Consulting Environmental Scientists

ISO 9001:2015 | B-BBEE Level Two

www.gptglobal.com

Department

Inorganic Business Unit

Project Name

Hydrogeological Impact Assessment for Beeshoek Mine

Client

Envirogistics (Pty) Ltd

GPT Ref No:

ETBEE-20-5804

Version

4

Offices in: Gauteng, Western Cape, KwaZulu-Natal & Mozambique

Report Type:	Specialist Study in Support of Application for Authorisation for Beeshoek Mine
Project Title:	Hydrogeological Impact Assessment for Beeshoek Mine
Site Name:	Hydrogeological Impact Assessment for Beeshoek Mine
Site Location:	Beeshoek Mine, Postmasburg, Northern Cape
Compiled For:	Envirogistics (Pty) Ltd
Compiled By:	S. C. Nkosi, MSc, Cand.Sci.Nat. (No. 100105/13); G. J. du Toit, D.Sc., Pr.Sci.Nat. (No 400043/86)
GPT Reference:	ETBEE-20-5804
Client Reference:	GPT-Q-18-4887
Version:	Final
Date:	May 2021
Distribution List (Current Version):	Ms T. Bekker (tanja@envirogistics.co.za)
Reviewed by:	V. d. A. Coetsee, PhD, Pr.Sci.Nat. (No. 400084/89)

Disclaimer:

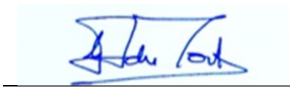
The results and conclusions of this report are limited to the Scope of Work agreed between GPT and the Client for whom this investigation has been conducted. All assumptions made and all information contained within this report and its attachments depend on the accessibility to and reliability of relevant information, including maps, previous reports and word-of-mouth, from the Client and Contractors.

Declaration:

I hereby declare:

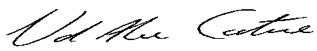
- I have no vested interest (present or prospective) in the project that is the subject of this report as well as its attachments. I have no personal interest with respect to the parties involved in this project.
- I have no bias with regard to this project or towards the various stakeholders involved in this project.
- I have not received, nor have I been offered, any significant form of inappropriate reward for compiling this report.

(*electronic signature*)
S. C. Nkosi, MSc, Cand.Sci.Nat.
Candidate Natural Scientist (No. 100105/13)
Geo Pollution Technologies – Gauteng (Pty) Ltd



(*electronic signature*)
G. J. du Toit, D.Sc., Pr.Sci.Nat.
Professional Natural Scientist (No 400043/86)
Geo Pollution Technologies – Gauteng (Pty) Ltd

This report was reviewed by:



Vd Ahee Coetsee, PhD, Pr.Sci.Nat.
Professional Natural Scientist (No 400084/89)
Geo Pollution Technologies – Gauteng (Pty) Ltd

Customer Satisfaction:

Feedback regarding the technical quality of this report (i.e. methodology used, results discussed and recommendations made), as well as other aspects, such as timeous completion of project and value of services rendered, can be posted onto GPT's website at www.gptglobal.com.

NEMA Regs (2014) - Appendix 6	Relevant section in report
Details of the specialist who prepared the report	Page i
The expertise of that person to compile a specialist report including a curriculum vitae	Page i
A declaration that the person is independent in a form as may be specified by the competent authority	Page i
An indication of the scope of, and the purpose for which, the report was prepared	Section 3
The date and season of the site investigation and the relevance of the season to the outcome of the assessment	Section 4
A description of the methodology adopted in preparing the report or carrying out the specialised process	Section 4
The specific identified sensitivity of the site related to the activity and its associated structures and infrastructure	Section 9
An identification of any areas to be avoided, including buffers	Section 9
A map superimposing the activity including the associated structures and infrastructure on the environmental sensitivities of the site including areas to be avoided, including buffers;	Figure 4
A description of any assumptions made and any uncertainties or gaps in knowledge;	Section 8
A description of the findings and potential implications of such findings on the impact of the proposed activity, including identified alternatives, on the environment	Section 9
Any mitigation measures for inclusion in the EMPr	Section 10
Any conditions for inclusion in the environmental authorisation	Section 9.5
Any monitoring requirements for inclusion in the EMPr or environmental authorisation	Section 10
A reasoned opinion as to whether the proposed activity or portions thereof should be authorised and	Section 9.5
If the opinion is that the proposed activity or portions thereof should be authorised, any avoidance, management and mitigation measures that should be included in the EMPr, and where applicable, the closure plan	
A description of any consultation process that was undertaken during the course of carrying out the study	N/A
A summary and copies if any comments that were received during any consultation process	N/A
Any other information requested by the competent authority	N/A

EXECUTIVE SUMMARY

Scope of work	Geo Pollution Technologies – Gauteng (Pty) Ltd (GPT) was appointed by Envirogistics (Pty) Ltd (Envirogistics) to update the hydrogeological impact assessment for the Beeshoek Iron Ore Mine. The study was conducted in support of an application for environmental authorisation of various expansions to the mining project. The purpose of this project is to give effect to the Regulation 23 of the Mineral and Petroleum Resources Development Act, 2002 (MPRDA) requirements for the optimisation of Mining Works Programme, as well as the implementation of the best practical environmental management measures for the operation and management of the Waste Rock Dumps (WRDs).
Completed work	Within the scope of work the following work was completed: • Quantification of the current groundwater status quo as it pertains to groundwater levels and groundwater quality • Impact prediction through numerical modelling • Groundwater risk assessment and impact quantification • Prescription of practicable management options and mitigation measures
Topography and drainage	The area is characterised by a gently undulating topography and in the area of the site the slope is more or less in the order 1% in a south western direction. Locally drainage is towards the Groenwaterspruit that flows from northeast to southwest to the east of the site and towards the Skeifonteinspruit that flows from northeast to southwest to the south of the study area. On a larger scale, drainage occurs towards the generalised flow of the Orange River.
Local geology	The mine is located on the Maramane Dome, which is dominated by carbonate rocks of the Campbellrand Subgroup and the iron formations of the Asbesheuwels Subgroup of the Transvaal Supergroup. The dome dips gently, at less than 10 degrees, in an arc to north and south. Only the eastern half of the dome is exposed, while the western part is covered by red beds, conglomerate, shale and quartzite of the Gamagara Formation. The Beeshoek-Olynfontein iron ore deposits are situated along the contact between the Gamagara Formation and the underlying Manganore Iron Formation.
Hydrogeology	The hydrogeology in the Postmasburg/Beeshoek area is extremely heterogeneous due to the complex geology of the area. Karoo Supergroup sediments, volcanics and karstic (dolomitic) formations are the main components of the groundwater regime in the area.

Acid/Leachate generation capacity	The leachable concentrations of solid waste were compared to the leachable concentration threshold (LCT) limits to determine the leachability of the different waste types at the mine. Solid waste types were described as either "type 4" or "type 3" waste types which are low hazard waste types with regards to the likelihood to release contaminants in dissolved phase.
Hydraulic conductivity	Hydraulic conductivity varies spatially and vertically, and the modelled conductivities vary by at least six orders of magnitude, from 10^{-3} m/d to 10^{+2} m/d (0.001 m/d to 100 m/d).
Groundwater levels	Groundwater levels range between 5 mbgl in unaffected areas to 180 - 200 mbgl in dewatered areas due to groundwater abstraction for dewatering and water supply. The effect of dewatering is more pronounced to the south of the mine (south of Olynfontein). The direction of groundwater flow is south to south easterly from the mining area. A cone of depression has developed within the active mining area with flow directed towards the mining excavation due to the active mining areas.
Potential contaminants	The potential influences on groundwater quality were identified as opencast mining, fuel storage and handling, sewage management, solid and liquid mining-related waste management at the mine (i.e. ore discards and impounded mine water).
Groundwater quality	Generally, the groundwater resources at all the sampling localities are described as being neutral to alkaline (pH levels between 7.8 and 8.0), non-saline to saline (TDS between 445.5 mg/l and 563.8 mg/l), and the hardness can be classified as very hard (> 300mg $CaCO3/l$). Water hardness at Beeshoek mine is not unlike most other boreholes in the area, resulting from the calcareous/dolomitic underlying geology characteristic of many parts of the Northern Cape. Metal concentrations were below detection limit or low at all the monitoring boreholes. Nitrate as N and combined nitrate and nitrite exceed the drinking water limit in the majority of external user boreholes regardless of location. The WUL identified nitrates as a contaminant of concern in relation to mining activity due to the use of N-based emulsions for blasting. Through the analysis of N-isotopes from nitrates, a contamination assessment was conducted in 2019 and it was concluded that mine's contribution to nitrate levels in and around the mine was minimal (<1%).
Aquifer characterisation	Groundwater Vulnerability: Medium Vulnerable (33%)
	Classification: Minor aquifer system
	Protection required: Medium level (Groundwater quality management index = 4)
Groundwater Impacts	Construction phase: This phase is not expected to influence the groundwater levels. With the exception of minor oil and diesel spills, there are also no activities expected that could impact on regional groundwater quality.

	Operational phase: During the operational phase, it is expected that the main impact on the groundwater environment will be dewatering of the surrounding aquifer. Water entering the mining areas will have to be pumped out to enable mining activities. This will cause a lowering in the groundwater table in- and adjacent to the mine. Mining in this area has been ongoing for many decades, and there are historical impacts on the surrounding aquifer which are impractical to simulate in a numerical model. Thus, current groundwater levels (obtained from various sources) have been used as baseline for this impact assessment, and all dewatering impacts related to the current water levels as a starting point. Considering the impact associated with each mining pit, the following observations were made: • The area to the south of the mining rights area is characterised by deep groundwater levels (>100 m) associated with large-scale dewatering at the neighbouring Kolomela Mine. • No drawdown is expected for further mining at East Pit as the declining groundwater levels is predicted to be below the bottom of mining. • Drawdown at Village pit is predicted to extent to up to 2km from the pit in a mostly westerly direction, for an insignificant drawdown of 5 – 10 metres. Areas of significant drawdown is expected only in in the immediate vicinity of the pit, which could even decline with time as Leeuwfontein mining impacts northward into this area. • HF Pit is predicted to have a minor impact limited to the immediate surroundings of the pit itself. • The BN Pit is predicted to have the largest area of impact due to substantial increase in mining depth. Drawdown of groundwater levels will be up to about 100 m but limited to an area of about 1 km around the pit. This is mainly due to different hydraulic characteristics in the area around the pit. • No groundwater-related impacts are expected on surface water resources.
	After closure and cessation of dewatering/groundwater abstraction, the water table will rise in the mine to reinstate equilibrium with the surrounding groundwater systems. The rebound period also depends on regional activity as large-scale dewatering is occurring at the neighbouring mines as well. Following the closure of the opencasts and the cessation of the dewatering it is assumed to lead to groundwater rebound and potential decanting. However, due to naturally deep-lying groundwater levels, no decant is predicted. The rise of solute concentrations in groundwater is expected to occur slowly in a south to south-westerly direction, at about 100 metres per year. No adverse effects are predicted on receptor boreholes with regards to increasing solute concentrations in groundwater.

Recommended monitoring	The mine was awarded a water licence on 01/12/2014, licence number 10/D73A/ABGJ/2592. The water licence covers section 21(a), 21(b), 21(g) and 21(j) of the National Water Act 1998 (Act 36 of 1998). The conditions as set out in the WUL serve as the guidelines for monitoring data interpretation and reporting for authorised activities. A monitoring programme is in place which entails quarterly water quality monitoring and monthly manual water level and daily telemetric/auto-level water level monitoring at select locations. The current water quality and water level monitoring network is considered adequate to detect and quantify the presence and migration of any contaminants in groundwater and measure the effects of large-scale groundwater abstraction for mining purposes on groundwater levels. A groundwater monitoring network should contain monitoring positions which can assess the groundwater status at certain areas. The boreholes can be grouped or classified according to the following purposes: • Source monitoring: Monitoring boreholes are placed close to or in the source of contamination to evaluate the impact thereof on the groundwater chemistry. Monitoring boreholes within the mining area satisfy this condition. • Pathway monitoring: Monitoring boreholes are placed in the primary groundwater migration pathways to evaluate the migration rates and chemical changes along the pathway. Monitoring boreholes located along groundwater flow paths satisfy this condition. • Impact monitoring: Monitoring of possible impacts of contaminated groundwater on sensitive ecosystems or other receptors. These monitoring points are also installed as early warning systems for contamination break-through at areas of concern. External user boreholes and monitoring placed in positions to detect and monitor impacts on groundwater availability and quality satisfy this condition. • Background monitoring: Background groundwater quality is essential to evaluate the impact of a specific action/pollution source on the groundwater chemistry. Monitoring boreholes located up-gradient/upstream of the mining area satisfy this condition.
Main mitigation measures	Dewatering and large-scale groundwater abstraction may pose significant risk to the groundwater regime and privately-owned boreholes within the dewatered areas. There are no obvious means of mitigating the impact of groundwater lowering by mining, except for monitoring surrounding boreholes and replacing lost groundwater extraction potential where applicable (where external users have been impacted upon by the mine).

Management of Dewatering Impacts	Dewatering is primarily achieved through wellfields of abstraction boreholes and in pit dewatering points, and the combination thereof functions with the purpose of keeping the pit floor dry by creating a cone of depression around the excavation. The pit floor was thus modelled as a drain, which in MODFLOW uses the bottom elevation of the drain as the hydraulic head that controls flow into the drain. In this way the individual position of dewatering boreholes has no effect on the extent of the cone of depression or groundwater level lowering. Dewatering borehole positions may be changed without notice as objectively they will be placed as close as possible to the excavation to maintain a dry pit floor.
Recommendations	Beeshoek is currently operating in a dynamic mining environment. Water levels are also impacted by various external sources, which directly impacts the water levels at Beeshoek. Currently, no additional groundwater is to be abstracted from the catchment as part of this project expansion. However, due to the nature of the environment in which the mine is operating, regular numerical model updates must be undertaken to determine whether the volumes for dewatering will still be sufficient to also supply the mine with the required volumes as approved in the Section 21a water uses.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

Page

LIST OF APPENDICES

LIST OF ABBREVIATIONS

Abbreviation	Explanation
ARD	Acid Rock Drainage
BPG	Best Practice Guidelines
CMS	Catchment Management Strategy
CSM	Conceptual Site Model
EC	Electrical Conductivity
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
IWRMP	Integrated Water Resources Management Plan
IWRM	Integrated Water Resources Management
km^2	Square kilometre
L/s	Litres per second
mamsl	Metres above mean sea level
Ml/d	Megalitres per day
m	metre
mm	Millimetre
mm/a	Millimetres per annum
mS/m	Millisiemens per metre
m^3	Cubic metre
MAP	Mean Annual Precipitation
MPRDA	Mining and Petroleum Resources Development Act (Act No. 73 of 2002) 1989)
NEMA	National Environmental Management Act (Act No. 107 of 1998)
NWA	National Water Act (Act No. 36 of 1998)
ppm	Parts per million
RDM	Resource Directed Measures
RQO	Resource Quality Objective
RWQO	Resource Water Quality Objective
TDS	Total Dissolved Solids
WMA	Water Management Area
WMP	Water Management Plan

DEFINITIONS

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

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

HYDROGEOLOGICAL IMPACT ASSESSMENT

BEESHOEK MINE

1 INTRODUCTION

Geo Pollution Technologies – Gauteng (Pty) Ltd (GPT) was appointed by Envirogistics (Pty) Ltd (Envirogistics) to update the hydrogeological impact assessment for the Beeshoek Iron Ore Mine. The study was conducted in support of an application for environmental authorisation of various expansions to the mining project.

The Beeshoek Iron Ore Mine was established in 1964 and exploits hematite iron ore deposits by opencast mining methods. All activity is located on portions of the farms Beesthoek 448 RD and Olynfontein 475 RD approximately 10 km west of the town of Postmasburg, Northern Cape Province.

A hydrogeological impact assessment was conducted to determine the current environmental status as it pertains to groundwater and potential impacts associated with the operation and proposed expansions. The impacts associated with mining are linked to groundwater quantity and quality, which are related to large-scale groundwater abstraction and exposure of reactive mineral surfaces and waste handling, respectively. The likely contaminants are acidity (low pH), iron, nitrates, as well mobilisation of metals due to acidity. Beeshoek is currently operating in a dynamic mining environment. Water levels are also impacted by various external sources, which directly impacts the water levels at Beeshoek. Currently, no additional groundwater is to be abstracted from the catchment as part of this project expansion.

The study was conducted with the framework of the National Water Act (Act 36 of 1998) and is structured to comply with regulations governing the procedural requirements for water use licence applications and appeals, Government Notice R267 in Government Gazette 40713 dated 24 March 2017. Commencement date: 24 March 2017. The purpose of this project is to give effect to the Regulation 23 of the Mineral and Petroleum Resources Development Act, 2002 (MPRDA) requirements for the optimisation of Mining Works Programme, as well as the implementation of the best practical environmental management measures for the operation and management of the Waste Rock Dumps (WRDs).

2 GEOGRAPHICAL SETTING

2.1 Site Location, Topography and Drainage

Beeshoek Mine is situated approximately 7 km to the west and northwest of the town of Postmasburg in the Northern Cape Province (Figure 1).

The topography (shown in Figure 2) can normally be used as a good first approximation of the hydraulic gradient in the unconfined aquifer. This discussion will focus on the slope and direction of fall of the area under investigation, features that are important from a groundwater point of view.

The area is characterised by a gently undulating topography and in the area of the site the slope is more or less in the order 1% in a south western direction.

Locally drainage is towards the Groenwaterspruit that flows from northeast to southwest to the east of the site and towards the Skeifonteinspruit that flows from northeast to southwest to the south of the study area. On a larger scale, drainage occurs towards the generalised flow of the Orange River.

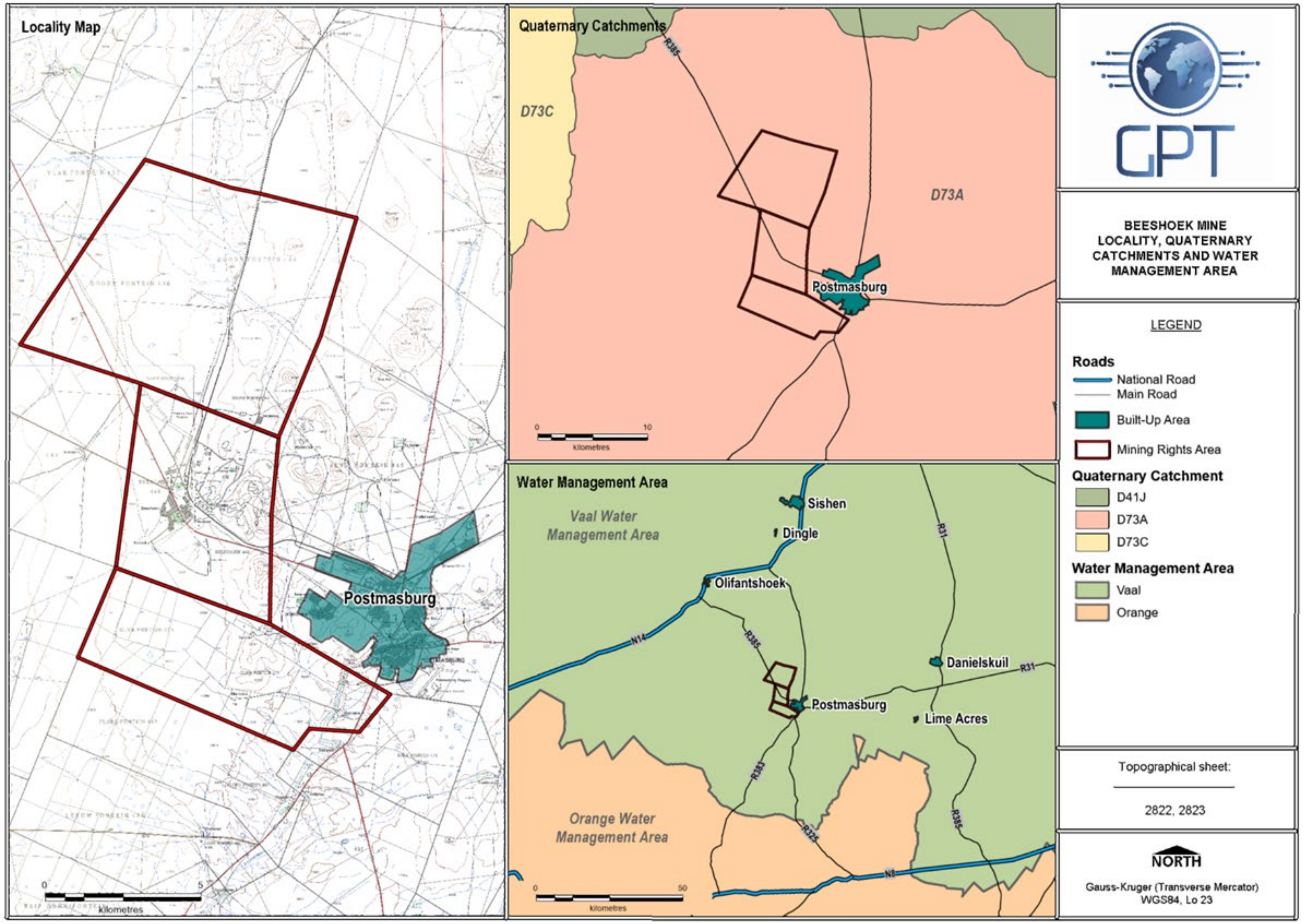


Figure 1: Site Location and Quaternary Catchment Boundaries.

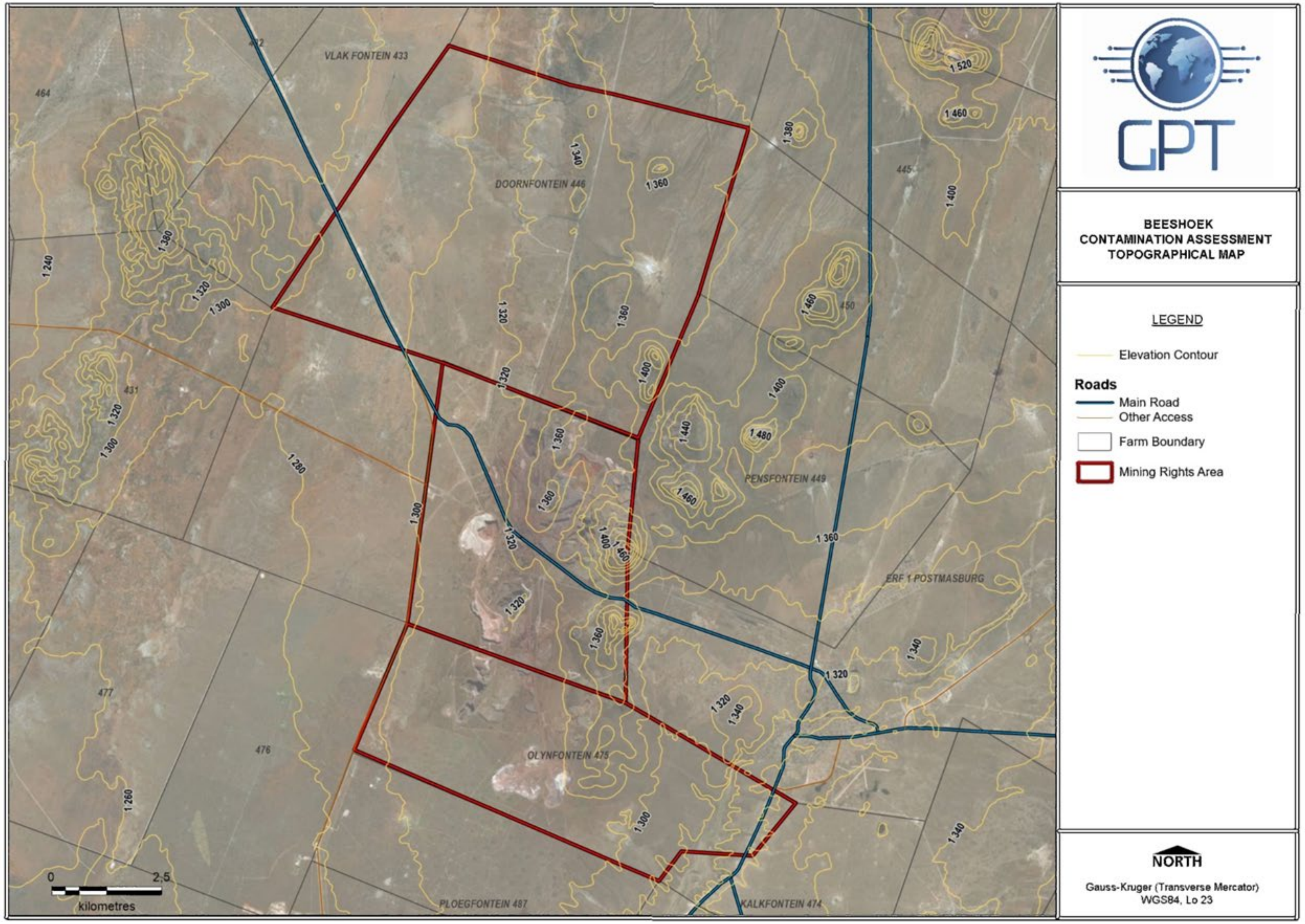


Figure 2: Site Topography.

2.2 Climate

Rainfall data was obtained from the weather station at Postmasburg, while the evapotranspiration data is from the Olifantshoek Dam (Table 1)[1]. The site is located in the summer rainfall region of Southern Africa with precipitation usually occurring in the form of convectional thunderstorms. The average annual rainfall (measured over a period of 70 years) is approximately 328.4 mm, with the high rainfall months between November and April.

Table 1: Climatic Data.

