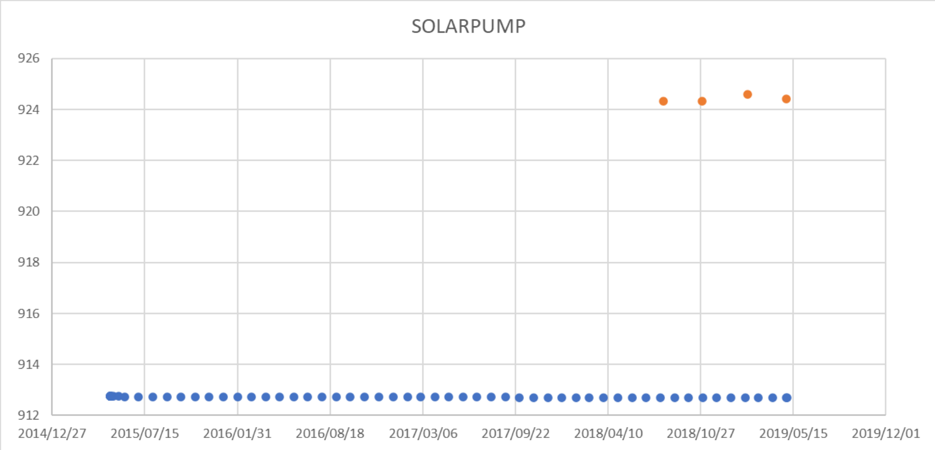
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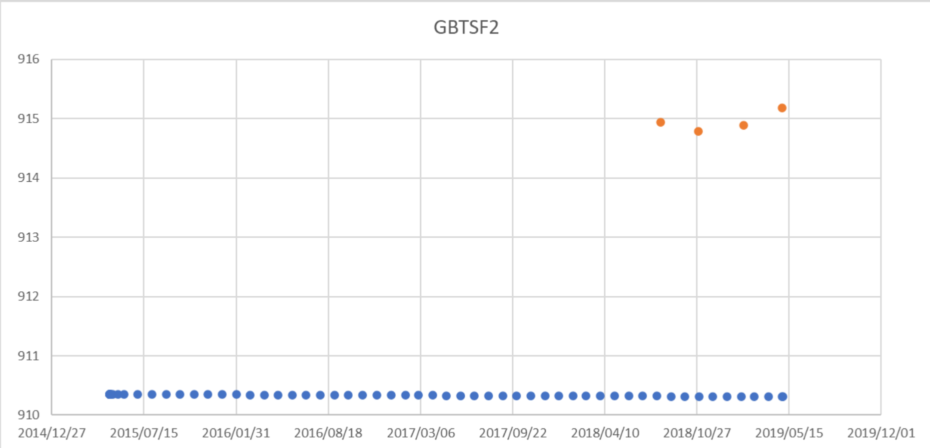
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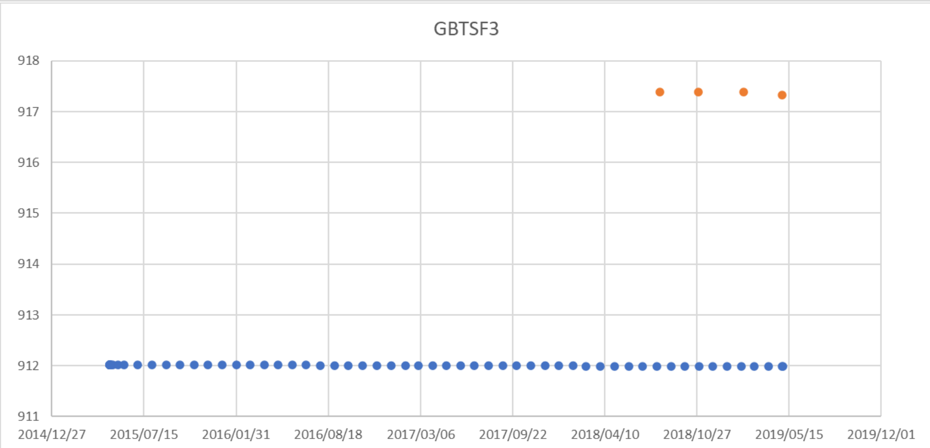
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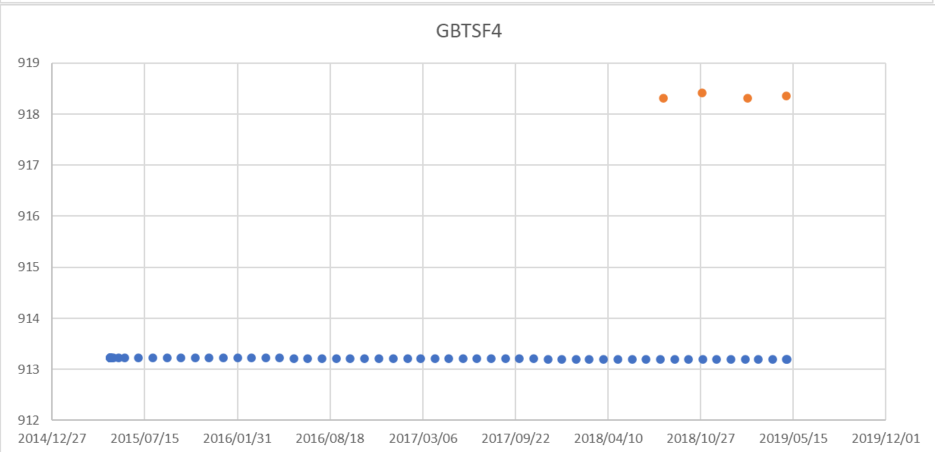
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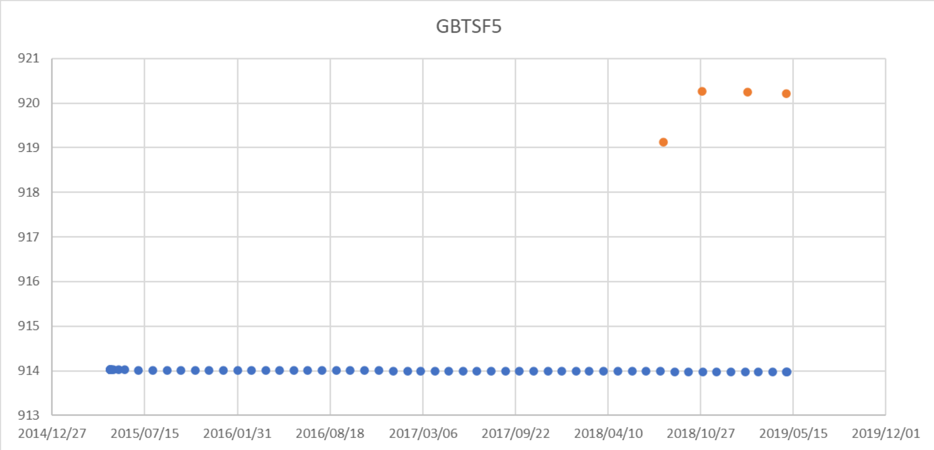
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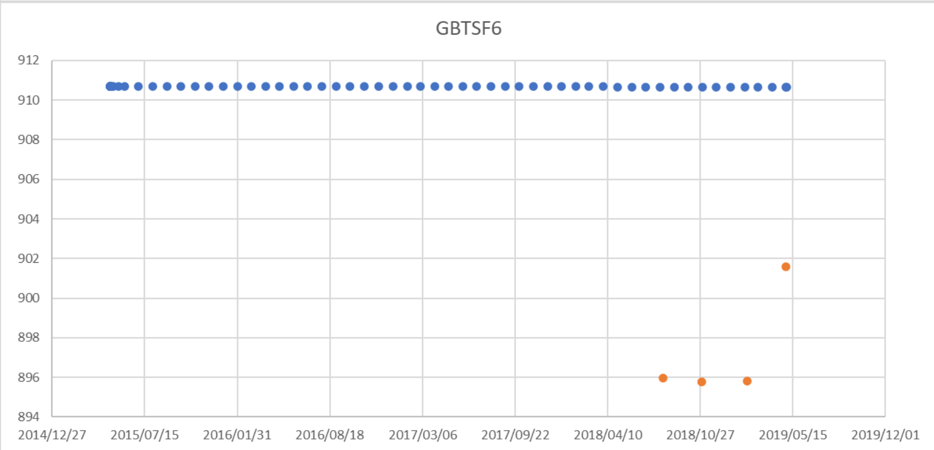
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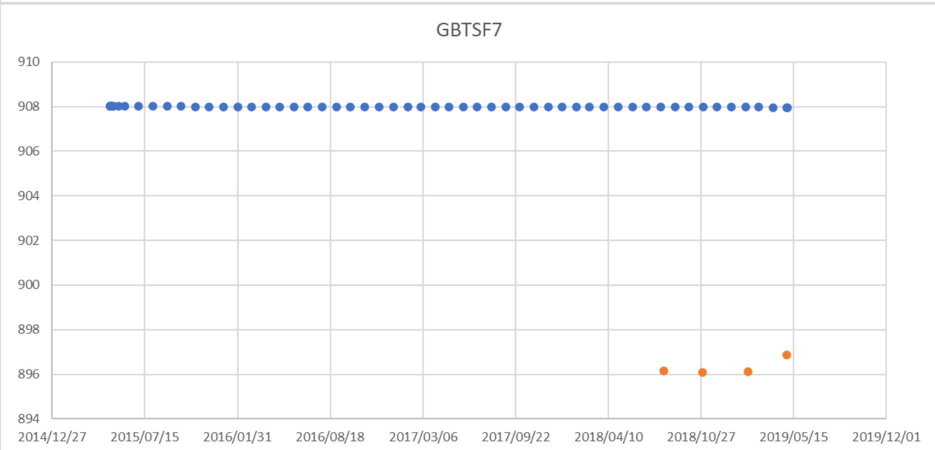
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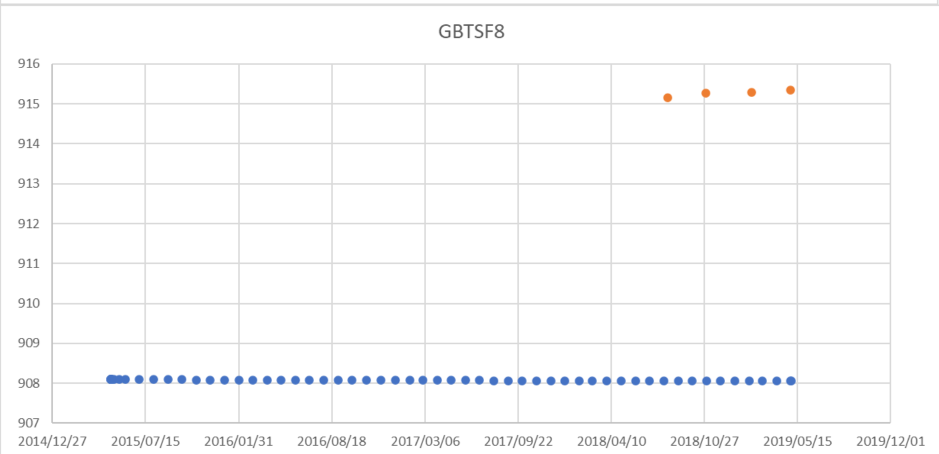
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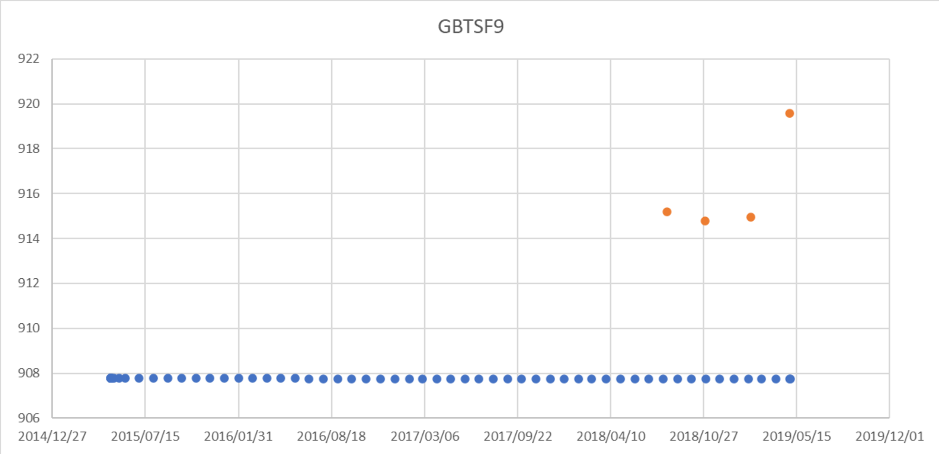
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APPENDIX F: WASTE CLASSIFICATION AND GEOCHEMICAL ASSESSMENT

Options assessment for Jarosite disposal, Gamsberg Zinc Mine

28 April 2020

Prepared by Dr Meris Mills - Mills Water

A specialist report prepared in terms of the Environmental Impact Regulations of 2014 (as amended in 2017) must contain:	**Relevant section in report**
Details of the specialist who prepared the report	Declaration
The expertise of that person to compile a specialist report including a curriculum vitae	Declaration Appendix B
A declaration that the person is independent in a form as may be specified by the competent authority	Declaration
An indication of the scope of, and the purpose for which, the report was prepared	Section 1
An indication of the quality and age of base data used for the specialist report;	Section 4.1 Section 3.1
A description of existing impacts on the site, cumulative impacts of the proposed development and levels of acceptable change	N/A
The duration, date and season of the site investigation and the relevance of the season to the outcome of the assessment	Section 3.1
A description of the methodology adopted in preparing the report or carrying out the specialised process inclusive of equipment and modelling used;	Section 3
Details of an assessment of the specific identified sensitivity of the site related to the proposed activity or activities and its associated structures and infrastructure, inclusive of a site plan identifying site alternative;	N/A
An identification of any areas to be avoided, including buffers	N/A
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;	N/A
A description of any assumptions made and any uncertainties or gaps in knowledge;	Section 7
A description of the findings and potential implications of such findings on the impact of the proposed activity or activities	Section 8
Any mitigation measures for inclusion in the EMPr	Section 8
Any conditions for inclusion in the environmental authorisation	N/A
Any monitoring requirements for inclusion in the EMPr or environmental authorisation	Section 8
A reasoned opinion as to whether the proposed activity or portions thereof should be authorised	Section 8
Regarding the acceptability of the proposed activity or activities; and	Section 8
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 8
A description of any consultation process that was undertaken during the course of carrying out the study	N/A
A summary and copies if any comments that were received during any consultation process	None received
Any other information requested by the competent authority.	N/A

Declaration

I, Meris Eleanor Mills, declare that:

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

Signature of the specialist

Name of company

Date

Specialist	Relevant qualifications and experience
Dr Meris Eleanor Mills Pr Sci Nat Registration number 400078/07 PhD (Geology) UCT 2006 MSc (Environmental Geochemistry) UCT 2001 BSc (Honours) (Environmental Geology) WITS 1996	Dr Mills has a PhD in geology and 15 years experience in environmental consulting. Her broad experience includes geochemical investigations for waste rock and discard materials associated with several commodities, including base metals, platinum, coal, uranium, iron ore and gold; reviews of water quality monitoring programs at large and industrial mining facilities; detailed interpretations of groundwater and surface water chemistry at large mining and industrial facilities; and development of conceptual site models and human health risk assessment for complex sites. She is an experienced geochemical modeller, having developed geochemical models in Phreeqc for a range of applications, including prediction of source terms for mine waste facilities, prediction of outputs from column leach tests, and modelling to obtain a better understanding of the controls on observed water quality.

Contents

Acronyms

AP – Acid potential

ARD – Acid rock drainage

ASLP – Australian standard leaching procedure

BTEX – Benzene, toluene, ethylbenzene, xylene

ETP – Effluent treatment plant

GHS – Globally harmonized system

GN – Government notice

HDPE – High density polyethylene

HH – High hazardous

ICP-MS - Inductively coupled plasma – mass spectrometry

ICP-OES – Inductively coupled plasma – optical emission spectrometry

LC – Leachable concentration

LCT – Leachable concentration threshold

NAG – Net acid generation

NEM:WA – National Environmental Management: Waste Act

NNP – Net neutralising potential

NP – Neutralising potential

NPR – Neutralising potential ratio

PCBs – Polychlorinated biphenyls

PHREEQC - PH REdox EQuilibrium (in C language)

PSD – Particle size distribution

SLF – Secured landfill facility

TC – Total concentration

TCT – Total concentration threshold

TDS – Total dissolved solids

TOC – Total organic carbon

TSF – Tailings storage facility

XRD – X-ray diffraction

1. Introduction

Mills Water was requested by SLR to assess options for disposal of Jarosite material generated at the proposed Gamsberg Zinc Smelter at the existing Gamsberg Zinc Mine in South Africa, and to calculate source terms for the preferred disposal option.

Jarosite will be a waste material generated by a proposed new processing plant which will smelt and refine zinc ore from the Gamsberg Zinc Mine. In order to assess the potential risks related to the disposal of the Jarosite, and to evaluate various co-disposal alternatives, SLR requested Mills Water to undertake the following scope of work:

- Conduct a preliminary acid rock drainage (ARD) and geochemical investigation on the waste material that will be generated as part of the project;
- Undertake a waste type assessment on the waste in terms of GN R.635 (23 August 2013);
- Identify the barrier design required for the waste in terms of GN R.636 (23 August 2013); and
- Provide a source term for input into the groundwater contaminant transport model for predictions of water quality impacts.

The disposal options that are under consideration include:

1. Disposal of the Jarosite-like residue on a dedicated facility (Secured Landfill Facility (SLF));
2. Co-disposal of Jarosite-like residue on the existing tailings storage facility (TSF) by mixing Jarosite (7%) with tailings (93%);
3. Co-disposal of Jarofix (a mixture of Jarosite-like residue, lime and cement) on the existing TSF by mixing Jarofix (7%) with tailings (93%); and
4. Disposal of the Jarofix residue on a dedicated facility (SLF).

