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GROUNDWATER & PROJECT MANAGEMENT SOLUTIONS

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MOEIJELIJK CHROME MINE

GROUNDWATER UPDATE STUDY

For

Red Kite Consulting

Future Flow Document: RKC.19.061/Groundwater Study Update_Report
08 February 2020

MOEIJELIJK CHROME MINE

GROUNDWATER UPDATE STUDY

For

Red Kite Consulting

Report Issue	FINAL		
Reference Number	RKC.19.061		
Title	Moeijelijk Chrome Mine - Groundwater Update Study Report		
	Name	**Signature**	**Date**
Author	Martiens Prinsloo (M.Sc.; Pr.Sci.Nat)		08 February 2020
Reviewed			

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This report is confidential to the client and we accept no responsibility of whatsoever nature to third parties to whom this report, or any part thereof, is made known. Any such parties rely on the report at their own risk.

EXECUTIVE SUMMARY

Introduction and terms of reference

Future Flow GPMS cc was contracted by Red Kite Consulting to update the geohydrological study for Moeijelijk Chrome Mine.

Bauba A Hlabirwa Mining Investments (Pty) Ltd. (Bauba) holds an existing Mining Right (LP 10096 MR) over the farm Moeijelijk 412 KS. This groundwater study is performed in order to update the existing impact assessment for the Moeijelijk Chrome Mine. Existing authorised activities include:

- The extension of the existing opencast pit across three watercourses to access the remainder of the LG6;
- The development of a new opencast pit across three watercourses to access the LG2 chromitite;
- The development of a new opencast pit to access the UG1 and UG2 layers;
- The inclusion of the commodity Platinum Group Metals over the farm Moeijelijk 412 KS;
- The inclusion of a wash plant and associated residue drying and stockpiling facilities;
- The extension of the Run of Mine (ROM) stockpile area;
- The construction of a river crossing (culvert);
- The removal of underground LG7 proposed mining activities; and
- Inclusion of the farm Brakfontein 464 KS into the existing Mining Right for chrome.

Additional activities that are applied for include:

- Backfilling of the opencast void with silica tailings;
- Increased groundwater abstraction volume via dedicated groundwater supply boreholes.

A desktop review was undertaken on previous studies that were undertaken for the Moeijelijk project. This was followed by a geochemical assessment of the waste material in order to determine the acid-mine-drainage (AMD) forming potential and the potential pollution source concentrations.

Once the collected data was analysed and a conceptual groundwater flow and contaminant transport model developed, a 3D numerical groundwater flow and contaminant transport model was constructed. The model was calibrated based on the groundwater levels recorded on site during the monitoring program and then applied to simulate the expected impacts from the mining related activities which include, amongst others, mine dewatering and surface stockpiling of material.

General site description

The mine is located on the side of the northwest / southeast trending Tshailane ridge. Site specific topographical elevations ranges between 1 293 metres above mean sea level (mamsl) on the top of the ridge to the southwest of the mine, and 800 mamsl in the valley northeast of the mine.

The ridge topography dips steeply at a gradient of approximately 1:2 to 1:7 towards the northeast. In the valley northeast of the mine the topographical gradient in calculated to be in the order of 1:35.

Due to the steep topography there are numerous unnamed, non-perennial streams that drain the mine area. One of these streams, is named the Moshashaneng. The streams drain the valley in a northern direction and join the Olifants River 8 km north of the mine.

The study area falls within the B71B quaternary sub-catchment of the Olifants River, and the Olifants Water Management Area (WMA). The Tshailane Ridge southwest of the mine for the boundary with the B52J quaternary catchment.

Climatic data from the Tours Dam weather station show that the mine falls within a summer rainfall region. The average annual rainfall is 874 mm.

Geology of the study area

The mining areas fall within the Rustenburg Layered Suite of the Bushveld Igneous Complex. Two different subsuites can be distinguished viz. the Rustenburg Layered Suite Lower Zone and the Rustenburg Layered Suite Critical Zone. The Rustenburg Layered Suite dips slightly to the southwest, following the emplacement geometry of the Bushveld Complex.

The Rustenburg Layered Suite Critical Zone, which is the youngest lithology in the mining area, is composed of anorthosite and pyroxenite indicating a predominantly mafic composition for this area; The Rustenburg Layered Suite Critical Zone is underlain by the Rustenburg Layered Suite Lower Zone. This subsuite is composed of harzburgite and bronzitite. This indicates a less differentiated magma and a transition from mafic to ultramafic with depth.

The LG2 chromitite horizon outcrops to the northeast of the LG6 and therefore represents a significant strike length available for mining on the Moeijelijk farm. The UG1 and UG2 chromitite layers outcrop along the plateau above the Moeijelijk LG6 opencast mine in the southwestern corner of the property.

Geochemical characterisation

- Total concentration test results:
    - None of the parameters from the GPT study exceed the TCT0 guideline values;

  - Results from the total concentration testing that was done on the silica tailings material as part of the Future Flow study and interpreted by Mills Water show that the major oxide content of the silica tailings is dominated by silica, magnesium, chrome and iron, with lesser amounts of calcium and manganese;
  - Apart from fluoride, the reported trace element concentrations are below detection limits. Fluoride was detected at 80 mg/kg;
- Leach concentration test results:
  - From the GPT study it is seen that barium (34.32 mg/L measured vs LCT0 of 0.7 mg/L), cobalt (14.15 mg/L measured vs LCT0 of 0.5 mg/L) and manganese (1.00 mg/L measured vs LCT0 of 0.5 mg/L) concentrations exceed the LCT0 guideline values, while the boron concentration 49.39 mg/L exceed the LCT1 guideline value of 25 mg/L;
  - Results from the Future Flow study show that the measured trace element and anion concentrations for the silica tails are all below detection limits, which are below their respective LCT0s;
- As the TCs are less than the TCT0s, and the LCs are less than the LCT0s, the waste is assessed as a Type 4 waste (Mills, 06 February 2020). It should be noted that if the XRF chromium, vanadium and manganese values are used in place of the acid digest value, the waste would be classified as a Type 3 waste as the XRF values are between the TCT0 and the TCT1.
- The silica tails are classified as Type IV i.e. no risk of acid generation, because sulphide sulphur was not detected. The sulphur in the sample takes the form of sulphate, which can potentially be leached from the tailings by rainwater, resulting in sulphate occurring in leachate from the silica tails.

Baseline groundwater conditions

Aquifers present in the area

There are two aquifers present in the area. These are associated with a.) the weathered material, and b.) the underlying competent, but fractured, bedrock respectively.

The main source of recharge into the shallow aquifer is rainfall that infiltrates the aquifer through the unsaturated (vadose) zone. Vertical movement of water is faster than lateral movement in this system as water moves predominantly under the influence of gravity. This aquifer may contain coarse, anorthositic sediment or turf clay sediment when underlain by anorthosite or gabbro-norite respectively.

Groundwater movement is predominantly associated with secondary structures in this aquifer (fractures, faults, dykes, etc.). Borehole yields in the Bushveld Complex fractured aquifers are generally low and can be expected to be between 0.1 and 2 L/s. These formations contain limited quantities of water resources due to the poor storage capacity of the igneous rock.

Aquifer transmissivity

The hydraulic conductivity of the upper weathered material aquifer ranges between 10^{-8} and 10^{-2} m/day, while the porosity ranges between 0.4 and 0.7 for turf clay sediments. The hydraulic conductivity of the coarse, anorthositic sediment can reach up to 20 m/day with porosities ranging between values of 0.25 to 0.5.

The expected hydraulic conductivity for igneous rock types, similar to those present in the Bushveld Complex, are 10^{-5} m/d.

Groundwater levels

The depth to groundwater level ranges between 19 and 56 mbgl. In general there groundwater levels in the area remain relatively constant over time.

Groundwater flow directions are directed from the higher lying areas towards the low-lying streams.

Groundwater qualities

In general the groundwater quality is good, with some individual parameters in individual samples exceeding the SANS241:2015 guideline values. Elements that exceed the guideline values are:

- **Chloride:** The chloride concentrations at borehole BH4 (398 mg/L) and BH5 (393 mg/L) exceed the guideline value of 300 mg/L. At the measured concentrations no health impacts are expected. At concentrations between 200 and 600 mg/L the water has a distinctly salty taste. There is a likelihood of noticeable increase in corrosion rates in domestic appliances;
- **Nitrate:** The nitrate concentrations in boreholes BH4 (37 mg/L) and BH6 (13.6 mg/L) exceed the guideline value of 11 mg/L. At concentrations greater than 10 mg/L methaemoglobinaemia may occur in infants. With increasing concentration to above 20 mg/L mucous membrane irritation in adults can occur;
- **Manganese:** The manganese concentration in borehole BH8 measured 93.7 mg/L. This exceeds the SANS241:2015 guideline value of 0.4 mg/L by 2 orders of magnitude. It has to be stated that this value is anomalous as all other groundwater points measured below detection level. In addition, previous results at borehole BH8 from December 2018 and March 2019 showed manganese concentrations below detection limit of 0.025 mg/L. It is possible that this is a laboratory error;
- **Chromium:** At borehole BH4 the total chromium measured 0.16 mg/L, which exceeds the SANS241:2015 guideline value of 0.05 mg/L
- **Cadmium:** The cadmium concentration in borehole BH7 measured 0.02 mg/L. This exceeds the guideline value of 0.002 mg/L. As a precautionary measure it is recommended that concentrations of 0.005 mg/L not be exceeded due to the potentially acute and/or irreversible effects of cadmium on human health. A concentration of 0.02 mg/L is the threshold for health damage with continuous exposure. Single incidence of exposure will

not have an observable effect. At concentrations greater than 0.02 mg/L there is a danger of kidney failure with long-term exposure (longer than 1 week);

- **Lead:** The lead concentration in borehole BH8 measured 7.88 mg/L which exceeds the guideline value of 0.01 mg/L by 2 orders of magnitude. As was the case with manganese this value for borehole BH8 is anomalous as it does not compare to previous sampling runs at BH8 from December 2018 and March 2019 when the lead concentrations measured below detection limit. Results for all other boreholes included in the sampling program also show lead concentrations below detection limit at all times.

Aquifer vulnerability

For aquifer vulnerability reference is made to the aquifer vulnerability map of South Africa which shows a low aquifer vulnerability for the project area.

Aquifer classification

The aquifers present in the area are classified as minor aquifers. The aquifers are of high importance to the local landowners in as it is their only source of water for domestic, gardening, and agricultural purposes.

Impact assessment

Construction phase

Moeijelijk Mine is already operational; therefore, there is no construction phase.

Operational phase

Groundwater inflow volumes into the opencast mine

It is expected that the groundwater inflow volumes into the underground mine will increase during the initial 5 years of operations from around 40 m^3/day to approximately 170 m^3/day due to the increase in the mined out area and the associated increase in groundwater inflows. However, as the depth of mining below surface increases over time, and the aquifer potential decrease, it is expected that there will be little additional groundwater inflows into the underground mine as the mining progresses during the later years of the life of mine.

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028
Groundwater inflow volume (m^3/day)	40	70	100	130	170	170	170	170	170

Groundwater level drawdown and associated impacts on aquifers, wetlands and stream flow volumes

During the life of operations the groundwater flow directions in the vicinity of the underground mine area will be directed toward the mine area. This is due to mine dewatering causing the groundwater levels to be drawn down towards the mine floor elevations. In addition to this, there a groundwater level drawdown cone will develop around the dewatering boreholes.

The zone of influence of the groundwater level drawdown in the fractured rock aquifer can reach up to 450 m from the underground mine area. The cone of depression does not extend to the furthest southwestern point of the underground mine due to the depth of the mine in that area (up to 655 m below surface) and the inactivity of the aquifers at that depth.

Around the groundwater supply boreholes the zone of influence of the groundwater level drawdown can extend up to 575 m from the boreholes.

There are a number of boreholes that fall within the groundwater level drawdown cone. However, the majority of these boreholes belong to the mine. The only privately owned borehole that fall within the drawdown cone is BH1. The borehole has been built over and is not in use anymore.

The mine dewatering will not have a noticeable impact on the groundwater levels in the weathered material aquifer. This is due to a combination of:

- The depth of the mining below surface (between 50 and 655 m);
- The groundwater level in the region ranges between 19 and 56 mbgl. This indicates that the weathered material aquifer, which is in the order of 10 m thick, is dry in portions of the study area.

The non-perennial streams in the area receive flows from surface runoff during rainfall events, and also from baseflow contribution from the weathered material aquifer. Due to the regional depth to groundwater level of at least 16 m it is expected that the baseflow contribution to the stream flow volumes will be a minor portion of the stream flow volumes.

The mine dewatering will have no impact on the stream flow volumes.

Contaminant migration away from pollution sources

It is assumed that with proper maintenance of mining vehicles and other operations related best practices there will be a limited impact on the groundwater quality from general surface activities.

Geochemical modelling results show that the nitrate concentrations are high (501 mg/L) during the operational phase. Chromium is predicted by geochemical modelling to be present exclusively as Cr^{6+} at a concentration of 0.3 mg/L.

Plumes can migrate up to 200 m from the surface stockpile footprint areas. Borehole BH1 fall within the plume migrating away from the overburden stockpile. This borehole has been built over and is not in use anymore.

Due to the groundwater level drawdown cone developing around the groundwater dewatering boreholes contamination migrating away from the discard dump will be drawn towards groundwater supply boreholes UGBH1 and UGBH2. Similarly, contamination migrating away from the topsoil stockpile will be drawn towards boreholes WPBH1 and WPBH2.

The migrating plume will reach boreholes UGBH1 and UGBH2 during 2020, or at the latest before the end of 2021. The nitrate concentration at the boreholes will increase over time to a maximum of approximately 250 mg/L.

The contaminant plume migrating away from the topsoil footprint is expected to reach boreholes WPBH1 and WPBH2 during 2024. The nitrate concentrations are expected to reach a maximum of approximately 35 mg/L in WPBH1 and 50 mg/L in WPBH2. Please note that a source concentration of 501 mg/L nitrate was used for the topsoil stockpile. This is possibly an overestimation due to the leached nature of the material compared to the tailings material that was used to determine the source concentration.

A short section (320 m) of one of the non-perennial streams is impacted by the pollution plume migrating away from the overburden stockpile. A 250 m section of a stream is impacted by the pollution plume migrating away from the topsoil stockpile. The impact on the overall stream qualities during the rainy season when the streams flow is less than 1 % based on the total length of the streams draining the mine area.

Groundwater flow patterns around the rehabilitated opencast areas will be directed towards the opencast mine areas due to the fact that the opencast mine areas are interlinked with the underground mine area via the decline shaft. This connection will drain the rehabilitated opencast areas into the underground mine and prevent the water levels within the rehabilitated opencast areas from recovering to near pre-mining levels, thereby containing contamination within the rehabilitated opencast areas. Therefore, there will be no general contaminant plumes migrating away from the opencast areas.

Decommissioning phase

During the decommissioning phase the mine dewatering will stop. This will allow the groundwater level within the underground mine to start rising. However, due to the relatively short time period of the decommissioning phase (less than 1 year) it is not expected that the underground mine will become fully submerged, or that there will be significant contaminant migration away from the mine.

Long term post-operational phase

Recovery of groundwater levels and decant potential

The recovering water levels will allow the groundwater flow patterns in the area to recover to near pre-mining levels. The time required for the water level in the underground mine to recover to near pre-mining levels is calculated to be approximately 18 years.

Decant from the mining area will occur. The underground mine and the previous opencast mine areas are interconnected via the decline shaft. Therefore, once the underground mine and the rehabilitated opencast mine areas are submerged decant will start.

The expected decant volume is calculated to be between 10 and 50 m^3/day depending on the quality of the rehabilitation of the opencast areas. Proper rehabilitation with re-established vegetation and proper sloping of the surface that prevent ponding of rainwater will reduce recharge into the rehabilitated opencast areas which in turn will reduce the decant volume.

Decant qualities are expected to reflect the results from the geochemical assessment. Nitrate concentrations can be up to 139 mg/L. Hexavalent chromium concentration can be 0.3 mg/L.

Contaminant migration away from pollution sources

Contaminant migration will continue from the overburden and top soil stockpile footprint areas. In addition, contaminant migration away from the opencast and underground mine areas will start once a driving head is established by die rising water levels in the mining areas.

The contaminant plume in the weathered material aquifer will migrate up to 1 500 m from the opencast mine areas. The plume migrates downgradient in a northern direction underneath the village. Five village boreholes are impacted by the migrating plume: The details of the boreholes are summarised in Table 5.8.

- BH1: This borehole has been built over and is not in use anymore;
- BH2: This borehole is at a residence. The borehole is used for domestic purposes. The borehole is not included in the monitoring program anymore;
- BH7: The borehole is for communal use in Tsibeng village;
- BH8: The borehole is located at Matianyane Primary School; and
- BH9: The borehole is located at Morwaswi Secondary School.

There is very little contaminant migration through the fractured rock aquifer away from the underground mine. This is due to the low expected aquifer activity at the depths of the underground mine (up to 655 m below surface).

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1. Introduction

1.1. Background introduction

Future Flow GPMS cc was contracted by Red Kite Consulting to update the geohydrological study for Moeijelijk Chrome Mine.

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- The development of a new opencast pit to access the UG1 and UG2 layers;
- The inclusion of the commodity Platinum Group Metals over the farm Moeijelijk 412 KS;
- The inclusion of a wash plant and associated residue drying and stockpiling facilities;
- The extension of the Run of Mine (ROM) stockpile area;
- The construction of a river crossing (culvert);
- The removal of underground LG7 proposed mining activities; and
- Inclusion of the farm Brakfontein 464 KS into the existing Mining Right for chrome.

Additional activities that are applied for include:

- Backfilling of the opencast void with silica tailings;
- Increased groundwater abstraction volume via dedicated groundwater supply boreholes.

Historically groundwater was abstracted from 7 boreholes:

- 3 x boreholes at the wash plant;
- 2 x boreholes at the opencast areas; and
- 2 x boreholes at the underground area.

Currently, no abstraction takes place from the opencast area as mining there has stopped. Therefore, only the boreholes at the wash plant and the underground mine area are being used. Historic dewatering volumes are available for each of the areas as a whole.

Moeijelijk Chrome mine is currently licenced to abstract 58 100 m^3/a, however application is being made to abstract 249 869 m^3/a.

A desktop review was undertaken on previous studies that were undertaken for the Moeijelijk project. This was followed by a geochemical assessment of the waste material in order to determine the acid-mine-drainage (AMD) forming potential and the potential pollution source concentrations.

Once the collected data was analysed and a conceptual groundwater flow and contaminant transport model developed, a 3D numerical groundwater flow and contaminant transport model was constructed. The model was calibrated based on the groundwater levels recorded on site during the monitoring program and then applied to simulate the expected impacts from the mining related activities which include, amongst others, mine dewatering. Dewatering through the dedicated groundwater abstraction boreholes, backfilling of the opencast pits, mining of the underground mine and surface stockpiling of material.

The geochemical assessment and geochemical modelling was performed by Dr Meris Mills of Mills Water.

1.2. Aim of the investigation

The aim of the groundwater investigation is twofold:

The first phase of the study focuses on characterising the current baseline groundwater environment. This includes aspects such as:

- Identification and characterisation of the aquifers present in the area;
- Aspects that control groundwater flow through the area (e.g. geological structures);
- Groundwater flow patterns;
- Recharge from rainfall;
- Predevelopment groundwater quality; and
- Surface water / groundwater interaction.

The second phase of the study involves a characterisation and quantification of the expected impacts on the surrounding groundwater environment due to the proposed mining activities.

1.3. Timing of the investigation

The study made reference to data collected during both the wet and dry season as part of the monitoring program (groundwater levels and qualities). Reference was also made to aquifer testing that was done during the wet season.

It can be said that the data used represents both the wet and the dry seasons.

1.4. Potential impacts

The proposed developments could impact on the surrounding groundwater environment. Impacts include:

- Dewatering of the aquifers due to groundwater abstraction via dedicated groundwater supply boreholes;
- Dewatering of the underground mine and the associated impacts on the surrounding groundwater environment;

- Contaminant migration away from the mining area, including the backfilled opencast areas and the proposed underground mine;
- Impacts on surface water flow volumes due to mine dewatering and the possible reduction in baseflow contribution to the streams;
- Impacts on the surface water quality due to contaminant migration away from the mining area (underground mine area, backfilled opencast areas, as well as surface infrastructure); and
- Potential decant from the mining area.

1.5. Declaration of independence

We, Future Flow Groundwater & Project Management Solutions cc, act as the independent specialists in the environmental authorisation and EMP amendment processes for the Moeijelijk Chrome Mine Project. We performed the work relating to the environmental authorisation applications in an objective manner, even if this results in views and findings that are not favourable to the applicant.

We declare that there are no circumstances that may compromise our objectivity in performing such work. We have expertise in conducting the groundwater specialist study and report relevant to the environmental authorisation applications. We confirm that we have knowledge of the relevant environmental Acts, Regulations and Guidelines that have relevance to the proposed activity and my/our field of expertise and will comply with the requirements therein.

We have no, and will not engage in, conflicting interests in the undertaking of the activity.

We undertake to disclose to the applicant and the competent authority all material information in my possession that reasonably has, or may have, the potential of influencing any decision to be taken with respect to the application by the competent authority.

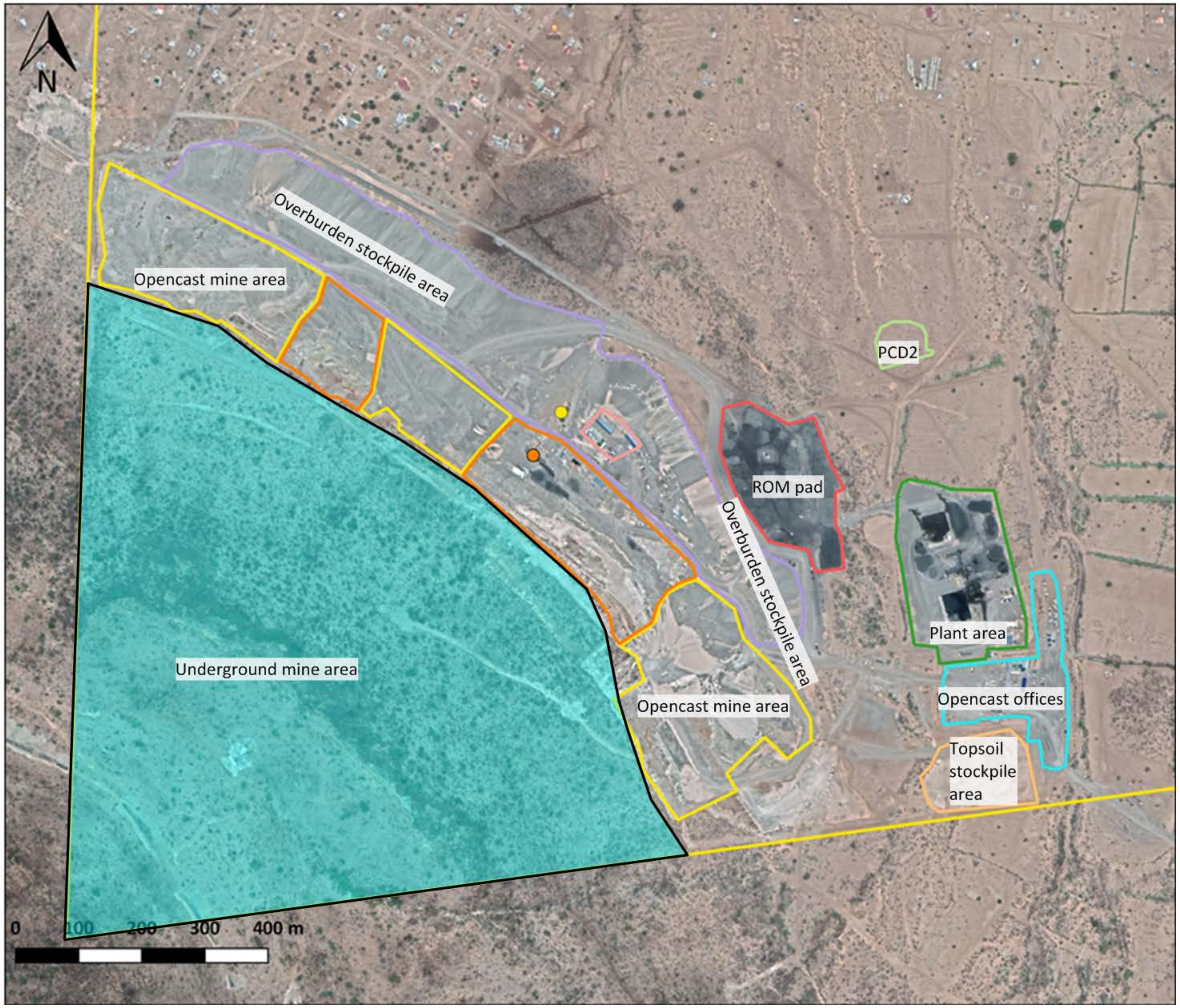
All particulars furnished by me/us in this report are true and correct. We realise that a false declaration is an offence in terms of regulation 48 of the National Environmental Management Act, 107 of 1998 (NEMA) and is punishable in terms of section 24F of the Act.

_________________________ ____2020/02/08____
Signed Date

1.6. Consultation process

The consultation process included:

- Discussion with the client: The client has a working relationship with the surrounding land owners.



N
W E
S

- ☐ Overburden stockpile
- ☐ PCD2
- ☐ Underground mine area
- ☐ Topsoil stockpile
- ☐ Plant area
- ☐ ROM pad
- ☐ Opencast (not backfilled)
- ☐ Opencast (backfilled)

Reference Maps
Mine Layout: As provided
Topographical: 2429 BB, 2429BD
2430 AA, 2430AC
Geological: 2428 - Nylstroom
Satelite Image: Google Earth
WGS 84, Traverse Mercator LO29

Client:
Red Kite Consulting

Project:
Moeijelijk Chrome Mine
Groundwater Impact Assessment

Figure Number: 1.1

Figure Name:
General site layout

Scale: As shown

Date: February 2020
Revision: 1

Designed: MP
Approved:

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2. Geographical setting

2.1. Topography and drainage

The mine is located on the side of the northwest / southeast trending Tshailane ridge. Site specific topographical elevations ranges between 1 293 metres above mean sea level (mamsl) on the top of the ridge to the southwest of the mine, and 800 mamsl in the valley northeast of the mine.

The ridge topography dips steeply at a gradient of approximately 1:2 to 1:7 towards the northeast. In the valley northeast of the mine the topographical gradient in calculated to be in the order of 1:35.

Due to the steep topography there are numerous unnamed, non-perennial streams that drain the mine area. One of these streams, is named the Moshashaneng. The streams drain the valley in a northern direction and join the Olifants River 8 km north of the mine.

The study area falls within the B71B quaternary sub-catchment of the Olifants River, and the Olifants Water Management Area (WMA). The Tshailane Ridge southwest of the mine for the boundary with the B52J quaternary catchment.

2.2. Climate

Climatic data from the Tours Dam weather station show that the mine falls within a summer rainfall region. The average annual rainfall is 874 mm.

3. Scope of work

- Phase 1: Waste classification sample analysis:
    - Analyse the samples for chemical constituents as recommended in Regulation 634, 635, and 636;
    - Acid-base-accounting analysis to determine the acid-mine-drainage forming potential of the material;
    - XRD analysis of the tailings material to determine the mineralogy of the material – this will feed into the geochemical modelling of the evolvement of water within the backfilled material;
    - Chemical analysis of the process water that is used as part of the wet deposition of the tailings material;
- Phase 2: Geochemical modelling:
    - A geochemical model will be constructed and the evolvement of water quality over time within the backfilled material will be modelled;
- Phase 3: Groundwater model update:
    - Construct numerical groundwater flow and contaminant transport models;
    - Update the impact simulations, including:

    - Impacts on underlying and surrounding groundwater flow patterns due to mine dewatering and surface storage facilities;
    - Impacts on surface stream flow volumes due to mine dewatering;
    - Impacts on underlying and surrounding groundwater qualities due to contamination from the mining area and surface storage facilities;
    - Decant potential and volumes;
- Phase 4: Reporting:
  - Analyse the chemical analysis results, classify the tailings material following Regulation 635;
  - Discuss the baseline groundwater environment;
  - Discuss the impact assessment:
    - Impacts on groundwater volumes in the area due to mine dewatering etc.;
    - Contaminant migration away from the backfilled pit and other contaminant sources and the associated impacts; and
  - Discuss mitigation measures.

4. Methodology

4.1. Desk study

Available hydrogeological reports, or sections of reports, were reviewed to gain a better understanding of the local geological and hydrogeological characteristics. The following reports were reviewed:

- GPT. Hydrogeological study for Moeijelijk Chrome Mine. GPT Reference number RKMOE-17-2723. December 2017.
- GPT. Hydrogeological assessment for water supply to Moeijelijk Chrome Mine. GPT reference number BHMOE-17-2873. January 2018.
- GPT. Hydrogeological study for Moeijelijk Chrome Mine. GPT Reference no RKMOE-18-3825.
- Jones & Wagener. Moeijelijk Chromitite Mine Hydrogeological audit. July 2019.
- Red Kite Environmental solutions. Various monitoring reports (November 2017, March, June, September, December 2018, March June 2019.
- Shango Solutions. Mine Work Programme Amendment. .

4.2. Groundwater recharge calculations

Groundwater recharge calculations are based on the total area of the sub-catchments covered by the proposed mining activities. Reference is made to the recharge values specified in the Groundwater Resource Assessment II – Task 3aE Recharge report (Department: Water Affairs and Forestry, 2006). An average recharge percentage of 3.87 % of the mean annual precipitation (MAP) is used in the resource calculation.

4.3. Groundwater modelling

The numerical flow model was constructed based on the conceptual groundwater flow model of the study area. The numerical model was constructed using MODFLOW based software, which is an internationally developed, recognised and used software package. The model takes into consideration aspects such as:

- The different aquifers present in the area and their interrelation to each other;
- Recharge from rainfall;
- Aquifer transmissivities, effective porosity, vertical hydraulic conductance etc.;
- Groundwater flow patterns and velocities;
- Geological lithological units and features;
- Topographical elevations of surface, the contact between weathered material and competent rock.

4.4. Groundwater availability assessment

The groundwater availability was assessed making use of:

- The geology encountered in the area, and the general groundwater potential associated with the lithologies;
- The results from the water supply study that was done (GPT, January 2018),

Results from the GPT water supply study show aquifer sustainable yields of 0.5 to 2.5 L/s.

5. Prevailing groundwater conditions

5.1. Geology

5.1.1. Regional geology

A description of the regional geology is taken from the GPT groundwater study update report (GPT, March 2019).

The mining areas fall within the Rustenburg Layered Suite of the Bushveld Igneous Complex (please refer to Figure 5.1). Two different sub-suites can be distinguished viz. the Rustenburg Layered Suite Lower Zone and the Rustenburg Layered Suite Critical Zone. The Rustenburg Layered Suite dips slightly to the southwest, following the emplacement geometry of the Bushveld Complex.