Month	Average Monthly Rainfall (mm)	Mean Monthly Evaporation
January	47.6	221.6
February	60.9	191.9
March	62.8	139.8
April	33.9	105.3
May	13.6	79.9
June	6.1	90.7
July	3.9	132.6
August	6.6	180.6
September	8.7	234.9
October	20.1	266.6
November	28.1	293.2
December	36.1	276.1
Annual	328.4	2165.6

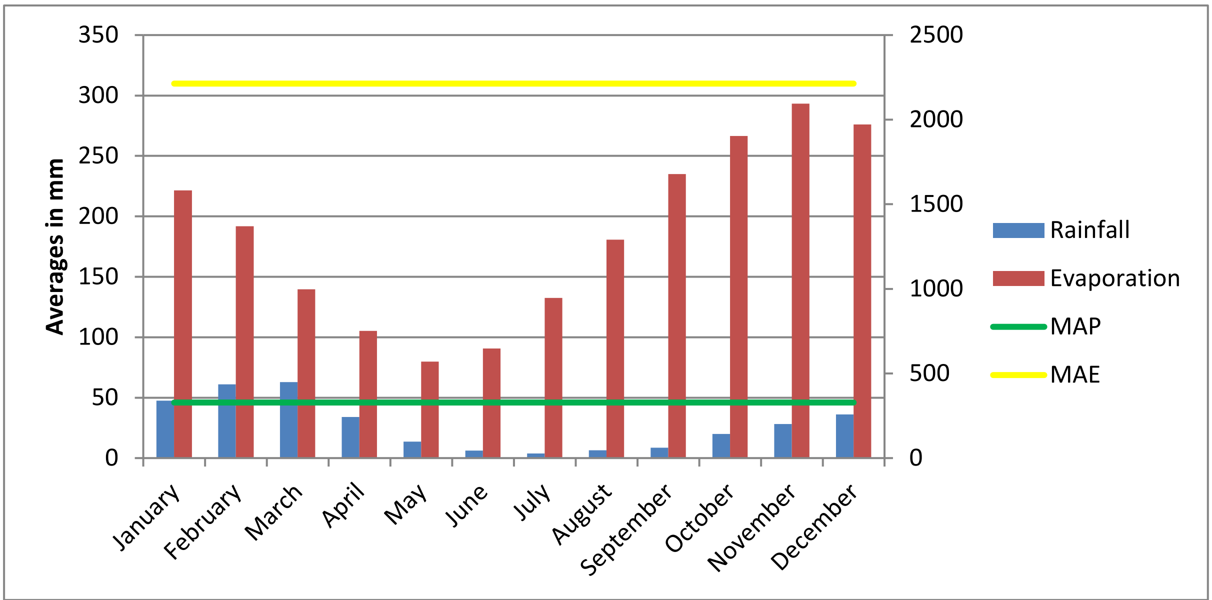


Figure 3: Climatic data representation.

[1] Department of Water Affairs (DWA): www.dwa.gov.za

3 SCOPE OF WORK

The scope of work is to address the potential impacts of the consolidation of mining activities at Village Pit, BN and HF Pit and associated WRDs. Previous calibrated numerical groundwater models will be consolidated to determine the groundwater dewatering impacts associated with the mining.

3.1 Project Objectives

Within the scope of work the groundwater study aimed to address the following:

- Quantify the current groundwater status quo as it pertains to groundwater levels and groundwater quality
- Impact prediction through numerical modelling
- Groundwater risk assessment and impact quantification
- Prescription of practicable management options and mitigation measures

A short report was compiled to address the potential for contamination from the material on site, the transport of contamination in the aquifer system as well as the area to be impacted upon by dewatering.

3.2 Activity Description

The project will comprise of WRD expansion, pit expansions, haul roads and the WHIMS and JIG plants and associated infrastructure for the following open pits and WRDs (see Figure 4):

- Open pits
  - BN Pit;
  - Village Pit;
  - Village East Pit;
  - Village South Pit;
  - BF Pit Expansion;
  - East Pit Expansion;
  - Detrital area
- WRDs
  - HF WRD;
  - GF WRD;
  - Discard Dump (for this an operational layout will suffice);
  - VP1 Village WRD;
  - Village Pit South WRD;
  - East Pit WRD
- ROM Stockpiles
  - South ROM Stockpiles and the
  - South BIS Stockpile

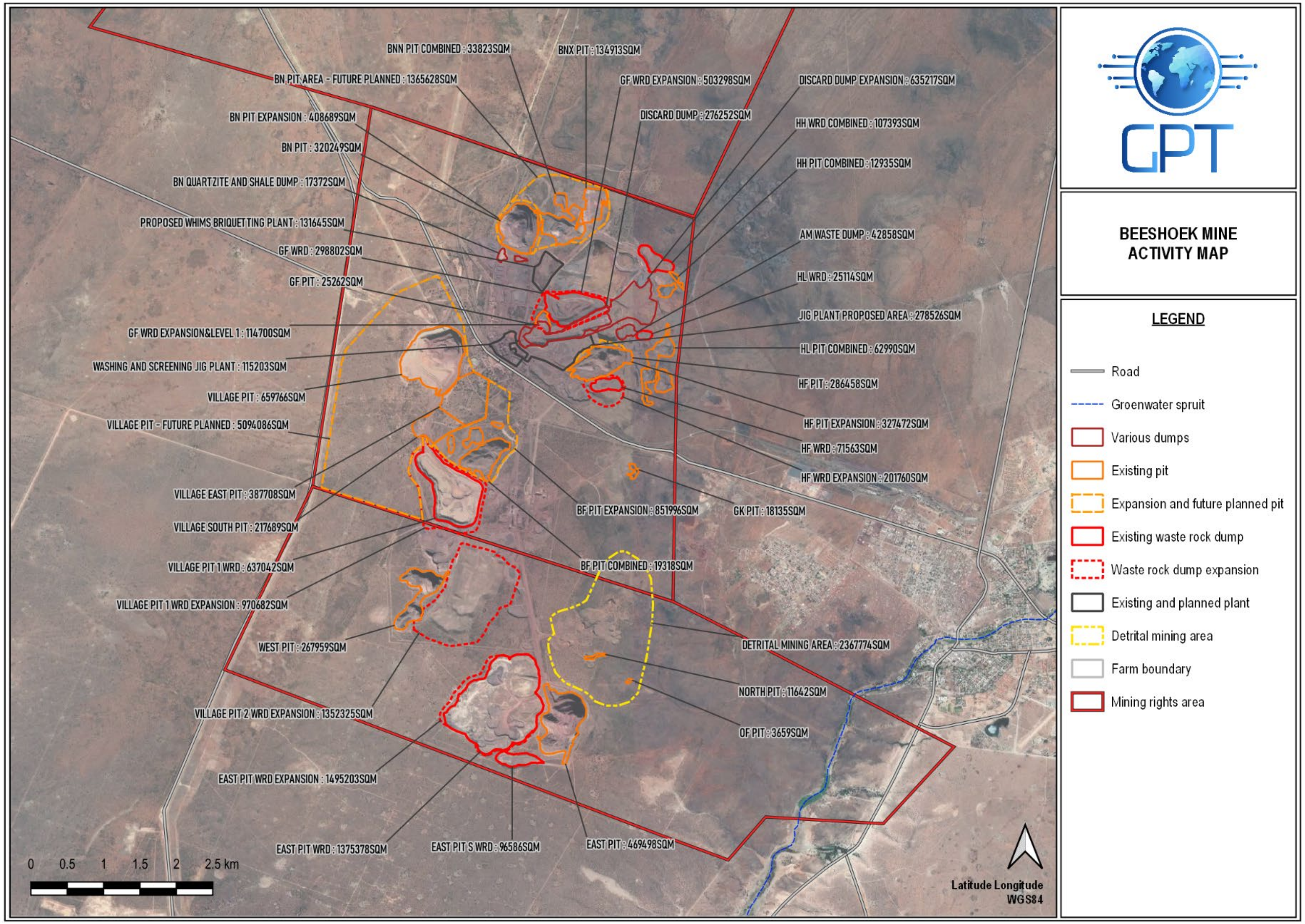


Figure 4: Current and planned activity map.

4 METHODOLOGY

4.1 Desk Study

The desktop study entailed the gathering of information through the collation, scrutiny, and evaluation of available and relevant meteorological, geographical, geological, hydrogeological and water quality data.

4.2 Groundwater Recharge Calculations

Recharge to the shallow, unconfined aquifer was calculated using the RECHARGE program developed by the Institute for Groundwater Studies at the University of the Free State, South Africa. The calculated recharge percentage equates to approximately 3.5%.

Table 2: Recharge calculation for the shallow unconfined aquifer.

Recharge Estimation			
Method	**mm/a**	**% of rainfall**	**Certainty (Very High = 5 ; Low = 1)**
Chloride	24.8	3.5	4
Various schematic maps			
Soil	38.0	3.0	3
Geology	25.6	3.5	3
Vegter	45.0	2.9	3
Acru	20.0	3.6	3
Harvest Potential	50.0	3.6	3

4.3 Groundwater Modelling

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

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

4.3.1 Numerical modelling

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

The finite difference numerical model was created using AquaVeo's Groundwater Modelling System (GMS10.0) as Graphical User Interface (GUI) for the well-established MODFLOW and MT3DMS numerical codes.

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

4.3.2 Transport modelling

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

5 PREVAILING GROUNDWATER CONDITIONS

5.1 Geological Setting

The investigated area falls within the 2822 Postmasburg 1:250 000 geology series maps. An extract of these maps is shown in Figure 4.

The Beeshoek Mine mines iron ore deposits of Griqualand West which is underlain by the Ghaap and Postmasburg groups of the Transvaal Supergroup. The iron ore deposits are associated with the Gamagara Formation in pre-Gamagara sinkholes occurring in the dolomites of the Campbell Subgroup. The Gamagara Formation is composed of shales (Sishen Shale) and hematite-rich Doornfontein conglomerate. The iron ore deposits as slumped hematitised iron formation in the aforementioned sinkholes with underlying chert-rich banded iron formation (BIF) and breccia of the Wolhaarkop Formation. To the west outcrops andesitic lava of the Ongeluk Formation and diamictite of the Makganyene Formation of the Postmasburg Group, and iron formation associated with quartz wacke of the Koegas Subgroup of the Ghaap Group, which is underlain by dolomites of the Campbell Subgroup.

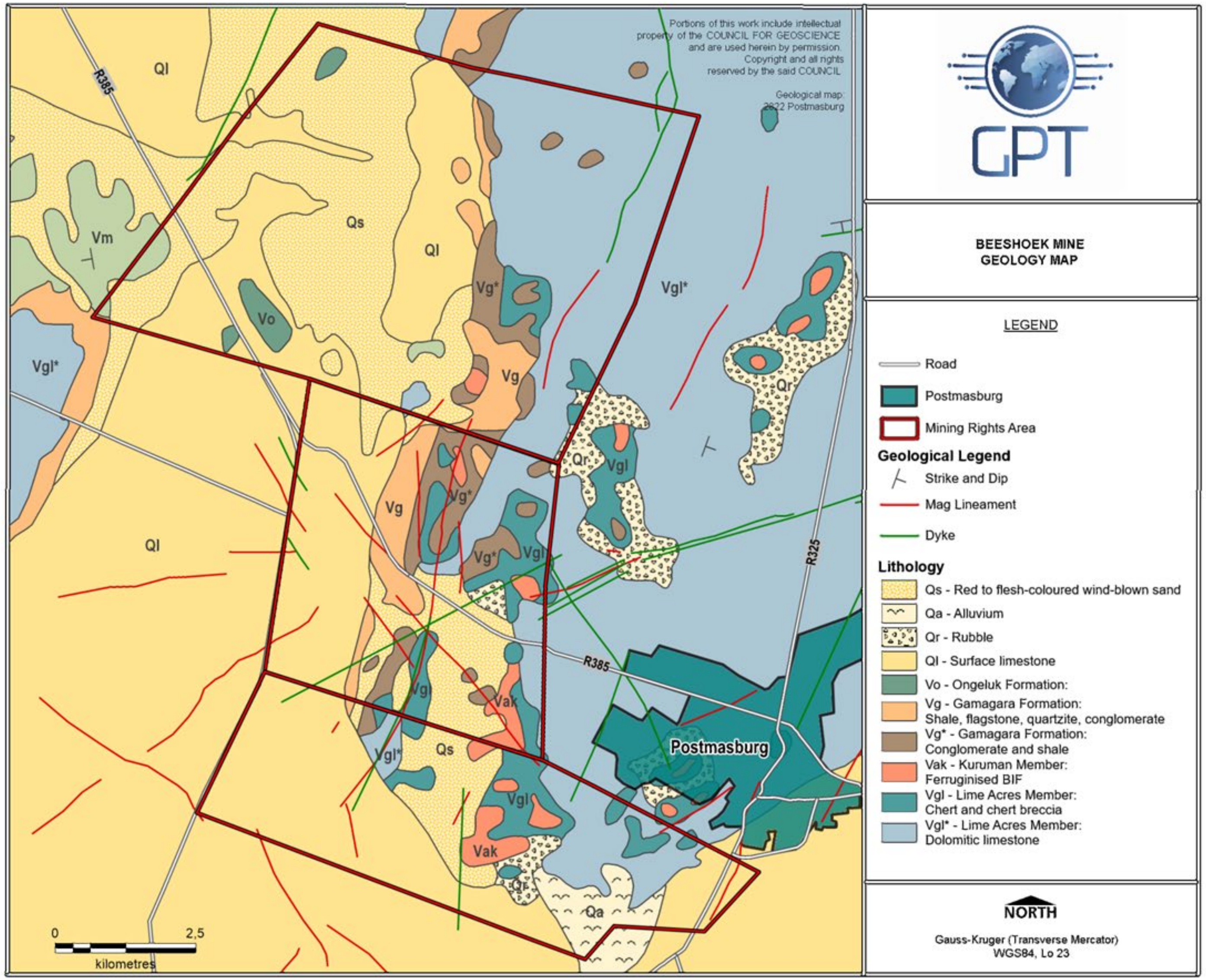


Figure 5: Regional Geology Map (1:250 000 geology series map).

5.2 Hydrogeological Setting

Karoo Supergroup sediments, volcanics and karstic (dolomitic) formations are the main components of the groundwater regime in the area.

5.2.1 Aquifers associated with sedimentary formations

Diamictite and shale have very low hydraulic conductivities (about 10^{-11} to 10^{-12} $m.s^{-1}$) and low primary porosity. Boreholes in these formations are expected to be low-yielding (<1 l/s) and water occurrence is confined within secondary structures like jointing and fracturing. Shale and diamictite are expected to form extensive aquitards in outcrop areas. Breccia is often non-cohesive in outcrop or shallow areas. The development of joints, fracturing leading to breccia formation in fault zones will cause an enhancement of permeability which may be reduced by cementation.

5.2.2 Aquifers associated with volcanic formations

In solidified lavas, due to low permeability, water commonly occurs in fault zones; the dip angle of fault zones is in this way important. Fault zones commonly act as hydraulic conduits to groundwater flow connecting shallow and deeper-lying geological units, however the fault cores of many faults may act as barriers to flow, such as thrust faults which have low permeability.

5.2.3 Aquifers associated with karstic formations

The permeability structures of carbonate rocks are controlled fluid-flow conduits. These aquifers are often high yielding (>5 l/s).

Groundwater storage occurs in the rock matrix and groundwater flow occurs in secondary geological structures like lithological contacts, faults, deformational zone, joints, and fractures. These structures are often drilling targets for water supply or monitoring boreholes. These structures generally act as conduits to groundwater flow but may also have a compartmentalising effect as barriers to groundwater flow.

The Griqualand West region is characterised by major deformational events including the Namaqua orogeny which resulted in a N-S trending regional thrust fault and other deformational structures. The following observations were made:

- The N-S trending regional strike fault (west of the mine) is thought to have a compartmentalising effect as water levels are shallower in boreholes bounded by the fault in comparison to boreholes outside (east) of the thrust fault, except where the surface area has been disturbed by excavation for open pit mining.

5.2.4 Hydraulic conductivity

Hydraulic conductivity varies spatially and vertically and for the purpose of this study a detailed description of hydraulic conductivities of various units are described under section 8 (GROUNDWATER FLOW AND TRANSPORT MODELLING).

5.3 Groundwater Levels

5.3.1 Monitoring

Water levels are measured on a monthly basis, by the Beeshoek personnel around Beeshoek Mine. Groundwater levels range between 5 mbgl in unaffected areas to 180 - 200 mbgl in dewatered areas due to groundwater abstraction for dewatering and water supply. The effect of dewatering is more pronounced to the south of the mine (south of Olynfontein). The direction of groundwater flow is south to south easterly from the mining area (**Figure 8**). A cone of depression has developed within the active mining area with flow directed towards the mining excavation due to the active mining areas. The groundwater monitoring network comprises of (**Figure 6**):

- 21 open monitoring boreholes that are monitored for groundwater level information on a monthly basis by Beeshoek, some boreholes are fitted with level loggers since 2018 which record water level fluctuation on a daily basis.
- 21 telemetric system boreholes are present in and around Beeshoek Mine from which are intended for monitoring changes in groundwater levels in and around the mine.

Therefore, it was possible to compare historic water levels with current water levels to determine any water level changes taking place. The trends in water levels can be seen in Appendix II. The following observations were made:

- The majority of mine monitoring boreholes show a declining trend in water levels since 2012 for boreholes located on the farm Beeshoek, where most of the mining pits are located.
- The mine monitoring boreholes located on the farm Doornfontein, north of active mining areas show a stable trend since 2013.

5.3.2 Hydrocensus

In June – July 2020 a hydrocensus was conducted on and around the site to a distance of about 30 km from the mining area so as to obtain a representative population of the boreholes in the area, which also corresponds with historical hydrocensus locations. The study also represents a repeat exercise of the hydrocensus studies conducted in and around Beeshoek Mine in 2002, 2005, 2010, 2013 and 2017 to understand hydrogeological changes in the area. During the hydrocensus, all available details of boreholes and borehole owners were collected and included in the hydrocensus forms in order to identify receptors of groundwater impacts. This includes the:

- Geographic position
- Owner details
- Existing equipment
- Current use
- Reported yield
- Reported or measured depth
- Depth to water level (at rest or pumped)
- Photograph

Information was collected on the use of the boreholes in the area, the water levels and yields of boreholes, etc. The information can be used to assess the risk which potential groundwater pollution, as well as dewatering, poses to groundwater users. A summary of the hydrocensus information is attached under Appendix I. The locations of hydrocensus or external user boreholes are shown in **Figure 6**.

Water levels of the boreholes vary between 2.08 mbgl (KALKFONTEIN) and 96.26 mbgl (DHL3 on Dunhill). A summary of the water levels recorded during the hydrocensus is shown in Table 3 and displayed on a map in Figure 7.

Table 3: Water level measurement record during July 2020.

Borehole ID	Farm	Date of Measurement	Water level (mbgl)	Field Observations
SOET491-3	Soetfontein	2020-06-08	7.7	
SFT1	Soetfontein	2020-06-08	5.42	
SOETHUIS3	Soetfontein	2020-06-08	5.29	
PFNUUT	Soetfontein	2020-06-08	5.98	
SFT2	Soetfontein	2020-06-08	5.57	
BOREHOLE10	Olynfontein	2020-06-08	11.7	
SLR1	Stillerus	2020-06-08	45.72	
230-1	Stillerus	2020-06-08	49.03	
230-3	Floradale	2020-06-08	13.35	
484-2	Floradale	2020-06-08	-	Not measured (sealed)
SFE007	Florade	2020-06-08	8.52	
FLORADALE	Floradale	2020-06-08	7.77	
KAR7	Kareepan	2020-06-08	40.07	
KAR6	Kareepan	2020-06-08	-	Blocked @ 5.6 m
PNF2	Pensfontein	2020-06-08	-	Not measured (sealed)
PNF3	Pensfontein	2020-06-08	7.77	
PNF1	Pensfontein	2020-06-08	14.4	
PE01	Pensfontein	2020-06-08	13.83	
PNF4	Pensfontein	2020-06-08	12.65	
PENS6	Pensfontein	2020-06-08	-	Blocked @ 2.39 m
PNF5	Pensfontein	2020-06-08	9.06	
PENS9	Pensfontein	2020-06-08	-	Dry
G0110NC	Pensfontein	2020-06-09	-	Blocked @ 8.9 m
G0109NC	Pensfontein	2020-06-09	9.45	
AU1	Aucampsrus	2020-06-09	16.3	
AU2	Aucampsrus	2020-06-09	17.44	
AU3	Aucampsrus	2020-06-09	11.59	
AU5	Aucampsrus	2020-06-09	15.66	
AU14	Aucampsrus	2020-06-09	13.16	
AU7	Aucampsrus	2020-06-09	41.2	
AU8	Aucampsrus	2020-06-09	43.2	
AU15	Aucampsrus	2020-06-09	10.78	
AU16	Aucampsrus	2020-06-09	-	Blocked

Borehole ID	Farm	Date of Measurement	Water level (mbgl)	Field Observations
AU10	Aucampsrus	2020-06-09	48.55	
AU12	Aucampsrus	2020-06-09	13.81	
PRAM2	Pramberg	2020-06-09	49.51	
OLYN1	Olynfontein	2020-06-09	5.31	
OLYN2	Olynfontein	2020-06-09	9.62	
OLYN2-1	Olynfontein	2020-06-09	11.3	
OLYN3	Olynfontein	2020-06-09	-	Blocked
OLYN4	Olynfontein	2020-06-09	21.52	
WLS4	Wildeals	2020-06-09	51.56	
KALKFONTEIN	Kalkfontein	2020-06-09	2.08	
KLF1	Kalkfontein	2020-06-09	8.95	
KALKFONTEIN(N& Z)	Kalkfontein	2020-06-09	9.54	
AU17	Aucampsrus	2020-06-10	14	
PFN1	Vogelwater	2020-06-11	10.44	
PFN3 WINDPOMP		2020-06-12	-	Not measured (Sealed)
KAM2	Kameelfontein	2020-06-10	26.01	
KB2	Klipbankfontein	2020-06-10	13.05	
KBF01	Klipbankfontein	2020-06-10	12.02	
BH1	Klipbankfontein	2020-06-10	27.45	
KBF01	Klipbankfontein	2020-06-10	-	Blocked
KBF02	Klipbankfontein	2020-06-10	12.3	
BOSCH1	Bospoort	2020-06-10	15.52	
BOSCH2	Boschpoort	2020-06-10	11.85	
BOSCH3	Boschpoort	2020-06-10	12.47	
MOOI5	Mooidraai	2020-06-10	21	
MOOI4	Mooidraai	2020-06-10	28.62	
MOOI3	Mooidraai	2020-06-10	20.11	
OLYN1	Olynfontein	2020-06-10	5.31	
OLYN2	Olynfontein	2020-06-10	9.62	
OLYN2-1	Olynfontein	2020-06-10	11.3	
OLYN3	Olynfontein	2020-06-10	-	Blocked
OLYN4	Olynfontein	2020-06-10	21.52	
KALKFONTEIN	Kalkfontein	2020-06-10	2.08	
KLF1	Kalkfontein	2020-06-10	8.95	
KALKFONTEIN(N& Z)	Kalkfontein	2020-06-10	9.54	
MOOI6	Mooidraai	2020-06-11	-	Blocked
MOOI2	Mooidraai	2020-06-11	24	
MOOI1	Mooidraai	2020-06-11	20.65	
MOOIDRAAI	Mooidraai	2020-06-11	20.45	
MOOI7	Mooidraai	2020-06-11	24.1	

Borehole ID	Farm	Date of Measurement	Water level (mbgl)	Field Observations
MAM4	Mamagodi	2020-06-12	-	Blocked
ELIM9	Elim	2020-06-12	14.04	
ELIM4	Elim	2020-06-12	14.22	
ELIM3	Elim	2020-06-12	-	Blocked
ELIM5	Elim	2020-06-12	15.52	
ELIM1	Elim	2020-06-12	16.3	
ELIM2	Elim	2020-06-12	15.4	
LCD1	Lucasdam	2020-06-15	23.15	
LCD2	Lacasdam	2020-06-15	35.72	
LCD4	Lucasdam	2020-06-15	9.8	
LCD5	Lucasdam	2020-06-15	7.9	
402-2	Lucasdam	2020-06-15	8.36	
G0108NC	Lucasdam	2020-06-15	7.71	
402-1	Lucasdam	2020-06-15	7.28	
DHL3	Dunhill	2020-06-15	96.26	
DHL4	Dunhill	2020-06-15	66.16	
DHL5	Dunhill	2020-06-15	56.6	
DHL6	Dunhill	2020-06-15	59.95	
362-6	Dunhill	2020-06-15	77	
DHL1	Dunhill	2020-06-15	59.12	
WLS1	Wildeals	2020-06-15	48.16	
WLS2	Wildeals	2020-06-15	60.8	
480-4	Vogelwater	2020-06-17	55.05	
PFN1	Vogelwater	2020-06-17	10.05	
NEW	Vogelwater	2020-06-17	9.02	
G0113NC	Vogelwater	2020-06-17		No Access
G0114NC	Vogelwater	2020-06-17		No Access
479-8	Broomlands	2020-06-17	10.59	
BRL4	Broomlands	2020-06-17	10.65	
BRL2	Broomlands	2020-06-17	10.57	
BRL3	Broomlands	2020-06-17	8.9	
479-6	Broomlands	2020-06-17	7.82	
BRL1	Broomlands	2020-06-17	7.47	
G454495	Postmasburg	2020-06-17	4.45	
G47753	Postmasburg	2020-06-17	-	Blocked @ 3 m
VLW2	Voelwater	2020-06-17	70	
VLW1	Voelwater	2020-06-17	59.58	
VLW4	Voelwater	2020-06-17	75	
PRB1	Pramberg	2020-06-17	36.3	
PRAM1	Pramberg	2020-06-17	48.9	
362-7	Pramberg	2020-06-17	52.2	

Borehole ID	Farm	Date of Measurement	Water level (mbgl)	Field Observations
PRB2	Pramberg	2020-06-17	70.65	
VLW5	Pramberg	2020-06-17	86.65	

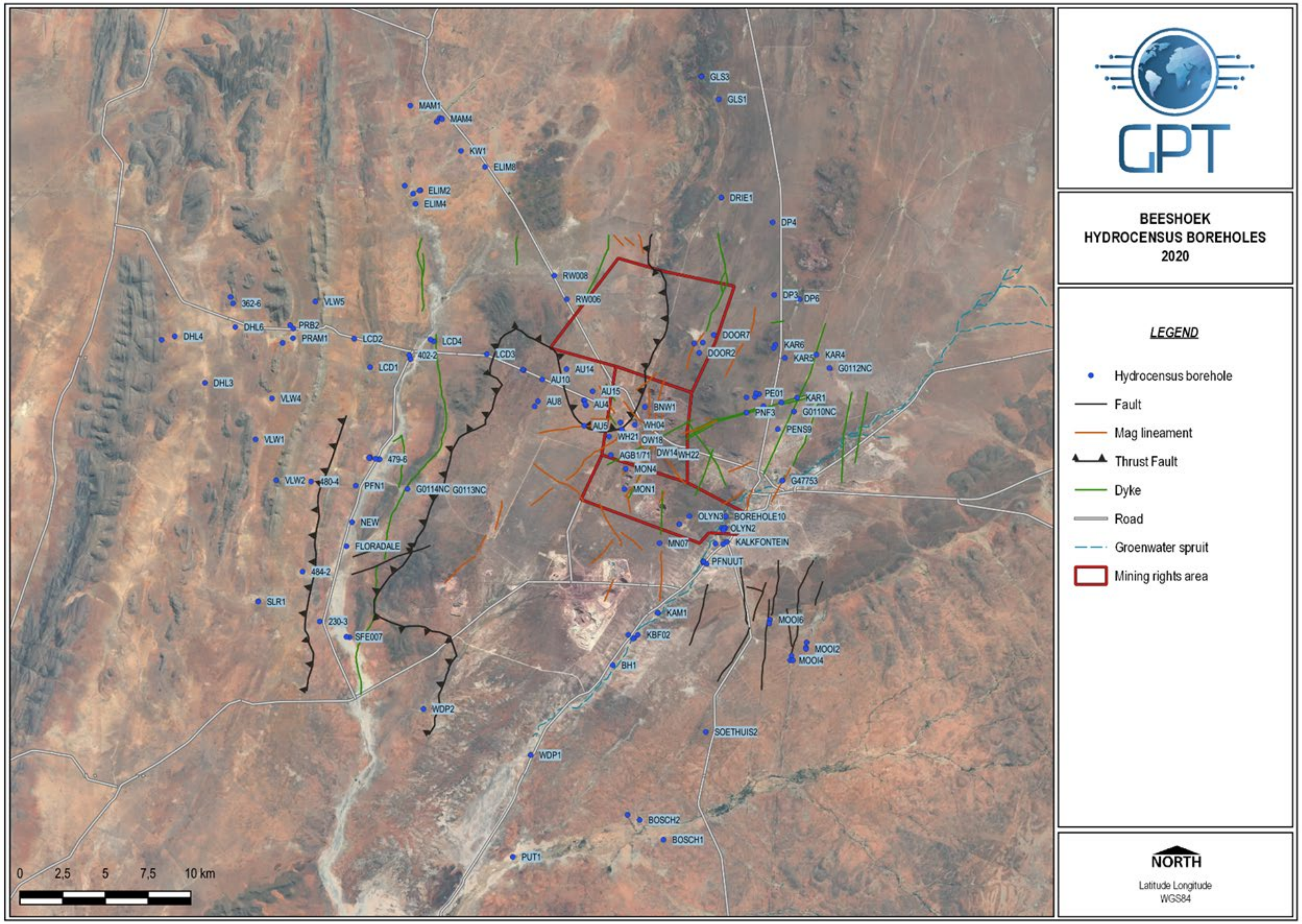


Figure 6: Hydrocensus and monitoring borehole location.