This report summarises the findings of the initial waste assessment options and the more detailed assessment and modelling completed on the preferred option.

2. Background

2.1. Regulatory Framework

- Waste assessment in South Africa is governed in terms of three National Environmental Management: Waste Act (NEM:WA Act 59/2008) regulations: R634 of 2013: NEM:WA (59/2008). Waste Classification and Management Regulations.
- R635 of 2013: NEM:WA (59/2008). National Norms and Standards for the Assessment of Waste for Landfill Disposal.
- R636 of 2013: NEM:WA (59/2008). National Norms and Standards for Disposal of Waste to Landfill.

According to R634 of 2013: NEM:WA (59/2008). Waste Classification and Management Regulations, waste is required to be classified in accordance with SANS 10234:2008, the South African National Standard Globally Harmonized System of Classification and Labelling of Chemicals (GHS), within 180 days of generation, and again every five years or when there are changes to the process or raw materials. Hazardous substances, including waste, are required to be classified to allow for safe transport and handling, and to identify environmental and physical hazards related to the waste. The GHS is to provide workers handling the waste with information for the protection of their health and safety.

R635 states that waste that is to be disposed to landfill must be assessed by measuring the total concentrations (TC) and leachable concentrations (LC) of chemical substances present within the waste, and by then comparing the TCs and LCs against the published total concentration thresholds (TCTs) and leachable concentration thresholds (LCTs) to determine the waste type. LCs must be determined using the Australian Standard Leaching Procedure (ASLP; AS4439.1, 4439.2 and 4439.3). The waste disposal scenario determines the type of leaching fluid used:

- A pH 2.9 or 5.0 acetic acid leachate is used if the waste is going to a mixed landfill which may include waste that can decompose to produce noxious odours and organic acids (putrescible wastes) e.g. waste food, garden waste.
- A pH 2.9 or 5.0 acetic acid leachate and a pH 9.2 sodium tetraborate decahydrate leachate is used with waste where there is unlikely to be putrescible material e.g. building rubble.
- A reagent water (distilled or deionised water) leachate is used when waste is disposed by itself.

Chemical substances of relevance for which TCTs and LCTs are published include:

- Metal ions – arsenic, boron, barium, cadmium, cobalt, total chromium, hexavalent chromium, copper, mercury, manganese, molybdenum, nickel, lead, antimony, selenium, vanadium and zinc.
- Inorganic ions – fluoride, cyanide (TCTs and LCTs)
    - total dissolved solids (TDS), chloride, sulphate, nitrate (LCTs only)

The concentration of chemical substances within the waste is compared to the TCTs and LCTs to determine the waste type, as indicated in Table 1. The disposal requirements for the different waste types are detailed in R636 and Table 2, which also describes the design specification for landfill containment (i.e. pollution barrier control system) based on the waste assessment.

Table 1: Determining waste types for landfill disposal

	TC<=TCT0	**TCT0<TC<=TCT1**	**TCT1<TC<=TCT2**	**TC>TCT2**
LC<=LCT0	Type 4*	Type 3*#	Type 3*#	Type 3*#
LCT0<LC<=LCT1	Type 3	Type 3		Type 0/1+
LCT1<LC<=LCT2	Type 2	Type 2		Type 0/1+
LCT2<LC<=LCT3	Type 1	Type 1	Type 1	Type 0/1+
LC>LCT3	Type 0	Type 0	Type 0	Type 0

* TCs of TOC, BTEX, PCBs, mineral oil and specified pesticides below specified limits.
# LCs of inorganic ions and metals below LCT0, waste must be stable and must be disposed to landfill with no other waste.
+ If the TC for an element cannot be reduced to <TCT2, but LC for the element is <LCT3, then it is a Type 1 waste.

Table 2: Landfill disposal requirements based on waste type

Waste Type	**Landfill disposal requirements**
Type 0	Not allowed. Must be treated and reassessed.
Type 1	Hazardous. Class A or Hh/HH landfill – double liner (HDPE geomembrane, clay layer x 2) plus leachate collection system
Type 2	Class B or GLB+ landfill - 1.5 mm HDPE geomembrane, 600 mm clay layer, under drainage and monitoring system
Type 3	Class C or GLB+ landfill – 1.5 mm HDPE geomembrane, 300 mm clay layer, under drainage and monitoring system
Type 4	Class D or GLB- landfill – no engineered liner required.

3. Methodology

3.1. Phase 1 - Assessment of co-disposal alternatives

Gamberg provided samples of the following materials (see Figure 1):

- Tailings material – from the Gamsberg site;
- Jarosite – a waste product from an equivalent zinc processing facility in India; and
- Jarofix – Jarosite as above mixed with a small amount (9 – 15%) of lime and cement.

The materials were collected in September 2019. The chemistry of the samples should not be influenced by season, but in the Jarofix sample, there will be a slow reaction of Jarosite with cement and lime, and the chemical behaviour of aged Jarofix samples may therefore be slightly different to fresh samples.

Figure 1: Jarosite (left, yellow) and Jarofix (right, orange) samples

The samples were submitted to SANAS accredited UIS Laboratory, who were instructed to prepare samples for analysis as follows:

- Tailings;
- Jarosite;
- Jarofix;
- Jarosite composite: 93% (14.25 parts by mass) of tailings mixed with 7% (1 part by mass) of Jarosite; and
- Jarofix composite: 93% (14.25 parts by mass) of tailings mixed with 7% (1 part by mass) of Jarofix.

Each of the samples were analysed in duplicate as follows:

- Total chemistry by digestion and analysis by ICP-OES (major elements) or ICP-MS (trace elements); and
- Leachate chemistry in a leachate prepared by mixing 1 part sample with 4 parts distilled water.

Although the waste assessment regulations require measurement of leachable concentrations in a 1:20 leach (1 part solid to 20 parts distilled water), the leach was conducted at a 1:4 ratio to ensure that concentrations of trace elements were not diluted below detection limits. The measured leachable chemistry values were divided by 5 to provide an estimate of the leach concentrations in a 1:20 leach, as required for waste assessment. This simple calculation does not account for minerals with which the solution is in equilibrium, and therefore may underestimate some of the concentrations. Where this may affect the waste assessment, it is highlighted. A 1:20 leach was completed on the selected preferred alternative to ensure an accurate waste assessment.

3.2. Phase 2 – Detailed analysis of preferred alternative

The results of the Phase 1 assessment were used to select one sample for the Phase 2 detailed analysis. The selected sample was analysed in duplicate for the following:

- Leachate chemistry in a leachate prepared by mixing one part sample with 20 parts distilled water as per the requirements of GN R.635 (23 August 2013);
- Mineralogical analysis by X-ray diffraction (XRD);
- Acid base accounting (ABA) including paste pH, sulphur speciation and measurement of neutralisation potential;
- Net acid generation (NAG); and
- Particle size distribution.

The results of the detailed analysis were used to undertake geochemical modelling to calculate a source term.

3.3. Geochemical modelling

Geochemical modelling was undertaken using the PHREEQC (PH Redox Equilibrium (in C language)) modelling program (Parkhurst and Appelo, 2013) version 3.4.0.12927. PHREEQC allows modelling of low-temperature aqueous geochemical reactions and can be used to model speciation, saturation indices, kinetics, mixing, inverse modelling and one-dimensional transport. The aim of the geochemical models is to emulate the conditions which would be experienced in the waste disposal scenario.

4. Results and Discussion

The laboratory certificates are included in Appendix A.

4.1. Data quality

Both the Phase 1 and Phase 2 samples were analysed in duplicate and the relative standard deviation (RSD) was calculated by dividing the standard deviation of the repeats by the average of the repeats. The RSD provides an indication of the homogeneity of the sample, as well as the laboratory precision. RSDs are considered acceptable if they are:

- <50% if results are within the same order of magnitude as the detection limits;
- <20% if results are within one order of magnitude of the detection limits; and
- <10% if results are more than one order of magnitude above the detection limits.

The results of duplicate analysis showed a high degree of precision. Of the 157 individual analyses completed as part of the Phase 1 and Phase 2 assessments, only 7 results exceeded the acceptable RSDs. These exceedances do not modify the interpretation of the data in any way, and the data quality is therefore considered sufficient to meet the objectives of this assessment.

4.2. Phase 1 – Assessment of co-disposal alternatives

The results for the total chemistry and leachable chemistry (1:20 leach estimates) are shown in Table 4 and Table 5 compared to the TCT and LCT values. The resultant waste assessment and required liner types are shown in Table 3.

Table 3 – Waste assessment and liner requirements for assessed materials

	Tailings	Jarosite	Jarofix	Comp Tail-Jarosite	Comp Tail - JF
TC class	TCT 1-2	>TCT2	>TCT2	TCT 1-2	TCT 1-2
LC class	LCT 0-1	>LCT3	LCT 0-1	LCT 1-2	LCT 1-2
Waste type	Type 3	Type 0	Type 1	Type 3	Type 3
Liner	Class C	Disposal not allowed	Class A	Class C	Class C

Using the results, a decision tree (Figure 2) was developed to assist in selecting the preferred alternative, and a meeting was held with SLR and Black Mountain Mining (Pty) Ltd. As indicated in Figure 2, disposal of Jarofix on the SLF was selected as the preferred alternative for the following reasons:

- The Jarosite has leachable concentrations which exceed the LCT3 value and therefore disposal is not permitted without treatment.
- The co-disposal of Jarosite or Jarofix with tailings would require a Class C liner. The existing liner for the tailings does not conform to the Class C requirements as per R635 and R636. It should be noted that this is because the tailings was constructed prior to the enactment of R635 and R636. The liner was approved by regulators and was legally compliant at the time of construction.).
- Jarosite or Jarofix co-disposed with tailings material may not be stable in the long term due to the potential for acidification of the tailings material. The tailings has total sulphur content of close to 10% which is anticipated to be present largely as sulphide, therefore it has a high potential for acid rock drainage in the long term.

Table 4 – Total concentrations compared to threshold limits

	Total concentration threshold limits (mg/kg)			**Results (mg/kg)**									
Elements & chemical substances in waste	TCT0	TCT1	TCT2	Tailings A	Tailings B	Jarosite A	Jarosite B	Jarofix A	Jarofix B	Comp Tail-Jarosite A	Comp Tail-Jarosite B	Comp Tail-Jarofix A	Comp Tail-Jarofix B
Metal Ions													
F, Fluoride	100	10000	40000	**1591**	**1723**	69	77	**105**	**131**	**1483**	**1434**	**1414**	**1426**
As, Arsenic	5.8	500	2000	2.9	2.7	*765*	*775*	**407**	**398**	**43**	**43**	**26**	**24**
B, Boron	150	15000	60000	48	48	6.0	6.1	8.3	8.1	45	49	50	54
Ba, Barium	62.5	6250	25000	29	30	**549**	**559**	**1015**	**1034**	61	59	**82**	**83**
Cd, Cadmium	7.5	260	1040	**108**	**107**	**168**	**170**	**221**	**226**	**112**	**119**	**123**	**122**
Co, Cobalt	50	5000	20000	2.1	2.3	2.5	2.6	5.0	5.3	4.0	3.8	4.1	3.9
Cr(VI), Chromium (VI)	6.5	500	2000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CrTotal (Chromium Total)	46000	800000	800000	1.1	1.2	237	236	168	176	15	15	12	12
Cu, Copper	16	19500	78000	**29**	**17**	**1090**	**1098**	**761**	**788**	**113**	**116**	**99**	**95**
Hg, Mercury	0.93	160	640	*195*	*197*	**8.2**	**5.6**	**3.6**	**3.4**	**140**	**152**	**155**	**152**
Mn, Manganese	1000	25000	100000	**8255**	**8231**	211	199	415	410	**7883**	**7708**	**7638**	**7571**
Mo, Molybdenum	40	1000	4000	0.4	0.4	13	14	9.2	9.2	1.4	1.4	1.2	1.1
Ni, Nickel	91	10600	42400	21	22	5.4	5.5	14	14	21	21	22	22
Pb, Lead	20	1900	7600	**728**	**724**	**42743**	**42713**	**30941**	**31312**	*3189*	*3198*	*2538*	*2487*
Sb, Antimony	10	75	300	1.0	1.0	*240*	*249*	*216*	*220*	**11**	**12**	**11**	**11**
Se, Selenium	10	50	200	1.3	1.3	0.6	0.7	0.8	0.9	0.6	0.6	1.2	1.1
V, Vanadium	150	2680	10720	48	48	88	89	89	89	50	52	53	51
Zn, Zinc	240	160000	640000	**33484**	**33774**	**24381**	**24451**	**22051**	**22228**	**31321**	**32249**	**31718**	**31591**

*Note – composite values were calculated by weighted averaging

Blue bold - BetweenTCT0 and TCT1

Orange italic – Between TCT1 and TCT2

Red fill - >TCT2

Table 5 – Leachable concentrations compared to threshold limits (calculated from 1:4 leach data)

	Leachable concentration threshold limits (mg/L)				Results (mg/L)									
Elements & chemical substances in waste	**LCT0**	**LCT1**	**LCT2**	**LCT3**	**Tailings A**	**Tailings B**	**Jarosite A**	**Jarosite B**	**Jarofix A**	**Jarofix B**	**Comp Tail-Jarosite A**	**Comp Tail-Jarosite B**	**Comp Tail-Jarofix A**	**Comp Tail-Jarofix B**
Inorganic Anions														
pH	6	6	6	6	9.26	9.39	**2.42**	**2.43**	8.97	8.94	9.20	9.19	9.19	9.17
F, Fluoride	1.5	75	150	600	<0.02	<0.02	0.10	0.09	0.06	0.05	0.26	0.42	0.43	0.45
NO_3 as N, Nitrate-N	11	550	1100	4400	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Chloride	300	15000	30000	120000	33.4	39.0	0.5	0.5	2.3	2.3	39.2	38.6	40.2	39.0
Sulphate	250	12500	25000	100000	2324	2659	442	447	532	503	2514	2571	2560	2568
TDS	1000	12500	25000	100000	2879	3379	739	749	725	722	3301	3362	3356	3363
Metal Ions														
As, Arsenic	0.01	0.5	1	4	0.001	0.001	0.024	0.023	0.024	0.023	<0.001	<0.001	<0.001	<0.001
B, Boron	0.5	25	50	200	0.068	0.072	0.019	0.022	0.003	0.003	0.140	0.147	0.138	0.132
Ba, Barium	0.7	35	70	280	0.008	0.008	0.007	0.008	0.014	0.013	0.004	0.004	0.006	0.006
Cd, Cadmium	0.003	0.15	0.3	1.2	0.001	0.003	**5.59**	**5.59**	0.020	0.016	0.001	0.001	0.001	0.001
Co, Cobalt	0.5	25	50	200	0.003	0.003	0.010	0.009	0.003	0.003	0.001	0.001	0.001	<0.001
CrTotal (Chromium Total)	0.1	5	10	40	0.005	0.006	0.095	0.093	0.001	0.001	0.003	0.003	0.003	0.003
Cu, Copper	2	100	200	800	0.004	0.007	1.262	1.243	0.011	0.009	<0.001	0.001	0.001	<0.001
Hg, Mercury	0.006	0.3	0.6	2.4	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002
Mn, Manganese	0.5	25	50	200	0.002	0.003	1.659	1.720	0.023	0.019	<0.001	<0.001	<0.001	<0.001
Mo, Molybdenum	0.07	3.5	7	28	0.002	0.002	<0.0002	<0.0002	0.045	0.047	0.002	0.002	0.003	0.003
Ni, Nickel	0.07	3.5	7	28	0.066	0.068	0.097	0.098	0.076	0.080	0.005	0.005	0.006	0.005
Pb, Lead	0.01	0.5	1	4	0.001	0.001	0.163	0.171	0.002	0.002	0.001	0.001	0.001	0.001
Sb, Antimony	0.02	1	2	8	0.000	0.000	0.016	0.015	0.145	0.140	0.001	0.001	0.002	0.002
Se, Selenium	0.01	0.5	1	4	0.004	0.006	0.047	0.044	0.004	0.004	0.001	0.002	0.002	0.002
V, Vanadium	0.2	10	20	80	0.002	0.002	0.009	0.007	0.007	0.007	0.001	0.001	0.001	<0.001
Zn, Zinc	5	250	500	2000	0.008	0.011	32.13	32.38	<0.001	0.002	0.015	0.016	0.016	0.015

