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GROUNDWATER FEASIBILITY STUDY

FOR

GLORIA MINE SFSF AND ASSOCIATED INFRASTRUCTURE

GPT Reference Number:	EEESB-19-4328
Client Reference Number:	N/A
Version:	Final
Date:	April 2020

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GPT Reference:	EEESB-19-4328
Version:	Final
Date:	April 2020
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I, (Marius Terblanche), in my capacity as the specialist (Hydrogeology) consultant under instruction from Geo Pollution Technologies and its Client, hereby declare that I -

- Act as an independent specialist:
- Do not have any financial interest in the undertaking of the activity, other than remuneration for the work performed in terms of the National Environmental Management Act, 1998 (Act 107 of 1998);
- Undertake to disclose, to the competent authority, any material information that has or may have the potential to influence the decision of the competent authority or the objectivity of any report, plan or document required in terms of the National Environmental Management Act, 1998 (Act 107 of 1998);
- As a registered member of the South African Council for Natural Scientific Professions, will undertake my profession in accordance with the Code of Conduct of the Council, as well as any other societies to which I am a member; and
- Based on information provided to me by the project proponent, and in addition to information obtained during the course of this study, have presented the results and conclusion within the associated document to the best of my professional judgement.

22/04/2020

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Date

EXECUTIVE SUMMARY

Geo Pollution Technologies – Gauteng (Pty) Ltd (GPT) was appointed by EScience Associates Pty (Ltd) to conduct a groundwater investigation for the proposed Super Fines Storage Facility (SFSF) Project at the Gloria Mine. The groundwater investigation is required for the design of the proposed SFSF.

Project objectives

Within the scope of work the groundwater study aimed to support the design process for the SFSF. The purpose of the hydrogeological investigation is to define the site conditions in order to evaluate the technical feasibility of this site at a higher level of confidence. This scope included:

- Potential groundwater impacts from the SFSF
- Unsaturated and saturated flow below the SFSF;
- Monitoring network for the SFSF;
- Determine the rate of movement of the groundwater pollution plumes from the SFSF;
- Predict long term groundwater pollution plume positions, using calculated contaminant loads that may be released by the SFSF;
- Determine the seepage to the potentially affected groundwater resources & rivers/streams in the area;

Hydraulic conductivities

The transmissivity values at the site are expected to vary between 1 and 2 m^2/day, with structurally-related values being as high as 5-10 m^2/day. From previous work done, the upper hydrogeological unit (i.e. <40 m depth) having hydraulic conductivities between 10^{-4} and 1 m/day, with the lower fractured/weathered unit (i.e. 40-68 m depth) values being in the order of 10^{-5} m/day.

Falling head tests conducted in the existing monitoring site boreholes showed hydraulic conductivity values between 0.068 m/day (GPT02) and 2.44 m/day (GPT04). The higher conductivity values are expected to be associated with geological structures at the Site (faulting etc.).

Potential groundwater impacts resulting from a leaking barrier

Although the planned SFSF's will be lined, both footprints were modelled as if they were un-lined. The inflow into the SFSF's were modelled as artificial recharge as wet deposition will be used.

Two potential STF positions were modelled, the preferred position and the alternative position. From the modelling results it was concluded that the preferred option would likely have the least potential impact on possible receptors (the Ga-Mogara River). The alternative location is closer to the River and would be less desirable from a hydrogeological point of view. In both of the modelled locations, the depth to water level (>30mbgl) as a result of active dewatering limits the risk to groundwater in an event where a leakage would occur. Contaminant that my emanate from the SFSF would likely flow downwards towards the aquifer.

The Ga-Mogara river is a non-perennial river that is not hydraulically connected to the aquifer. If the Preferred SFSF Position is selected as the locality for the SFSF the expected plume will only reach the river after 50 years. The alternative option is closer to the Ga-Mogara River and should a leakage from the tailings exist this could flow to the river before infiltrating to the deeper aquifer due to the presence of hardpan calcrete in the regolith layer. The predicted plume would reach the river within 10 years of operation

Due to the slow groundwater movement, no groundwater users are likely to be impacted. The only likely receptors will be the Ga-Mogara river and the monitoring boreholes. The Ga-Mogara river is not connected to the aquifer due to the water level depth. The remaining receptors will be the monitoring boreholes GPT01 and GPT02. These are monitoring boreholes and are not used for any other purpose. These boreholes can thus be used to determine and confirm modelled impacts, should they exist.

Even though the depth to groundwater limits risk, sound construction and management practices for the planned SFSF must still be adhered to in order to limit risk to the underlying aquifer and the River. These include installing a suitable liner as well as limiting stormwater ingress to the SFSF and diverting stormwater away from it. Furthermore, the results from the leaching analysis of the tailings material indicated that the tailings material exceeds the LCT0 threshold, requiring a class C or GLB lined facility.

Monitoring Network

Currently a monitoring network does not exist for the planned SFSF, only for the mine area itself. One of these existing monitoring boreholes is located within the footprint of the preferred site. This borehole will likely be destroyed during the development of the SFSF. The proposed monitoring boreholes can be utilised for water level monitoring during operations, as well as groundwater quality monitoring after decommissioning of the site. These boreholes should be sited using geophysical methods to optimise the drilling program. The details of the monitoring network are as follows:

ID	Latitude (South)	Longitude (East)	Owner	Borehole Depth (mbgl)	Reasoning	Frequency	Existing/ New
GPT01	-27.166477	22.911302	BRMO	100	Impact Monitoring	Quarterly	Existing
GLBH01	-27.178645	22.897758	BRMO	100	Impact Monitoring	Quarterly	New
GLBH02	-27.17121	22.90436	BRMO	100	Impact Monitoring	Quarterly	New

However, a monitoring network should be dynamic. This means that the network should be extended over time to accommodate the migration of contaminants through the aquifer as well as the expansion of infrastructure and/or addition of possible pollution sources. An audit on the monitoring network should be conducted annually in terms of borehole maintenance and the areal extent of the groundwater contamination plume.

Recommendations

The following recommendations are put forward:

- Two proposed monitoring boreholes (GLBH01 and GLBH02) should be added to current monitoring network. These boreholes should be monitored on a quarterly basis prior to construction phase, and during the operational phase for the parameters analysed in this report.

- The monitoring boreholes should be sited using geophysical methods in order to identify geological structures that may act as preferential flow paths for contaminant transport.
- Monitoring boreholes drilling should be supervised by a qualified hydrogeologist and care should be taken to accurately log the geology during drilling and to construct the boreholes appropriately
- The aquifer parameters should be measured by conducting an aquifer test (pump test , slug test etc.) on each of the newly drilled boreholes. 24-Hour pumping tests are recommended. This information can be used to update the numerical model.
- A hydrocensus within a radius of 5km around the boundary of the Gloria SFSF site should be conducted every 2 years. This will be used to determine the status in terms of potential groundwater impacts regarding quality and quantity.
- Upon decommissioning of the facility, the monitoring programme undertaken during the operational phase will need to be continued after decommissioning and during the closure phase.
- Monitoring will continue until the groundwater quality trends are within the Resource Quality Objective (RQO) for the catchment and to ensure that sufficient information is available to calibrate and confirm the accuracy of the numerical model.
- The groundwater monitoring information should be used to update the numerical groundwater model used during the operations phase. The updated groundwater model will be used in the closure modelling and closure planning. The model should be updated on a 3-yearly basis against monitored groundwater quality data.
- Finally, from a hydrogeological perspective and based on the available information supplied by the client, it is recommended that the proposed preferred SFSF is authorised on condition that the lining requirements as set out in the waste classification are met, and that the proposed groundwater monitoring is conducted and reported as described in the DWAF Best Practice Guidelines A2: Water Management for Mine Residue Deposits.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
ARD	Acid Rock Drainage
BPG	Best Practice Guidelines
CMS	Catchment Management Strategy
CSM	Conceptual Site Model
EC	Electrical Conductivity
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
IWRMP	Integrated Water Resources Management Plan
IWRM	Integrated Water Resources Management
Km^2	Square Kilometre
L/s	Litres per second
mamsl	Metres above mean sea level
Ml/d	Megalitres per day
m	meter
mm	Millimetre
mm/a	Millimetres per annum
mS/m	Millisiemens per metre
m^3	Cubic metre
MAP	Mean Annual Precipitation
MPRDA	Mining and Petroleum Resources Development Act (Act No. 73 of 2002)
NEMA	National Environmental Management Act (Act No. 107 of 1998)
NWA	National Water Act (Act No. 36 of 1998)
ppm	Parts per million
RDM	Resource Directed Measures
RQO	Resource Quality Objective
RWQO	Resource Water Quality Objective
TDS	Total Dissolved Solids
TMF	Tailings Management Facility
SFSF	Super Fines Storage Facility
WMA	Water Management Area
WMP	Water Management Plan

DEFINITIONS

Definition	**Explanation**
Aquiclude	A geologic formation, group of formations, or part of formation through which virtually no water moves
Aquifer	A geological formation which has structures or textures that hold water or permit appreciable water movement through them. Source: National Water Act (Act No. 36 of 1998).
Borehole	Includes a well, excavation, or any other artificially constructed or improved underground cavity which can be used for the purpose of intercepting, collecting or storing water in or removing water from an aquifer; observing and collecting data and information on water in an aquifer; or recharging an aquifer. Source: National Water Act (Act No. 36 of 1998).
Boundary	An aquifer-system boundary represented by a rock mass (e.g. an intruding dolerite dyke) that is not a source of water, and resulting in the formation of compartments in aquifers.
Cone of Depression	The depression of hydraulic head around a pumping borehole caused by the withdrawal of water.
Confining Layer	A body of material of low hydraulic conductivity that is stratigraphically adjacent to one or more aquifers; it may lie above or below the aquifer.
Dolomite Aquifer	See “Karst” Aquifer
Drawdown	The distance between the static water level and the surface of the cone of depression.
Fractured Aquifer	An aquifer that owes its water-bearing properties to fracturing.
Groundwater	Water found in the subsurface in the saturated zone below the water table.
Groundwater Divide or Groundwater Watershed	The boundary between two groundwater basins which is represented by a high point in the water table or piezometric surface.
Groundwater Flow	The movement of water through openings in sediment and rock; occurs in the zone of saturation in the direction of the hydraulic gradient.
Hydraulic Conductivity	Measure of the ease with which water will pass through the earth's material; defined as the rate of flow through a cross-section of one square metre under a unit hydraulic gradient at right angles to the direction of flow (m/d).
Hydraulic Gradient	The rate of change in the total hydraulic head per unit distance of flow in a given direction.
Infiltration	The downward movement of water from the atmosphere into the ground.
Intergranular Aquifer	A term used in the South African map series referring to aquifers in which groundwater flows in openings and void spaces between grains and weathered rock.
Karst (Karstic)	The type of geomorphological terrain underlain by carbonate rocks where significant solution of the rock has occurred due to flowing groundwater.

Definition	Explanation
Karst (Karstic) Aquifer	A body of soluble rock that conducts water principally via enhanced (conduit or tertiary) porosity formed by the dissolution of the rock. The aquifers are commonly structured as a branching network of tributary conduits, which connect together to drain a groundwater basin and discharge to a perennial spring.
Monitoring	The regular or routine collection of groundwater data (e.g. water levels, water quality and water use) to provide a record of the aquifer response over time.
Observation Borehole	A borehole used to measure the response of the groundwater system to an aquifer test.
Phreatic Surface	The surface at which the water level is in contact with the atmosphere: the water table.
Piezometric Surface	An imaginary or hypothetical surface of the piezometric pressure or hydraulic head throughout all or part of a confined or semi-confined aquifer; analogous to the water table of an unconfined aquifer.
Porosity	Porosity is the ratio of the volume of void space to the total volume of the rock or earth material.
Production Borehole	A borehole specifically designed to be pumped as a source of water supply.
Recharge	The addition of water to the saturated zone, either by the downward percolation of precipitation or surface water and/or the lateral migration of groundwater from adjacent aquifers.
Recharge Borehole	A borehole specifically designed so that water can be pumped into an aquifer in order to recharge the ground-water reservoir.
Saturated Zone	The subsurface zone below the water table where interstices are filled with water under pressure greater than that of the atmosphere.
Specific Capacity	The rate of discharge from a borehole per unit of drawdown, usually expressed as m3/d•m.
Specific Yield	The ratio of the volume of water that drains by gravity to that of the total volume of the saturated porous medium.
Storativity	The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.
Transmissivity	Transmissivity is the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It is expressed as the product of the average hydraulic conductivity and thickness of the saturated portion of an aquifer.
Unsaturated Zone (Also Termed Vadose Zone)	That part of the geological stratum above the water table where interstices and voids contain a combination of air and water.
Watershed (Also Termed Catchment)	Catchment in relation to watercourse or watercourses or part of a watercourse means the area from which any rainfall will drain into the watercourses or part of a watercourse through surface flow to a common point or points. Source: National Water Act (Act No. 36 of 1998).
Water Table	The upper surface of the saturated zone of an unconfined aquifer at which pore pressure is equal to that of the atmosphere.

1 INTRODUCTION

Geo Pollution Technologies – Gauteng (Pty) Ltd (GPT) was appointed by EScience Associates Pty (Ltd) to conduct a groundwater impact assessment for activities associated with the development of the proposed Super Fines Storage Facility (SFSF) Project at the Gloria Manganese Mine. This assessment is required for the design of the proposed SFSF.

1.1 Normative references

The following references are applicable to this study:

- SRK Consulting, September 2019. New Super Fines Storage Facility, Gloria Mine, Northern Cape: Preliminary Geotechnical Investigation Report.

1.2 Project objectives

Within the scope of work the groundwater study aimed to assist the design process for the SFSF to minimise potential future impacts on the groundwater environment. The scope included:

- Potential groundwater impacts from the SFSF
- Unsaturated and saturated flow below the SFSF;
- Monitoring network for the SFSF;
- Determine the rate of movement of the groundwater pollution plumes from the SFSF;
- Predict long term groundwater pollution plume positions, using calculated contaminant loads that may be released by the SFSF;
- Determine the seepage to the potentially affected groundwater resources & rivers/streams in the area;

2 PROJECT METHODOLOGY

The impact of the planned SFSF was investigated through data analyses, the use of numerical models (flow and transport models) and previous reports. The methodology to be followed will be discussed in the headings below.

2.1 Desk study

All available groundwater data (previous reports, site and external databases) crucial to the area, in terms of groundwater was reviewed.

2.2 Conceptual site model

A conceptual groundwater model was compiled to aid in the understanding of groundwater flow and flow drivers and was used to inform the numerical flow model.

2.3 Modelling

Modelling was performed as a representation of a groundwater flow system and/or geochemical system that attempts to mimic the natural processes. It is therefore a simplified version of the natural system, compiled with geological, hydrogeological, hydrological and meteorological data, which utilises governing equations to incorporate all this data and simulates the hydraulic properties or geochemical properties of the system.

These models were utilised to provide a quantitative understanding of a groundwater system in terms of existing conditions as well as induced stresses, which inherently aids in the identification of cost-effective and efficient solutions to groundwater contamination and management challenges.

2.3.1 Numerical modelling

Numerical groundwater modelling is considered to be the most reliable method of anticipating and quantifying the likely impacts on the groundwater regime.

The numerical model was constructed using MODFLOW and MT3DS. MODFLOW is a modular three-dimensional groundwater flow model, published by the United States Geological Survey. MODFLOW and MT3DS use 3D finite difference discretization and flow codes to solve the governing equations. MODFLOW and MT3DS are widely used simulation codes, which is well documented. MODFLOW is used to simulate groundwater flow rate and direction.

2.3.2 Transport modelling

Transport modelling was performed using MT3DMS. MT3DMS is a 3-D model for the simulation of advection, dispersion, and chemical reactions of dissolved constituents in groundwater systems. MT3DMS uses a modular structure similar to the structure utilized by MODFLOW and is used in conjunction with MODFLOW in a two-step flow and transport simulation. Heads are computed by MODFLOW during the flow simulation and utilized by MT3DMS as the flow field for the transport portion of the simulation. MT3DS is superimposed on the MODFLOW simulation results and is used to predict the rate and direction of contaminant movement in the aquifer.

2.4 Mitigation and management measures

The groundwater management measures were developed by taking in consideration the National Water Act, Act 36 of 1998 (NWA) and, to a lesser extent, the Mineral and Petroleum Resources Development Act, Act No. 28 of 2002 (MPRDA) and the National Environmental Management Act, Act 107 of 1998 (NEMA). Chapter 4 of the NWA addresses the use of water.

The Department of Water and Sanitation (DWS) has recognised the challenges facing both the water user and the authorities in managing groundwater in an integrated manner. This recognition has resulted in a number of guideline documents that provides the mining industry with an opportunity to marry together legislation and best practice into useable tools of implementation. The management measures discussed in this report were based on these Best Practice Guidelines (BPG) series (DWAF, 2008). The relevant guidelines for this report are listed below:

- Activity Series Guidelines
    - BPG A2. Water Management for Mine Residue Deposits
- Hierarchy Series Guidelines
    - H1. Pollution prevention
    - H2. Minimisation of impacts
- General Series Guidelines
    - G3. Water monitoring systems
    - G4. Impact prediction

3 DESK STUDY

A desk study was done on all available information pertaining to the groundwater situation at the planned Gloria SFSF.

3.1 Information reviewed

The following reports serves as normative references to this study:

- Geo Pollution Technologies (Pty) Ltd (GPT), 2017a. Groundwater Supply Feasibility Study for Black Rock Mine Operations. GPT Report No. ASBRM-17-2161.
- Geo Pollution Technologies (Pty) Ltd (GPT), 2017b. Groundwater Assessment for Liner Feasibility for Black Rock Mine Operations. GPT Report No. EEESB-17-2127.
- Hydrogeological Impact Assessment for ASSMANG Nchwaning II Manganese Mine Tailings Facility Expansion. GPT 2015
- Hydrogeological Assessment for the Gloria Mine River Front Rehabilitation. GPT 2016
- SRK Consulting, August 2019. New Super Fines Storage Facility, Gloria Mine, Northern Cape: Preliminary Geotechnical Investigation Report., Johannesburg.
- ENVASS Environmental Assurance (Pty) Ltd. Geohydrological Investigation ASSMANG (Pty) Ltd – Black Rock Mining Operations. GEO-REP-107-18_19

4 PHYSIOGRAPHY

4.1 Site Location

The site located approximately 5 km north-west of Hotazel, Northern Cape Province. (Figure 1). The site can be accessed from the R380.

4.2 Topography and Drainage

The site is situated within the D41K quaternary catchment (Figure 1). The planned SFSF sites are flat and the surface topography slopes slightly in a northerly direction between elevations 1040 m above mean sea level (mamsl) and 1030 mamsl over a distance of 1.3km, a slope of 1.3% (Figure 2).