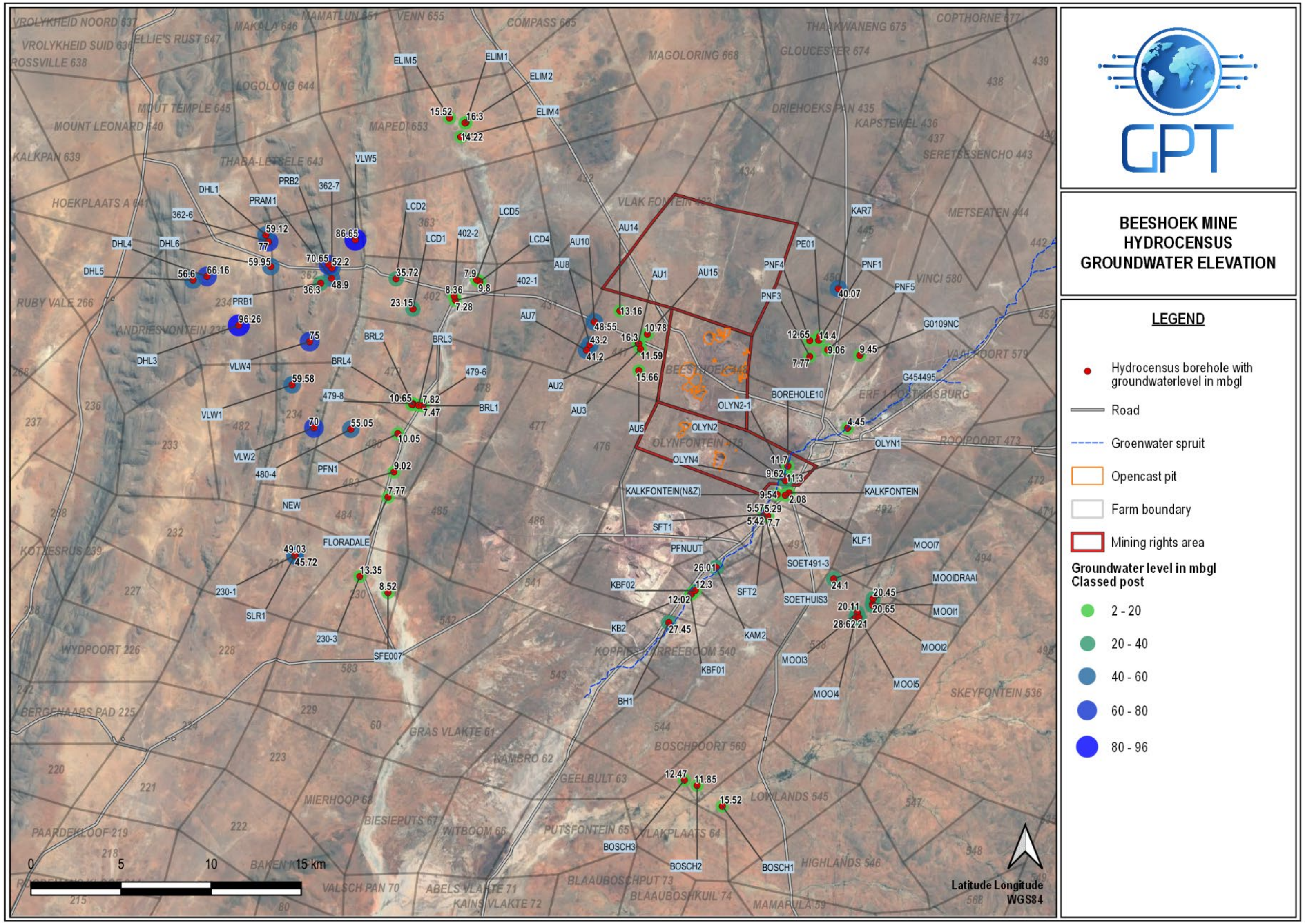


Figure 7: Water levels in mbgl recorded in July 2020 in external user boreholes.

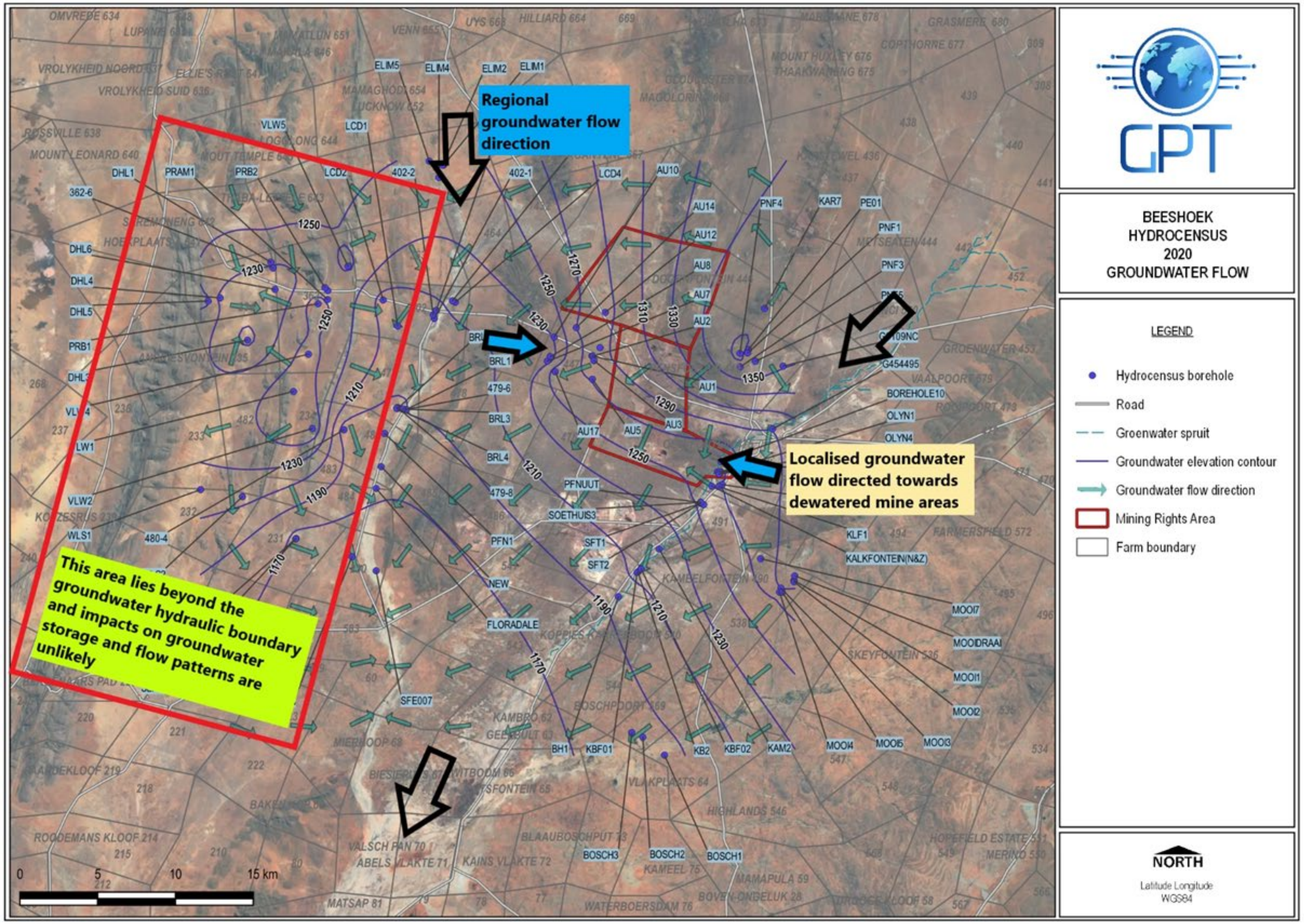


Figure 8: Contoured water levels of the water table aquifer.

5.4 Potential Groundwater Contaminants

An audit of the existing monitoring network as well as a waste classification exercise was carried out to characterise contaminant sources to determine the adequacy of the monitoring network[2]. The following findings were made:

- The leachable concentrations of solid waste were compared to the leachable concentration threshold (LCT) limits[3] to determine the leachability of the different waste types at the mine. Solid waste types were described as either “type 4” or “type 3” waste types which are low hazard waste types with regards to the likelihood to release contaminants in dissolved phase.
- Liquid waste (mine water) was compared to the SANS 241-1:2015[4] drinking water standards and the majority of constituents were found to lie within acceptable limits with the occurrence of elevated nitrate in some liquid waste handling facilities (viz. D90, 26TK01, Fine Residue Dam, Thickener and Clarifier)
- The majority of potential sources of contaminants are located within the dewatered area, directing groundwater flow towards the active mining areas. Therefore, expansion of the groundwater **quality** monitoring network was not deemed necessary, as the effects of potential sources on the groundwater environment are likely to be negligible and are unlikely to be observed in samples as the chemical signatures (composition) of the different mediums are similar.[5]

5.5 Contaminants of Concern

The following constituents/chemical substances were considered as contaminants of concern in relation to mining and waste management at the Beeshoek Mine:

- Ba, Mn and NO_3 which were regarded as contaminants of concern in the WUL were found to be naturally occurring and meet the groundwater quality objectives as prescribed in the WUL in the form of maximum allowable concentrations. The occurrence of NO_3 in groundwater indicates that it is natural outside of the mining area with minor contribution (<1%) from using N-based explosives within the mining area for blasting.[6]
- The dominant ions in groundwater samples have a Ca^{2+}, Mg^{2+} and HCO_3^- typical of unpolluted groundwater enriched in Ca and Mg due to the presence of dolomite [$CaMg(CO_3)_2$] in the area which can influence the carbonate concentration in the groundwater by dissolution.[7]

5.5.1 Sewage Management

The mine makes use of below-ground sewage collection systems (sewage sumps) and above-ground polyethylene tanks for human waste management. The sumps are located at shallow depth (<20 mbgl)

---

[2] Geo Pollution Technologies (Pty) Ltd (2018). Waste Characterisation and Groundwater Monitoring Network Audit for ASSMANG Beeshoek Iron Ore Mine. Contract Report (Reference: ASBEE-16-1987).

[3] National Environmental Management: Waste Act (Act 59 of 2008).

[4] South African National Standard (SANS) 241 Part 1 (2015). Microbiological, Physical, Aesthetic and Chemical Determinands. Edition 2. Published by South African Beaureu of Standards, Pretoria.

[5] Geo Pollution Technologies (Pty) Ltd (2018). Waste Characterisation and Groundwater Monitoring Network Audit for ASSMANG Beeshoek Iron Ore Mine. Contract Report (Reference: ASBEE-16-1987).

[6] Geo Pollution Technologies (Pty) Ltd (2019). Contamination Assessment at Beeshoek Iron Ore Mine in terms of Nitrate, Barium and Manganese as Contaminants of Concern. Contract Report (Reference: ASBEE-19-4097).

[7] Geo Pollution Technologies (Pty) Ltd (2019). Contamination Assessment at Beeshoek Iron Ore Mine in terms of Nitrate, Barium and Manganese as Contaminants of Concern. Contract Report (Reference: ASBEE-19-4097).

and are emptied manually with a honey sucker. The presence of bacteriological parameters in groundwater is monitored quarterly from water supply boreholes.

5.5.2 Fuel Storage and Handling

There are above-ground diesel storage tanks, located in the South and North mines for filling load and haul trackless mobile machinery (TMM), each with a capacity of about 80 m^3, calibrated as needed on a regular basis. Each tank farm consists of four tanks kept in a bunded area to contain unintended release or washing by rainfall of potentially polluting diesel. Remote refuelling of TMM is allowed which may extend the footprint potential hydrocarbon contamination.

The impact of diesel storage and handling on groundwater quality is currently not being monitored. It is generally required that source monitoring boreholes be constructed within 10 – 50 m down-gradient of the storage area up to a depth of 20 m[8]. However, due to the average depth to the water table being in excess of 50 m within the operational mining area, it is recommended that the existing diesel handling management measures be maintained to prevent negative impacts on the surface and subsurface. The construction deep boreholes (>50 m) for non-aqueous phase liquid (NAPL) monitoring may create a conduit for surficial contaminants to reach the water table.

5.6 Groundwater Quality

The groundwater water monitoring programme conducted at Beeshoek Mine occur on a quarterly basis. The groundwater monitoring program consists of monitoring boreholes which pump water to reservoirs which are sampled and analysed for water quality monitoring.

5.6.1 Monitoring Boreholes

The water results are compared with the maximum recommended concentrations set out in the WUL (Class 2) (Table 4), in which the average value of the year 2019 of each parameter were used for each monitoring borehole.

Generally, the groundwater resources at all the sampling localities are described as being neutral to alkaline (pH levels between 7.8 and 8.0), non-saline to saline (TDS between 445.5 mg/l and 563.8 mg/l), and the hardness can be classified as very hard (> 300mg $CaCO_3$/l). Water hardness at Beeshoek mine is not unlike most other boreholes in the area, resulting from the calcareous/dolomitic underlying geology characteristic of many parts of the Northern Cape Province. Metal concentrations were below detection limit or low at all the monitoring boreholes during 2019.

The analytical results for external user boreholes in 2020 were compared with the maximum recommended concentrations for domestic use as defined by the SANS 241-1: 2015 target water quality limits. The SANS 241-1: 2015 standard is applicable to all water services institutions and sets numerical limits for specific determinants to provide the minimum assurance necessary that the drinking water is deemed to present an acceptable health risk for lifetime consumption. Highlighted individual cells exceed the drinking water classification of the specific determinant in the groundwater sample.

The results of the screening for groundwater are presented in Table 5 and the following observations were made:

- Nitrate as N and combined nitrate and nitrite exceed the drinking water limit in the majority of external user boreholes regardless of location. The WUL identified nitrates as a contaminant of

[8] SANS 10089-3: 2010 Guidelines for the Installation, Modification and Decommissioning of Underground Storage Tanks, Pumps/Dispensers and Pipework at Service Stations and Consumer Installations.

concern in relation to mining activity due to the use of N-based emulsions for blasting. Through the analysis of N-isotopes from nitrates, a contamination assessment was conducted in 2019[9] and it was concluded that mine's contribution to nitrate levels in and around the mine was minimal within the mining area.

5.6.1.1 Summary of water quality observations

From the results of water quality monitoring and various groundwater impact assessments the following observations were made:

- All samples complied with the Class 2 limits set in the WUL.
- All samples have a Ca2+/Mg2+-HCO3- hydrochemical signature typical of unpolluted groundwater enriched in Ca and Mg due to the presence of dolomite [Ca.Mg(CO_3)2] in the area which can influence the carbonate concentration in the groundwater by dissolution.
- The use of N-based explosives for mine blasting is likely to contribute to elevated nitrate levels in groundwater as most explosives contain between 70 – 90% ammonium nitrate. Nitrates are highly soluble in water. The occurrence of nitrate in groundwater and the pit water indicates that nitrate is naturally occurring (outside of the mining area) with contribution from N-based explosives in the mining area. In the mining environment, the leaching of blasting residue from waste rock, tailings and mine water impoundment are also potential sources of nitrate in groundwater. The contribution of N-based-explosives to nitrate concentration in groundwater is negligible compared to background values.
- The time series graph (Figure 9) indicates that the nitrate concentrations fluctuate over time and that concentrations in WG62 and WG74 are increasing from September 2019 onwards. The remaining boreholes reported a decreasing trend from April 2019 onwards. The average value of the NO^3 concentrations in the boreholes is 9.62mg/.
- Nitrate occurrence may be attributed to nitrogen cycling in the environment and the use of N-based explosives (for mine blasting). Nitrate circulation in water is complicated, involving multiple sources. The sources of nitrates around the mine may be attributed to either natural occurrence in soil and/or the use of N-based fertiliser on irrigated soils.

5.7 Water Spatial Analysis

The results from the chemical analyses were plotted on pie diagrams for mine monitoring boreholes and hydrocensus (external user) boreholes. The pie diagrams show the individual ions present in a water sample as a presentation of the total ion concentrations. The scale for the radius of the circle represents the total ion concentrations, while the subdivisions represent the individual ions. It is useful in making comparisons between waters from different sources and presents the data in a convenient manner for visual inspection.

It can be deduced from the pie diagrams (Figure 10 and Figure 11) that the water chemistry in the majority of the boreholes and surface water monitoring points are dominated by Ca, Mg, Cl and HCO_3, represents fresh, clean, relatively young groundwater that has started to undergo Mg ion-exchange, often found in dolomitic terrain.

[9] Geo Pollution Technologies (May 2019). Contamination Assessment at Beeshoek Iron Ore Mine in terms of Nitrate, Barium and Manganese as Contaminants of Concern. Technical Report, Reference Nr.: ASBEE-19-4097.

Table 4: Average results of the analysis for groundwater as per WUL for January 2020.

Sample Nr.	WG37	WG28	WG62	WG70	WG74	Landfill	Class 0	Class 1	Class 2	Class 3	Class 4
pH	7.46	7.09	7.80	7.64	7.80	7.74	5-9.5	4.5-5;9.5-10	4-4.5;10-10.5	3-4;10.5-11	<3;>11
EC	82.10	96.30	82.90	84.80	80.40	71.20	<70	70-150	150-370	370-520	>520
TDS	561.00	585.00	555.00	552.00	538.00	435.00	<450	450-1000	1000-2400	2400-3400	>3400
Cl	39.90	52.20	47.60	41.90	42.10	46.50	<100	100-200	200-600	600-1200	>1200
SO_4	33.40	13.10	31.40	22.40	28.30	14.80	<200	200-400	400-600	600-1000	>1000
NO_3-N	8.67	3.97	17.70	9.42	15.70	2.20	6	6.0-10	10.0-20	20-40	>40
F	-0.26	-0.26	0.27	-0.26	0.34	-0.26	<0.7	0.7-1	1-1.5	1.5-3.5	<3.5
Ca	91.70	106.00	79.80	87.80	74.20	77.20	80	80-150	150-300	>300	~
Mg	54.80	57.30	49.60	54.20	52.00	45.80	<70	70-100	100-200	200-400	>400
Na	12.60	12.20	18.80	14.30	17.00	11.20	<100	100-200	200-400	400-1000	>1000

Notes

Negative value = below detection limit of analytical technique

*In the WUL Class 1 is indicated as Class 2 for pH and Mg.

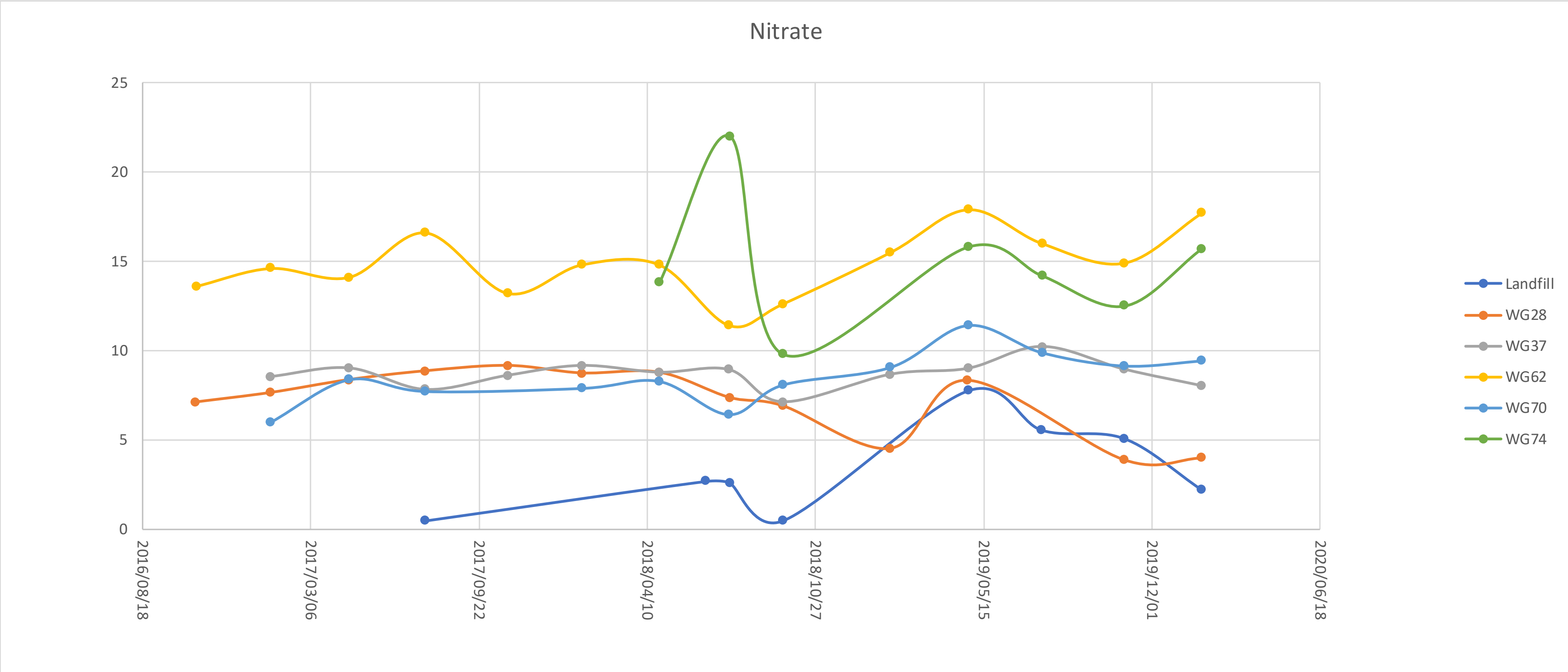


Figure 9: Time series graph of NO_3 in monitoring boreholes.

Table 5: Water qualities compared to SANS 241-1:2015 guidelines for external user boreholes (2020).