Blue bold – BetweenLCT0 and LCT1

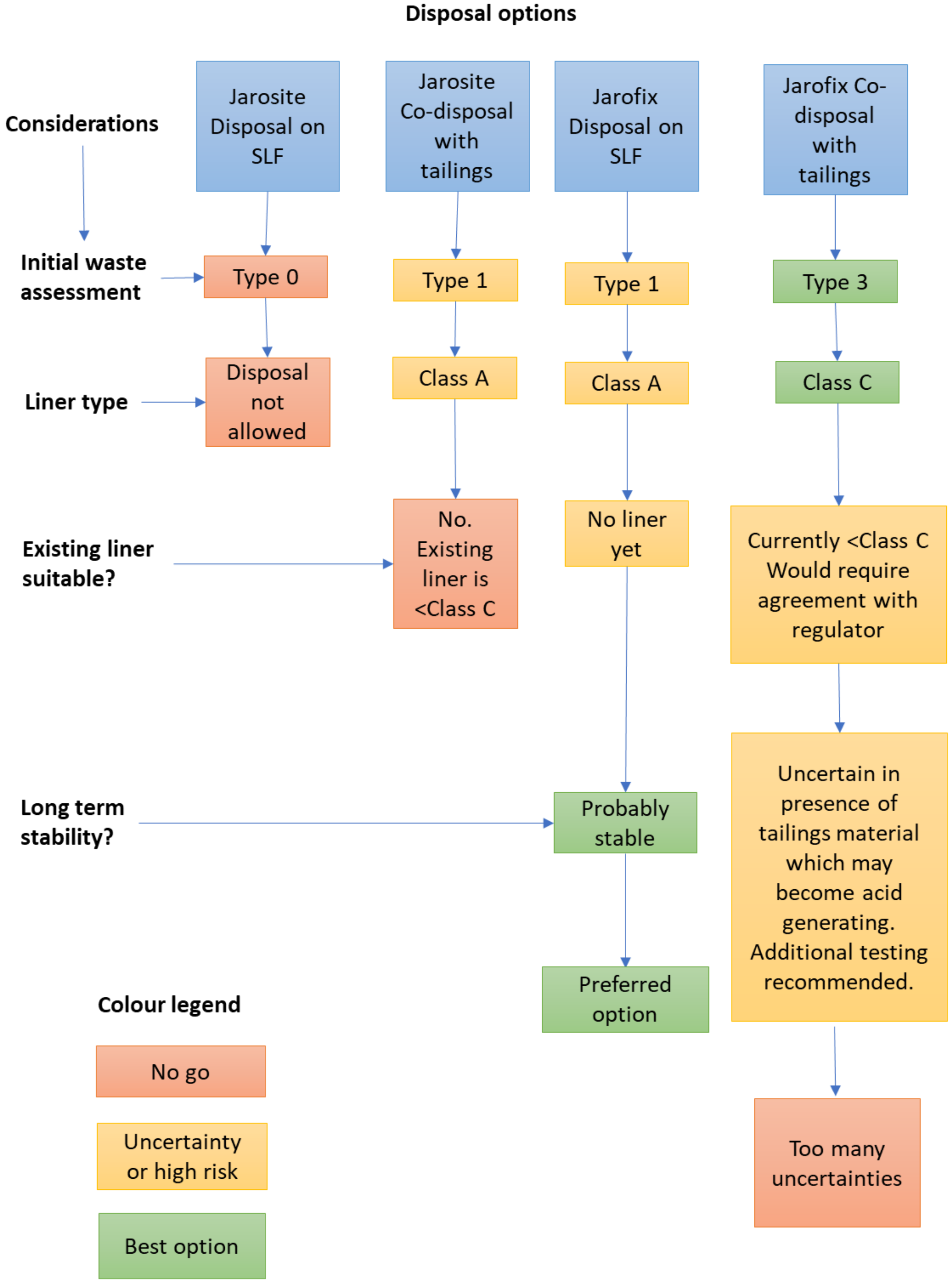
Orange italic – Between LCT1 and LCT2

Grey fill – Between LCT2 and LCT3

Red fill - >LCT3

NA – not analysed

Figure 2: Decision tree for selecting optimal disposal option

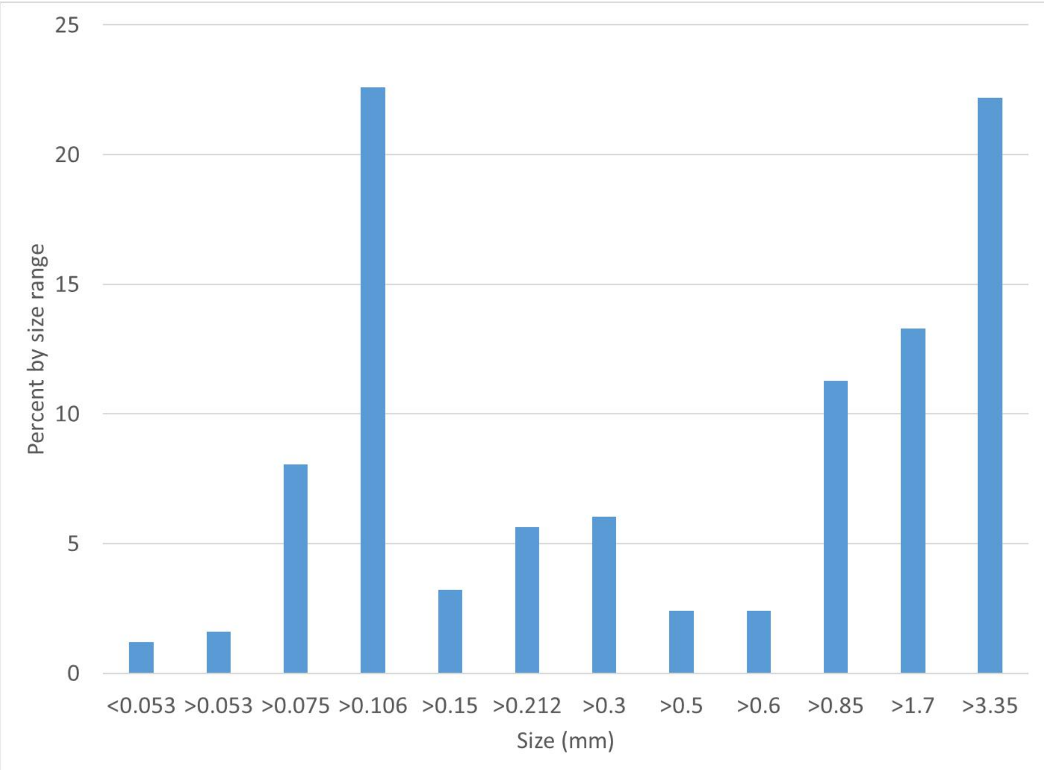


4.3. Phase 2 - Detailed analysis of Jarofix

4.3.1. Particle size distribution

A particle size distribution (PSD) was conducted to allow estimation of the reactive surface area of the Jarofix (Figure 3). The PSD also allows high level estimation of the porosity and permeability of the material. The Jarofix is composed of about 35% gravel size particles (greater than 1.7 mm in diameter), 60% of sand-sized particles (0.075 – 1.7 mm in diameter), and approximately 2% silt and clay sized particles.

Figure 3: PSD for Jarofix



4.3.2. Waste classification

The 1:20 measured distilled water leach results are presented in Table 6. The waste classification remains as Type 1 due to the high total lead concentrations.

Table 6 – Leachable concentrations compared to threshold limits (1:20 leach data)

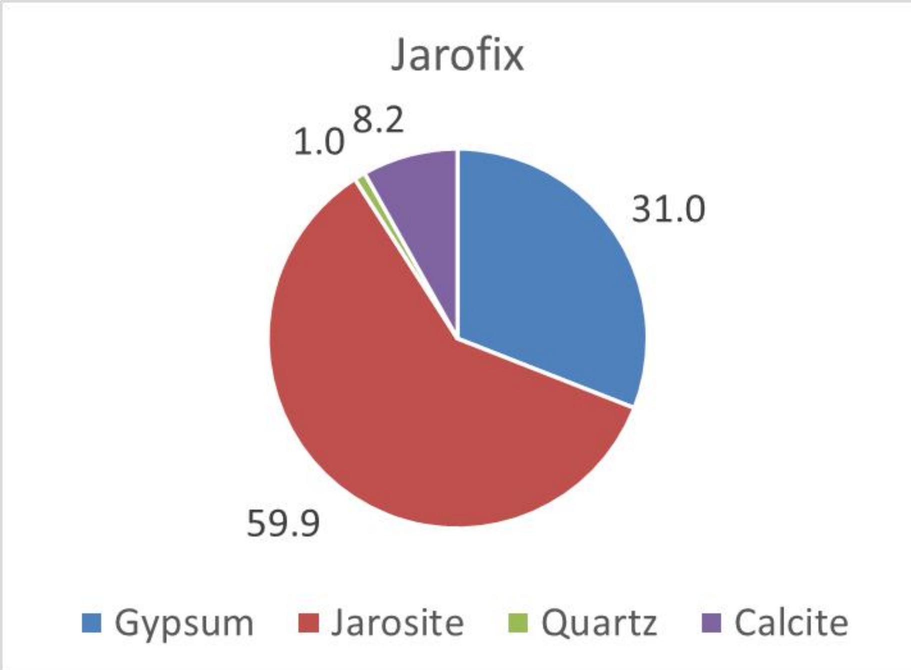
	Leachable concentration threshold limits (mg/L)				
Elements & chemical substances in waste	**LCT0**	**LCT1**	**LCT2**	**LCT3**	**Average (n=3)**
Inorganic Anions					
pH	6	6	6	6	8.80
F, Fluoride	1.5	75	150	600	0.34
NO_3 as N, Nitrate-N	11	550	1100	4400	<0.1
Chloride	300	15000	30000	120000	2.18
Sulphate	250	12500	25000	100000	1759
TDS	1000	12500	25000	100000	2659
Metal Ions					
As, Arsenic	0.01	0.5	1	4	0.042
B, Boron	0.5	25	50	200	0.040
Ba, Barium	0.7	35	70	280	0.108
Cd, Cadmium	0.003	0.15	0.3	1.2	0.001
Co, Cobalt	0.5	25	50	200	<0.001
Cr(VI), Chromium (VI)	0.05	2.5	5	20	<0.05
CrTotal (Chromium Total)	0.1	5	10	40	<0.001
Cu, Copper	2	100	200	800	0.004
Hg, Mercury	0.006	0.3	0.6	2.4	<0.0001
Mn, Manganese	0.5	25	50	200	0.003
Mo, Molybdenum	0.07	3.5	7	28	0.033
Ni, Nickel	0.07	3.5	7	28	0.007
Pb, Lead	0.01	0.5	1	4	<0.001
Sb, Antimony	0.02	1	2	8	0.193
Se, Selenium	0.01	0.5	1	4	0.009
V, Vanadium	0.2	10	20	80	0.013
Zn, Zinc	5	250	500	2000	0.004

Blue bold - BetweenTCT0 and TCT1
Orange italic – Between TCT1 and TCT2
Red fill - >TCT2

4.3.3. Mineralogy

Jarofix was found to consist of approximately 60% Jarosite ($KFe^{3+}_3(OH)_6(SO_4)_2$), with 31% gypsum ($CaSO_4.2H_2O$), 8% calcite ($CaCO_3$) and 1% quartz (SiO_2) (Figure 3).

Figure 3: Pie chart of Jarofix mineralogy measured by XRD



4.3.4. Potential for acid generation

Development of ARD is typically associated with the oxidation of sulphide minerals, in most cases pyrite (Drever, 1997):

$$FeS_2 + {}^{15}/_{4}\,O_2 + {}^{7}/_{2}\,H_2O \rightarrow Fe(OH)_3 + 2SO_4^{2-} + 4H^+$$

In the absence of sulphide minerals, as is the case here, ARD is unlikely to develop. However, some oxide minerals like Jarosite can store acidity. When Jarosite dissolves, it can release hydrogen ions causing the pH to decrease:

$$KFe_3^{3+}(OH)_6(SO_4)_2 + 3H_2O \rightarrow K^+ + 2SO_4^{2-} + 3Fe(OH)_3 + 3H^+$$

Addition of lime slurry ($Ca(OH)_2$) and cement to the Jarosite to form Jarofix results in a neutralising of the acidity:

$$Ca(OH)_2 + 2H^+ \rightarrow Ca^{2+} + 2H_2O$$
$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$
$$CaCO_3 + 2H^+ \rightarrow Ca^{2+} + 2H_2CO_3$$

A standard acid base accounting (ABA) assessment, which assumes that 1 mole of calcite is required to neutralise the acidity generated from 1 mole of sulphur in pyrite, is not appropriate in this case. The acid potential (AP) calculation can be modified for Jarosite based on the stoichiometry of the above reactions i.e. that 0.75 moles of neutralising potential (as $CaCO_3$) can neutralise acidity generated from 1 mole of sulphur. Not all the sulphur present in the Jarofix is due to Jarosite, some is due to gypsum, which is not acid generating. The AP calculation is therefore conducted using only the sulphur that is present in Jarosite. The amount of sulphur present in Jarosite is estimated using two methods:

- XRD data, with results as in Section 4.2.3.
- Using a normative mineralogy approach with the total chemistry. All carbon is assumed to occur as calcite, which gives an amount of calcite of 4.4 wt%. The remaining calcium is assumed to be present in gypsum, giving an amount of gypsum of 30.5 wt%. Finally, the amount of sulphur remaining is assumed to be present in Jarosite, giving an amount of Jarosite of 35 wt%.

The calculated calcite and gypsum concentrations are similar to XRD results, but the Jarosite amount is far lower. Quantitative XRD provides only order of magnitude estimates of quantities due to preferred orientation and crystallite size effects. In addition, XRD does not readily detect amorphous minerals. Based on the change in colour of Jarosite (yellow) to Jarofix (red) with addition of cement and lime slurry, it seems likely that amorphous iron oxide minerals have formed which are not accounted for in the XRD analysis, and result in overestimation of other mineral quantities. The results from the normative calculation are therefore used to estimate the acid potential of the Jarofix.

The results of the ABA screening are presented in Table 7. The amount of sulphur present in Jarosite is sufficient to potentially generate acidity, but this is balanced by the presence of calcite and lime, which can neutralise the acidity. The calculated neutralising potential ratio (NPR) and net neutralising potential (NNP) values are within the ranges for which there is uncertainty as to whether acid will be produced. This is because of how close the AP and NP values are, meaning that the potential for acid generation will depend on the relative rates at which the Jarosite, lime and calcite react. The paste pH and NAG pH do provide some confidence that the initial pH of leachate from Jarofix will be near neutral to slightly alkaline.

Table 7 – Modified ABA screening of Jarofix

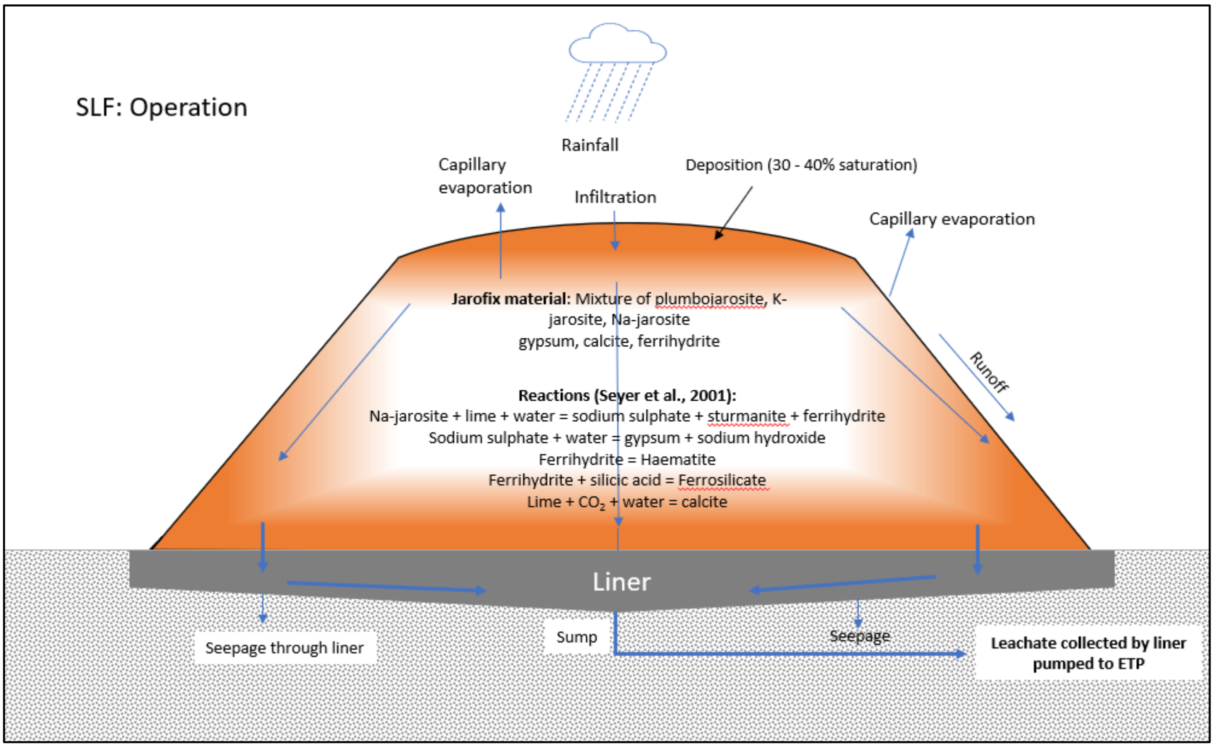
Parameter	**Units**	**Screening criteria**				**Average Jarofix (n=3)**
		Type I: High	**Type II: Possible/ uncertain**	**Type III: Low/ uncertain**	**Type IV: No risk**	
S in Jarosite	Wt%	>0.3	0.2 - 0.3	0.01 - 0.2	<0.1	4.0
Paste pH		<5	<7	>7	>7	8.9
NAG pH		<4.5	<4.5	<4.5	>4.5	7.9
NAG Acidity	kg/t H2SO4	>5	<5	<5	0	<0.01
Modified AP from Jarosite S	kg/t CaCO3					87.8
NP	kg/t CaCO3					92.9
NPR		<1	1-2	2-4	>4	1.1
NNP		<-20	-20	0 - 20	>20	5.1

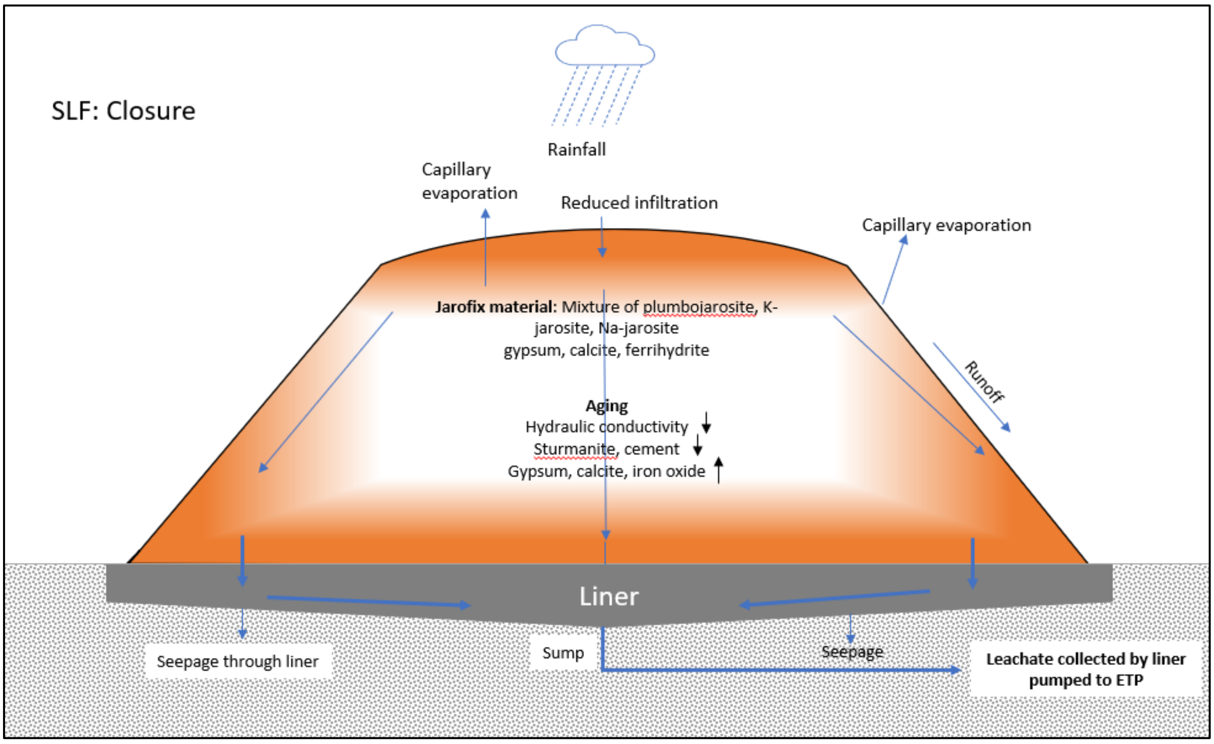
5. Development of Source Terms for Jarofix SLF

5.1. Conceptual site model

A conceptual model is required to understand the relationship between the physical and chemical processes occurring within the Jarofix SLF, and is used as a basis for geochemical modelling. The conceptual models for operation and closure are shown in Figure 5.