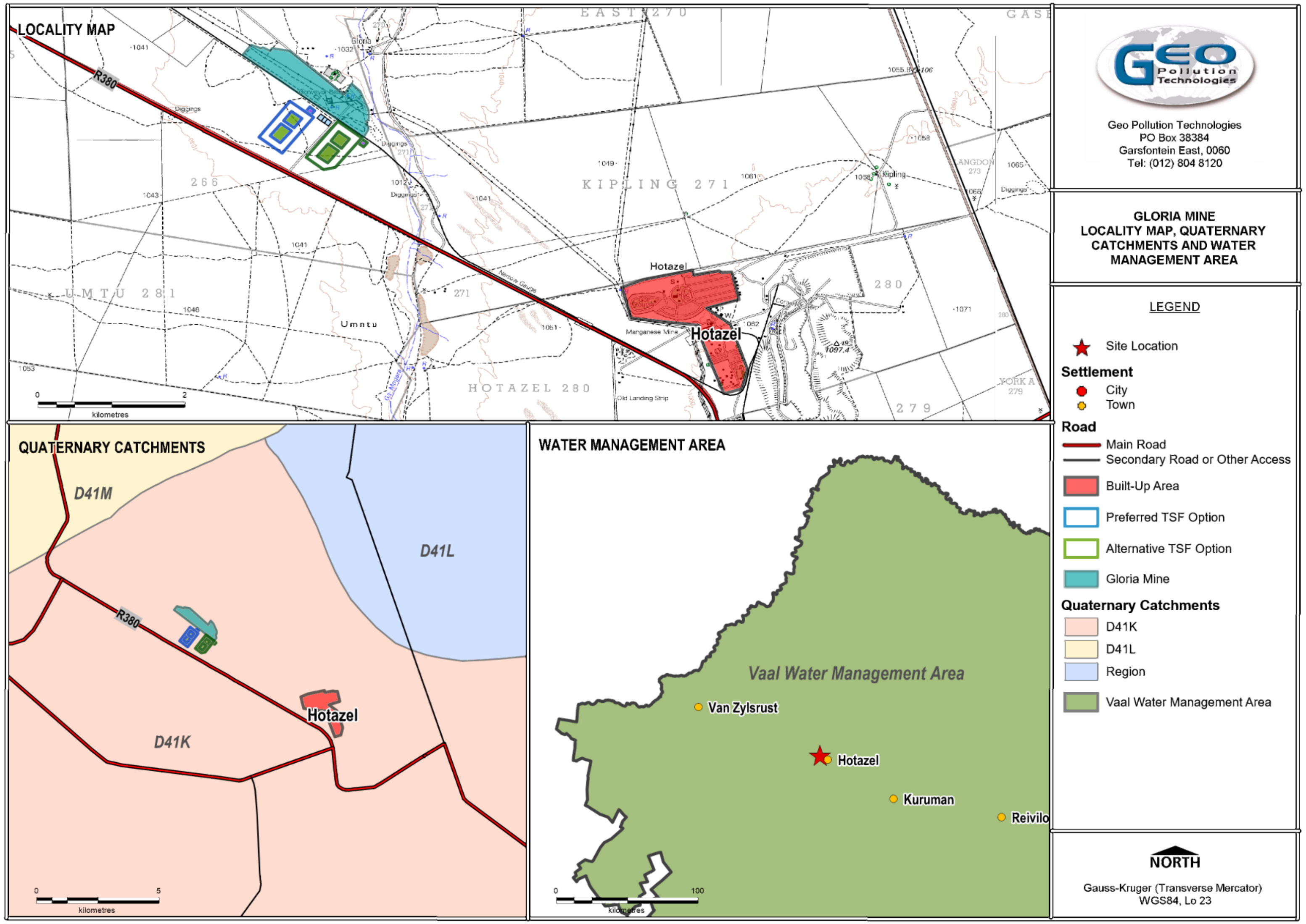


Figure 1: Locality map of the study site.

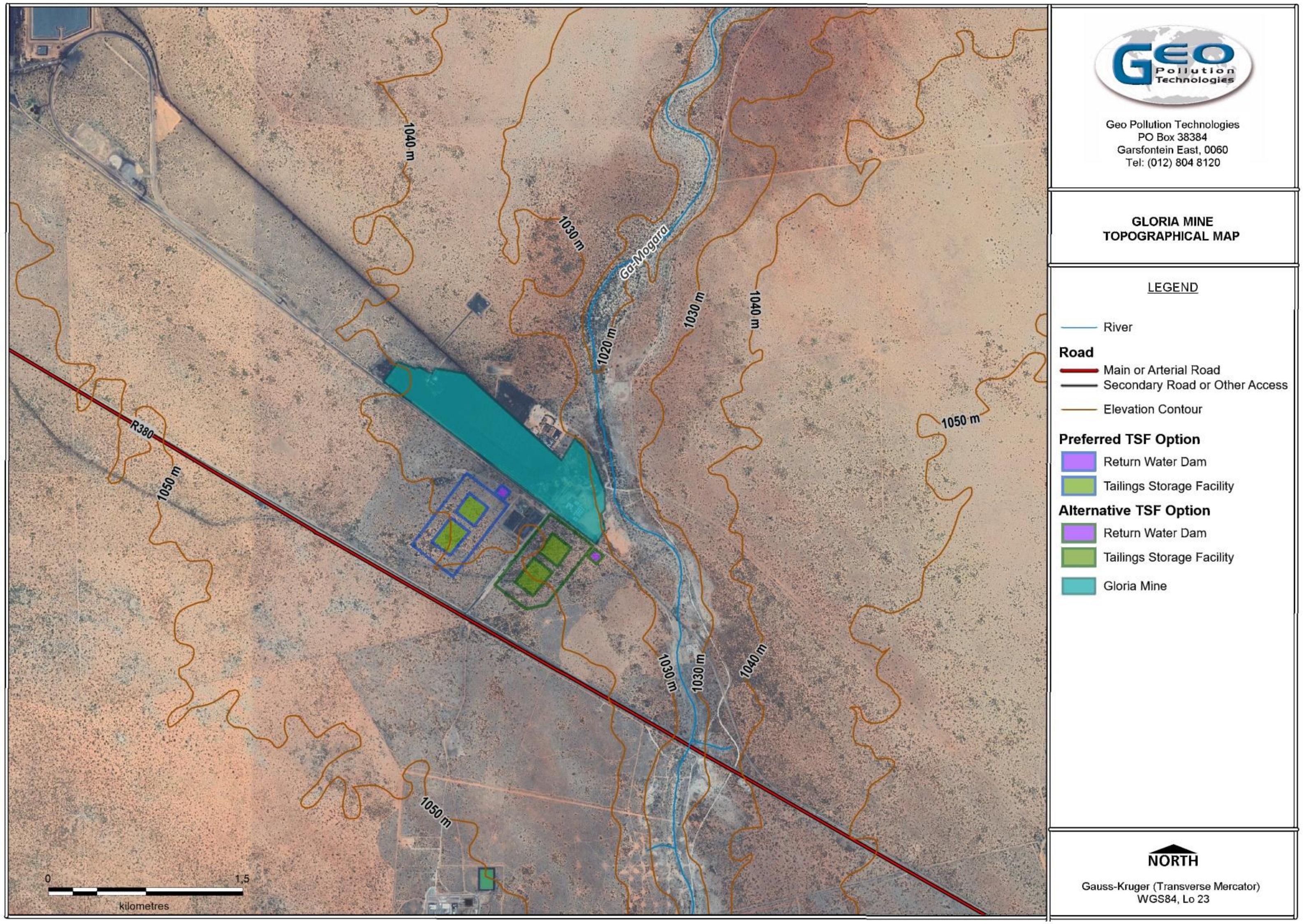


Figure 2: Topographical Map of the Study Area.

4.3 Climate

Climatic data was obtained from the DWA weather station Kuruman (rainfall data and evaporation data) for the Hotazel area (Table 1). The Gloria site is located in the summer rainfall region of Southern Africa with precipitation usually occurring in the form of convectional thunderstorms. The average annual rainfall (measured over a period of 65 years) is approximately 337 mm, with the high rainfall months between November and March (Figure 3).

Table 1: Climatic Data

Month	Average Monthly Rainfall (mm)	Mean Monthly Evaporation (mm)
January	86	203
February	83	191
March	87	157
April	45	132
May	21	125
June	7	109
July	3	119
August	9	139
September	8	165
October	27	196
November	46	205
December	44	217
Annual	337.3	1997

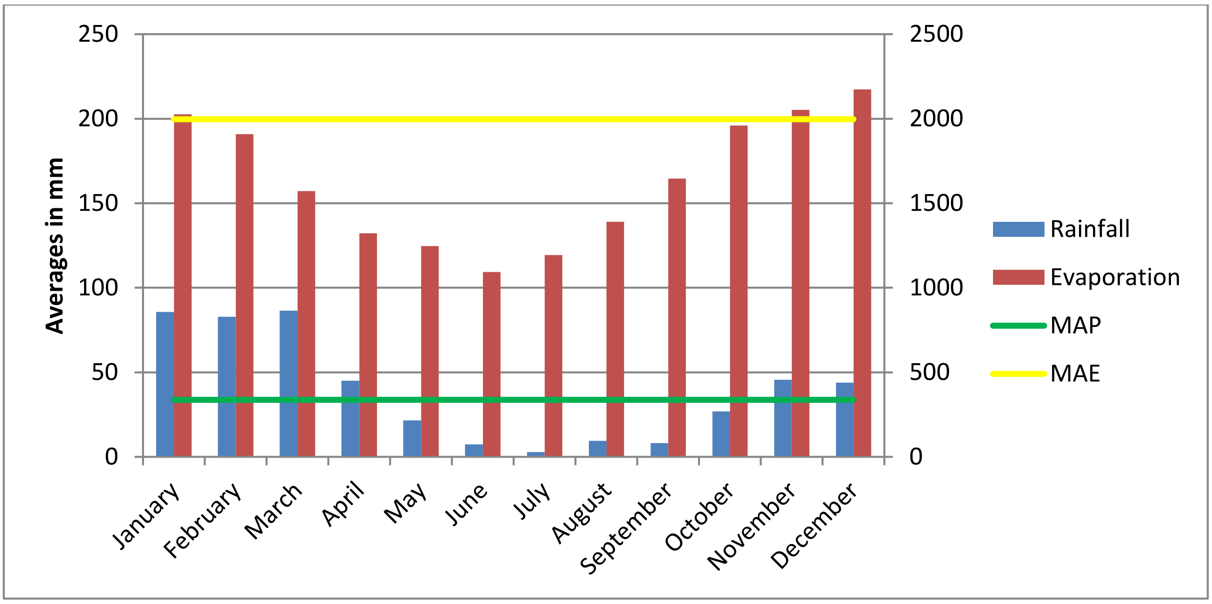


Figure 3: Climatic Data Representation.

5 GEOLOGICAL SETTING

5.1 Regional Setting

The investigated area falls within the 2722 Kuruman 1:250 000 geology series map. An extract of this map is shown in Figure 4.

The Kalahari Manganese Field (KMF) in the Kuruman area has a covering of calcretized sediments of the Kalahari Group, which is comprised of aeolian, unconsolidated sand of the Gordonia Formation unconformably overlying calcified sand and gravel (Puchner, 2002). The Kalahari Group is up to 125 m thick (GPT, 2012), underlain by a ~30 m thick red clay layer and the Olifantshoek Supergroup (Puchner, 2002). The Olifantshoek Supergroup is comprised of the shales and quartzites of the Lucknow Formation, underlain by the Mapedi Formation shale with quartzite bands (Puchner, 2002).

Unconformably below this sequence is the volcanogenic-sedimentary jaspilites and manganiferous ore deposits of the Hotazel Member, contained in the Voëlwater Formation (Puchner, 2002). At the base of the stratigraphic column is the Ongeluk Andesite Formation of the Griqualand West Supergroup.

Regionally, the entire Olifantshoek Supergroup and the underlying Ongeluk Formation have been influenced by the Kheis and Namaqualand orogenies, with thrust faulting within the area presenting evidence of compressional tectonics associated with the Kheis orogeny (Puchner, 2002). Beukes & Smit (1987) named the major thrust fault at Black Rock area the 'Kheis Thrust', which has a north-south trend and extends ~270 km north of the mine and south to the Rooinekke Mine (Puchner, 2002). The site is situated within a large and imbricate thrust fault complex, where the Black Rock outcrop represents part of the thrust nappe structure.

5.2 Local Setting

The local geology was interpreted from the borehole and test pit logs as set out in the SRK Consulting report. From the excavated test pits, it was found that the site in general is underlain by poorly developed Topsoil / Aeolian Soils from surface to an average depth of 0.3 m underlain by orange brown to yellow brown silty fine sand to an average depth of 3.3 m. Pedogenic soils in the form of powder calcrete, nodular and strongly cemented hardpan calcrete was also noted underlying the Aeolian soils..

According to L. Ngalela (2019), the proposed Gloria Tailings Facility is underlain by approximately 100 metres of unconsolidated Kalahari Formation (KF) consisting of fine Aeolian sand, gravels, calcrete and clays. The Kalahari Formation overlie older rock. Based of the best available information, there are no underlying dolomites in the proposed area that could compromise or pose subsidence risk to the proposed tailings facility.

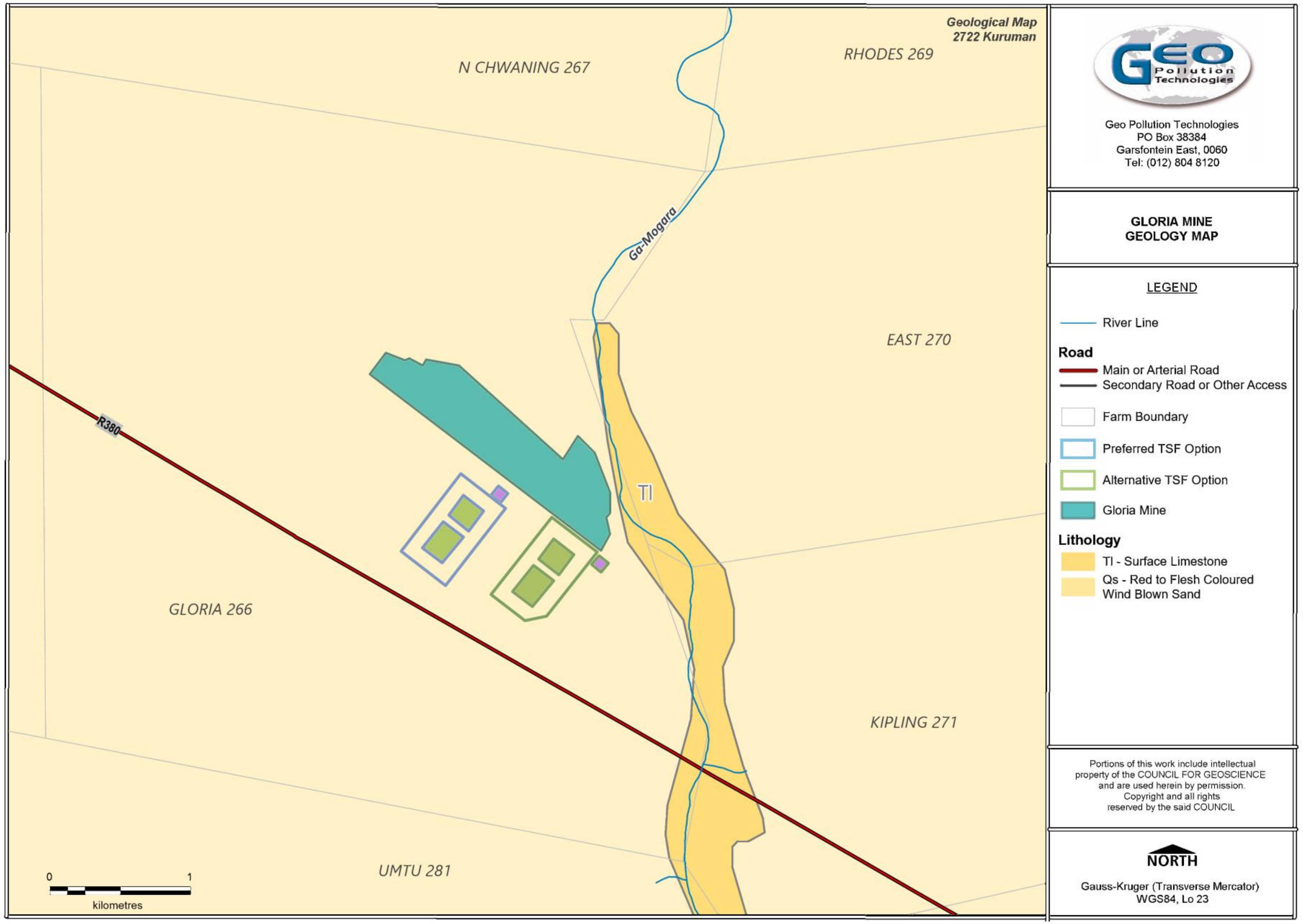


Figure 4: Geology Map of the Study Area.

6 HYDROGEOLOGICAL SETTING

The backbone of any groundwater impact prediction or management system is to understand the hydrogeological setting and how the potential stresses will influence the natural groundwater conditions. The hydrogeological setting is described under the headings below.

6.1 Regional Hydrogeology

The area of concern is situated in the Lower Orange Water Management area. According to the 1:500’000 Hydrogeological Map Series (2722 Kimberley) (Moseki & Meyer, 2003) the site is underlain by intergranular aquifer units, with a median borehole yield between 0.1 and 0.2 l/s. Aquifers to the west and east of the site are mapped as intergranular and fractured aquifers, with the same median borehole yield. Most boreholes within the site region were drilled to depths between 60 and 150 m, few boreholes were drilled deeper than 175 m with the maximum borehole at a depth of 307 m. Water strikes within the site region were intersected predominantly between 40 and 70 m depths, with limited intersections after 125 m (i.e. approximate depth of the Kalahari Formation).

The hydrogeology of the mining area can be described in terms of the saturated and unsaturated zones:

6.1.1 Saturated Zone

In the saturated zone, at least two aquifer types may be inferred from knowledge of the geology of the area:

- A shallow aquifer formed in the weathered zone, perched on the fresh bedrock.
- An intermediate aquifer formed by fracturing of the underlying tillite, shales, iron formation and manganese ore bearing layers.

Although these aquifers vary considerably regarding hydrogeological characteristics, they are seldom observed as isolated units. Usually they would be highly interconnected by means of fractures and faults. Groundwater will thus flow through the system by means of the path of least resistance in a complicated manner that might include any of these components.

6.1.2 Shallow perched aquifer

A near surface weathered zone is comprised of transported quaternary sediments and *in-situ* weathered rock and is underlain by tillite, shales, iron formation and manganese ore bearing rock. Groundwater flow patterns usually follow the topography, often coming very close to surface in topographic lows, sometimes even forming natural springs. The average groundwater recharge to the perched groundwater aquifer can reach up to 10% of the Mean Annual Precipitation (MAP) in the unconsolidated sand and calcrete.

6.1.3 Fractured rock aquifers

The host geology of the mining area consists of tillite, shales and banded iron formation with interbedded manganese ore bearing rock. Geology underlying the mining area consists mainly of lavas from the Ongeluk Formation. Most of the groundwater flow will be along the fracture zones that occur in the relatively competent host rock. The geology map does not indicate any major fractures zones in the mining area, but from experience it can be assumed that numerous major and minor fractures do exist in the host rock. These conductive zones effectively interconnect the strata, both vertically and horizontally into a single, but highly heterogeneous and anisotropic unit. Major fault zones were, however, observed on the geology map, west of the mining area, running in a north-south direction.

6.1.4 Unsaturated Zone

Although a detailed characterization of the unsaturated zone is beyond the scope of this study, a brief description thereof is supplied.

The unsaturated zone in the mining area can be up to 40 metres thick (based on static groundwater levels from the monitoring as done by Aquatico for Assmang (Pty) LTD - Black Rock, measured in the existing boreholes and consists of quaternary sediments at the top, underlain by tillite, shale and banded iron formation with interbedded manganese ore bearing rock that become less weathered with depth.

6.2 Water Levels

Water level data was obtained from the client for the entire monitoring period. A total of 9 water boreholes were measured by Aquatico over a period of 6 years. The water levels vary between 33.47 m up to 101.10 m below ground level in the area surrounding the mine.

Usually a good relationship should hold between topography and static groundwater level. This relationship can be used to distinguish between boreholes with water levels at rest, and boreholes with anomalous groundwater levels due to disturbances such as pumping or local hydrogeological heterogeneities. The relationship using the boreholes from the report by Aquatico is shown in Figure 5 below.

This general relationship shows a correlation with a regression value (R^2) of 0.26. A likely reason for this correlation could be that borehole GPT09 and GPT02 with water levels of 99.22 and 70 meters below ground level is being pumped. These static water levels (excluding borehole being pumped) were also subtracted from the elevations to determine the unsaturated aquifer thicknesses of different points over the study area. These values are intrinsically the same as the depth to the natural groundwater level measured from the surface. The average depth to the groundwater level in the intergranular and fractured aquifer in the project area is 46 meters.