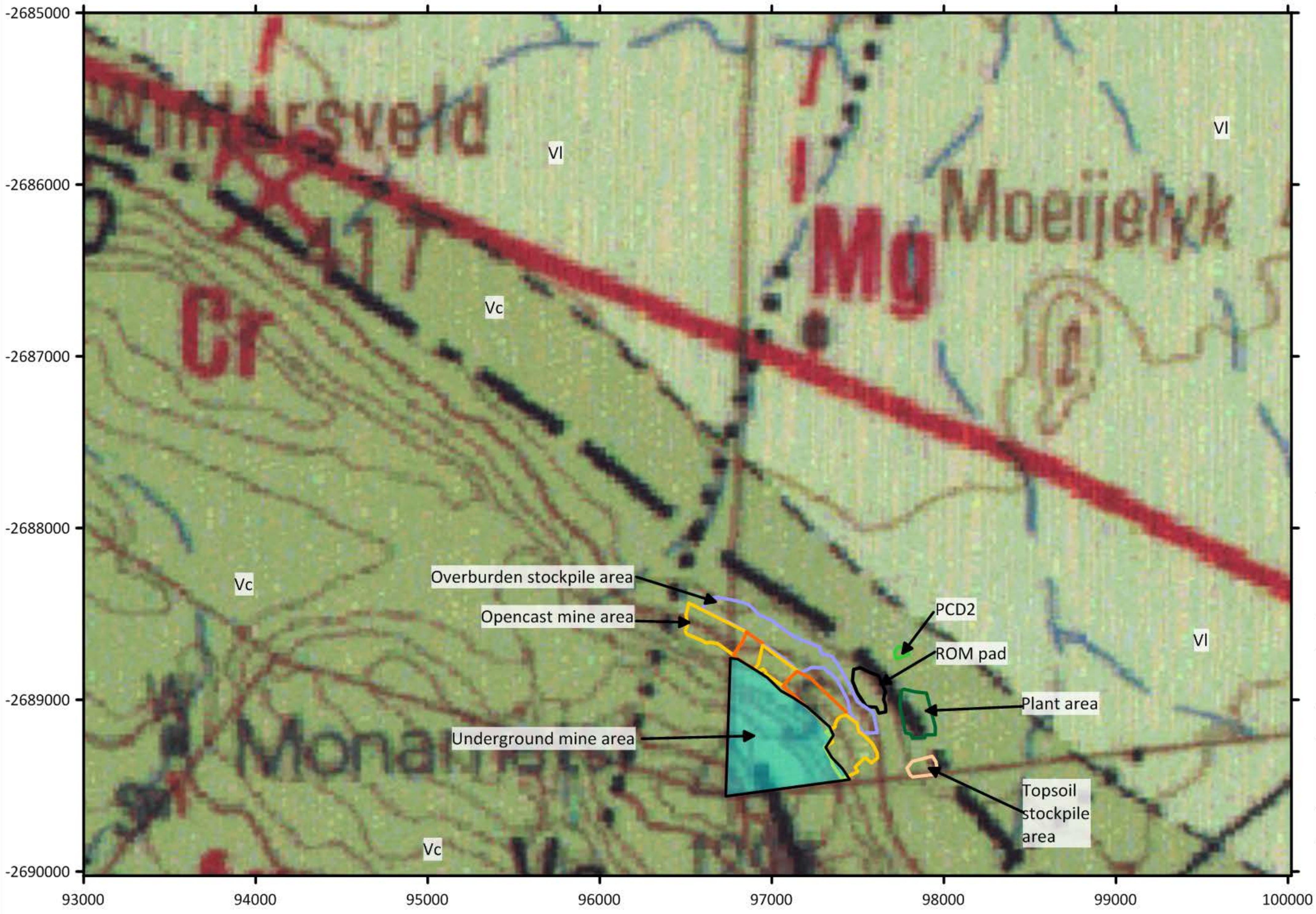
The Rustenburg Layered Suite Critical Zone, which is the youngest lithology in the mining area, is composed of anorthosite and pyroxenite indicating a predominantly mafic composition for this area.

The Rustenburg Layered Suite Critical Zone is underlain by the Rustenburg Layered Suite Lower Zone. This subsuite is composed of harzburgite and bronzitite. This indicates a less differentiated magma and a transition from mafic to ultramafic with depth.

5.1.2. Site specific geology

A description of the site specific geology is taken from the Mine works Program report (Shango Solutions).

The LG2 chromitite horizon outcrops to the northeast of the LG6 and therefore represents a significant strike length available for mining on the Moeijelijk farm. The UG1 and UG2 chromitite layers outcrop along the plateau above the Moeijelijk LG6 opencast mine in the southwestern corner of the property.



Geological legend

Vc = Pyroxenite, porhyritic pyroxenite, anorthosite, leuconorite, melanorite, chromitite layer

Vl = Melanorite, pyroxenite, serpentised harxburgite, chromitie layer

□	Overburden stockpile
□	PCD2
■	Underground mine area
□	Topsoil stockpile
□	Plant area
□	ROM pad
□	Opencast (not backfilled)
□	Opencast (backfilled)

Reference Maps

Mine Layout: As provided
Topographical: 2429 BB, 2429BD
2430 AA, 2430AC
Geological: 2428 - Nylstroom
Satelite Image: Google Earth
WGS 84, Traverse Mercator LO29

Client:
Red Kite Consulting

Project:
Moeijelijk Chrome Mine
Groundwater Impact Assessment

Figure Number: 5.1

Figure Name:
Regional geology of the study area

Scale: As shown

Date: February 2020
Revision: 1

Designed: MP
Approved:

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5.2. Geochemical characterisation

Geochemical characterisation was done on two occasions:

- The 2019 GPT hydrogeological study; and
- This current study. The assessment included:
    - Geochemical analysis of the silica tailings sample provided by the client (the sample represents the material that is proposed to be used to backfill the opencast pit areas);
    - Geochemical modelling to determine the short to medium term (up to the end of life of the underground mine) and long term post-closure pollution source concentrations.

During the GPT study overburden material was analysed. This current Future Flow study focused on the tailings material.

During the Future Flow study the interpretation of the geochemical results as well as the geochemical modelling was performed by Dr Meris Mills of Mills Water (Mills, 06 February 2020).

5.2.1.1. Total concentration testing

Total concentration analysis results are summarised in Table 5.1.

A number of the elements analysed during the GPT study show a concentration value of 0 mg/kg. The analysis certificate is not included in the report. It is assumed that the 0 values are assigned to elements that fall below detection limit.

None of the parameters from the GPT study exceed the TCT0 guideline values.

Results from the total concentration testing that was done on the silica tailings material as part of the Future Flow study and interpreted by Mills Water (Mills, 06 February 2020) show that the major oxide content of the silica tailings is dominated by silica, magnesium, chrome and iron, with lesser amounts of calcium and manganese (please refer to Figure 5.2).

Apart from fluoride, the reported trace element concentrations are below detection limits (Table 5.1). Fluoride was detected at 80 mg/kg. Two things to note are (Mills, 06 February 2020):

- Chromite does not readily dissolve in the acid solution used to determine total trace elemental concentrations. Therefore trace elements associated with chromite would not be detected by this method. This effect can clearly be seen because the XRF-measured Cr is 14.879 wt%, equating to 148 790 mg/kg, and XRD reports 13 wt% chromite, equating to 78 022 mg/kg Cr, yet, <962 mg/kg is reported in the total trace element concentrations. Assuming the chromite in the silica tailings is stable and does not weather on backfilling, this is not a concern. However, low concentrations of total CrT and Cr6+ have been detected in process water, suggesting that chromite may be slightly soluble under the site conditions.

- The laboratory detection limits for some of the trace elements are high e.g. the detection limit for manganese is 962 mg/kg.

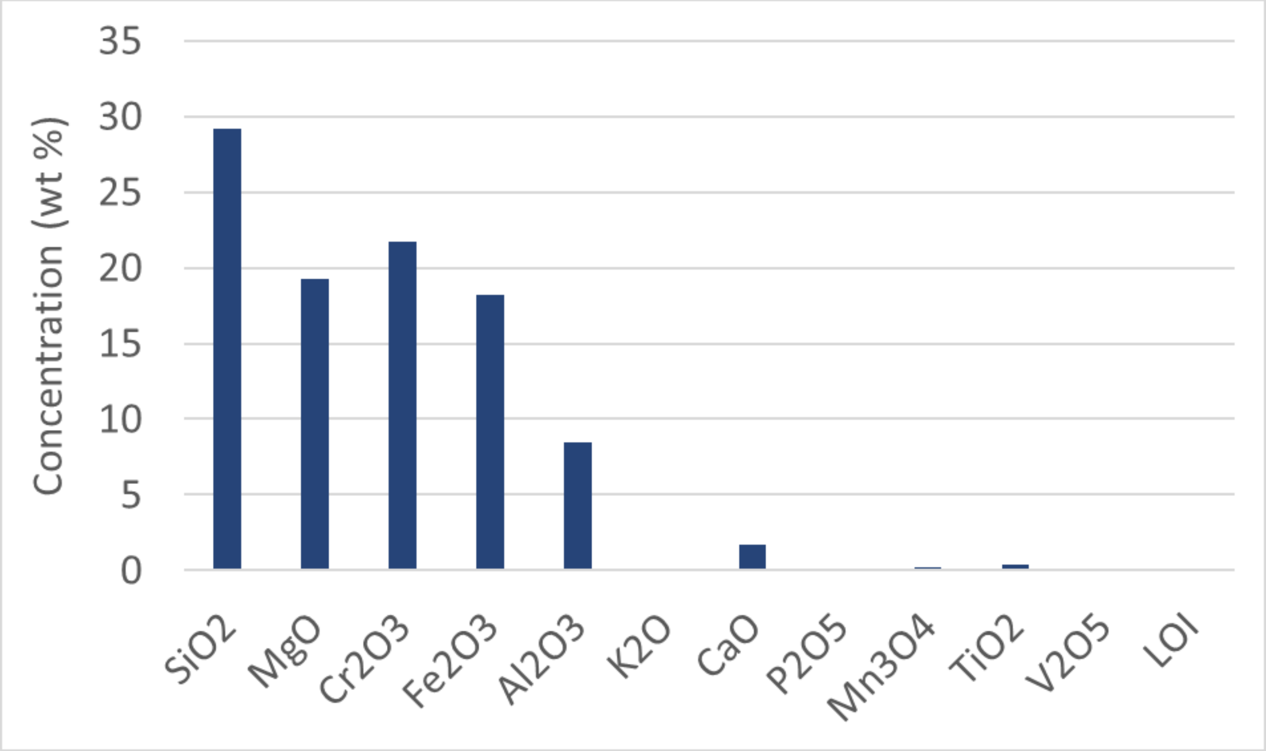


Figure 5.2: Major elemental content of the silica tails (after Mills, 2020)

5.2.1.2. Leach concentration testing

Leach testing results as summarised in Table 5.2. As with the total concentration results a number of the elements analysed during the GPT study show a concentration value of 0 mg/L. It is assumed that these values fall below the laboratory detection limits.

From the GPT study (GPT, March 2019) it is seen that barium (34.32 mg/L measured vs LCT0 of 0.7 mg/L), cobalt (14.15 mg/L measured vs LCT0 of 0.5 mg/L) and manganese (1.00 mg/L measured vs LCT0 of 0.5 mg/L) concentrations exceed the LCT0 guideline values, while the boron concentration 49.39 mg/L exceed the LCT1 guideline value of 25 mg/L.

Results from the Future Flow study, and as interpreted by Mills Water (Mills, 06 February 2020) show that the measured trace element and anion concentrations for the silica tails are all below detection limits, which are below their respective LCT0s. It should be noted that for many elements the detection limits are unusually high e.g. sulphate detection limit is 50 mg/L, therefore no detection does not mean that there is no sulphate present.

5.2.1.3. Waste classification

The waste classification as defined in Section 7 of GN 635 are summarised as:

- Wastes with any element or chemical substance concentration above LCT3 or TCT2 limits (LC>LCT3 or TC>TCT2) are Type 0 Wastes;
- Wastes with any element or chemical substance concentration above the LCT2 but below or equal to the LCT3 limits, or above the TCT1 but below or equal to the TCT2 limits (LCT2<LC<LCT3 or TCT1<TC<TCT2), are Type 1 Wastes;
- Wastes with any element or chemical substance concentration above the LCT1 but below or equal to the LCT2 limits, and all concentrations below or equal to the TCT1 limits (LCT1<LC<LCT2 or TC<TCT1), are Type 2 Wastes;
- Wastes with any element or chemical substance concentration above the LCT0 but below or equal to the LCT1 limits, and all concentrations below or equal to the TCT1 limits (LCT0<LC<LCT1 or TC<TCT1), are Type 3 Wastes; or
- Wastes with all elements and chemical substance concentration levels for metal ions and inorganic anions below or equal to the LCT0 and TCT0 limits (LC≤LCT0 and TC≤TCT0), and with all chemical substance concentration levels also below the relevant concentration limits for organics and pesticides, are Type 4 Wastes (no organics or pesticides are included in the waste rock material and therefore that requirement is not applicable);
- If a particular chemical substance in a waste is not listed with corresponding LCT and TCT limits in the norms and standards, and the waste has been classified as hazardous in terms of regulation 4(2) of the Regulations based on the health or environmental hazard characteristics of the particular element or chemical substance, the waste is considered to be Type 1 Waste (not applicable to this study);
- If the TC of an element or chemical substance is above the TCT2 limit, and the concentration cannot be reduced to below TCT2 limit, but the LC for the particular element or chemical substance is below the LCT3 limit, the waste is considered Type 1 Waste;
- Wastes listed in item (2)(b) of Annexure 1 to the regulations are considered to be Type 1 Waste, unless assessed and determined otherwise in terms of the Norms and Standards;
- Wastes with all element or chemical substances leachable concentration levels for metal ions and inorganic anions below or equal to the LCT0 limits are considered to be Type 3 Waste, irrespective of the total concentration of elements or chemical substances in the waste provided that:
    - The concentration levels are below the relevant limits for organics and pesticides;
    - The inherent waste and chemical character of the waste is stable and will not change over time; and
    - The waste is disposed of to landfill without any other waste.

As the TCs are less than the TCT0s, and the LCs are less than the LCT0s, the waste is assessed as a Type 4 waste (Mills, 06 February 2020). It should be noted that if the XRF chromium, vanadium and manganese values are used in place of the acid digest value, the waste would be classified as a Type 3 waste as the XRF values are between the TCT0 and the TCT1.

Table 5.1: Total concentration test results

Constituent	Units	TCT Guidelines Values			Overburden (GPT study)	Silica Tailings (Future Flow study)
		TCT0	TCT1	TCT2		
Arsenic (As)	mg/kg	5.8	500	2 000	0	<5.58
Boron (B)	mg/kg	150	15 000	60 000	49.30	<144
Barium (Ba)	mg/kg	62.5	6 250	25 000	34.20	<60.1
Cadmium (Cd)	mg/kg	7.5	260	1 040	0	<7.21
Cobalt (Co)	mg/kg	50	5 000	20 000	14.15	<48.1
Total Chromium (Cr)	mg/kg	46 000	800 000	N/A	238.50	<962
Copper (Cu)	mg/kg	16	19 500	78 000	14.12	<15.4
Mercury (Hg)	mg/kg	0.93	160	640	0	<0.865
Manganese (Mn)	mg/kg	1 000	25 000	100 000	139.40	<962
Molybdenum (Mo)	mg/kg	40	1 000	4 000	0	<9.62
Nickel (Ni)	mg/kg	91	10 600	42 400	59.16	<48.1
Lead (Pb)	mg/kg	20	1 900	7 600	0	<19.2
Antimony(Sb)	mg/kg	10	75	300	7.59	<9.62
Selenium (Se)	mg/kg	10	50	200	0	<9.62
Vanadium (V)	mg/kg	150	2 680	10 720	4.93	<96.2
Zinc (Zn)	mg/kg	240	160 000	640 000	12.71	<212
Total Cyanide (CN)	mg/kg	14	10 500	42 000	0	<9.62
Fluoride (F)	mg/kg	100	10 000	40 000	-	80

🟩 Exceed TCT0

Table 5.2: Leachable concentration test results

Constituent	Units	LCT Guidelines Values				Overburden (GPT study)	Silica Tailings (Future Flow study)
		LCT0	LCT1	LCT2	LCT3		
Total dissolved solids (TDS)	mg/L	1 000	12 500	25 000	100 000	0	<100
Chloride (Cl)	mg/L	300	15 000	30 000	120 000	0	<50.0
Sulphate (SO_4)	mg/L	250	12 500	25 000	100 000	0	<50.0
Nitrate (NO_3)	mg/L	11	550	1 100	4 400	0	<10.0
Fluoride (F)	mg/L	1.5	75	150	600	0	<1.00
Total cyanide (CN)	mg/L	0.07	3.5	7	28	0	<0.05
Arsenic (As)	mg/L	0.01	0.5	1	4	0.01	<0.01
Boron (B)	mg/L	0.5	25	50	200	49.39	<0.500
Barium (Ba)	mg/L	0.7	35	70	280	34.32	<0.700
Cadmium (Cd)	mg/L	0.003	0.15	0.3	1.2	0	<0.003
Cobalt (Co)	mg/L	0.5	25	50	200	14.15	<0.400
Total Chromium (Cr)	mg/L	0.1	5	10	40	0	<0.100
Hexavalent Chromium (Cr^{6+})	mg/L	0.05	2.5	5	20	0	<0.020
Copper (Cu)	mg/L	2.0	100	200	800	0	<1.00
Mercury (Hg)	mg/L	0.006	0.3	0.6	2.4	0	<0.006
Manganese (Mn)	mg/L	0.5	25	50	200	1.00	<0.500
Molybdenum (Mo)	mg/L	0.07	3.5	7	28	0.02	<0.070
Nickel (Ni)	mg/L	0.07	3.5	7	28	0.04	<0.070
Lead (Pb)	mg/L	0.01	0.5	1	4	0	<0.010
Antimony (Sb)	mg//L	0.02	1.0	2	8	0	<0.020
Selenium (Se)	mg/L	0.01	0.5	1	4	0	<0.010
Vanadium (V)	mg/L	0.2	10	20	80	0	<0.200
Zinc (Zn)	mg/L	5.0	250	500	2 000	0.02	<2.00

🟩	Exceed LCT0 guideline value
🟧	Exceed LCT1 guideline value

5.2.2. Acid-base-accounting testing

ABA involves a combined measurement of sulphur contents (total sulphur, sulphuric acid, sulphur, and organic sulphur), neutralisation capacity (NP), paste pH and the calculation of acid potential (AP), net neutralisation potential (NNP) and NP/AP ratio (NPR).

Guidelines on ABA test analysis set by Robertson and Broughton (Broughton & Robertson, 1992) are summarised in Table 5.3 to Table 5.5 below. Table 5.3 summarises the criteria against which the acid forming potential is measured based on the neutralisation potential ratio (NPR). Table 5.4 summarises the deduced acid generating potential based on the net neutralising potential (NNP). Table 5.5 summarises the rock classification based on a combination of the potential for acid formation and the sulphur content.

Table 5.3: Neutralisation Potential Ratio (NPR) guidelines

NPR = NP/AP	Acid generating potential	Comments
<1:1	Likely	Likely AMD generating
1:1 to 2:1	Possible	Possibly AMD generating if NP is insufficiently reactive or is depleted at a faster rate than sulphides
2:1 to 4:1	Low	Not potentially AMD generating unless significant preferential exposure of sulphides along fracture planes, or extremely reactive
>4:1	Unlikely	No further AMD testing required unless materials are to be used as a source of alkalinity

Table 5.4: Net neutralising potential guideline

Net neutralising potential (NNP) NNP = NP-AP	Acid generating potential
< -20	Likely to be acid generating
>20	Not likely to be acid generating
Between -20 and 20	Uncertain range

Table 5.5: Rock classification guidelines

Sample ID	Total S%	Sulphide S%	Sulphate S%	Paste pH	AP from sulphide S (kg/t CaCO3)	NP (kg/t CaCO3)	NPR	NNP	Type	Comment
Screening criteria	>0.3	>0.3		<5			<1	<-20	Type I: High	
	0.2 - 0.3	0.2 - 0.3		<7			1 - 2	-20 - 0	Type II: Possible/uncertain	
	0.01 - 0.2	0.01 - 0.2		>7			2 - 4	0 - 20	Type III: Low/uncertain	
	<0.1	<0.1		>7			>4	>20	Type IV: No risk	
Silica tails	0.013	bdl	0.013	8.6	bdl	12.4	39.7	12.4	IV	No sulphide S, no AP

The silica tails are classified as Type IV i.e. no risk of acid generation, because sulphide sulphur was not detected (Table 5.5). The sulphur in the sample takes the form of sulphate, which can potentially be leached from the tailings by rainwater, resulting in sulphate occurring in leachate from the silica tails.

5.3. Aquifer description

An aquifer description is taken from the 2019 GPT hydrogeological study (GPT, March 2019).

There are two aquifers present in the study area as discussed below.

5.3.1. Upper weathered material aquifer

The main source of recharge into the shallow aquifer is rainfall that infiltrates the aquifer through the unsaturated (vadose) zone. Vertical movement of water is faster than lateral movement in this system as water moves predominantly under the influence of gravity. This aquifer may contain coarse, anorthositic sediment or turf clay sediment when underlain by anorthosite or gabbro-norite respectively.

5.3.2. Fractured, bedrock aquifer

Groundwater movement is predominantly associated with secondary structures in this aquifer (fractures, faults, dykes, etc.). Borehole yields in the Bushveld Complex fractured aquifers are generally low and can be expected to be between 0.1 and 2 L/s with regional flow resembling flow in the porous medium (i.e. obeying Darcy's law). These formations contain limited quantities of water resources due to the poor storage capacity of the igneous rock. Groundwater quality in the area is also expected to be intermediate to poor with EC values ranging from 4.4 to 120 mS/m and possibly elevated Ca, Mg, Cl, and SO_4 as well as carbonate alkalinity concentrations.

Movement of groundwater in this aquifer will be preferential in secondary structures such as joints, faults and fractures.

5.4. Aquifer transmissivity

Aquifer transmissivity/ hydraulic conductivity values are obtained from the 2019 GPT hydrogeological study report (GPT, March 2019). No aquifer tests were done as part of the 2019 GPT hydrogeological study. Aquifer tests were done during the 2017 GPT water supply study (GPT, January 2018), but no aquifer transmissivity values are quoted in that report.

The hydraulic conductivity of the upper weathered material aquifer ranges between 10^{-8} and 10^{-2} m/day, while the porosity ranges between 0.4 and 0.7 for turf clay sediments. The hydraulic conductivity of the coarse, anorthositic sediment can reach up to 20 m/day with porosities ranging between values of 0.25 to 0.5.

Both the porosity and the hydraulic conductivity of the Bushveld Complex fractured bedrock aquifers are known to be low. The commonly expected values of porosity and permeability for igneous rock types, similar to those present in the Bushveld Complex, are 0.05 (porosity) and 10^{-5}

m/d (hydraulic conductivity) respectively (Kruseman & de Ridder, 1994) as quoted in (GPT, January 2018).

5.5. Groundwater levels

The depth to groundwater level is being monitored on a monthly basis. A total of 15 boreholes are included in the monitoring program. The results from the monitoring program are summarised in Table 5.6. The groundwater levels since September 2017 are shown in Figure 5.3.

From Table 5.6 and Figure 5.3 it can be seen that the depth to groundwater level ranges between 19 and 56 metres below ground level (mbgl). The figure also shows that in general there groundwater levels in the area remain relatively constant over time. Boreholes where there are changing groundwater level trends are:

- Borehole MonBH2 show a sudden decrease in groundwater level between February and March 2019. This borehole is an abstraction borehole, which could explain the anomalous depth to groundwater level;
- Borehole WPBH2 is used for top-up water to the wash plant. This water abstraction could explain the increase in depth to groundwater level from around 28 m to 35 to 40 m depth between February 2019 and March onwards;
- The groundwater level in borehole BH4 rose from around 55 m to 35 m. This borehole is used for domestic use in the village; and
- The depth to groundwater level in boreholes OCBH1 and OCBH2 changed from around 40 to 41 m, to 47 m since July 2019.

Plotting the groundwater level elevation against topography normally indicates areas where external influences such as large scale mine dewatering influences the groundwater levels. The plot can be viewed in Figure 5.4. Omitting the large scale abstraction boreholes which show anomalously deep groundwater levels in recent months (OCBH1 and UGBH2) a 71.71 % correlation is achieved between the surface elevations and the groundwater table elevations.

Bayesian interpolation is used to interpolate the groundwater levels throughout the study area and shown in Figure 5.5. Groundwater flow directions are directed from the higher lying areas towards the low-lying streams.

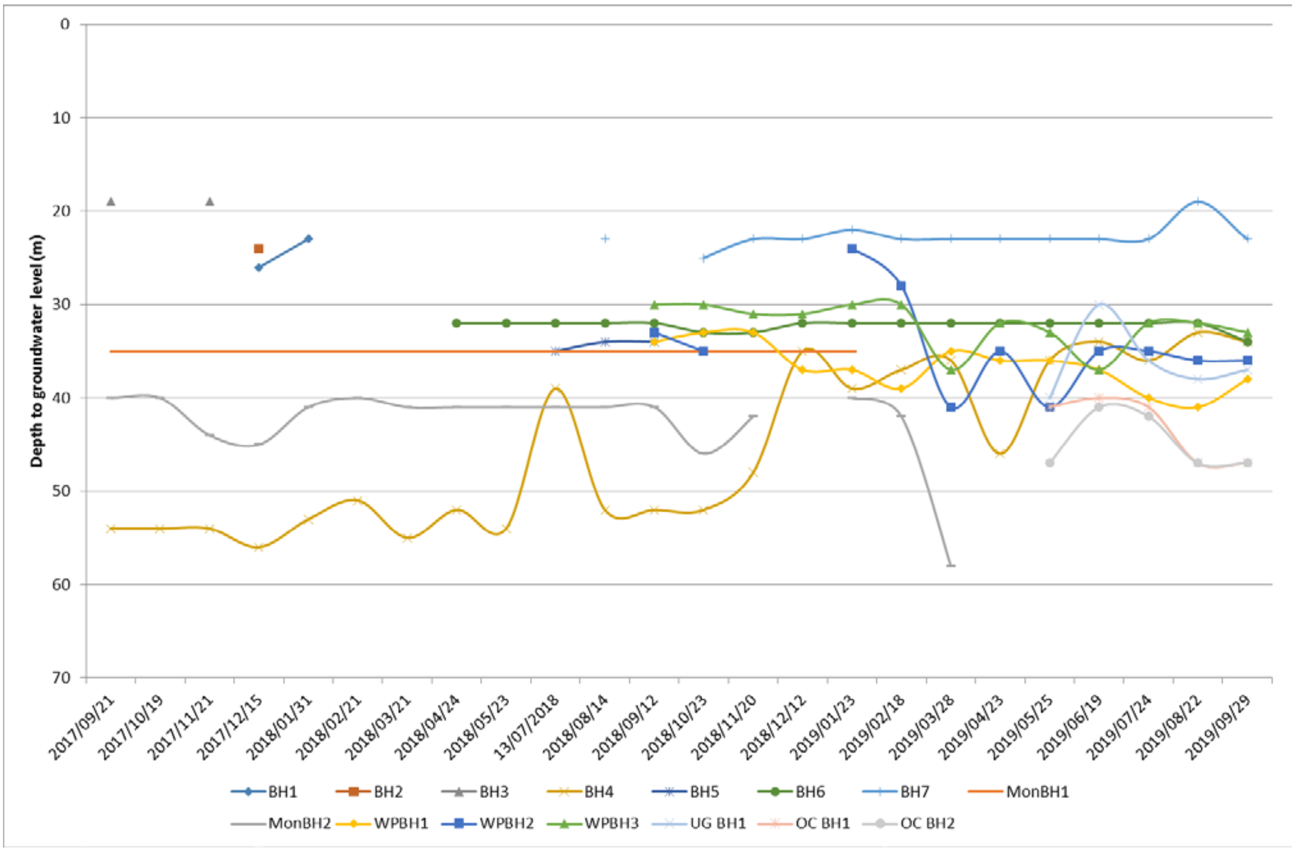


Figure 5.3: Depth to groundwater level trends

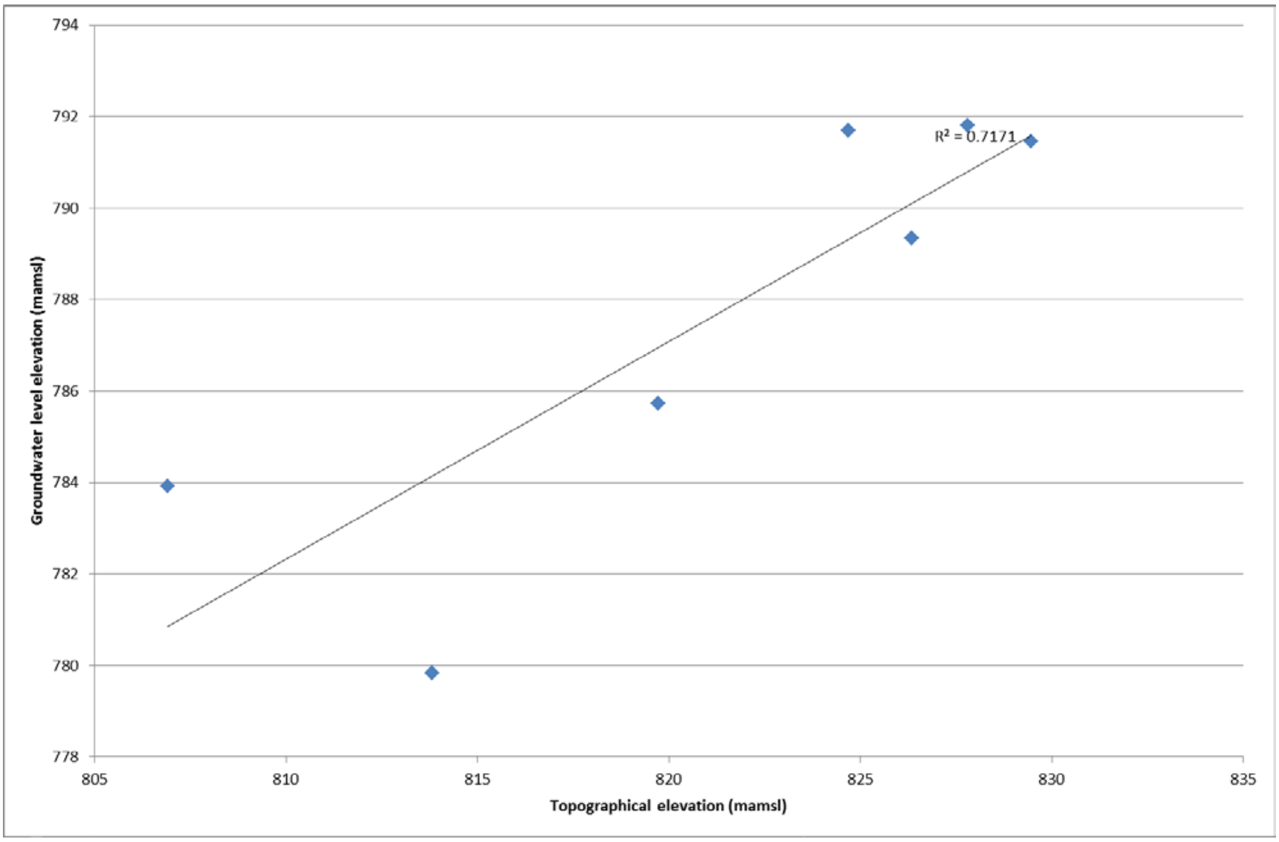
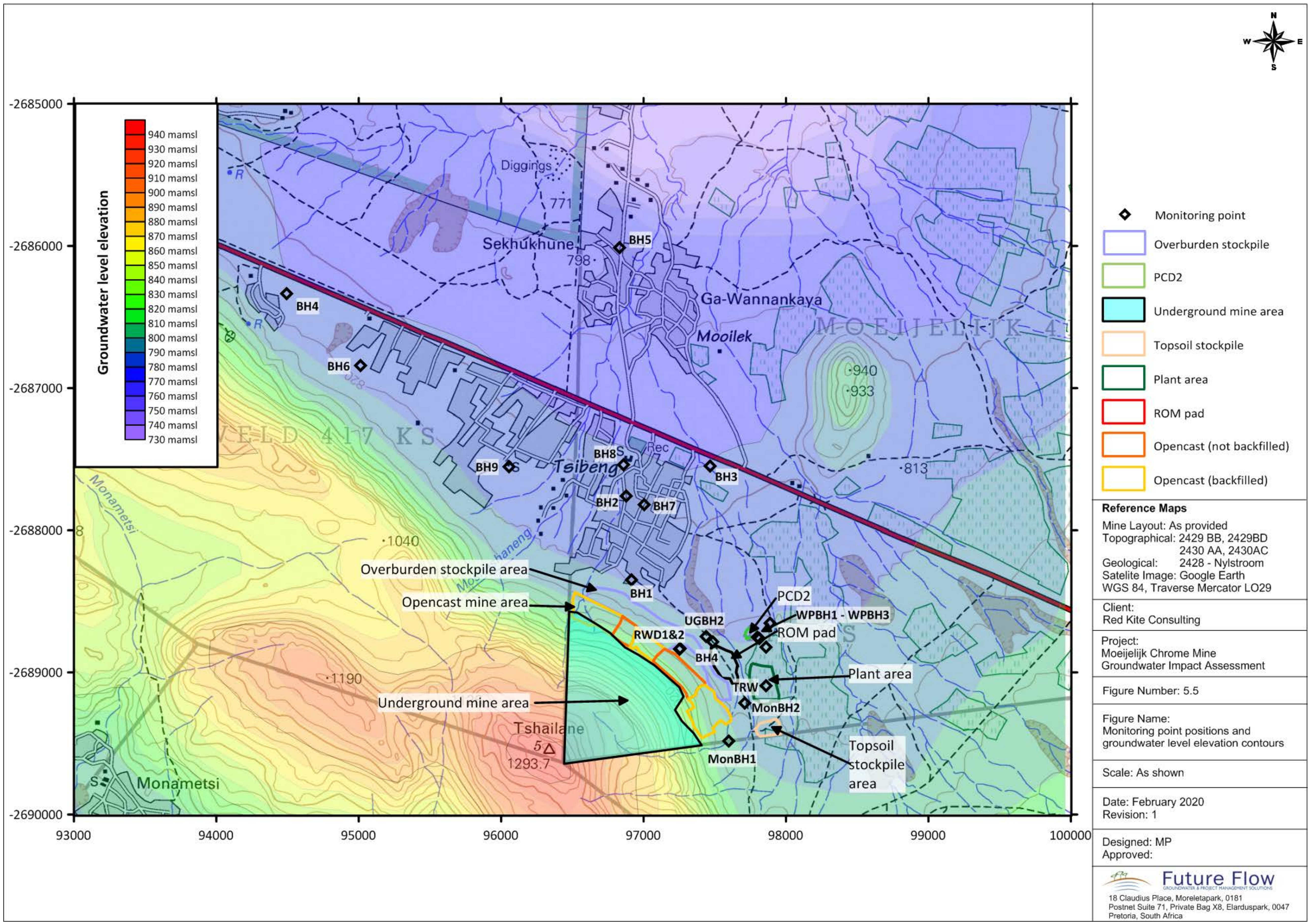