Figure 5: Conceptual models for operation and closure of the SLF

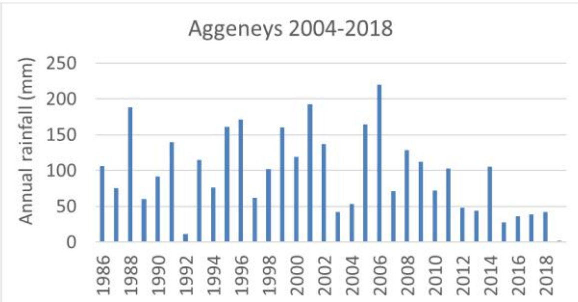


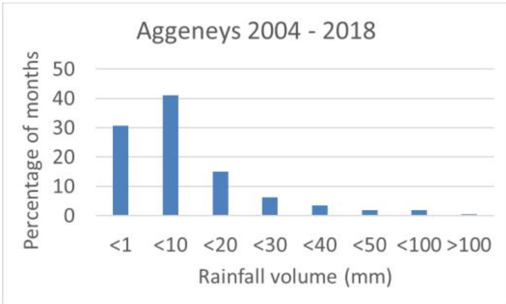


Jarofix is dewatered to produce a cake with a moisture content of 30-40% which is trucked to the disposal site. The disposal site is currently planned to cover an area of 21 hectares, and to reach a height of 25 m over a life of 15 years. The disposal rate will be 290 000 tons per annum. Effluent treatment plant (ETP) waste will be co-disposed with the Jarofix at a rate of 24 000 tons per annum.

Once on the SLF, the Jarofix will be exposed to rainfall and evaporation. The Northern Cape Province where the Gamsberg Zinc Mine is situated is, however, an arid area. The average annual rainfall at Aggeneys between 2004 and 2018 was 99.1 mm, falling mostly between January and April (Figure 4). Between 2015 and 2018 the annual rainfall was less than 50 mm. Monthly rainfall amounts are less than 10 mm more than 70% of the time. Between 2004 and 2018, monthly rainfall of over 50 mm was only recorded on 6 occasions.

Figure 4: Rainfall statistics for Aggeneys (2004-2018)





Rain falling on the SLF can either:

- Run off the sides of the SLF as surface runoff;
- Infiltrate into the SLF, flow through the SLF and be captured by the line. This leachate will be directed to a sump from where it will be pumped to the ETP; or
- Infiltrate into groundwater.

As the SLF will be lined with a Class A liner with a leachate collection system, the volume of seepage into groundwater is likely to be low and limited by the permeability of the liner. In addition, the presence of cement in the Jarofix is likely to cause it to solidify with time, greatly reducing the potential for infiltration into the SLF.

Surface run-off from the material or water that short-circuits through preferential pathways (e.g. cracks) will likely dissolve salts present on the surface of the disposed material, whereas rainwater that infiltrates the pore spaces in the disposed material will have more time to react, and concentrations in the leachate may reflect equilibrium with the minerals present in the SLF. For the purposes of modelling, only the long residence-time seepage is considered.

Within the SLF, the Jarosite will react with the cement to form Jarofix. Details of these reactions are given in Section 5.2. Over time, the Jarofix will age, and become more consolidated, changing the flow conditions of the SLF. Different scenarios are modelled to consider consolidated and unconsolidated material.

The geochemical model used in this assessment is a transport model, which predicts the change in water quality as water flows through a system. The system is set-up as a one-dimensional column divided into 15 cells each 1.5 m long. This column can be imagined to represent a vertical cross-section through the centre of the SLF. The waste is initially saturated with the water that is present at the time of disposal.

Water (either rainfall or added water) infiltrates the waste from the top and reacts with the components in the first cell for a specified length of time, and then flows into the next cell, where it reacts before flowing into the following cell etc. Leachate that emerges from the base of the column represents water that has infiltrated from the surface of the waste and undergone reactions with the full thickness of the waste pile. This does not represent all scenarios of interaction of water with the Jarofix, as some water may interact only with surface material and become surface run-off. This procedure is continued for a total amount of time as specified by the modeller, with inflow of water from the top of the column, and outflow of leachate from the bottom. The leachate quality at the base of the column is reported.

The chemistry of a leachate from the SLF will be controlled by four main variables which are discussed in detail below:

1. The mineralogy of Jarofix;
2. The reactive portion of the materials within the SLF;
3. The flow rate through the SLF; and
4. The composition of the water in the system.

5.2. Mineralogy of Jarofix

Jarofix is a chemically and physically stable material formed by mixing Jarosite precipitates with pre-set ratios of Portland cement (10%), hydrated lime (2%) and water. Jarosite reacts with the alkaline constituents of cement, forming stable phases which immobilise zinc and other metals. Jarofix is a preferred disposal option for Jarosite waste in India and Canada, and there have been investigations into its use as a construction material (Sinha, et al., 2019; Shijith, 2015; Seyer et al., 2001).

A Canadian study found that, after three months of curing, the mineralogy of Jarofix is dominated by sodium Jarosite and gypsum, with minor amounts of newly formed minerals forming a matrix which cements together the partially reacted sodium Jarosite. These minerals include Ca-Al-Fe silicate-sulphate-hydrate, sturmanite ($Ca_6Fe_2(SO_4)_3(OH)_{12}.nH_2O$), Ca-Al-Fe oxide, haematite (Fe_2O_3), Ca-Fe sulphate, quartz (SiO_2), ferrihydrite ($Fe(OH)_3$), lime ($Ca(OH)_2$), calcite ($CaCO_3$) and unreacted cement. Ferrihydrite may react further to form complex silicate species. Zinc is immobilised by being structurally incorporated into a Ca-Al-Fe silicate-sulphate-hydrate cement reaction product.
After 6 years, Jarofix is compact, dry and harder. At this point there is no residual cement and no sturmanite, but greater amounts of gypsum, calcite and cement reaction products (Ca-Al-Fe silicate-sulphate-hydrate, Ca-Fe sulphate). With time amorphous iron becomes more stable (Seyer et al., 2001).

Given the dominance of Jarosite in Jarofix, an understanding of this mineral is required for modelling purposes. Jarosite is a hydrated iron sulphate mineral. It is well known in ARD environments, where it can accommodate many other elements (Swayze et al., 2008). The standard formula for Jarosite is $KFe_3^{3+}(OH)_6(SO_4)_2$ however other members of the Jarosite supergroup include:

- Natrojarosite - $NaFe_3^{3+}(OH)_6(SO_4)_2$
- Hydronium Jarosite - $(H_3O)Fe_3^{3+}(OH)_6(SO_4)_2$
- Plumbojarosite - $PbFe_6^{3+}(OH)_{12}(SO_4)_4$
- Alunite - $KAl_3^{3+}(OH)_6(SO_4)_2$

Jarosite is relatively insoluble in water, however, dissolution of Jarosite can release acidity (Blowes et al., 2003; Swayze et al., 2008). According to Sinha et al. (2013), Jarosite in Jarofix takes the form of

Plumbojarosite. High levels of lead were measured in the Jarofix in this study, therefore this is likely to be the case.

Based on normative calculations of mineralogy using the total concentrations from this study, the Jarosite in the waste is assumed to consist of a mixture of Potassium-Jarosite (16%), Sodium-Jarosite (60%) and Plumbojarosite (24%). In reality, the Jarosite is probably a complex solid solution containing potassium, sodium and lead, as well as a range of other trace elements. In the absence of site specific data, the solubility products used in the model for Sodium and Potassium Jarosite are the defaults from the minteq.v4 database. Information provided by Forray et al. (2010) suggests that Plumbojarosite has a lower solubility product than Sodium and Potassium Jarosite, and the solubility product from this reference is used. It should be noted that Jarosite solubility is strongly dependent on chemical composition and grain size.

Although not directly identified by XRD, the reddish colour of the Jarofix suggests the presence of ferrihydrite, an amorphous iron hydroxide mineral. Iron hydroxides have a high capacity for adsorbing trace elements from solution. Trace element adsorption onto precipitating iron hydroxides is allowed in the model. This is often the main control on trace element concentrations at neutral pH. Trace elements generally do not form minerals of their own, but often substitute for more common elements within the crystal lattice of other minerals. Trace elements measured in the distilled water leach are likely to have been released from dissolving minerals such as gypsum or Jarosite. Trace elements in solution are allowed to adsorb to precipitating iron hydroxide minerals.

Geochemical modelling databases do not incorporate many of the reaction products that form through the reaction of Jarosite and cement, therefore the approach taken was to include the major minerals (Jarosite, gypsum, calcite) as well as known cement reaction products (e.g. ettringite) and potential sinks for sodium, lead, barium, fluoride and sulphate (e.g. mirabilite, $Pb_4(OH)_6SO_4$, fluorite, barite).

The chemistry of leachate is determined by the minerals present and by whether the water reaches equilibrium with the minerals. Calculation of saturation indices for the distilled water leach tests shows that the leach test solutions are in equilibrium with gypsum. Gypsum is therefore used as the equilibrium control on sulphate and calcium concentrations in the model. The degree of saturation of each of the other minerals is controlled by adjusting the saturation indices to be the same as those in the 1:4 distilled water leach test.

5.3. Reactive portion of the materials in the SLF

PHREEQC models are normalised to 1 L of water. Therefore, the amount of mineral reactant used in the model must be scaled to the amount of reactant that would react with 1 L of water. This requires assumptions about the porosity of the rock, the surface area of the minerals and the proportion of the various minerals within the rock that are available to react with water. The finer the grain size of the material, the more exposed surfaces there will be for reaction. It is generally the <2 mm particle size grains that affect drainage chemistry (Price, 2009).

During operation, the waste is assumed to be water saturated, and the water:rock ratio is therefore controlled by the porosity and the surface area. Post closure, the water:rock ratio is likely to be controlled by the field capacity i.e. the percentage saturation level at which water is able to drain through the material. Typical values for field capacity in a waste facility are 8-10% (Price, 2009).

A porosity of 30% has been assumed for unconsolidated material based on data for unconsolidated sand and gravel provided by Manger (1963). This means that 1 L of water will be in contact with approximately 3 kg of rock. However, studies of Jarofix have shown that only 30% of the original

Natrojarosite present reacts (Seyer et al., 2001). A percentage reactivity of 30% is assumed, therefore 1 L of water is assumed to react with 1 kg of rock. Consolidated Jarofix is noted to be very porous (Nova and Arroyo, 2005), therefore a porosity of 20% is assumed. Note that these are fairly arbitrary assumptions, but are aimed at providing a conservative estimate of the amount of the material available for reaction. These mineral relationships can only be fully understood by undertaking a mineralogical study. In the absence of a mineralogical study, the geochemical model can be calibrated over time by using field studies and groundwater quality data.

5.4. Flow rate through SLF

The rate at which water flows through the material determines the rate at which new reactants are brought into the system, and the rate at which reaction products are flushed from the system. Where no flow occurs, or where flow is slower than the rate of reaction, reaction products will build up in solution, and the system will reach an equilibrium.

During operation, the waste facility is likely to be saturated due to ongoing deposition of Jarofix with a 30-40% moisture content. The rate of water flow will therefore be governed by the hydraulic properties of the material and the design of the waste facility. Hydraulic conductivity in tailings has been measured at between 1×10^{-4} and 1×10^{-8} m/s, with vertical hydraulic conductivity an order of magnitude lower than horizontal hydraulic conductivity (Price, 2009). Physically, Jarofix hardens with time to a consistency similar to stiff clay, with hydraulic conductivity similar to silt (Demers and Haile, 2003). The amount of rainfall during operation is unlikely to affect water quality as the volume of rainfall relative to the volume of water deposited in the tailings is likely to be low. Post-closure, the flow rate is dependent on the amount of rainfall and the degree to which the rainfall infiltrates. For uncovered, unconsolidated waste material, it is assumed that infiltration will be high due to the unevenness of the material surface and the high porosity. If material is consolidated by cement, the infiltration rate will be far lower and most water will run-off.

In order to assess the sensitivity of the source terms to flow rate, four flow-rate scenarios are considered as follows:

- Unconsolidated during operation;
- Consolidated during operation;
- Unconsolidated post-closure; and
- Consolidated post-closure.

Ultimately the volume of leachate that penetrates the liner and enters the receiving environment will depend on the liner specifications, with any excess leachate captured in the leachate collection system for treatment. The input parameters for each of these scenarios are summarised in Table 8.

Table 8 – Input parameters for modelling scenarios

Scenario	Units	Operation unconsolidated	Operation consolidated	Closure unconsolidated	Closure consolidated
Hydraulic conductivity	m/s	1 x 10^{-7}	1 x 10^{-10}	1 x 10^{-7}	1 x 10^{-10}
Porosity		0.3	0.2	0.3	0.2
Infiltration	%MAP	50	5	50	5
Infiltration	m/a	0.05	0.005	0.05	0.005
Seepage rate	m/a	11	0.015	0.15	0.004
Years/cell (1.5 m)	a	0.14	100	10	410
Reactive proportion	%	30	20	30	20
Initial solution		Water in equilibrium with Jarofix at 30% saturation	Water in equilibrium with Jarofix at 30% saturation	Water in equilibrium with Jarofix at 10% saturation	Water in equilibrium with Jarofix at 10% saturation
Leaching solution		Water in equilibrium with Jarofix	Water in equilibrium with Jarofix	Rain	Rain

5.5. Composition of water in the system

The quality of the water in the system can affect the rate and type of reactions occurring within the system.

Water within the SLF during operation will be in equilibrium with the waste material at a saturation level of 30%. This initial water composition is calculated from the 1:4 distilled water leachate results concentrated by a factor of 13.3, and then allowed to equilibrate with selected minerals (calcite, gypsum, ferrihydrite, fluorite, barite, plumbojarosite, K-jarosite, Na-jarosite, $Pb_4(OH)_6SO_4$).

Post-closure, when no further water is being added in the waste material, and evaporation and drying of the material has progressed, water within the SLF is still assumed to be in equilibrium with the waste material at a saturation level of 30%. However, rainwater is assumed to infiltrate the waste material from the surface and percolate through the waste material. The rainwater is assumed to be pure water equilibrated with oxygen and carbon dioxide at atmospheric partial pressures, resulting in an inflow solution with a pH of approximately 5.7.

6. Model Results

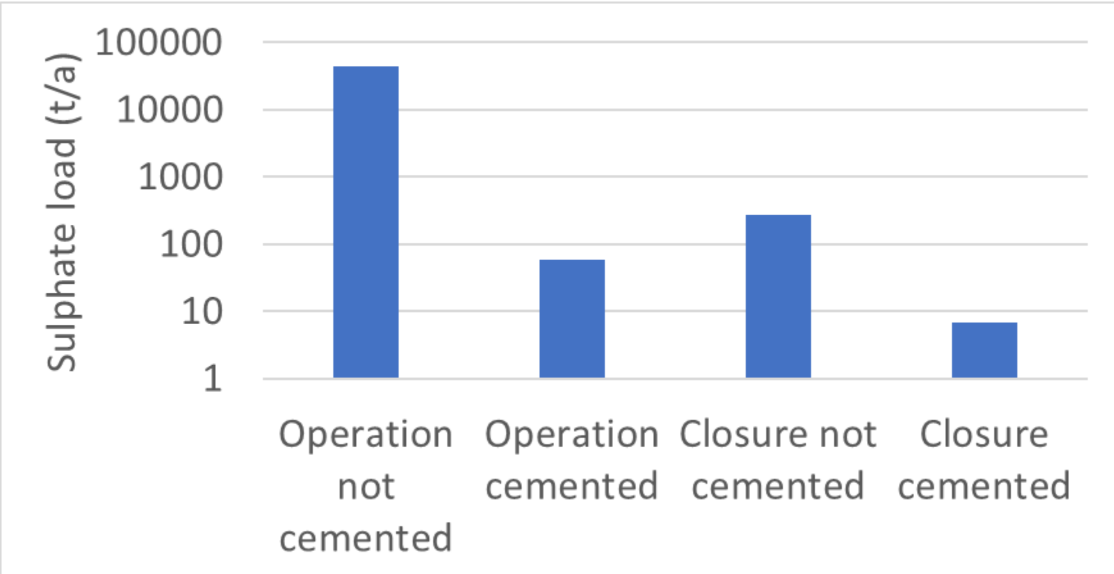
6.1. Scenario 1 - Operation

Selected modelling results for unconsolidated and consolidated material during operation are shown in Figure 6.

