Groundwater Complete

RIETKOL SILICA PROJECT

REPORT ON GEOHYDROLOGICAL INVESTIGATION AS PART OF THE ENVIRONMENTAL IMPACT ASSESSMENT AND ENVIRONMENTAL MANAGEMENT PROGRAMME

MAY 2021

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DECLARATION OF INDEPENDENCE AND SPECIALIST INFORMATION

I, Gerhard Steenekamp and Wiekus du Plessis (Groundwater Complete) declare that:

- We act as independent specialists in this application to Jacana Environmentals;
- We performed the work relating to the application in an objective manner, even if this results in views and findings that are not favorable to the applicant;
- We declare that there were no circumstances that may compromise our objectivity in performing such work;
- We have no vested financial, personal or any other interest in the application;
- We have no, and will not engage in, conflicting interests in the undertaking of the activity;
- We undertake to disclose to the applicant and the competent authority all material information in our possession that reasonably has or may have the potential of influencing - any decision to be taken with respect to the application by the competent authority; and - the objectivity of any report, plan or document to be prepared by ourselves for submission to the competent authority; and
- All the particulars furnished by us in this form are true and correct.

Wiekus du Plessis is a geohydrologist with 10 years' experience in all consulting aspects of geohydrology. He holds a Master's degree in Geohydrology and is registered with the South African Council for Natural Scientific Professions as a Water Resource Science Professional (registration number 400148/15).

He provides groundwater consulting service to the whole spectrum of geohydrological related projects, from groundwater supply, management plans, monitoring, interpretation, groundwater quality management and remediation of groundwater pollution for projects ranging from diamond, coal, platinum, chromium, anthracite, base mineral and metal mining to power stations. He also has experience in performing numerical modeling and calculations for mine closure purposes and post closure planning.

Gerhard Steenekamp
Pr.Sci.Nat. 400385/04

Wiekus du Plessis
Pr.Sci.Nat. 400148/15

May 2021

LEGAL REQUIREMENTS FOR ALL SPECIALIST STUDIES CONDUCTED

Legal Requirement		Relevant Section in Specialist study
(1)	A specialist report prepared in terms of these Regulations must contain-	
(a)	details of-	
	(i) the specialist who prepared the report; and	Page 1
	(ii) the expertise of that specialist to compile a specialist report including a curriculum vitae	Page 1
(b)	a declaration that the specialist is independent in a form as may be specified by the competent authority;	Page 1
(c)	an indication of the scope of, and the purpose for which, the report was prepared;	Section 1 and 3
(cA)	an indication of the quality and age of base data used for the specialist report;	Section 4.2
(cB)	a description of existing impacts on the site, cumulative impacts of the proposed development and levels of acceptable change;	Section 5.4 and 5.6
(d)	the duration, date and season of the site investigation and the relevance of the season to the outcome of the assessment;	Section 4.2
(e)	a description of the methodology adopted in preparing the report or carrying out the specialised process inclusive of equipment and modelling used;	Section 3 and 4
(f)	details of an assessment of the specific identified sensitivity of the site related to the proposed activity or activities and its associated structures and infrastructure, inclusive of a site plan identifying site alternatives;	N/A
(g)	an identification of any areas to be avoided, including buffers;	N/A
(h)	a map superimposing the activity including the associated structures and infrastructure on the environmental sensitivities of the site including areas to be avoided, including buffers;	N/A
(i)	a description of any assumptions made and any uncertainties or gaps in knowledge;	Section 7.1
(j)	a description of the findings and potential implications of such findings on the impact of the proposed activity or activities;	Section 7.9 and 8
(k)	any mitigation measures for inclusion in the EMPr;	Section 8
(l)	any conditions for inclusion in the environmental authorisation;	None
(m)	any monitoring requirements for inclusion in the EMPr or environmental authorisation;	Section 9
(n)	a reasoned opinion:	

Legal Requirement		Relevant Section in Specialist study
	whether the proposed activity, activities or portions thereof should be authorised;	N/A
	regarding the acceptability of the proposed activity or activities; and	N/A
	if the opinion is that the proposed activity, activities or portions thereof should be authorised, any avoidance, management and mitigation measures that should be included in the EMPr, and where applicable, the closure plan;	Section 8
(o)	a description of any consultation process that was undertaken during the course of preparing the specialist report;	Section 4.2
(p)	a summary and copies of any comments received during any consultation process and where applicable all responses thereto; and	Appendix B
(q)	any other information requested by the competent authority.	None

SITE SENSITIVITY VERIFICATION STATEMENT

Nhlabathi applied for a Mining Right to mine silica in February 2018 and commenced with the Environmental Impact Assessment (EIA) process as contemplated in the National Environmental Management Act 107 of 1998 (NEMA) and Government Notice (GN) No. R. 982-986 of 4 December 2014: NEMA: Environmental Impact Assessment Regulations, as amended (2014 EIA Regulations), for the Rietkol Project.