Figure 5.4: Topographical versus groundwater level elevations

Table 5.6: Hydrocensus results

Borehole	East	South	Elevation	SWL		Comment
	(WGS84, LO29)	(WGS84, LO29)	(mamsl	(mbgl)	(mamsl)	
BH1	96 915	-2 688 349	822.46			In community, at a residence. Downstream of mine. Domestic use.
BH2	96 880	-2 687 760	807.50			In community, at a residence. Downstream of mine. Domestic use.
BH3	97 469	-2 687 547	796.91			In community, at workshop. Downstream of mine. Domestic use.
BH4	94 493	-2 686 336	813.83	34	779.83	In community, at Mr. Moloto's residence. Downstream of mine. Domestic use.
BH5	96 830	-2 686 013	779.91			In community, north of the R37. Domestic use.
BH6	95 013	-2 686 842	819.72	34	785.72	Borehole for communal use in Tsibeng village.
BH7	97 005	-2 687 821	806.91	23	783.91	Borehole for communal use in Tsibeng village. Domestic use. Borehole well situated for groundwater pollution monitoring.
BH8	96 858	-2 687 537	801.29			
BH9	96 053	-2 687 554	815.17			
MonBH1	97 600	-2 689 481	856.98			Outside mining area. Upstream of mine.
MonBH2	97 709	-2 689 218	838.88			On mining site. Abstraction borehole.
WPBH1	97 860	-2 688 824	829.46	38	791.46	Borehole used for groundwater abstraction for top-up in wash plant. Downstream of mining area.
WPBH2	97 797	-2 688 754	827.80	36	791.80	Borehole used for groundwater abstraction for top-up in wash plant. Downstream of mining area.
WPBH3	97 889	-2 688 654	824.69	33	791.69	Borehole used for groundwater abstraction for top-up in wash plant. Downstream of mining area.
UG BH1	97 488	-2 688 783	826.35	37	789.35	Borehole used for groundwater abstraction for top-up in underground mining. Downstream of mining area.
OC BH1	97 812	-2 688 761		47	780.94	Borehole used for groundwater abstraction for dust suppression and potable water at the opencast section.
OC BH2						Borehole used for groundwater abstraction for dust suppression and potable water at the opencast section.

N/A = Not available
SWL = Static water level
mbgl = metres below ground level
mamsl = metres above mean sea level
All coordinates are provided in Transverse Mercator projection, LO29, and WGS84 datum



Reference Maps
Mine Layout: As provided
Topographical: 2429 BB, 2429BD
2430 AA, 2430AC
Geological: 2428 - Nylstroom
Satelite Image: Google Earth
WGS 84, Traverse Mercator LO29

Client:
Red Kite Consulting

Project:
Moeijelijk Chrome Mine
Groundwater Impact Assessment

Figure Number: 5.5

Figure Name:
Monitoring point positions and groundwater level elevation contours

Scale: As shown

Date: February 2020
Revision: 1

Designed: MP
Approved:

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5.6. Groundwater potential contaminants

The opencast and underground mine areas and surface stockpiles act as potential sources of contamination to the aquifers in the area. It is assumed that good housekeeping such as storage of potentially hazardous material will be within properly constructed and lined or paved areas. Oil traps will be sized, operated and maintained to contain all discarded oil from working areas.

To supplement the leach test results which indicated a large number of elements below detection limit, it was decided to also reference the site water quality data to estimate the potential for leaching from the tailings material (Mills, 06 February 2020). Process water that is used to transport the tailings will have interacted with the tailings and will have a chemistry related to the tailings. In addition, on drying of the tailings, salts precipitating from the entrained process water will contribute to the contaminants that can leach from the tailings once backfilled.

The average plant return water (TRW) quality is given in Table 5.7 (taken from (Mills, 06 February 2020). Mills further states that:

> “The average background groundwater quality (from upstream monitoring well MonBH1) is also given so that the difference in water quality due to the process and interactions with tailings can be identified. The ratio between the average process water and the average background groundwater is calculated to highlight those parameters which are highly enriched in the process water and could therefore pose a risk of contaminating groundwater. The parameters which have concentrations more than 10 times higher in the process water than in the background groundwater are Na, K, NH_3, NO_3^- and NO_2^-. Sulphate and chloride are around 5 times more concentrated and cadmium, chromium and Cr^{6+} are about twice as concentrated in the process water than the background groundwater. The values are also compared to SANS241:2015 drinking water limits in order to identify parameters that could pose a risk to users of groundwater for domestic purposes should they enter groundwater.
>
> Chromium was detected in process water and groundwater. The concentrations of total chromium in groundwater are generally below the SANS241 limit (with two exceptions), but it should be noted that most of the detected chromium occurs as Cr^{6+} (Figure 5.6 top). In contrast, chromium detected in the process water appears to occur mostly as Cr^{3+} (Figure 5.6 bottom). It is clear that chromium can be mobilised into groundwater as Cr^{6+}, and therefore it is considered to be a potential contaminant of concern.
>
> Based on analytical results, nitrogen occurs in process water and in groundwater predominantly as nitrate (Figure 5.7). Nitrite and ammonia concentrations are close to detection limits in the groundwater, and nitrite is close to detection in the process water, so they are not apparent on the graph.
>
> Given the potential health risks associated with nitrate and Cr^{6+} and their presence in both site process water and groundwater, they are considered to be potential contaminants of concern.”

Table 5.7: Average process and background groundwater concentrations compared to SANS241:2015 (after Mills, February 2020)

Analyte	**Units**	**Average plant return water (TRW) (n=3)**	**Average background groundwater (MonBH1) (n=7)**	**Ratio process water : background groundwater**	**SANS241:2015**
pH	-	7.9	7.5		5 – 9.7
Na	mg/L	177	16	***11***	200*
K	mg/L	9.7	1.0	***10***	-
Ca	mg/L	60	51	1.2	-
Mg	mg/L	43	62	0.7	-
NH_3	mg/L as N	***3.5***	0.2	***20***	1.5*
Cl	mg/L	103	24	4.3	300*
SO_4	mg/L	131	24	5.5	250*
NO_3	mg/L as N	***99***	2.8	***35***	11
NO_2	mg/L as N	0.9	0.1	***30***	0.9
Alkalinity (estimated)	mg/L as CaCO3	702	530	1.3	
Al	mg/L	***0.450***	0.549	0.8	0.300*
Ba	mg/L	0.025	0.015	1.7	0.700
B	mg/L	0.085	0.028	3.0	2.400
Cd	mg/L	***0.008***	<0.003	2.7	0.003
CrT	mg/L	***0.060***	0.029	2.0	0.050
Cr^{6+}	mg/L	0.019	<0.010	1.9	
Fe	mg/L	***0.330***	***0.416***	0.8	0.300*
Mn	mg/L	0.034	0.045	0.8	0.100*
Pb	mg/L	<0.01	<0.01	1.0	0.010
V	mg/L	<0.01	0.034	0.3	

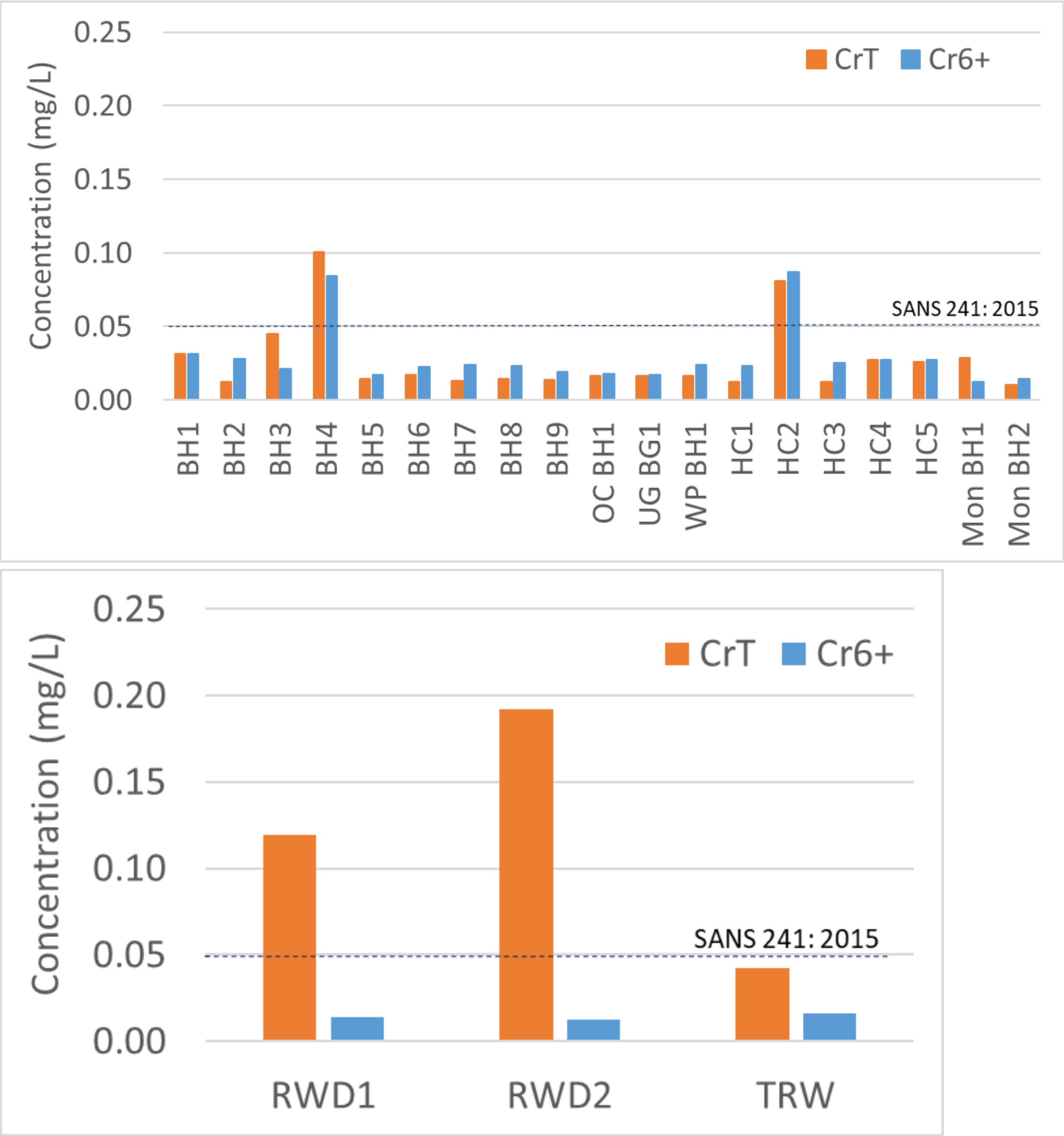


Figure 5.6: Concentrations of CrT and Cr6+ in groundwater (top) and process water (bottom) – taken from Mills, February 2020

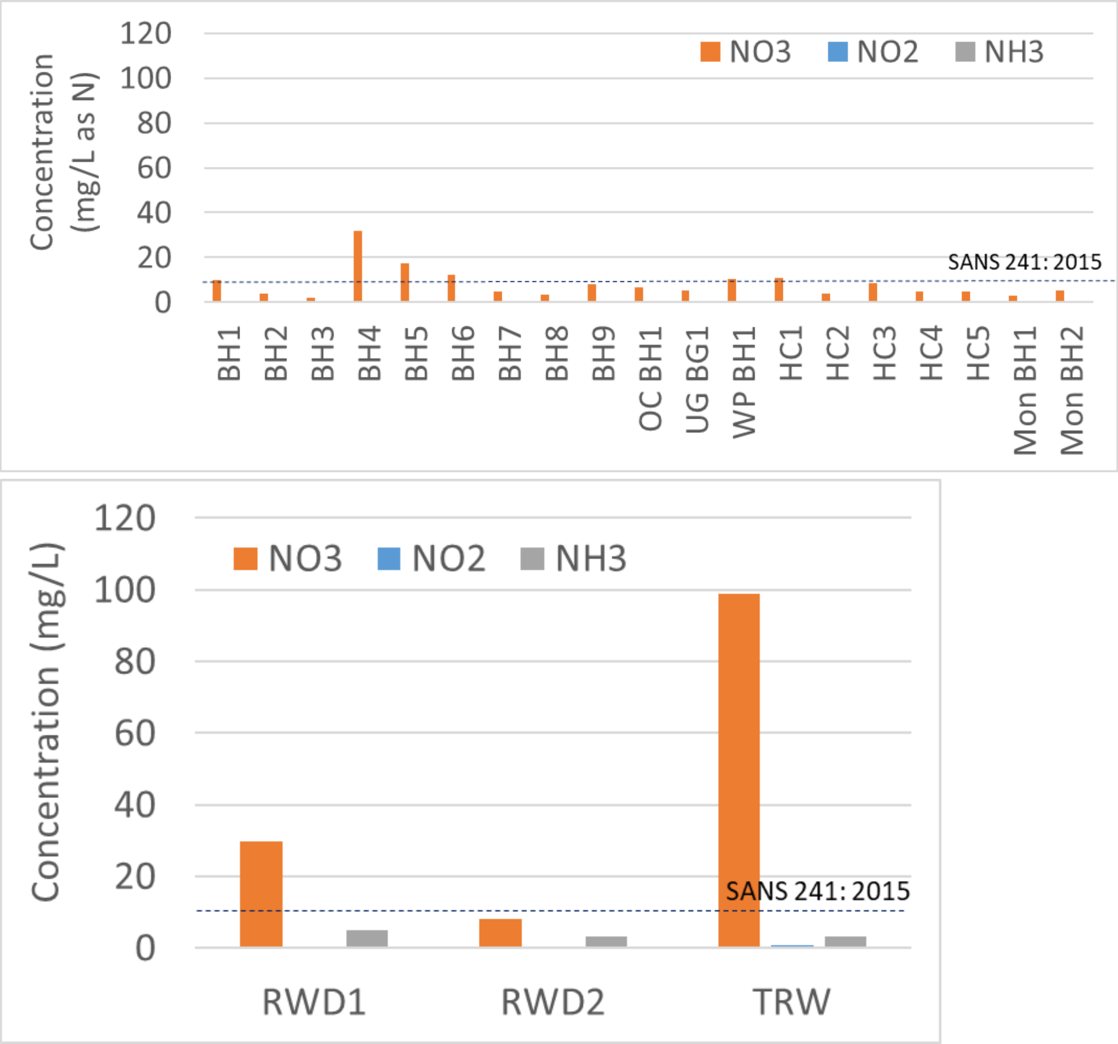


Figure 5.7: Concentrations of nitrogen species in groundwater (top_ and process water (bottom) – taken from Mills, February 2020

5.7. Groundwater quality

5.7.1. Element concentrations

There is an existing water monitoring program in place. A total of nine boreholes are currently included the program. Please refer to Table 5.8 for a summary of the latest (September 2019) chemical analysis results.

The water qualities are compared to the SANS 241:2015 drinking water standards. The standard represents a numerical limit of the listed element concentrations that will protect the health of the consumer over a lifetime of consumption. All elements that exceed the guidelines are highlighted.

From Table 5.8 it can be seen that in general the groundwater quality is good, with some individual parameters in individual samples exceeding the SANS241:2015 guideline values. Expected health impacts are discussed that the hand of domestic use guidelines published by the then Department of Water Affairs and Forestry (Department of Water Affairs and Forestry, 1996).

Elements that exceed the SANS241:2015 guideline values are:

Chloride: The chloride concentrations at borehole BH4 (398 mg/L) and BH5 (393 mg/L) exceed the guideline value of 300 mg/L. At the measured concentrations no health impacts are expected. At concentrations between 200 and 600 mg/L the water has a distinctly salty taste. There is a likelihood of noticeable increase in corrosion rates in domestic appliances.

Nitrate: The nitrate concentrations in boreholes BH4 (37 mg/L) and BH6 (13.6 mg/L) exceed the guideline value of 11 mg/L. At concentrations greater than 10 mg/L methaemoglobinaemia may occur in infants. With increasing concentration to above 20 mg/L mucous membrane irritation in adults can occur.

Manganese: The manganese concentration in borehole BH8 measured 93.7 mg/L. This exceeds the SANS241:2015 guideline value of 0.4 mg/L by 2 orders of magnitude.

It has to be stated that this value is anomalous as all other groundwater points measured below detection level. In addition, previous results at borehole BH8 from December 2018 and March 2019 showed manganese concentrations below detection limit of 0.025 mg/L. It is possible that this is a laboratory error.

Chromium: At borehole BH4 the total chromium measured 0.16 mg/L, which exceeds the SANS241:2015 guideline value of 0.05 mg/L.

Cadmium: The cadmium concentration in borehole BH7 measured 0.02 mg/L. This exceeds the guideline value of 0.002 mg/L. As a precautionary measure it is recommended that concentrations of 0.005 mg/L not be exceeded due to the potentially acute and/or irreversible effects of cadmium on human health. A concentration of 0.02 mg/L is the threshold for health damage with continuous exposure. Single incidence of exposure will not have an observable effect. At concentrations greater than 0.02 mg/L there is a danger of kidney failure with long-term exposure (longer than 1 week).

Lead: The lead concentration in borehole BH8 measured 7.88 mg/L which exceeds the guideline value of 0.01 mg/L by 2 orders of magnitude. As was the case with manganese this value for borehole BH8 is anomalous as it does not compare to previous sampling runs at BH8 from December 2018 and March 2019 when the lead concentrations measured below detection limit. Results for all other boreholes included in the sampling program also show lead concentrations below detection limit at all times.

Table 5.8: Groundwater chemical analysis results – September 2019 monitoring program results

Analysis	Units	SANS 241:2015 guideline value	BH4	BH5	BH6	BH7	BH8	BH9	OCBH1	UGBH1	WPBH1
pH		≥5 - ≤9.7	8.11	7.93	8.02	7.54	4.64	8.23	7.94	8.02	7.94
Total Dissolved Solids (TDS)	mg/L	≤1 200	1751	1050	599	649	26.6	601	486	481	467
Chloride (Cl)	mg/L	≤300	398	393	74.8	161	212	156	36.7	39.6	38.7
Sulphate (SO_4)	mg/L	≤500 (health)	389	114	30.3	28.6	52.9	26.2	26.5	22.7	22.2
Nitrate (NO_3)	mg/L	≤11	37	8.48	13.6	<0.01	<0.01	9.13	6.84	5.95	5.91
Nitrite (NO_2)	mg/L	N/G	<0.01	<0.01	<0.01	5.04	<0.01	<0.01	<0.01	<0.01	<0.01
Calcium (Ca)	mg/L	N/G	54.9	30	44.9	80.5	81.6	65.5	68.6	65.9	60.3
Magnesium (Mg)	mg/L	N/G	282	177	107	87.9	<0.01	97.7	67.3	67.6	67.6
Sodium (Na)	mg/L	≤200	152	94.8	33.3	50.1	0.57	19.6	29.8	30	29.9
Potassium (K)	mg/L	N/G	5.73	4.95	2.03	0.67	<0.01	1.81	0.37	0.49	0.51
Aluminium (Al)	mg/L	≤0.3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.01	<0.01	<0.01
Barium (Ba)	mg/L	≤0.7	0.02	0.01	0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01
Boron (B)	mg/L	≤2.4	0.43	0.15	0.09	0.02	0.02	0.02	0.02	0.02	0.02
Iron (Fe)	mg/L	≤2 (health)	0.09	<0.01	<0.01	<0.01	<0.09	<0.01	<0.01	<0.01	<0.01
Manganese (Mn)	mg/L	≤0.4 (health)	<0.01	<0.01	<0.01	<0.01	93.7	<0.01	<0.01	<0.01	<0.01
Chromium (Cr)	mg/L	≤0.05	0.16	0.02	0.02	<0.002	0.02	0.02	0.02	0.02	0.02
Hexavalent Chromium (Cr^{6+})	mg/L	N/G	0.12	<0.02	<0.02	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Cadmium (Cd)	mg/L	≤0.003	<0.002	<0.002	<0.002	0.02	<0.002	<0.002	<0.002	<0.002	<0.002
Lead (Pb)	mg/L	≤0.01	<0.01	<0.01	<0.01	<0.01	7.88	<0.01	<0.01	<0.01	<0.01
Vanadium (V)	mg/L	N/G	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
COD	mg/L	N/G	14	9	24	14	697	9	14	7	17

🟩 Exceed SANS241:2015 guideline value

mS/m = milliSiemens/metre

mg/L = milligram per litre

N/A = Not analysed

N/G = No guideline value specified

6. Aquifer characterisation

6.1. Groundwater vulnerability

For aquifer vulnerability reference is made to the aquifer vulnerability map of South Africa which shows a low aquifer vulnerability for the project area.

6.2. Aquifer classification

The aquifers present in the area are classified as minor aquifers. The aquifers are of high importance to the local landowners in as it is their only source of water for domestic, gardening, and agricultural purposes.

7. Groundwater modelling

7.1. Key assumptions

7.2. Software model choice

The numerical model was constructed using MODFLOW based software, which is an internationally developed, recognised and used software package. The model includes all parameters discussed in previous sections of this report and takes into consideration aspects such as:

- The different aquifers present in the area and their interrelation to each other;
- Recharge from rainfall;
- Aquifer transmissivities, effective porosity, vertical hydraulic conductance;
- Groundwater flow patterns and velocities;
- Geological lithological units and features such as the faulting that could occur in the area; and
- Topographical elevations of surface, the contact between weathered material and competent rock.

7.3. Model setup and boundaries

The model domain is irregularly shaped and defined by the following boundaries:

- On the southern boundary by the Tshailane ridge that forms a topographical high which acts as a water flow divide;
- On the eastern boundary by the Poloro, the Motswadibe the Seotlong, and other unnamed ridges which acts as water flow divides;
- The northern boundary by a ridge and then also the Olifants River which acts as water flow divides;
- On the western boundary by the Olifants River.

7.4. Groundwater elevation and gradient

Groundwater elevations and gradients used in the numerical models were derived from the groundwater levels and flow gradients recorded during the groundwater monitoring program of the mine. The data was incorporated as “initial heads” and further consolidated during the calibration process where the groundwater levels and flow contours obtained from the model calculations replicated those measured in the field.

7.5. Geometric structure of the model

The model grid was designed within the delineated model boundary and the proposed developments. The high resolution grid areas overlay the opencast and underground mining areas, as well as the surface infrastructure areas; with a coarser grid in the far reaches of the model (please refer to Figure 7.1). At the finest resolution the model grid is 12.5 m x 12.5 m, while the coarsest grid size at the outer limits of the model area is 100 m x 100 m.

Due to the depth of the underground mine, the numerical model contained a total of 10 layers in order to be able to properly define the mining areas at depth to the required level of detail. The layers include:

- Layer 1 – Upper, weathered material aquifer (average 10 m thick);
- Layer 2 – Upper section the fractured rock aquifer (40 m thick);
- Layer 3 – Upper section of the fractured rock aquifer (40 m thick); and
- Layers 4 to 10 – Lower section of the fractured rock aquifer (each layer is 40 m thick).

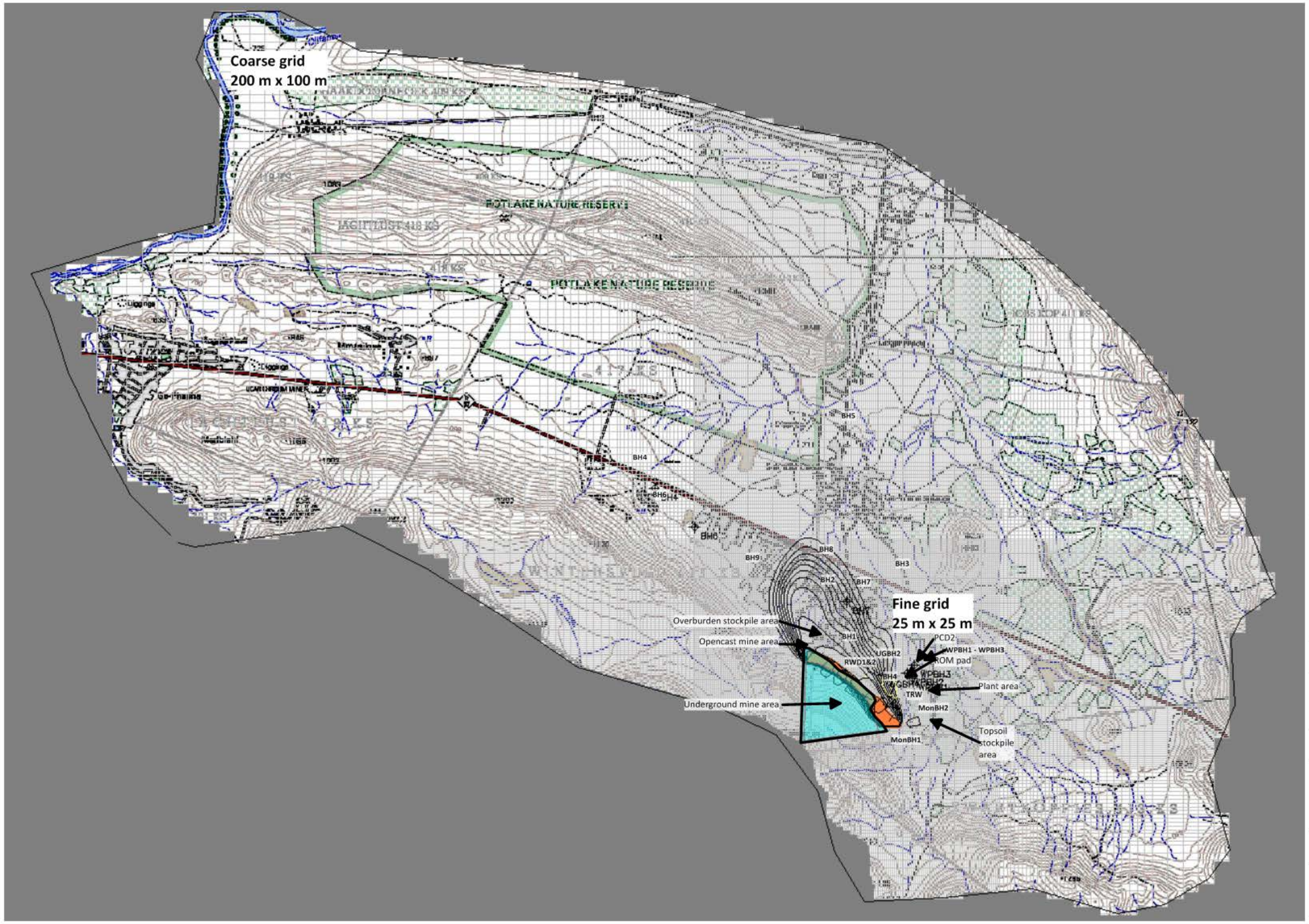
7.6. Groundwater sources and sinks

Groundwater sources include:

- Rainfall recharge (represented by the “recharge” package); and
- Recharge from surface streams (represented by the “river” package).

Groundwater sinks include:

- Springs (represented by the “drain” package);
- Baseflow contribution to streams (represented by the “river” package);
- Evapotranspiration (incorporated in the “recharge” package); and
- Mine dewatering (represented by the “drain” package).



N
W E
S

◆ Monitoring point

☐ Overburden stockpile

☐ PCD2

🟦 Underground mine area

☐ Topsoil stockpile

☐ Plant area

☐ ROM pad

☐ Opencast (not backfilled)

☐ Opencast (backfilled)

Reference Maps

Mine Layout: As provided
Topographical: 2429 BB, 2429BD
2430 AA, 2430AC
Geological: 2428 - Nylstroom
Satelite Image: Google Earth
WGS 84, Traverse Mercator LO29

Client:
Red Kite Consulting

Project:
Moeijelijk Chrome Mine
Groundwater Impact Assessment

Figure Number: 7.1

Figure Name:
Numericla model area,
mesh sizing and boundaries

Scale: As shown

Date: February 2020
Revision: 1

Designed: MP
Approved:

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7.7. Conceptual model

7.7.1. Groundwater flows

There are two aquifers present in the area. These are associated with a.) the weathered material, and b.) the underlying competent, but fractured, bedrock respectively.