For the unconsolidated scenario, where water flow rates are relatively high, the pH is alkaline and sulphate concentrations increase to more than 18 000 mg/L. Arsenic and antimony are plotted because they exceeded the LCT0 values in the waste assessment. Lead and zinc are included due to their elevated total concentrations. In the predicted leachate from the SLF the concentrations of lead, zinc and arsenic are low (less than LCT0 value) until after about 2 years in the unconsolidated material when lead concentrations increase to between the LCT0 and LCT1 threshold values. The change in concentrations of lead and sulphate after 2 years occurs because the plumbojarosite included in the model is completely dissolved and lead solubility is then controlled by a more soluble lead hydroxysulphate mineral. Antimony concentrations exceed the LCT3 value (8 mg/L) because there does not appear to be a mineral control on antimony solubility, and it does not sorb strongly to ferrihydrite. Antimony should be included in monitoring program.

For the consolidated scenario, the concentrations remain stable over the operational period. Concentrations of most analytes are lower than the unconsolidated scenario, and arsenic, lead and zinc concentrations are well below leachate thresholds. Antimony concentrations are similar to the unconsolidated scenario. It must be noted that the volume of water that will leach under the consolidated scenario is lower than the unconsolidated scenario, therefore the overall contaminant load is less (Figure 5).

Figure 5: Estimated annual sulphate loads (volume of leachate multiplied by concentration of leachate) for each of the modelled scenarios

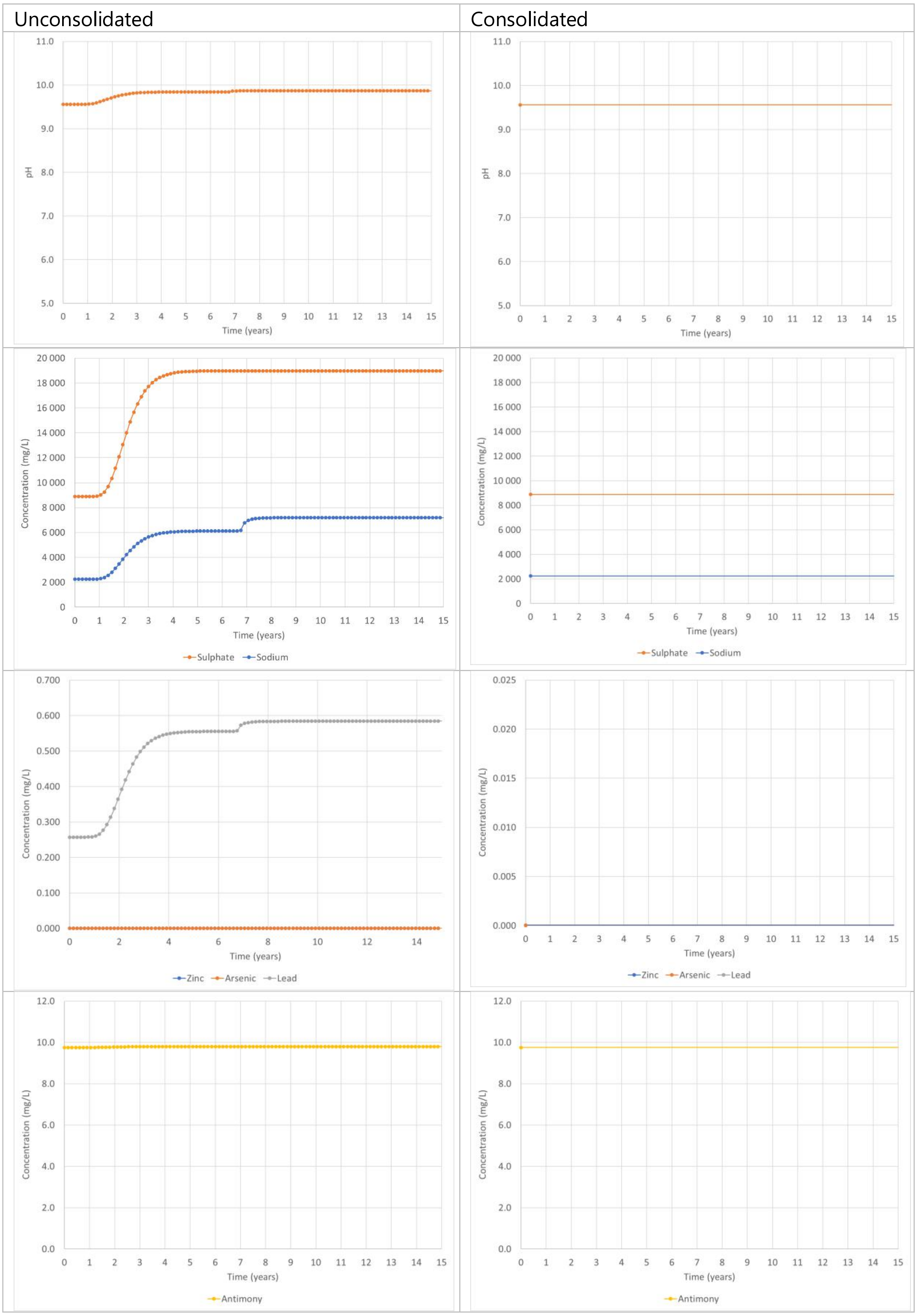


Because the jarofix will be deposited in an unconsolidated form and will gradually consolidate, at any stage during the growth of the SLF there is likely to be a mixture of unconsolidated and consolidated material on the SLF, therefore the actual leachate quality is likely to be somewhere between the quality of the leachate from the unconsolidated and the consolidated material. Suggested source terms are given in Table 9.

Table 9 – Suggested source terms for operation and closure

Parameter	Operation	Closure
pH	10	9.6
Sulphate (mg/L)	19 000	9 000
Sodium (mg/L)	7 000	2 000
Lead (mg/L)	0.6	0.3
Antimony (mg/L)	10	10

Figure 6: Predicted leachate quality with time during operation



6.2. Scenario 2 - Closure

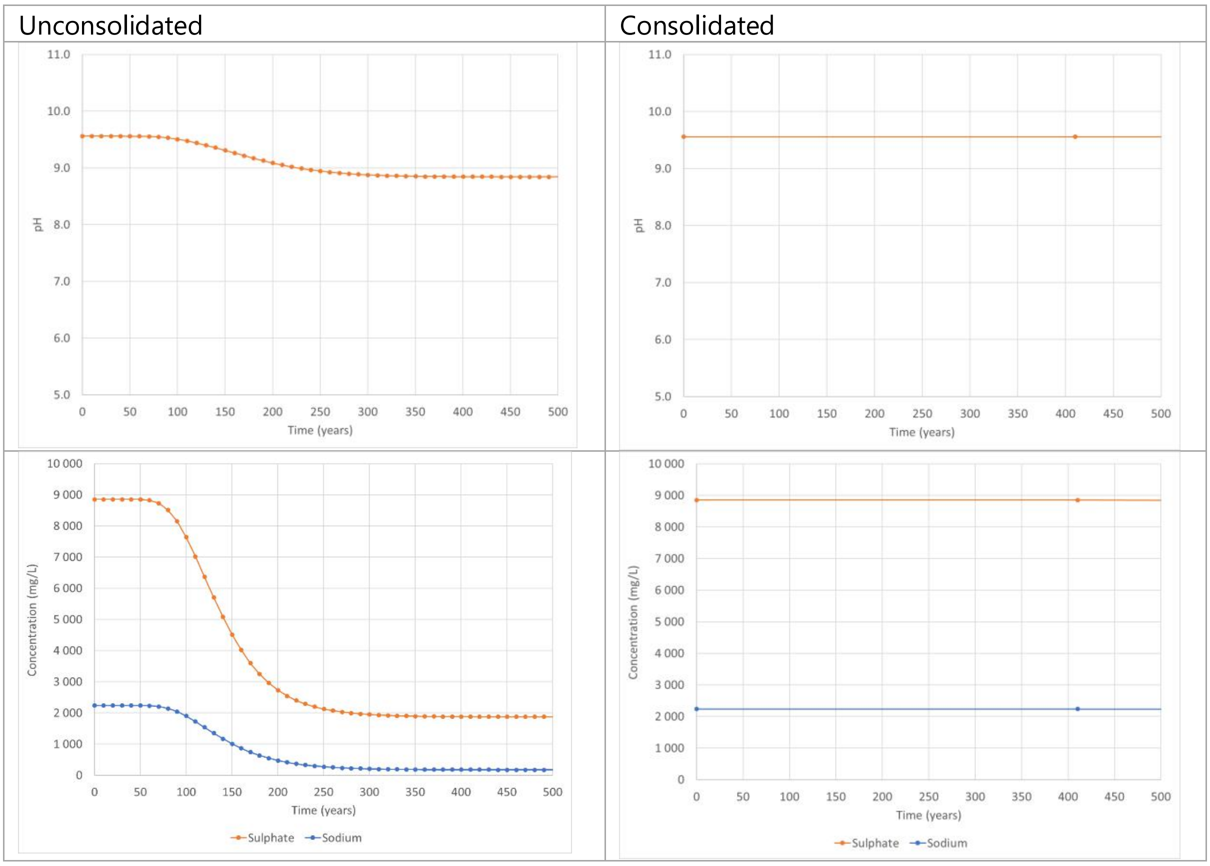
There are two differences between the geochemical model for closure and post-closure:

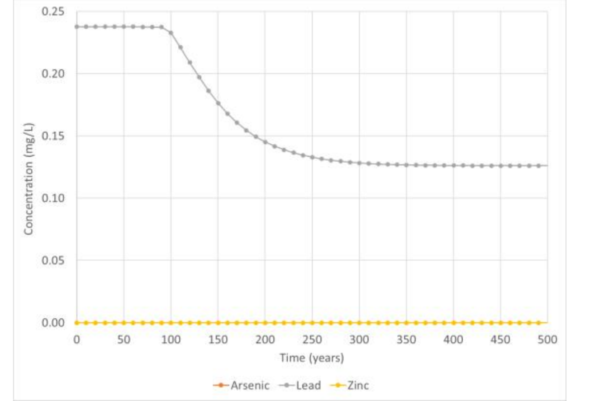
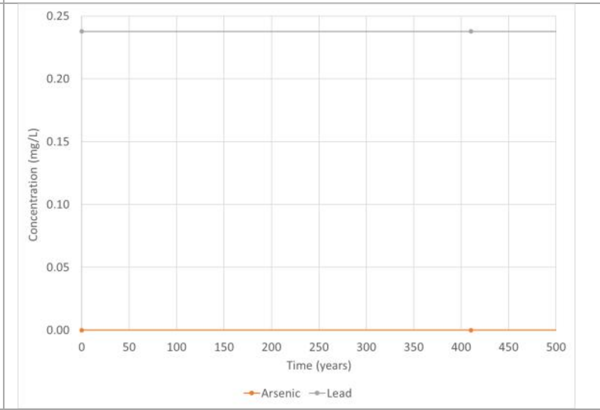
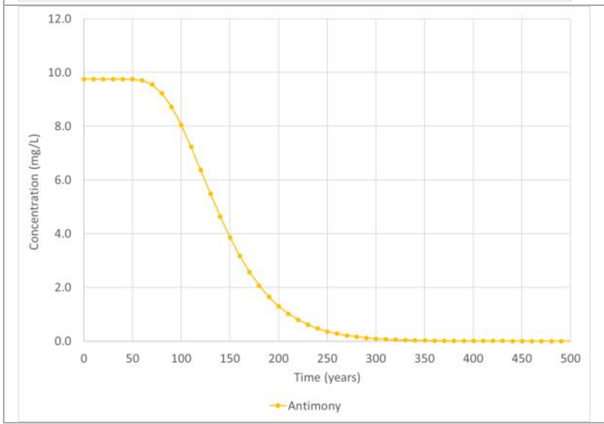
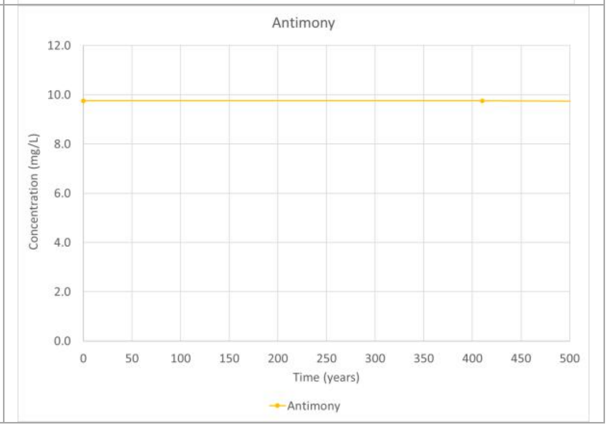
1. The degree of saturation of the material is assumed to be far lower post closure, with the difference between the amount of water at saturation (assumed 30%) and on consolidation (assumed 10%) assumed to be lost by seepage.
2. The SLF is now flushed by rainwater only, with no water being added in new material that is deposited.

The predicted leachate quality results are shown in Figure 7, and suggested single concentration source terms are given in Table 9.

Flushing by rainwater will gradually remove salts within the waste material, resulting in a reduction in leachate concentrations. However, due to the low volumes of rainfall experienced at the site, this is likely to occur over an extended period of time, with no observed difference in leachate concentration for hundreds to thousands of years from consolidated material. The estimated annual sulphate loads for the consolidated and unconsolidated scenarios post-closure are shown in Figure 5. The sulphate load is higher for the unconsolidated scenario due to the lower assumed seepage rates.

Figure 7: Predicted leachate quality with time during closure



Unconsolidated	Consolidated
	
	

7. Limitations of the Assessment

In terms of the geochemical samples collected, the following should be noted:

- The Jarofix and Jarosite samples were produced in India from ore mined in India. Although they provide a good indication of the likely chemistry of the waste materials to be produced in South Africa, there may be differences in chemistry which have not been accounted for in this assessment;
- The samples were collected by a third party and are assumed to be representative of the respective waste materials; and
- Although a high degree of repeatability was found between the duplicate samples, two samples (per waste material) do not provide a statistically robust population and the samples collected do not provide defensible information on the variability in sample composition.

In terms of the geochemical model, it should be noted:

- Geochemical models are representations of reality and are based on numerous assumptions. Model predictions can be improved as the project progresses by calibrating the model with site specific data as and when this is received. At this stage of the assessment, the model provides an order of magnitude indication of the leachate quality;
- There is little literature available on the long-term behaviour of Jarofix and as such, the models are the best interpretation of available data and expected geochemical reactions;
- Data on flow rates, evaporation, mineral contact etc. are estimates and can only be confirmed by calibration against on-site monitoring data;

- Literature thermodynamic data for various forms of Jarosite differ widely, which has a significant effect on the model results; and
- The model has been developed assuming equilibrium conditions within the Jarofix. The model outcomes could differ if the dissolution of any of the minerals is kinetically limiting.

8. Summary and Recommendations

The optimal waste disposal approach was selected for waste Jarosite from a proposed zinc smelter at the Gamsberg Zinc Mine. Four disposal options were considered, namely:

- Disposal of Jarosite on a dedicated facility;
- Generation of jarofix (mixture of Jarosite, cement and lime) and disposal on a dedicated facility;
- Co-disposal of Jarosite on the existing tailings facility at Gamsberg Zinc Mine; and
- Co-disposal of jarofix on the existing tailings facility at Gamsberg Zinc Mine.

A waste assessment was conducted which showed that disposal of Jarosite either on its own or with tailings was unacceptable due to leachable cadmium concentrations which exceeded the threshold for Type 0 waste (i.e. waste which is not allowed to be disposed without further treatment). Co-disposal of Jarofix with tailings was not considered further due to the uncertainty regarding the long term behaviour of the tailings, which are expected to become acidic in the future. Disposal of Jarofix on a dedicated SLF was therefore selected as the preferred disposal option.

The Jarofix material was further tested and a geochemical model was developed to determine source terms for the SLF. Jarofix was found to be largely composed of Jarosite, gypsum, calcite and a small amount of quartz. Despite having high total concentrations of lead and zinc, the leachable concentrations of these metals were below the LCT1 threshold value in the waste assessment leach test. Only arsenic and antimony exceeded the LCT0 threshold value. The waste is classified as a Type 1 waste due to the high total lead concentrations.

Addition of cement to Jarosite results in a complex series of reactions occurring which largely immobilise metals. Geochemical models were developed to determine the source term for the SLF. The source term depends strongly on a number of factors:

- The flow rate of water through the SLF. This will be impacted by the porosity and permeability of the material, the amount of water added in the waste, and the degree of hardening (cementation) of the Jarofix. Four different flow rates were modelled to assess differences in these parameters, reflecting consolidated and unconsolidated material, and operational and closure water volumes; and
- The solubility of the various minerals in the Jarofix. Literature thermodynamic data for various forms of Jarosite differ widely, which has a significant effect on the model results. Ultimately the model was calibrated based on observed concentrations in the 1:4 and 1:20 leach tests. This assumes that these leach tests reflect equilibrium conditions.