Determinand	Risk	Unit	Standard limits	SOETHUIS3	OLYN2	OLYN2-1	KAM2	OLYN1
Physical and aesthetic determinands								
Conductivity at 25 °C	Aesthetic	mS/m	170	119	223	152	123	152
Total dissolved solids	Aesthetic	mg/L	1 200	834	1560	1060	862	1070
pH at 25 °C	Operational	pH units	5 to 9.7	7.32	7.23	7.31	7.48	7.38
Chemical determinands — macro-determinands								
Nitrate as N (NO_3 - N)	Acute health	mg/L	11	3.19	6.48	4.6	0	1.44
Nitrite as N (NO_2 - N)	Acute health	mg/L	0.9	0.002	0.002	0.002	0.002	0.003
Combined nitrate plus nitrite (NO_3+NO_2)	Acute health		1	14.105	28.706	20.406	0	6.389
Sulfate as SO_4^{2-}	Acute health	mg/L	500	69.5	243	153	141	86.6
Fluoride as F^-	Chronic health	mg/L	1.5	0.197	0.155	0.166	0.243	0.288
Ammonia as N	Aesthetic	mg/L	1.5	0	0	0	0	0
Chloride as Cl^-	Aesthetic	mg/L	300	77.6	238	131	79.6	171
Sodium as Na	Aesthetic	mg/L	200	45	120	70.2	26.4	109
Zinc as Zn	Aesthetic	mg/L	5	0	0	0	0	0
Chemical determinands — micro-determinands								
Barium as Ba	Chronic health	mg/L	0.7	0	0	0	0.09	0
Boron as B	Chronic health	mg/L	2.4	0.15	0.27	0.15	0.1	0.17
Iron as Fe	Aesthetic	mg/L	0.3	0	0	0	0	0
Manganese as Mn	Aesthetic	mg/L	0.1	0	0	0	0	0
Aluminium as Al	Operational	mg/L	0.3	0	0	0	0	0
pH, conductivity or Concentration deemed unacceptable for lifetime consumption								

Determinand	Risk	Unit	Standard limits	KALKFONTEIN	AU15	PNF2	KB2	AU3	AU14	AU2	230-1	480-4	BRL-3
Physical and aesthetic determinands													
Conductivity at 25 °C	Aesthetic	mS/m	170	122	91.2	97.6	129	83	86.5	101	95.3	105	101
Total dissolved solids	Aesthetic	mg/L	1 200	854	639	683	905	581	605	709	667	735	704
pH at 25 °C	Operational	pH units	5 to 9.7	7.3	7.35	7.5	7.48	7.49	7.47	7.32	7.36	7.24	7.6
Chemical determinands — macro-determinands													
Nitrate as N (NO_3 - N)	Acute health	mg/L	11	1.34	11.2	6.78	3.21	10.7	22	16.4	13.8	22.5	14.7
Nitrite as N (NO_2 - N)	Acute health	mg/L	0.9	0.004	0.002	0.002	0.002	0.002	0.004	0.002	0.002	0.003	0.002
Combined nitrate plus nitrite (NO_3+NO_2)	Acute health		1	5.942	49.406	30.007	14.206	47.406	97.212	72.608	61.006	99.711	64.908
Sulfate as SO_4^{2-}	Acute health	mg/L	500	92.4	17	16.5	115	20.4	22.3	30.8	31	24.9	46.3
Fluoride as F^-	Chronic health	mg/L	1.5	0.153	0.312	0.162	0.257	0.248	0.257	0.222	0.16	0.377	0.436
Ammonia as N	Aesthetic	mg/L	1.5	0	0	0	0.017	0.009	0	0	0	0.082	0
Chloride as Cl^-	Aesthetic	mg/L	300	114	15.4	22.8	83.6	23.9	21.4	45	53.4	26.9	59.5
Sodium as Na	Aesthetic	mg/L	200	74.5	12.4	12.9	50.8	15.8	20.1	19.1	31.9	30.7	67.2
Zinc as Zn	Aesthetic	mg/L	5	0	0	0	0	0	0	0	0	0	0
Chemical determinands — micro-determinands													
Barium as Ba	Chronic health	mg/L	0.7	0	0.18	0	0	0.18	0.18	0.21	0	0.07	0.05
Boron as B	Chronic health	mg/L	2.4	0.11	0.07	0.05	0.17	0.1	0.11	0.11	0.11	0.14	0.33
Iron as Fe	Aesthetic	mg/L	0.3	0	0	0	0	0	0	0	0	0	0
Manganese as Mn	Aesthetic	mg/L	0.1	0	0	0	0	0	0	0	0	0	0
Aluminium as Al	Operational	mg/L	0.3	0	0	0	0	0.07	0	0	0	0	0
pH, conductivity or Concentration deemed unacceptable for lifetime consumption													

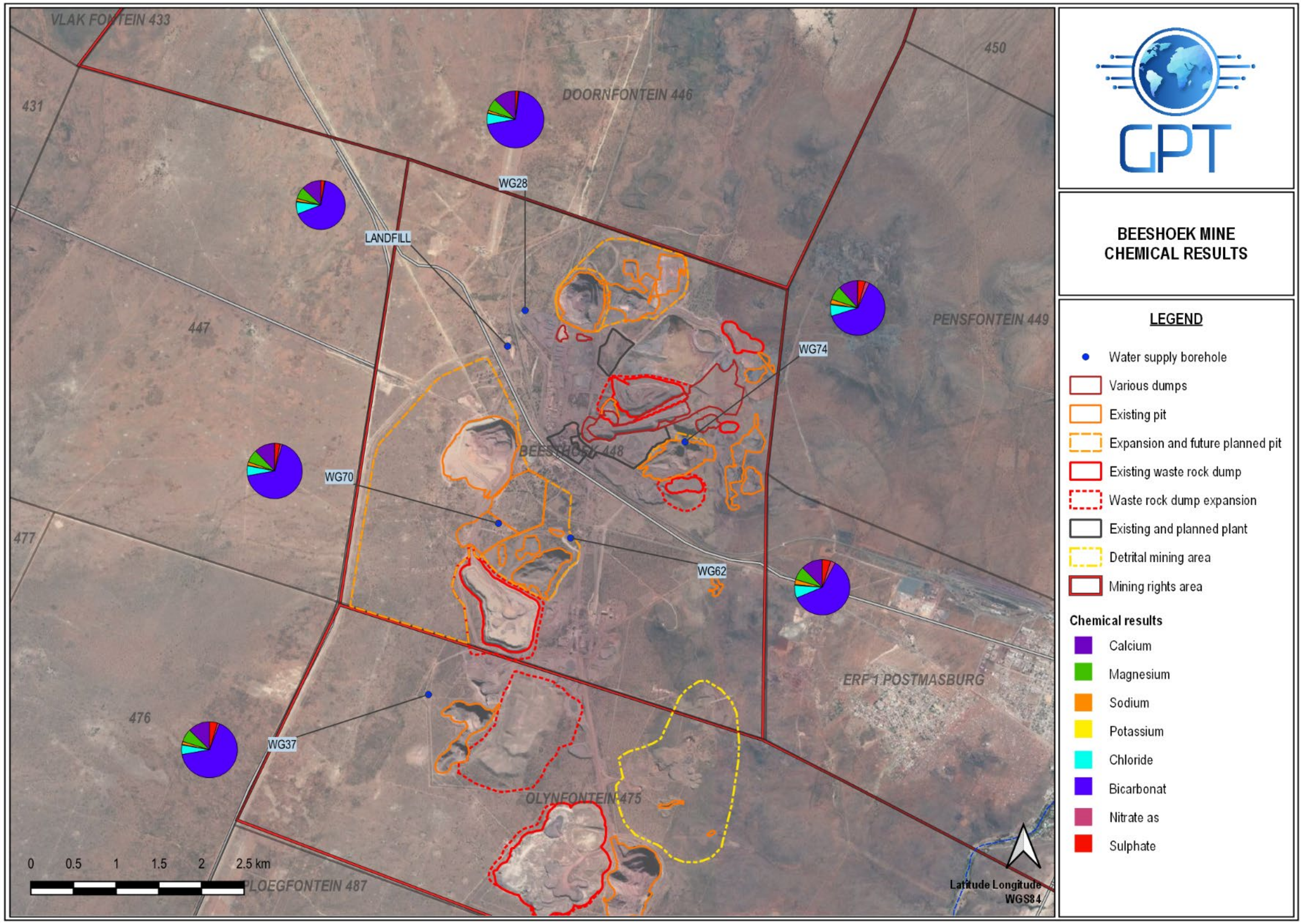


Figure 10: Pie diagrams of major cations and anions (mine monitoring boreholes) -January 2020.

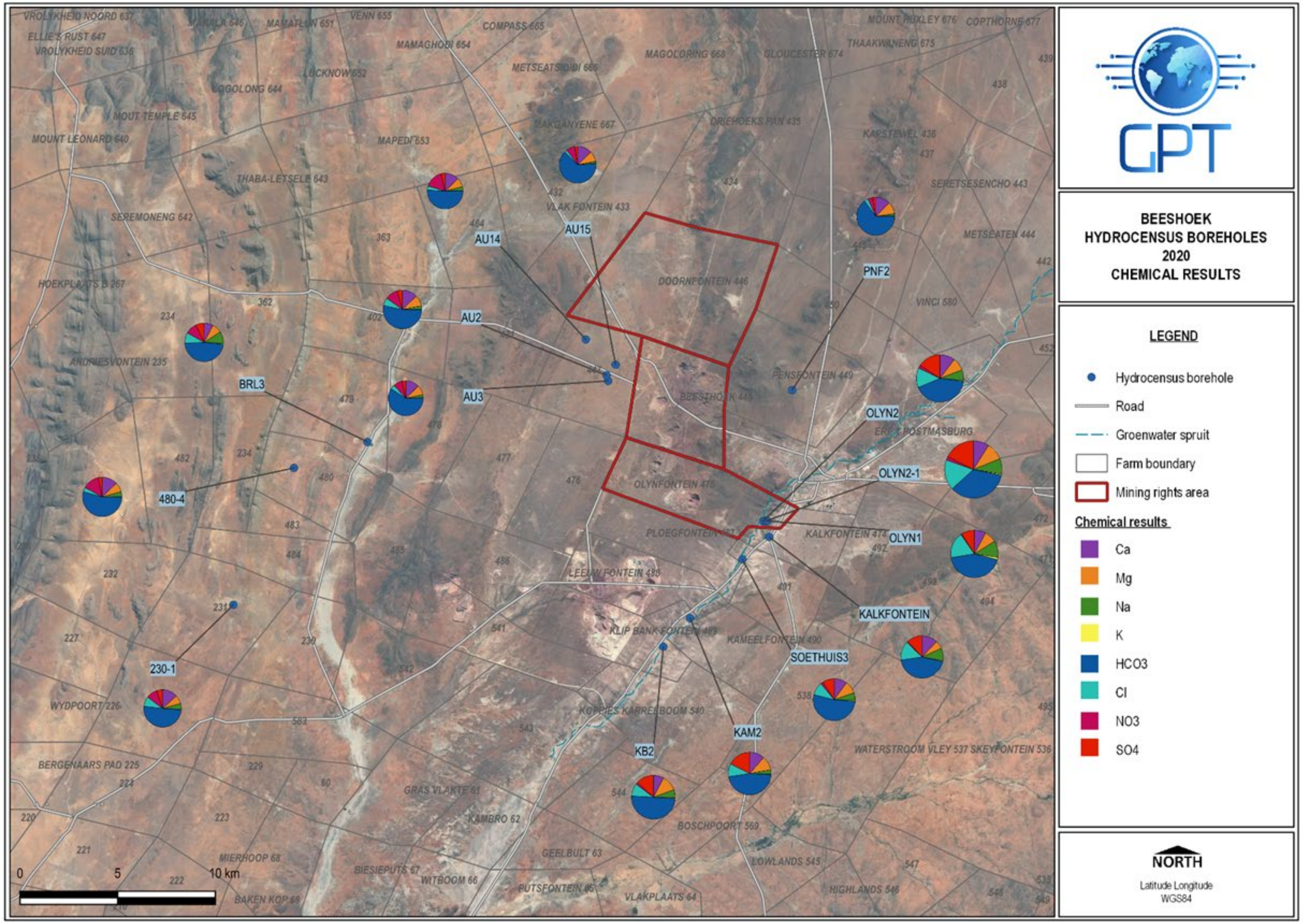


Figure 11: Pie diagrams of major cations and anions (groundwater) – external user boreholes in 2020.

6 AQUIFER CHARACTERISATION

The term aquifer refers to a strata or group of interconnected strata comprising of saturated earth material capable of conducting groundwater and of yielding usable quantities of groundwater to boreholes and /or springs (Vegter, 1994). In the light of South Africa's limited water resources, it is important to discuss the aquifer sensitivity in terms of the boundaries of the aquifer, its vulnerability, classification and finally protection classification, as this will help to provide a framework in the groundwater management process.

6.1 Aquifer Vulnerability

Aquifer vulnerability assessment indicates the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer. Stated in another way, it is a measure of the degree of insulation that the natural and manmade factors provide to keep contamination away from groundwater.

- Vulnerability is high if natural factors provide little protection to shield groundwater from contaminating activities at the land surface.
- Vulnerability is low if natural factors provide relatively good protection and if there is little likelihood that contaminating activities will result in groundwater degradation.

The following factors have an effect on groundwater vulnerability:

- Depth to groundwater: Indicates the distance and time required for pollutants to move through the unsaturated zone to the aquifer.
- Recharge: The primary source of groundwater is precipitation, which aids the movement of a pollutant to the aquifer.
- Aquifer media: The rock matrices and fractures which serve as water bearing units.
- Soil media: The soil media (consisting of the upper portion of the vadose zone) affects the rate at which the pollutants migrate to groundwater.
- Topography: Indicates whether pollutants will run off or remain on the surface allowing for infiltration to groundwater to occur.
- Impact of the vadose zone: The part of the geological profile beneath the earth's surface and above the first principal water-bearing aquifer. The vadose zone can retard the progress of the contaminants.

The Groundwater Decision Tool (GDT) was used to quantify the vulnerability of the aquifer underlying the site using the below assumptions.

- Depth to groundwater below the site was estimated from water levels measured during the hydrocensus inferred to be at mean of ~65 mbgl.
- Groundwater recharge of ~20-25 mm/a (3.5% recharge),
- Sandy soil vadose zone
- Gradient of 1% were assumed and used in the estimation.

The aquifer vulnerability for a contaminant released from surface to a specified position in the groundwater system after introduction at some location above the uppermost aquifer was determined using the criteria described below and assuming a worst-case scenario:

- Highly vulnerable (> 60), the natural factors provide little protection to shield groundwater from contaminating activities at the land surface.
- Medium Vulnerable = 30 to 60%, the natural factors provide some protection to shield groundwater from contaminating activities at the land surface, however based on the contaminant toxicity mitigation measures will be required to prevent any surface contamination from reaching the groundwater table.
- Low Vulnerability (< 30 %), natural factors provide relatively good protection and if there is little likelihood that contaminating activities will result in groundwater degradation.
- The GDT calculated a vulnerability value of 33%, which is medium.

6.2 Aquifer Classification

The aquifer(s) underlying the subject area were classified in accordance with “A South African Aquifer System Management Classification, December 1995.”

The main aquifers underlying the area were classified in accordance with the Aquifer System Management Classification document[10]. The aquifers were classified by using the following definitions:

- Sole Aquifer System: An aquifer which is used to supply 50% or more of domestic water for a given area, and for which there is no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.
- Major Aquifer System: Highly permeable formations, usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (Electrical Conductivity of less than 150 mS/m).
- Minor Aquifer System: These can be fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important for local supplies and in supplying base flow for rivers.
- Non-Aquifer System: These are formations with negligible permeability that are regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer unusable. However, groundwater flow through such rocks, although imperceptible, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.

Based on information collected during the hydrocensus it can be concluded that the aquifer system in the study area can be classified as a “minor aquifer system”, based on the fact that the local population is dependent on groundwater.

In order to achieve the Aquifer System Management and Second Variable Classifications, as well as the Groundwater Quality Management Index, a points scoring system as presented in Table 6 and Table 7 was used.

[10] Department of Water Affairs and Forestry & Water Research Commission (1995). A South African Aquifer System Management Classification. WRC Report No. KV77/95.

Table 6: Ratings - Aquifer System Management and Second Variable Classifications.

Aquifer System Management Classification		
Class	Points	Study area
Sole Source Aquifer System:	6	
Major Aquifer System:	4	
Minor Aquifer System:	2	2
Non-Aquifer System:	0	
Special Aquifer System:	0 - 6	
Second Variable Classification (Weathering/Fracturing)		
Class	Points	Study area
High:	3	
Medium:	2	2
Low:	1	

Table 7: Ratings - Groundwater Quality Management (GQM) Classification System.

Aquifer System Management Classification		
Class	Points	Study area
Sole Source Aquifer System:	6	
Major Aquifer System:	4	
Minor Aquifer System:	2	2
Non-Aquifer System:	0	
Special Aquifer System:	0 - 6	
Aquifer Vulnerability Classification		
Class	Points	Study area
High:	3	
Medium:	2	2
Low:	1	

As part of the aquifer classification, a Groundwater Quality Management (GQM) Index is used to define the level of groundwater protection required. The GQM Index is obtained by multiplying the rating of the aquifer system management and the aquifer vulnerability. The GQM index for the study area is presented in Table 8.

The vulnerability, or the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer, in terms of the above, is classified as **medium.**

The level of groundwater protection based on the Groundwater Quality Management Classification:

GQM Index = Aquifer System Management x Aquifer Vulnerability

= 2 x 2 = 4

Table 8: GQM Index for the Study Area.

GQM Index	Level of Protection	Study Area
<1	Limited	
1 - 3	Low Level	
3 - 6	Medium Level	4
6 - 10	High Level	
>10	Strictly Non-Degradation	

6.3 Aquifer Protection Classification

A Groundwater Quality Management Index of 4 was estimated for the study area from the ratings for the Aquifer System Management Classification. According to this estimate a **medium level groundwater protection** is required for the aquifer. Reasonable and sound groundwater protection measures based on the modelling will therefore be recommended to ensure that no cumulative pollution affects the aquifer, even in the long term.

DHSWS's water quality management objectives are to protect human health and the environment. Therefore, the significance of this aquifer classification is that measures must be taken to limit the risk to the following environments.

- The protection of the underlying aquifer.
- Groundwater users in and around the mine.

7 CONCEPTUAL SITE MODEL (CSM)

7.1 Geological Framework

Geologically, the mine is located on the Maramane dome, which is defined by carbonate rocks of the Campbellrand Subgroup and the iron formations of the Asbesheuwels Subgroup of the Transvaal Supergroup. The dome dips gently, at less than 10 degrees, in an arc to north and south. Only the eastern half of the dome is exposed, while the western part is covered by red beds, conglomerate, shale and quartzite of the Gamagara Formation. The Beeshoek-Olynfontein iron ore deposits are situated along the contact between the Gamagara Formation and the underlying Manganore Iron Formation. The latter being a distorted iron formation, wedged unconformably between the Gamagara Formation and the Campbellrand carbonate sequence.

The iron ore deposits in the Beeshoek-Olynfontein area are resistant to weathering and form part of the more prominent topographical features of the Gamagara Hills, striking in a north – south direction between Postmansburg and Sishen. A generalised schematic cross section representing the mining method relative to groundwater occurrence is shown in Figure 12.

The Groenwaterspruit, to the south of the mine, forms a local depression in the topography. This non-perennial stream serves mainly as a rainwater drainage feature.

7.2 Contaminant Sources/Source Terms

The potential influences on groundwater quality were identified as opencast mining, fuel storage and handling, sewage management, solid and liquid mining-related waste management at the mine (i.e. ore discards and impounded mine water).

The waste disposal and handling facilities within the active mining area are located within the dewatered zone. Due to dewatering for mining purposes, the average depth to water level within the mining area has increased in excess of 50 mbgl, increasing the thickness of the unsaturated zone which acts as a buffer between the water table and potential sources of contamination on the surface.

7.3 Contaminant Pathways

Pathways along which contaminants may be mobilized and migrate toward groundwater receptors include:

- The vadose zone/ unsaturated zone
- Shallow weathered aquifer
- Fractured aquifer
- Surface runoff as storm water or water courses (rivers and streams)
- Air – dust particles

From a hydrogeological point of view, it is expected that the potential contaminants will be mobilised by surface and groundwater from the contaminant sources. Thereafter the contaminants will move from the surface into the sub-surface through the unsaturated (vadose) zone and into the saturated zone.

For an accurate prediction of the behaviour of a contaminant plume along its pathways, it is critical that the monitoring and field measurements are representative of the physical environment. It is also important to keep seasonal and annual trends in mind, as they affect the water quality.

7.4 Receptors

Any user of a groundwater or surface water resource that is affected by pollution from any of the above-mentioned sources is defined as a receptor. The pollution potential of an iron mine is minimal in comparison to coal or gold mines. Furthermore, a borehole or river may also be a receptor. The following possible receptors may be found:

- Groundwater users in and around the mine.

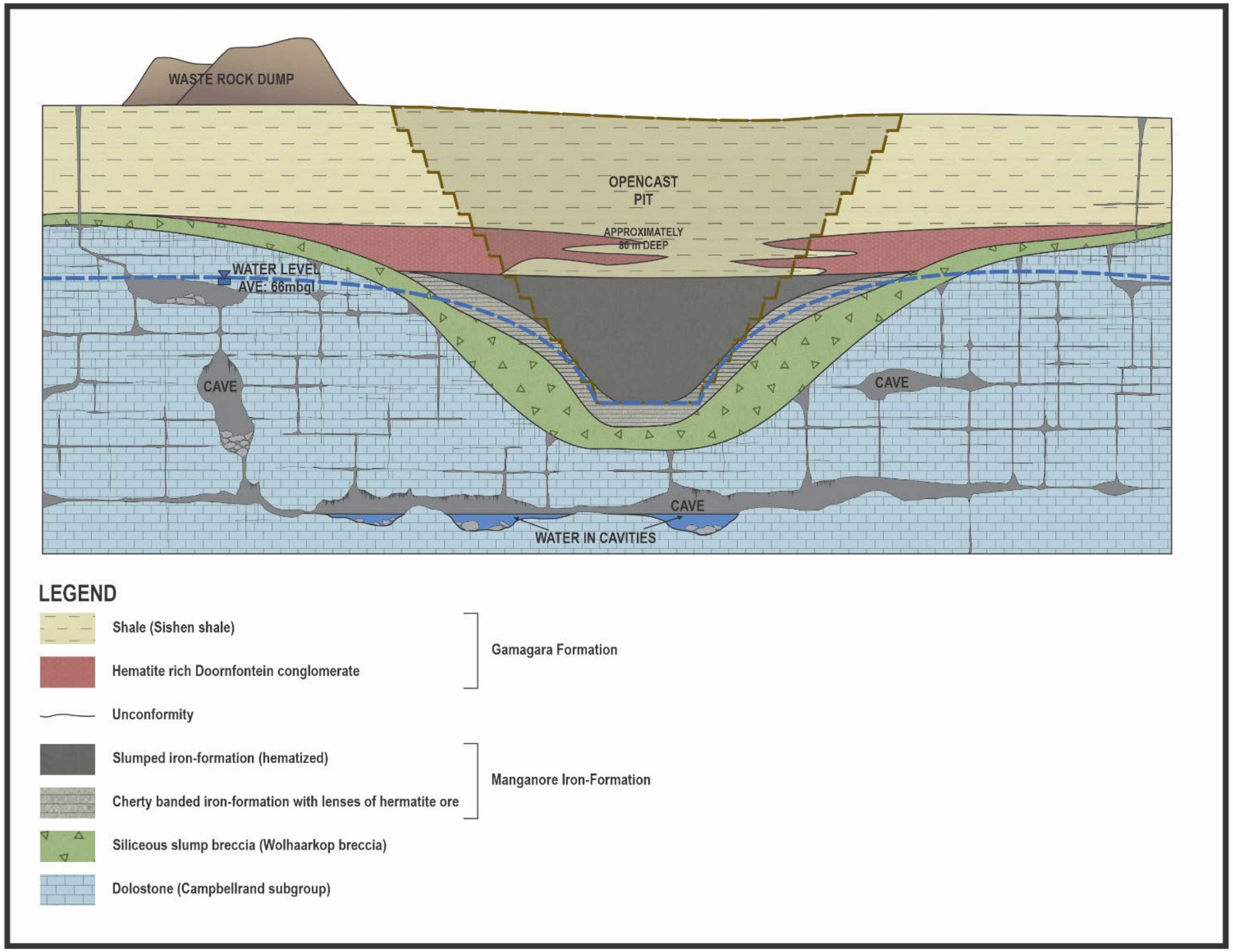


Figure 12: General conceptual site model for Beeshoek type iron ore in cross-section.

8 GROUNDWATER FLOW AND TRANSPORT MODELLING

The numerical groundwater flow model is constructed and simulated to aid in decision making processes and environmental management.

The purpose of this numerical model is to develop a tool than can be used to assess the impact of the current and planned activity (mostly dewatering associated with the opencast mining) during the operational phase also considering existing operations. Together with this, simulate the impacts associated with potential pollution sources.

The groundwater regime of the study area is highly heterogeneous due to the existence of dissolution cavities in the dolomites superimposed on complex faulting, fracturing and intrusions; all which which influence the groundwater flow patterns. Especially the dissolution cavities are almost undetectable by surface investigations, barring intrusive techniques such as drilling.

However, groundwater models are almost without exception based on homogenous conditions and flow founded on Darcy`s law, thus assuming at least semi-homogenous conditions where flow from cell to cell can be mathematically characterized by hydraulic conductivity.

It must be stated that some programs can model structures such as cavities (the Connected Linear Network om Modflow is such an example), but then the network has to be known, which is normally not the case in Karst areas.

Thus, a compromise has to be made between modelling the extreme heterogenous situation, and the homogenous assumption using Darcy`s law on the other hand. Such a compromise has indeed been reached and will be described later in this paragraph.

8.1 Software Model Choice

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

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

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

8.2 Model Set-up and Boundaries

Boundaries were chosen to include the area where the groundwater pollution plume could reasonably be expected to spread and simultaneously be far enough removed from site boundaries not to be affected by groundwater abstraction. These boundaries are described in Table 9.

These boundaries resulted in an area of about 30 to 40 km around the proposed mining, which is considered far enough for the expected groundwater effects not to be influenced by boundary conditions.