The weathered material aquifer is recharged at an average rate of 3.9 % of the rainfall. The infiltrating rainwater joins the saturated zone and migrates down gradient to where it daylights as springs or baseflow contribution the numerous streams that characterise the area. The yield of this aquifer varies throughout the year depending on the rainfall recharge and it is possible that it is laid dry in some areas during the dry season. This aquifer is also most vulnerable to contamination from surface.

A portion of the water within the weathered material aquifer infiltrates into the underlying fractured rock aquifer. Groundwater flow in this aquifer is mostly associated with individual groundwater bearing zones (faults, fractures, and geological contacts).

Depth to groundwater level ranges between 19 and 56 mbgl. This indicates that the weathered material aquifer is dry in most places.

Groundwater flows from the topographical highs formed by the various ridges in the area where recharge occurs towards the low lying Olifants River in the west and northwest where the groundwater exit the system as baseflow contribution to the Olifants River.

7.7.2. Contaminant transport

The opencast and underground mines, as well as the surface stockpiles can act as potential sources of contamination to the aquifers.

For the purpose of this discussion it is assumed that good housekeeping such as storage of potentially hazardous material is within properly constructed and lined or paved areas. Oil traps are sized, operated and maintained to contain all discarded oil from working areas.

In terms of contaminant production, the following risks exist:

- The opencast and underground mine areas are in direct contact with the upper weathered material and the fractured rock aquifers. This enables direct contamination of the aquifers from the mining areas. It is planned that the opencast areas be backfilled with silica tailings material;
- Leachate emanating from the surface stockpiles can contaminate the underlying aquifers;
- Leachate emanating from the overburden stockpiled on site, or the overburden exposed in the opencast pit walls, can be enriched in nitrate and hexavalent chromium.

Various surface stockpiles and water management dams are lined which mitigate contamination of the underlying aquifers. These surface areas which are lined include:

- The wet tailings area;
- The product stockpile area; and
- The pollution control dam.

Unlined areas which pose a greater risk to the underlying aquifers include:

- The oversized area;
- The run of mine (ROM) area (this essentially the same as the oversized area);

The geochemical modelling results show (Mills, 06 February 2020):

- Operational phase contaminants:
  - Nitrate concentrations are high (501 mg/L) under the oxidizing conditions associated with operation because nitrate is highly soluble and there are no sinks in this scenario. Nitrate can be removed from groundwater by denitrification, but this requires anaerobic conditions which are not anticipated to develop in unsaturated backfilled tailings;
  - Chromium is predicted by geochemical modelling to be present exclusively as Cr^{6+} at a concentration of 0.3 mg/L;
- Post-closure phase contaminants:
  - Nitrate concentrations are expected to reduce to 139 mg/L due to denitrification, which is more likely to occur in a saturated environment; and
  - The Cr^{6+} source term remains 0.3 mg/L.

8. Geohydrological impacts

The environmental impact assessment is conducted based on the available information and the 3D numerical groundwater flow and contaminant transport modelling that was done. The model was constructed based on site specific information gathered during the study and calibrated using the groundwater levels measured during the hydrocensus.

Impacts from the mining activities were evaluated and include:

- Impacts on groundwater levels, flow patterns and volumes;
- Impacts on groundwater qualities and plume migration; and
- Impacts on surface water qualities due to poor quality groundwater seeping into the surface water in the form of baseflow contribution.

During the risk assessment the risk to the groundwater levels and quality were evaluated. Each of the identified risks was then rated. The rating methodology used is as described in Table 8.1.

The rating is described as follows:

Score out of 100	**Significance**
1 to 20	Low
21 to 40	Moderate to Low
41 to 60	Moderate
61 to 80	Moderate to high
81 to 100	High

Will **mitigation** be possible (yes or no)? Mitigation measures are further discussed in the EMP section, where post mitigation significance of impacts is also given.

The **Degree of irreplaceable loss of resource** has also been evaluated in the impact assessment table. This has been rated in three categories, including:

Degree of loss	
Low	The resource is renewable or able to recover and therefore negligible loss expected.
Moderate	Resource is at risk of permanent loss but management measures can reduce risk of loss or resource can recover over time or with rehabilitation efforts.
High	Resource will be severely affected and loss will be irreplaceable or very long term, or rehabilitation efforts would be unduly expensive and not economically viable.

Table 8.1: Impact rating methodology

The status of an impact		
Score	**Status**	**Description**
Pos	Positive:	a benefit to the holistic environment
Neg	Negative:	a cost to the holistic environment
Neut	Neutral:	no cost or benefit
The duration of the impact		
Score	**Duration**	**Description**
1	Short term	Less than 2 years
2	Short to medium term	2 – 5 years
3	Medium term	6 – 25 years
4	Long term	26 – 45 years
5	Permanent	46 years or more
The extent of an impact		
Score	**Extent**	**Description**
1	Site specific	Within the site boundary
2	Local	Affects immediate surrounding areas
3	Regional	Extends substantially beyond the site boundary
4	Provincial	Extends to almost entire province or larger region
5	National	Affects country or possibly world
The reversibility of the impact		
Score	**Reversibility**	**Description**
1	Completely reversible	Reverses with minimal rehabilitation & negligible residual affects
3	Reversible	Requires mitigation and rehabilitation to ensure reversibility
5	Irreversible	Cannot be rehabilitated completely/rehabilitation not viable
The effect (severe or beneficial) of the impact		
Score	**Severe/beneficial effect**	**Description**
1	Slight	Little effect - negligible disturbance/benefit
2	Slight to moderate	Effects observable - environmental impacts reversible with time
3	Moderate	Effects observable - impacts reversible with rehabilitation
4	Moderate to high	Extensive effects - irreversible alteration to the environment
5	High	Extensive permanent effects with irreversible alteration
The probability of the impact		
Score	**Rating**	**Description**
1	Unlikely	Less than 15% sure of an impact occurring
2	Possible	Between 15% and 40% sure of an impact occurring
3	Probable	Between 40% and 60% sure that the impact will occur
4	Highly Probable	Between 60% and 85% sure that the impact will occur
5	Definite	Over 85% sure that the impact will occur
The Consequence		= Severity + Spatial Scale + Duration + Reversibility.
The Significance		= Consequence x Probability.

8.1. Construction phase

Moeijelijk mine is already operational; therefore, there is no construction phase.

8.2. Operational phase

8.2.1. Impacts on groundwater quantity

8.2.1.1. Groundwater inflows into the underground mine

The opencast mine areas are mined out. Going forward only the underground mine will be operational. The underground mine start relatively shallow at approximately 50 m below surface. However, due to the combined effect of the fact that the mine moves south-westwards into the Tshailane ridge and the fact that the ore body dips at 20 degrees to the southwest, the depth of mining below surface quickly increases. At the furthest point the underground mine is 655 m below surface.

Groundwater inflows volumes into the underground mine over the life of operations were calculated using the numerical groundwater flow model. The obtained results are summarised in Table 8.2. From the table it can be seen that it is expected that the groundwater inflow volumes into the underground mine will increase during the initial 5 years of operations from around 40 m^3/day to approximately 170 m^3/day. This is due to the increase in the mined out area and the associated increase in groundwater inflows. However, as the depth of mining below surface increases over time, and the aquifer potential decrease, it is expected that there will be little additional groundwater inflows into the underground mine as the mining progresses during the later years of the life of mine.

The flow model is based on the available mine development plan. The numerical model only takes average values such as the average annual recharge from rainfall into consideration. No seasonality is included in the mine inflow calculations.

Table 8.2: Groundwater inflow volumes into the underground mine

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028
Groundwater inflow volume (m^3/day)	40	70	100	130	170	175	170	170	170

8.2.1.2. Groundwater level drawdown and associated impacts on aquifers, wetlands and stream flow volumes

The mine floor elevations in the underground mine area are below the general groundwater level. This will cause groundwater to flow into the underground mining area from the surrounding aquifers during operations. The numerical groundwater flow model was used to simulate the development of the drawdown cone around the mine over time.

In addition to the mine dewatering, the groundwater level will also be drawn down by the groundwater abstraction for water supply. As mentioned previously, Moeijelijk Mine is applying to increase their lawful groundwater abstraction from 58 100 m^3/a to 249 869 m^3/a. Groundwater will be abstracted from dedicated groundwater supply boreholes at the underground and the wash plant.

The boreholes that are currently used for groundwater abstraction for water supply are:

- Underground area: UGBH1 and UGBH2; and
- Wash plant area: WPBH1, WPBH2, and WPBH3. Please note that these boreholes correspond to those in the January 2018 GPT report (GPT, January 2018):
  - WPBH1 = MBH9
  - WPBH2 = MBH4; and
  - WPBH3 = MBH6.

The details of the groundwater supply boreholes that are being used are summarised in Table 8.3.

Table 8.3: Groundwater abstraction borehole details

Borehole	East	South	Elevation	Depth	SWL		Sustainable yield
	WGS84, LO29	WGS84, LO29	mamsl	m	mbgl	mamsl	L/s
UGBH1	97 489	-2 688 783	823.42	100	37	786.42	3.8
UGBH2	97 497	-2 688 787	826.54	100	-	-	3.0
WPBH1	97 860	-2 688 824	829.49	75	38	791.49	1.3
WPBH2	97 797	-2 688 754	827.80	71	36	791.80	2.5
WPBH3	97 883	-2 688 660	824.71	75	33	791.71	1.6

SWL = Static Water Level
mamsl = metres above mean sea level
mbgl = metres below ground level
L/s = litres per second

The groundwater abstraction boreholes were incorporated into the numerical groundwater flow and contaminant migration models in order to determine the impact of the groundwater abstraction on the surrounding groundwater levels and flow patterns, as well as the impact that the mine dewatering has on the sustainable yields of the boreholes.

Individual pumping rates for the groundwater supply boreholes are not known, only total abstraction from each cluster of boreholes (underground and wash plant). Reportedly, the abstraction volumes are roughly equally shared between the boreholes at each cluster. Current information that the combined average abstraction volumes in recent times (mid 2018 to mid 2019 as well as mid-2019 to January 2020) are:

- Underground: 1 665 m^3/month; and
- Wash plant: 3 970 m^3//month.

It should be kept in mind that this is under a maximum abstraction of approximately 5 000 m^3/month (Groundwater Pollution Technologies, July 2019). Assuming a similar distribution, it is calculated that the abstraction from each cluster under a 20 822 m^3/month (249 869 m^3/a) program will be:

- Underground: 6 935 m^3/month; and
- Wash plant: 16 535 m^3/month.

Numerical modelling shows that during the life of operations the groundwater flow directions in the vicinity of the underground mine area will be directed toward the mine area. This is due to mine dewatering causing the groundwater levels to be drawn down towards the mine floor elevations. In addition to this, there a groundwater level drawdown cone will develop around the dewatering boreholes.

The zone of influence of the groundwater level drawdown around the underground mining area and the dewatering boreholes is dependent on several factors, including amongst others the depth of the mine floor below the groundwater level around the mine, the pump depth in the groundwater supply boreholes, the pump volume, the pump schedule and the aquifer transmissivity.

The groundwater level drawdown in the fractured rock aquifer at the end of life of the underground mining area is shown in Figure 8.2. From Figure 8.2 it can be seen that the zone of influence of the groundwater level drawdown in the fractured rock aquifer can reach up to 450 m from the underground mine area. The cone of depression does not extend to the furthest southwestern point of the underground mine due to the depth of the mine in that area (up to 655 m below surface) and the inactivity of the aquifers at that depth.

Around the groundwater supply boreholes the zone of influence of the groundwater level drawdown can extend up to 575 m from the boreholes.

There are a number of boreholes that fall within the groundwater level drawdown cone. However, the majority of these boreholes belong to the mine. The only privately owned borehole that fall within the drawdown cone is BH1. The details of this borehole can be seen in Table 5.6. The borehole has been built over and is not in use anymore.

It is not expected that the mine dewatering and the groundwater supply boreholes will have a noticeable impact on the groundwater levels in the weathered material aquifer. This is due to a combination of:

- The depth of the mining below surface (between 50 and 655 m);
- The groundwater level in the region ranges between 19 and 56 mbgl. This indicates that the weathered material aquifer, which is in the order of 10 m thick, is dry in portions of the study area.

The non-perennial streams in the area receive flows from surface runoff during rainfall events, and also from baseflow contribution from the weathered material aquifer. Due to the regional depth to groundwater level of at least 16 m it is expected that the baseflow contribution to the stream flow volumes will be a minor portion of the stream flow volumes.

Based on the above, it is concluded that the mine dewatering and groundwater abstraction via the groundwater supply boreholes will have a negligible to no impact on the stream flow volumes.

8.2.2. Contaminant migration away from pollution sources

It is assumed that with proper maintenance of mining vehicles and other operations related best practices there will be a limited impact on the groundwater quality from general surface activities. Based on available geochemical information the overburden material that is stockpiled on surface could have elevated boron, barium, cobalt and manganese concentrations.

The numerical contaminant migration model was used to simulate the contaminant migration away from potential surface pollution sources over the life of mine. These sources include the unlined oversize areas and the backfilled opencast pit areas.

As discussed in Section 7.7.2 of this report, other surface areas are lined which mitigates contamination of the underlying aquifers in those areas. Geochemical modelling results show that the nitrate concentrations are high (501 mg/L) under the oxidizing conditions associated with the operational phase because nitrate is highly soluble and there are no sinks in this scenario (Mills, 06 February 2020). Nitrate can be removed from groundwater by denitrification, but this requires anaerobic conditions which are not anticipated to develop in unsaturated backfilled tailings. Chromium is predicted by geochemical modelling to be present exclusively as Cr^{6+} at a concentration of 0.3 mg/L

Results from the numerical modelling show that the plumes can migrate up to 200 m from the surface stockpile footprint areas. Borehole BH1 fall within the plume migrating away from the overburden stockpile. Modelling simulation results show that the nitrate concentration at BH1 at the end of life of mine is expected to be in the order of 15 mg/L. As mentioned previously this borehole has been built over and is not in use anymore.

A groundwater level drawdown cone will develop around the groundwater dewatering boreholes as discussed in Section 8.2.1.2 of this report. Contamination migrating away from the discard dump will be drawn towards groundwater supply boreholes UGBH1 and UGBH2. Similarly, contamination migrating away from the topsoil stockpile will be drawn towards boreholes WPBH1 and WPBH2.

The migrating plume will reach boreholes UGBH1 and UGBH2 within 1 to 2 years of the life of the operations (thus sometime before the end of 2020, or at the latest before the end of 2021). The nitrate concentration entering the boreholes is expected to increase over time to a maximum of approximately 250 mg/L. The nitrate breakthrough curve at boreholes UGBH1 and UGBH2 are shown in Figure 8.1.

The contaminant plume migrating away from the topsoil footprint is expected to reach boreholes WPBH1 and WPBH2 after approximately 5 years (thus sometime during 2024). The nitrate concentrations are expected to reach a maximum of approximately 35 mg/L in WPBH1 and 50 mg/L in WPBH2. The nitrate breakthrough curves for these two boreholes are also included in Figure 8.1. Please note that a source concentration of 501 mg/L nitrate was used for the topsoil stockpile. This is possibly an overestimation due to the leached nature of the material compared to the tailings material that was used to determine the source concentration.

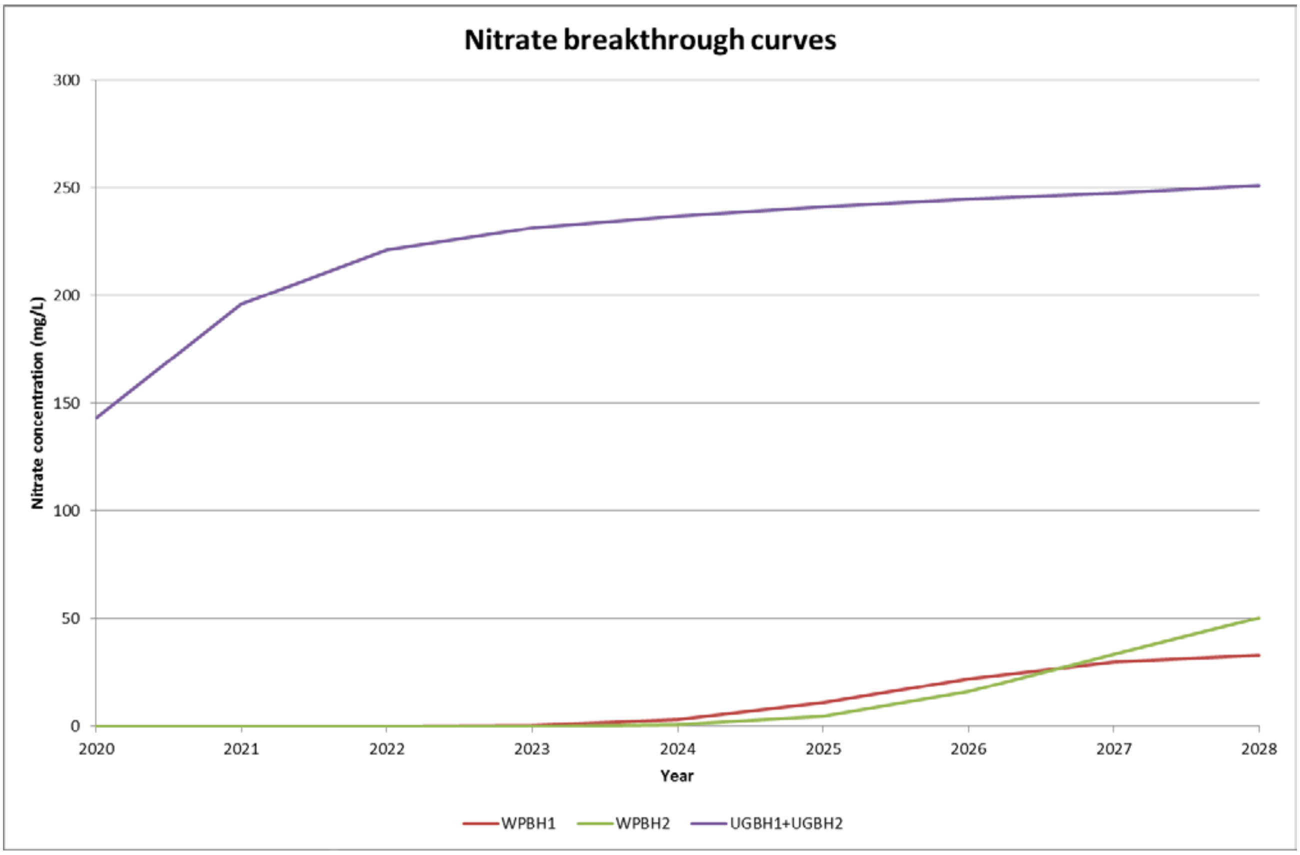
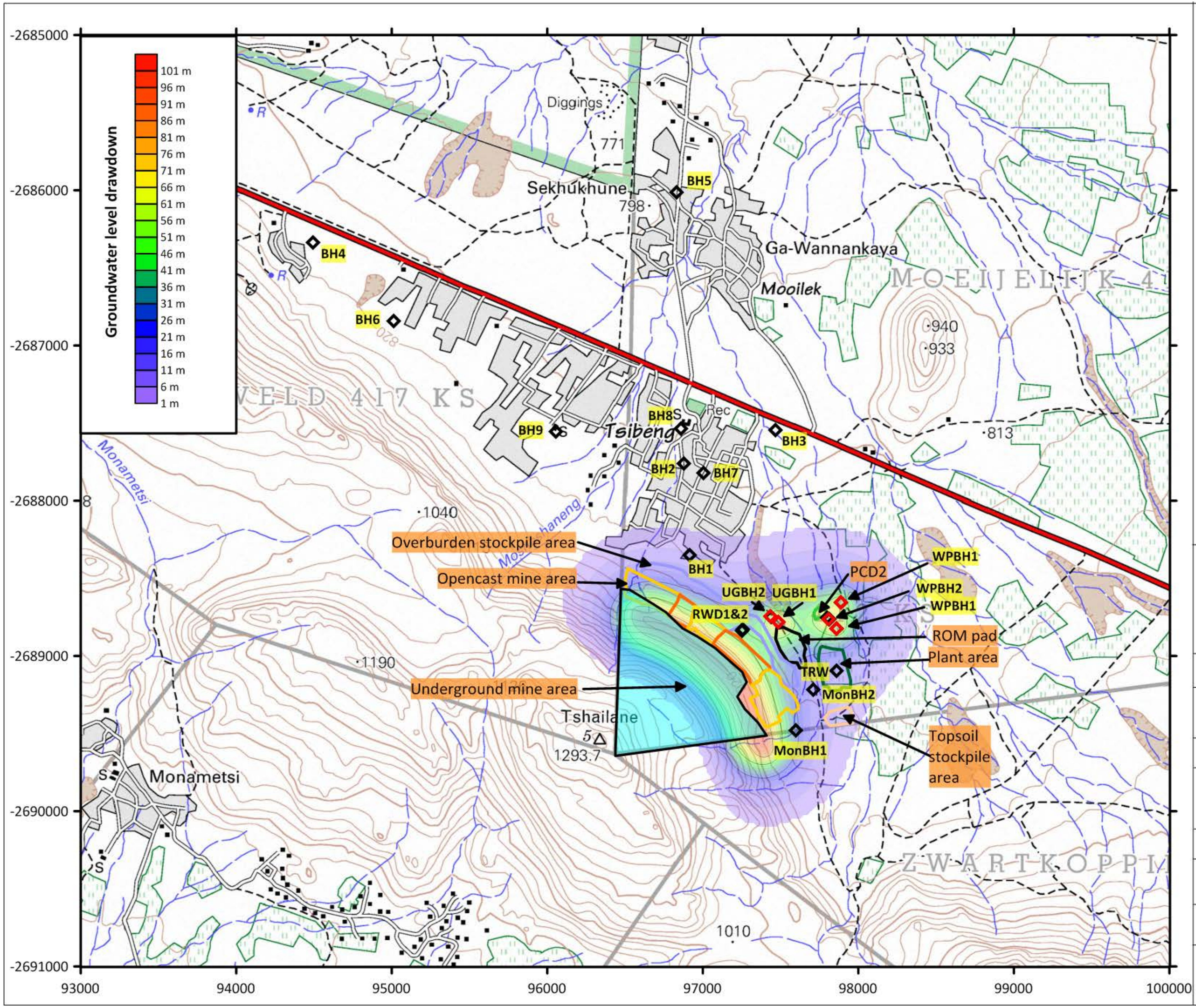


Figure 8.1: Nitrate breakthrough curve in groundwater supply boreholes

A short section (320 m) of one of the non-perennial streams is impacted by the pollution plume migrating away from the overburden stockpile. A 250 m section of a stream is impacted by the pollution plume migrating away from the topsoil stockpile. The impact on the overall stream qualities during the rainy season when the streams flow is less than 1 % based on the total length of the streams draining the mine area.

Groundwater flow patterns around the rehabilitated opencast areas will be directed towards the opencast mine areas due to the fact that the opencast mine areas are interlinked with the underground mine area via the decline shaft. This connection will drain the rehabilitated opencast areas into the underground mine and prevent the water levels within the rehabilitated opencast areas from recovering to near pre-mining levels, thereby containing contamination within the rehabilitated opencast areas. Therefore, there will be no general contaminant plumes migrating away from the opencast areas.



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◇ Groundwater supply borehole

◆ Monitoring point

▭ Overburden stockpile

▭ PCD2

▭ Underground mine area

▭ Topsoil stockpile

▭ Plant area

▭ ROM pad

▭ Opencast (not backfilled)

▭ Opencast (backfilled)

Reference Maps
Mine Layout: As provided
Topographical: 2429 BB, 2429BD
2430 AA, 2430AC
Geological: 2428 - Nylstroom
Satelite Image: Google Earth
WGS 84, Traverse Mercator LO29

Client:
Red Kite Consulting

Project:
Moeijelijk Chrome Mine
Groundwater Impact Assessment

Figure Number: 8.2

Figure Name:
Groundwater level drawdown
Fractured rock aquifer
End of life of mine

Scale: As shown

Date: February 2020
Revision: 2

Designed: MP
Approved:

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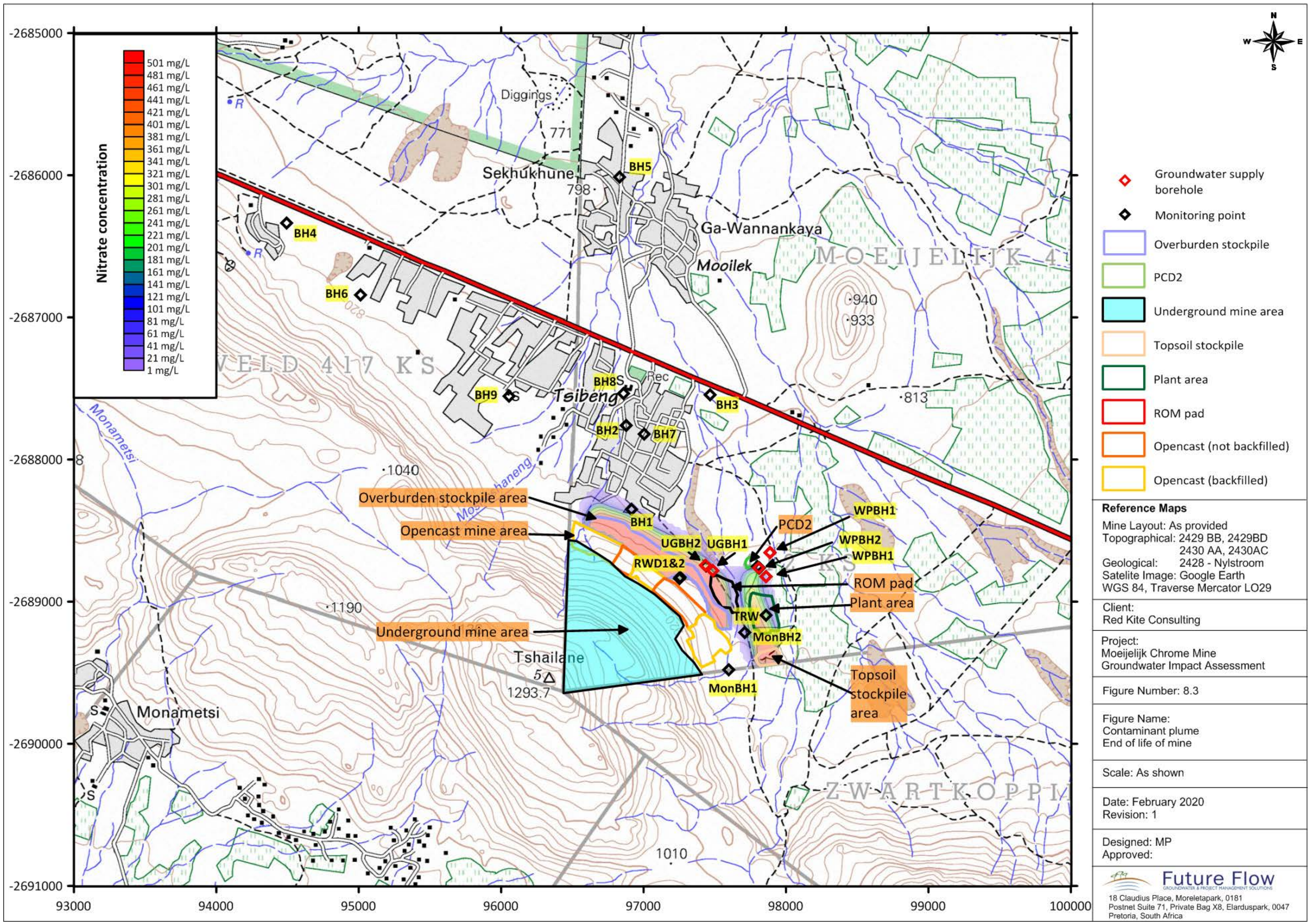

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Client:
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Project:
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Groundwater Impact Assessment

Figure Number: 8.3

Figure Name:
Contaminant plume
End of life of mine

Scale: As shown

Date: February 2020
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Table 8.4: Impact rating – Operational phase

Impact	Status	Effect	Extent	Duration	Reversibility	Consequence	Probability	Significance	Mitigation	Degree of irreplaceable loss	Mitigation	Status	Effect	Extent	Duration	Reversibility	Consequence	Probability	Significance
Impacts on groundwater volumes due to active dewatering of the underground mining area	Neg	2	2	3	3	10	5	50	Y	Mod	Monitor groundwater levels; Monitor for surface subsidence; Seal off individual high yielding inflow zones intercepted during mining.	Neg	1	2	3	3	9	5	45
Impacts on surface water and wetland volumes due to active dewatering of the underground mining area	Neg	1	2	3	3	9	2	18	Y	Mod	Monitor groundwater levels; Monitor stream flow volumes; Seal off individual high yielding inflow zones intercepted during mining	Neg	1	1	3	3	8	1	8
Impacts on surface quality due to poor quality seepage from the pollution source areas	Neg	1	1	5	5	12	2	24	Y	Mod - low	Appropriate lining and monitoring of the pollution source areas	Neg	1	1	3	5	10	1	10
Impacts on groundwater quality due to poor quality seepage from the mining area	Neg	1	1	5	5	12	1	12	Y	Low	Monitor the groundwater quality; Seal off individual high yielding inflow zones intercepted during mining.	Neg	1	1	5	5	12	1	12

8.3. Decommissioning phase

During the decommissioning phase the mine dewatering will stop. This will allow the groundwater level within the underground mine to start rising. However, due to the relatively short time period of the decommissioning phase (less than 1 year) it is not expected that the underground mine will become fully submerged, or that there will be significant contaminant migration away from the mine.

8.4. Long term post-operational phase

8.4.1. Recovery of groundwater levels and decant potential

In the post operational environment the water level within the mined out underground area will continue to recover.

The recovering water levels will allow the groundwater flow patterns in the area to recover to near pre-mining levels. The time required for the water level in the underground mine to recover to near pre-mining levels is calculated to be approximately 18 years. As the water level within the underground mine rises the hydraulic gradient between the regional groundwater levels and the water level within the underground mine will reduce, thereby reducing the groundwater inflow volume into the mine.

It is expected that decant from the mining area will occur. The underground mine and the previous opencast mine areas are interconnected via the decline shaft. Therefore, once the underground mine and the rehabilitated opencast mine areas are submerged decant will start. The expected decant points are indicated in Figure 8.4.

The expected decant volume is calculated to be between 10 and 50 m^3/day depending on the quality of the rehabilitation of the opencast areas. Proper rehabilitation with re-established vegetation and proper sloping of the surface that prevent ponding of rainwater will reduce recharge into the rehabilitated opencast areas which in turn will reduce the decant volume.

Decant qualities are expected to reflect the results from the geochemical assessment. Nitrate concentrations can be up to 139 mg/L. Hexavalent chromium concentration can be 0.3 mg/L.

8.4.2. Contaminant migration away from pollution sources

Contaminant migration will continue from the overburden and top soil stockpile footprint areas. In addition, contaminant migration away from the opencast and underground mine areas will start once a driving head is established by die rising water levels in the mining areas.