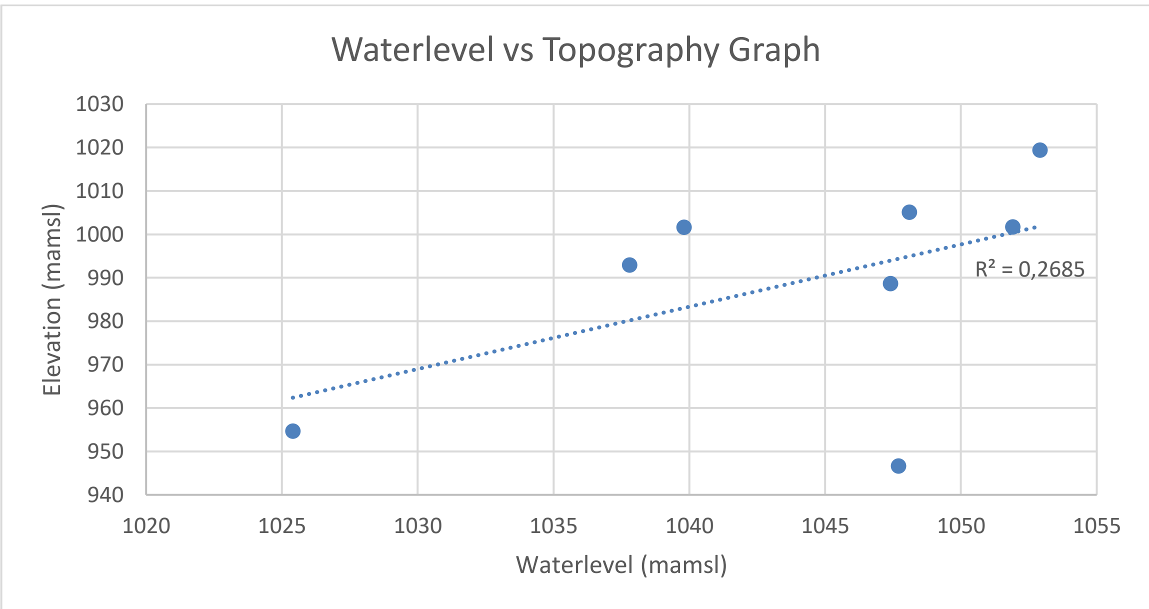


Figure 5: Waterlevel versus topographical elevation graph.

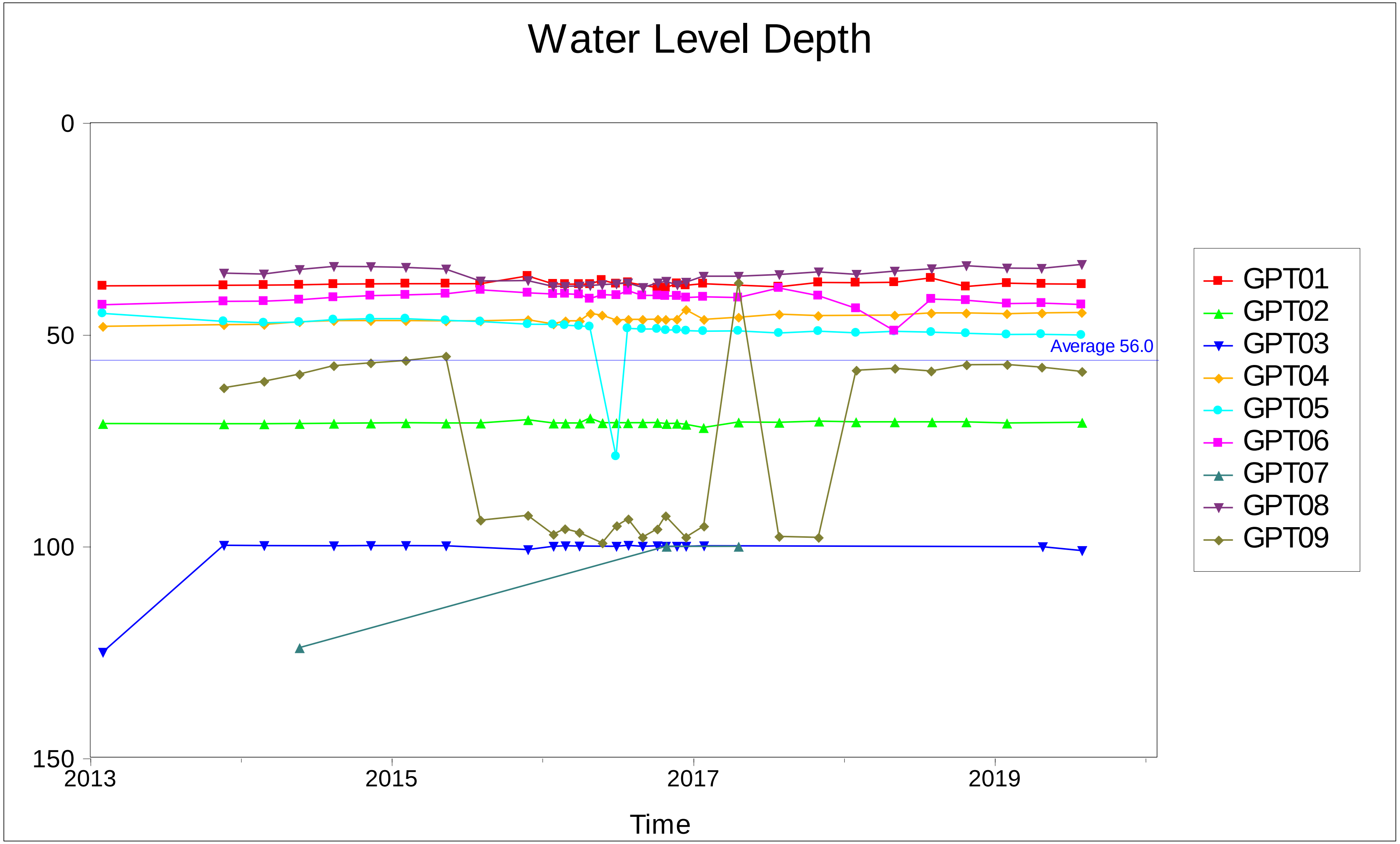


Figure 6: **Time series graph of water levels.**

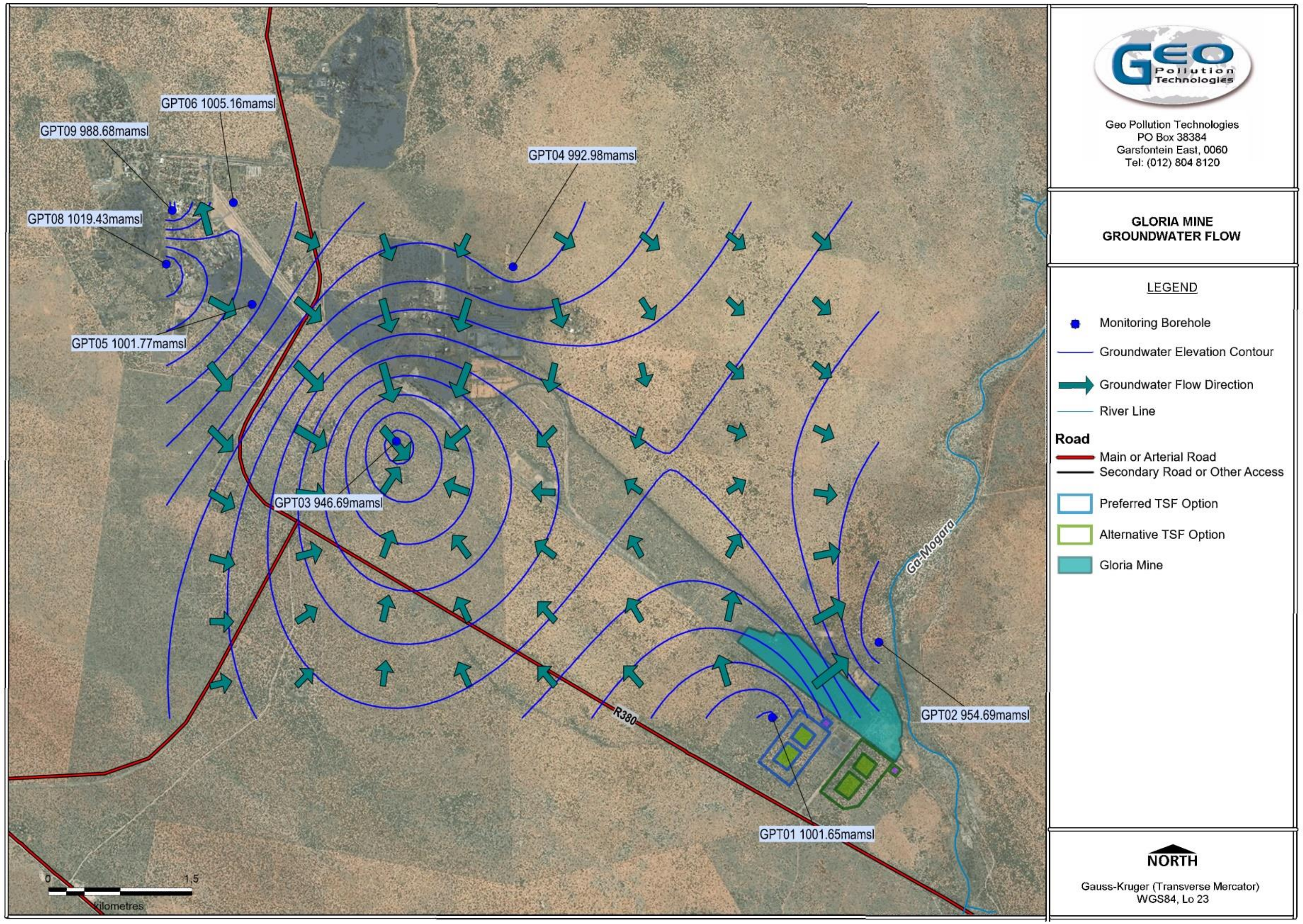


Figure 7: Available water levels and groundwater flow directions.

6.3 Water quality

The water quality results for the monitoring boreholes are compared with the maximum recommended concentrations for domestic use as defined by the SANS 241-1: 2015 target water quality limits. The SANS 241-1: 2015 standard is applicable to all water services institutions and sets numerical limits for specific determinants to provide the minimum assurance necessary that the drinking water is deemed to present an acceptable health risk for lifetime consumption. Colours of individual cells refer to the drinking water classification of the specific groundwater sample (Table 3).

From this comparison, the following is evident:

- TDS exceeds the allowable limit in samples GPT2, GPT8.
- Nitrate as N exceeds the allowable limit in samples GPT1, GPT2, GPT5, GPT6, GPT8, GPT9.
- Sodium exceeds the allowable limit in samples GPT2, GPT4.
- Chloride exceeds the allowable limit in samples GPT04.
- Fluoride exceeds the allowable limit in samples GPT03.

6.4 Hydraulic Conductivity

The regional transmissivity values at the site are expected to vary between 1 and 2 m^2/day, with structurally-related values being as high as 5-10 m^2/day locally. GPT (2017a) described the upper hydrogeological unit (i.e. <40 m depth) having hydraulic conductivities between 10^{-4} and 1 m/day, with the lower fractured/weathered unit (i.e. 40-68 m depth) values being in the order of 10^{-5} m/day.

Falling head tests conducted by GPT (2017b) at Site boreholes showed hydraulic conductivity values between 0.068 m/day (GPT02) and 2.44 m/day (GPT04), as summarised in Table 2. The higher conductivity values are expected to be associated with geological structures at the Site such as faulting.

Table 2: Falling Head Test Results

Borehole ID	Calculated Hydraulic Conductivity (m/d)
GPT01	1.74
GPT02	0.068
GPT04	2.44
GPT05	0.201
GPT06	0.156
GPT08	0.100

Table 3: Chemical results of the monitoring boreholes compared to the SANS 241:2015 2nd edition Standards.

Parameter		Unit	SANS 241: 215 Recommended Limits	Risk	Results							
					GPT01	GPT02	GPT03	GPT04	GPT05	GPT06	GPT08	GPT09
Physical & Aesthetic Determinants												
Electrical conductivity at 25C	EC	mS/m	≤ 170	Aesthetic	135	185	94.8	156	130	162	176	147
Total Dissolved Solids	TDS	mg/liter	≤ 1200	Aesthetic	972	1289	617	957	922	1106	1303	1050
pH at 25C		pH units	≥ 5 to ≤9.7	Aesthetic	7.37	7.52	8.03	8.37	7.19	7.27	7.18	7.16
Chemical Determinants - Macro Determinants												
Nitrate as N	NO_3	mg/liter	≤ 11	Acute Health	20	11.8	-0.459	-0.459	42.5	43.1	78.8	42.9
Sulphate	SO_4	mg/liter	Acute Health ≤500; Aesthetic ≤250	Acute Health/Aesthetic	80.6	186	37.3	67.1	20.5	39.1	105	98.8
Fluoride	F	µg/liter	≤1500	Chronic Health	489	521	1730	-466	-466	-466	-466	-466
Chloride	Cl	mg/liter	≤ 300	Aesthetic	164	259	94.5	313	115	164	175	141
Sodium	Na	mg/liter	≤ 200	Aesthetic	92.1	294	180	205	47.7	76.5	74.8	87.8
Total Iron	Fe	mg/liter	Acute Health ≤ 2; Aesthetic ≤0.3	Acute/Aesthetic	0	0	0	0	0	0	0	0
Total manganese	Mn	mg/liter	Acute Health ≤0.4; Aesthetic ≤0.1	Acute/Aesthetic	0.028	0.013	0.085	-0.001	-0.001	0.013	0.003	0.004
Concentration deemed to present an unacceptable health risk for lifetime consumption.												

7 WASTE CLASSIFICATION

7.1 Waste Classification

A sample was taken of the tailings material and submitted to a laboratory for analysis for waste classification purposes (Appendix I).

The waste classification was done in terms of Regulation R.635 – National Norms and Standards for the Assessment of Waste for Landfill Disposal published under Section 7(1)(c) of the National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008).

7.1.1 Methodology

Sampling and analysis of waste collected determined the leachable concentrations (LC) of the elements and chemical substances in the waste product.

The LC values of the samples were compared to the threshold limits of the specific elements and in accordance with the prescribed limits published in the Norms and Standards to determine the total concentrations (TCT limits).

7.1.2 LCT Limits

The Leachable Concentration Threshold (LCT) of elements were determined by an accredited SANAS Laboratory. Results of exceedances were recorded as follows:

LCT Inorganic Analysis

- Boron, fluoride manganese, molybdenum and nitrate exceeded the LCT0 threshold.

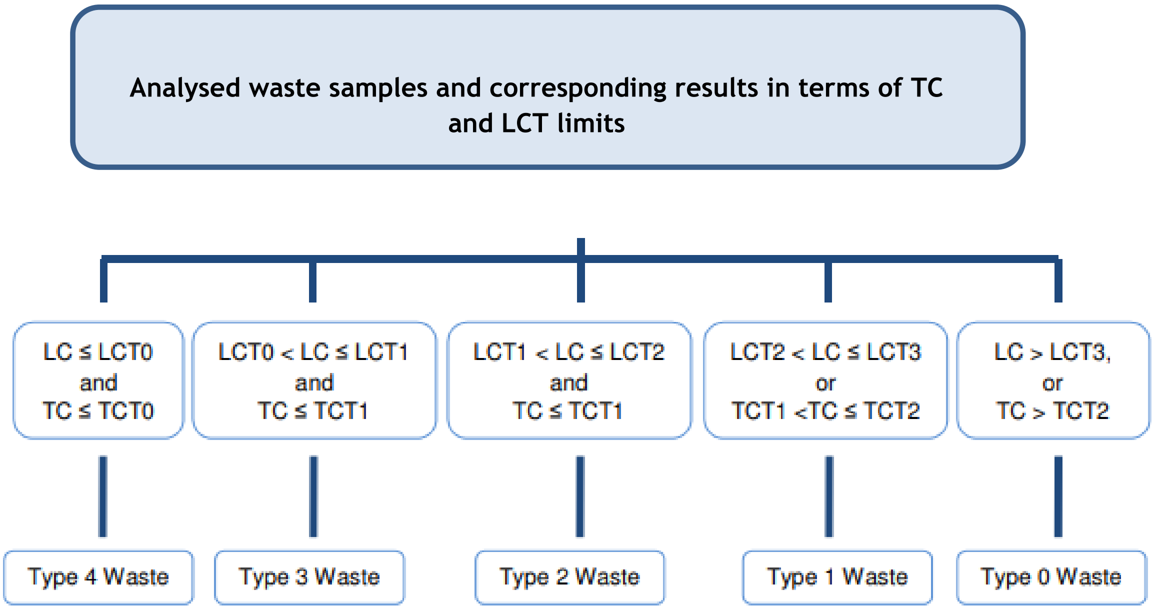
Table 4: Waste Classification Results

Parameter	Leachable Concentration Threshold (LCT)					
	Unit	Sample	LCT0	LCT1	LCT2	LCT3
As as Arsenic	mg/l	na	0.01	0.5	1	4
B as Boron	mg/l	4.1	0.5	25	50	200
Ba as Barium	mg/l	na	0.7	35	70	280
Cd as Cadmium	mg/l	na	0.003	0.15	0.3	1.2
Chloride as Cl	mg/l	249	300	15000	30000	120000
CN total as Cyanide total	mg/l	na	0.07	3.5	7	28
Co as Cobalt	mg/l	0.09	0.5	25	50	200
Cr as Total Chromium	mg/l	0.09	0.1	5	10	40
Cr (VI) as Chromium (VI)	mg/l	na	0.05	2.5	5	20
Cu as Copper	mg/l	0.04	2	100	200	800
F as Fluoride	mg/l	4	1.5	75	150	600
Hg as Mercury	mg/l	na	0.006	0.3	0.6	2.4
Mn as Manganese	mg/l	6.4	0.5	25	50	200
Mo as Molybdenum	mg/l	1.4	0.07	3.5	7	28
Ni as Nickel	mg/l	na	0.07	3.5	7	28
Nitrate as N	mg/l	27	11	550	1100	4400
Pb as Lead	mg/l	na	0.01	0.5	1	4

Parameter	Leachable Concentration Threshold (LCT)					
	Unit	Sample	LCT0	LCT1	LCT2	LCT3
Sb as Antimony	mg/l	na	0.02	1	2	8
Se as Selenium	mg/l	na	0.01	0.5	1	4
Sulphate as SO4	mg/l	217	250	12500	25000	100000
V as Vanadium	mg/l	na	0.2	10	20	80
Zn as Zinc	mg/l	na	5	250	500	2000
TDS	mg/l	na	1000	12500	25000	100000
NA: Not applicable/Below Threshold						

7.1.3 Waste Type for Landfill Disposal

Waste destined for disposal are determined by comparing Total concentration (TC) and Leachable Concentration (LC) of the elements with the Total concentration Threshold (TCT) and Leachable Concentration Treshold (LCT) limits.



Considering the results presented in Appendix I the waste is classified as a Type 3 waste as the sample exceeded LCT0 values. Boron, fluoride manganese, molybdenum,and nitrate exceeded the LCT0 limits.

Type 3 waste in terms of the Waste Act should be disposed of in a Class C or GLB- lined facility.

8 CONCEPTUAL SITE MODEL

The conceptual model is a simplified representation of the conditions at and in the vicinity of the SFSF and will provide the framework during the development of the risk assessment and numerical flow and transport model.

8.1 Water Levels & Flow directions

The groundwater flow around the planned SFSF is towards the east to the Ga-Mogara River. The water levels around the planned SFSF area is relatively deep (>30mbgl) , with water levels measured in the two monitoring boreholes having a mean value of 54mbgl. The deep-water level is a regional phenomenon as illustrated by the hydro census data that was gathered by Envass (August 2018) as well as being caused by the dewatering being conducted by the mine. The Ga-Mogara river is a non-perennial river that is not hydraulically connected to the aquifer.

8.2 Hydraulic Conductivities

The average hydraulic conductivity (K) of the unconsolidated soils is in the region of 1 m/d. The shallow weathered unsaturated zone has a hydraulic conductivity of between $2.44x10^{0}$ and $6.8x10^{-3}$ m/d These values are given in the geohydrological assessment report (Envass 2018) and was measured in situ on site using double ring infiltrometer tests and falling head tests respectively. The water levels on the site do not follow the topography and is likely as a result of compartmentalization caused by several faults in the area as well as active dewatering.