8.3 Groundwater Elevation and Gradient

The calibrated static water levels as modelled have been contoured (**Figure 8**). Groundwater flow direction should be perpendicular to these contours and inversely proportional to the distance between contours. As can be expected, the groundwater flow is mainly from topographical high to low areas, eventually draining towards hydraulic discharge points.

8.4 Geometric Structure of the Model

The modelling area was discretised by a 140 x 140 grid refined at the active mining area, resulting in finite difference elements of about 50 x 50 m at the active mining area increasing to just more than 1 km^2. All modelled features, like mining areas, etc., are sizably larger than these dimensions, and the grid is thus adequate for the purpose. The total amount of active cells over all layers added up to about 20 000, resulting in relatively large model.

8.5 Groundwater source and sinks

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

Table 9: Input parameters to the numerical flow model.

Model Parameter	Value	Unit	Reason
Recharge to the aquifer	0.00008	m/d	Calculated as percentage from rainfall
Evapotranspiration	0.006	m/d	Calculated from E-pan evaporation data
Boundaries	Topographic water divides	-	Existing boundary conditions present at the site that would potentially include modelled impacts
Refinement	50	m	Based on the scale of the mining area
Grid dimensions	240 x 280	Cell count	Product of the grid refinement
Hydraulic conductivity	Variable	m/d	Existing hydrogeological report (Du Toit, 2008 and 2017)
Effective porosity	Variable	%	Existing hydrogeological report (Du Toit, 2008 and 2017)
Layers	1	-	Method of Pilot Points, see below
Longitudinal dispersion	50	m	Schulze-Makuch (2005)
Head error range	10	m	Calculated as 10% of the difference between the maximum and minimum calculated head elevations

8.6 Conceptualisation of Pilot Point Method

The most applicable attempt for modelling the extreme heterogeneity of dolomitic solution cavities is the so-called “Pilot Point” inverse parameter estimation process. Contrary to other approaches, this scheme does not require hydrogeological parameters to be allocated as a constant over any spatial extent. Instead, it utilises manually created points spread over the modelled area at which the hydraulic conductivity is calculated to best fit the observed groundwater levels. The hydraulic conductivity of the area is then interpolated from these points. This is a tremendous advantage as fewer assumptions of hydrogeological structures are required to obtain a solution that matches the observed data.

The downside, however, lies in the computer run-time to obtain a solution. As the model nears completion and the amount of pilot point is increased to improve resolution, a typical run time takes up to five hours on a modern computer. If this is compared with the typical run time of seconds for a forward solution, or minutes for a standard homogeneous inverse solution, it is clear that there is a price to be paid for the advantage gained.

8.6.1 Locating the pilot points

As the unknown parameter (hydraulic conductivity in this case) is determined at the pilot points and then interpolated to the modelled area, it can be envisaged that the spatial position of these points must be an important consideration. Improper distribution of the point could result in an unrealistic outcome of the inverse model. Previously, the number of pilot points was limited to the number of observed groundwater levels. This restriction was overcome by the introduction of regularisation on the latest version of the inverse model. Regularisation limits the difference between values at neighbouring pilot points, thus introducing “stiffening” in the inverse solution that released the restriction on the number of points.

For the first model it was decided that the most logical distribution of pilot points would be to locate a point at each groundwater extraction borehole and at each observation borehole as well as at an interim point between the pumping and observation boreholes. This would allow the model to adjust the hydraulic conductivity at the source of pumping, at an observation borehole and in the general area between these two features.

In 2017, the amount of pilot points in and directly around the Village Pit area were increased drastically as more data became available in this area. These points were added to this latest model. Additionally, points were added to the model by visual inspection where a scarcity was noticed. Choices of points are depicted in Figure 15 below.

8.7 Calibration of the Numerical Model

Calibration of hydraulic conductivity by the pilot point method entailed running the model in the inverse parameter estimation model, using the Parameter Estimation (PEST) program in conjunction with MODFLOW. All pilot points were allocated the initial steady state value and allowed to vary between 0.00001 and 50 m/d during PEST execution. PEST runs were extremely time consuming, running up to 12 hours. This limited the amount of variables that could be evaluated within reasonable time. This excessive running time is the main disadvantage of the pilot point method that is otherwise recognised as an extremely powerful technique.

The results of the process are best illustrated by comparison of the calculated and observed groundwater levels at observation points as depicted in the figures below. It is not possible to illustrate the correlations at all of the 45 observation boreholes, thus a selection of a few points are presented. These were selected to represent the area to the north, west and south of the main dewatering.

From these figures it is evident that good correlations with observed groundwater levels have been reached. The closer to the pits, the better the correlation as can be expected with the overriding impact of high extraction rates at the pits. What is more important is that the slopes of the decline of groundwater correlate well with observation. This is directly related to the hydraulic conductivity and inspires confidence in the calculated hydraulic conductivities.

The final spatial distribution of hydraulic conductivity is depicted in Figure 13 below. This figure illustrates that the calibrated conductivity varies by at least six orders of magnitude, from 10^{-3} m/d to 10^{+2} m/d (0.001 m/d to 100 m/d).

It is important to note that the calculated hydraulic conductivity is not an exact representation of the inhomogeneous dissolution cavities and fractures/faults (which cannot be achieved), but rather a hydraulic conductivity field that results in similar groundwater reaction to stresses such as dewatering extraction. But then, if the model could successfully predict reactions on past dewatering, it can be assumed that it will be reasonable accurate in predicting future impacts on groundwater levels.

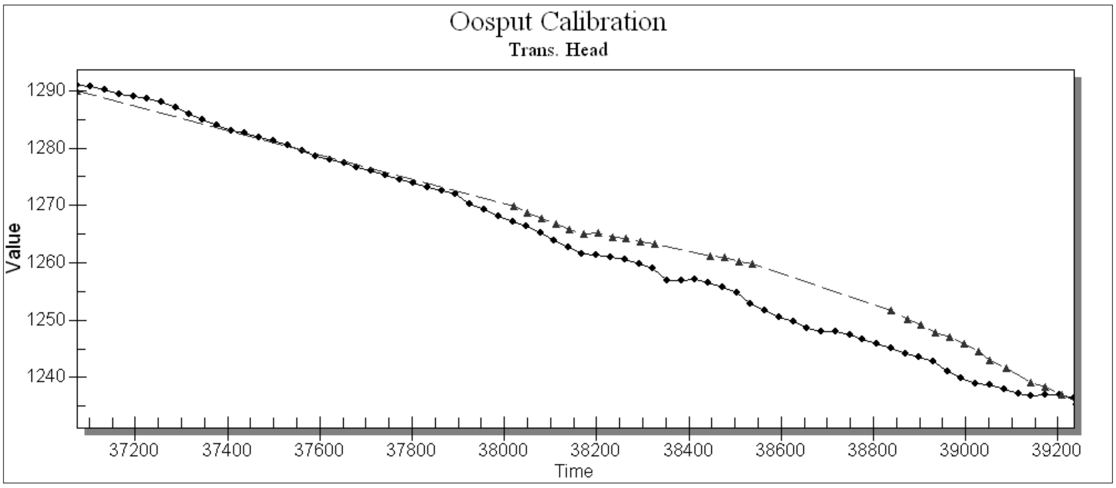


Figure 13: Calibration Graph at East Pit.

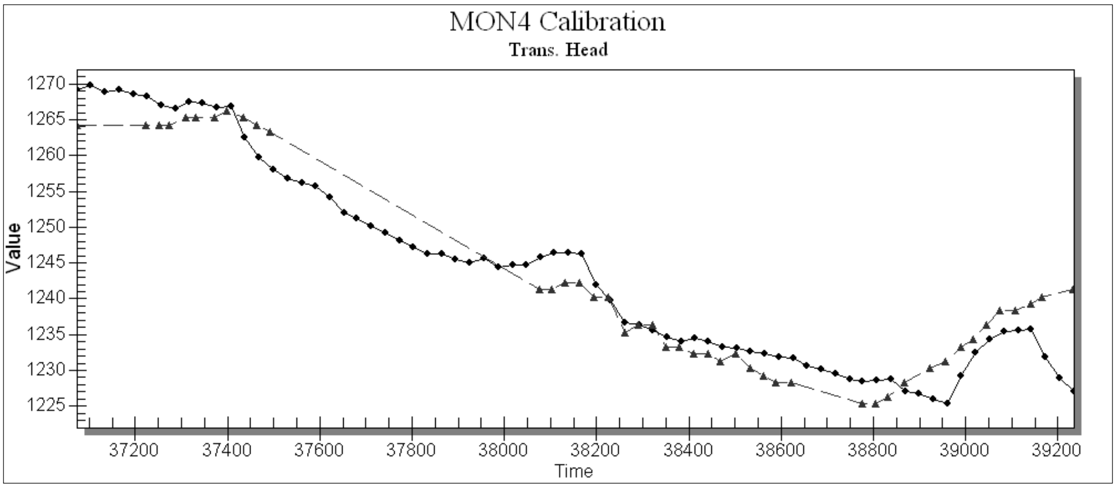


Figure 14: Calibration Graph at West Pit.

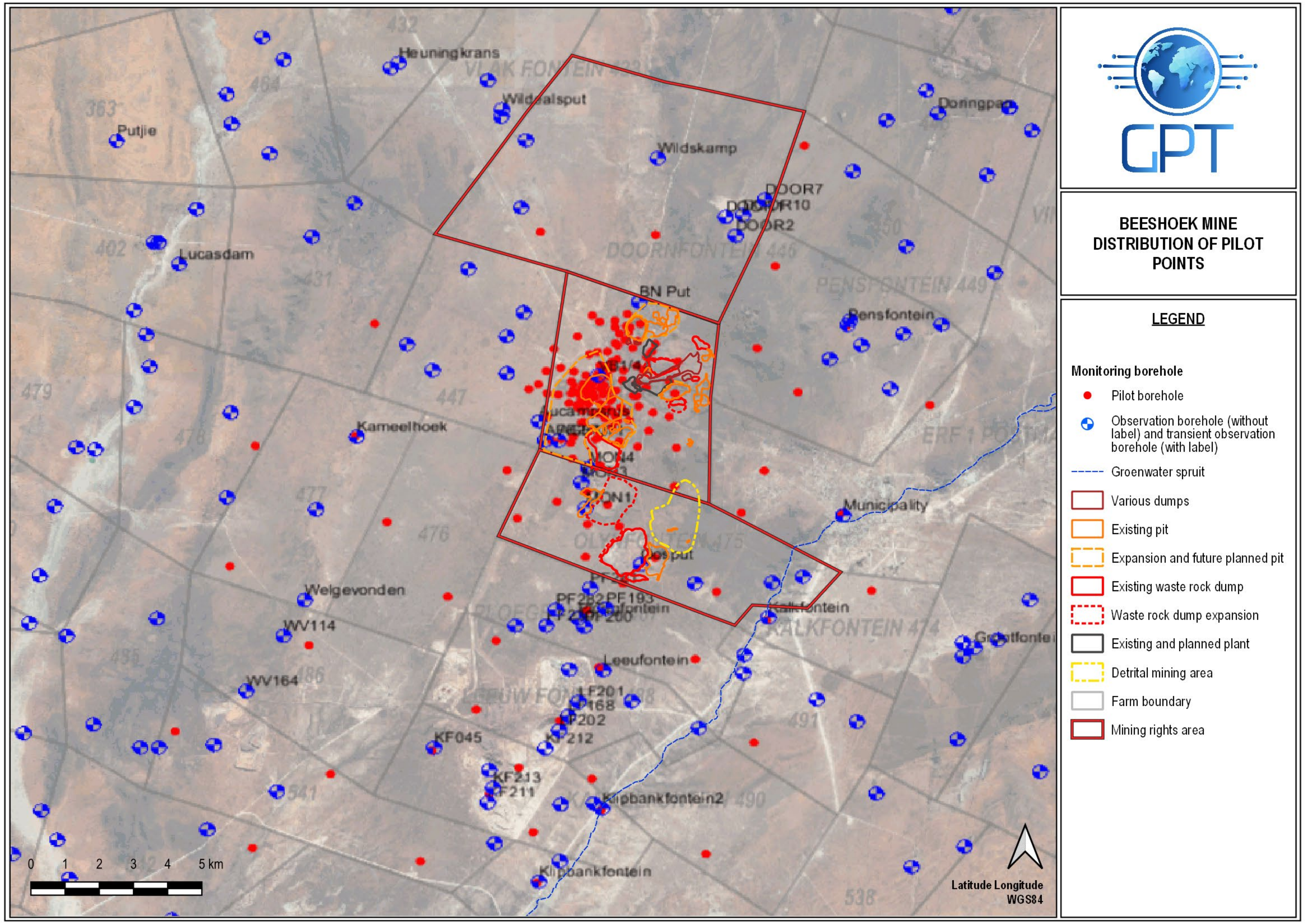


Figure 15: Distribution of Pilot Points.

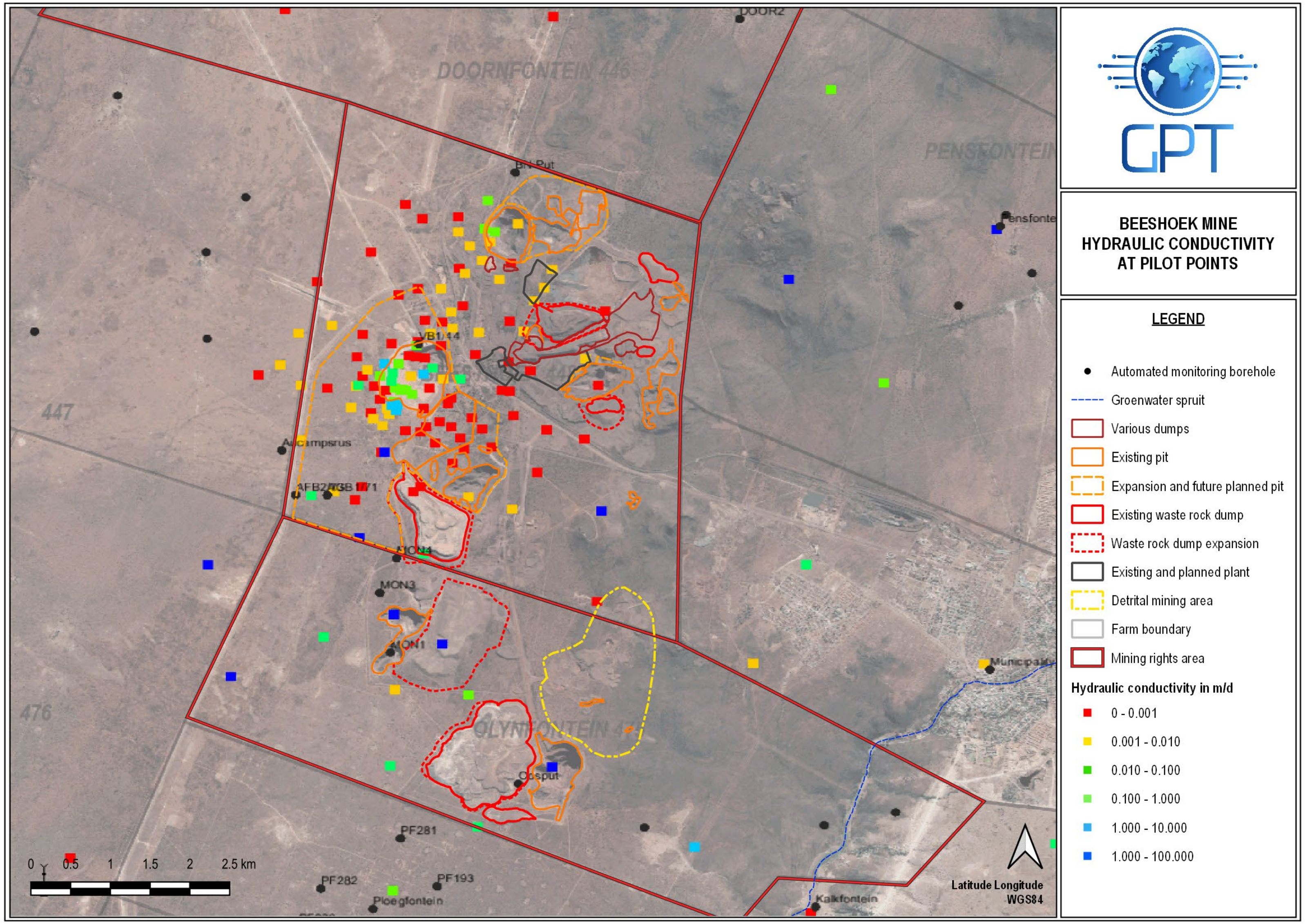


Figure 16: Calibrated Hydraulic Conductivity at Pilot Points.

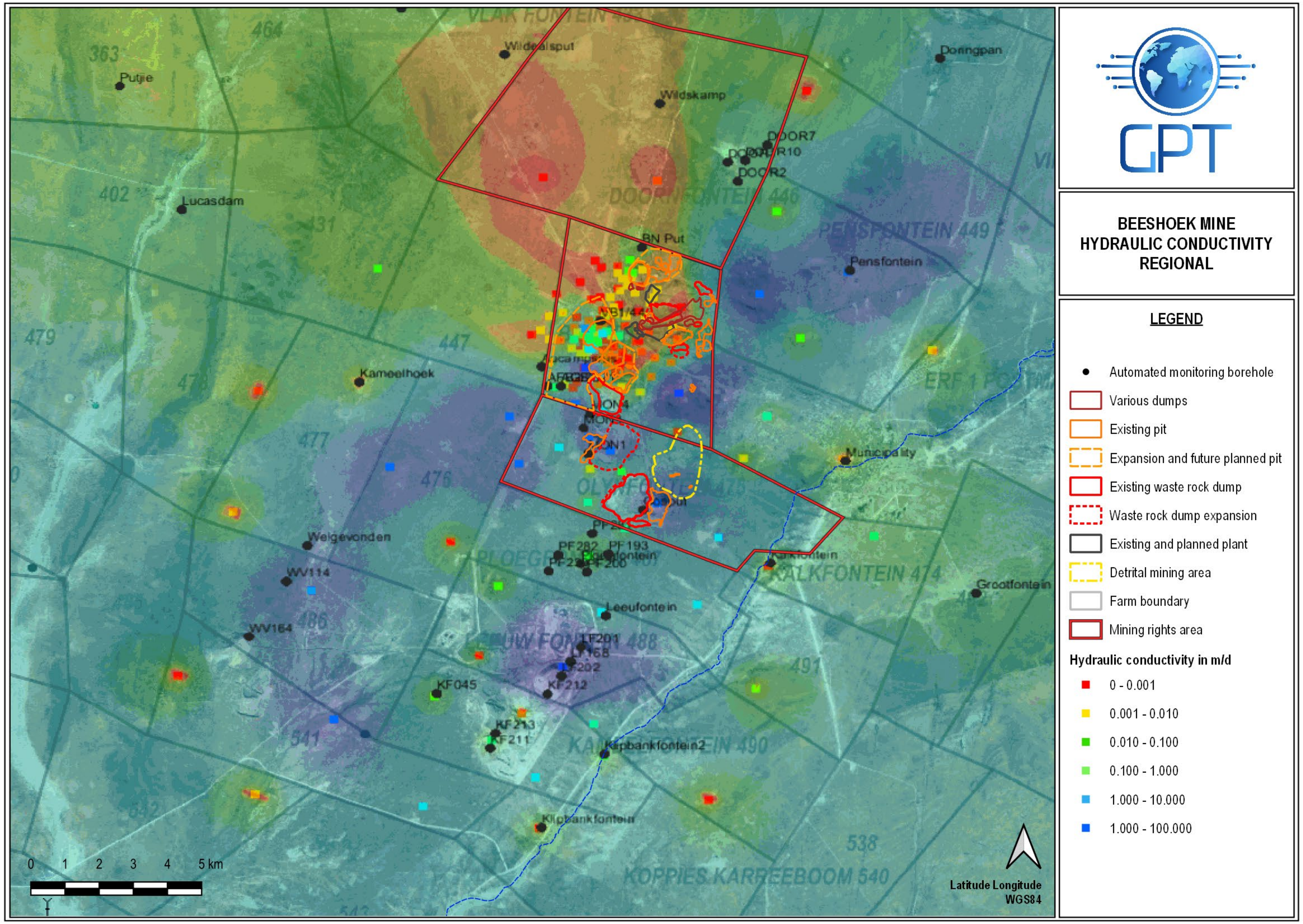


Figure 17: Calibrated Hydraulic Conductivity Field.

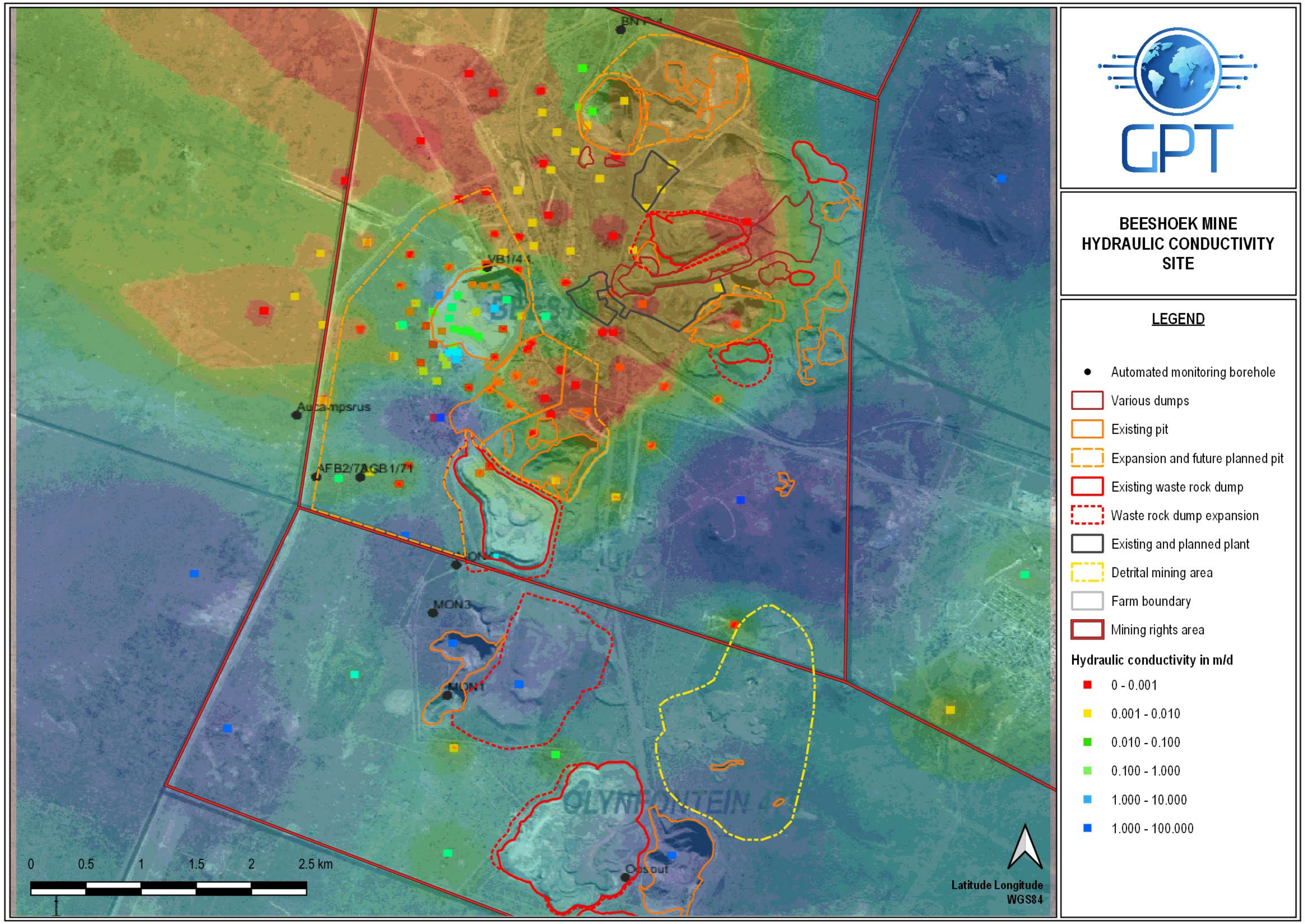


Figure 18: Calibrated Hydraulic Conductivity Field.

9 HYDROGEOLOGICAL IMPACTS

It is the aim of this chapter to assess the likely hydrogeological impact that the proposed extensions of the opencast pits might have on the receiving environment. The typical operational stages that will be considered in this section are:

- Construction Phase: Preparations at the specific site before actual operations commence.
- Operational Phase: The conditions expected to prevail during the operation of the site.
- Decommissioning Phase: The closing of operations as well as site clean-up and rehabilitation.
- Post-mining Phase: This relates to the steady-state conditions following site-closure. A period will be considered after which it is assumed that impacts will steadily decrease and the system will commence its return to the natural state.

9.1 Construction Phase Impacts

It is accepted for the purposes of this document that the construction phase will consist of preparations for the pit extensions, which is assumed to consist mainly of establishment of infrastructure on site, the mobilisation of earth moving equipment. The construction phase was not considered as part of this assessment as the mine is in the operational phase.

9.1.1 Impacts in groundwater quantity

This phase is not expected to influence the groundwater levels. With the exception of minor oil and diesel spills, there are also no activities expected that could impact on regional groundwater quality.

9.1.2 Impacts on groundwater quality

This phase should thus cause very little additional impacts in the groundwater quality. It is expected that the current status quo will be maintained.

9.2 Operational Phase Impacts

The operational phase is interpreted as the active mining of the proposed pit extensions. It is inevitable that these effects will impact on the groundwater regime. The potential impacts that will be considered are the groundwater quantity and quality. A summary of the potential impacts during operation can be seen in Table 10.

For this iron ore mines in dolomitic areas, groundwater drawdown is the most severe impact on the groundwater environment. With high hydraulic conductivities in the dolomite, cones of groundwater depressions are large, stretching over tens of kilometres. In comparison, groundwater contamination is minor due to the chemical inactive iron ore.