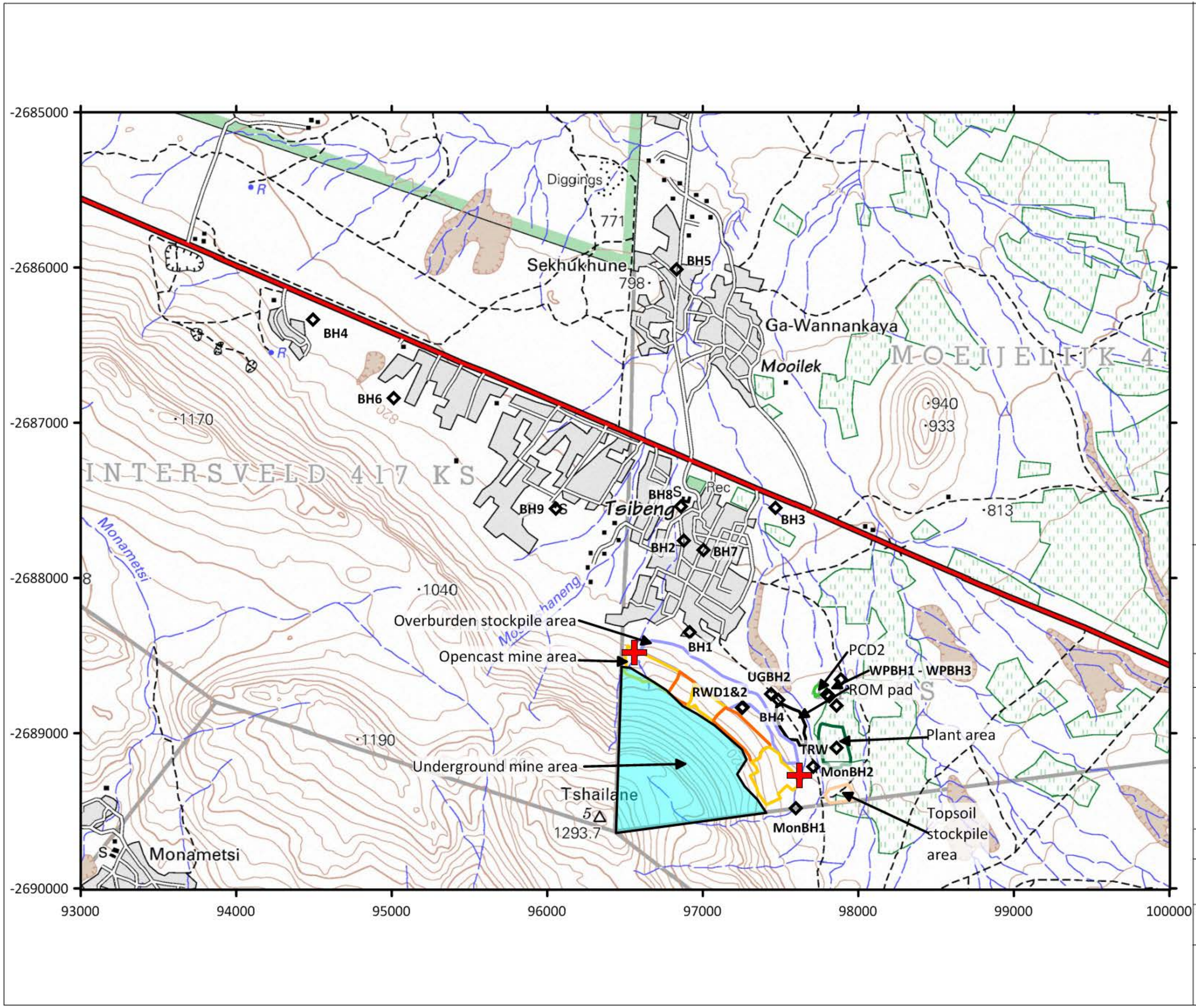
The numerical contaminant migration model was used to simulate the contaminant plume migration up to 100 years post closure. The geochemical modelling results were used. Nitrate concentrations at the end of the decommissioning phase was specified as 501 mg/L and reduced overtime to reach 139 mg/L when the mining areas are submerged.

The calculated plumes in the weathered material and the fractured rock aquifers at 100 years post closure can be seen in Figure 8.5 and Figure 8.6 respectively.

From Figure 8.5 it can be seen that the contaminant plume in the weathered material aquifer will migrate up to 1 800 m from the opencast mine areas. The plume migrates downgradient in a northern direction underneath the village. Four village boreholes are impacted by the migrating plume: The details of the boreholes are summarised in Table 5.6.

- BH1: This borehole has been built over and is not in use anymore;
- BH2: This borehole is at a residence. The borehole is used for domestic purposes. The borehole is not included in the monitoring program anymore;
- BH7: The borehole is for communal use in Tsibeng village; and
- BH8: The borehole is located at Matianyane Primary School.

From Figure 8.6 it can be seen that there is very little contaminant migration through the fractured rock aquifer away from the underground mine. This is due to the low expected aquifer activity at the depths of the underground mine (up to 655 m below surface).



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- ✚ Expected decant point
- ◇ Monitoring point
- ☐ Overburden stockpile
- ☐ PCD2
- ☐ Underground mine area
- ☐ Topsoil stockpile
- ☐ Plant area
- ☐ ROM pad
- ☐ Opencast (not backfilled)
- ☐ Opencast (backfilled)

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WGS 84, Traverse Mercator LO29

Client:
Red Kite Consulting

Project:
Moeijelijk Chrome Mine
Groundwater Impact Assessment

Figure Number: 8.4

Figure Name:
Expected decant positions

Scale: As shown

Date: February 2020
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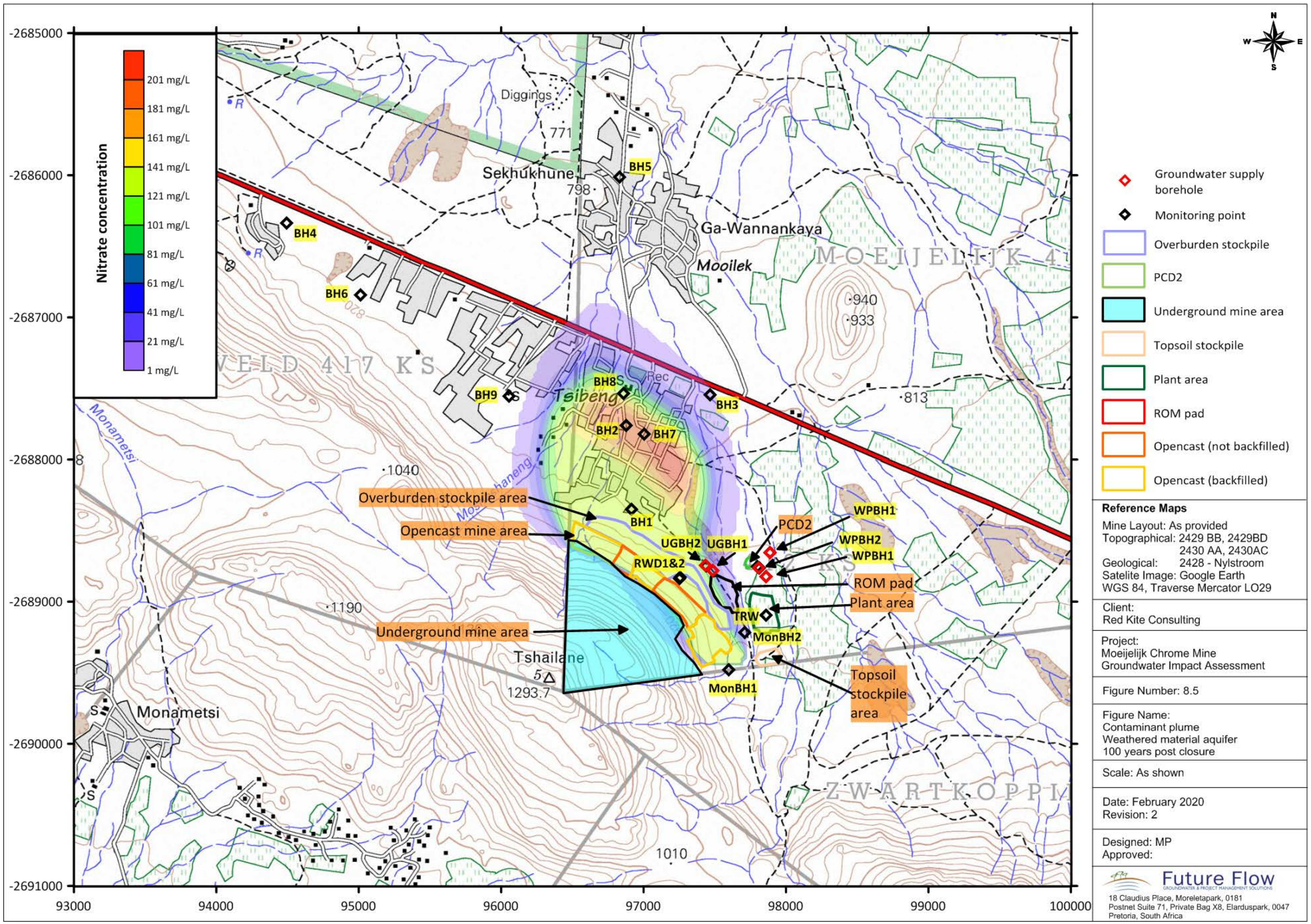

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WGS 84, Traverse Mercator LO29

Client:
Red Kite Consulting

Project:
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Groundwater Impact Assessment

Figure Number: 8.5

Figure Name:
Contaminant plume
Weathered material aquifer
100 years post closure

Scale: As shown

Date: February 2020
Revision: 2

Designed: MP
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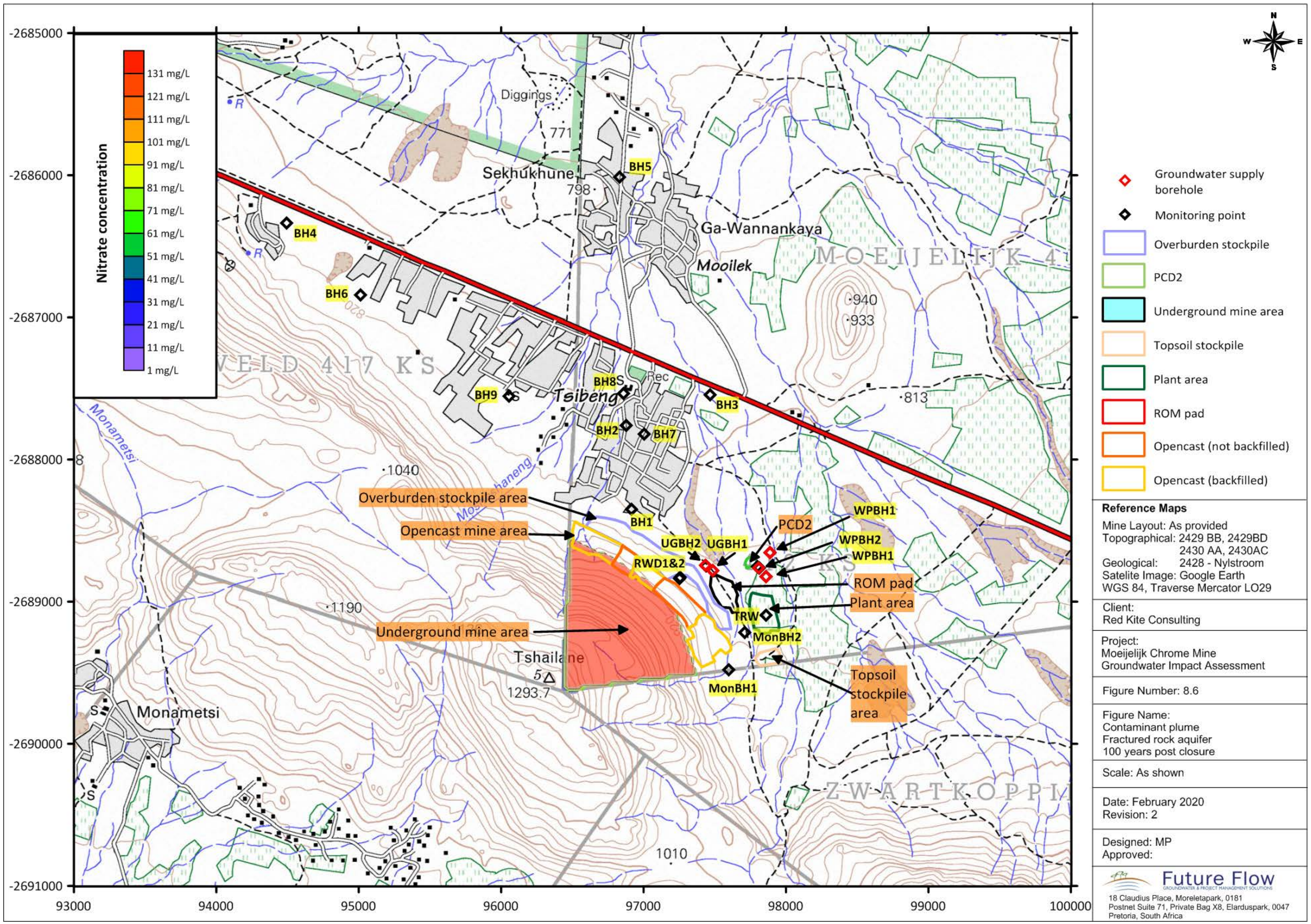

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Client:
Red Kite Consulting

Project:
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Groundwater Impact Assessment

Figure Number: 8.6

Figure Name:
Contaminant plume
Fractured rock aquifer
100 years post closure

Scale: As shown

Date: February 2020
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Table 8.5: Impact rating – long term post-operational phase

Impact	Status	Effect	Extent	Duration	Reversibility	Consequence	Probability	Significance	Mitigation	Degree of irreplaceable loss	Mitigation	Status	Effect	Extent	Duration	Reversibility	Consequence	Probability	Significance
Recovery of groundwater level after dewatering stopped	Pos	4	3	5	5	17	5	85	N	High	Positive impact – no remediation needed	-	-	-	-	-	-	-	-
Impacts on groundwater quality due to poor quality seepage from the mining area	Neg	3	2	5	5	15	5	75	Y	Mod	Monitor the groundwater quality; Seal off individual high yielding inflow zones intercepted during mining.	Neg	2	2	5	5	14	5	70
Impacts on surface quality due to poor quality seepage from the pollution source areas	Neg	1	1	5	5	12	2	24	Y	Mod - low	Appropriate lining and monitoring of the pollution source areas	Neg	1	1	3	5	10	1	10

9. Groundwater monitoring system

9.1. Groundwater monitoring network

9.1.1. Source, plume, impact and background monitoring

A water monitoring program is already active at Moeijelijk Mine. The underground mine is located directly up-gradient of the opencast mine and surface infrastructure. It is considered that the current monitoring program is sufficient to monitor the future developments.

9.1.2. Monitoring frequency

The groundwater level monitoring takes place on a monthly interval while the groundwater chemical analysis is done on a quarterly interval. This is considered to be sufficient and should continue.

9.2. Monitoring parameters

Parameters and elements to be monitored for should continue as per the existing monitoring program.

9.3. Monitoring boreholes

The existing monitoring boreholes are sufficient.

10. Groundwater environmental management programme

10.1. Current groundwater conditions

Please refer to Section 5 of this report.

10.2. Predicted impacts of facility

Please refer to Section 8 of this report.

10.3. Mitigation measures

10.3.1. Lowering of groundwater levels during facility operation

Groundwater inflows into the underground mine and the associated dewatering of the surrounding aquifers will lead to a lowering of the groundwater levels around the mining area. The impacts are described in more detail in Section 8.2.1.2 of this report.

Lowering of the groundwater levels can be managed by sealing off of individual high yielding zones intercepted during mining.

10.3.2. Rise of groundwater levels post-facility operation

This is a positive impact and does not require any mitigation measures.

10.3.3. Spread of groundwater pollution post-facility operation

The spread of groundwater contamination is discussed in more detail in Section 8.4.2 of this report. It is not expected that there will be major impacts on the groundwater qualities.

11. Post closure management plan

11.1. Remediation of physical activity

The opencast areas will be rehabilitated and backfilled using the overburden and tailings stockpiles. The surface infrastructure areas should be remediated during the decommissioning phase.

11.2. Remediation of storage facilities

Surface storage facilities are being used to backfill the opencast pit areas. The footprint areas should be remediated. Surface stockpiles that cannot be cleared should be sloped, capped and vegetated. This will reduce rainfall recharge and the subsequent leach volumes from the surface storage facilities to the underlying aquifers.

11.3. Remediation of environmental impacts

It will be impossible to prevent and rehabilitate the impacts of contaminant migration away from the pollution sources. Therefore, it is recommended that the groundwater monitoring program be continued for a period of at least 5 years after mine closure to monitor the contaminant migration. Based on these results remediation requirements can be identified and a remediation plan put in place.

11.4. Remediation of water resources impacts

The contaminant migration simulation results show that it is expected that there will be a limited impact on the surface water courses in the area, should such contaminant migration occur.

It is recommended that the streams be monitored and management systems be put in place. This could include cut-off trenches down gradient of the pollution sources and management of the seepage.

12. Conclusions and recommendations

12.1. General conclusions

- The mine is located on the side of the northwest / southeast trending Tshailane ridge. Site specific topographical elevations ranges between 1 293 metres above mean sea level (mamsl) on the top of the ridge to the southwest of the mine, and 800 mamsl in the valley northeast of the mine;
- The ridge topography dips steeply at a gradient of approximately 1:2 to 1:7 towards the northeast. In the valley northeast of the mine the topographical gradient in calculated to be in the order of 1:35;
- Due to the steep topography there are numerous unnamed, non-perennial streams that drain the mine area. One of these streams, is named the Moshashaneng. The streams drain the valley in a northern direction and join the Olifants River 8 km north of the mine;
- The study area falls within the B71B quaternary sub-catchment of the Olifants River, and the Olifants Water Management Area (WMA). The Tshailane Ridge southwest of the mine for the boundary with the B52J quaternary catchment; and
- Climatic data from the Tours Dam weather station show that the mine falls within a summer rainfall region. The average annual rainfall is 874 mm.

12.2. Geology of the study area

- The mining areas fall within the Rustenburg Layered Suite of the Bushveld Igneous Complex. Two different sub-suites can be distinguished viz. the Rustenburg Layered Suite Lower Zone and the Rustenburg Layered Suite Critical Zone. The Rustenburg Layered Suite dips slightly to the southwest, following the emplacement geometry of the Bushveld Complex;
- The Rustenburg Layered Suite Critical Zone, which is the youngest lithology in the mining area, is composed of anorthosite and pyroxenite indicating a predominantly mafic composition for this area;
- The Rustenburg Layered Suite Critical Zone is underlain by the Rustenburg Layered Suite Lower Zone. This subsuite is composed of harzburgite and bronzitite. This indicates a less differentiated magma and a transition from mafic to ultramafic with depth; and
- The LG2 chromitite horizon outcrops to the northeast of the LG6 and therefore represents a significant strike length available for mining on the Moeijelijk farm. The UG1 and UG2 chromitite layers outcrop along the plateau above the Moeijelijk LG6 opencast mine in the southwestern corner of the property.

12.3. Geochemical characterisation

- Total concentration test results:
    - None of the parameters from the GPT study exceed the TCT0 guideline values;
    - Results from the total concentration testing that was done on the silica tailings material as part of the Future Flow study and interpreted by Mills Water show that

  - the major oxide content of the silica tailings is dominated by silica, magnesium, chrome and iron, with lesser amounts of calcium and manganese;
  - Apart from fluoride, the reported trace element concentrations are below detection limits. Fluoride was detected at 80 mg/kg;
- Leach concentration test results:
  - From the GPT study it is seen that barium (34.32 mg/L measured vs LCT0 of 0.7 mg/L), cobalt (14.15 mg/L measured vs LCT0 of 0.5 mg/L) and manganese (1.00 mg/L measured vs LCT0 of 0.5 mg/L) concentrations exceed the LCT0 guideline values, while the boron concentration 49.39 mg/L exceed the LCT1 guideline value of 25 mg/L;
  - Results from the Future Flow study show that the measured trace element and anion concentrations for the silica tails are all below detection limits, which are below their respective LCT0s;
- As the TCs are less than the TCT0s, and the LCs are less than the LCT0s, the waste is assessed as a Type 4 waste. It should be noted that if the XRF chromium, vanadium and manganese values are used in place of the acid digest value, the waste would be classified as a Type 3 waste as the XRF values are between the TCT0 and the TCT1.
- The silica tails are classified as Type IV i.e. no risk of acid generation, because sulphide sulphur was not detected. The sulphur in the sample takes the form of sulphate, which can potentially be leached from the tailings by rainwater, resulting in sulphate occurring in leachate from the silica tails.

12.4. Baseline groundwater conditions

- There are two aquifers present in the area. These are associated with a.) the weathered material, and b.) the underlying competent, but fractured, bedrock respectively;
  - The main source of recharge into the shallow aquifer is rainfall that infiltrates the aquifer through the unsaturated (vadose) zone. Vertical movement of water is faster than lateral movement in this system as water moves predominantly under the influence of gravity. This aquifer may contain coarse, anorthositic sediment or turf clay sediment when underlain by anorthosite or gabbro-norite respectively;
  - Groundwater movement is predominantly associated with secondary structures in this aquifer (fractures, faults, dykes, etc.). Borehole yields in the Bushveld Complex fractured aquifers are generally low and can be expected to be between 0.1 and 2 L/s. These formations contain limited quantities of water resources due to the poor storage capacity of the igneous rock;
- Aquifer transmissivity:
  - The hydraulic conductivity of the upper weathered material aquifer ranges between 10^{-8} and 10^{-2} m/day, while the porosity ranges between 0.4 and 0.7 for turf clay sediments. The hydraulic conductivity of the coarse, anorthositic sediment can reach up to 20 m/day with porosities ranging between values of 0.25 to 0.5;
  - The expected hydraulic conductivity for igneous rock types, similar to those present in the Bushveld Complex, are 10^{-5} m/d.
- Groundwater levels:

  - The depth to groundwater level ranges between 19 and 56 mbgl. In general there groundwater levels in the area remain relatively constant over time;
  - Groundwater flow directions are directed from the higher lying areas towards the low-lying streams;
- Groundwater qualities:
  - In general the groundwater quality is good, with some individual parameters in individual samples exceeding the SANS241:2015 guideline values. Elements that exceed the guideline values are:
    - **Chloride:** The chloride concentrations at borehole BH4 (398 mg/L) and BH5 (393 mg/L) exceed the guideline value of 300 mg/L. At the measured concentrations no health impacts are expected. At concentrations between 200 and 600 mg/L the water has a distinctly salty taste. There is a likelihood of noticeable increase in corrosion rates in domestic appliances;
    - **Nitrate:** The nitrate concentrations in boreholes BH4 (37 mg/L) and BH6 (13.6 mg/L) exceed the guideline value of 11 mg/L. At concentrations greater than 10 mg/L methaemoglobinaemia may occur in infants. With increasing concentration to above 20 mg/L mucous membrane irritation in adults can occur;
    - **Manganese:** The manganese concentration in borehole BH8 measured 93.7 mg/L. This exceeds the SANS241:2015 guideline value of 0.4 mg/L by 2 orders of magnitude. It has to be stated that this value is anomalous as all other groundwater points measured below detection level. In addition, previous results at borehole BH8 from December 2018 and March 2019 showed manganese concentrations below detection limit of 0.025 mg/L. It is possible that this is a laboratory error;
    - **Chromium:** At borehole BH4 the total chromium measured 0.16 mg/L, which exceeds the SANS241:2015 guideline value of 0.05 mg/L
    - **Cadmium:** The cadmium concentration in borehole BH7 measured 0.02 mg/L. This exceeds the guideline value of 0.002 mg/L. As a precautionary measure it is recommended that concentrations of 0.005 mg/L not be exceeded due to the potentially acute and/or irreversible effects of cadmium on human health. A concentration of 0.02 mg/L is the threshold for health damage with continuous exposure. Single incidence of exposure will not have an observable effect. At concentrations greater than 0.02 mg/L there is a danger of kidney failure with long-term exposure (longer than 1 week);
    - **Lead:** The lead concentration in borehole BH8 measured 7.88 mg/L which exceeds the guideline value of 0.01 mg/L by 2 orders of magnitude. As was the case with manganese this value for borehole BH8 is anomalous as it does not compare to previous sampling runs at BH8 from December 2018 and March 2019 when the lead concentrations measured below detection limit. Results for all other boreholes included in the sampling program also show lead concentrations below detection limit at all times.
- Aquifer vulnerability:

  - For aquifer vulnerability reference is made to the aquifer vulnerability map of South Africa which shows a low aquifer vulnerability for the project area;
- Aquifer classification:
  - The aquifers present in the area are classified as minor aquifers. The aquifers are of high importance to the local landowners in as it is their only source of water for domestic, gardening, and agricultural purposes.

12.5. Impact assessment

12.5.1. Construction phase

- Moeijelijk Mine is already operational; therefore, there is no construction phase.

12.5.2. Operational phase

12.5.2.1. Groundwater inflow volumes into the opencast mine

- It is expected that the groundwater inflow volumes into the underground mine will increase during the initial 5 years of operations from around 40 m^3/day to approximately 170 m^3/day due to the increase in the mined out area and the associated increase in groundwater inflows. However, as the depth of mining below surface increases over time, and the aquifer potential decrease, it is expected that there will be little additional groundwater inflows into the underground mine as the mining progresses during the later years of the life of mine.

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028
Groundwater inflow volume (m^3/day)	40	70	100	130	170	170	170	170	170

12.5.2.2. Groundwater level drawdown and associated impacts on aquifers, wetlands and stream flow volumes

- During the life of operations the groundwater flow directions in the vicinity of the underground mine area will be directed toward the mine area. This is due to mine dewatering causing the groundwater levels to be drawn down towards the mine floor elevations. In addition to this, there a groundwater level drawdown cone will develop around the dewatering boreholes;
- The zone of influence of the groundwater level drawdown in the fractured rock aquifer can reach up to 450 m from the underground mine area. The cone of depression does not extend to the furthest southwestern point of the underground mine due to the depth of the

mine in that area (up to 655 m below surface) and the inactivity of the aquifers at that depth;

- Around the groundwater supply boreholes the zone of influence of the groundwater level drawdown can extend up to 575 m from the boreholes;
- There are a number of boreholes that fall within the groundwater level drawdown cone. However, the majority of these boreholes belong to the mine. The only privately owned borehole that fall within the drawdown cone is BH1. The borehole has been built over and is not in use anymore;
- The mine dewatering will not have a noticeable impact on the groundwater levels in the weathered material aquifer. This is due to a combination of:
  - The depth of the mining below surface (between 50 and 655 m);
  - The groundwater level in the region ranges between 19 and 56 mbgl. This indicates that the weathered material aquifer, which is in the order of 10 m thick, is dry in portions of the study area.
- The non-perennial streams in the area receive flows from surface runoff during rainfall events, and also from baseflow contribution from the weathered material aquifer. Due to the regional depth to groundwater level of at least 16 m it is expected that the baseflow contribution to the stream flow volumes will be a minor portion of the stream flow volumes;
- The mine dewatering will have no impact on the stream flow volumes.

12.5.2.3. Contaminant migration away from pollution sources

- It is assumed that with proper maintenance of mining vehicles and other operations related best practices there will be a limited impact on the groundwater quality from general surface activities;
- Geochemical modelling results show that the nitrate concentrations are high (501 mg/L) under the oxidizing conditions associated with the operational phase because nitrate is highly soluble and there are no sinks in this scenario. Nitrate can be removed from groundwater by denitrification, but this requires anaerobic conditions which are not anticipated to develop in unsaturated backfilled tailings. Chromium is predicted by geochemical modelling to be present exclusively as Cr^{6+} at a concentration of 0.3 mg/L
- Plumes can migrate up to 200 m from the surface stockpile footprint areas. Borehole BH1 fall within the plume migrating away from the overburden stockpile. As mentioned previously this borehole has been built over and is not in use anymore;
- Due to the groundwater level drawdown cone developing around the groundwater dewatering boreholes contamination migrating away from the discard dump will be drawn towards groundwater supply boreholes UGBH1 and UGBH2. Similarly, contamination migrating away from the topsoil stockpile will be drawn towards boreholes WPBH1 and WPBH2;
- The migrating plume will reach boreholes UGBH1 and UGBH2 during 2020, or at the latest before the end of 2021. The nitrate concentration at the boreholes will increase over time to a maximum of approximately 250 mg/L;
- The contaminant plume migrating away from the topsoil footprint is expected to reach boreholes WPBH1 and WPBH2 during 2024. The nitrate concentrations are expected to

reach a maximum of approximately 35 mg/L in WPBH1 and 50 mg/L in WPBH2. Please note that a source concentration of 501 mg/L nitrate was used for the topsoil stockpile. This is possibly an overestimation due to the leached nature of the material compared to the tailings material that was used to determine the source concentration;

- A short section (320 m) of one of the non-perennial streams is impacted by the pollution plume migrating away from the overburden stockpile. A 250 m section of a stream is impacted by the pollution plume migrating away from the topsoil stockpile. The impact on the overall stream qualities during the rainy season when the streams flow is less than 1 % based on the total length of the streams draining the mine area; and
- Groundwater flow patterns around the rehabilitated opencast areas will be directed towards the opencast mine areas due to the fact that the opencast mine areas are interlinked with the underground mine area via the decline shaft. This connection will drain the rehabilitated opencast areas into the underground mine and prevent the water levels within the rehabilitated opencast areas from recovering to near pre-mining levels, thereby containing contamination within the rehabilitated opencast areas. Therefore, there will be no general contaminant plumes migrating away from the opencast areas.

12.5.3. Decommissioning phase

- During the decommissioning phase the mine dewatering will stop. This will allow the groundwater level within the underground mine to start rising. However, due to the relatively short time period of the decommissioning phase (less than 1 year) it is not expected that the underground mine will become fully submerged, or that there will be significant contaminant migration away from the mine.

12.5.4. Long term post-closure phase

12.5.4.1. Recovery of groundwater levels and decant potential

- The recovering water levels will allow the groundwater flow patterns in the area to recover to near pre-mining levels. The time required for the water level in the underground mine to recover to near pre-mining levels is calculated to be approximately 18 years;
- Decant from the mining area will occur. The underground mine and the previous opencast mine areas are interconnected via the decline shaft. Therefore, once the underground mine and the rehabilitated opencast mine areas are submerged decant will start;
- The expected decant volume is calculated to be between 10 and 50 m^3/day depending on the quality of the rehabilitation of the opencast areas. Proper rehabilitation with re-established vegetation and proper sloping of the surface that prevent ponding of rainwater will reduce recharge into the rehabilitated opencast areas which in turn will reduce the decant volume; and
- Decant qualities are expected to reflect the results from the geochemical assessment. Nitrate concentrations can be up to 139 mg/L. Hexavalent chromium concentration can be 0.3 mg/L.

12.5.4.2. Contaminant migration away from pollution sources

- Contaminant migration will continue from the overburden and top soil stockpile footprint areas. In addition, contaminant migration away from the opencast and underground mine areas will start once a driving head is established by die rising water levels in the mining areas;
- The contaminant plume in the weathered material aquifer will migrate up to 1 500 m from the opencast mine areas. The plume migrates downgradient in a northern direction underneath the village. Four village boreholes are impacted by the migrating plume: The details of the boreholes are summarised in Table 5.6.
    - BH1: This borehole has been built over and is not in use anymore;
    - BH2: This borehole is at a residence. The borehole is used for domestic purposes. The borehole is not included in the monitoring program anymore;
    - BH7: The borehole is for communal use in Tsibeng village; and
    - BH8: The borehole is located at Matianyane Primary School.
- There is very little contaminant migration through the fractured rock aquifer away from the underground mine. This is due to the low expected aquifer activity at the depths of the underground mine (up to 655 m below surface).