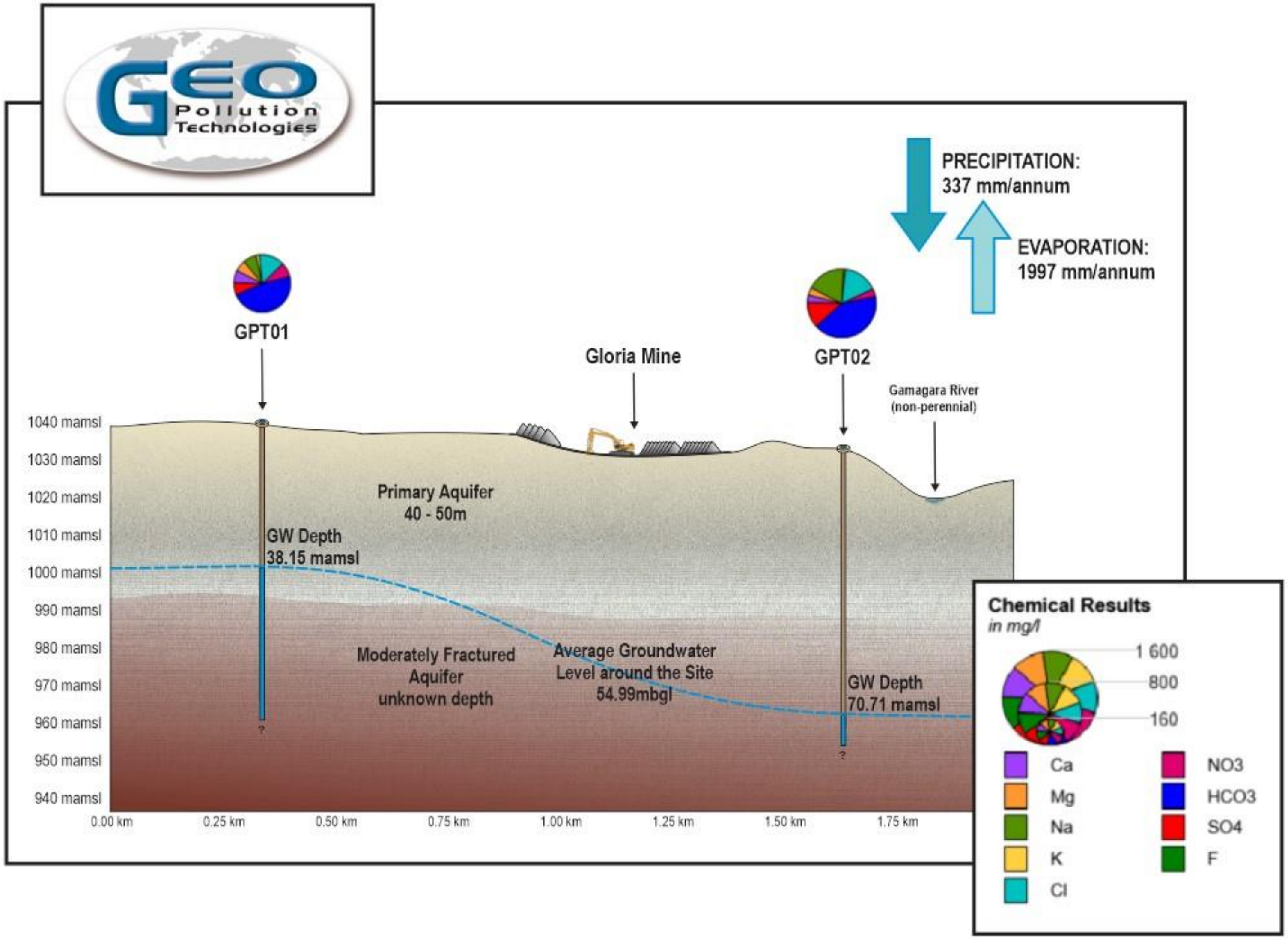


Figure 8: Conceptual Site Model (Not to scale).

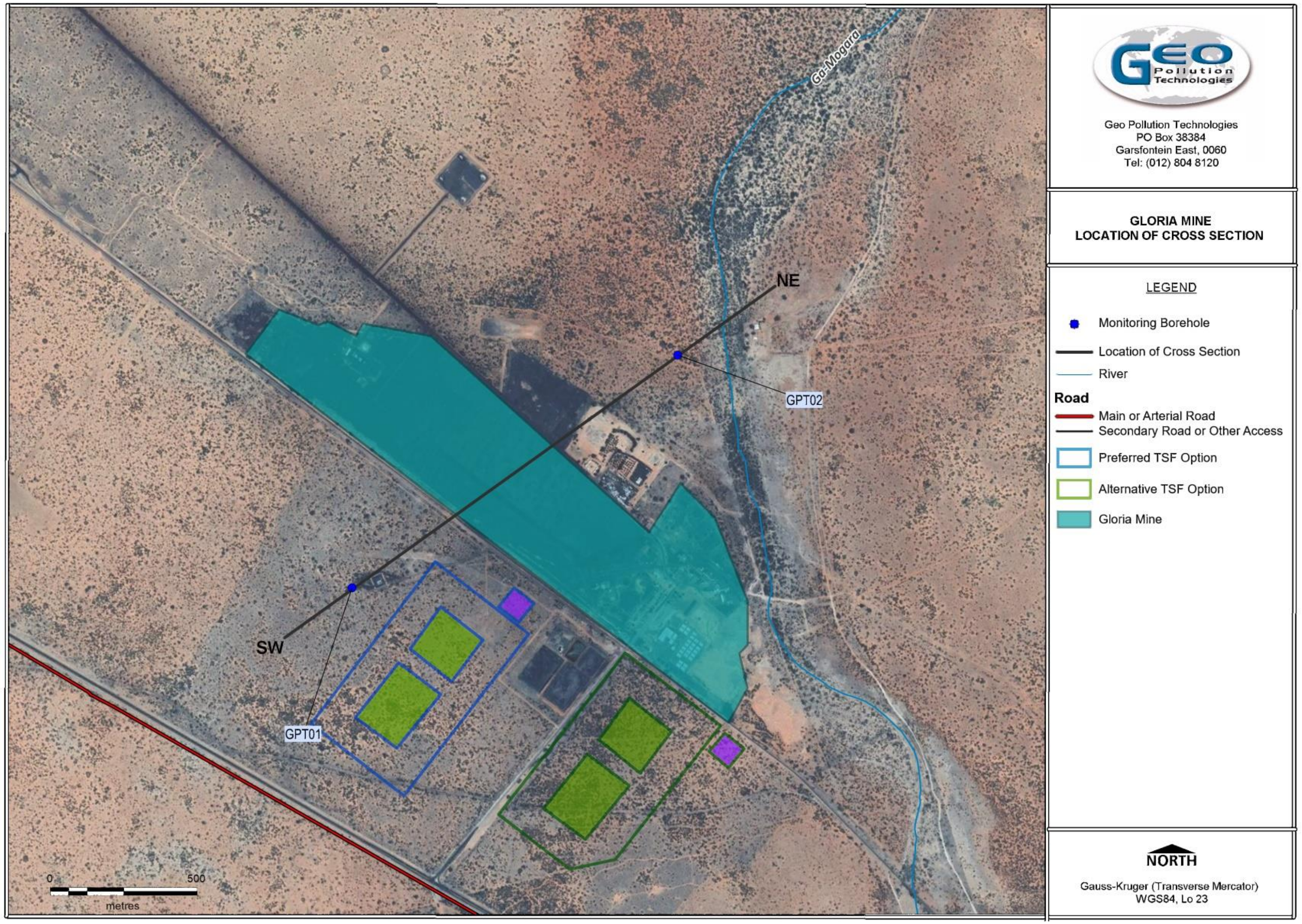


Figure 9: Location of the Cross Section.

9 GROUNDWATER FLOW AND TRANSPORT MODELLING

The numerical groundwater flow model is constructed and simulated for the quantification of impacts associated with the quality and quantity of the groundwater. Utilising this information management plans can be developed to assist in the mitigation of potential impacts.

The groundwater regime of the study area is highly heterogeneous due to complex faulting and intrusions, which ultimately influence the groundwater flow patterns. Constructing a groundwater flow model with all the detail is close to impossible; however, assumptions are made based on data gathered in the field and used to simulate different scenarios to conclude with management protocol.

9.1 Software Model Choice

The finite difference numerical model was created using AquaVeo's Groundwater Modelling System (GMS10) as Graphical User Interface (GUI) for the well-established Modflow and MT3DMS numerical codes.

MODFLOW is a 3D, cell-centred, finite difference, saturated flow model developed by the United States Geological Survey. MODFLOW can perform both steady state and transient analyses and has a wide variety of boundary conditions and input options. It was developed by McDonald and Harbaugh of the US Geological Survey in 1984 and underwent eight overall updates since. The latest update (Modflow-NWT) incorporates several improvements extending its capabilities considerably, the most important being the introduction of the Newton formulation of Modflow. This dramatically improved the handling of dry cells that has been a problematic issue in Modflow in the past.

MT3DMS is a 3-D model for the simulation of advection, dispersion, and chemical reactions of dissolved constituents in groundwater systems. MT3DMS uses a modular structure similar to the structure utilized by MODFLOW, and is used in conjunction with MODFLOW in a two-step flow and transport simulation. Heads are computed by MODFLOW during the flow simulation and utilized by MT3DMS as the flow field for the transport portion of the simulation.

9.2 Model Set-up and Boundaries

Boundaries were chosen to include the area where the groundwater pollution plume could reasonably be expected to spread and simultaneously be far enough removed from site boundaries not to be affected by groundwater abstraction. These boundaries are described in Table 5.

These boundaries resulted in an area of about 6 to 30 km around the proposed development, which is considered far enough for the expected groundwater effects not to be influenced by boundaries.

9.3 Groundwater Elevation and Gradient

The calibrated static water levels as modelled have been contoured (Figure 12). Groundwater flow direction should be perpendicular to these contours and inversely proportional to the distance between contours. As can be expected, the groundwater flow is mainly from topographical high to low areas, eventually draining to the local streams.

9.4 Geometric Structure of the Model

The geometric structure of the model is discussed in Appendix II, with only the conceptual model input and fixed aquifer parameters discussed below.

9.5 Groundwater source and sinks

Although the most relevant aquifer parameters are optimised by the calibration of the model, many parameters are calculated and/or judged by conventional means. The fixed assumptions and input parameters were used for the numerical model of this area.

Table 5: Input parameters to the numerical flow model

Model Parameter	Value	Unit	Reason
Recharge to the aquifer	0.00002	m/d	Calculated as 2.2% of recharge
Recharge to the tailings facility	0.003	m/d	Wet deposition derived from vertical K of tailings. Modelled scenarios
Evapotranspiration	0.0054	m/d	Calculated from E-pan evaporation data
Boundaries	Topographic water divides	-	Existing water divide (no flow) boundary conditions present at the site
Refinement	50	m	Based on the scale of the SFSFs
Grid dimensions	120x122	Cell count	Product of the grid refinement
Preliminary hydraulic conductivity	0.5	m/d	GPT 2012 Falling head tests
Hydraulic anisotropy (vertical)	10	-	Anderson et al. (2015)
Effective porosity	30 for regolith, 5 for fractured rock	%	Wang et al. (2009)
Layers	4	Count	Hydrogeological decision
Longitudinal dispersion	50	m	Schulze-Makuch (2005)
Head error range	10	m	Calculated as 10% of the difference between the maximum and minimum calculated head elevations

9.6 Conceptual model input

For the purpose of this study, the subsurface was envisaged to consist of the following hydrogeological units.

- The upper few metres below surface consist of unconsolidated material, this layer is anticipated to have a high hydraulic conductivity but is in general unsaturated.
- The next few tens of metres comprise of weathered sedimentary rock.
- The next few tens of metres comprise of fractured sedimentary rock. The permanent groundwater level resides in this unit and is about 30 to 60 metres below ground level.
- In the last unit, the fracturing of the aquifer is less frequent and fractures less significant due to increased pressure. This results in an aquifer of lower hydraulic conductivity.

9.7 Calibration of the Numerical Model

Water level and quality data obtained from the site monitoring data was used to calibrate the steady state numerical groundwater flow model. A reasonable calibration was obtained (Figure 10). However, the boreholes at the site could not be fitted adequately as the water levels in them are unusually deep and does not follow the topography. A similar tendency was found in the baseline study conducted by Envass (2018) and is illustrated in Figure 11.

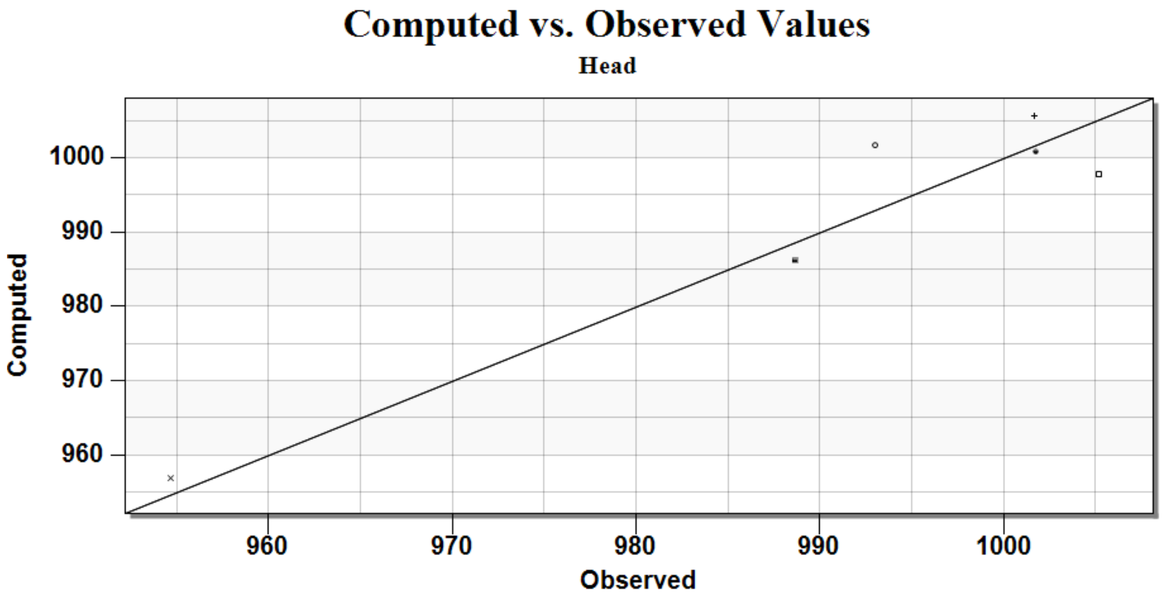


Figure 10: Water level Calibration Graph

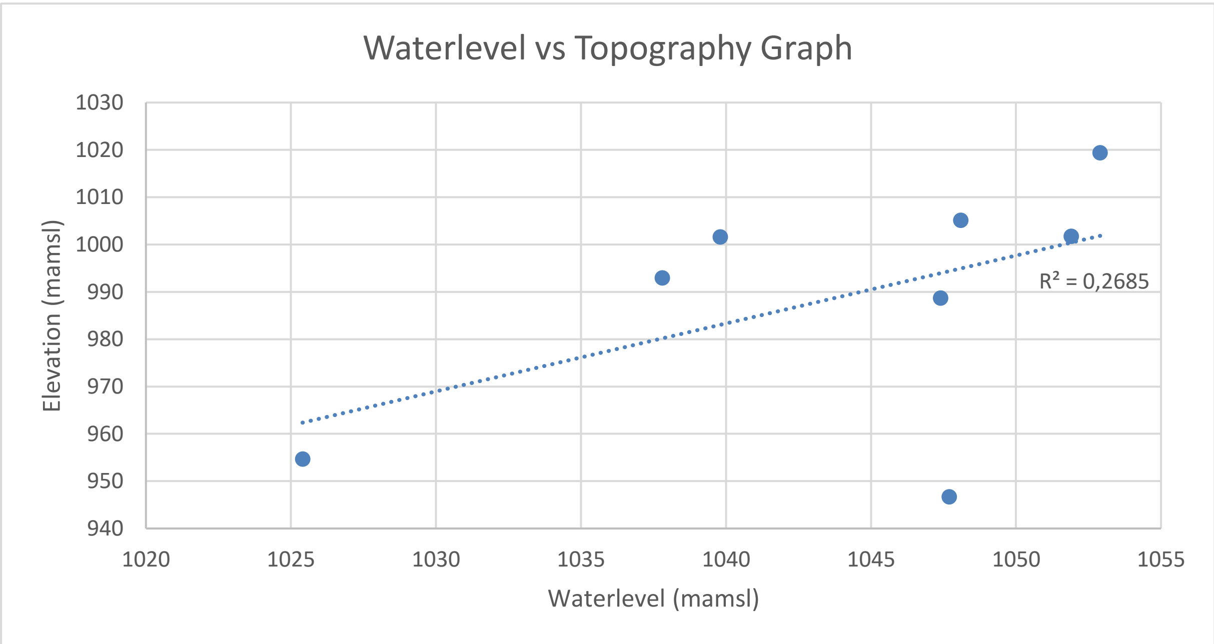


Figure 11: Water level elevation vs topographical elevation.

The calibration error statistics can be seen in Table 6. The mean residual head error is below 1 metre, which can be regarded as good. A adequate fit was also obtained for the measured groundwater levels (Figure 10 to Figure 12).

Table 6: Optimal Calibrated Aquifer Parameters.

Aquifer	Model layer	Layer thickness (m)*	Porosity (%)	Hydraulic conductivity (m/d)
Regolith	Layer 1	10	30	1.0
Shallow Weathered Aquifer	Layer 2	30	5	0.25
Weathered and Fractured Aquifer	Layer 3	30	4	0.11
Fractured Aquifer	Layer 4	30	3	0.05

Table 7: Calibration Statistics.

Description	Value
Mean Residual (Head)	-0.67
Mean Absolute Residual (Head)	4.3
Root Mean Squared Residual (Head)	5.16

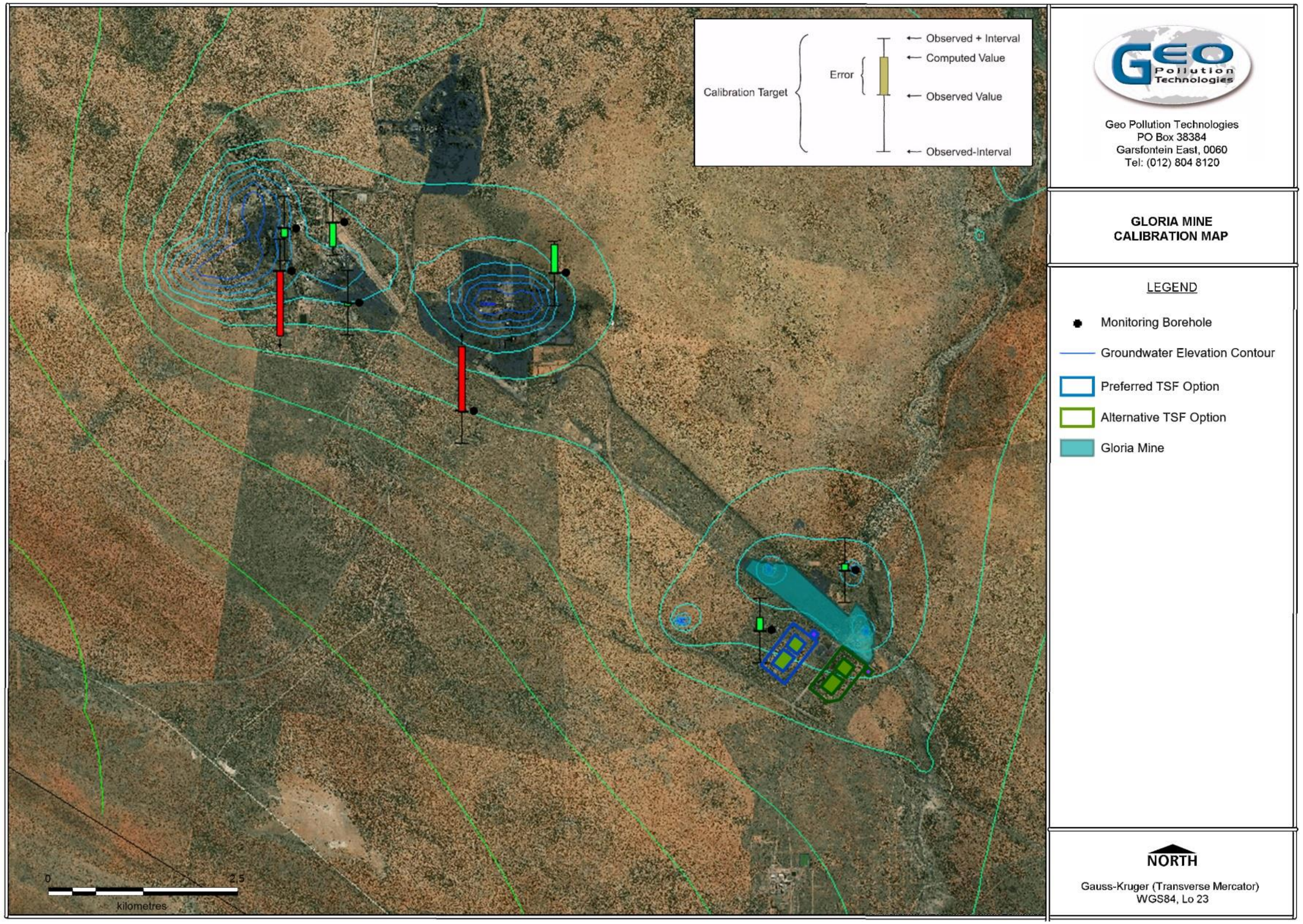


Figure 12: Water Level Calibration Map (bars 10 m head interval).