9.2.1 Impacts on groundwater quantity

During the operational phase, it is expected that the main impact on the groundwater environment will be dewatering of the surrounding aquifer. Water entering the mining areas will have to be pumped out to enable mining activities. This will cause a lowering in the groundwater table in- and adjacent to the pits being actively mined.

Mining in this area has been ongoing for many decades, and there are historical impacts on the surrounding aquifer which are impractical to simulate in a numerical model. Thus, the currently prevailing groundwater levels (obtained from N&Z telemetric data from the UWQ website, mine monitoring data and the WIMS/Tshiping database) have been used as baseline for this study, and all dewatering impacts related to the current water levels. Using this data in the model entailed interpolation between data point and extrapolation to model boundaries using modelled rest values. The baseline groundwater levels obtained thus is shown in Figure 19 below.

In addition, it was assumed that mining at Kolomela will continue to be mined at least for the lifetime of the Beeshoek mine. As a full cumulative impact study is beyond the scope of work for this study, and limited data Kolomela and other neighbouring mines are available, current groundwater levels were taken as guide to current and future dewatering. The areas where dewatering is effectively occurring can be seen in figure Figure 20, and Figure 21 in more detail. The minimum groundwater contour at these mines were taken as the effective dewatering areas. These might not coincide precisely with the opencast mining perimeters but reflect effective dewatering areas that could be due to unknown underground solution cavities. It has been reported (e-mail dated Friday, 12 March 2021 from Kolomela) that Leeuwfontein will be mined to 900 mamsl and Kapstevel South to 930 mamsl and was modelled as such. The 2020 measured groundwater levels were thus augmented with expected Kolomela dewatering to create future reference groundwater levels against which Beeshoek dewatering is determined.

With the groundwater levels baseline established, the dewatering of the aquifer has been calculated for the Beeshoek pits using the calibrated numerical model as described above. A worst-case scenario has been modelled, assuming that all opencasts would be dewatered simultaneously or within the same timescale (LoM). This will obviously not be the case, and the actual water table drawdown could thus be less. However, as the recovery of groundwater is expected to be very slow, it could well be that some opencasts could still be in an early stage of recovery when the last are mined. Thus, the worst-case scenario could also be close to the actual scenario. The calculated drawdown is depicted in Figure 19 below, as contours of drawdown for the mines being dewatered simultaneously. Areas where the groundwater is predicted to lower between 5 - 10 m is shown in green (minor impact), between 10 – 20 m in yellow (definite impact) and more than 30 m in red (significant impact). A drawdown less than 5 metres was considered insignificant compared to seasonal variations in groundwater levels and within the predictable capability of the model.

The following observations were made:

- No drawdown is expected for further mining at East Pit as the declining groundwater levels is predicted to be below the bottom of mining.
- Drawdown at Village pit is predicted to extent to up to 2km from the pit in a mostly westerly direction, for an insignificant drawdown of 5 – 10 metres. Areas of significant drawdown is expected only in in the immediate vicinity of the pit, which could even decline with time as Leeuwfontein mining impacts northward into this area.
- HF Pit is predicted to have a minor impact limited to the immediate surroundings of the pit itself.
- The BN Pit will have the biggest area of impact due to substantial increase in mining depth. Drawdown of groundwater levels will be up to about 100 m but limited to an area of about 1 km around the pit. The different behaviour of this pit is due to the hydraulic isolation of the pit as was concluded during calibration of the model, illustrated in Figure 17.

9.2.2 Management of Dewatering Impacts

There are no obvious means of mitigating the impact of groundwater lowering by mining, except for monitoring surrounding boreholes and replacing lost groundwater extraction potential where applicable (where it can be demonstrated that external groundwater users have been impacted upon by the mine).

Dewatering is primarily achieved through wellfields of abstraction boreholes and in pit dewatering points, and the combination thereof functions with the purpose of keeping the pit floor dry by creating a cone of depression around the excavation. The pit floor was thus modelled as a drain, which in MODFLOW uses the bottom elevation of the drain as the hydraulic head that controls flow into the drain. In this way the individual position of dewatering boreholes has no effect on the extent of the cone of depression or groundwater level lowering. Dewatering borehole positions may be changed without notice as objectively they will be placed as close as possible to the excavation to maintain a dry pit floor. Currently, no additional groundwater is to be abstracted from the catchment as part of this project expansion.

9.2.3 Numerical Model Limitations

Despite the modelled predictions, it must be stressed that structures of preferred groundwater flow have not been modelled. It is known that groundwater in dolomite flow mostly through dissolution cavities, but details are limited and not adequate to model this structure(s). If such a structure is dewatered, any boreholes drilled into the same structure might be affected, beyond what the model could predict. These direct flow effects cannot be predicted with the current knowledge and can only be established through continuous groundwater level monitoring.

9.2.4 Impacts on surface water

Surface water structures in this area is limited and serve mostly only as stormwater conduits. Furthermore, groundwater levels in the area are generally deep below surface, well beyond the depth of streams. Streams are not supported by baseflow (i.e. groundwater discharge into streams/rivers). It will thus not be affected by lowering of the groundwater levels.

9.2.5 Impacts on groundwater quality

There have been several studies in the past proving that there are very little contamination potential at the mine. Nevertheless, the flow of a hypothetical contamination has been modelled to be thorough. A contaminant with a concentration of 100 (reflecting a value of 100% of initial contamination) has been modelled and projected 50 years into the future as if mining will extend that long.

The flow in the aquifer will be directed mainly towards the mine at this stage and very little groundwater pollution is thus expected (Figure 22). It follows from the figure that some contamination could escape from the source in the north-east but is drawn into BN and Village Pit cone of depression. It is thus concluded that no contamination of the surrounding aquifer could take place during mining.

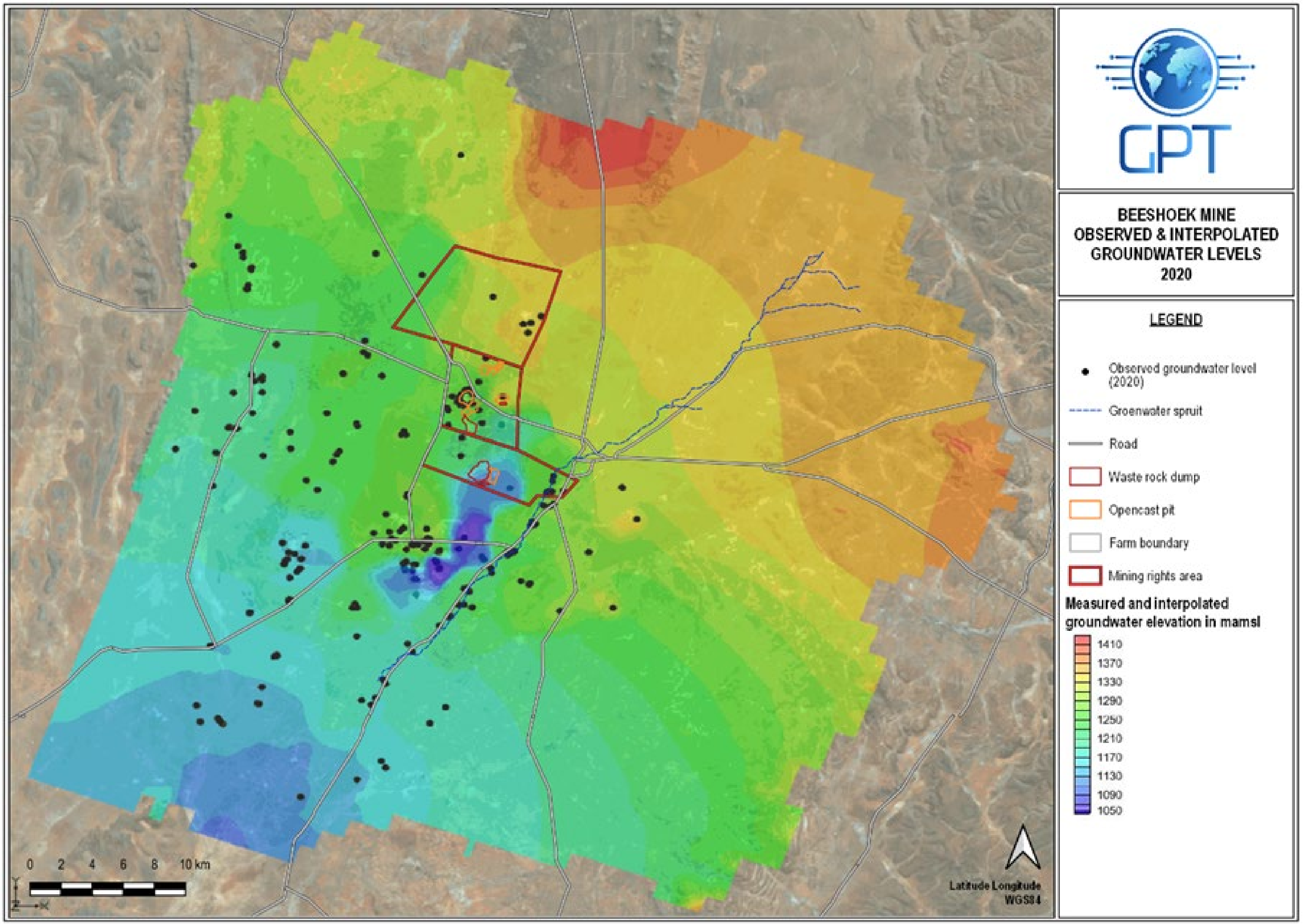


Figure 19: Observed and inferred groundwater level elevation (2020).

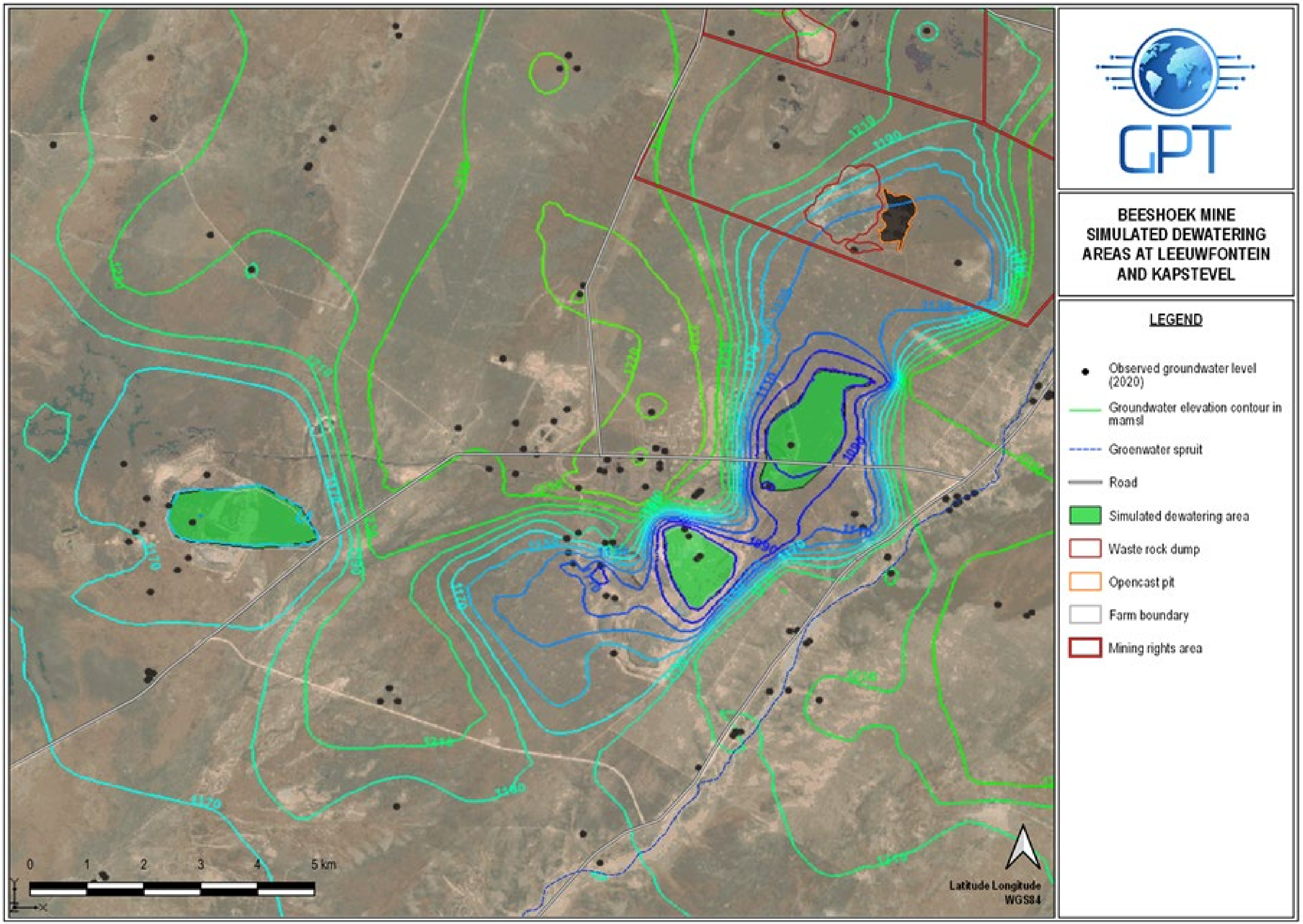


Figure 20: Simulated groundwater dewatering areas underlying Leeuwfontein and Kapstevel.

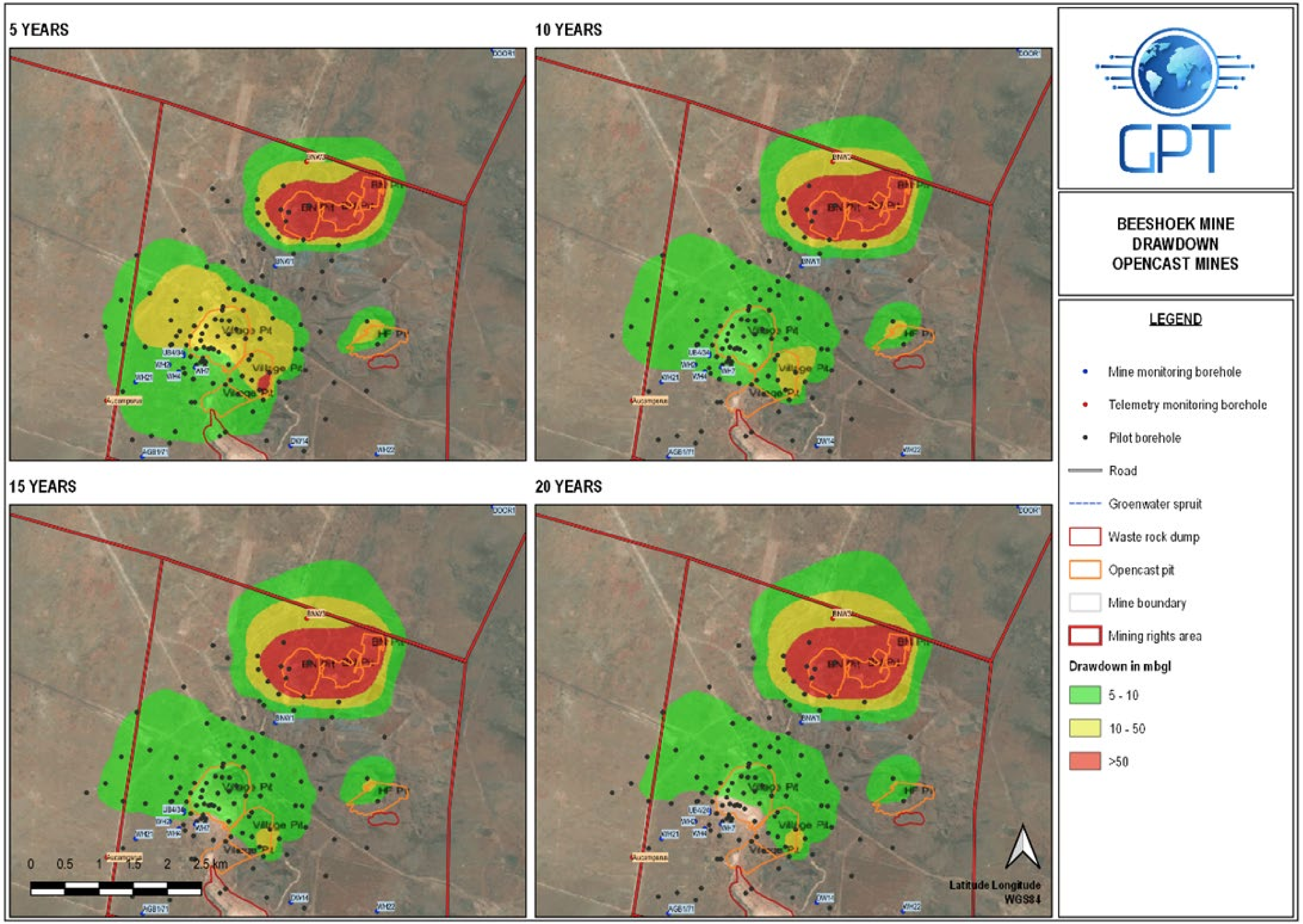


Figure 21: Groundwater Drawdown During Mining - All Pits

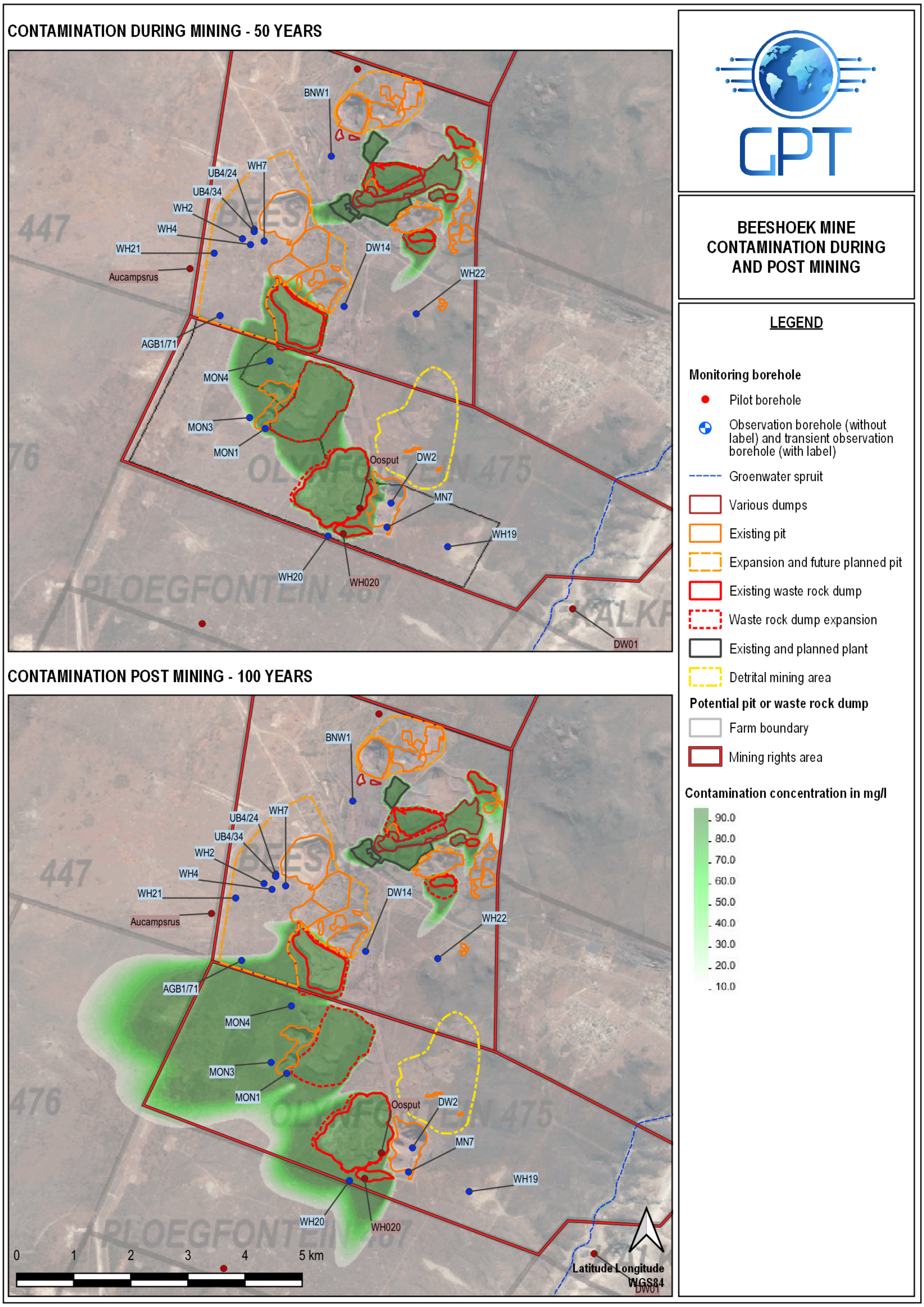


Figure 22: Groundwater Contamination During and Post-Mining.

Table 10: Summary of potential impacts during operation - dewatering.

Mining Area	Area (ha)	Maximum Drawdown (m)	Cone of depression from edge of pit (km)	Potential Impacted Sensitive Receptor (Areas)	Expected Water Level Decline at receptor (m)
Village Pit	510	130	1 - 2	The area of groundwater lowering in relation to mining-related dewatering is limited to the mining rights area, on the farms Beeshoek and Olynfontein.	10 - >30
BN Pit	136	115	1		10 - >30
BF Pit	86	120	1-2		10 - >30
East Pit	47	150	1-2		<10
Detrital Area	237	0	0		0

9.3 Groundwater management

9.3.1 General

The following groundwater management considerations should be considered during operation:

- Identify and where possible, maximise areas of the mine that will result in clean storm water runoff (for example open veld areas) as well as infrastructure associated with the mine (for example office areas) and ensure that runoff from these areas is routed directly to natural watercourses and not contained or contaminated.
- Ensure that clean storm water is only contained if the volume of the runoff poses a risk, if the water cannot be discharged to watercourses by gravitation, for attenuation purposes, or when the clean area is small and located within a large dirty area. This contained clean water should then be released into natural watercourses under controlled conditions.
- Ensure the minimisation of contaminated areas, reuse of dirty water wherever possible and planning to ensure that clean areas are not lost to the catchment unnecessarily.
- Ensure that seepage losses from storage facilities (such as polluted dams) are minimised and overflows are prevented.
- Ensure that all possible sources of dirty water have been identified and that appropriate collection and containment systems have been implemented and that these do not result in further unnecessary water quality deterioration.
- Ensure that less polluted water or that: moderately polluted water is not further polluted. Where possible less and more polluted water should be separated. This will assist in the reuse water strategy and improve possibilities for reuse based on different water quality requirements by different mine water uses.
- Where contaminants are transported along construction roads, emergency containment and mitigation measures must be developed to minimize impacts should accidental spillages occur along the transport routes.
- Store all potential sources of contamination in secure facilities with appropriate Storm Water management systems in place to ensure that contaminants are not released to the water resource through Storm Water runoff.
- Separate and collect all storm water that has a quality potentially poorer than the water quality specified and negotiated for the specific catchment into dirty water storage facilities for reuse within the mining operations.
- Ensure that all storm water structures that are designed to keep dirty and clean water separate can accommodate a defined precipitation event. (The magnitude of the precipitation event used in such an objective statement must, as a minimum, adhere to the relevant legal requirements.)
- Route all clean storm water directly to natural watercourses without increasing the risk of a negative impact on safety and infrastructure, e.g. loss of life or damage to property due to an increase in the peak runoff flow.
- Ensure that the maximum volume of clean water runoff is diverted directly to watercourses and the minimum amount of storm water reports to the pit floor of an open cast mine.
- Develop and implement proper environmental management and auditing systems to ensure that pollution prevention and impact minimisation plans and measures developed in the design and feasibility stages are fully implemented.

- The size of unrehabilitated areas (pit, spoils, unvegetated areas) that produce contaminated runoff should be minimised.
- Rehabilitation should be planned to promote free drainage and to minimise or eliminate ponding of storm water. On-going rehabilitation as mining operations progress is required.
- The clean and dirty water flow areas on a mine site should be identified.
- Every effort should be made to maximise the clean area and minimise the dirty area when locating the diversion berms, channels, and dams. In the case of a new mine, the maximisation of the clean areas should have an influence in overall mine planning and the location of the mine infrastructure.
- The mine planning should consider concurrent rehabilitation of mine workings and waste management facilities, to maximise the areas of clean runoff that can be discharged to the natural watercourses.

9.3.2 Waste rock deposits and pollution control dams

The following groundwater management considerations should be considered during operation of waste management facilities:

- Monitoring of water storage facilities, particularly pollution control dams, is imperative to manage the risk of spillage from the dams. Stage-storage (elevation-capacity) curves are useful tools to monitor the remaining capacity within a water storage facility.
- Prevent the erosion or leaching of materials from any residue deposit or stockpile from any area and contain material or substances so eroded or leached in such area by providing suitable barrier dams, evaporation dams or any other effective measures to prevent this material or substance from entering and polluting any water resources.
- Water quantity and quality data should be collected on a regular, ongoing basis during mine operations. These data will be used to recalibrate and update the mine water management model, to prepare monitoring and audit reports, to report to the regulatory authorities against the requirements of the IWWMP and other authorisations and as feedback to stakeholders in the catchment, perhaps via the catchment management agency.
- Water that has been in contact with residue, and must therefore be considered polluted, must be kept within the confines of the MRD until evaporated, treated to rendered acceptable for release, or re-used in some other way.
- All water that falls within the catchment area of the MRD must be retained within that area. For most MRDs the catchment can be divided into component catchments, as follows:
    - The top area of the MRD together with any return water storage dams which have been connected to the top area of the MRD by means of an outfall penstock, and
    - The faces of the MRD together with the catchment paddocks provided to receive run-off from the faces and any additional catchment dams associated with the faces and catchment paddocks.
- The design, operation, and closure of MRDs should incorporate consideration of the risk of changes in the mining and plant operations, and hence the mine water balance, through the life cycle of the mine.
- A system of storm water drains must be designed and constructed to ensure that all water that falls outside the area of the MRD is diverted clear of the deposit. Provision must be made for the maximum precipitation to be expected over a period of 24 hours with a probability of once in

one hundred years. A freeboard of at least 0.5 m must be provided throughout the system above the predicted maximum water level. This requirement applies to all MRDs, both fine and coarse-grained MRDs.