The results suggest that the salt concentrations (predominantly sodium and sulphate) in the leachate will be high, but that generally metal concentrations will be low, with the exception of antimony. Initially the volumes of leachate are likely to be controlled by the volumes of water in the Jarofix that is placed on the SLF, but as time progresses and the Jarofix hardens, the volumes of leachate should decrease and the overall load of contaminants in seepage will decrease. The use of a Class A liner which captures seepage for treatment will aid in limiting the risk of groundwater impact during operation, however seepage which may leach through the liner is likely to have high sulphate concentrations. Post-closure, assuming the material hardens and the SLF is covered with a low permeability cap to encourage run-off and prevent infiltration, the risk of groundwater impact will be less but should be assessed through hydrogeological modelling. Groundwater monitoring up and down-gradient of the SLF should be undertaken to ensure there is no groundwater impact, including sulphate and metal concentrations (especially arsenic, antimony, lead, zinc and cadmium). Cladding of the SLF sides with unreactive material during operation and capping with compacted, unreactive material post closure should reduce the potential for rainfall interaction with Jarofix.

Improved confidence in the findings can be obtained by:

- Analysis of Jarofix produced in the local plant as soon as this becomes available;
- Undertaking a detailed mineralogical analysis of the material to understand changes in composition as the Jarofix ages;
- Assessment of the reduction in hydraulic conductivity of the Jarofix as it ages; and
- Conducting kinetic leach tests to confirm how the leachate quality will change with time.

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APPENDIX G: COMMENTS RECEIVED DURING CONSULTATION PROCESS

#	I&AP Details (X = contact has been added to stakeholder database)		Date and mode of communication	Issue raised	Response (as amended for the purposes of the scoping report)
1	**Environmental related comments and responses**				
1.1	K.A. Fortuin	X	Email, Emailed registration form, 18 October 2019	How will the pollution be controlled? Environmental impacts and their controls? Social impacts on residing community? Water consumption control?	Various specialist studies including biodiversity, ground water, surface water and air quality are being undertaken to identify potential impacts and provide mitigation measures. These will be addressed in the EIA and EMPr which will be circulated for public review at a later stage in the process.
1.2	M. Botha	X	Emailed registration form, 18 October 2019	Who is the CEA for the smelter? There is incomplete or non-compliant mitigation from previous environmental authorisations. How will this be managed in the EIA process? DEFF is not listed as regulatory authority or an interested party.	The Competent Environmental Authority for the smelter application is the DMR. Please raise any concerns related to suspected non-compliance with previous environmental authorisations with the applicable authority – DMR, DENC or DWS. The Department of Environment, Forestry and Fisheries (DEFF, formerly DEA) has been included as an I&AP. A focus group meeting with the Department of Environment and Nature Conservation, Northern Cape, with whom BMM signed the original Gamsberg Biodiversity offset Agreement, will be held once the specialist biodiversity studies and air quality model are completed to get their inputs, comments and recommendations.
1.3	I. Basson o.b.o Pella NCMACA Branch	X	Emailed letter, 28 October 2019	Firstly, we are sorry that we are responding so late, but we had to hold a meeting with our role players first. By email we thank you for taking us into account with the 3rd pipeline of the Orange River by Pella to Gamsberg. Secondly, we as Pella residents and riparian farmers have discovered a few years back that the invader plants are sucking up Orange River water at a tremendous rate. It	Black Mountain Mining (Pty) Ltd is proposing to upgrade the existing underground pipeline on behalf of Sedibeng Water. In order to do this the existing underground pipeline will be removed and a new one installed with a larger diameter in its place. There would, thus, still be only 2 pipelines within the servitude. This proposed pipeline upgrade will be undertaken as a separate Basic Assessment process and will have the relevant specialist study done to inform the project.

#	I&AP Details (X = contact has been added to stakeholder database)		Date and mode of communication	Issue raised	Response (as amended for the purposes of the scoping report)
				stands along the banks of the river all the way to Witbank ridge. Thirdly, we as Pella residents have also discovered that the Orange River is saturated and will not be able to supply a third pipeline, so we say no to a third pipeline. It will not happen in the next 10 years, not in our river and not on our land. Sorry. Fourth, As Pella community forum, in 2017 we asked Vedanta to remove the invasive plant by the roots from the riverbanks. To date nothing has happened so where do they think the river should get enough water for their pipeline? They should have listened to us and done as we said, then maybe the Orange River could have been saved. We are sorry, but we refuse the construction of a third pipeline, because we want to protect this little bit of water for our community and future generations. We will not allow any pipeline construction. We wish you a thousand failures in the future.	The volume of water to be extracted by the upgraded pipeline is within the already authorised abstraction volumes which are included and allocated in the DWS reserve determination for the Orange River. No additional water volumes are being requested in this application. We note your concern regarding the presence and impacts of alien vegetation species along the river.
1.4	S.A.C Hockaday	X	Emailed registration form, 1 November 2019	I would like to know if any measures were considered to limit direct and indirect greenhouse gas emissions.	A Climate Change specialist study has been commissioned for the Gamsberg Smelter Project to assess the emissions from the project and the potential impact on greenhouse gases.
1.5	A. Young o.b.o the Mesemb Study Group	X	Emailed registration form,	Current safeguards concerning preservation of succulent flora at the Gamsberg have been shown to be inadequate and until these issues are resolved no further developments that are likely to negatively impact the biodiversity of the Gamsberg should be undertaken. What specific measures	As part of the Gamsberg Smelter Project a Biodiversity specialist study is being undertaken to understand the current impacts from the Gamsberg Zinc Mine as well potential impacts from the

#	I&AP Details (X = contact has been added to stakeholder database)		Date and mode of communication	Issue raised	Response (as amended for the purposes of the scoping report)
			6 November 2019	will be taken by the mine to ensure that the floral biodiversity in the area is protected as a result of this development?	operation of the smelter and associated facilities on the vegetation of the area. In addition to this an Offset Agreement is currently in place as well as a Biodiversity Management Plan (BMP) to manage the impacts of the mine. This BMP will be updated to include the Proposed Gamsberg Smelter Project. A focus group meeting with the Department of Environment and Nature Conservation, Northern Cape, with whom BMM signed the original Gamsberg Biodiversity offset Agreement, will be held once the specialist biodiversity studies and air quality model are completed to get their inputs, comments and recommendations. Implementation of Biodiversity Offset Agreement has resulted in the Proclamation of the Gamsberg Nature Reserve as Gazetted in the Northern Cape Provincial Gazette on 5 August 2019. The Gamsberg Nature Reserve was proclaimed as a Protected Area under the National Environmental Management Protected Area Act and the Management Plan as required by the NEMPA is currently being compiled by DENC. This will safeguard the conservation of succulents within the secured Gamsberg Nature Reserve for future generations.
1.6	P. Mokomele o.b.o the Industrial Development Corporation	X	Emailed registration form, 12 November 2019	How will waste be treated and what will be the environmental effects?	Process waste produced by the Gamsberg Smelter Project is proposed to be stored in a new Secured Landfill Facility as stabilised Jarofix. A full specialist ground and surface water studies will be undertaken to inform requirements and any potential impacts. Domestic and general waste will be sent to the existing Black Mountain Mining landfill facilities.

#	I&AP Details (X = contact has been added to stakeholder database)		Date and mode of communication	Issue raised	Response (as amended for the purposes of the scoping report)
					Hazardous wastes will be removed by licenced contractors as is current practice at Gamsberg Zinc Mine.
1.7	P. Mokomele o.b.o the Industrial Development Corporation	X	Emailed registration form, 12 November 2019	Will the building of a smelter mean that there will be more people coming to the area? How will the influx be handled? Has the capacity of the municipality in terms of infrastructure been assessed to accommodate (the project?).	Black Mountain Mining (Pty) Ltd and its associated Business Partners will follow a recruitment process that maximises the use of local skills as far as possible. It is anticipated that there will be some additional people moving to the area particularly where those skills are not available locally. There is a skills database in place which is planned to be reviewed in consultation with the DoL and the Khâi-Ma Municipality. A Socio-economic specialist study has been commissioned to assess the potential impact on the local infrastructure.
1.8	K. Purnell, o.b.o Wilderness Foundation Africa	X	Emailed registration form, 15 December 2019	Wilderness Foundation Africa is concerned with the loss of biodiversity and whether it is being offset sufficiently.	As part of the Gamsberg Smelter Project a Biodiversity specialist study is being undertaken to understand the current impacts of the Gamsberg Zinc Mine as well potential impacts from the operation of the smelter and associated facilities on the vegetation of the area. A focus group meeting with the Department of Environment and Nature Conservation, Northern Cape, with whom BMM signed the original Gamsberg Biodiversity offset Agreement, will be held once the specialist biodiversity studies and air quality model are completed to get their inputs, comments and recommendations. Implementation of Biodiversity Offset Agreement of Gamsberg has resulted in the Proclamation of the Gamsberg Nature Reserve as Gazetted in the Northern Cape Provincial Gazette on 5 August 2019. The Gamsberg Nature Reserve was proclaimed as a Protected area under the National Environmental Management Protected Area Act and the Management Plan as required by the NEMPA are currently being compiled by DENC. This will safeguard

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					the conservation of succulents within the secured Gamsberg Nature Reserve for future generations.
1.9	K. Purnell, o.b.o Wilderness Foundation Africa	X	Emailed registration form, 15 December 2019	We are very concerned with the fallout from sulphur and its impacts on the surrounding environment, which could affect a large area around the smelter. This needs to be adequately addressed through a thorough modelling of the sulphur fallout in the EIA.	An Air Quality specialist study is being undertaken to understand emissions from the proposed Gamsberg Smelter. These emissions will be modelled to give an understanding of potential impacts on the surrounding environment as well as mitigation measures provided to minimise potential impacts. Predicted fallout from the modelling of emissions will be interpreted by biodiversity specialists to assess the potential impact on vegetation. Especially the succulent species. In addition, the Gamsberg Smelter has been designed with the latest technology to minimise SO_2 emissions during the acid making process and in adherence with relevant national guidelines and legal requirements.
1.10	Johan van Dyk	X	Emailed registration form, 29 January 2020	My only concern is sustainability, hence my question: 1. History in the wider Namaqualand area shows that mining activities are continuing in the area, and once the resource has been depleted, little infrastructure is left behind to support, maintain and create sustainable work and long term investment opportunities for the community. There are various examples of historical mining activities in the area that left the area as “ghost towns” with little sustainable businesses established (which only benefits a few)…i.e. Koiingnaas, Kleinzee, Alexanderbay, Baken / Sanddrift, Nababeep, O’okiep, Carolusberg….. to name a few. Springbok is the only “big hub” in the area. 2. My question is, what legacy will the responsible company leave once the resource is completed for example in 20/30	Black Mountain Mining (Pty) Ltd and Vedanta Zinc International are engaging with a range of government authorities to develop a long-term, post-mining economy for the Aggeneys area.

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				years' time? Another Ghost Town? Aggeneys is a mining town with majority mining activities. How will the company ensure long term sustainability and employment opportunities post life of mine? Could you present a long term Social Development Plan post life of mine?	
2	**Technical / Technology related comments and responses**				
2.1	J. Crowder o.b.o Standard Bank	X	Email, 18 October 2019	Thank you very much for the information. Do you perhaps have timelines for the proposed project please?	Pending approval of the EIA and EMPr, construction is planned to start in 2021. The construction phase will take 2 to 3 years.
2.2	J. Leader	X	Emailed registration form, 18 October 2019	Is there a proposed finish date yet?	Pending approval of the EIA and EMPr, construction is planned to start in 2021. The construction phase will take 2 to 3 years.
2.3	S. Meijers o.b.o ELB Engineering Services	X	Emailed registration form, 22 October 2019	Has phase 2 been considered in your layouts?	Phase 2 has been considered and is already included in all layouts as it is part of the existing Environmental Authorisation and EMPr for the Gamsberg Zinc Mine. The anticipated impacts of Phase 2 will also be assessed cumulatively with additional impacts from the proposed Gamsberg Smelter Project.
2.4	C. Steyn o.b.o Connolee Investment	X	Emailed registration form,	I am interested in the renewable energy section.	A zinc smelter is a power intensive plant and electrical power plays a major role in the operation with power outages severely affecting production capacity. As such it is essential that power sourcing be reliable with 100 percent availability for uninterrupted

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			25 October 2019		operation of the plant. The following alternative power sources are being considered: • Eskom grid substation; • Captive solar power plant; • Wind based power plant; and • Hybrid model (including both Eskom and renewable source). Considerable focus is placed on utilising alternative/hybrid energy sources such as wind and solar power sources, and not total reliance on the ESKOM grid.
2.5	S.A.C Hockaday	X	Emailed registration form, 1 November 2019	I would like to know the measures taken to ensure water conservation.	The design of the smelter has looked at minimising water consumption against the benchmark of existing zinc smelters with similar capacity around the world and has been designed to include an effluent recycling system with zero liquid discharge. Black Mountain Mining (Pty) Ltd will also not exceed the current water allowance.
2.6	S.A.C Hockaday	X	Emailed registration form, 1 November 2019	I would like to know the process alternatives considered and how the electrolytic process was selected to ensure it is appropriate to the resource	A process selection study was carried out by Vedanta Zinc International at conceptual level which involved identifying the technologies currently being used by the largest zinc producers worldwide as a benchmark. The study resulted in the selection of the following two process options: • Roast-Leach-Electrowinning (R-L-E) with Jarosite precipitation; and • High Pressure/ Atmospheric Acid Leach. The survey of the largest global zinc producers confirmed that conventional Roast-Leach-Electrowinning (R-L-E) is by far the most

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					used and efficient processing route within excess of 85% of the zinc producers using variations of the process.
2.7	S.A.C Hockaday	X	Emailed registration form, 1 November 2019	I would like to know if the use of renewable energy sources were considered as alternative to grid electricity dependence.	A zinc smelter is a power intensive plant and electrical power plays a major role in the operation with power outages severely affecting production capacity. As such it is essential that power sourcing be reliable with 100 percent availability for uninterrupted operation of the plant. The following alternative power sources are being considered: • Eskom grid substation; • Captive solar power plant; • Wind based power plant; and • Hybrid model (including both Eskom and renewable source). Considerable focus is placed on utilising alternative/hybrid energy sources such as wind and solar power sources, and not total reliance on the Eskom grid.
2.8	N. Uys o.b.o Minerals to Metals Initiative, University of cape Town	X	Emailed registration form, 13 November 2019	Is the use of the term smelter not misleading? Our understanding is that it is a Roast-Leach-Electrowinning (R-L-E) process as opposed to a smelter. Roasting: A pyrometallurgical process where ore/concentrates is heated to below its melting point, in the presence of air, in order to oxidise impurities. In the case of zinc sulphide ores, sulphur is oxidised. Most common equipment for this process is a rotary kiln. Smelting: A pyrometallurgical process where metals are extracted from ore/concentrate heating above the melting point of all constituents in a furnace and separating into	"Zinc smelter" is the most commonly used terminology worldwide for extracting zinc metal from zinc bearing concentrate. Conventional R-L-E is one of the process routes which is intended to be implemented to treat the Gamsberg zinc concentrate. At the Gamsberg Zinc Smelter it is the intention to apply the Roasting process, where in the presence of air, the zinc sulphide is oxidised to zinc oxide and sulphur in concentrate is oxidised to sulphur dioxide which is cleaned and converted to sulphuric acid. The process is exothermic and auto thermal.

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			metal rich (blister, matte) and oxide-rich (slag) phases that are tapped separately from the furnace.
			
			Questions:
			
			Technology
			
			• What was the driving factor for the Roast-Leach-Electrowinning (R-L-E) technology choice?
			  ○ What is the fuel source for the roasting step (coal, gas, diesel), where is it coming from and how is it stored?
			  ○ What are the exhausts from the R-L-E process?
			  ○ What is the expected CO2 footprint?
			  ○ Are there any deleterious metals/dust in the exhaust gas?
			  ○ Has gas dispersion been modelled?
			  ○ Has any means of CO2 capture been considered?
			• What other technology options (as opposed to R-L-E) were considered (e.g. pressure leaching)?
			Products
			
			• Apart from zinc and sulphuric acid, are there any other proposed or potential sellable products (e.g. metal impurities such as silver, indium, germanium which are removed during purification)? If there are potential other sellable products, what is hindering their inclusion in the process flowsheet?
			• Is there a reliable market for sulphuric acid?
			  ○ If so where is the market?
			  ○ How will it be stored and transported?
				The technical process queries have been addressed in Section **Error! Reference source not found.**.

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				• Is there potential for a close-by facility for fertiliser production?
				  ○ Is there a market for fertiliser?
				• Will all the concentrate be processed by the proposed refining process, or will a portion of the concentrate be exported?
				Waste
				• What are the proposed waste management strategies?
				  ○ In terms of leach residues, impurity removal products, flue-gas precipitates, etc.
				  ○ What is the current plan for iron precipitates (Jarosite) and gypsum products?
				  ○ Have any other options for minimisation/elimination of waste production been considered?
				• What is the expected deportment of deleterious elements into waste streams?
				Utilities
				• Is the Eskom Aggeneys Substation the sole source of the plant's electricity requirements?
				  ○ What is the anticipated electrical power demand for the process, particularly the energy intensive electrowinning step?
				  ○ Can Eskom Aggeneys Substation accommodate this additional electricity demand?
				  ○ What are the impacts associated with this (locally and nationally)?
					Leach residues with a potential market value such as Mangenese oxides will be sold into the market. The remaining hazardous waste streams such as Jarosite will be stabilised to Jarofix and disposed of to a dedicated secure landfill facility in close proximity to the smelter complex.
					
					Samples of Jarosite and jarofix obtained from sister operations in India that have a similar concentrate make-up as the Gamsberg Zinc Mine will be analysed to determine waste content and assist with the waste classification.
					
					When fully reliant on Eskom for electricity supply the Aggeneys Substation will be the sole source of electricity, however, as part of the design of the project the sole reliance on Eskom is being offset by investigating the implementation of alternative sources for electricity such as solar, wind power and various combinations thereof.