9.8 Scenarios Modelled

Two potential SFSF sites are considered for the Gloria Mine, as depicted in Figure 13. The purpose of the investigation is to predict the impact of the two sites on nearby receptors and to classify the sites in terms of environmental impact on the receptors.

The SFSFs were modelled as if no liners will be present. The inflow into the SFSF's were modelled as artificial recharge as wet deposition will be used.

A conservative tracer with an initial concentration of 1000mg/l was used. This value was chosen as it is easy to calculate the impact at any given point for any of the potential contaminants as outlined in the waste classification. It must be noted that no decay or natural attenuation has been modelled as the geochemical information required for this was not available. The various predicted concentrations are discussed in Section 10.1.

The active dewatering at the site was also simulated by placing abstraction points in the positions where the dewatering boreholes are located. The dewatering boreholes details are presented in Table Table 8 below:

Table 8: Details of the dewatering boreholes

BH Id	Latitude	Longitude	Dewatering Volumes (m^3.day)
BRS6	-27.12264	22.8304	65.6
BRS7	-27.12989	22.83003	293.0
BRS7A	-27.13092	22.82625	70.7
BRS8	-27.12792	22.83164	65.6
Gloria BH	-27.17247	22.8881	22.8
Gloria Shaft2	-27.17247	22.88822	236.8
Nchwaning 2	-27.13528	22.86553	1783.5
Nchwaning 3	-27.13528	22.86553	482.8

9.9 Assumptions and Limitations

The modelling was done within the limitations of the scope of work of this study and the amount of data available. Although all efforts have been made to base the model on sound assumptions and has been calibrated to observed data, the results obtained from this exercise should be considered in accordance with the assumptions made. Especially the assumption that a fractured aquifer will behave as a homogeneous porous medium can lead to error. However, on a large enough scale (bigger than the REV, Representative Elemental Volume) this assumption should hold reasonably well. Additionally, the contaminant transport are simplistic chemical simulations with no attenuation or natural decay taken into account.

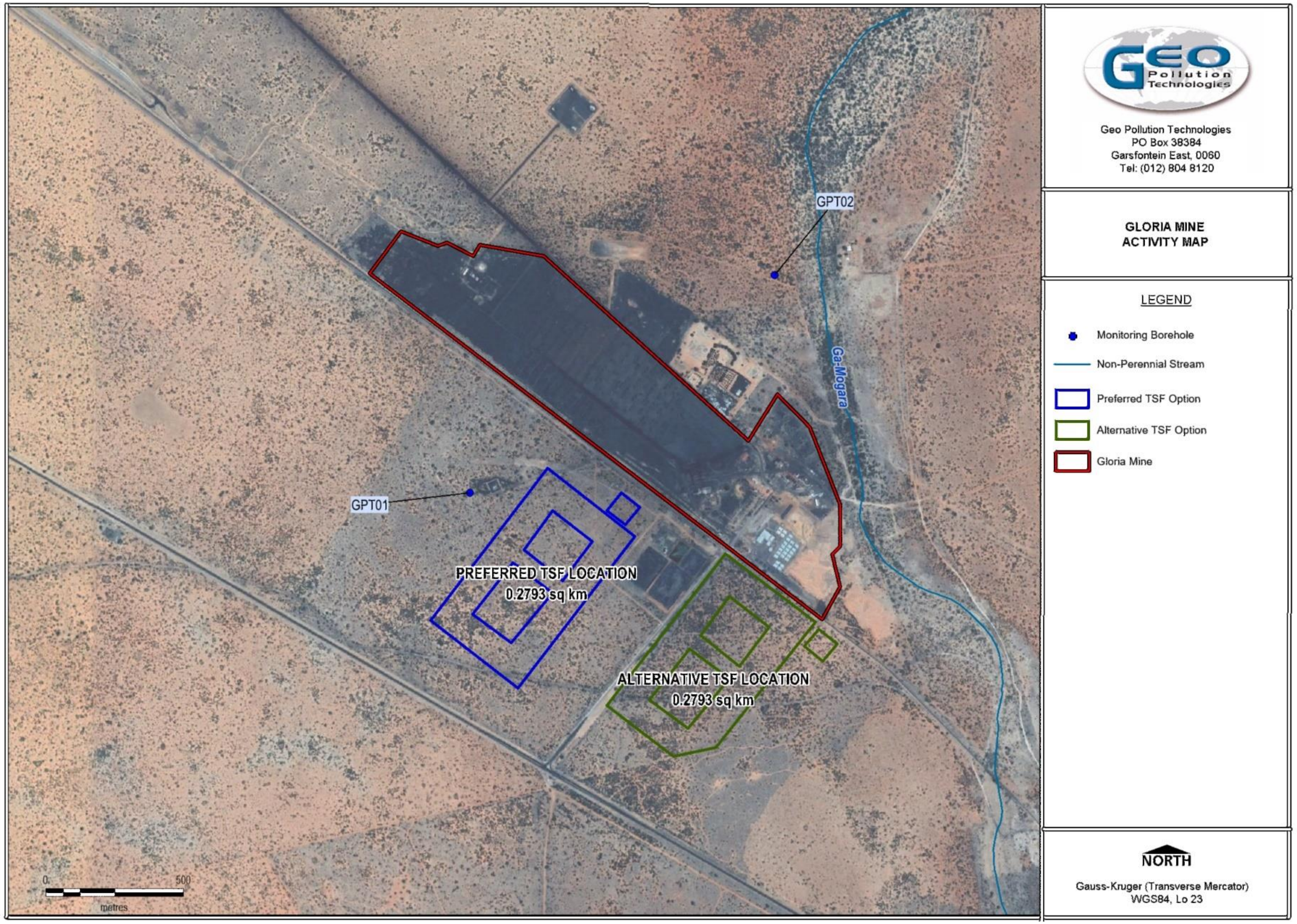


Figure 13: Locality of the proposed SFSF footprints.

10 HYDROGEOLOGICAL IMPACTS

It is the aim of this chapter to assess the likely hydrogeological impact that the proposed SFSFs might have on the receiving environment. The two tailings options were modelled namely the preferred and alternative positions.

10.1 Conclusions from Modelling Results

Based on the scenarios modelled, it is concluded that:

- The preferred option is the recommended position for the SFSF location, mainly due to its distance from the Ga-Mogara River and the depth to groundwater in the area (Figure 14).
- If the Preferred SFSF Position is selected as the locality for the SFSF, little impact to sensitive groundwater receptors are predicted due to the depth to groundwater as a result of active dewatering. Contaminant that may emanate from the SFSF would likely flow downwards towards the aquifer. The expected plume will only reach the river after 50 years.
- The alternative option is closer to the Ga-Mogara River and should a leakage form the tailings exist this could flow to the river before infiltrating to the deeper aquifer due to the presence of hardpan calcrete in the regolith layer. The predicted plume would reach the river within 10 years of operation.
- However, the deep groundwater levels likely mean that the Ga-Mogara River is unconnected to the aquifer. In the preferred scenario, the modelled contamination movement will not reach the river within 50 years. Due to the uncertainties in the waterlevels around the area and thus flow directions, this is an aspect that is worth further investigation.
- Due to the slow groundwater movement, no groundwater users is likely to be impacted. The only likely receptors will be the Ga-Mogara river, although as previously stated, this river is not connected to the aquifer due to the water level depth. The remaining receptors will be the monitoring boreholes GPT01 and GPT02. These are monitoring boreholes and are not used for any other purpose. These boreholes can thus be used to determine and confirm modelled impacts, should they exist.

The expected contamination for the receptors for each of the options can be seen in Table 9 below:

Table 9: Predicted contaminant concentrations at potential receptors.

Parameter	Leachable Concentration (mg/l)	Concentration at Receptor (mg/l) (50 Years)			
		Alternative SFSF		Preferred SFSF	
		GPT02	River	GPT02	River
B	4.1	4.1	0.2	4.1	0
Mn	6.4	6.4	0.03	6.4	0
Mo	1.4	1.4	0.007	1.4	0
NO_3	27	27	0.135	27	0

In terms of potential groundwater contamination, the preferred SFSF position should be considered as the preferred option while ensuring that no leakages as little as possible leakages occur to potentially impact on the Ga-Mogara River.

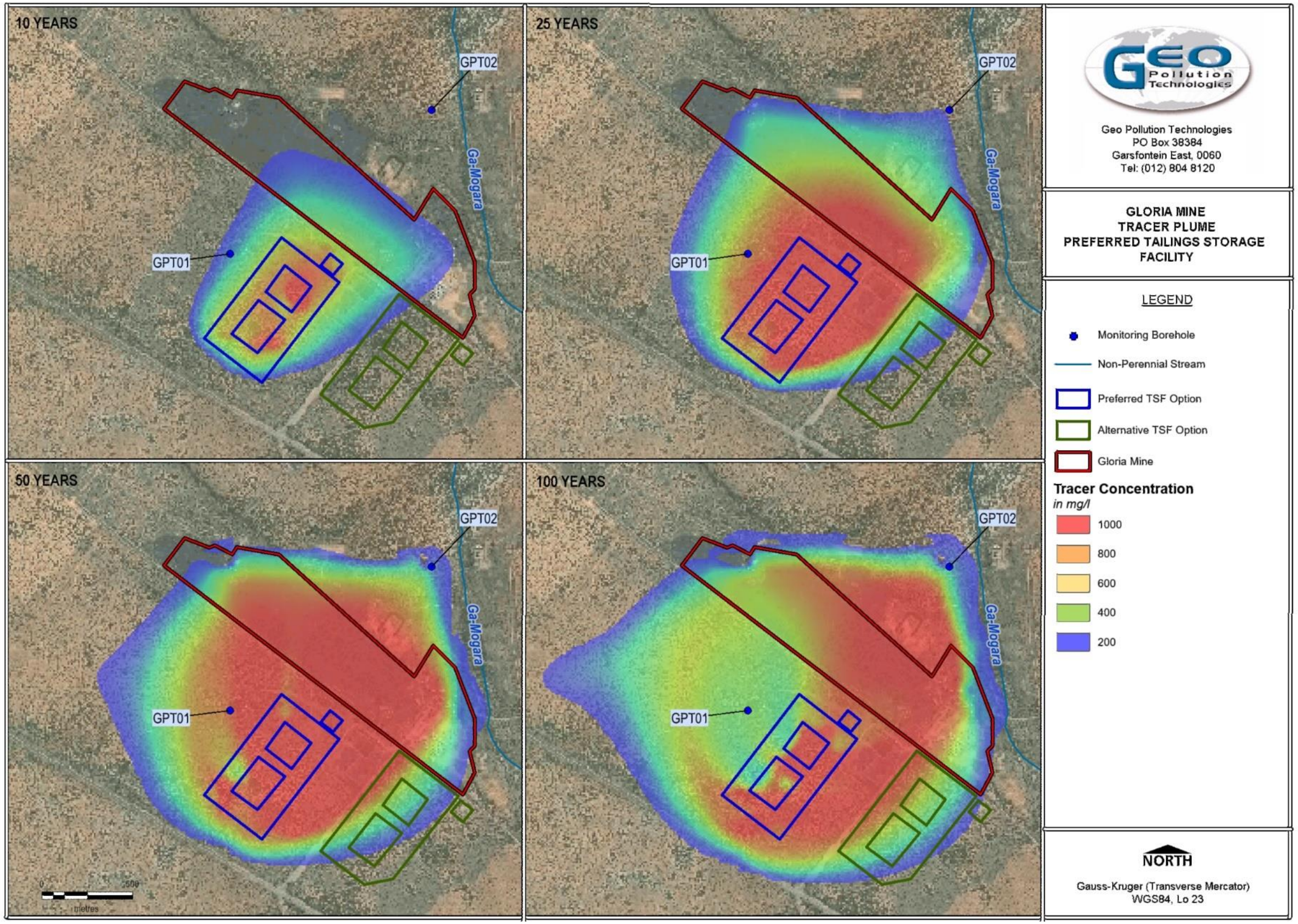


Figure 14: Predicted plume migration over time – Preferred SFSF Location.

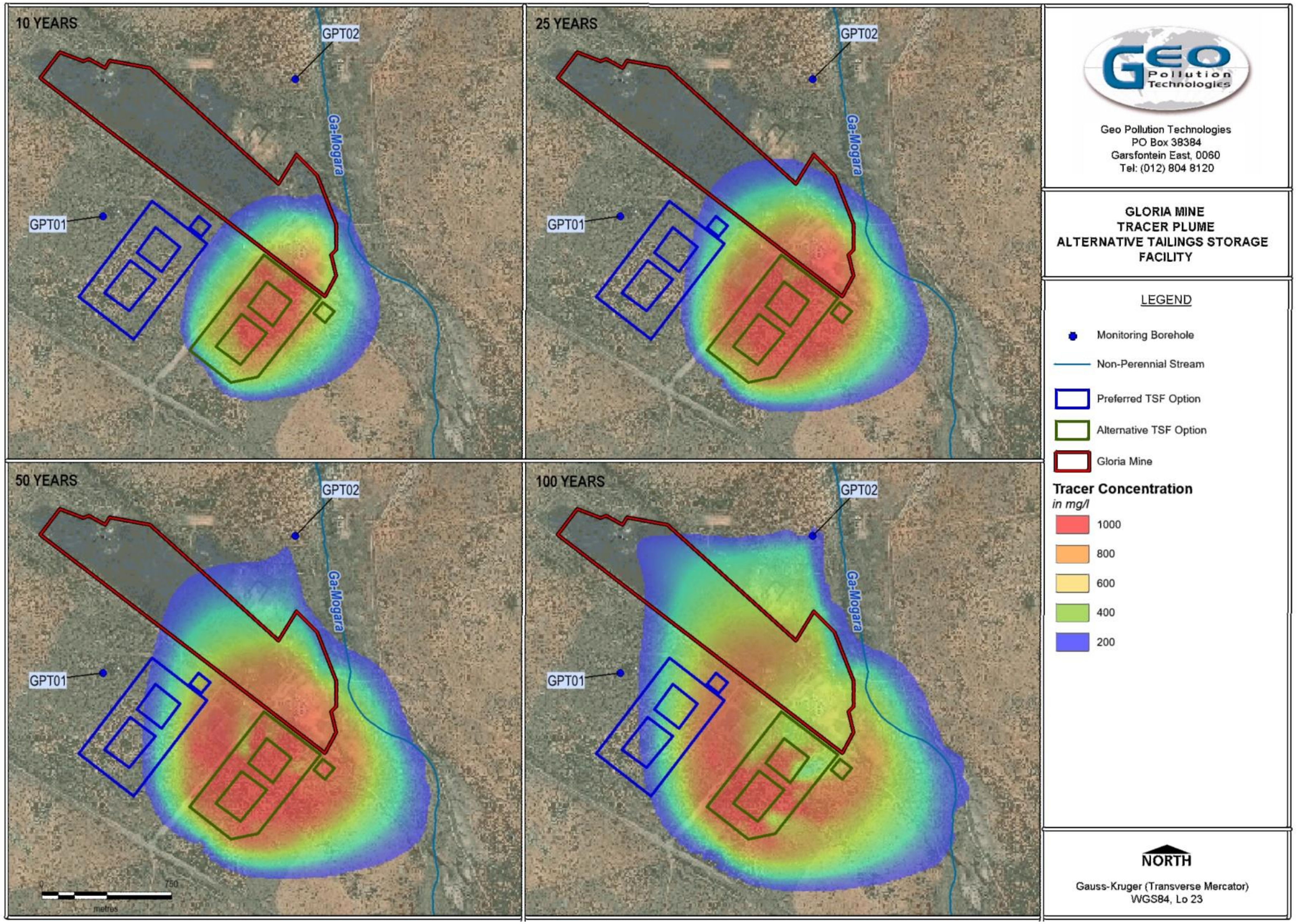


Figure 15: Predicted plume migration over time – Alternative SFSF Location.

11 GROUNDWATER RISK ASSESSMENT

The groundwater risk assessment methodology is based on defining and understanding the three basic components of the risk, i.e. the source of the risk (source term), the pathway along which the risk propagates, and finally the target that experiences the risk (receptor). The risk assessment approach is therefore aimed at describing and defining the relationship between cause and effect. In the absence of any one of the three components, it is possible to conclude that groundwater risk does not exist.

11.1 Source term(s)

The approach to define the behaviour of the source term is detailed below.

- Waste material will be generated that has the potential to contaminate.
- The waste is deemed to have a negative impact on the environment based on the waste classification conducted
- Based on the leach test there is potential for leachate generation. It is theoretically possible, by using synthetic liners, to completely contain leachate from a waste site. This is, however, mostly impractical and very costly. It is also generally accepted that all liners leak to a greater or lesser (or to some) extent. In reality, therefore, leachate that is generated at the planned SFSF may eventually reach the groundwater regime.

It needs to be recognised that source terms are dynamic in nature and could exhibit a variable quality over time, due to changes in hydrology and to changes in the chemistry. An impact assessment that defines the source term as a static constant feature over time is unlikely to be realistic and would be inappropriate for anything other than the most basic screening level assessment.

11.2 Pathways

With respect to potential impacts on the water resource, the groundwater pathways through which contaminants could move are the following:

- Movement through the regolith which has a thickness of ±10 m and high hydraulic conductivity of 1 m/day.
- Movement through the weathered aquifer which has a thickness of ±30 m and moderate hydraulic conductivity of 0.25 m/day.
- Movement through the weathered and fractured aquifer which has a hydraulic conductivity of 0.11 m/day. No preferential pathways were modelled as a lack of information about these exist, although they could accelerate flow tempos if present.

11.3 Receptors

As the final component of the risk assessment, the receptors in the context of the water resource would be users of the resource itself. During the hydro-census as done by Envass (2018) some groundwater users were found within a 5km radius of the planned SFSF areas. The groundwater was used for domestic and livestock watering purposes. However, none of the boreholes are located within the modelled plumes of the proposed SFSF foot prints. The Ga-Mogara River is located in close proximity to the planned SFSF and therefore is likely the only potential receptor of contamination. The preferred option is the recommended position for the SFSF location, mainly due to its distance from the Ga-Mogara River and the depth to groundwater in the area. If the Preferred SFSF Position is selected as the preferred locality for the SFSF, little impact to sensitive groundwater receptors are predicted. Contaminant that my emanate from the SFSF would likely flow downwards towards the aquifer.