Bibliography

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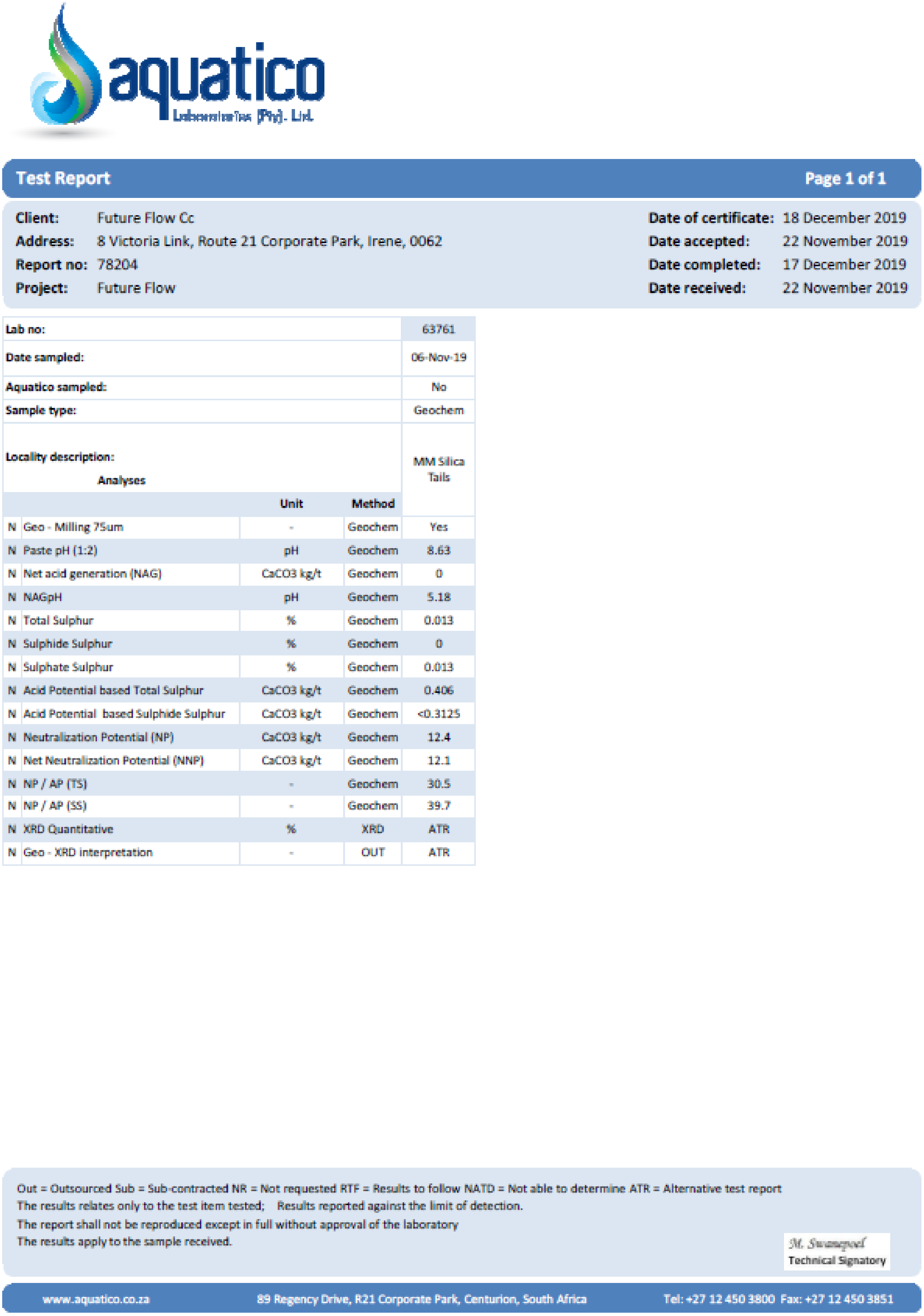
APPENDIX A:

GEOCHEMICAL ANALYSIS CERTIFICATE



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Test Report **Page 1 of 1**

Client: Future Flow Cc
Address: 8 Victoria Link, Route 21 Corporate Park, Irene, 0062
Report no: 78204
Project: Future Flow

Date of certificate: 18 December 2019
Date accepted: 22 November 2019
Date completed: 17 December 2019
Date received: 22 November 2019

Lab no:				63761
Date sampled:				06-Nov-19
Aquatico sampled:				No
Sample type:				Geochem
Locality description:				MM Silica Tails
	Analyses	**Unit**	**Method**	
N	Geo - Milling 75um	-	Geochem	Yes
N	Paste pH (1:2)	pH	Geochem	8.63
N	Net acid generation (NAG)	CaCO3 kg/t	Geochem	0
N	NAGpH	pH	Geochem	5.18
N	Total Sulphur	%	Geochem	0.013
N	Sulphide Sulphur	%	Geochem	0
N	Sulphate Sulphur	%	Geochem	0.013
N	Acid Potential based Total Sulphur	CaCO3 kg/t	Geochem	0.406
N	Acid Potential based Sulphide Sulphur	CaCO3 kg/t	Geochem	<0.3125
N	Neutralization Potential (NP)	CaCO3 kg/t	Geochem	12.4
N	Net Neutralization Potential (NNP)	CaCO3 kg/t	Geochem	12.1
N	NP / AP (TS)	-	Geochem	30.5
N	NP / AP (SS)	-	Geochem	39.7
N	XRD Quantitative	%	XRD	ATR
N	Geo - XRD interpretation	-	OUT	ATR

Out = Outsourced Sub = Sub-contracted NR = Not requested RTF = Results to follow NATD = Not able to determine ATR = Alternative test report
The results relates only to the test item tested; Results reported against the limit of detection.
The report shall not be reproduced except in full without approval of the laboratory
The results apply to the sample received.

M. Swanepoel
Technical Signatory

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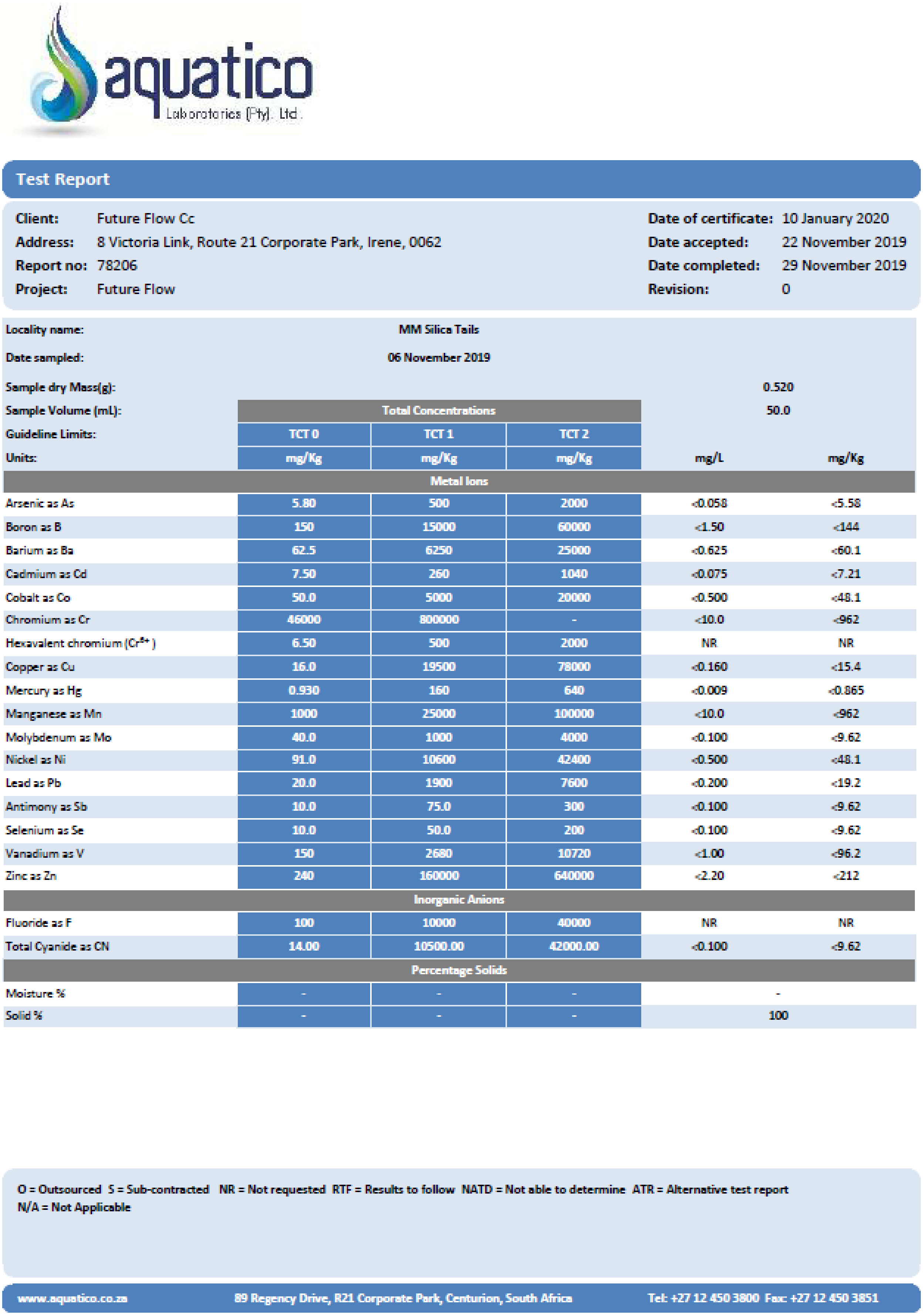

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Test Report

Client:	Future Flow Cc	**Date of certificate:**	10 January 2020
Address:	8 Victoria Link, Route 21 Corporate Park, Irene, 0062	**Date accepted:**	22 November 2019
Report no:	78206	**Date completed:**	29 November 2019
Project:	Future Flow	**Revision:**	0

Locality name:		**MM Silica Tails**			
Date sampled:		**06 November 2019**			
Sample dry Mass(g):				0.520	
Sample Volume (mL):	**Total Concentrations**			50.0	
Guideline Limits:	TCT 0	TCT 1	TCT 2		
Units:	mg/Kg	mg/Kg	mg/Kg	mg/L	mg/Kg
Metal Ions					
Arsenic as As	5.80	500	2000	<0.058	<5.58
Boron as B	150	15000	60000	<1.50	<144
Barium as Ba	62.5	6250	25000	<0.625	<60.1
Cadmium as Cd	7.50	260	1040	<0.075	<7.21
Cobalt as Co	50.0	5000	20000	<0.500	<48.1
Chromium as Cr	46000	800000	-	<10.0	<962
Hexavalent chromium (Cr^{6+})	6.50	500	2000	NR	NR
Copper as Cu	16.0	19500	78000	<0.160	<15.4
Mercury as Hg	0.930	160	640	<0.009	<0.865
Manganese as Mn	1000	25000	100000	<10.0	<962
Molybdenum as Mo	40.0	1000	4000	<0.100	<9.62
Nickel as Ni	91.0	10600	42400	<0.500	<48.1
Lead as Pb	20.0	1900	7600	<0.200	<19.2
Antimony as Sb	10.0	75.0	300	<0.100	<9.62
Selenium as Se	10.0	50.0	200	<0.100	<9.62
Vanadium as V	150	2680	10720	<1.00	<96.2
Zinc as Zn	240	160000	640000	<2.20	<212
Inorganic Anions					
Fluoride as F	100	10000	40000	NR	NR
Total Cyanide as CN	14.00	10500.00	42000.00	<0.100	<9.62
Percentage Solids					
Moisture %	-	-	-	-	
Solid %	-	-	-	100	

O = Outsourced S = Sub-contracted NR = Not requested RTF = Results to follow NATD = Not able to determine ATR = Alternative test report
N/A = Not Applicable

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Test Report

Client: Future Flow Cc
Address: 8 Victoria Link, Route 21 Corporate Park, Irene, 0062
Report no: 78206
Project: Future Flow

Date of certificate: 10 January 2020
Date accepted: 22 November 2019
Date completed: 29 November 2019
Revision: 0

Locality name:	**MM Silica Tails**				
Date sampled:	**06 November 2019**				
Sample dry Mass(g):				**0.520**	
Sample Volume (mL):	**Total Concentrations**			**50.0**	
Guideline Limits:	**TCT 0**	**TCT 1**	**TCT 2**		
Units:	**mg/Kg**	**mg/Kg**	**mg/Kg**	**mg/L**	**mg/Kg**
Variables					
Aluminium (Al)	-	-	-	20.9	2010
Iron as Fe	-	-	-	19.0	1827
Magnesium as Mg	-	-	-	NR	NR

O = Outsourced S = Sub-contracted NR = Not requested RTF = Results to follow NATD = Not able to determine ATR = Alternative test report
N/A = Not Applicable

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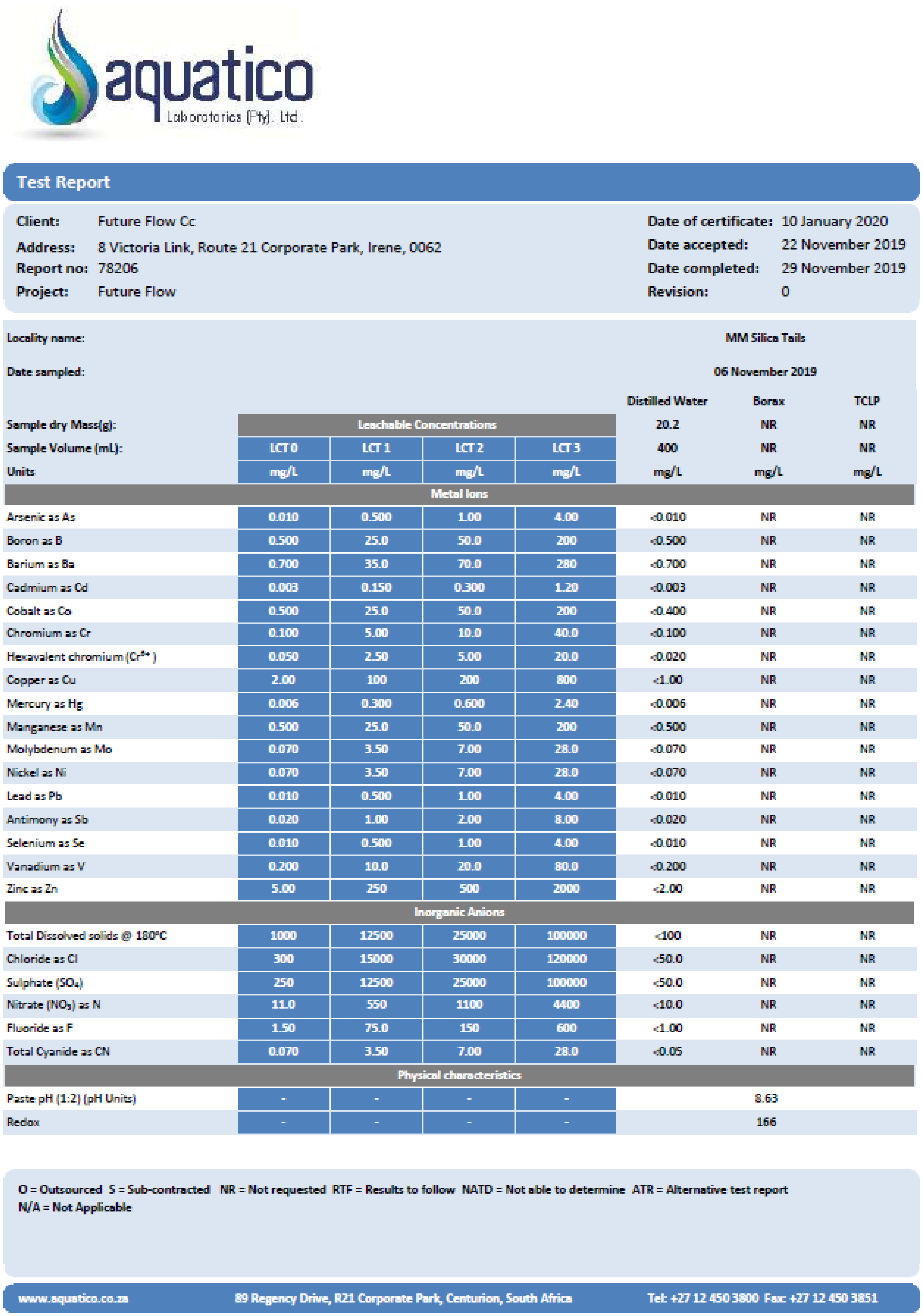

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Test Report

Client: Future Flow Cc
Address: 8 Victoria Link, Route 21 Corporate Park, Irene, 0062
Report no: 78206
Project: Future Flow

Date of certificate: 10 January 2020
Date accepted: 22 November 2019
Date completed: 29 November 2019
Revision: 0

Locality name:					MM Silica Tails		
Date sampled:					06 November 2019		
					Distilled Water	Borax	TCLP
Sample dry Mass(g):	Leachable Concentrations				20.2	NR	NR
Sample Volume (mL):	LCT 0	LCT 1	LCT 2	LCT 3	400	NR	NR
Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Metal Ions							
Arsenic as As	0.010	0.500	1.00	4.00	<0.010	NR	NR
Boron as B	0.500	25.0	50.0	200	<0.500	NR	NR
Barium as Ba	0.700	35.0	70.0	280	<0.700	NR	NR
Cadmium as Cd	0.003	0.150	0.300	1.20	<0.003	NR	NR
Cobalt as Co	0.500	25.0	50.0	200	<0.400	NR	NR
Chromium as Cr	0.100	5.00	10.0	40.0	<0.100	NR	NR
Hexavalent chromium (Cr^{6+})	0.050	2.50	5.00	20.0	<0.020	NR	NR
Copper as Cu	2.00	100	200	800	<1.00	NR	NR
Mercury as Hg	0.006	0.300	0.600	2.40	<0.006	NR	NR
Manganese as Mn	0.500	25.0	50.0	200	<0.500	NR	NR
Molybdenum as Mo	0.070	3.50	7.00	28.0	<0.070	NR	NR
Nickel as Ni	0.070	3.50	7.00	28.0	<0.070	NR	NR
Lead as Pb	0.010	0.500	1.00	4.00	<0.010	NR	NR
Antimony as Sb	0.020	1.00	2.00	8.00	<0.020	NR	NR
Selenium as Se	0.010	0.500	1.00	4.00	<0.010	NR	NR
Vanadium as V	0.200	10.0	20.0	80.0	<0.200	NR	NR
Zinc as Zn	5.00	250	500	2000	<2.00	NR	NR
Inorganic Anions							
Total Dissolved solids @ 180°C	1000	12500	25000	100000	<100	NR	NR
Chloride as Cl	300	15000	30000	120000	<50.0	NR	NR
Sulphate (SO_4)	250	12500	25000	100000	<50.0	NR	NR
Nitrate (NO_3) as N	11.0	550	1100	4400	<10.0	NR	NR
Fluoride as F	1.50	75.0	150	600	<1.00	NR	NR
Total Cyanide as CN	0.070	3.50	7.00	28.0	<0.05	NR	NR
Physical characteristics							
Paste pH (1:2) (pH Units)	-	-	-	-	8.63		
Redox	-	-	-	-	166		

O = Outsourced S = Sub-contracted NR = Not requested RTF = Results to follow NATD = Not able to determine ATR = Alternative test report
N/A = Not Applicable

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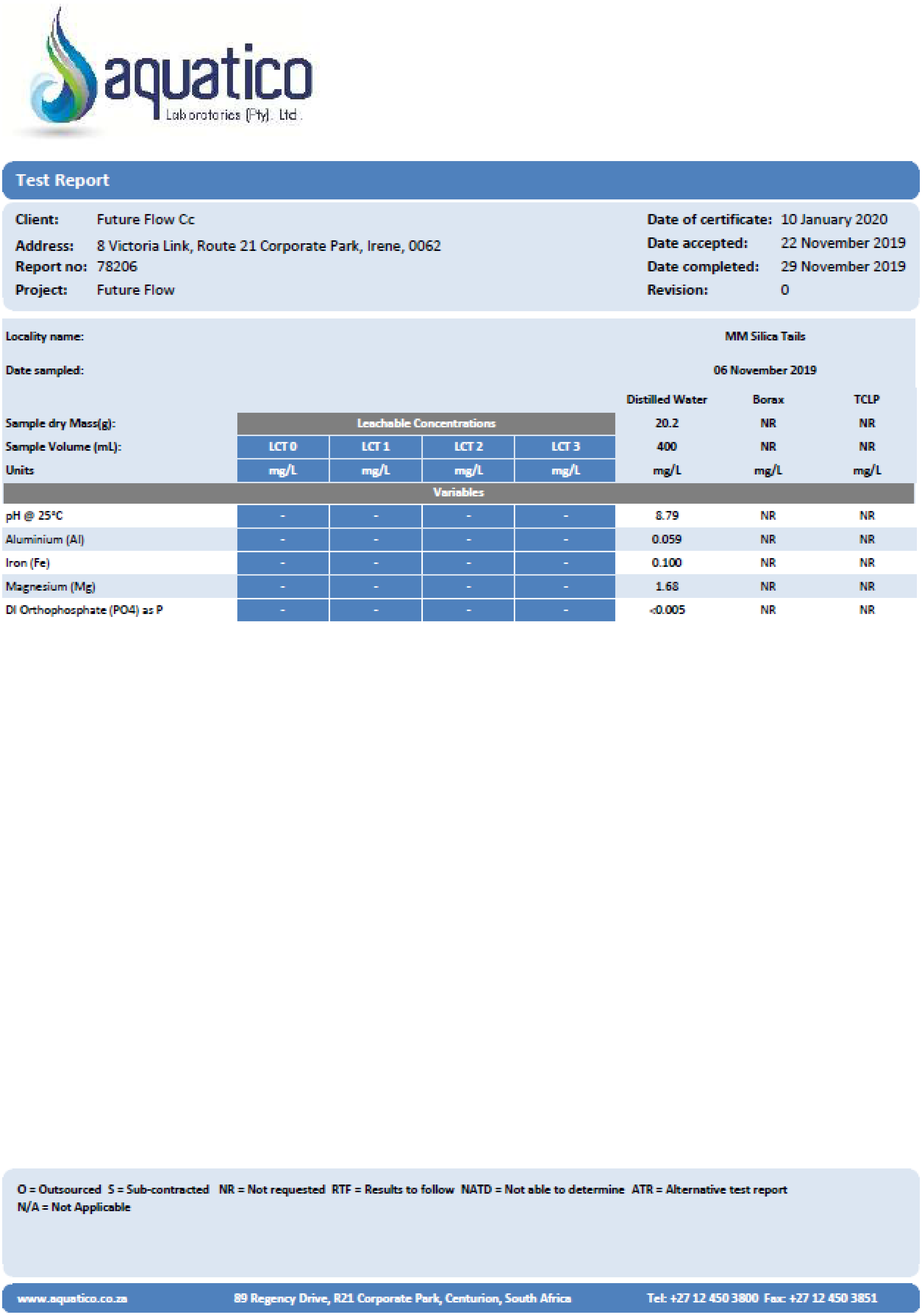

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Test Report

Client: Future Flow Cc
Address: 8 Victoria Link, Route 21 Corporate Park, Irene, 0062
Report no: 78206
Project: Future Flow

Date of certificate: 10 January 2020
Date accepted: 22 November 2019
Date completed: 29 November 2019
Revision: 0

Locality name: MM Silica Tails
Date sampled: 06 November 2019

	Leachable Concentrations				Distilled Water	Borax	TCLP
Sample dry Mass(g):					20.2	NR	NR
Sample Volume (mL):	LCT 0	LCT 1	LCT 2	LCT 3	400	NR	NR
Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Variables							
pH @ 25°C	-	-	-	-	8.79	NR	NR
Aluminium (Al)	-	-	-	-	0.059	NR	NR
Iron (Fe)	-	-	-	-	0.100	NR	NR
Magnesium (Mg)	-	-	-	-	1.68	NR	NR
DI Orthophosphate (PO4) as P	-	-	-	-	<0.005	NR	NR

O = Outsourced S = Sub-contracted NR = Not requested RTF = Results to follow NATD = Not able to determine ATR = Alternative test report
N/A = Not Applicable

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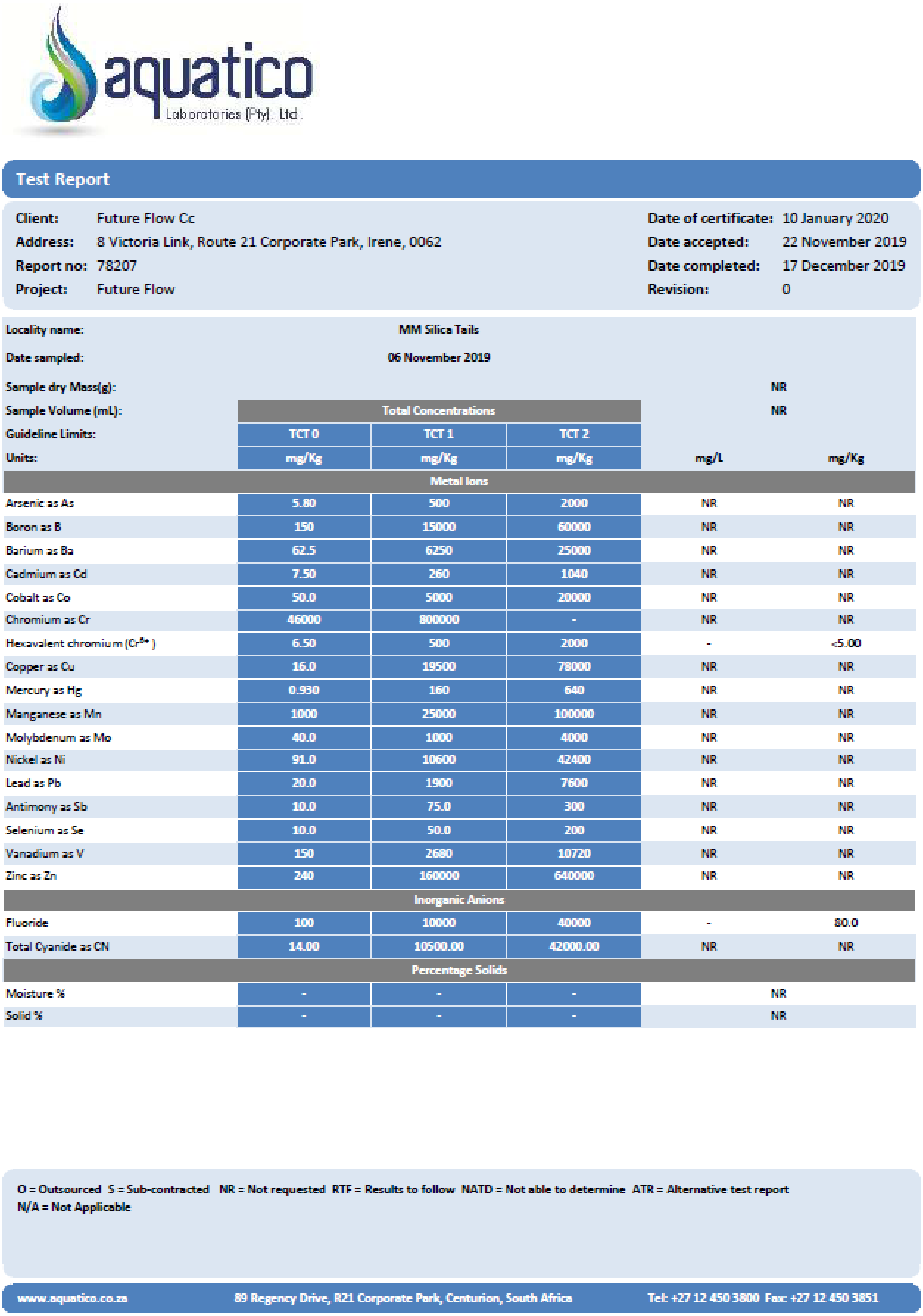

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Test Report

Client: Future Flow Cc
Address: 8 Victoria Link, Route 21 Corporate Park, Irene, 0062
Report no: 78207
Project: Future Flow

Date of certificate: 10 January 2020
Date accepted: 22 November 2019
Date completed: 17 December 2019
Revision: 0

Locality name:		**MM Silica Tails**			
Date sampled:		**06 November 2019**			
Sample dry Mass(g):				NR	
Sample Volume (mL):	**Total Concentrations**			NR	
Guideline Limits:	**TCT 0**	**TCT 1**	**TCT 2**		
Units:	**mg/Kg**	**mg/Kg**	**mg/Kg**	**mg/L**	**mg/Kg**
Metal Ions					
Arsenic as As	5.80	500	2000	NR	NR
Boron as B	150	15000	60000	NR	NR
Barium as Ba	62.5	6250	25000	NR	NR
Cadmium as Cd	7.50	260	1040	NR	NR
Cobalt as Co	50.0	5000	20000	NR	NR
Chromium as Cr	46000	800000	-	NR	NR
Hexavalent chromium (Cr^{6+})	6.50	500	2000	-	<5.00
Copper as Cu	16.0	19500	78000	NR	NR
Mercury as Hg	0.930	160	640	NR	NR
Manganese as Mn	1000	25000	100000	NR	NR
Molybdenum as Mo	40.0	1000	4000	NR	NR
Nickel as Ni	91.0	10600	42400	NR	NR
Lead as Pb	20.0	1900	7600	NR	NR
Antimony as Sb	10.0	75.0	300	NR	NR
Selenium as Se	10.0	50.0	200	NR	NR
Vanadium as V	150	2680	10720	NR	NR
Zinc as Zn	240	160000	640000	NR	NR
Inorganic Anions					
Fluoride	100	10000	40000	-	80.0
Total Cyanide as CN	14.00	10500.00	42000.00	NR	NR
Percentage Solids					
Moisture %	-	-	-	NR	
Solid %	-	-	-	NR	

O = Outsourced S = Sub-contracted NR = Not requested RTF = Results to follow NATD = Not able to determine ATR = Alternative test report
N/A = Not Applicable

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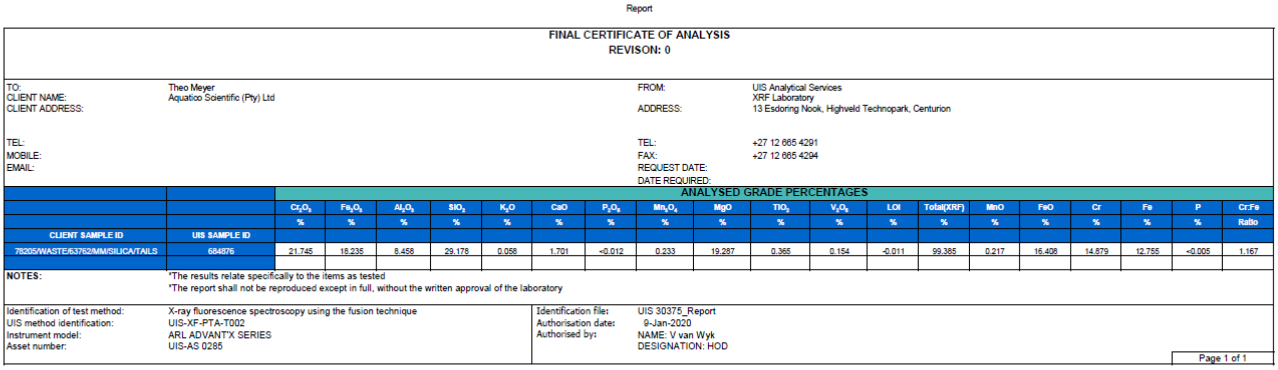