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				○ What additional environmental concerns need to be addressed in building the power line from the substation? Given an already constrained national grid, what is the 'backup' plan if Eskom's electricity provision is constrained (periods of less or no electricity)?	The maximum demand anticipated is 150MW. The current Aggneys Eskom substation will be upgraded as part of the project and additional transformers will be installed at the substation. Installation of the additional transformers will increase the footprint of the current substation slightly. The current power pylons of the installed power line could be utilised as it was constructed to enable the replacement of only the power line itself and not the pylons Active partnerships is being investigated with alternative power producers as per the IPP process. Currently there have been no such developments in the vicinity of the Gamsberg Smelter Project due to lack of contracts with Eskom.
3	**Procurement of Services (people offering their services) related comments and responses**				
3.1	C.G. March	X	Emailed registration form, 16 October 2019	Mostly interested in the job creation aspects as well as the prospect(ive) projects social economic development objectives.	During the construction phase approximately 6 000 jobs will be created and 1 200 during operations. During the construction phase the Business Partners will be aligned with Black Mountain Mining (Pty) Ltd/ Department of Labour (DoL)/ Khâi-Ma Municipality requirements. For the operational phase the normal Black Mountain Mining (Pty) Ltd recruitment process will be in place. Black Mountain Mining (Pty) Ltd have invested more than R100 million in LED projects incl. community development between April 2014 and December 2019 towards empowering of community members. Black Mountain Mine (Pty) Ltd has further

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					committed to spend close to R150 million over the next five years (2019-2023) on local economic development initiatives.
3.2	E. Beukes	X	Emailed registration form, 17 October 2019	With the development of the new Gamsberg Zinc Mine there has been no significant differences in our communities in terms of development and economic empowerment despite millions of rand raised through the SLP being spent. How will the new smelter help improve the economic empowerment of our local communities? How can it help to employ fewer contractors outside the Northern Cape who are impoverishing our small businesses? How can incumbent contractors be forced to subcontract small businesses for the purpose of building them? Will the mine stop bringing in (external, outside Khâi-Ma) people and companies while we have local capacity? Compared to Postmasburg which expanded to the new mines, how will the smelter contribute so that we see similar development in our towns? "Contact details for L. Steenkamp provided."	Black Mountain Mining (Pty) Ltd currently contributes towards the employment of approximately 2 850 people (direct/indirect). Of the 1 804 people directly employed, Khâi-Ma employees represent 25% of the total employment and Namakwa as a whole 61%. Gamsberg Zinc Mine has contributed significantly to the local employment increase experienced since the start of its plant operations in 2018. Currently 177 community members are enrolled at the TVET College in Upington. This is planned to increase to approximately 250 over 2020. All candidates will have the opportunity to be employed. Black Mountain Mining (Pty) Ltd will ensure that the Business Partners follow the required recruitment process and prioritise local people. Black Mountain Mining (Pty) Ltd have invested more than R100 million in LED projects including community development between April 2014 and December 2019 towards empowering of community members. Local skills will be prioritised for employment. There is a skills database in place which is planned to be reviewed in consultation with the DoL and the Khâi-Ma Municipality. Black Mountain Mining (Pty) Ltd will be implementing a preferential procurement policy in April 2020 which aims to address the current shortcoming in the Enterprise and Local Supplier Development process.

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					Black Mountain Mining (Pty) Ltd has spent just over R4.2 million towards small business support and enterprise development. It is Black Mountain Mining (Pty) Ltd's aim to ensure that SMME mentoring and support are implemented and provided. There is a process in place for businesses to register for providing services to Black Mountain Mining (Pty) Ltd. Black Mountain Mining (Pty) Ltd is committed and will continue to encourage our business partners to procure material or services as far as possible from our local suppliers.
3.3	G. Stock, o.b.o Moolmans	X	Emailed registration form, 17 October 2019	Please to keep us informed of the EIA development as it progresses.	I&AP has been registered on the I&AP database to receive any and all future public communications regarding the project.
3.4	I. Andrea o.b.o Southey Contracting	X	Emailed registration form, 17 October 2019	We were part of Phase 1 and completed the scaffolding for civils and mechanical work without any injuries.	Thank you for your comment.
3.5	M. van Kuijeren o.b.o B&W Instrumentation & Electrical	X	Emailed registration form, 17 October 2019	B&W complied 100% on the Vedanta Environmental Management Phase throughout the Project Construction Phase. B&W complied 100% on the Vedanta Safety Management Plan, achieving 100% Safety Audit via Vedanta and their Safety Agents 8 months in a row.	Thank you for your comment.

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				B&W also received the Safety Excellence award for the Gamsberg Zinc Mine 1st Phase presented by Vedanta CEO and Chairman. B&W also won the Reticulation Contractor of the Year by the ECA (Electrical Contractors Association) for the OHL and Sub-station Installation Scope of Work on the Gamsberg Project. B&W was runner-up for the National Safety Award Contractor of the Year by the ECA for the Gamsberg Project. B&W was also runner-up for the Installation Contractor of the Year-Industrial by the ECA for the Gamsberg Project.	
3.6	T. Padotan o.b.o Roadlab	X	Emailed registration form, 17 October 2019	We conduct civil engineering materials testing.	Thank you for your comment
3.7	C. Steyn o.b.o EOH	X	Emailed registration form, 27 October 2019	Job opportunities should be positive.	During the construction phase approximately 6 000 jobs will be created and 1 200 during operations. During the construction phase the Business Partners will be aligned with Black Mountain Mining (Pty) Ltd/ Department of Labour (DoL)/ Khâi-Ma Municipality requirements. For the operational phase the normal Black Mountain Mining (Pty) Ltd recruitment process will be in place.
3.8	M. Vogel o.b.o CSG Foods (Pty) Ltd	X	Emailed registration form,	We are South African registered company and a subsidiary of CSG Group of Companies. CSG Foods specialize in Camp Construction, Camp Management, Catering, Cleaning, Laundry and Related Services. We will without hesitation take you to some of our current sites in order to introduce	Thank you for your comment

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			5 November 2019	you to our current clients for reference purposes and will be able to assist you immediately with proposed solutions and pricing you might require.	
3.9	P. Mokomele o.b.o the Industrial Development Corporation	X	Emailed registration form, 12 November 2019	I would be interested in knowing how unemployment will be impacted.	During the construction phase approximately 6 000 jobs will be created and 1 200 during operations. During the construction phase the Business Partners will be aligned with Black Mountain Mining (Pty) Ltd/ Department of Labour (DoL)/ Khâi-Ma Municipality requirements. For the operational phase the normal Black Mountain Mining (Pty) Ltd recruitment process will be in place.
3.10	D. Bursic o.b.o Novatec	X	Emailed registration form, 12 November 2019	As supplier of control system (system integrator), LV equipment (MCC, PLC, RIO, LCS and other similar types) on Gamsberg Project phase 1, we are showing interest for future project phases (smelter, second concentrator plant) that will follow.	I&AP has been registered on the I&AP database to receive any and all future public communications regarding the project.
3.11	R. Stuurman, o.b.o Desert Road Inn	X	Emailed registration form, 18 November 2019	As the Social and Labour Plan says, local small business must be uplifted. We as small business owners in Khâi-Ma gained nothing from the projects at Gamsberg. I hope this project will not be the same as the first one.	Black Mountain Mining (Pty) Ltd has spent just over R4.2 million towards small business support and enterprise development. It is Black Mountain Mining (Pty) Ltd's aim to ensure that SMME mentoring and support are implemented and provided. Black Mountain Mining (Pty) Ltd
3.12	R. Nortje, o.b.o Rowena's Cottage	X	Email, 18 November 2019	As an entrepreneur, and as an interested party, I would like to congratulate you in development that is taking place in our Municipal Area. Question will be who will benefit in this project and how? With the first development of the current Plant that is operational, outside company's benefited and left with the	Thank you for your comment . There is a process in place for businesses to register for providing services to Black Mountain Mining (Pty) Ltd. Black Mountain Mining (Pty) Ltd is committed and will continue to encourage our

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				Capital. Will it be the repeat of future beneficiaries? I am a black female business owner. My business does purified water whereby the machine is an upmarket RO 4000 Reverse Osmosis Machine. My company did not benefit from the first project. Pofadder itself was not developed and business shift to Springbok and Kakamas. Are we going to see a repeat? My Company's name is Rowena's Cottage, producing 'Pofadder Water'.	business partners to procure material or services as far as possible from our local suppliers. Rowena's cottage is currently benefitting from business from the current operations at Gamsberg and Deeps. Black Mountain Mining (Pty) Ltd will continue to encourage business partners to procure material or services, as far as possible, from local suppliers.
3.13	S. Williams o.b.o BVI	X	Emailed registration form, 19 November 2019	BVI Consulting Engineers was involved with the previous phase 1 of this project.	Thank you for your comment
3.14	B. Harley, o.b.o B&W Instrumentation and electrical	X	Email, 22 November 2019	Thank you for the comprehensive report on the project and indeed the existing environment. B&W were involved extensively on the concentrator project particularly when building the overhead line from Aggeneys to site regarding the line route and the process and procedures we had to adhere to. Both B&W and the client team I believe achieved the goals set in maintaining and preserving the environment ensuring absolute minimum damage and relocation. B&W will be attending the public meeting at Pofadder on the 4th of December 2019.	Thank you for your comment.
3.15	N. Bruhns, o.b.o FCS	X	Emailed registration form, 26 November 2019	We are Suppliers, based in Upington in the Northern Cape, and would be so glad if you list us as an interested party for the Gamsberg Smelter and Bulk Water Pipeline Project. Please be so kind and keep us updated.	I&AP has been registered on the I&AP database to receive any and all future public communications regarding the project.

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3.16	Harry Ruiters	X	Emailed registration form, 15 January 2019	Please find attached the registration form as received to get more information regarding the Gamsberg Smelter and it's process. I wish to also know more about the following: Which vacancies will be available at the Gamsberg Smelter including job titles? What are the requirements and training needs for the construction phase?	Thank you for your comment . There is a process in place for businesses to register for providing services to Black Mountain Mining (Pty) Ltd. Black Mountain Mining (Pty) Ltd is committed and will continue to encourage our business partners to procure material or services as far as possible from our local suppliers. The list of vacancies and specific requirements would be finalised at a later stage.
3.17	Blaize Magee	X	Emailed, 29 January 2019	We provided the plant substation 11kV and 66kV protective relaying and SCADA integration for the Black Mountain project. We would like to be of assistance on the new smelter. Would you let me know who we should talk to in this regard ?	Thank you for your comment . There is a process in place for businesses to register for providing services to Black Mountain Mining (Pty) Ltd. Black Mountain Mining (Pty) Ltd is committed and will continue to encourage our business partners to procure material or services as far as possible from our local suppliers. The list of vacancies and specific requirements would be finalised at a later stage.
4	**I&AP registration related comments and responses**				
4.1	M. Letsoso, o.b.o NCPG	X	Email, 16 October 2019	New I&AP contact details provided for NCPG	Thank you for the update. The database has been updated accordingly.
4.2	A. Van Schalkwyk o.b.o Waltons	X	Email, 16 October 2019	Please remove me from this mailing communication, thanks.	Thank you for the update. The database has been updated accordingly.
4.3	L. Ntobela o.b.o NCPG	X	Email,	New I&AP contact details provided for NCPG Renee Williams and Lucretia van der Westhuizen	Thank you for the update. The database has been updated accordingly.

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			16 October 2019		
4.4	F. Scott o.b.o Osborn Engineered Products SA	X	Email, 16 October 2019.	Osborn Engineered Products will be interested in participating on this Project, I will submit the document back to you.	Comment noted. No further correspondence received to date.
4.5	A. Costa o.b.o the IDC	X	Email, 16 October 2019	I don't require communications on this matter, thank you.	Thank you for the update. The database has been updated accordingly.
4.6	Dr L. Kirsten o.b.o SMEC	X	Email, 16 October 2019	We are not an interested or party in relation to this notice. It should therefore be ok if you removed me from the circulation list.	Thank you for the update. The database has been updated accordingly.
4.7	I. Coetzee o.b.o Radio NFM	X	Emailed registration form, 16 October 2019	"Request I&AP registration."	I&AP has been registered on the I&AP database to receive any and all future public communications regarding the project.
4.8	A. Duff o.b.o MV Switchgear	X	Email, 17 October 2019	We would appreciate receiving any further applicable information.	I&AP has been registered on the I&AP database to receive any and all future public communications regarding the project.
4.9	L. Smith o.b.o NCPG	X	Email, 18 October 2019	1. Ms D Stander - Environmental Management 2. Dr L Mabona - Infrastructure Management	I&AP has been registered on the I&AP database to receive any and all future public communications regarding the project.

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				Please receive this communique for your attention and noting. The HOD requests that this office be kept updated in this regard.	
4.10	JA. Kruger	X	Email, 18 October 2019	"Additional I&AP contact details provided for Cassie Kruger."	I&AP has been registered on the I&AP database to receive any and all future public communications regarding the project.
4.11	K.A. Fortuin,	X	Email, Emailed registration form, 18 October 2019	How many I&AP participants do you have, and can anyone join? Also, when will the first meeting be held and where? Lastly, is there a formal process of research being done on this project?	There are currently just under 1 050 participants registered on the stakeholder database. Initial public meetings were held from 2 to 5 December 2019 which all registered I&AP's were informed of. Further meetings will be held later in the process.
4.12	M. Swarts o.b.o Labex	X	Emailed registration form, 18 October 2019	Suppliers of lab equipment and chemicals	Thank you for your comment. I&AP has been registered on the I&AP database to receive any and all future public communications regarding the project.
4.13	M. Ferreira o.b.o Quality Tube Services	X	Emailed registration form, 18 October 2019	We are very interested in the project. Supply of steel pipe and related fittings as well as rubber lining and HDPE lining and HDPE pipes and fittings.	Thank you for your comment. I&AP has been registered on the I&AP database to receive any and all future public communications regarding the project.
4.14	R. Stuurman o.b.o Desert Road Inn	X	Emailed registration form,	As a small business owner, my question is whether they will give us businesses in Khâi-Ma opportunity to benefit from the project? On the original project there were only promises.	There is a process in place for businesses to register for providing services to Black Mountain Mining (Pty) Ltd. Black Mountain Mining (Pty) Ltd is committed & will continue to encourage our

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			18 October 2019		business partners to procure material or services as far as possible from our local suppliers. Black Mountain Mining (Pty) Ltd will continue to encourage their business partners to procure materials and services as far as possible form local enterprises/suppliers or service providers.
4.15	C. Vele o.b.o Industrial Analytical	X	Emailed registration form, 18 October 2019	To be the supplier of certified reference materials, high purity compounds, chemicals and claisse fusion equipment for sample preparation.	Thank you for your comment. I&AP has been registered on the I&AP database to receive any and all future public communications regarding the project.
4.16	JA. Wessels	X	Emailed registration form, 8 November 2019	May I please be given opportunity to comment on the EIA documentation/reports.	All registered I&APs will be afforded the opportunity to comment on the scoping report and EIA report when these reports are distributed for public review. I&AP has been registered on the I&AP database to receive any and all future public communications regarding the project.
4.17	D. McIvor o.b.o Baltimo Engineering Agency	X	Email, 19 November 2019	Please include us on correspondence relating to this project.	I&AP has been registered on the I&AP database to receive any and all future public communications regarding the project.
4.18	H. Yingsheng, o.b.o ENFI	X	Email, 20 November 2019	Sorry for the late reply due to annual leave. I copied in Maggie. She will contact you.	I&AP has been registered on the I&AP database to receive any and all future public communications regarding the project. As of this time, no further comment has been received from the I&AP.
4.19	M. Lee, o.b.o ENFI	X	Email,	Thank you very much for your information. Please feel free to let us know if there's any updated or request.	Thank you for your comment. I&AP has been registered on the I&AP database to receive any and all future public communications regarding the project.

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			21 November 2019		
4.20	J. Whon	X	Email, 25 November 2019	As discussed over the phone, could you please send me more info regarding this EIA?	I&AP has been registered on the I&AP database to receive any and all current and future public communications regarding the project. Draft Scoping Report was emailed for comment on 29 January 2020.
4.21	R. Kamish. O.b.o Mainstream Renewable Power	X	Email, 10 January 2020	Could you kindly register myself as an Interested and Affected Party?	I&AP has been registered on the I&AP database to receive any and all future public communications regarding the project.
5	**Comments received during the Scoping Phase**				
5.1	Dr Philip Desmet	X	Emailed comments, 28 February 2020	Thank you for the draft scoping report. I am mostly happy with the content of the report in terms of project description and impact identification. I do feel, however, that the document does downplay somewhat the scale of the project particularly the scale of the air quality impacts. It should be recognised that this is a sulphuric acid mine that produces zinc as a by-product. Even if the smelting process is 95% efficient at capturing emission that still leaves approximately 22 500 tpa. of SO_2 that escapes into the local environment. I think the scoping report could have done a better job at discussing the quantum of emissions impacts given that there is detailed knowledge of the input chemistry and there is a detailed breakdown of the smelter	The design of the Acid plant will meet the requirements of the IFC Performance standards where a maximum of 1.5 kg of SO_2 is emitted per tonne of Sulphuric Acid. Cognisance is taken that even at this design and operational requirement the volume of emissions equates to a maximum of 817.5 tonnes of sulphur dioxide emitted annually." The impact of emissions of the Acid plant is potentially the single most significant impact in conjunction with storing and transporting acid. The models for emission was run against the legal limits as per the Air Quality Act. Cognisance is taken that this approach is potentially not sufficient to address the biodiversity impacts and your advice to rather utilise the 5% of background approach is appreciated. As part of the further studies the modelling will be recalculated based on the 5% background to

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				outputs. I hope that greater detail on emissions will be provided in the final scoping report. On page 148 the draft scoping report already attempts to downplay the significance of the smelter emissions. Given that nothing is presented in the draft document quantifying the chemistry, quantity or extent of emissions there is no factual basis for making these assumptions. We need to bare in mind that this smelter will be the largest zinc concentrate smelter in the world by volume of output and it is processing an ore with an exceptionally high sulphur content. A quick scan of the scientific literature on smelter emission impacts on biodiversity paint a very different picture to your comments in the draft scoping report: 1. http://repository.unam.edu.na/bitstream/handle/11070/361/Nunes2007.pdf?sequence=2&isAllowed=y Here in a savanna system they are picking up significant plant community impacts 1km from the smelter. 2. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1442-9993.2000.tb00071.x A quote from the abstract:"...Species richness in high SO2 plots (up to 5 km from the source) was approximately half that of control plots..." 3. https://www.sciencedirect.com/science/article/abs/pii/S0006320797000293 4. https://www.nrcresearchpress.com/doi/abs/10.1139/e98-001#.Xj00xy17GAw A quote from the abstract on this one:	determine the impact on succulent species and determine the extent of the potential plume. To address the cumulative impacts of the various planned developments by Black Mountain Mining (Pty) Ltd a strategic biodiversity roadmap will be developed to ensure that the integrity of the current offsets is not destroyed.