- Ensure that the water use practices on and around the MRD do not result in unnecessary water quality deterioration, e.g. use of the return water dam for storage of poorer quality water.

Please note that further investigation will be required for the above especially the siting and pumping rate of the dewatering boreholes.

9.4 Decommissioning and Post-closure Phase Impacts

During this phase it is assumed that dewatering of the proposed opencast mining will be ceased, and it will be allowed to flood. The groundwater regime will return to a state of equilibrium once mining has stopped and the removal of water from the mining void has been discontinued.

The following possible impacts were identified at this stage:

- Following closure of the mine, the groundwater level will rise to an equilibrium that will differ from the pre-mining level due to the disturbance of the bedrock.
- Groundwater within the contaminated areas is expected to deteriorate and the resulting groundwater pollution plume is expected to commence with downstream movement.

A summary of the potential impacts during the closure of the mine is shown in Table 10.

9.4.1 Impacts on groundwater quantity

After closure, the water table will rise in the mine to reinstate equilibrium with the surrounding groundwater systems.

Following the closure of the opencasts and the cessation of the dewatering it is assumed to lead to groundwater rebound and potential decanting. No decant is predicted.

9.4.2 Impacts on groundwater quality

Once the normal groundwater flow conditions have been re-instated, polluted water could potentially migrate away from the mining areas.

9.4.2.1 Spread of pollution

Once the normal groundwater flow conditions have been re-instated, polluted water could potentially migrate away from the contamination areas.

The spread of contamination is depicted in Figure 22. It follows from the figure that there will be a slow flow towards the west and south, at about 100 metres per year. No adverse effects are predicted on receptor boreholes with regards to increasing contaminant concentrations in groundwater. However, it must be stressed that the iron ore mine has minimal contamination potential, which has been substantiated by several studies.

Table 11: Summary of potential impacts post operations.

Mining Area	Area (m^2)	Potential impacted receptor	Estimated increase in concentrations during closure (mg/ℓ)	Potential decant (Yes/No)
Village Pit	510	None	None	No
BN Pit	136	None	None	No
BF Pit	86	None	None	No
East Pit	47	None	None	No
Detrital Area	237	None	None	No

9.4.3 Cumulative effects

The cumulative pollution impacts of all current and historic mining at the Beeshoek mine have been included in this study. However, the iron ore mines to the south of Beeshoek were not included in the study and it is known that there is hydrogeological interaction.

9.5 Groundwater Management

9.5.1 Waste rock deposits

- Update the numerical and geochemical model against monitored data at closure phase.
- After a geochemical investigation the WRD can be managed as follows;
    - Use as waste backfill in open pits or underground.
    - Segregation/isolation/encapsulation.

9.6 Assumptions and Limitations

The modelling was done within the limitations of the scope of work of this study and the amount of data available. Although all efforts have been made to base the model on sound assumptions and has been calibrated to observed data, the results obtained from this exercise should be considered in accordance with the assumptions made. Especially the assumption that a fractured aquifer will behave as a homogeneous porous medium can lead to error. However, on a large enough scale (bigger than the REV, Representative Elemental Volume) this assumption should hold reasonably well.

10 GROUNDWATER MONITORING SYSTEM

10.1 Groundwater Monitoring Network

The DHSWS requires a water quality monitoring plan as part of the permitting requirements. This involves background analyses, detection monitoring, investigative monitoring, and post-closure monitoring. The water quality monitoring plan ensures that the water quality in the vicinity of a waste generating or management facility is regularly monitored and reported upon throughout its life, so that, where necessary, remedial action can be taken. A groundwater monitoring system has to adhere to the criteria described below.

10.2 Water Use License

The mine operates within the framework of the National Water Act 36 of 1998 and was awarded a water licence on 01/12/2014, licence number 10/D73A/ABGJ/2592. The water licence covers section 21(a), 21(b), 21(g) and 21(j) of the National Water Act 1998 (Act 36 of 1998). The water use license was amended in 21/08/2018. The conditions as set out in the WUL serve as the guidelines for monitoring data interpretation and reporting for the following authorised activities:

- Section 21(a): Taking water from a water resource, subject to the conditions as set out in the WUL.
- Section 21(b): Storing of water, subject to the conditions set out in the WUL.
- Section 21(g): Disposing of waste in a manner which may detrimentally impact on a water resource, subject to the conditions set out in the WUL.
- Section 21(j): Removing, discharging or disposing of water found underground, subject to the conditions set out in the WUL.

10.3 WUL Monitoring Requirements

The main purpose of a monitoring system concerned with the control of pollution and the migration of contaminants is to detect and quantify the presence and migration of any contaminants in groundwater[11] The WUL recommends the following distances and frequencies for different types of waste environments as listed in the table below (Table 12).

Table 12: WUL Monitoring Requirements.

Type of waste	Number of holes	Distance from waste	Monitoring frequency
Ore discards	2 - 5	50 - 500 m	Quarterly
Mine water (impounded areas)	1 - 6	50 - 500 m	
Waste disposal facilities	1 - 5	10 - 50 m	

The objective of the monitoring system is to:

- Prevent and/or minimize the environmental impact associated with the mining operation;
- Ensure that the environmental management system at the mine performs according to specifications;

[11] Department of Water Affairs and Forestry, Second Edition (1998). Waste Management Series. Minimum Requirements for Water Monitoring as Waste Management Facilities. Pretoria.

- Ensure conformance with the environmental objectives;
- Ensure timely implementation of the environmental strategies and implementation programme;
- Act as a pollution early-warning system;
- Obtain the necessary data required to address knowledge gaps;
- Check compliance with license requirements;
- Ensure consistent auditing and reporting protocols.

10.3.1 Source, plume, impact and background monitoring

A groundwater monitoring network should contain monitoring positions which can assess the groundwater status at certain areas. The boreholes can be grouped or classified according to the following purposes (see Figure 23):

- **Source monitoring:** Monitoring boreholes are placed close to or in the source of contamination to evaluate the impact thereof on the groundwater chemistry. Monitoring boreholes within the mining area satisfy this condition.
- **Pathway monitoring:** Monitoring boreholes are placed in the primary groundwater migration pathways to evaluate the migration rates and chemical changes along the pathway. Monitoring boreholes located along groundwater flow paths satisfy this condition.
- **Impact monitoring:** Monitoring of possible impacts of contaminated groundwater on sensitive ecosystems or other receptors. These monitoring points are also installed as early warning systems for contamination break-through at areas of concern. External user boreholes and monitoring placed in positions to detect and monitor impacts on groundwater availability and quality satisfy this condition.
- **Background monitoring:** Background groundwater quality is essential to evaluate the impact of a specific action/pollution source on the groundwater chemistry. Monitoring boreholes located up-gradient/upstream of the mining area.

10.4 Groundwater Level and Quality Monitoring

The risk register, as well groundwater response monitoring systems were reviewed and update in July 2019[12]. A monitoring programme is in place which entails quarterly water quality monitoring and monthly manual water level and daily telemetric/auto-level water level monitoring at select locations. The current water quality and water level monitoring network is considered adequate to detect and quantify the presence and migration of any contaminants in groundwater and measure the effects of large-scale groundwater abstraction for mining purposes on groundwater levels.

[12] Geo Pollution Technologies (July 2019). Beeshoek Iron Ore Mine Groundwater Risk Assessment Review. Technical Report for Beeshoek Iron Ore Mine, Reference Nr.: ASBEE-19-4312.

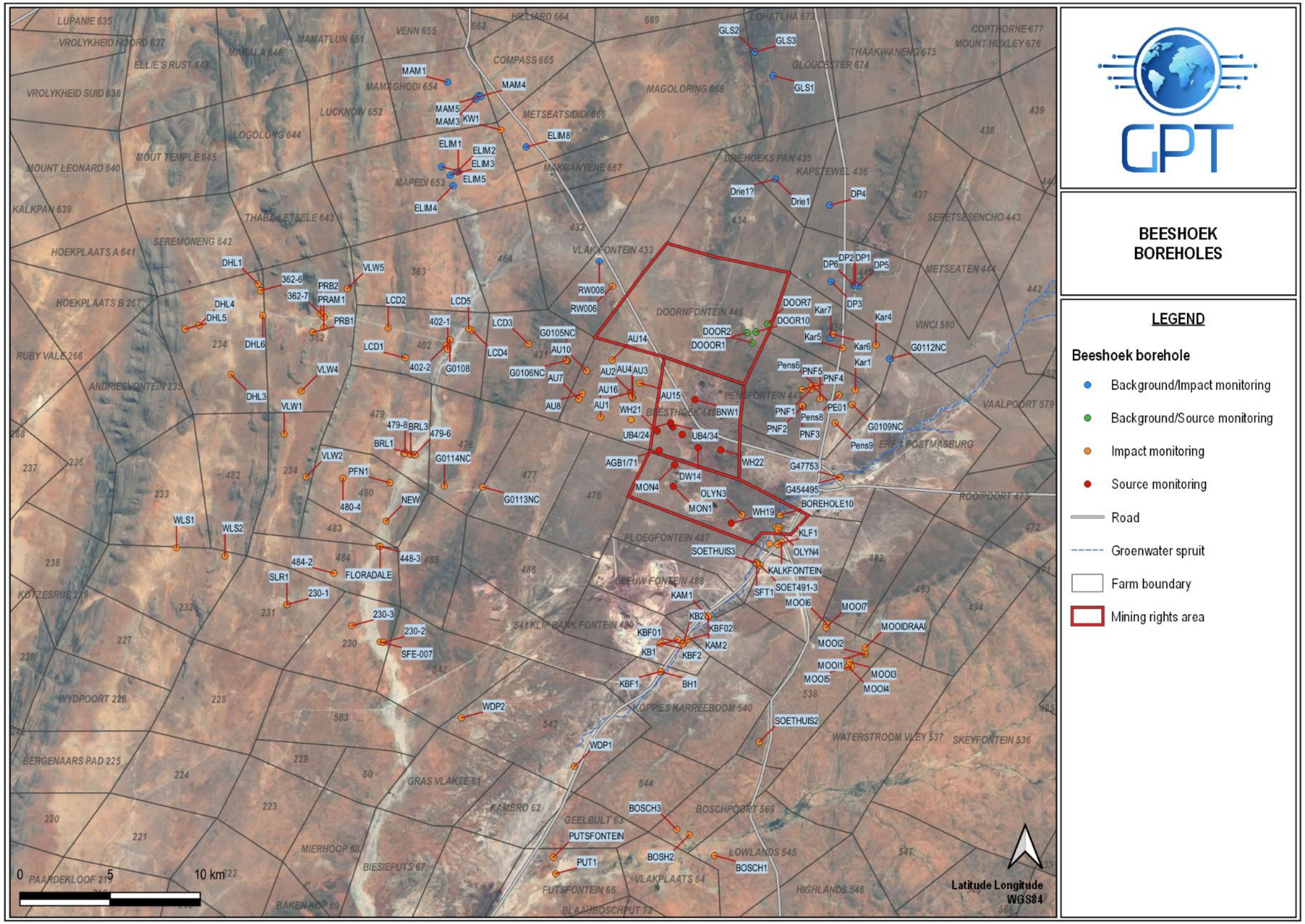


Figure 23: Borehole classification as per the source-pathway-receptor model.

11 IMPACTS QUANTIFICATION

The impact quantification was done using the procedures for the assessment and minimum criteria for reporting aquatic biodiversity in terms of sections 24(5)(a) and (h) and 44 of the National Environmental Management Act, 1998. In terms of groundwater the proposed development impact on the functioning of the aquatic feature in terms of:

- Base flows.
- Quantity of water including change in the hydrological regime or hydroperiod of the aquatic ecosystem.
- Quality of water.
- The location of areas not suitable for development, which are to be avoided during construction and operation, where relevant.
- Additional environmental impacts expected from the proposed development.
- The degree to which impacts, and risks can be mitigated.
- The degree to which the impacts and risks can be reversed.
- The degree to which the impacts and risks can cause loss of irreplaceable resources.
- A suitable construction and operational buffer for the aquatic ecosystem, using the accepted methodologies.

11.1 Environmental Impact Assessment (EIA) Regulations

The Environmental Impact Assessment (EIA) 2014 Regulations [as amended] promulgated in terms of Sections 24 (5), 24M and 44 of the National Environmental Management Act, 1998 (Act No. 107 of 1998) [as amended] (NEMA), requires that all identified potential impacts associated with the proposed project be assessed in terms of their overall potential significance on the natural, social and economic environments. The criteria identified in the EIA Regulations (2014) include the following:

- Status of the impact.
- Nature of the impact.
- Extent of the impact.
- Duration of the impact.
- Probability of the impact occurring.
- Degree to which impact can be reversed.
- Degree to which impact may cause irreplaceable loss of resources.
- Degree to which the impact can be mitigated, and
- Cumulative impacts.

The impact assessment methodology (as defined below) whereby the Significance of a potential impact is determined through the assessment of the relevant temporal and spatial scales determined of the Extent, Magnitude and Duration criteria associated with a particular impact. This method does not explicitly define each of the criteria but rather combines them and results in an indication of the overall significance.

11.1.1 Status of the impact

The nature or status of the impact is determined by the conditions of the environment prior to construction and operation. The description for the status of the impact is given in the table below:

Table 13: Status of the impact.

Rating	Description	Quantitative rating
Positive	A benefit to the receiving environment.	Positive
Neutral	No cost or benefit to the receiving environment.	-
Negative	A cost to the receiving environment.	Negative

11.1.2 Extent of the impact

The extent of the impact is the physical extent/area of impact or influence. The ratings for the extent of the impact are given in the table below:

Table 14: Extent of the impact.

Rating	Description	Quantitative rating
Low	Site specific; Occurs within the site boundary.	1
Medium	Local; Extends beyond the site boundary; Affects the immediate surrounding environment (i.e. up to 5 km from the Project Site boundary).	2
High	Regional; Extends far beyond the site boundary; Widespread effect (i.e. 5 km and more from the Project Site boundary).	3
Very High	National and/or international; Extends far beyond the site boundary; Widespread effect.	4

11.1.3 Duration of the impact

The duration of an impact is the expected period of time the impact will have an effect. The ratings for the duration of the impact are given in the table below:

Table 15: Duration of the impact.

Rating	Description	Quantitative rating
Low	Short term; Quickly reversible; Less than the project lifespan; 0 – 5 years.	1
Medium	Medium term; Reversible over time; Approximate lifespan of the project; 5 – 17 years.	2
High	Long term; Permanent; Extends beyond the decommissioning phase; >17 years.	3

11.1.4 Probability of the impact

The probability of an impact is the severity of the impact on the ecosystem structure. The ratings for the probability of the impact occurring are given in the table below:

Table 16: Probability of the impact.

Rating	Description	Quantitative rating
Improbable	Possibility of the impact materialising is negligible; Chance of occurrence <10%.	1
Probable	Possibility that the impact will materialise is likely; Chance of occurrence 10 – 49.9%.	2
Highly Probable	It is expected that the impact will occur; Chance of occurrence 50 – 90%.	3
Definite	Impact will occur regardless of any prevention measures; Chance of occurrence >90%.	4
Definite and Cumulative	Impact will occur regardless of any prevention measures; Chance of occurrence >90% and is likely to result in in cumulative impacts	5

11.1.5 Degree to which impact can be reversed

The reversibility of an impact is the severity of the impact on the ecosystem structure. The ratings for the degree to which the impact can be reversed are given in the table below:

Table 17: Degree to which impact can be reserved.

Score	Reversibility	Description
1	Completely reversible	The impact is reversible without any mitigation measures and management measures
2	Nearly completely reversible	The impact is reversible without any significant mitigation and management measures. Some time and resources required.
3	Partly reversible	The impact is only reversible with the implantation of mitigation and management measures. Substantial time and resources required.
4	Nearly irreversible	The impact is can only marginally be reversed with the implantation of significant mitigation and management measures. Significant time and resources required to ensure impact is on a controllable level.
5	Irreversible	The impact is irreversible.

11.1.6 Intensity of the impact

The intensity of an impact is the expected amplitude of the impact. The ratings for the degree of the intensity of the impact are given in the table below:

Table 18: Intensity of the impact.

Rating	Description	Quantitative rating
Maximum Benefit	Where natural, cultural and / or social functions or processes are positively affected resulting in the maximum possible and permanent benefit.	5
Significant Benefit	Where natural, cultural and / or social functions or processes are altered to the extent that it will result in temporary but significant benefit.	4
Beneficial	Where the affected environment is altered but natural, cultural and / or social functions or processes continue, albeit in a modified, beneficial way.	3
Minor Benefit	Where the impact affects the environment in such a way that natural, cultural and / or social functions or processes are only marginally benefited.	2
Negligible Benefit	Where the impact affects the environment in such a way that natural, cultural and / or social functions or processes are negligibly benefited.	1
Neutral	Where the impact affects the environment in such a way that natural, cultural and / or social functions or processes are not affected.	0
Negligible	Where the impact affects the environment in such a way that natural, cultural and / or social functions or processes are negligibly affected	-1
Minor	Where the impact affects the environment in such a way that natural, cultural and / or social functions or processes are only marginally affected.	-2
Average	Where the affected environment is altered but natural, cultural and / or social functions or processes continue, albeit in a modified way.	-3
Severe	Where natural, cultural and / or social functions or processes are altered to the extent that it will temporarily cease.	-4
Very Severe	Where natural, cultural and / or social functions or processes are altered to the extent that it will permanently cease.	-5

11.2 Mitigation Efficiency

The most effective means of deriving a quantitative value of mitigated impacts is to assign each significance rating value a mitigation effectiveness rating. The allocation of such a rating is a measure of the efficiency and effectiveness, as identified through professional experience and empirical evidence of how effectively the proposed mitigation measures will manage the impact. This means that the lower the assigned value the greater the effectiveness of the proposed mitigation measures and subsequently, the lower the impacts with mitigation as demonstrated by the equation below:

Significance Rating (WM) = Significance Rating (without mitigation) x Mitigation Efficiency (2)

11.3 Impact Significance Calculation

The significance is determined through a combination of the abovementioned impact characteristics. The total number of points scored for the potential intensity, duration and extent (referred to as "impact magnitude") is multiplied by the probability scores in order to indicate the level of significance of the impacts (i.e. the significance ratings). The formula for the impact significance ratings is indicated in Table 20.

The risk rating and significance of ratings for the siding are presented in Table 19 and Table 20 the following conclusions can be drawn:

- The activity and associated infrastructure will have a negative impact on the receiving environment.
- Based on the current status with regards to groundwater quality, existing mitigation measures and findings of this assessment, the activity, poses a low risk to the groundwater environment and identified receptors.

Table 19: Risk rating description.

Impact	Rating	Description	Quantitative rating
Positive	High	Of the highest positive order possible within the bounds of impacts that could occur.	+ 12 - 16
	Medium	Impact is real, but not substantial in relation to other impacts that might take effect within the bounds of those that could occur. Other means of achieving this benefit are approximately equal in time, cost and effort.	+ 6 - 11
	Low	Impacts is of a low order and therefore likely to have a limited effect. Alternative means of achieving this benefit are likely to be easier, cheaper, more effective, and less time-consuming.	+ 1 - 5
No Impact	No Impact	Zero impact.	0
Negative	Low	Impact is of a low order and therefore likely to have little real effect. In the case of adverse impacts, mitigation is either easily achieved or little will be required, or both. Social, cultural, and economic activities of communities can continue unchanged.	- 1 - 5
	Medium	Impact is real, but not substantial in relation to other impacts that might take effect within the bounds of those that could occur. In the case of adverse impacts, mitigation is both feasible and fairly possible. Social cultural and economic activities of communities are changed but can be continued (albeit in a different form). Modification of the project design or alternative action may be required.	- 6 - 11
	High	Of the highest order possible within the bounds of impacts that could occur. In the case of adverse impacts, there is no possible mitigation that could offset the impact, or mitigation is difficult, expensive, time-consuming or a combination of these. Social, cultural and economic activities of communities are disrupted to such an extent that these come to a halt.	-28

Table 20: Significance Rating of Impact(s).

Impacts	Extent	Duration	Intensity	Probability	Significance = Irreplaceability (Intensity + Duration + Extent) X Probability (WOM)		Mitigation Efficiency (ME)	Significance Rating (WM) = Significance Rating (WOM) x Mitigation Efficiency	
Groundwater quality deterioration	3	4	-2	2	-10	Medium	0.2	-2	Very low
Groundwater quantity due to dewatering and abstraction	3	4	-4	4	-12	High	0.2	-2.4	Very low

12 CONCLUSIONS AND RECOMMENDATIONS

Geo Pollution Technologies – Gauteng (Pty) Ltd (GPT) was appointed by Envirogistics (Pty) Ltd (Envirogistics) to update the hydrogeological impact assessment for the Beeshoek Iron Ore Mine.

The study was conducted in support of an application for environmental authorisation of various expansions to the mining project. The purpose of this project is to give effect to the Regulation 23 of the Mineral and Petroleum Resources Development Act, 2002 (MPRDA) requirements for the optimisation of Mining Works Programme, as well as the implementation of the best practical environmental management measures for the operation and management of the Waste Rock Dumps (WRDs).

12.1 Completed work

Within the scope of work the following work was completed:

- Quantification of the current groundwater status quo as it pertains to groundwater levels and groundwater quality
- Impact prediction through numerical modelling
- Groundwater risk assessment and impact quantification
- Prescription of practicable management options and mitigation measures

12.2 Topography and drainage

The area is characterised by a gently undulating topography and in the area of the site the slope is more or less in the order 1% in a south western direction.

Locally drainage is towards the Groenwaterspruit that flows from northeast to southwest to the east of the site and towards the Skeifonteinspruit that flows from northeast to southwest to the south of the study area. On a larger scale, drainage occurs towards the generalised flow of the Orange River.

12.3 Local geology

The mine is located on the Maramane Dome, which is dominated by carbonate rocks of the Campbellrand Subgroup and the iron formations of the Asbesheuwels Subgroup of the Transvaal Supergroup. The dome dips gently, at less than 10 degrees, in an arc to north and south. Only the eastern half of the dome is exposed, while the western part is covered by red beds, conglomerate, shale and quartzite of the Gamagara Formation. The Beeshoek-Olynfontein iron ore deposits are situated along the contact between the Gamagara Formation and the underlying Manganore Iron Formation.

12.4 Hydrogeology

The hydrogeology in the Postmasburg/Beeshoek area is extremely heterogeneous due to the complex geology of the area. Karoo Supergroup sediments, volcanics and karstic (dolomitic) formations are the main components of the groundwater regime in the area.

Acid/Leachate generation capacity:The leachable concentrations of solid waste were compared to the leachable concentration threshold (LCT) limits to determine the leachability of the different waste types at the mine. Solid waste types were described as either “type 4” or “type 3” waste types which are low hazard waste types with regards to the likelihood to release contaminants in dissolved phase.

12.5 Hydraulic conductivity

Hydraulic conductivity varies spatially and vertically, and the modelled conductivities vary by at least six orders of magnitude, from 10^{-3} m/d to 10^{+2} m/d (0.001 m/d to 100 m/d).

12.6 Groundwater levels

Groundwater levels range between 5 mbgl in unaffected areas to 180 - 200 mbgl in dewatered areas due to groundwater abstraction for dewatering and water supply. The effect of dewatering is more pronounced to the south of the mine (south of Olynfontein). The direction of groundwater flow is south to south easterly from the mining area. A cone of depression has developed within the active mining area with flow directed towards the mining excavation due to the active mining areas.

12.7 Potential contaminants

The potential influences on groundwater quality were identified as opencast mining, fuel storage and handling, sewage management, solid and liquid mining-related waste management at the mine (i.e. ore discards and impounded mine water). Based on the groundwater quality analyses (Waste Characterisation and Groundwater Monitoring Network Audit – 2018), solid waste analyses and liquid waste analyses, as well as the statistical analysis of the data, it can be deduced that the chemical signatures of the 3 mediums are quite similar. Additionally, it was found that the constituents found to exceed the relevant screening levels for each of the three mediums are also similar. Also, most of the sources are located within the dewatered area, directing any potential contaminants towards the active mining areas.

12.8 Groundwater quality

Generally, the groundwater resources at all the sampling localities are described as being neutral to alkaline (pH levels between 7.8 and 8.0), non-saline to saline (TDS between 445.5 mg/l and 563.8 mg/l), and the hardness can be classified as very hard (> 300mg $CaCO_3$/l). Water hardness at Beeshoek mine is not unlike most other boreholes in the area, resulting from the calcareous/dolomitic underlying geology characteristic of many parts of the Northern Cape.

Metal concentrations were below detection limit or low at all the monitoring boreholes.

Nitrate as N and combined nitrate and nitrite exceed the drinking water limit in the majority of external user boreholes regardless of location. The WUL identified nitrates as a contaminant of concern in relation to mining activity due to the use of N-based emulsions for blasting. Through the analysis of N-isotopes from nitrates, a contamination assessment was conducted in 2019 and it was concluded that mine's contribution to nitrate levels in and around the mine was minimal (<1%). This was confirmed by the monitoring done in 2020, where the time series graph indicates that the nitrate concentrations fluctuate over time and that concentrations in WG62 and WG74 are increasing from September 2019 onwards. The remaining boreholes reported a decreasing trend from April 2019 onwards. The average value of the NO3 concentrations in the boreholes is 9.62mg/.