Report

FINAL CERTIFICATE OF ANALYSIS
REVISON: 0

TO: Theo Meyer
CLIENT NAME: Aquatico Scientific (Pty) Ltd
CLIENT ADDRESS:

TEL:
MOBILE:
EMAIL:

FROM: UIS Analytical Services
XRF Laboratory
ADDRESS: 13 Esdoring Nook, Highveld Technopark, Centurion

TEL: +27 12 665 4291
FAX: +27 12 665 4294
REQUEST DATE:
DATE REQUIRED:

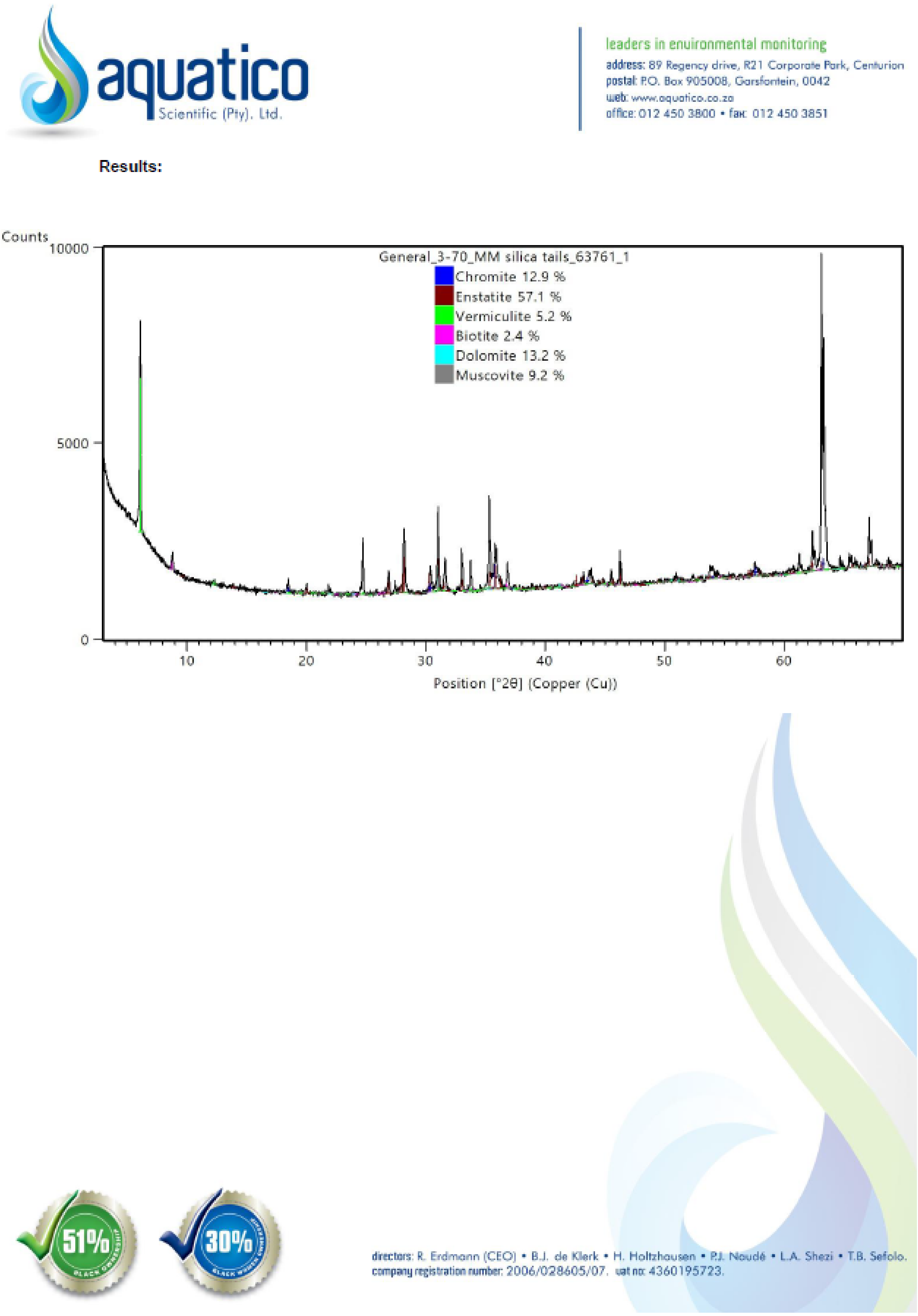
		ANALYSED GRADE PERCENTAGES																		
		Cr_2O_3	Fe_2O_3	Al_2O_3	SiO_2	K_2O	CaO	P_2O_5	Mn_3O_4	MgO	TiO_2	V_2O_5	LOI	Total(XRF)	MnO	FeO	Cr	Fe	P	Cr:Fe
		%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	Ratio
CLIENT SAMPLE ID	**UIS SAMPLE ID**																			
78205/WASTE/63762/MM/SILICA/TAILS	684876	21.745	18.235	8.458	29.178	0.058	1.701	<0.012	0.233	19.287	0.365	0.154	-0.011	99.385	0.217	16.408	14.879	12.755	<0.005	1.167

NOTES:
*The results relate specifically to the items as tested
*The report shall not be reproduced except in full, without the written approval of the laboratory

Identification of test method: X-ray fluorescence spectroscopy using the fusion technique
UIS method identification: UIS-XF-PTA-T002
Instrument model: ARL ADVANT'X SERIES
Asset number: UIS-AS 0285

Identification file: UIS 30375_Report
Authorisation date: 9-Jan-2020
Authorised by: NAME: V van Wyk
DESIGNATION: HOD

Page 1 of 1



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leaders in environmental monitoring
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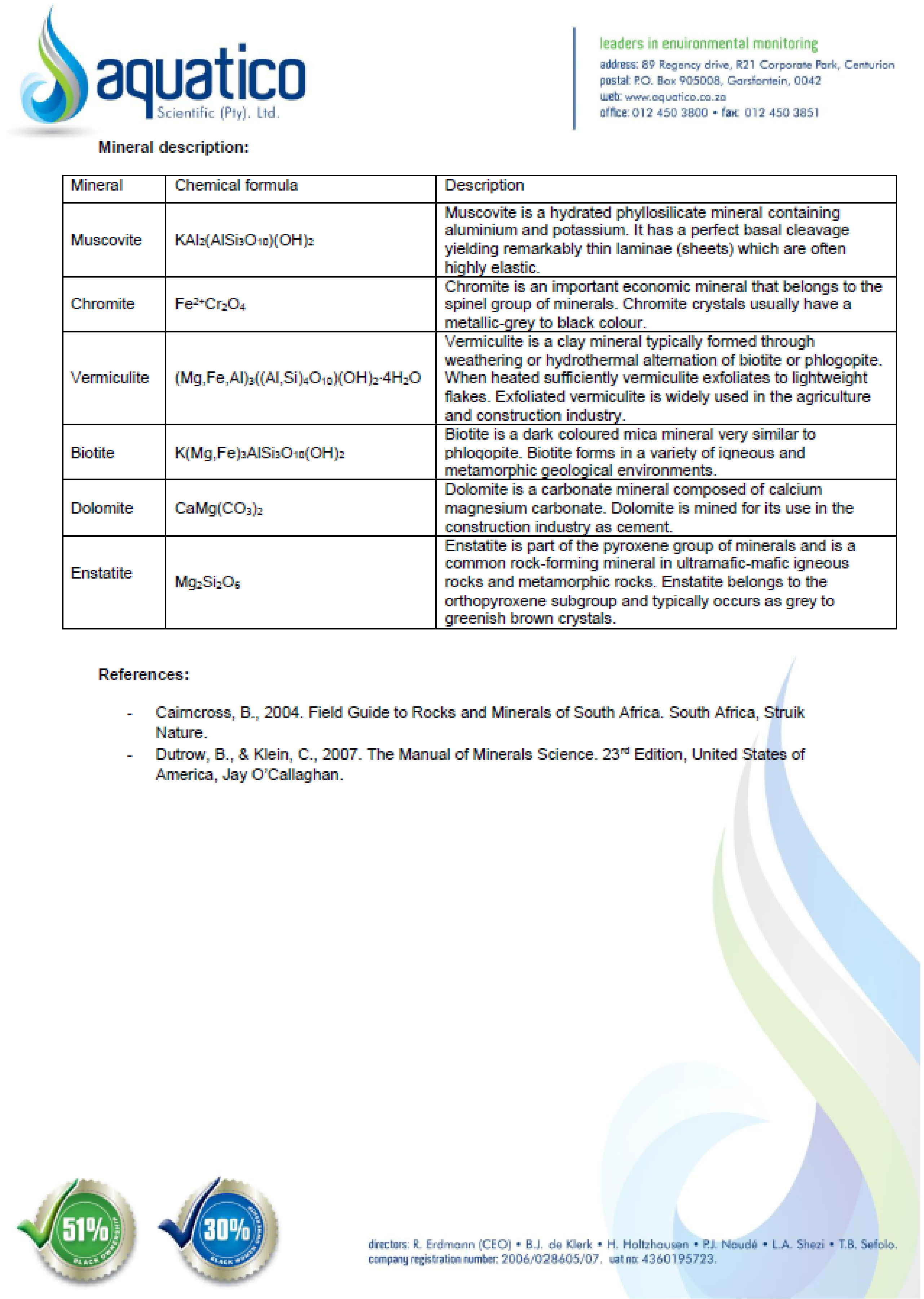
postal: P.O. Box 905008, Garsfontein, 0042
web: www.aquatico.co.za
office: 012 450 3800 • fax: 012 450 3851

Results:

directors: R. Erdmann (CEO) • B.J. de Klerk • H. Holtzhausen • P.J. Naudé • L.A. Shezi • T.B. Sefolo.
company registration number: 2006/028605/07. vat no: 4360195723.



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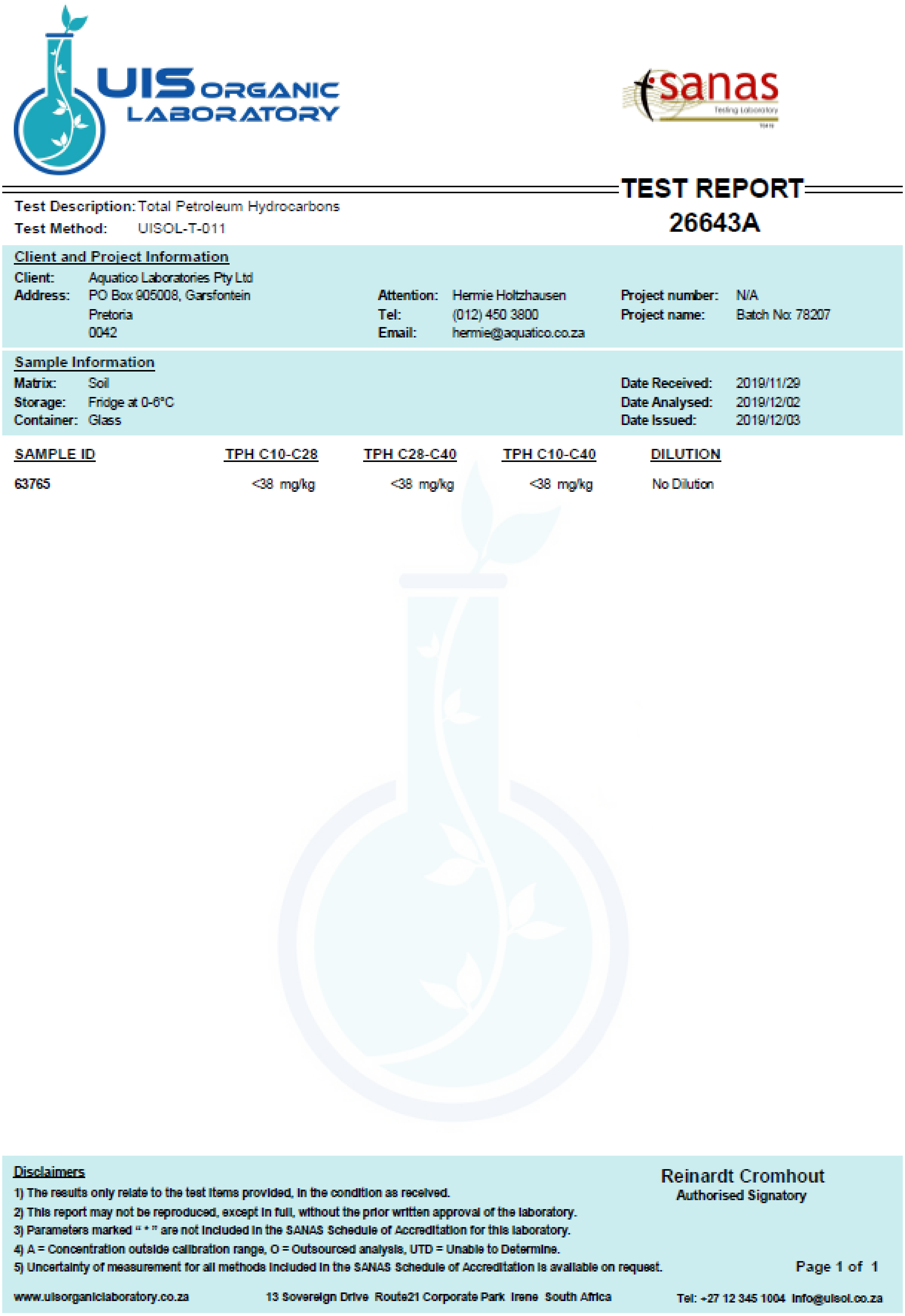
web: www.aquatico.co.za
office: 012 450 3800 • fax: 012 450 3851

Mineral description:

Mineral	Chemical formula	Description
Muscovite	$KAl_2(AlSi_3O_{10})(OH)_2$	Muscovite is a hydrated phyllosilicate mineral containing aluminium and potassium. It has a perfect basal cleavage yielding remarkably thin laminae (sheets) which are often highly elastic.
Chromite	$Fe^{2+}Cr_2O_4$	Chromite is an important economic mineral that belongs to the spinel group of minerals. Chromite crystals usually have a metallic-grey to black colour.
Vermiculite	$(Mg,Fe,Al)_3((Al,Si)_4O_{10})(OH)_2\cdot 4H_2O$	Vermiculite is a clay mineral typically formed through weathering or hydrothermal alternation of biotite or phlogopite. When heated sufficiently vermiculite exfoliates to lightweight flakes. Exfoliated vermiculite is widely used in the agriculture and construction industry.
Biotite	$K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$	Biotite is a dark coloured mica mineral very similar to phlogopite. Biotite forms in a variety of igneous and metamorphic geological environments.
Dolomite	$CaMg(CO_3)_2$	Dolomite is a carbonate mineral composed of calcium magnesium carbonate. Dolomite is mined for its use in the construction industry as cement.
Enstatite	$Mg_2Si_2O_6$	Enstatite is part of the pyroxene group of minerals and is a common rock-forming mineral in ultramafic-mafic igneous rocks and metamorphic rocks. Enstatite belongs to the orthopyroxene subgroup and typically occurs as grey to greenish brown crystals.

References:

- Cairncross, B., 2004. Field Guide to Rocks and Minerals of South Africa. South Africa, Struik Nature.
- Dutrow, B., & Klein, C., 2007. The Manual of Minerals Science. 23rd Edition, United States of America, Jay O'Callaghan.



UIS ORGANIC LABORATORY

sanas
Testing Laboratory

TEST REPORT

26643A

Test Description: Total Petroleum Hydrocarbons
Test Method: UISOL-T-011

Client and Project Information

Client: Aquatico Laboratories Pty Ltd
Address: PO Box 905008, Garsfontein
Pretoria
0042

Attention: Hermie Holtzhausen
Tel: (012) 450 3800
Email: hermie@aquatico.co.za

Project number: N/A
Project name: Batch No: 78207

Sample Information

Matrix: Soil
Storage: Fridge at 0-6°C
Container: Glass

Date Received: 2019/11/29
Date Analysed: 2019/12/02
Date Issued: 2019/12/03

SAMPLE ID	TPH C10-C28	TPH C28-C40	TPH C10-C40	DILUTION
63765	<38 mg/kg	<38 mg/kg	<38 mg/kg	No Dilution

Disclaimers
1) The results only relate to the test items provided, in the condition as received.
2) This report may not be reproduced, except in full, without the prior written approval of the laboratory.
3) Parameters marked " * " are not included in the SANAS Schedule of Accreditation for this laboratory.
4) A = Concentration outside calibration range, O = Outsourced analysis, UTD = Unable to Determine.
5) Uncertainty of measurement for all methods included in the SANAS Schedule of Accreditation is available on request.

Reinardt Cromhout
Authorised Signatory

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APPENDIX B:

GEOCHEMICAL ASSESSMENT REPORT (MILLS WATER)

Source terms for backfilled tailings, Moeijelijk Mine

6 February 2020

Prepared by Dr Meris Mills - Mills Water

Source terms for backfilled tailings, Moeijelijk Mine

6 February 2020

1. Introduction

Mills Water was requested by Future Flow GPMS cc to undertake a geochemical assessment and geochemical modelling for Bauba Platinum's Moeijelijk Mine in Limpopo. The objective of the assessment is to predict long term environmental behaviour and contaminant release from tailings material, referred to as Silica Tails, which has been backfilled into opencast mine voids.

The backfilling process is as follows: tailings are pumped from the plant and deposited onto a wet tailings pad. Run-off water from the pad is collected and re-used in the plant. Once the material has a water content of <6%, it is transported by truck to the dry tailings stockpile, from where it is trucked to the opencast area for backfilling. On completion of backfilling, a 30 to 60 cm thick layer of overburden will be placed over the tailings, and a 30 to 60 cm thick layer of topsoil will be placed over the overburden.

During mine operation, water infiltrating into the backfilled opencast mine areas will drain into the underground mine because the opencast areas are connected to the underground mine through a decline shaft. Water entering the underground mine is pumped to surface, therefore any impacted groundwater is contained. On closure of the underground mine and recovery of groundwater levels, it is predicted that there will be decant from the opencast areas. It is also predicted that a contaminant plume will develop in the weathered aquifer, migrating towards the Tsibeng village.

This report focusses on interpretation of geochemical data and geochemical modelling to predict the quality of water that may be expected to be generated in backfilled material, and to provide source terms for use in contaminant transport modelling.

2. Methodology

2.1. Sampling and analysis

A single composite tailings sample, called "Silica tails" was provided by the client. The sample was analysed by Aquatico for all analytes except XRF, which was completed by UIS. Both laboratories are SANAS accredited laboratory. The analyses conducted were as follows:

- Acid Base Accounting (ABA) – this is a set of simple analytical procedures for screening rocks to determine their potential to become acid producing, and includes assessment of:
    - Paste pH - a measure of the pH of the crushed sample (< 300 mm) in a slurry with distilled water which provides a rapid measure of the current geochemical condition of the sample due to the presence of weathering products on the surfaces, and ion exchange (Usher et. al., 2003). An acidic (<5) paste pH indicates potential for acid generation;

  - Total sulphur (wt %) - a first level screening parameter for ARD potential. Total sulphur concentrations below 0.30 % are believed to be too low to sustain acid generation;
  - Sulphur speciation – breakdown of total sulphur concentration into sulphide sulphur and sulphate sulphur. Sulphides are capable of generating ARD, whereas sulphates are less likely to produce acid but contribute to saline mine drainage.
  - Neutralising Potential (NP; kg $CaCO_3$ equivalent per t) - a measure of the potential of the rock material to neutralise acidity that it produces. It measures the buffering capacity present in the rock due to carbonate and other minerals by titrating the sample with an acid.

- The measured ABA parameters are used to calculate the following variables:
  - Acid Potential (AP; kg $CaCO_3$ equivalent per t) - a measure of the potential of the rock material to produce acid calculated by multiplying the total S by 31.25 (Usher et al., 2003). Using the total S concentration instead of the sulphide S concentration can overestimate the potential for ARD as some S may be present as sulphate or in organic components of the rock;
  - Net neutralisation potential (NNP; kg $CaCO_3$ equivalent per t): NNP = NP – AP
    NNP < 0 indicates that the sample has the potential to generate acid, and NNP > 0 indicates that the sample has the potential to neutralise the acid produced. In reality, NNP values between -20 and 20 are indeterminate i.e. could be acid producing or acid neutralising (Usher et. al., 2003);
  - Neutralising potential ratio (NPR) – the ratio of NP to AP. An NPR <1 indicates a potentially acid forming rock, and an NPR >4 indicates a non-acid forming rock. An NPR between 1 and 4 is indeterminate, and further tests would be required to establish whether there is potential for ARD.

- Net acid generation (NAG) – The sample is reacted with hydrogen peroxide to force total oxidation of sulphides present in the sample. The resulting pH is measured, as well as the quantity of acid generated. A NAG pH of <4.5 is considered to indicate a risk of acid generation.

- X-ray diffraction (XRD) – the mineralogical composition of the materials is identified using XRD. The relative proportions of the minerals can be estimated, however it should be noted that phases that constitute <0.5 - 3% of the material may not be detected.

- Total chemistry – major element chemistry is determined by x-ray fluorescence (XRF) on a whole rock samples, while for trace elements, the sample is digested in strong acid and then analysed to determine the total major and trace element composition of the material.

- Leachable chemistry – 20 g of dry fine sample material is mixed with 400 L of distilled water for 24 hours, and the water is then extracted and analysed for major and trace elements. The results indicate the presence of soluble salts on the material surfaces which are generated through weathering of the rocks.

2.2. Geochemical modelling

Geochemical modelling was undertaken using the PHREEQC modelling program (Parkhurst and Appelo, 2013) version 3.4.0.12927. PHREEQC allows modelling of low-temperature aqueous geochemical reactions and can be used to model speciation, saturation indices, kinetics, mixing, inverse modelling and one-dimensional transport. Details of specific models are described in the text.

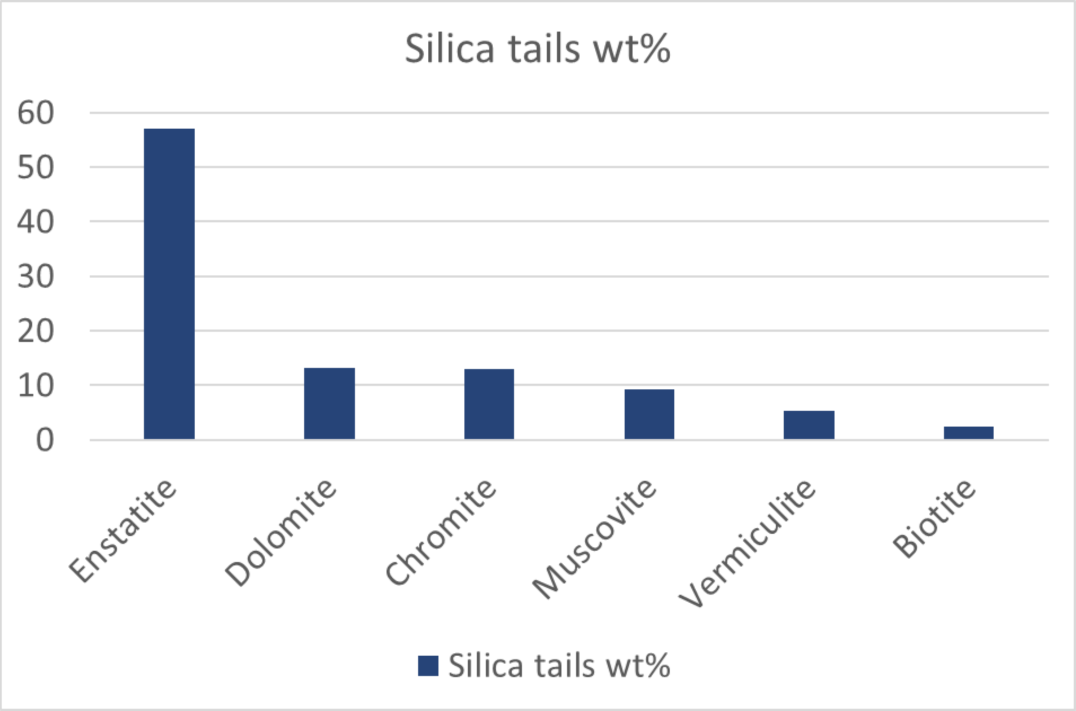
3. Analytical Results

Full laboratory certificates are provided in Annex A.

3.1. Mineralogy

The silica tails are comprised predominantly (57%) of the mineral enstatite ($MgSiO_3$), a magnesium-rich pyroxene mineral. Dolomite ($CaMg(CO_3)_2$) and chromite ($FeCr_2O_4$) each make up about 13% of the material, the remainder composed of mica minerals, muscovite and biotite, and the clay mineral, vermiculite (Figure 1).

Figure 1: Mineralogy of the silica tails



With time, enstatite is likely to weather to clay minerals, such as talc or vermiculite (Wilson, 2004). Chromite has very low solubility under most geological and industrial refining conditions and there are few natural oxidants for Cr^{3+}. However, manganese oxide minerals, such as birnessite, can oxidize Cr^{3+} to Cr^{6+} in natural environments (Oze et al., 2007).

3.2. Acid base accounting

Acid base accounting provides an indication of the potential risk of the development of ARD. The silica tails are classified according to a simple system modified from Price (2009) and Usher et al. (2003) which classifies samples as Type I to Type IV based on combinations of criteria and experience. The silica tails are classified as Type IV i.e. no risk of acid generation, because sulphide sulphur was not detected (Table 1). The sulphur in the sample takes the form of sulphate, which can potentially be leached from the tailings by rainwater, resulting in sulphate occurring in leachate from the silica tails.

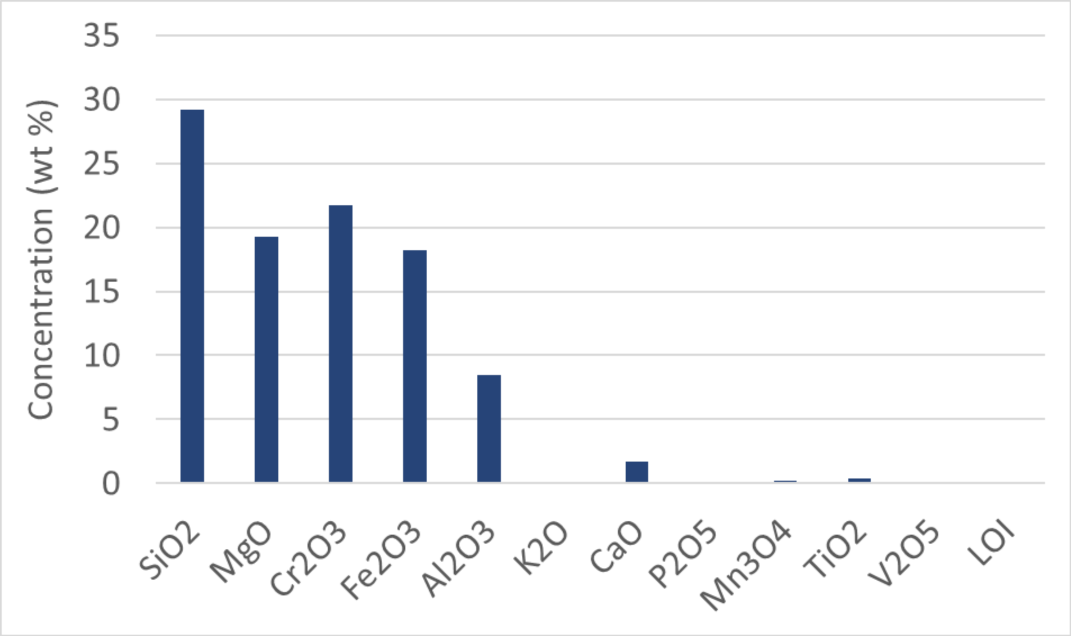
Table 1 ABA results for material samples

Sample ID	**Total S%**	**Sulphide S%**	**Sulphate S%**	**Paste pH**	**AP from sulphide S (kg/t CaCO3)**	**NP (kg/t CaCO3)**	**NPR**	**NNP**	**Type**	**Comment**
Screening criteria	>0.3	>0.3		<5			<1	<-20	Type I: High	
	0.2 - 0.3	0.2 - 0.3		<7			1 - 2	-20 - 0	Type II: Possible/uncertain	
	0.01 - 0.2	0.01 - 0.2		>7			2 - 4	0 - 20	Type III: Low/uncertain	
	<0.1	<0.1		>7			>4	>20	Type IV: No risk	
Silica tails	0.013	bdl	0.013	8.6	bdl	12.4	39.7	12.4	IV	No sulphide S, no AP

3.3. Total concentrations

The major oxide content of the silica tailings is dominated by silica, magnesium, chrome and iron, with lesser amounts of calcium and manganese (Figure 2).

Figure 2: Major elemental content of silica tails



Apart from fluoride, the reported trace element concentrations are below detection limits (Table 2). Fluoride was detected at 80 mg/kg. Two things to note are:

- Chromite does not readily dissolve in the acid solution used to determine total trace elemental concentrations. Therefore trace elements associated with chromite would not be detected by this method. This effect can clearly be seen because the XRF-measured Cr is 14.879 wt%, equating to 148 790 mg/kg, and XRD reports 13 wt% chromite, equating to 78 022 mg/kg Cr, yet, <962 mg/kg is reported in the total trace element concentrations. Assuming the chromite in the silica tailings is stable and does not weather on backfilling, this is not a concern. However, low concentrations of total CrT and Cr6+ have been detected in process water, suggesting that chromite may be slightly soluble under the site conditions.
- The laboratory detection limits for some of the trace elements are high e.g. the detection limit for manganese is 962 mg/kg.

The measured concentrations for trace elements in the whole rock are less than the waste assessment TCT0 limits (Table 2).

Table 2 Total and leachable concentrations compared to waste assessment threshold values

	Total concentrations				**Leachable concentrations**	
	TCT0 mg/kg	**TCT1 mg/kg**	**Silica tails mg/kg (acid leach)**	**Silica tails mg/kg (XRF)**	**LCT0 mg/L**	**Silica tails mg/L**
As	5.8	500	<5.58		0.01	<0.01
B	150	15 000	<144		0.5	<0.5
Ba	62.5	6 250	<60.1		0.7	<0.7
Cd	7.5	260	<7.21		0.003	<0.003
Co	50	5 000	<48.1		0.5	<0.4
Cr	46 000	800 000	<962	**148 778**	0.1	<0.1
Cr6+	6.5	500	<5		0.05	<0.02
Cu	16	19 500	<15.4		2	<1
Hg	0.93	160	<0.865		0.006	<0.06
Mn	1 000	25 000	<962	**1 678**	0.5	<0.5
Mo	40	1 000	<9.62		0.07	<0.07
Ni	91	10 600	<48.1		0.07	<0.07
Pb	20	1 900	<19.2		0.01	<0.01
Sb	10	75	<9.62		0.02	<0.02
Se	10	50	<9.62		0.01	<0.01
V	150	2 680	<96.2	**863**	0.2	<0.2
Zn	240	160 000	<212		5	<2
TDS					1000	<100
Cl					300	<50
SO_4					250	<50
NO_3					11	<10
F	100	10 000	80		1.5	<1
CN	14	10 500	<9.62		0.07	<0.05

3.4. Leachate chemistry

The results from the 1:20 distilled water leach of the silica tails are shown in Table 2 compared to the waste assessment LCT0s. The measured trace element and anion concentrations for the silica tails are all below detection limits, which are below their respective LCT0s. Again, it should be noted that for many elements the detection limits are unusually high e.g. sulphate detection limit is 50 mg/L, therefore no detection does not mean that there is no sulphate present. As the TCs are less than the TCT0s, and the LCs are less than the LCT0s, the waste is assessed as a Type 4 waste. It should be noted that if the XRF chromium, vanadium and manganese values are used in place of the acid digest value, the waste would be classified as a Type 3 waste as the XRF values are between the TCT0 and the TCT1.