12 GROUNDWATER MONITORING SYSTEM

12.1 Groundwater Monitoring Network

A groundwater monitoring system has to adhere to the criteria mentioned below. As a result, the system should be developed accordingly.

12.1.1 Source, plume, impact and background monitoring

A groundwater monitoring network should contain monitoring positions which can assess the groundwater status at certain areas. The boreholes can be grouped classification according to the following purposes:

- **Source monitoring:** Monitoring boreholes are placed close to or in the source of contamination to evaluate the impact thereof on the groundwater chemistry.
- **Plume monitoring:** Monitoring boreholes are placed in the primary groundwater plume's migration path to evaluate the migration rates and chemical changes along the pathway.
- **Impact monitoring:** Monitoring of possible impacts of contaminated groundwater on sensitive ecosystems or other receptors. These monitoring points are also installed as early warning systems for contamination break-through at areas of concern.
- **Background monitoring:** Background groundwater quality is essential to evaluate the impact of a specific action/pollution source on the groundwater chemistry.

12.1.2 System Response Monitoring Network

Groundwater levels: The response of water levels to abstraction is monitored. Static water levels are also used to determine the flow direction and hydraulic gradient within an aquifer. Where possible all of the above-mentioned borehole's water levels need to be recorded during each monitoring event.

12.1.3 Monitoring Frequency

In the operational phase and closure phase, quarterly monitoring of groundwater quality and groundwater levels is recommended. Quality monitoring should take place before after and during the wet season, i.e. during September and March. It is important to note that a groundwater-monitoring network should also be dynamic. This means that the network should be extended over time to accommodate the migration of potential contaminants through the aquifer as well as the expansion of infrastructure and/or addition of possible pollution sources.

12.1.4 Monitoring Parameters

The identification of the monitoring parameters is crucial and depends on the chemistry of possible pollution sources. They comprise a set of physical and/or chemical parameters (e.g. groundwater levels and predetermined organic and inorganic chemical constituents). Once a pollution indicator has been identified it can be used as a substitute to full analysis and therefore save costs. The use of pollution indicators should be validated on a regular basis in the different sampling positions. The parameters should be revised after each sampling event; some metals may be added to the analyses during the operational phase, especially if the pH drops.

12.1.5 Abbreviated analysis (pollution indicators)

Physical Parameters:

- Groundwater levels

Chemical Parameters:

- Field measurements:
    - pH, EC
- Laboratory analyses:
    - Major anions and cations (Ca, Na, Cl, SO4)
    - Other parameters (EC)

12.1.6 Full analysis

Physical Parameters:

- Groundwater levels

Chemical Parameters:

- Field measurements:
    - pH, EC
- Laboratory analyses:
    - Anions and cations (Ca, Mg, Na, K, NO3, Cl, SO4, F, Fe, Mn, Al, & Alkalinity)
    - Other parameters (pH, EC, TDS)

12.2 Monitoring Boreholes

DWAF (1998) states that "A monitoring hole must be such that the section of the groundwater most likely to be polluted first, is suitably penetrated to ensure the most realistic monitoring result."[1]

Currently a monitoring network does not exist for the planned SFSF. The recommended boreholes are listed in Table 10 and the areas to site these monitoring boreholes are shown in Figure 16. These boreholes can be utilised for water level monitoring during operations, as well as groundwater quality monitoring after decommissioning of the site. The proposed boreholes should be sited using geophysical methods.

However, a monitoring network should be dynamic. This means that the network should be extended over time to accommodate the migration of contaminants through the aquifer as well as the expansion of infrastructure and/or addition of possible pollution sources. An audit on the monitoring network should be conducted annually.

---

[1] Department of Water Affairs and Forestry (DWAF). (1998). Minimum Requirements for the Water Monitoring at Waste Management Facilities. CTP Book Printers. Cape Town.

Table 10: Proposed Monitoring Positions (New boreholes to be sited using geophysics)

ID	Latitude (South)	Longitude (East)	Owner	Borehole Depth (mbgl)	Reasoning	Frequency	Existing/ New
GPT01	-27.166477	22.911302	BRMO	100	Impact Monitoring	Quarterly	Existing
GLBH01	-27.178645	22.897758	BRMO	100	Impact Monitoring	Quarterly	New
GLBH02	-27.17121	22.90436	BRMO	100	Impact Monitoring	Quarterly	New

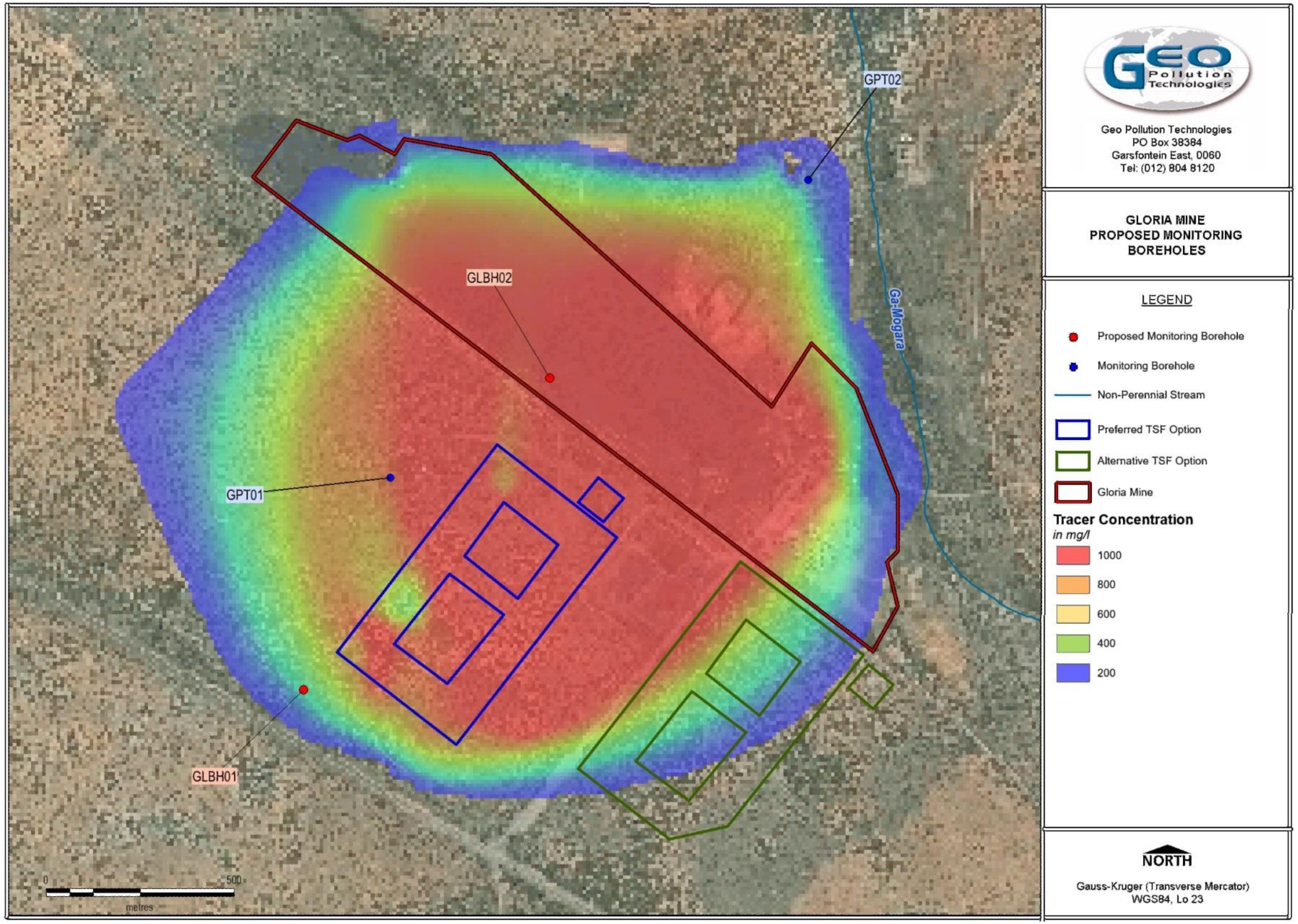


Figure 16: Proposed monitoring positions (new boreholes to be sited by geophysics)

13 CONCLUSIONS AND RECOMMENDATIONS

13.1 Project objectives

Within the scope of work the groundwater study aimed to address the following through a technical feasibility study:

- Select a site based on the forecasted impact as determined from the modelling results.
- Determine potential groundwater impacts from the SFSF considering the proposed location
- Assess the unsaturated and saturated flow below the SFSF
- Design a monitoring network for the planned SFSF

13.2 Hydraulic conductivities

The regional transmissivity values at the site are expected to vary between 1 and 2 m^2/day, with structurally-related values being as high as 5 to 10 m^2/day locally. From previous work done, the upper hydrogeological unit (i.e. <40 m depth) having hydraulic conductivities between 10^{-4} and 1 m/day, with the lower fractured/weathered unit (i.e. 40-68 m depth) values being in the order of 10^{-5} m/day.

Falling head tests conducted in the existing monitoring site boreholes showed conductivity values between 0.068 m/day (GPT02) and 2.44 m/day (GPT04). The higher conductivity values are expected to be associated with geological structures at the Site.

13.3 Potential groundwater impacts resulting from a the planned SFSF

The planned SFSF was modelled as if it would not be lined. Should the liner however leak as was simulated by the numerical model, the impact on potential receptors is expected to be minimal as limited receptors exist in the vicinity of the planned SFSF. The inflow into the SFSF's were modelled as artificial recharge as wet deposition will be used.

Two potential SFSF positions were modelled, the preferred position and the alternative position. From the modelling results it was concluded that the preferred option would likely have the least potential impact on possible receptors (the Ga-Mogara River). The alternative location is closer to the River and would be less desirable from a hydrogeological point of view. In both of the modelled locations, the depth to water level limits the risk to groundwater in an event where a leakage would occur.

Due to the slow groundwater movement, no groundwater users are likely to be impacted. The only likely receptors will be the Ga-Mogara river and the monitoring boreholes. The Ga-Mogara river is not connected to the aquifer due to the water level depth. The remaining receptors will be the monitoring boreholes GPT01 and GPT02. These are monitoring boreholes and are not used for any other purpose. These boreholes can thus be used to determine and confirm modelled impacts, should they exist.

Even though the depth to groundwater limits risk, sound construction and management practices for the planned SFSF must still be adhered to in order to limit risk to the underlying aquifer and the River. These include installing a suitable liner as well as limiting stormwater ingress to the SFSF and diverting stormwater away from it. Furthermore, the results from the leaching analysis of the tailings material indicated that the tailings material exceeds the LCT0 threshold, requiring a class C or GLB lined facility.

13.4 Monitoring Network

Currently a monitoring network does not exist for the planned SFSF although one of the existing monitoring boreholes is located within the footprint of the preferred site. The recommended boreholes are listed in Table 10 and the areas to site these monitoring boreholes are shown in Figure 16. These boreholes can be utilised for water level monitoring during operations, as well as groundwater quality monitoring after decommissioning of the site. All of the boreholes should be sited using geophysical methods.

However, a monitoring network should be dynamic. This means that the network should be extended over time to accommodate the migration of contaminants through the aquifer as well as the expansion of infrastructure and/or addition of possible pollution sources. An audit on the monitoring network should be conducted annually.

13.5 Recommendations

The following recommendations are put forward:

- A system of storm water drains must be designed and constructed to ensure that all rainwater that falls outside the area of the SFSF is diverted clear of the deposit.
- The boreholes GLBH01 and GLBH02 should be added to current monitoring network. These should be monitored on a quarterly basis prior to construction, during construction and operational phases for the parameters analysed in this report. The following parameters should be monitored:
    - Abbreviated analysis (pollution indicators)
        - Physical Parameters:
        - Groundwater levels
        - Chemical Parameters:
            - Field measurements - pH, EC
    - Laboratory analyses:
        - Major anions and cations (Ca, Na, Cl, SO4)
        - Other parameters (EC)
    - Full analysis
        - Physical Parameters:
            - Groundwater levels
        - Chemical Parameters:
            - Field measurements - pH, EC
    - Laboratory analyses:
        - Anions and cations (Ca, Mg, Na, K, NO3, Cl, SO4, F, Fe, Mn, Al, & Alkalinity)
        - Other parameters (pH, EC, TDS)
- The monitoring boreholes should be sited using geophysical methods in order to identify geological structures that may act as preferential flow paths for contaminant transport.

- Monitoring boreholes drilling should be supervised by a qualified hydrogeologist and care should be taken to accurately log the geology during drilling and construct the boreholes appropriately
- The aquifer parameters should be measured by conducting an aquifer test (pump test =, slug test etc.) on each of the newly drilled boreholes. 24-Hour pumping tests are recommended. This information can be used to update the numerical model with accurately measured parameters.
- A hydrocensus within a radius of 5km around the boundary of the Gloria SFSF site should be conducted every 2 years.
- A re-evaluation of the risk to the aquifer should be conducted every 2 years.
- Upon decommissioning of the facility, the monitoring programme undertaken during the operational phase will need to be continued after decommissioning and during the closure phase.
- Monitoring will continue until the groundwater quality trends are within the RQO for the catchment and to ensure that sufficient information is available to calibrate and confirm the accuracy of the numerical model.
- The groundwater monitoring information should be used to update the numerical groundwater model used during the operations phase. The updated groundwater model will be used in the closure modelling and closure planning.
- Finally, from a hydrogeological perspective and based on the available information supplied by the client, it is recommended that the proposed preferred SFSF is authorised on condition that the lining requirements as set out in the waste classification are met, and that the proposed groundwater monitoring is conducted and reported as described in the DWAF Best Practice Guidelines A2: Water Management for Mine Residue Deposits.

APPENDIX I: WASTE CLASSIFICATION LABORATORY RESULTS

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CERTIFICATE OF ANALYSES

TCLP / ACID RAIN / DISTILLED WATER EXTRACTIONS

Date received:	**22 07 2019**		**Date completed:**	**12 08 2019**
Project number:	**1000**	**Report number: 84895**	**Order number:**	

Client name:	**EScience Associates (PTY) LTD**	**Contact person:**	**Zayd Ebrahim**
Address:	**PO Box 2950, Saxonwold, 2132**	**Email:**	**zayd@escience.co.za**
Telephone:	**011 718 6380**	**Cell:**	**---**

Analyses	**ASGN TSF Dry**	
Sample Number	**69696**	
TCLP / Acid Rain / Distilled Water / H_2O_2	**Distilled Water**	
Dry Mass Used (g)	**50**	
Volume Used (mℓ)	**1000**	
Inorganic Anions	**mg/ℓ**	**mg/kg**
Chloride as Cl	7	140
Sulphate as SO4	6	120
Nitrate as N	0.8	16
Fluoride as F	<0.2	<4.0
Ortho-Phosphate as P	<0.1	<2.0
ICP-MS Scan	See ICP DW tab	
X-ray Diffraction [o]	See attached report 84895 XRD	
X-ray Fluorescence [o]	See attached report 84895 XRF	
Particle size distribution [o]	See attached report 84895 PSD	

[o] = Outsourced

S. Laubscher___________________
Assistant Geochemistry Project Manager

WATERLAB (PTY) LTD

CERTIFICATE OF ANALYSES

ICP-MS SCAN ANALYSIS

Date received:	22 07 2019	Date Completed:	12 08 2019
Project number:	1000	Report number:	84895

Client name:	EScience Associates (PTY) LTD	Contact person:	Zayd Ebrahim
Address:	PO Box 2950, Saxonwold, 2132	Email:	zayd@escience.co.za

Extract	Sample Mass (g)	Volume (ml)	Factor
Distilled Water	50	1000	20

Sample Id	Sample Number	Ag	Ag	Al	Al	As	As
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.100	<2.00	<0.010	<0.200
ASGN TSF Dry	69696	<0.010	<0.200	<0.100	<2.00	<0.010	<0.200

Sample Id	Sample Number	Au	Au	B	B	Ba	Ba
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
ASGN TSF Dry	69696	<0.010	<0.200	0.112	2.24	0.202	4.03

Sample Id	Sample Number	Be	Be	Bi	Bi	Ca	Ca
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<1	<20
ASGN TSF Dry	69696	<0.010	<0.200	<0.010	<0.200	8	160

Sample Id	Sample Number	Cd	Cd	Ce	Ce	Co	Co
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
ASGN TSF Dry	69696	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	Cr	Cr	Cs	Cs	Cu	Cu
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
ASGN TSF Dry	69696	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	Dy	Dy	Er	Er	Eu	Eu
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
ASGN TSF Dry	69696	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	Fe	Fe	Ga	Ga	Gd	Gd
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.025	<0.500	<0.010	<0.200	<0.010	<0.200
ASGN TSF Dry	69696	<0.025	<0.500	0.013	0.259	<0.010	<0.200

Sample Id	Sample Number	Ge	Ge	Hf	Hf	Hg	Hg
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
ASGN TSF Dry	69696	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	Ho	Ho	In	In	Ir	Ir
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
ASGN TSF Dry	69696	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	K	K	La	La	Li	Li
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.5	<10.0	<0.010	<0.200	<0.010	<0.200
ASGN TSF Dry	69696	0.3	6.0	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	Lu	Lu	Mg	Mg	Mn	Mn
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<1	<20	<0.025	<0.500
ASGN TSF Dry	69696	<0.010	<0.200	2	40	0.096	1.92

Sample Id	Sample Number	Mo	Mo	Na	Na	Nb	Nb
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<1	<20	<0.010	<0.200
ASGN TSF Dry	69696	<0.010	<0.200	6	120	<0.010	<0.200

Sample Id	Sample Number	Nd	Nd	Ni	Ni	Os	Os
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
ASGN TSF Dry	69696	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	P	P	Pb	Pb	Pd	Pd
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
ASGN TSF Dry	69696	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	Pr	Pr	Pt	Pt	Rb	Rb
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
ASGN TSF Dry	69696	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	Rh	Rh	Ru	Ru	Sb	Sb
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
ASGN TSF Dry	69696	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	Sc	Sc	Se	Se	Si	Si
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.2	<4.00
ASGN TSF Dry	69696	<0.010	<0.200	<0.010	<0.200	0.7	13.7

Sample Id	Sample Number	Sm	Sm	Sn	Sn	Sr	Sr
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
ASGN TSF Dry	69696	<0.010	<0.200	<0.010	<0.200	0.047	0.938

Sample Id	Sample Number	Ta	Ta	Tb	Tb	Te	Te
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
ASGN TSF Dry	69696	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	Th	Th	Ti	Ti	Tl	Tl
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
ASGN TSF Dry	69696	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	Tm	Tm	U	U	V	V
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
ASGN TSF Dry	69696	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	W	W	Y	Y	Yb	Yb
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200	<0.010	<0.200
ASGN TSF Dry	69696	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200

Sample Id	Sample Number	Zn	Zn	Zr	Zr
		mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<0.200	<0.010	<0.200
ASGN TSF Dry	69696	<0.010	<0.200	<0.010	<0.200

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CERTIFICATE OF ANALYSES
TOTALS

Date received:	**22 07 2019**		**Date completed:**	**12 08 2019**
Project number:	**1000**	**Report number:** 84895	**Order number:**	

Client name:	**EScience Associates (PTY) LTD**	**Contact person:**	**Zayd Ebrahim**
Address:	**PO Box 2950, Saxonwold, 2132**	**Email:**	**zayd@escience.co.za**
Telephone:	**011 718 6380**	**Cell:**	**---**

Analyses	ASGN TSF Dry	
Sample Number	69696	
Digestion	HNO3 : HF	
Dry Mass Used (g)	0.25	
Volume Used (mℓ)	100	
Units	mg/ℓ	mg/kg
ICP-MS Scan	See ICP Digestion tab	

[o] = Outsourced

S. Laubscher
Assistant Geochemistry Project Manager

WATERLAB (PTY) LTD

CERTIFICATE OF ANALYSES

ICP-MS SCAN ANALYSIS

Date received:	22 07 2019	**Date Completed:**	12 08 2019
Project number:	1000	**Report number:**	84895