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				"...The maximum radius of contamination varies among the major smelter metals, ranging from 70 km for Cd to 104 km for As...." In terms of any air quality/emission studies that are conducted for the final scoping report I would like to request that raw model outputs are provided (i.e. continuous value surfaces with emissions extrapolated to limit of detection) and not summarised isobar maps indicating particular significant thresholds. Typically, threshold maps use indicators set for human receptors which may be legislated or recommended in local or international air quality standards. A unique attribute of the local landscape is the incredible small size of many of the species of conservation concern. Some species are barely larger than a pinhead. In this context, thresholds acceptable for human health and safety are not necessarily acceptable for biodiversity health and safety. In the absence of any quantitative research to the contrary I would recommend using an emissions threshold of 5% of background rate for defining the default threshold for impact significance. Given what I read in the literature, it is highly likely that this threshold even with mitigation will extend far beyond the dust impact quantified for the mine EIA. How then will a biodiversity offset be calculated given (1) that existing offset and set aside sites will be impacted by emissions; (2) there will be a cumulative impact of new mining (Swartberg), prospecting and the smelter; and, (3) given points 1 and 2	

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				that impacted biodiversity features will now become more un-offsettable meaning that the “no net loss” goal of Vedanta will be pushed even further from their grasp?	
5.2	John Geeringh, Senior Consultant Environmental Management, Eskom Transmission Division: Land & Rights	X	By email, 3 February 2020	Eskom requirements for work in or near Eskom servitudes. 1. Eskom’s rights and services must be acknowledged and respected at all times. 2. Eskom shall at all times retain unobstructed access to and egress from its servitudes. 3. Any cost incurred by Eskom as a result of non-compliance to any relevant environmental legislation will be charged to the developer. 4. If Eskom has to incur any expenditure in order to comply with statutory clearances or other regulations as a result of the developer’s activities or because of the presence of his equipment or installation within the servitude restriction area, the developer shall pay such costs to Eskom on demand. 5. The use of explosives of any type within 500 metres of Eskom’s services shall only occur with Eskom’s previous written permission. If such permission is granted the developer must give at least fourteen working days prior notice of the commencement of blasting. This allows time for arrangements to be made for supervision and/or precautionary instructions to be issued in terms of the blasting process. It is advisable to make application separately in this regard. 6. Changes in ground level may not infringe statutory ground to conductor clearances or statutory visibility clearances.	Thank you for the input. Black Mountain Mining (Pty) Ltd is aware of Eskom’s requirements. Relevant mitigation measures will be included in the EMPr.

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				After any changes in ground level, the surface shall be rehabilitated and stabilised so as to prevent erosion. The measures taken shall be to Eskom's satisfaction. 7. Eskom shall not be liable for the death of or injury to any person or for the loss of or damage to any property whether as a result of the encroachment or of the use of the servitude area by the developer, his/her agent, contractors, employees, successors in title, and assignees. The developer indemnifies Eskom against loss, claims or damages including claims pertaining to consequential damages by third parties and whether as a result of damage to or interruption of or interference with Eskom's services or apparatus or otherwise. Eskom will not be held responsible for damage to the developer's equipment. 8. No mechanical equipment, including mechanical excavators or high lifting machinery, shall be used in the vicinity of Eskom's apparatus and/or services, without prior written permission having been granted by Eskom. If such permission is granted the developer must give at least seven working days' notice prior to the commencement of work. This allows time for arrangements to be made for supervision and/or precautionary instructions to be issued by the relevant Eskom Manager Note: Where an electrical outage is required, at least fourteen work days are required to arrange it. 9. Eskom's rights and duties in the servitude shall be accepted as having prior right at all times and shall not be obstructed or interfered with.	

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				10. Under no circumstances shall rubble, earth or other material be dumped within the servitude restriction area. The developer shall maintain the area concerned to Eskom's satisfaction. The developer shall be liable to Eskom for the cost of any remedial action which has to be carried out by Eskom. 11. The clearances between Eskom's live electrical equipment and the proposed construction work shall be observed as stipulated by Regulation 15 of the Electrical Machinery Regulations of the Occupational Health and Safety Act, 1993 (Act 85 of 1993). 12. Equipment shall be regarded electrically live and therefore dangerous at all times. 13. In spite of the restrictions stipulated by Regulation 15 of the Electrical Machinery Regulations of the Occupational Health and Safety Act, 1993 (Act 85 of 1993), as an additional safety precaution, Eskom will not approve the erection of houses, or structures occupied or frequented by human beings, under the power lines or within the servitude restriction area. 14. Eskom may stipulate any additional requirements to highlight any possible exposure to Customers or Public to coming into contact or be exposed to any dangers of Eskom plant. 15. It is required of the developer to familiarise himself with all safety hazards related to Electrical plant. 16. Any third party servitudes encroaching on Eskom servitudes shall be registered against Eskom's title deed at the developer's own cost. If such a servitude is brought into	

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				being, its existence should be endorsed on the Eskom servitude deed concerned, while the third party's servitude deed must also include the rights of the affected Eskom servitude.	
5.3	Cliffy o.b.o. Upington Container Park	X	Email, 3 February 2020	We (Upington Container Park) specialise in converting containers into Offices, Storages and Spaza Shops. These are just a few examples of what we are able to provide to the public. We came across the Gamsberg Smeltery Project, and it seems they will be needing offices and libraries. Will you be able to help me with the specification on these above mention, because we would like to help you by submitting a quote as soon as possible.	Thank you for your interest in providing services to the project. I&AP has been registered on the I&AP database to receive any and all future public communications regarding the project.
5.4	Robin Clarke, B.Sc (Mech Eng) SAIMechE, Executive Director Hot Dip Galvanizers Association Southern Africa	X	Email, 5 February 2020	The Hot Dip Galvanizers Association of Southern Africa represents the interests of 20 Galvanizers situated in Southern Africa. These Galvanizing companies probably represent about 80% of the value of galvanizing in the region and possibly approximately 90% of the weight of steel that is galvanized. Since galvanizing technologies represents over 60% of all zinc consumption there is therefore strong congruence between the mining and production of zinc and our industry. Vedanta Resources is an Associate member of our organization and has a vested interest in our efforts to stimulated market conditions for the galvanizing industry. The news of the zinc smelter/ processing plant is therefore excellent news.	Thank you for your input to the process. I&AP has been registered on the I&AP database to receive any and all future public communications regarding the project.

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				It is, we believe, imperative that the technical specification related to the corrosion protection for the steelwork of the new smelter be that of hot dip galvanized to ISO 1461:2011 standards and that fabrication of this steelwork as well as the galvanizing thereof be performed locally in S.A. The following commercial benefits and positive social responsibility spin-offs for both parties are listed: • local Increase in Zinc sales for Vedanta Resources related to the project - short term. • Stimulation of the S.A. galvanizing industry, presently operating with at least 30% spare capacity – creates a platform for longer term market and stimulation for zinc sales. • Positive social impact resultant from localizing of fabrication and galvanizing of steelworks through job creation at both fabricators and galvanizers. Accountability for project deliverables is localized and simplified.	
5.5	Karen Low, Project Development Manager, juwi Renewable Energies (Pty) Ltd ·	X	Email, 21 February 2020	Please can you register me as an I&AP for the Gamsberg Smelter EIA (SLR project reference: 720.22013.00002).	I&AP has been registered on the I&AP database to receive any and all future public communications regarding the project.
5.6	Leonardo Steenkamp	X	Email, 3 February 2020	Thank you for the synopsis. I humbly request a full copy of the Scoping Report. This will assist in affording us an opportunity to peruse the full impact and to exploit	Mr Steenkamp was sent an electronic copy of the Draft Scoping Report and was also referred to the SLR Project website on 4 February 2020.

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				opportunities for the community and going forward how do we protect the environment as well.	
5.7	Sasha McPherson, Business Development, Webber Wentzel	X	Email, 3 February 2020	Please amend the key email contact at Webber Wentzel from Stuart Boyd (COO) to Sean Testa (Senior Business Development Manager (Mining and Energy))? This will enable us to review and assess your emails and then liaise with the most appropriate legal experts more efficiently.	Contact has been updated in the I&AP database.
5.8	**Gerhard Visser, Landowner**	**X**	**Emailed letter, 9 March 2020**	**I oppose the approval of the proposed smelter, namely Gamsberg.** **Firstly, there is not enough water available in the Orange River for the proposed 10 ML additional water the smelter will require. The existing Water Use Licence allowing 44 ML (Sedibeng) will therefore need to be increased. This is against the background of the Orange River which has run dry on two occasions in the last ten years with agriculture (primary work provider and food provider) under pressure due to water restrictions.**	**Thank you for your comments.** **The volume of water to be abstracted to supply the Smelter is within the already authorised abstraction volumes which are included and allocated in the DWS reserve determination for the Orange River. No additional water volumes are being requested in this application. Gamsberg will operate the current activities and the Smelter within the approved water allocation.**
				Secondly farmers around Gamsberg Mine have an agreement with Vedanta – which is recorded in the EMPr – to provide them and all farmers with water should the groundwater in the area be affected as a consequence of open cast mining. It was clear from the Background Information Document of 4 December 2019 that the mine did not account for this potential requirement.	**Black Mountain Mining (Pty) Ltd is aware of the commitment in the mine's EMPr and Farmer's Impact Agreement to provide farmers with an alternative water source should groundwater resources be impacted by mining. The Background Information Document is a summary document which is unable to reflect the full complexities of a project. The Smelter EIA water balance will include consideration of the potential volumes of water for farmers covered by the agreement if their resource is impacted by mining.**

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					Current and historic groundwater monitoring conducted since 2015 does not reflect any impacts on groundwater levels and in the quality of farms production and monitoring boreholes. Monitoring of these boreholes as well as the BMM and Gamsberg Zinc Mine groundwater monitoring programme will continue for the life of mine. Groundwater monitoring closer to the BMM operations has not indicated any impacts to date on groundwater quantities. Monitoring boreholes close to operations would serve as early warning indicators to impacts on groundwater levels (quantity) and the quality of production boreholes that are located further away on farmers properties. Should impacts on groundwater levels (quantity) and quality at monitoring boreholes in the immediate surroundings of operations be recorded, Black Mountain Mining (Pty) Ltd will investigate and commence with contingency plans to supply water as and when farmers production boreholes are impacted.
				With the existing shortages for electricity provision, the power required for the proposed smelter is not available. Renewable energy projects which are referred to as alternatives, do not provide more than 5% - 10% of the current national energy generation capacity. The increased roll out of renewable energy projects in the Gamsberg area for the purpose of providing the smelter with electricity, has the consequence that further destruction of the base in the environment takes place.	The impact of power supply and the potential new renewable energy projects in the area will be included in the cumulative impact assessment in the EIA Report. The Project team is also investigating partnerships with regional approved alternative power producers to expand the capacity for sole supply of power to the project and reduce reliance on ESKOM for power supply.
				The pollution impact of the smelter is unacceptable in a region where organic, extensive production of meat is the only feasible farming practice. This low rainfall region has	An Air Quality Impact Assessment (AQIA) is being undertaken which will model the dispersion of pollutants from the smelter. This will then be assessed against baseline conditions, South

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				unique pastures, which gives lamb meat a very specific taste and smell. New generation consumers place an extremely high premium on organically produced meat products as well as the unique meat taste due to the area. With the inevitable polluting of the area and pastures by the proposed smelter the farmers will lose these marketing and premium advantages. Even for future generations. Farmers bordering Gamsberg Mine have since 2016 been bringing to Vedanta's attention the fact that dust pollution in the area is unacceptably high. This dust spreads up to a radius of 30 km around the mine. Up to now, 4 years later, Vedanta still has no solution for it. This again underlines the fact that our businesses will be negatively affected. Farms which will be affected first are: Namies 146/0/1, Namies Suid 212/0, Rozynbosch 41/0/1/2, Haramoep 53/0/1, Koeris 54/0/1/2/3/4, Aroams 57/0/1/2/3/4/5, Koupsleegte 58/0/1/2/3, Achab 59/0, gams 60/0/1/2, Bloemhoek 61/0/1, Zuurwater 62/0/1/2/3/4/5/6, Kykgat 87/0/1/2, Vogelstruishoek 88/0/1, Wolfkop and Kalkvlei.	African and international standards, and the resultant impacts assessed. The secondary impact on animals that graze these areas will be included. Dust monitoring around the Gamsberg Zinc Mine operations indicates that the dust liberated by blasting and dumping activities at the waste rock dump in particular does not travel as far as the neighbouring properties (fallout dust). From the onsite electronic sampling network the PM10 and smaller fraction is measured to be within the national limits as per the National Air Quality Act.
				Sulphur Dioxide, cadmium, copper, arsenic, cobalt etc. are very detrimental elements to the environment which the smelter will pollute. The installation of a sulphur dioxide scrubber system makes the operation of the smelter complicated. A sulphuric acid plant requires a specific volume of gas at a specific temperature and a specific dust loading. If these criteria are not met, the pollution of the area is increased dramatically. Whilst the focus is on zinc production and not sulphuric acid, the pollution on the environment is a given. What will happen later when the	These potential pollutants will be included in the Air Quality Impact Assessment modelling. Technologies included in the smelter design will limit the emissions from the smelter and other stacks at the plant to reduce the impact of the gaseous emissions from the plant on the surrounding environment. Start-up of the roaster section will entail the heating of the roasters by utilising diesel to a temperature in excess of 900°C before concentrate is entered into the roaster. This will maximise the collection of sulphur dioxide gas thus removing up to 99% of the gas from the stack.

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				market for this large volume of sulphuric acid, which is produced as a by-product, is oversupplied?	The capturing of sulphur dioxide gas is important to the process as this will be the basis for the sulphuric acid required in the process. Excess acid is a product and will be sold into the market and the establishment of industries such as a fertiliser plant is being investigated to allow creation of third party industries in South Africa as additional benefits from the smelter. Black Mountain Mining (Pty) Ltd is currently engaging with government at a national and provincial level to investigate these alternative consumers for the sulphuric acid.
				From the Background Information Document of 4 December 2019, about the proposed smelter project, it is indicated that the existing Tailings Storage Facility will be used, when the proposed smelter is in operation. The existing tailings storage facility is already too small. It already has, to an extent over flowed and the discharged material ended up in the environment. How much more if the smelter is in operation? Environmental and underground water pollution is then unavoidable.	A groundwater study will be undertaken to model potential contamination plumes associated with the smelter development and the disposal of jarofix waste. Alternative disposal sites for the disposal of the jarofix have been assessed as part of the Scoping phase. At this stage it is likely that the jarofix will be disposed of in a separate waste disposal facility to the existing tailings storage facility. Due to the classification of the Jarofix an impermeable liner is being designed as per the National Waste Act and associated Regulations to prevent seepage from the Jarofix to the environment. The current tailings storage facility is constructed to cater for the first phase of the Gamsberg Zinc Mine where production is limited to 4 million tons of ore per annum. The current size of the TSF is just 50% of the approved size. The overflow of the return water dam occurred during commissioning of the plant when an excess of water was present in the water circuit. The water balance for the plant has subsequently been restored and with approval from DWS a

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					series of evaporative cannons was acquired to use as an emergency measure to evaporate water.
				Vedanta's record for environmental pollution is doubtful, for example look at the class action by 2000 Zambian citizens against Vedanta to the pollution of their environment by The Vedanta Konkola Copper Mine in Zambia.	As a global company Vedanta is committed to the protection of the environment. In this specific case we are dealing with this problem in collaboration with the Government of Zambia and the surrounding communities. Vedanta Zinc International have also been tasked to assist with addressing the current situation in Zambia and have established a task team to assist at KCM
				With Environmental Impact Studies it is non-negotiable that a baseline value of all the potential polluting substances for at least 24 months be carried out before the construction of the proposed Smelter takes place. These measurements must also be integrated with the existing monitoring program of the mine and also quarterly with the Environmental Liaison Committee meetings report. As far as emissions monitoring is concerned (Emissions determination techniques) at the proposed Smelter project in order to monitor air pollution at the smelter only the "Direct Measurement Technique" must be used to measure true pollution concentrations.	During the construction of the smelter a monitoring station to establish a baseline for ambient SO_2 and NOx will be established. This ambient monitoring station will then be onsite for the duration of the operation of the smelter. This monitoring will be used to establish what the potential impact is on vegetation In stack inline monitoring probes will also be installed to determine the point source emissions from the stack. This will continuously monitor the levels of SO_2 and NOx and other gas emissions that are emitted from the various stacks at the smelter.
				Finally, it is once again non-negotiable, should the proposed smelter project continue, that a proper impact management agreement between Vedanta and all affected parties is agreed upon and that Vedanta will ensure that	An existing agreement is in place regarding the potential impacts associated with the opencast mining activities at Gamsberg Zinc Mine. Gamsberg Zinc Mine is willing to revisit the agreement with the farmers if the studies for the Smelter indicate that the smelter will impact on the neighbouring farms.

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				this impact management agreement is recorded in the EMPr.	