12.9 Aquifer characterisation

- Groundwater Vulnerability: Medium Vulnerable (33%)
- Classification: Minor aquifer system

- Protection required: Medium level (Groundwater quality management index = 4)

12.10 Groundwater Impacts

The following impacts were predicted during the different stages of the life of mine:

- **Construction phase:** This phase is not expected to influence the groundwater levels. With the exception of minor oil and diesel spills, there are also no activities expected that could impact on regional groundwater quality.
- **Operational phase:** Operational phase: During the operational phase, it is expected that the main impact on the groundwater environment will be dewatering of the surrounding aquifer. Water entering the mining areas will have to be pumped out to enable mining activities. This will cause a lowering in the groundwater table in- and adjacent to the mine. Mining in this area has been ongoing for many decades, and there are historical impacts on the surrounding aquifer which are impractical to simulate in a numerical model. Thus, current groundwater levels (obtained from various sources) have been used as baseline for this impact assessment, and all dewatering impacts related to the current water levels as a starting point. Considering the impact associated with each mining pit, the following observations were made:
    - The area to the south of the mining rights area is characterised by deep groundwater levels (>100 m) associated with large-scale dewatering at the neighbouring Kolomela Mine.
    - No drawdown is expected for further mining at East Pit as the declining groundwater levels is predicted to be below the bottom of mining.
    - Drawdown at Village pit is predicted to extent to up to 2km from the pit in a mostly westerly direction, for an insignificant drawdown of 5 – 10 metres. Areas of significant drawdown is expected only in in the immediate vicinity of the pit, which could even decline with time as Leeuwfontein mining impacts northward into this area.
    - HF Pit is predicted to have a minor impact limited to the immediate surroundings of the pit itself.
    - The BN Pit is predicted to have the largest area of impact due to substantial increase in mining depth. Drawdown of groundwater levels will be up to about 100 m but limited to an area of about 1 km around the pit. This is mainly due to different hydraulic characteristics in the area around the pit.
    - No groundwater-related impacts are expected on surface water resources.
- **Closure/Post-mining phases:** After closure, the water table will rise in the mine to reinstate equilibrium with the surrounding groundwater systems. Following the closure of the opencasts and the cessation of the dewatering it is assumed to lead to groundwater rebound and potential decanting. However, due to naturally deep-lying groundwater levels, no decant is predicted. Further, the spread of contamination is expected to occur slowly in a south to south-westerly direction, at about 100 metres per year. No adverse effects are predicted on receptor boreholes with regards to increasing contaminant concentrations in groundwater.

12.11 Management of Dewatering Impacts

There are no obvious means of mitigating the impact of groundwater lowering by mining, except for monitoring surrounding boreholes and replacing lost groundwater extraction potential where applicable (where it can be demonstrated that external groundwater users have been impacted upon by the mine).

Dewatering is primarily achieved through wellfields of abstraction boreholes and in pit dewatering points, and the combination thereof functions with the purpose of keeping the pit floor dry by creating a cone of depression around the excavation. The pit floor was thus modelled as a drain, which in MODFLOW uses the bottom elevation of the drain as the hydraulic head that controls flow into the drain. In this way the individual position of dewatering boreholes has no effect on the extent of the cone of depression or groundwater level lowering. Dewatering borehole positions may be changed without notice as objectively they will be placed as close as possible to the excavation to maintain a dry pit floor. Currently, no additional groundwater is to be abstracted from the catchment as part of this project expansion.

12.12 Recommended monitoring

The mine was awarded a water licence on 01/12/2014, licence number 10/D73A/ABGJ/2592. The water licence covers section 21(a), 21(b), 21(g) and 21(j) of the National Water Act 1998 (Act 36 of 1998). The conditions as set out in the WUL serve as the guidelines for monitoring data interpretation and reporting for authorised activities. A monitoring programme is in place which entails quarterly water quality monitoring and monthly manual water level and daily telemetric/auto-level water level monitoring at select locations.

The current water quality and water level monitoring network is considered adequate to detect and quantify the presence and migration of any contaminants in groundwater and measure the effects of large-scale groundwater abstraction for mining purposes on groundwater levels.

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

Source monitoring: Monitoring boreholes are placed close to or in the source of contamination to evaluate the impact thereof on the groundwater chemistry. Monitoring boreholes within the mining area satisfy this condition.

Pathway monitoring: Monitoring boreholes are placed in the primary groundwater migration pathways to evaluate the migration rates and chemical changes along the pathway. Monitoring boreholes located along groundwater flow paths satisfy this condition.

Impact monitoring: Monitoring of possible impacts of contaminated groundwater on sensitive ecosystems or other receptors. These monitoring points are also installed as early warning systems for contamination break-through at areas of concern. External user boreholes and monitoring placed in positions to detect and monitor impacts on groundwater availability and quality satisfy this condition.

Background monitoring: Background groundwater quality is essential to evaluate the impact of a specific action/pollution source on the groundwater chemistry. Monitoring boreholes located up-gradient/upstream of the mining area.

12.13 Main mitigation measures

Dewatering and large-scale groundwater abstraction may pose significant risk to the groundwater regime and privately-owned boreholes within the dewatered areas. There are no obvious means of mitigating the impact of groundwater lowering by mining, except for monitoring surrounding boreholes and replacing lost groundwater extraction potential where applicable (where external users have been impacted upon by the mine).

12.14 Recommendations

Based on the findings of this assessment, the following recommendations are brought forward:

- Beeshoek is currently operating in a dynamic mining environment. Water levels are also impacted by various external sources, which directly impacts the water levels at Beeshoek. Currently, no additional groundwater is to be abstracted from the catchment as part of this project expansion. However, due to the nature of the environment in which the mine is operating, regular numerical model updates must be undertaken to determine whether the volumes for dewatering will still be sufficient to also supply the mine with the required volumes as approved in the Section 21(a) water uses.

APPENDIX I: HYDROCENSUS INFORMATION

No.	Borehole ID	Latitude	Longitude	Owner	Property	Use	Comments
1	Kar7	-28.2445	23.07646	Chris Victor	Kareepan	Other	Pumps to 3 x 1 000 L tanks
2	Kar6	-28.2425	23.0776	Chris Victor	Kareepan		Blocked at 5.6 m
3	Drie1	-28.15458	23.04514	Ithumeleng Ghotlekai	Driehoek		
4	Drie1?	-28.15449	23.04505	Ithumeleng Ghotlaekai	Driehoek	Livestock watering and domestic	
5	PNF2	-28.2836	23.06056	Jaques van wyk	Pensfontein		Pumps into cement dam
6	PNF3	-28.283	23.06022	Jaques an Wyk	Pensfontein		Borehole sealed; Water level not measured
7	PNF1	-28.2738	23.0653	Jaques van wyk	Pensfontein		
8	PE01	-28.2715	23.0659	Jaques van Wyk	Pensfontein		N&Z telemetric borehole
9	PNF4	-28.274	23.06022	Jaques van Wyk	Pensfontein	Domestic	
10	Pens6	-28.2721	23.06781	Jaques van Wyk	Pensfontein		Blocked at 2.39 m
11	PNF5	-28.2792	23.07039	Jaques van Wyk	Pensfontein	Other	
12	Pens9	-28.293	23.07895	Jaques van wyk	Pensfontein		**Dry**
13	G0110NC	-28.2825	23.08857	Jaques van Wyk	Pensfontein		Blocked at 8.9 m
14	G0109NC	-28.2824	23.08863	Jaques van Wyk	Pensfontein		
15	Kar1	-28.2742	23.09044	Chris Victor	Kareepan		
16	G0112NC	-28.2565	23.10986	Chris Victor	Kareepan		Level logger installed
17	Kar4	-28.2485	23.10205	Chris Victor	Kareepan		Not in use, wind pump broken
18	Kar5	-28.2504	23.08322	Chris Victor	Kareerand	Livestock watering	
19	Pens8	-28.277	23.08107	unknown	Knoffelfontein		Wind pump broken
20	DP6	-28.2148	23.08959	James Letlakana	Doornpan		Wind pump broken
21	DP5	-28.2153	23.09208	James Letlakana	Doornpan	Livestock watering	Well
22	DP2	-28.2148	23.08959	James Letlakana	Doornpan		Destroyed
23	DP1	-28.2148	23.09048	James Letlakana	Doornpan		
24	DP3	-28.2127	23.07681	Community owned	Doornpan	Livestock watering and domestic	
25	GLS2	-28.08212	23.0333	Gert Olivier	Glossam		
26	GLS3	-28.08226	23.03327	Gert Olivier	Glossam		Low yielding hole

No.	Borehole ID	Latitude	Longitude	Owner	Property	Use	Comments
27	GLS1	-28.0957	23.04369	Gert Olivier	Glossam		
28	DP4	-28.1693	23.07582	Community Owned	Doornpan		Wind pump broken
29	SOET491-3	-28.3736	23.03635	Albertus Viljoen	Soetfontein	Livestock watering and domestic	
30	SOETHUIS2	-28.474	23.0359	Johan Viljoen	Soetfontein		
31	SFT1	-28.3727	23.03438	Albertus Viljoen	Soetfontein		
32	SOETHUIS3	-28.3721	23.03448	Albertus Viljoen	Soetfontein	Livestock watering and domestic	
33	PFNUUT	-28.372	23.03423	Albertus Viljoen	Soetfontein	Domestic	
34	SFT2	-28.3726	23.03442	Albertus Viljoen	Soetfontein		
35	KAM2	-28.4028	23.00706	Johan Van Zyl	Kameelfontein	Domestic	Recharge borehole was drilled very close to KAM2
36	KAM1	-28.4027	23.00717	Johan van Zyl	Kameelfontein		Wind pump pumps into small cement dam
37	KB1	-28.41593	22.98954	F Bredenkamp	Klipbankfontein		Not in use
38	KB2	-28.4178	22.99312	F Bredenkamp	Klipbankfontein	Domestic	
39	KBF01	-28.41822	22.99253	F Bredenkamp	Klipbankfontein	Other	
40	BH1	-28.4341	22.9802	Daniel Jooste	Klipbankfontein	Domestic	
41	KBF2	-28.4178	22.9801	Daniel Jooste	Klipbankfontein	Irrigation and Domestic	
42	KBF1	-28.434	22.979885	Daniel Jooste	Klipbankfontein		Blocked
43	KBF02	-28.4159	22.99522	Fransiena Bredenkamp	Klipbankfontein	Other	N&Z telemetric borehole
44	BOSCH1	-28.5384	23.01055	Johan van der Merwe	Bospoort		
45	BOSH2	-28.5266	22.99632	Johan van der Merwe	Boschpoort	Irrigation and Livestock watering	Used to water peaken nut orchid and for bucks.
46	BOSCH3	-28.5236	22.98909	Johan van der Merwe	Boschpoort	Domestic	Used for drinking and a rusk bakery.
47	MOOI6	-28.4069	23.07423	Chris van der Merwe	Mooidraai	Irrigation and Domestic	Borehole used to water 3 ha peaken nut orchid
48	MOOI5	-28.4312	23.08806	Chris van der Merwe	Mooidraai		
49	MOOI4	-28.4312	23.08628	Chris van der Merwe	Mooidraai	Irrigation and Domestic	Citrus irrigation
50	MOOI3	-28.4285	23.08715	Chris van der Merwe	Mooidraai	Domestic	
51	MOOI2	-28.4244	23.09588	Chris van der Merwe	Mooidraai	Livestock watering	
52	MOOI1	-28.4235	23.09577	Chris van der Merwe	Mooidraai		Borehole not in use, poor yield.

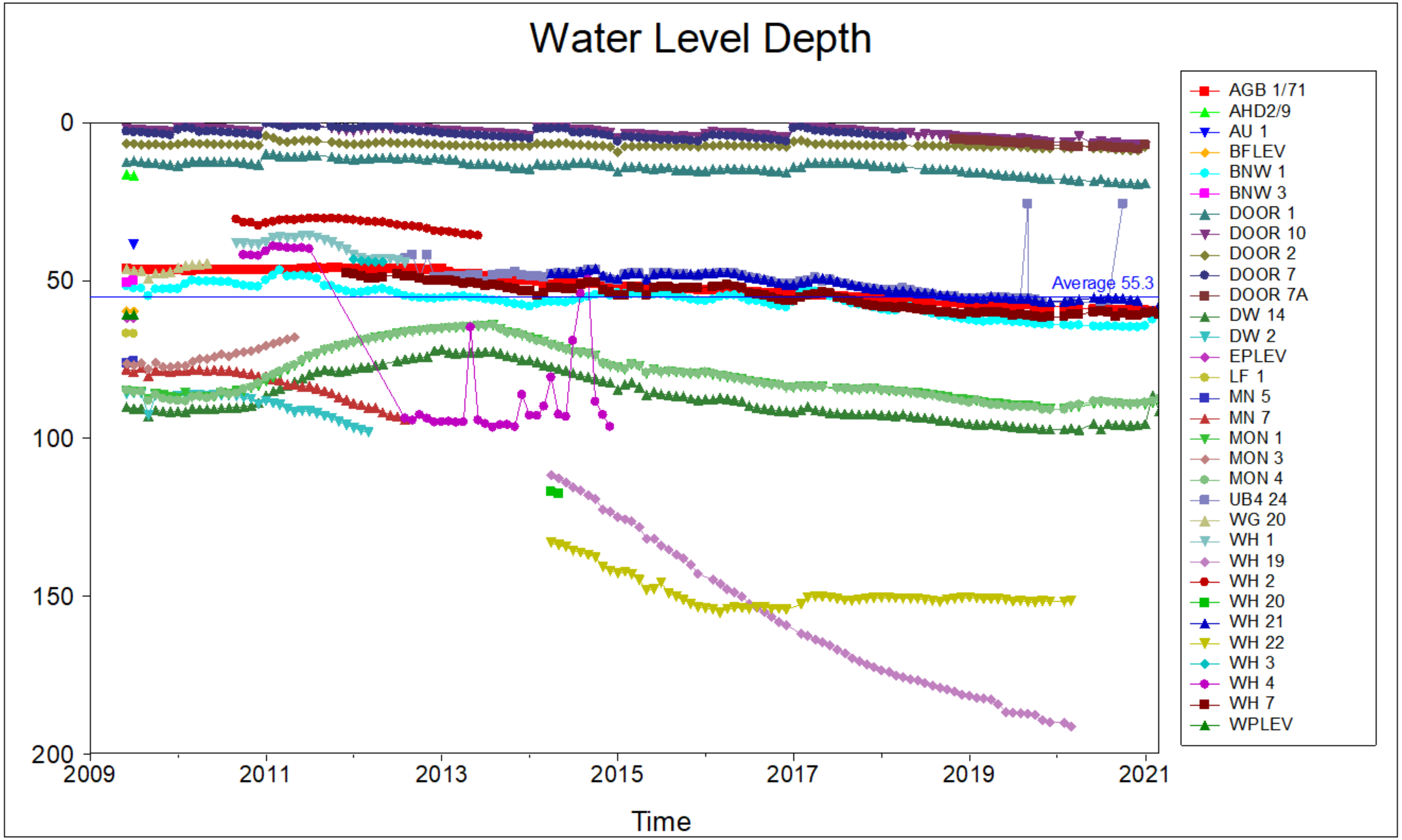
No.	Borehole ID	Latitude	Longitude	Owner	Property	Use	Comments
53	MOOIDRAAI	-28.42046	23.09622	Chris van der Merwe	Mooidraai		
54	MOOI7	-28.40916	23.07379	Chris van der Merwe	Mooidraai	Irrigation and Domestic	Waters 3 ha of peaken nut orchid
55	OLYN1	-28.3521	23.04764	Charl Viljoen	Olynfontein	Livestock watering	
56	OLYN2	-28.3521	23.0454	Charl Viljoen	Olynfontein	Irrigation	Garden watering
57	OLYN2-1	-28.352	23.04683	Charl Viljoen	Olynfontein	Livestock watering and domestic	
58	OLYN3	-28.345	23.02609	Charl Viljoen	Olynfontein		Blocked
59	OLYN4	-28.3535	23.04644	Charl Viljoen	Olynfontein	Irrigation	
60	PUT1	-28.5487	22.92041	Reitz Coetsee	Putsfontein		No access to property
61	BOREHOLE10	-28.3452	23.04778	Charl Viljoen	Olynfontein		Not in use
62	KALKFONTEIN	-28.3604	23.04853	Andries van der Walt	Kalkfontein	Livestock watering and domestic	Fountain
63	KLF1	-28.3618	23.04629	Andries van der Walt	Kalkfontein		
64	PUTSFONTEIN	-28.5394	22.91915	Reitz Coetsee	Putsfontein		No access to property
65	KALKFONTEIN (N&Z)	-28.36142	23.04168	Andries van der Walt	Kalkfontein		Destroyed
66	BNW1	-28.2797	22.99946	Assmang	Beeshoek	Other	Monitoring borehole
67	WH22	-28.30823	23.0141	Assmang	Beeshoek	Other	Monitoring borehole
68	WH19	-28.34978	23.02006	Assmang	Beeshoek	Other	Monitoring borehole
69	WHO7	-28.2952	22.98692	Assmang	Beeshoek	Other	Monitoring borehole
70	AGB1/71	-28.3085	22.97907	Assmang	Beeshoek	Other	Monitoring borehole
71	DW14	-28.3069	23.00121	Assmang	Beeshoek	Other	Monitoring borehole
72	MON4	-28.3167	22.98795	Assmang	Beeshoek	Other	Monitoring borehole
73	MON1	-28.3288	22.98713	Assmang	Beeshoek	Other	Monitoring borehole
74	UB4/34	-28.29321	22.98569	Assmang	Beeshoek	Other	Monitoring borehole
75	UB4/24	-28.29276	22.98569	Assmang	Beeshoek	Other	Monitoring borehole
76	DOOOR1	-28.2417	23.02896	Assmang	Doornfontein	Other	Monitoring borehole
77	DOOR2	-28.2474	23.03192	Assmang	Doornfontein	Other	Monitoring borehole
78	DOOR7	-28.2366	23.04067	Assmang	Doornfontein	Domestic	Monitoring borehole

No.	Borehole ID	Latitude	Longitude	Owner	Property	Use	Comments
79	DOOR10	-28.2412	23.03406	Assmang	Doornfontein	Domestic	Monitoring borehole
80	WH21	-28.29738	22.978	Assmang	Beeshoek	Other	Monitoring borehole
81	OW18	-28.29942	22.99219	Assmang	Beeshoek	Other	Monitoring borehole
82	MAM1	-28.0995	22.85913	Anglo	Mamagodi		Borehole sealed
83	MAM2	-28.107	22.87667	Anglo	Mamagodi		Borehole sealed
84	MAM3	-28.1092	22.87498	Anglo	Mamagodi		-
85	MAM4	-28.1074	22.87795	Anglo	Mamagodi		Not in use
86	MAM5	-28.1076	22.8781	Anglo	Mamagodi	Livestock watering	Pumps into dam
87	WDP1	-28.4878	22.93107	Anglo	Wildealsput		No access
88	WDP2	-28.46024	22.86696	Anglo	Wildealsput		
89	ELIM4	-28.1583	22.86222	Pierre Becker	Elim	Other	
90	ELIM3	-28.1522	22.86073	Pierre Becker	Elim		Blocked
91	ELIM5	-28.14746	22.85576	Pierre Becker	Elim	Domestic	Pit
92	ELIM1	-28.1502	22.8652	Pierre Becker	Elim		Well, not in use
93	ELIM2	-28.1503	22.86461	Pierre BeXker	Elim		Well, not in use
94	ELIM8	-28.1362	22.90378	Pierre Becker	Elim	Livestock watering	
95	KW1	-28.12663	22.88941	David Calitz	Kouwater	Livestock watering	
96	LCD1	-28.256	22.83507	John Daniels	Lucasdam	Livestock watering	Solar pump
97	LCD2	-28.2389	22.82549	John Daniels	Lacasdam	Livestock watering	Wind pump
98	LCD3	-28.2481	22.90492	John Daniels	Lucasdam	Livestock watering	Wind pump
99	LCD4	-28.2404	22.87303	John Daniels	Lucasdam	Livestock watering	Solar pump
100	LCD5	-28.2394	22.87109	John Daniels	Lucasdam		Hand-dug well
101	402-2	-28.2487	22.85839	John Daniels	Lucasdam	Livestock watering and domestic	Well with solar pump
102	G0108	-28.2457	22.86051	John Daniels	Lucasdam	Other	
103	402-1	-28.2511	22.85918	John Daniels	Lucasdam	Domestic	Well
104	VLW2	-28.3235	22.77889	Oelof Horn	Voelwater		Not in use

No.	Borehole ID	Latitude	Longitude	Owner	Property	Use	Comments
105	VLW1	-28.2991	22.76652	Oelof Horn	Voelwater		
106	VLW4	-28.2746	22.77638	Oelof Horn	Voelwater	Livestock watering	Solar pump
107	PRB1	-28.2414	22.7827	Oelof Horn	Pramberg		
108	PRAM1	-28.2386	22.78894	Oelof Horn	Pramberg	Livestock watering	Solar pump
109	362-7	-28.2328	22.78909	Oelof Horn	Pramberg		
110	PRB2	-28.2308	22.78719	Oelof Horn	Pramberg	Domestic	
111	VLW5	-28.2167	22.80235	Oelof Horn	Pramberg	Livestock watering	Solar pump
112	DHL3	-28.2653	22.73623	Kobie Horn	Dunhill	Livestock watering	
113	DHL4	-28.2375	22.71818	Kobie Horn	Dunhill	Livestock watering	
114	DHL5	-28.2396	22.7103	Kobie Horn	Dunhill	Livestock watering	Solar pump
115	DHL6	-28.23193	22.75437	Kobie Horn	Dunhill	Livestock watering	
116	362-6	-28.2178	22.75305	Kobie Horn	Dunhill	Domestic	
117	DHL1	-28.214	22.75158	Kobie Horn	Dunhill		Destroyed
118	WLS1	-28.36371	22.70542	Kobie Horn	Wildeals	Livestock watering and domestic	Solar pump
119	WLS2	-28.36836	22.73294	Kobie Horn	Wildeals		
120	SLR1	-28.3961	22.76807	Eksteen Kotze	Stillerus	Livestock watering and domestic	
121	230-1	-28.3959	22.76813	Eksteen Kotze	Stillerus	Livestock watering and domestic	
122	230-3	-28.4079	22.80493	Conrad Kotze	Floradale	Livestock watering and domestic	
123	484-2	-28.3782	22.79466	Conrad Kotze	Floradale		Could not measure
124	SFE-007	-28.4171	22.8209	Conrad Kotze	Florade		Exploration hole.
125	230-2	-28.4174	22.82271	Conrad Kotze	Floradale		
126	448-3	-28.3628	22.82014	Conrad Kotze	Floradale		
127	FLORADALE	-28.36293	22.82092	Conrad Kotze	Floradale	Livestock watering	N&Z hole, has a solar pump in.
128	AU1	-28.2757	22.96287	Altus Viljoen	Aucampsrus		Used as backup hole for AU2, low yielding
129	AU2	-28.27579	22.96334	Altus Viljoen	Aucampsrus		
130	AU3	-28.2788	22.96421	Altus Viljoen	Aucampsrus	Livestock watering	Solar pump

No.	Borehole ID	Latitude	Longitude	Owner	Property	Use	Comments
131	AU4	-28.2781	22.96375	Altus Viljoen	Aucampsrus		
132	AU5	-28.291	22.96315	Altus Viljoen	Aucampsrus	Livestock watering	Wind pump
133	AU14	-28.2571	22.95252	Altus Viljoen	Aucampsrus	Livestock watering	Hand-dug well
134	AU7	-28.2794	22.93353	Altus Viljoen	Aucampsrus	Livestock watering	
135	AU8	-28.2763	22.93549	Altus Viljoen	Aucampsrus	Other	Monitoring borehole
136	AU15	-28.2703	22.96814	Altus Viljoen	Aucampsrus	Livestock watering	
137	AU16	-28.2896	22.9459	Altus Viljoen	Aucampsrus		Blocked (Not in use)
138	AU10	-28.2633	22.93799	Altus Viljoen	Aucampsrus		
139	480-4	-28.3243	22.7998	Rudi Erasmus	Vogelwater	Livestock watering	
140	PFN1	-28.3268	22.82649	Rudi Erasmus	Vogelwater	Livestock watering	
141	NEW	-28.3486	22.82425	Rudi Erasmus	Vogelwater	Livestock watering	
142	G0113NC	-28.3293	22.87911	Rudi Erasmus	Vogelwater		No access
143	G0114NC	-28.3287	22.85737	Rudi Erasmus	Vogelwater		No access
144	479-8	-28.3097	22.83501	B Bredenkamp	Broomlands	Irrigation	
145	BRL4	-28.31015	22.83439	B Bredenkamp	Broomlands		
146	BRL2	-28.3103	22.835	B Bredenkamp	Broomlands	Livestock watering	
147	BRL3	-28.3107	22.83825	B Bredenkamp	Broomlands	Domestic	
148	479-6	-28.3109	22.84048	B Bredenkamp	Broomlands	Livestock watering	
149	BRL1	-28.311	22.84077	B Bredenkamp	Broomlands		
150	G454495	-28.3237	23.08172	Municipality	Postmasburg		
151	G47753	-28.3238	23.08161	Municipality	Postmasburg	Other	Blocked at 3 m
152	RW008	-28.2012	22.94516	Adam Wahl	Wildeals	Other	
153	G0104NC	-28.25766	22.92693	Government	Unknown	Other	
154	G0105NC	-28.2575	22.92653	Government	Unknown	Other	
155	G0106NC	-28.25746	22.9264	Government	Unknown	Other	
156	RW006	-28.2153	22.95273	Adam Wahl	Wildeals		

APPENDIX II: TRENDS IN GROUNDWATER LEVELS


Water Level Depth
0
50
100
150
200
2009
2011
2013
2015
2017
2019
2021
Time
Average 55.3
AGB 1/71
AHD2/9
AU 1
BFLEV
BNW 1
BNW 3
DOOR 1
DOOR 10
DOOR 2
DOOR 7
DOOR 7A
DW 14
DW 2
EPLEV
LF 1
MN 5
MN 7
MON 1
MON 3
MON 4
UB4 24
WG 20
WH 1
WH 19
WH 2
WH 20
WH 21
WH 22
WH 3
WH 4
WH 7
WPLEV