Client name:	EScience Associates (PTY) LTD	**Contact person:**	Zayd Ebrahim
Address:	PO Box 2950, Saxonwold, 2132	**Email:**	zayd@escience.co.za

Extract	Sample Mass (g)	Volume (ml)	Factor
HNO3 : HF	0.25	100	400

Sample Id	Sample Number	Ag	Ag	Al	Al	As	As
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<0.100	<40	<0.010	<4.00
ASGN TSF Dry	69696	<0.010	<4.00	1.75	700	0.023	9.17

Sample Id	Sample Number	Au	Au	B	B	Ba	Ba
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<0.010	<4.00	<0.010	<4.00
ASGN TSF Dry	69696	<0.010	<4.00	1.29	516	7.24	2895

Sample Id	Sample Number	Be	Be	Bi	Bi	Ca	Ca
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<0.010	<4.00	<1	<400
ASGN TSF Dry	69696	<0.010	<4.00	<0.010	<4.00	157	62800

Sample Id	Sample Number	Cd	Cd	Ce	Ce	Co	Co
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<0.010	<4.00	<0.010	<4.00
ASGN TSF Dry	69696	<0.010	<4.00	<0.010	<4.00	0.123	49

Sample Id	Sample Number	Cr	Cr	Cs	Cs	Cu	Cu
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<0.010	<4.00	<0.010	<4.00
ASGN TSF Dry	69696	0.012	4.79	<0.010	<4.00	<0.010	<4.00

Sample Id	Sample Number	Dy	Dy	Er	Er	Eu	Eu
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<0.010	<4.00	<0.010	<4.00
ASGN TSF Dry	69696	<0.010	<4.00	<0.010	<4.00	<0.010	<4.00

Sample Id	Sample Number	Fe	Fe	Ga	Ga	Gd	Gd
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.025	<10	<0.010	<4.00	<0.010	<4.00
ASGN TSF Dry	69696	113	45200	0.327	131	<0.010	<4.00

Sample Id	Sample Number	Ge	Ge	Hf	Hf	Hg	Hg
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<0.010	<4.00	<0.010	<4.00
ASGN TSF Dry	69696	<0.010	<4.00	<0.010	<4.00	<0.010	<4.00

Sample Id	Sample Number	Ho	Ho	In	In	Ir	Ir
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<0.010	<4.00	<0.010	<4.00
ASGN TSF Dry	69696	<0.010	<4.00	<0.010	<4.00	<0.010	<4.00

Sample Id	Sample Number	K	K	La	La	Li	Li
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.5	<200	<0.010	<4.00	<0.010	<4.00
ASGN TSF Dry	69696	0.7	280	<0.010	<4.00	0.014	5.53

Sample Id	Sample Number	Lu	Lu	Mg	Mg	Mn	Mn
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<1	<400	<0.025	<10
ASGN TSF Dry	69696	<0.010	<4.00	32	12800	933	373200

Sample Id	Sample Number	Mo	Mo	Na	Na	Nb	Nb
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<1	<400	<0.010	<4.00
ASGN TSF Dry	69696	<0.010	<4.00	<1	<400	<0.010	<4.00

Sample Id	Sample Number	Nd	Nd	Ni	Ni	Os	Os
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<0.010	<4.00	<0.010	<4.00
ASGN TSF Dry	69696	<0.010	<4.00	0.032	13	<0.010	<4.00

Sample Id	Sample Number	P	P	Pb	Pb	Pd	Pd
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<0.010	<4.00	<0.010	<4.00
ASGN TSF Dry	69696	0.487	195	<0.010	<4.00	<0.010	<4.00

Sample Id	Sample Number	Pr	Pr	Pt	Pt	Rb	Rb
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<0.010	<4.00	<0.010	<4.00
ASGN TSF Dry	69696	<0.010	<4.00	<0.010	<4.00	<0.010	<4.00

Sample Id	Sample Number	Rh	Rh	Ru	Ru	Sb	Sb
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<0.010	<4.00	<0.010	<4.00
ASGN TSF Dry	69696	<0.010	<4.00	<0.010	<4.00	<0.010	<4.00

Sample Id	Sample Number	Sc	Sc	Se	Se	Si	Si
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<0.010	<4.00	<0.2	<80
ASGN TSF Dry	69696	0.033	13	<0.010	<4.00	98	39200

Sample Id	Sample Number	Sm	Sm	Sn	Sn	Sr	Sr
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<0.010	<4.00	<0.010	<4.00
ASGN TSF Dry	69696	<0.010	<4.00	<0.010	<4.00	0.320	128

Sample Id	Sample Number	Ta	Ta	Tb	Tb	Te	Te
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<0.010	<4.00	<0.010	<4.00
ASGN TSF Dry	69696	<0.010	<4.00	<0.010	<4.00	<0.010	<4.00

Sample Id	Sample Number	Th	Th	Ti	Ti	Tl	Tl
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<0.010	<4.00	<0.010	<4.00
ASGN TSF Dry	69696	<0.010	<4.00	0.269	108	<0.010	<4.00

Sample Id	Sample Number	Tm	Tm	U	U	V	V
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<0.010	<4.00	<0.010	<4.00
ASGN TSF Dry	69696	<0.010	<4.00	<0.010	<4.00	<0.010	<4.00

Sample Id	Sample Number	W	W	Y	Y	Yb	Yb
		mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<0.010	<4.00	<0.010	<4.00
ASGN TSF Dry	69696	<0.010	<4.00	<0.010	<4.00	<0.010	<4.00

Sample Id	Sample Number	Zn	Zn	Zr	Zr
		mg/l	mg/kg	mg/l	mg/kg
Det Limit		<0.010	<4.00	<0.010	<4.00
ASGN TSF Dry	69696	0.097	39	<0.010	<4.00

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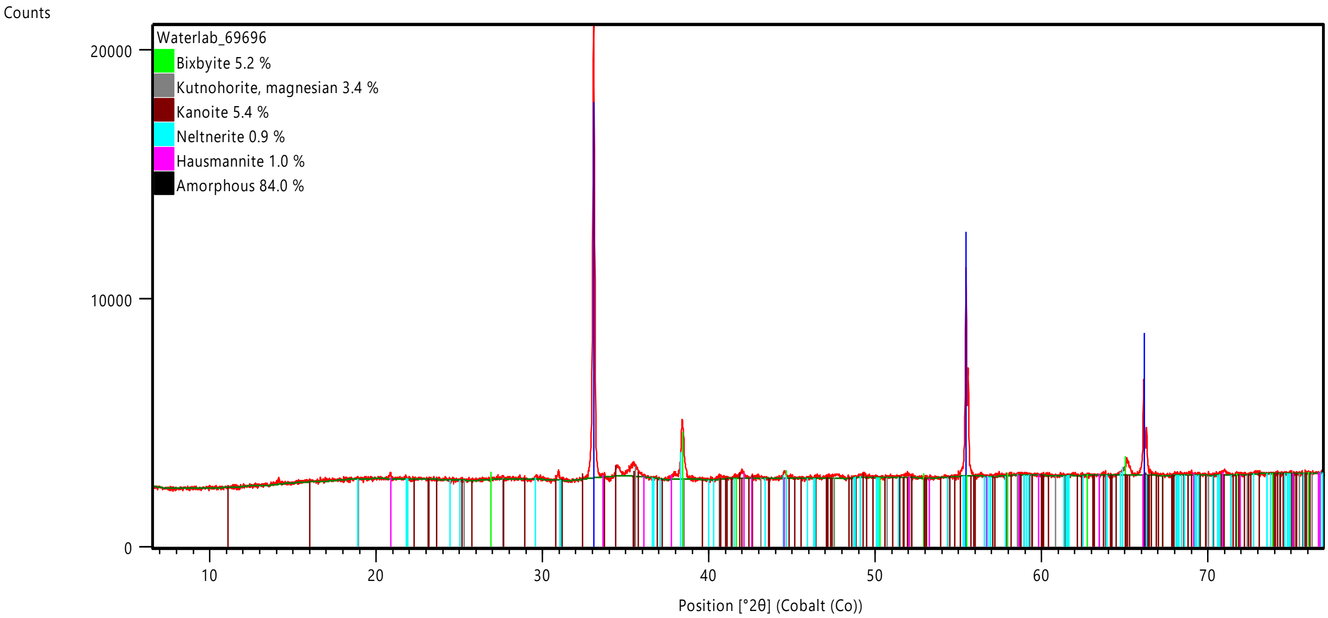
CERTIFICATE OF ANALYSES
X-RAY DIFFRACTION

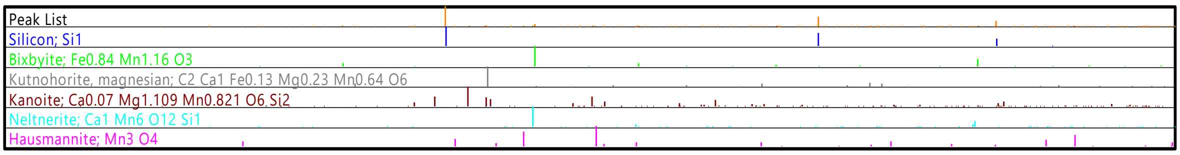
Date received: 2019-07-22
Project number: 1000
Report number: 84895
Date completed: 2019-08-12
Order number:

Client name: EScience Associates (Pty) Ltd
Address: PO Box 2950, Saxonwold, 2132
Telephone: 011 718 6380
Facsimile: 086 610 6703
Contact person: Zayd Ebrahim
Email: zayd@escience.co.za
Cell: -----

Composition (%) [o]	
ASGN TSF Dry	
69696	
Mineral	Amount (weight %)
Bixbyite	5.2
Kutnohorite	3.4
Kanoite	5.4
Neltnerite	0.9
Hausmannite	1
Amorphous fraction	84

[o] = Outsourced





S. Laubscher______________________
Assistant Geochemistry Project manager

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CERTIFICATE OF ANALYSES
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Contact person: Zayd Ebrahim
Email: zayd@escience.co.za
Cell: -----

Note:

The material was scanned after addition of 20 % Si for quantitative determination of amorphous content and micronizing in a McCrone micronizing mill. The material was prepared for XRD analysis using a back loading preparation method.
It was analysed with a Malvern Panalytical Aeris diffractometer with PIXcel detector and fixed slits with Fe filtered Co-Kα radiation. The phases were identified using X'Pert Highscore plus software.
The relative phase amounts (weight %) were estimated using the Rietveld method.

Comment:

- In case the results do not correspond to results of other analytical techniques, please let me know for further fine tuning of XRD results.
- Mineral names may not reflect the actual compositions of minerals identified, but rather the mineral group.
- Due to preferred orientation and crystallite size effects, results may not be as accurate as shown.
- Traces of additional phases may be present.
- Determination of amorphous content can carry an error of +- 15 weight per cent.

Ideal Mineral compositions:

Compound Name	Ideal Chemical Formula
Bixbyite	Mn_2O_3
Kutnohorite	$Ca Mn (C O_3)_2$
Kanoite	$Mn Mg (Si_2 O_6)$
Neltnerite	$Ca Mn_6 Si O_{12}$
Hausmannite	Mn_3O_4

S. Laubscher__________________
Assistant Geochemistry Project manager

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CERTIFICATE OF ANALYSES
X-RAY FLUORESENCE

Date received: 2019-07-22
Project number: 1000
Report number: 84895
Date completed: 2019-08-12
Order number:

Client name: EScience Associates (Pty) Ltd
Address: PO Box 2950, Saxonwold, 2132
Telephone: 011 718 6380
Facsimile: 086 610 6703
Contact person: Zayd Ebrahim
Email: zayd@escience.co.za
Cell: -----

Major Elements		Major Element Concentration (wt %)[o]
		ASGN TSF Dry
		69696
Silica	SiO_2	9.28
Titanium	TiO_2	<0.01
Aluminium	Al_2O_3	0.12
Iron	Fe_2O_3	7.72
Manganese	MnO	49.23
Magnesium	MgO	3.43
Calcium	CaO	13.51
Sodium	Na_2O	0.16
Potassium	K_2O	0.03
Phosphorous	P_2O_5	0.07
Chromium	Cr_2O_3	0.02
Sulphur	SO_3	0.41
Loss on Ignition (1000 ^oC)	LOI	16.5
Total		100.48
Loss of Moisture (105 ^oC)	H_2O-	0.01

[o] = Outsourced

Notes: % g/g is equivalent to wt %; mg/kg is equivalent to ppm; n.d. = not determined; bold italicised font represents semi-quantitative data; * represents measurements reported in % g/g or wt%.

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Trace Element		Trace Element Concentration (ppm) [o]
		ASGN TSF Dry
		69696
Arsenic	As	<0.43
Barium	Ba	6 474
Bismuth	Bi	<0.68
Cadmium	Cd	<3.04
Cerium	Ce	<3.08
Chlorine	Cl	225
Cobalt	Co	<0.56
Caesium	Cs	0.51
Copper	Cu	43.2
Galium	Ga	<3.21
Germanium	Ge	<0.50
Hafnium	Hf	<0.38
Mercury	Hg	<1.00
Lanthanum	La	9.99
Lutetium	Lu	<0.61
Molybdenum	Mo	3.29
Niobium	Nb	7.3
Neodymium	Nd	55.3
Nickel	Ni	<5.14
Lead	Pb	67
Rubidium	Rb	<0.42
Antimony	Sb	36.1
Scandium	Sc	109
Selenium	Se	<0.36
Samarium	Sm	<1.62
Tin	Sn	<0.08
Strontium	Sr	202
Tantalum	Ta	8.01
Tellurium	Te	<0.16
Thorium	Th	<0.88
Thallium	Tl	28.9
Uranium	U	<0.74
Vanadium	V	89.3
Tungsten	W	5.78
Yttrium	Y	6.1
Ytterbium	Yb	<1.05
Zinc	Zn	5 128
Zirconium	Zr	7.75

[o] = Outsourced

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Client name: EScience Associates (Pty) Ltd **Contact person: Zayd Ebrahim**
Address: PO Box 2950, Saxonwold, 2132 **Email: zayd@escience.co.za**
Telephone: 011 718 6380 **Facsimile: 086 610 6703** **Cell: -----**

XRF: Major Element Analysis (Geological)

The samples were prepared by first drying the samples at 100$_o$C for ~3 hours in order to determine loss of moisture content (H_2O-), followed by ashing of the sample at 1000$_o$C until completely ashed, to determine the loss on ignition (LOI). XRF analyses were performed using a PANalytical Epsilon 3 XL ED-XRF spectrometer, equipped with a 50kV Ag-anode X-ray tube, 6 filters, a helium purge facility and a high resolution silicon drift detector, calibrated using a number of international and national certified reference materials (CRMs).

XRF: Trace Element Analysis (Geological)

XRF analyses were performed using a PANalytical Epsilon 3 XL ED-XRF spectrometer, equipped with a 50kV Ag-anode X-ray tube, 6 filters, a helium purge facility and a high resolution silicon drift detector, calibrated using international and national certified reference materials (CRMs).

S. Laubscher
Assistant Geochemistry Project Manager

APPENDIX II: NUMERICAL MODEL METHODOLOGY AND SETUP

In this paragraph the setup of the flow model will be discussed in terms of the conceptual model as envisaged for the numerical model, elevation data used, boundaries of the numerical model and assumed initial conditions.

ELEVATION DATA

Elevation data is crucial for developing a credible numerical model, as the groundwater table in its natural state tend to follow topography.

The best currently available elevation data is derived from the STRM (Shuttle Radar Tomography Mission) DEM (Digital Elevation Model) data. The SRTM consisted of a specially modified radar system that flew on board the Space Shuttle Endeavour during an 11-day mission in February of 2000, during which elevation data was obtained on a near-global scale to generate the most complete high-resolution digital topographic database of Earth[2]. Data is available on a grid of 30 metres in the USA and 90 metres in all other areas.

Several studies have been conducted to establish the accuracy of the data, and found that the data is accurate within an absolute error of less than five metres and the random error between 2 and 4 metres for Southern Africa[3]. Over a small area as in this study, the relative error compared to neighbouring point is expected to be less than one metre. This is very good for the purpose of a numerical groundwater model, especially if compared to other uncertainties; and with the wealth of data this results in a much-improved model.

2 http://www2.jpl.nasa.gov/srtm/

3 Rodriguez, E., et al, 2005. An assessment of the SRTM topographic products. Technical Report JPL D-31639, Jet Propulsion Laboratory, Pasadena, California.