4. Development of source terms

4.1. Contaminants of concern

To supplement the leach test results which indicated a large number of elements below detection limit, it was decided to also reference the site water quality data to estimate the potential for leaching from the tailings material. Process water that is used to transport the tailings will have interacted with the tailings and will have a chemistry related to the tailings. In addition, on drying of the tailings, salts precipitating from the entrained process water will contribute to the contaminants that can leach from the tailings once backfilled.

The average plant return water (TRW) quality is given in Table 3. The average background groundwater quality (from upstream monitoring well MonBH1) is also given so that the difference in water quality due to the process and interactions with tailings can be identified. The ratio between the average process water and the average background groundwater is calculated to highlight those parameters which are highly enriched in the process water and could therefore pose a risk of contaminating groundwater. The parameters which have concentrations more than 10 times higher in the process water than in the background groundwater are Na, K, NH_3, NO_3^- and NO_2^-. Sulphate and chloride are around 5 times more concentrated and cadmium, chromium and Cr^{6+} are about twice as concentrated in the process water than the background groundwater. The values are also compared to SANS241:2015 drinking water limits in order to identify parameters that could pose a risk to users of groundwater for domestic purposes should they enter groundwater.

Table 3 Average process and background groundwater concentrations compared to SANS241

Analyte	Units	Average plant return water (TRW) (n=3)	Average background groundwater (MonBH1) (n=7)	Ratio process water : background groundwater	SANS241:2015
pH	-	7.9	7.5		5 – 9.7
Na	mg/L	177	16	***11***	200*
K	mg/L	9.7	1.0	***10***	-
Ca	mg/L	60	51	1.2	-
Mg	mg/L	43	62	0.7	-
NH_3	mg/L as N	***3.5***	0.2	***20***	1.5*

Analyte	**Units**	**Average plant return water (TRW) (n=3)**	**Average background groundwater (MonBH1) (n=7)**	**Ratio process water : background groundwater**	**SANS241:2015**
Cl	mg/L	103	24	4.3	300*
SO_4	mg/L	131	24	5.5	250*
NO_3	mg/L as N	***99***	2.8	***35***	11
NO_2	mg/L as N	0.9	0.1	***30***	0.9
Alkalinity (estimated)	mg/L as CaCO3	702	530	1.3	
Al	mg/L	***0.450***	0.549	0.8	0.300*
Ba	mg/L	0.025	0.015	1.7	0.700
B	mg/L	0.085	0.028	3.0	2.400
Cd	mg/L	***0.008***	<0.003	2.7	0.003
CrT	mg/L	***0.060***	0.029	2.0	0.050
Cr^{6+}	mg/L	0.019	<0.010	1.9	
Fe	mg/L	***0.330***	***0.416***	0.8	0.300*
Mn	mg/L	0.034	0.045	0.8	0.100*
Pb	mg/L	<0.01	<0.01	1.0	0.010
V	mg/L	<0.01	0.034	0.3	

* Value is determined on an aesthetic or operational basis, and it not an acute or chronic health risk.

Chromium was detected in process water and groundwater. The concentrations of total chromium in groundwater are generally below the SANS241 limit (with two exceptions), but it should be noted that most of the detected chromium occurs as Cr^{6+} (Figure 3). In contrast, chromium detected in the process water appears to occur mostly as Cr^{3+} (Figure 3). It is clear that chromium can be mobilised into groundwater as Cr^{6+}, and therefore it is considered to be a potential contaminant of concern.

Based on analytical results, nitrogen occurs in process water and in groundwater predominantly as nitrate (Figure 4). Nitrite and ammonia concentrations are close to detection limits in the groundwater, and nitrite is close to detection in the process water, so they are not apparent on the graph.

Given the potential health risks associated with nitrate and Cr^{6+} and their presence in both site process water and groundwater, they are considered to be potential contaminants of concern.

Figure 3 Concentrations of CrT and Cr6+ in groundwater (top) and process water (bottom).

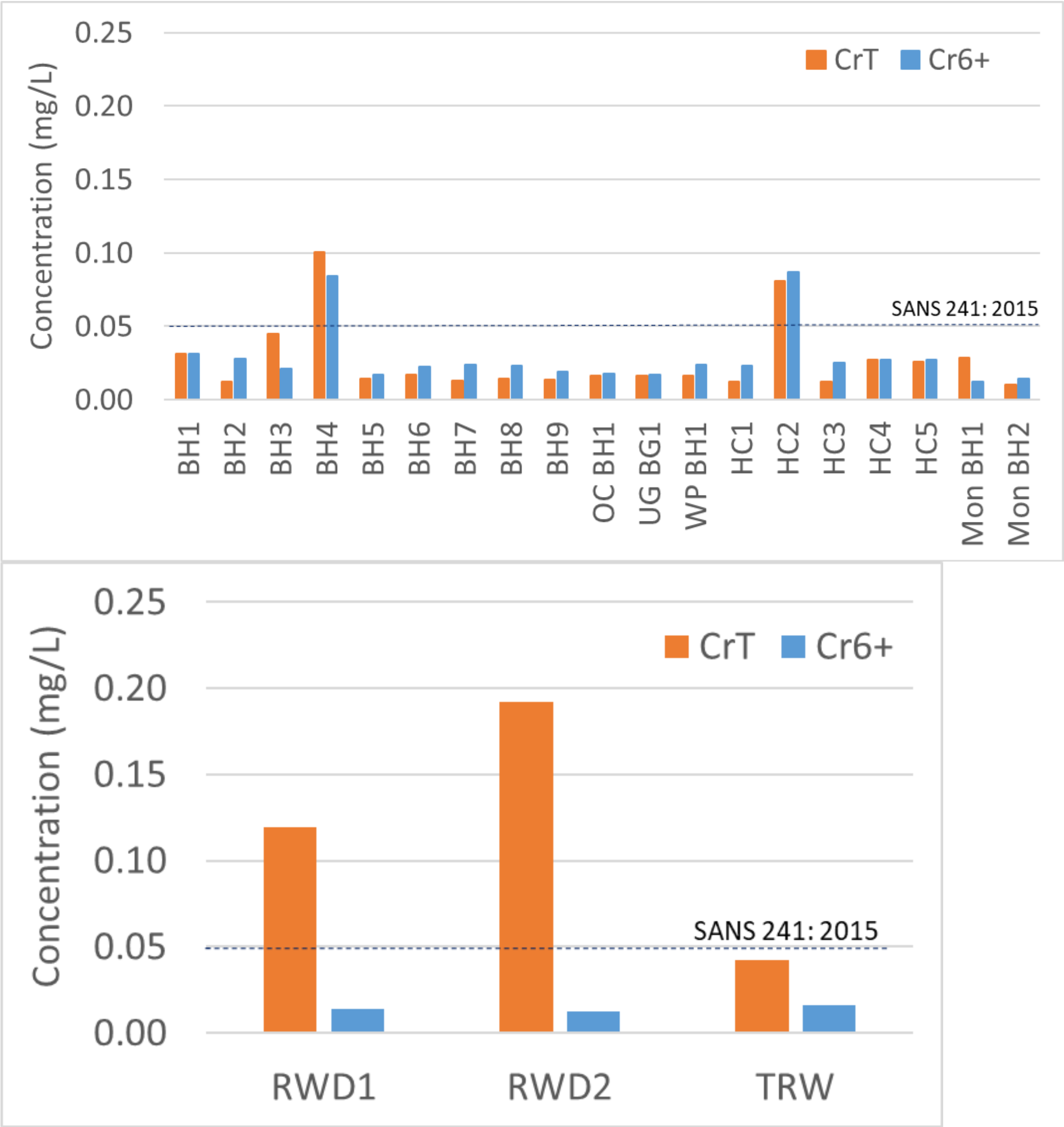
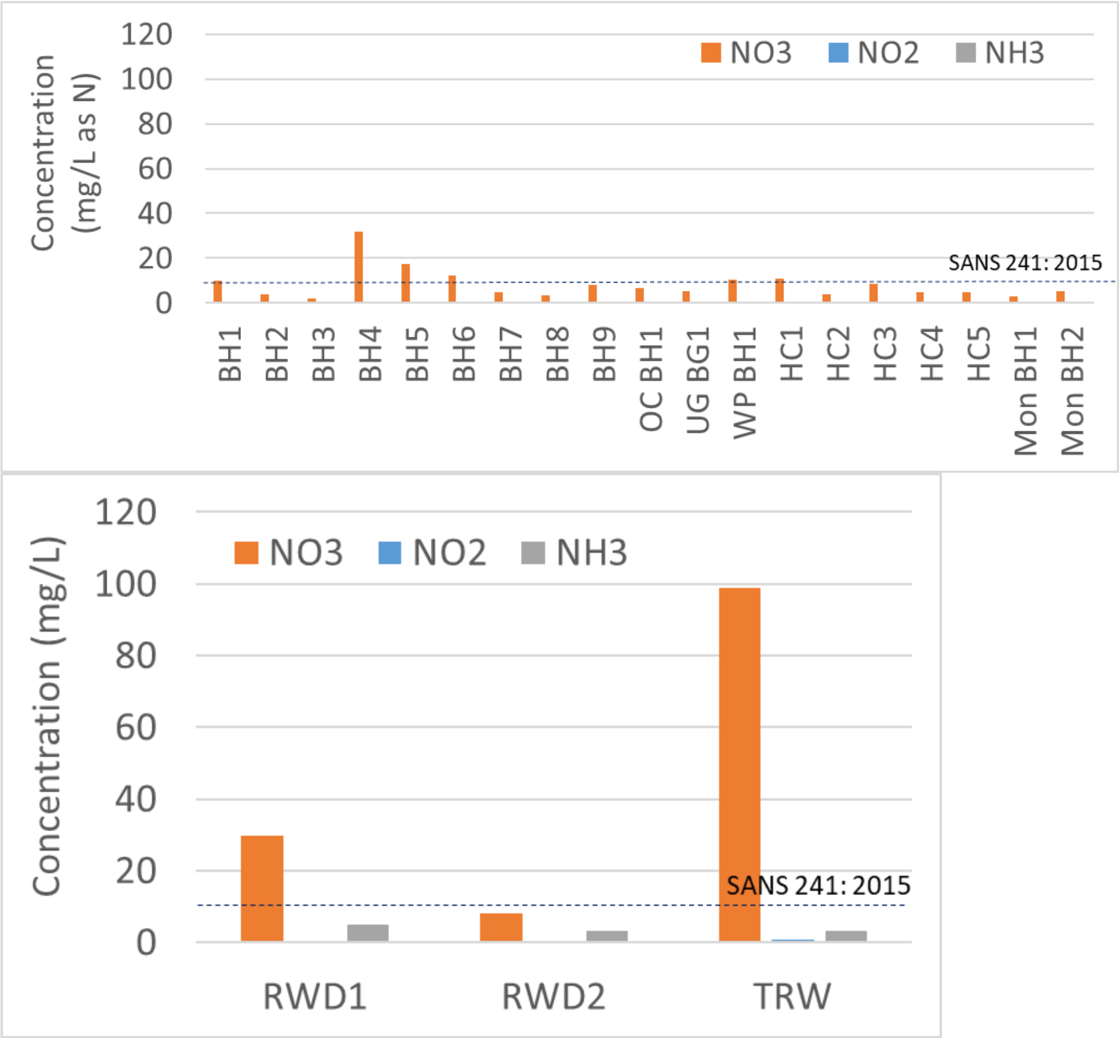


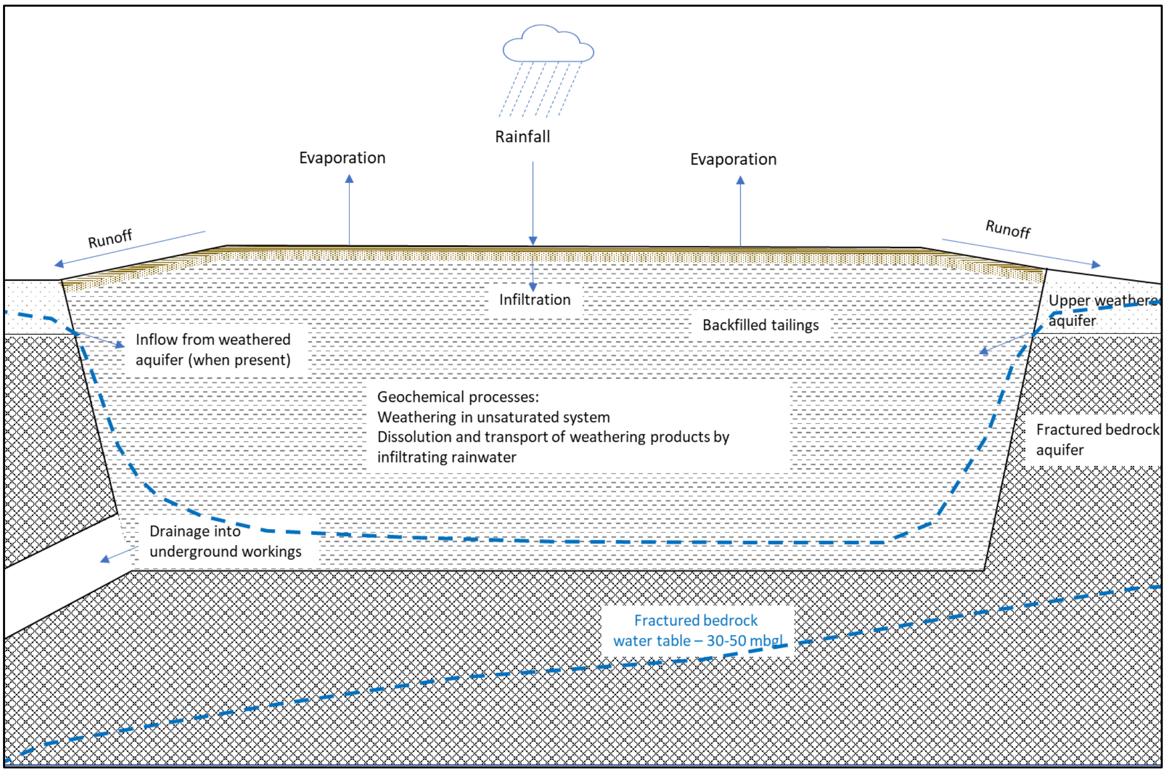
Figure 4 Concentrations of nitrogen species in groundwater (top) and process water (bottom).



4.2. Operational phase source terms

The operational phase conceptual site model is shown in Figure 5. During mine operation, the water table in the opencast areas was lowered due to mine dewatering. The opencast areas are connected to the underground workings via an incline shaft, therefore water that enters the backfilled opencast either as rain infiltration or as groundwater inflows from the surrounding aquifers is likely to drain through the backfilled tailings and ultimately report to the sumps in the underground mine, from where it will be pumped to surface.

Figure 5: Conceptual model during operation



The geochemistry of the leachate that drains from the tailings backfilled into the rehabilitated opencast areas will be controlled by the interaction of rainwater with tailings material in an unsaturated system. There is no potential for ARD therefore sulphide oxidation is not included in the model. The quality of rainwater in contact with tailings is usually estimated using leach test data, concentrated to account for the different water:rock ratios expected within the tailings as compared to what is used in the leachate test. However, in this case, the leachate concentrations are not useable as they are below detection limits. The average plant process water (TRW) (Table 3) concentrations are used instead. The ratio of solid to liquid to generate the TRW is assumed to be 1 part solid to 1 part liquid. In the opencast, the ratio of solid to liquid is likely to be determined by the field capacity i.e. the volume of water in a material that is sufficient to still allow movement of water within the material. The field capacity can be between 10 and 35%, with lower values for sandy materials and higher values for clayey materials. Based on the mineralogical data, the sample is likely to be approximately 60% sandy and 40% clay size particles, and a field capacity of 20% is assumed. This is a ratio of solid to liquid of 5 parts solid to 1 part liquid.

The geochemical modelling process follows these steps:

1. Estimate the concentrations for a leachate at a ratio of 5:1 by applying a concentration factor;
2. Equilibrate the concentrated leachate with dissolved oxygen and dissolved carbon dioxide at atmospheric partial pressure (i.e. open system).
3. Determine which element concentrations are likely to be controlled by equilibrium with mineral phases and allow the solution to equilibrate with these phases.

The mineral phases included in the model are: $Fe(OH)_3$, SiO_2(am), barite ($BaSO_4$), gibbsite ($Al(OH)_3$), Calcite ($CaCO_3$), manganite (MnOOH), magnesite ($MgCO_3$) and enstatite ($MgSiO_3$). These minerals were all found to be supersatured in the concentrated leachate. Barite, calcite, Fe(OH)3, gibbsite, magnesite and manganite precipitate, while enstatite dissolves.

The modelled leachate concentrations in equilibrium with the backfilled tailings under operational conditions are given in Table 4. Nitrate concentrations are high under the oxidizing conditions associated with operation because nitrate is highly soluble and there are no sinks in this scenario. Nitrate can be removed from groundwater by denitrification, but this requires anaerobic conditions which are not anticipated to develop in unsaturated backfilled tailings.

Chromium is predicted by geochemical modelling to be present exclusively as Cr^{6+} at a concentration of 0.3 mg/L.

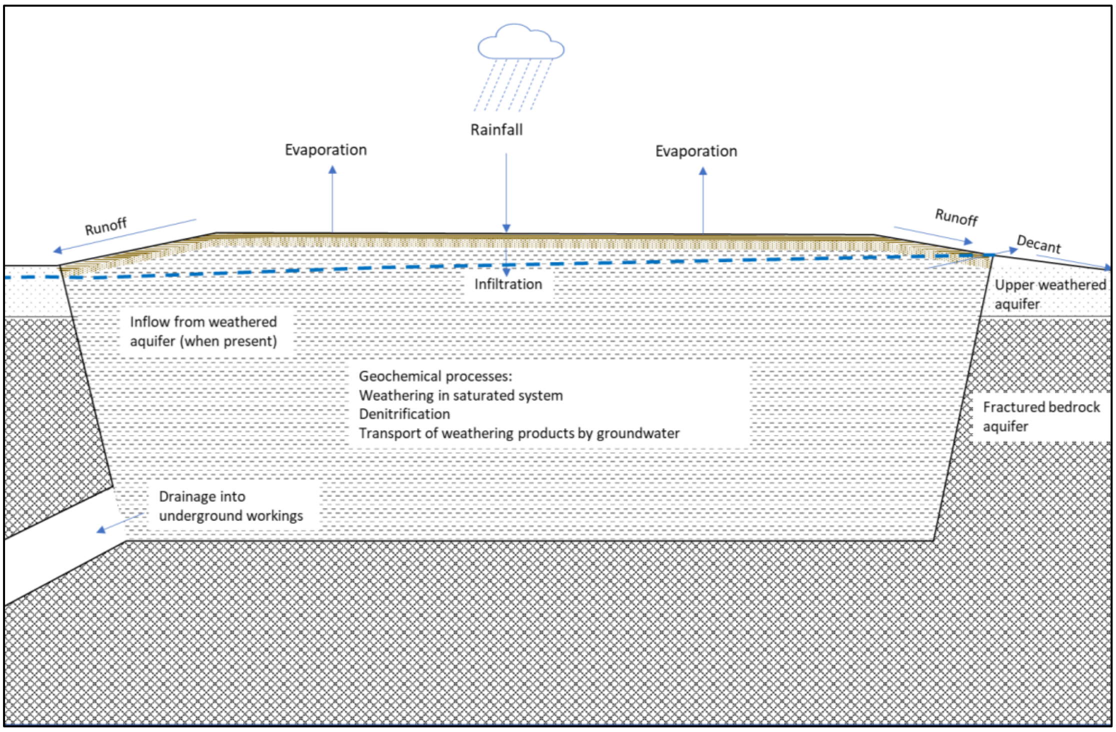
Table 4 Modelled tailings leachate concentrations during operation and post-closure.

Analyte	**Units**	**Tailings leachate (operational)**	**Tailings leachate (closure)**
pH	-	9.0	8.2
Na	mg/L	885	885
K	mg/L	47	47
Ca	mg/L	17	20
Mg	mg/L	26	33
NH_3	mg/L as N	<0.001	<0.001
Cl	mg/L	515	515
SO_4	mg/L	655	655
NO_3	mg/L as N	501	139
NO_2	mg/L as N	<0.001	<0.001
Alkalinity (estimated)	mg/L as CaCO3	309	1604
Al	mg/L	0.026	0.004
Ba	mg/L	0.014	0.013
Cd	mg/L	0.040	0.040
CrT	mg/L	0.300	0.300
Cr^{6+}	mg/L	0.300	0.300
Fe	mg/L	0.011	0.009
Mn	mg/L	<0.001	<0.001

4.3. Closure phase

The post-closure phase conceptual site model is shown in Figure 6. Following mine closure, the water table in the opencast areas will gradually recover, saturating a large proportion of the backfilled tailings. The ability for oxygen to diffuse into the system will be reduced. Nitrogen is present in groundwater in the area predominantly as nitrate, indicating that conditions are not ideal for complete denitrification, either due to an ongoing source, or the presence of sufficient oxygen in the groundwater to limit this reaction. In the model it is assumed that the oxygen content of the groundwater is sufficient to maintain some nitrate in solution and not allow complete denitrification.

Figure 6: Conceptual model post-closure



The geochemistry of the leachate that decants from the backfilled tailings will be controlled by the interaction of groundwater with tailings material in a saturated system. There is no potential for ARD therefore sulphide oxidation is not included in the model. The quality of leachate in contact with the tailings is estimated as per the operational phase, using the TRW (Table 4) concentrations.

The geochemical modelling process follows these steps:

1. Estimate the concentrations for a leachate at a ratio of 5:1 by applying a concentration factor;
2. Equilibrate the concentrated leachate with dissolved oxygen and dissolved carbon dioxide at partial pressures representing a semi-open system i.e. limited communication with the atmosphere.
3. Determine which element concentrations are likely to be controlled by equilibrium with mineral phases and allow the solution to equilibrate with these phases.

The mineral phases included in the model are: $Fe(OH)_3$, SiO_2(am), barite ($BaSO_4$), gibbsite ($Al(OH)_3$), Calcite ($CaCO_3$), manganite (MnOOH), magnesite ($MgCO_3$) and enstatite ($MgSiO_3$). These minerals were all found to be supersatured in the concentrated leachate. Barite, calcite, Fe(OH)3, gibbsite, magnesite and manganite precipitate, while enstatite dissolves.

The modelled leachate concentrations in equilibrium with the backfilled tailings under closure conditions are given in Table 4. Nitrate concentrations are lower than during operation due to denitrification, which is more likely to occur in a saturated environment, but most of the other analyte concentrations are similar to the operational values. This includes Cr^{6+}, which remains a contaminant of concern.

5. Conclusions and Recommendations

Source terms were determined for silica tailings material that is proposed to be backfilled into opencast areas using geochemical modelling. Operational (unsaturated) and post closure (saturated) scenarios were considered.

The silica tailings consist largely of the pyroxene mineral enstatite, as well as chromite, dolomite and mica and clay minerals. No sulphidic material or sulphide sulphur were detected in the tailings, therefore there is no risk for the generation of acid rock drainage. The total concentration and leachable concentration results as per the waste assessment process were all below the respective TCT0 and LCT0 limits, suggesting a Type 4 waste. However, the acid digestion results for metals were much lower than the XRF results for the same analytes, and there is therefore some uncertainty as to the total concentrations of the sample. Certainly, considering that the sample is composed of 12% of the mineral chromite, it seems unlikely that no chromium would be detected in the TCs. The leachable concentrations were also found to be extremely low, and a decision was made to rather use the chemistry of the water used to transport the tailings as the starting point for geochemical modelling, as this makes a reasonable proxy for leach test data.

In order to identify potential contaminants of concern to include in the model, the available groundwater and process water chemistry data were reviewed. The process water was found to have much higher concentrations of Na, K, nitrogen species, sulphate and chloride than the background groundwater, and marginally higher concentrations of cadmium, chromium and Cr^{6+}. Based on considerations of potential to impact groundwater and human health effects, nitrate and Cr^{6+} are considered to be contaminants of potential concern.

Geochemical modelling of the operational phase assumed an unsaturated, open environment with a field capacity of 20%. This resulted in source terms for nitrate of 501 mg/L as N and Cr^{6+} of 0.3 mg/L respectively. Under the saturated conditions at closure, the source term for nitrate reduces to 139 mg/L (due to denitrification) but the Cr^{6+} source term remains 0.3 mg/L.

This geochemical model is based on limited information, and provides an order-of-magnitude estimate of possible tailings leachate concentrations during operation and post-closure. In order to improve the estimate of potential leachate concentrations, it is recommended to:

- Collect filtered, acidified samples of drainage water from the wet tailings pad and analyse for a full suite of major and trace elements;
- Assess the water losses from the tailings between deposition on the wet tailings pad and disposal into the opencast areas so that degree of evaporation of process water can be quantified;
- Undertake repeat analysis of TCs and LCs on tailings on a statistically representive number of samples and at a laboratory capable of using an appropriate analytical technique with better analytical detection limits.
- Undertake kinetic testing under specific conditions (e.g. aerobic versus anaerobic) to assess the weathering rate of minerals, and the degree to which Cr^{6+} will be mobilised under different conditions.

6. References

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7. Annex A – Laboratory certificates

APPENDIX C:

CURRICULUM VITAE

PERSONAL DETAILS

NAME:	Martiens Prinsloo
DATE OF BIRTH:	14 January 1976
NATIONALITY:	South African
MARITAL STATUS:	Married

ACADEMIC QUALIFICATIONS

Year	Qualification & Institution
2008	MBA: Graduate School of Business, University of Cape Town
2005	M.Sc. (Geohydrology): University of the Free State (Bloemfontein)
1997	B.Sc. (Hons) (Geohydrology): University of the Free State (Bloemfontein)
1996	B.Sc. (Earth Sciences): University of Pretoria

PROFESSIONAL REGISTRATION AND AFFILIATIONS

Registered Professional Natural Scientist S.A. (SACNASP Reg. No. 400248/04)
Groundwater Division of the Geological Society of South Africa (Membership no. 234)
International Association of Hydrogeologists (IAH membership no. 122757)
International Mine Water Association (IMWA membership no. 1121)

OTHER COURSES

Course	Institution
FeFlow (2009)	DHI WASY (Johannesburg)
Geochemical and reactive transport modelling – PHREEQC, MT3DMS and PHT3D (2006)	University of the Western Cape (Cape Town)
Model sensitivity analysis, data assessment, calibration and uncertainty evaluation (2006)	USGS (Cape Town)
Contaminant Site Risk Assessment and Groundwater Modelling (2004)	Waterloo Hydrogeologic Inc. (Johannesburg)
Groundwater Modelling Course (2002)	Summer University of Bremen (Germany)

EMPLOYMENT HISTORY

Date	Company & Position
July 2008 - Present	Future Flow Groundwater & Project Management Solutions cc Founding Member
January 2019 - Present	Rison Groundwater Consulting Owner – bought out company on emigration of previous owner
January 2014 – September 2017	AquaStrata Laboratories (Pty) Ltd (ISO17025 / SANAS accredited testing laboratory) Founding Member
Feb 2007 – June 2008	GCS (Pty) Ltd Manager: Water Resources Unit
Jan 2006 – Jan 2007	GCS (Pty) Ltd Manager: Mining & Modelling Sub-Unit (part of Water Resources Unit)
Apr 2002 – Dec 2005	GCS (Pty) Ltd Hydrogeological modeller / Senior hydrogeologist
Sept 2000 – Mar 2002	GCS (Pty) Ltd Field hydrogeologist
Feb 1998 – Aug 2000	Council for Geoscience Scientific Officer - Hydrogeology

SCIENTIFIC EXPERIENCE

Mining related hydrogeology:

- Hydrogeological investigations for various types of mines including: coal, gold, platinum, nickel, copper, cobalt, uranium, heavy mineral sands and diamond. Work experience range from field data collection to data analysis, chemical characterisation, acid base accounting and waste classification, numerical flow and contaminant transport modelling, water balance calculations and compilation of reports;
- Groundwater monitoring and audit reports. The evaluation of groundwater level fluctuation and water quality data. The compilation of monthly, quarterly and annual monitoring reports;
- Groundwater monitoring well field designs. The siting and design of monitoring boreholes for the assessment of the influence of mining activities on the regional groundwater environment;
- Groundwater investigations and numerical modelling of both fractured rock and primary aquifers;
- Hydrogeological assessments for both opencast and underground mines;
- Water supply for mining activities;
- Mine dewatering assessments and dewatering program designs; and
- Tailings and waste storage facility site selection and impact assessments.

Groundwater resource assessment and development:

- Water supply studies and well field design ranging from rural water supply (hand pump) to large scale water supply for construction and irrigation projects (4 000 m^3/hr);
- Assessment of geological controls, geophysical exploration methods and the quantification of groundwater exploitation potential in complex and problematic terrain;
- Hydrogeological mapping investigations and catchment resource analysis; and
- Regional hydrogeological and chemical investigations involving reconnaissance investigations, geophysical surveys, drilling and test pumping for the planning and development and utilisation of groundwater resources in Southern Africa.

Waste disposal management:

- Environmental Impact Assessments for the manufacturing and petroleum industries. Experience includes field data collection, hydrogeological and chemical data analysis and report compilation;
- Environmental Impact Assessments and site suitability assessments for waste disposal sites (including HH classified sites); and
- Characterisation and numerical modelling of contaminant plume migration.

Energy:

- Conventional coal powered power stations, including underground coal gasification: Site selection and risk assessment, environmental impact assessments, geochemical characterisation of fly ash disposal facilities, and impact mitigation;
- CSP and PV renewable energy: Site selection and risk assessment and environmental impact assessments;
- Bio-mass-to-energy (various energy sources from plant matter to biological waste products): Site selection and risk assessment and environmental impact assessments;
- Hydropower: Impact and risk assessment.

COUNTRIES WORKED IN

Australia, Burkina Faso, Democratic Republic of the Congo (DRC), Ivory Coast, Lesotho, Liberia, Madagascar, Mali, Mozambique, Namibia, Senegal, South Africa, Tanzania, Zambia, and Zimbabwe.

LANGUAGE PROFICIENCY

English and Afrikaans – Speak, read, write.

TEACHING

- Part time lecturing at the University of Johannesburg (2001 – 2005): Civil Engineering Course – Hydrogeology.
- Ad hock lecturing at the University of the Witwatersrand (2007 – 2008): Postgraduate / Industrial Masters Course: Coal mining extraction and exploitation – Groundwater contaminant transport modelling;
- Annual course lecturing at the University of Pretoria (2009, 2011 – 2018): Postgraduate course: Groundwater Numerical Modelling.

PAPERS AND PUBLICATIONS

- Prinsloo, M.J. (2004). "Characterisation of the dolomitic aquifer in the Copperbelt Province, Northern Zambia". Waternet / WARFSA Symposium, Windhoek, Namibia.
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