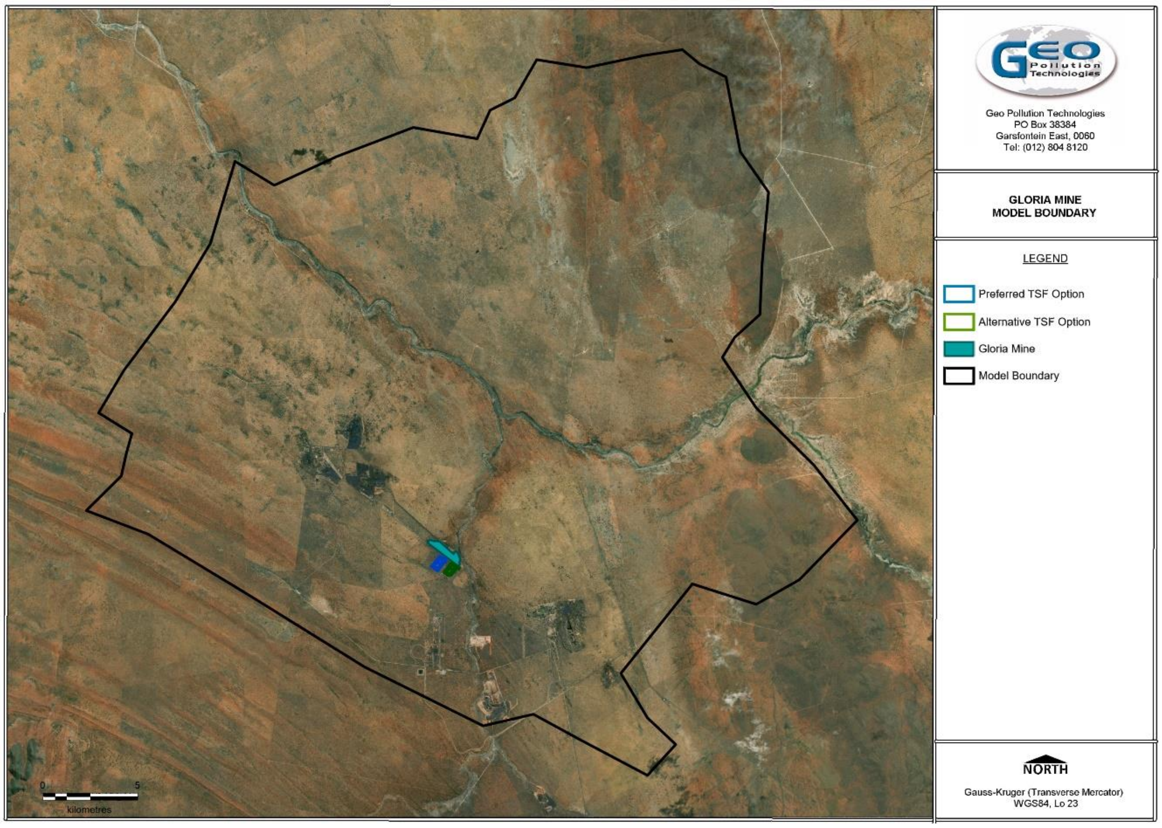

Figure 17: Model Boundaries

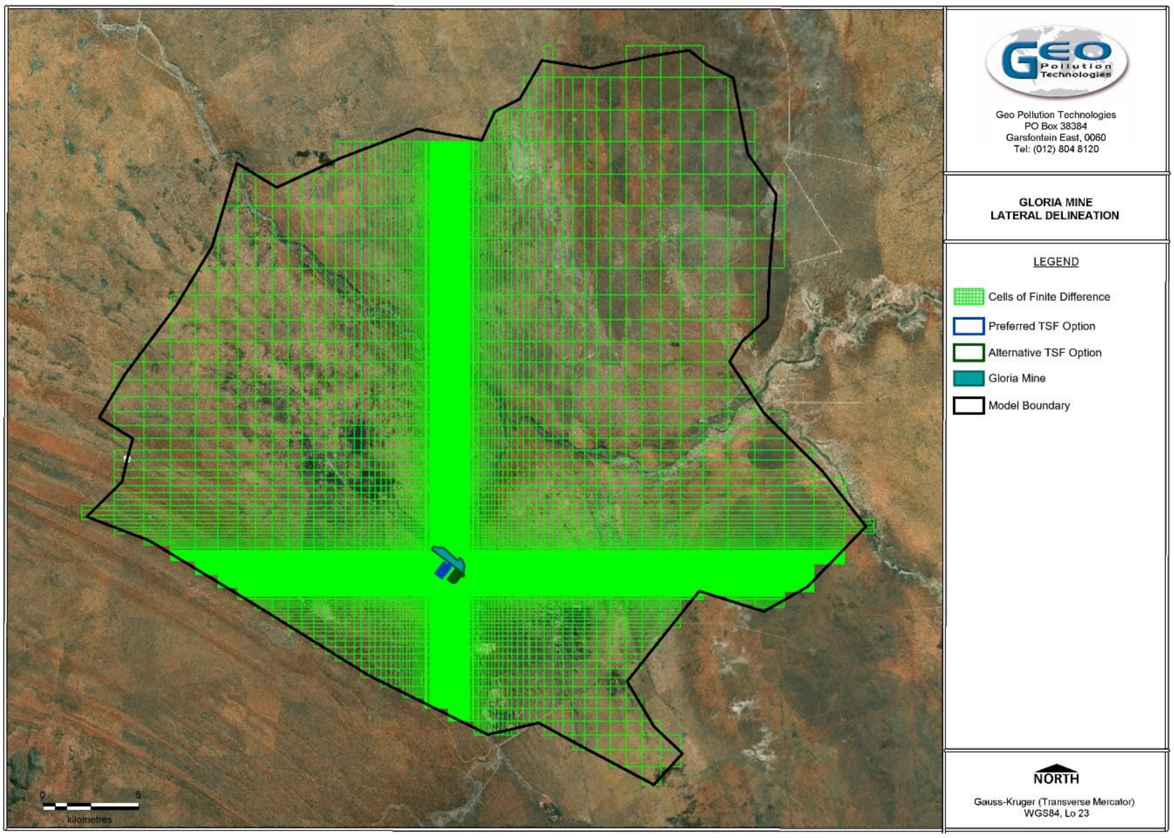

Figure 18: Lateral Delineation of the Regional Model

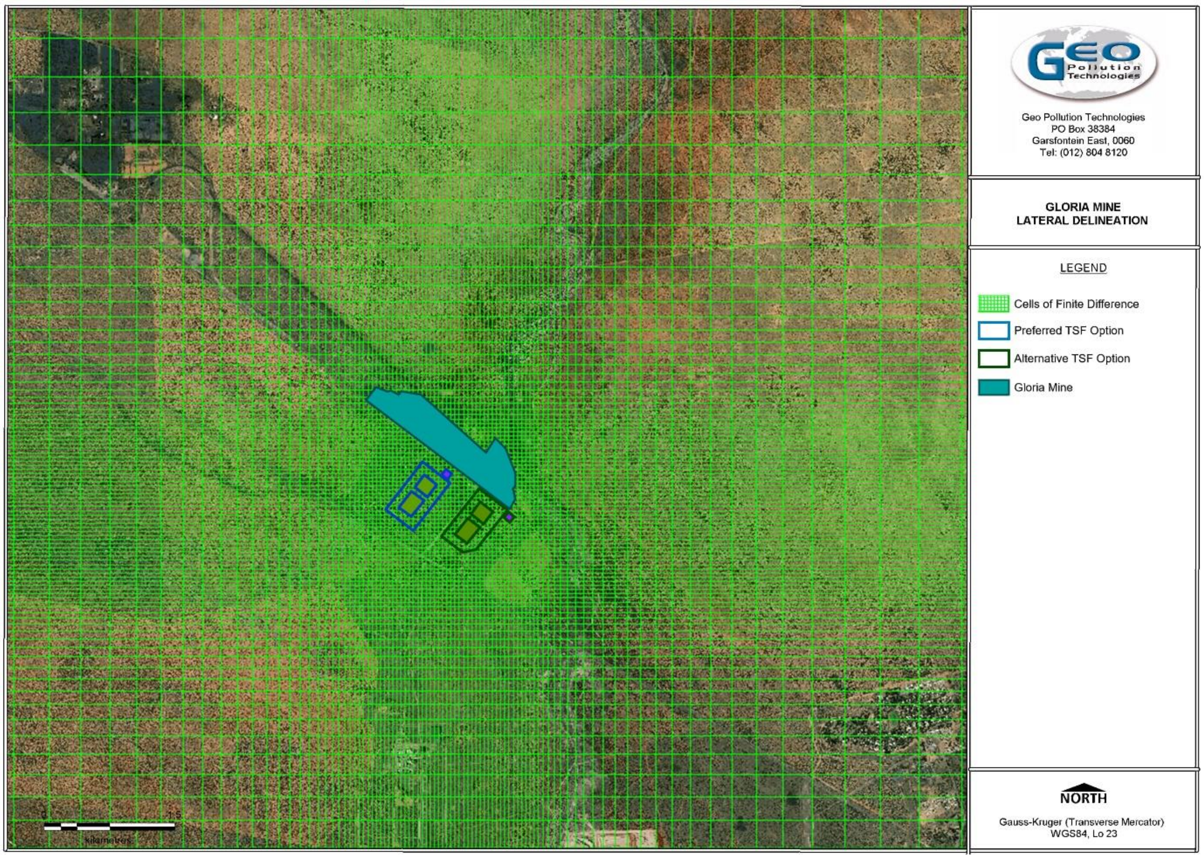

Figure 19: Lateral Delineation in the Mining Area

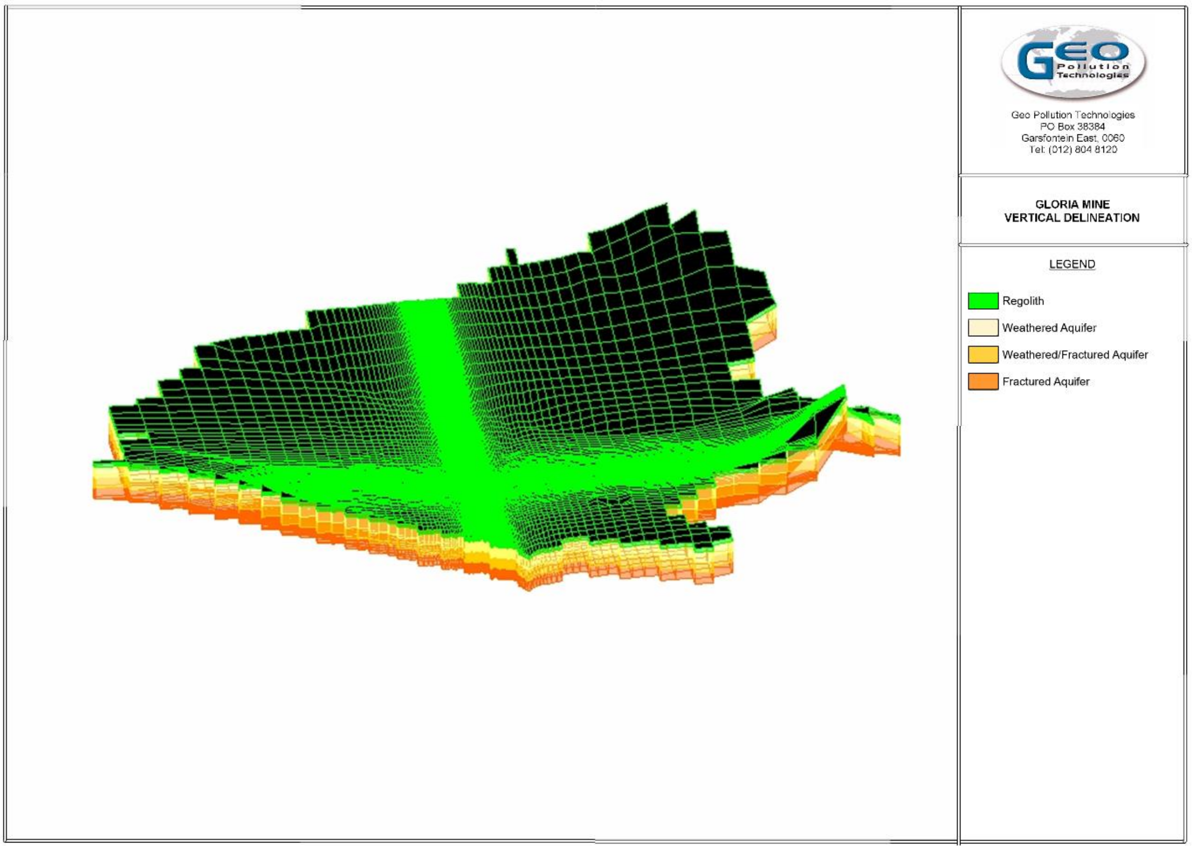

Figure 20: Vertical Delineation of the Modelled Area

APPENDIX III: CURRICULUM VITAE OF REPORT AUTHORS

Curriculum Vitae – V d Ahee Coetsee

PERSONAL DETAILS

Date of Birth	:	14 July 1959
Profession/Specialisation	:	Geophysicist/Geohydrologist
Nationality	:	South African
Languages	:	Afrikaans, English
Years Experience	:	35 years

AREA OF EXPERTISE

- mineral exploration
- groundwater exploration and resource evaluation
- groundwater management, monitoring and evaluation of pollution
- borehole siting and drilling supervision
- hydrocarbon pollution investigations
- environmental auditing

ACADEMIC QUALIFICATIONS

B.Sc. Geology and Physics	:	University of Stellenbosch	:	1982
B.Sc. (Hons.) Applied Geophysics	:	University of Pretoria	:	1983
M.Sc. (cum laude) Applied Geophysics	:	University of Pretoria	:	1987
B.Sc. (Hons.)(cum laude) Geohydrology	:	University of OFS	:	1988
Ph.D (Geohydrology)	:	University of OFS	:	1994

PROFESSIONAL MEMBERSHIP AND SOCIETY AFFILIATIONS

Registered with the SA Council for Natural Scientists as a Professional Natural Scientist

Associate Member of the Geological Society of South Africa (GSSA)

Member of the Institute of Waste Management (Southern Africa) (IWM)

Member of the South African Geophysical Association (SAGA)

Member of the Ground Water Division of the Geological Society of South Africa (GWDSSA)

Member of the Mine Water Division of the Water Institute of South Africa (WISA)

Member of the American Association of Ground Water Scientists and Engineers (AGWSE)

EMPLOYMENT RECORD

1980 - 1983	:	Anglo American Corporation bursary holder
1984 - 1993	:	EMATEK, CSIR, Pretoria
1994 - 2001	:	Director of Geo-Hydro Technologies
2001 - date	:	Director of Geo Pollution Technologies

PROFESSIONAL EXPERIENCE RECORD

- Resistivity and time domain sounding surveys in geohydrological projects
- Both shallow and deep resistivity and time domain electromagnetic sounding surveys for diamond and base metal exploration
- Research into the application of geophysical and geostatistical methods to study groundwater pollution
- Research into the combined use of direct current and time domain electromagnetic sounding methods
- Numerical modelling of aquifer systems
- Test-pumping analysis on aquifers
- Village and urban water supply
- Hydrogeological investigations into industrial ground- and surface water pollution
- Environmental impact studies of mining activities on ground- and surface water pollution
- Hydrogeological investigations at general waste landfills and the selection of waste disposal sites
- Borehole siting, drilling and pump testing supervision for groundwater projects
- Environmental auditing relating to soil, ground water and surface water quality and quantity management

PROJECTS

Project Leader
1984-1993
Council for Scientific Industrial Research

Project Description: -
Numerous groundwater and geophysical exploration projects, e.g. base metal and diamond exploration projects.
Numerous groundwater rural water supply projects
Position in Team: - Project Leader
Assigned Tasks: - Oversee and conduct geophysical exploration. Drilling supervision and borehole logging.

1994
Petrochemical Contamination Assessments
Client: - South African Oil Industry
Project Description:
Interpretation of the hydrocensus data to identify the extent of the contamination and to determine the associated human health risks.

Position in Team: - Project Leader
Assigned Tasks: - Conduct the physical field work. Geohydrological analysis of the data and liaise with the effected parties.

Geophysical Exploration for diamonds
1994
South Africa
Client: - De Beers
Project Description:
Conduct electromagnetic, direct current and magnetic surveys to map palaeo channels for alluvial diamond exploration project
Position in Team: - Project Leader
Assigned Tasks: - Geophysical exploration and interpretation of the data. Select borehole drilling positions for further geological exploration.

Rural Water Supply for numerous villages in Northern Kwa Zulu Natal
1994-1998
South Africa
Client: - Department of Water Affairs & Forestry (DWAF)
Project Description: -
Conduct an electromagnetic, direct current and magnetic surveys to map groundwater preferred flow paths in Kwazulu Natal. Select drilling targets and oversee the exploration of groundwater.
Position in Team: - Project Manager.
Assigned Tasks: - Project team coordination, geohydrological studies and liaise with the local community.

Groundwater Contamination Studies at South African Mines
1994-Ongoing
South Africa
Client: - Different South African Mining Companies
Project Description:
Develop groundwater monitoring networks at mines to quantify the lateral and vertical extent of the pollution. Interpret the chemical data and the design of remedial measures
Position in Team: - Specialist Technical Advisor
Assigned Tasks: - Oversee the geohydrological studies. Analysis and rehabilitation design of the system.

Waterval Catchment Study
1998
South Africa
Client: - Water Research Commission
Project Description:
Evaluate all the groundwater data within the Waterval catchment and recommend management practices.
Position in Team: - Project leader
Assigned Tasks: - Oversee the groundwater research.

Footprint Behaviour after Mine Dump Rehabilitation
1999-2000
South Africa
Client: - Water research Commission

Project Description:
Evaluate all residual pollution potential of the unsaturated zones beneath reclaimed mine dumps.
Position in Team: - Project leader
Assigned Tasks: - Oversee the groundwater research.

Assess the soil and groundwater contamination status of petroleum retail sites in Cameroon and Democratic Republic of Congo.
2006-2008
Cameroon and DRC
Client: - Shell International
Project Description:
Conduct numerous pollution assessment studies to quantify the impact of hydrocarbon pollution on the soil and groundwater. Conduct health risk assessments and make recommendations on remedial measures.
Position in Team: - Project Manager
Assigned Tasks: - Oversee the implementation of the project and client liaises.

Development of groundwater remediation schemes at some airports in South Africa.
2002-2009
South Africa
Client: - Airports Company of South Africa
Project Description:
Quantification of soil and groundwater pollution at the Airports. Design and instigate remedial actions
Position in Team: - Team Leader
Assigned Tasks: - Project team coordination, detailed geohydrological and geophysical studies.

Groundwater Impact Assessments
1990-current
South Africa
Client: - South Africa Mining Companies
Project Description:
Groundwater Impact Assessment as input to the Environmental Management Plans (EMP's) of Mines
Position in Team: - Team Leader
Assigned Tasks: - Formulation and compilation of a groundwater contamination assessment studies and the design of remedial measures.

Specialist Groundwater Environmental Auditor
2000-Date
South Africa and Mozambique
Client: - SABS, Sasol and other private South African Companies
Project Description:
Act as a groundwater specialist while auditing ISO14001 companies. Obtained formal training in ISO14001, environmental auditing and environmental law.
Position in Team: - Environmental auditing
Assigned Tasks: - Audit companies within the ISO 14001 framework.

PUBLICATIONS

Contract reports : More than 300

Conference proceedings	:	10
Technical publications	:	2

Curriculum Vitae – Marius Terblanche

PERSONAL DETAILS

Date of Birth	:	14 April 1984
Profession/Specialization	:	Hydrogeologist/Geologist
Nationality	:	RSA (South Africa)
Languages	:	English/Afrikaans (Fluent)
Years' Experience	:	11 years
Email	:	marius@gptglobal.com
Cell nr	:	0718607305

AREA OF EXPERTISE

Marius Has experience in hydrogeological investigations in diverse locations. He also has experience in exploration geology; groundwater exploration, geophysics (magnetic, electromagnetic and resistivity) drilling and pump testing supervision; hydrocensus experience; data analysis, numerical modelling and reporting.

He also worked on projects that encompass rural water supply programmes (RWSP), environmental impact assessments (EIAs), extensive hydro-censuses, as well as water use license applications (WULA), environmental management programmes (EMPs) and groundwater management programmes.

ACADEMIC QUALIFICATIONS

NDip Geology	:	Tshwane University of Technology 2008
BTech Geology	:	Tshwane University of Technology 2010
B.Sc. (Hons) Geohydrology	:	University of Free State, 2015

PROFESSIONAL MEMBERSHIP AND SOCIETY AFFILIATIONS

- South African Council for Natural Scientific Professions (SACNASP, Membership nr: 400296/12)
- Ground Water Division South Africa (GWDSA)

EMPLOYMENT RECORD

2009-2018: Hydrogeologist, Aurecon SA Pty Ltd

2018- Date: Scientist (Hydrogeology) Geo Pollution Technologies, South Africa

PROFESSIONAL EXPERIENCE RECORD

- Project Leader in inorganic groundwater related studies
- Analytical modelling
- Numerical modelling of aquifer systems using Modflow (GMS) and other related modelling software programs
- Test-pumping analysis on aquifers

- Hydrogeological investigations into mine ground- and surface water pollution
- Environmental impact studies of mining activities on ground- and surface water pollution
- Hydrogeological investigations on numerous different mining environments
- Borehole siting, construction, drilling and pump testing supervision
- Water quality and stable environmental isotope interpretations
- Site Investigations
- Contamination Assessments
- Groundwater Monitoring
- Groundwater Management
- Groundwater Risk Assessments

RECENT PROJECTS

- January 2019 to April 2019: Numerical modelling for several col mines in the Mpumalanga Province.
- June 2019 – December 2019: Prieska Copper Mine Tailings storage facility numerical modelling, Northern Cape.
- January 2019 – November 2019: Numerical Flow Modelling for the Eskom Medupi Power Station, Limpopo Province.
- October 2018 - January 2019: Sedibeng Iron Ore Mine Water Use License Application Assessment, Northern Cape.
- May 2018 – October 2018: Anglo American Mponeng Tailings Storage Facility Modelling, North West.
- 2017 – Present: Ground- and surface water monitoring at Eskom Medupi Powerstation, Limpopo Province.
- 2016 – 2018: Groundwater supply programme for the upgrade of the roads in the Ga-Seleka area near Lephalale, Limpopo Province
- 2015 – 2017: Groundwater Investigation for the optimisation of the Kupferberg landfill waste disposal facility near Windhoek
- 2015 – 2016: Borehole development as water supply for the Vingerkraal community
- 2014 – 2015: Feasibility and complete engineering (FEL 3 and 4) for the Overvaal tunnel
- 2014 – 2015: Groundwater investigation for the upgrading of the Mogalakwena wastewater treatment works (WWTW), in Mokopane, Limpopo
- 2009 – 2015: Groundwater investigation for the environmental management plan (EMP) for the ash dumps at Kriel Power Station
- 2014 – 2015: Geohydrological investigation for the Baviaanspoort wastewater treatment works (WWTW) in fulfilment of the water use licence application (WULA) of the WWTW
- 2013 – 2014: Environmental Impact Assessment for the construction of a second bridge across the River Niger, Delta State, Nigeria
- 2013 – 2014: Groundwater exploration programme for the Ngaka Modiri Molema District Municipality (NMMDM) as part of the Ottosdal water supply upgrade
- 2009 – 2013: Groundwater exploration for the Madibogo water supply upgrade project in Madibogo, North West

PUBLICATIONS

Contract reports	:	More than 100
Publications	:	1
Conference proceedings	:	2