Several specialist studies were conducted within the Mining Right Application (MRA) area in support of the EIA process, and a comprehensive Public Participation process was initiated. The Final Scoping Report was submitted on 3 April 2018 and accepted by the Department of Mineral Resources and Energy (DMRE) on 26 April 2018. However, the MRA was rejected by the DMRE Mpumalanga Mine Economics Directorate on the basis that the MRA formed part of another right granted in terms of the MPRDA. This decision resulted in a delay in the EIA process, ultimately causing the application for Environmental Authorisation to lapse.

Nhlabathi has recently re-initiated the MRA process and applied for a Mining Right over the same farm portions in early 2020. The MRA was accepted by the DMRE on 21 January 2021 and Nhlabathi has since re-initiated the EIA process with Jacana Environmentals cc (Jacana) appointed as the independent Environmental Assessment Practitioner (EAP).

Several additional requirements when applying for Environmental Authorisation (EA) have emerged since the 2018 EIA process, including but not limited to:

1. Notice was given in Government Notice No. 960 (GN 960) dated 5 July 2019 of the requirement to submit a report generated by the National Web Based Environmental Screening Tool in terms of section 24(5)(h) of the NEMA and regulation 16(1)(b)(v) of the 2014 EIA Regulations. Such a Screening Rreport became compulsory when applying for an EA 90 days from publication of GN 960 (5 October 2019). The purpose of the Screening Report is to identify the list of specialist assessments that needs to be conducted in support of the EA application, based on the selected classification, and the environmental sensitivities of the proposed development footprint.
2. Government Notice No. 320 (GN 320) dated 20 March 2020 prescribes general requirements for undertaking site sensitivity verification and for protocols for the assessment and minimum report content requirements of environmental impacts for environmental themes for activities requiring EA in terms of sections 24(5)(a), (h) and 44 of NEMA. These procedures and requirements came into effect 50 days after publication of GN 320 (15 May 2020). The purpose of the site sensitivity verification is to verify (confirm or dispute) the current use of the land and the environmental sensitivity of the site under consideration as identified in the Screening Report. This will determine the level of assessment required for each environmental theme, i.e. Specialist Assessment or Compliance Statement.

As indicated above, several specialist studies were commissioned for the Rietkol Project during 2016-2018 in support of the previous application, including:

- Soils, land use and capability, Hydropedology;

- Terrestrial / Aquatic Biodiversity;
- Groundwater;
- Air Quality;
- Ambient Noise;
- Blasting & Vibration;
- Traffic;
- Heritage and Cultural Resources;
- Palaeontology;
- Visual and Aesthetics;
- Social;
- Hazard Identification and Risk Assessment (HIRA); and
- Land Trade-off & Macro-Economic Analysis

Comprehensive specialist assessments were conducted for all the environmental and social themes listed above, irrespective of the sensitivity identified by the specialist assessment (2018) or the Screening Report. Therefore, no site sensitivity verification has been done for this EA application as all themes have been considered to have a **high to very high sensitivity**, requiring a full Specialist Assessment.

The list of specialist assessments listed in the Screening Report and the extent to which it has been addressed in the re-application for EA for the Rietkol Project is indicated below. Where applicable, motivation is provided for the exclusion of certain specialist assessments.

GN 960 requirement	Extent to which it is included in the Plan of Study
Agricultural Impact Assessment	Soil and Land Capability Assessment by Scientific Aquatic Services.
Landscape/Visual Impact Assessment	Visual Impact Assessment by Scientific Aquatic Services.
Archaeological and Cultural Heritage Impact Assessment	Phase 1 Heritage Impact Assessment by R&R Cultural Resource Consultants.
Palaeontology Impact Assessment	Palaeontology Impact Assessment by ASG Geo Consultants (Pty) Ltd {Dr Gideon Groenewald}.
Terrestrial Biodiversity Impact Assessment	Faunal, Floral and Freshwater Assessment by Scientific Terrestrial Services.
Aquatic Biodiversity Impact Assessment	Faunal, Floral and Freshwater Assessment by Scientific Terrestrial Services.
Hydrology Assessment	Baseline Water Quality Assessment by Scientific Aquatic Services. Water Management Plan – Preliminary Design Report by Onno Fortuin Consulting.
Noise Impact Assessment	Environmental Noise Impact Assessment by Enviro Acoustic Research.

GN 960 requirement	Extent to which it is included in the Plan of Study
Radioactivity Impact Assessment	Waste Classification by Groundwater Complete. Analysis will include Uranium and Thorium to determine potential for radioactivity within the resource.
Traffic Impact Assessment	Traffic Impact Assessment by Avzcons Civil Engineering Consultant.
Geotechnical Assessment	A geotechnical assessment will be undertaken as part of the engineering package for the project, if required. This is not included in the application for EA.
Climate Impact Assessment	A greenhouse gas emissions statement is included in the Air Quality Impact Assessment by EBS Advisory.
Health Impact Assessment	Hazard Identification and Risk Assessment by AirCheck Occupational Health, Environmental & Training Services.
Socio-Economic Assessment	Socio-Economic Impact Assessment by Diphororo Development.
Ambient Air Quality Impact Assessment	Air Quality Impact Assessment by EBS Advisory.
Seismicity Assessment	A Blasting Impact Assessment is included and has been conducted by Blast Management Consulting. It deals extensively with the potential impact in respect of air blast and vibration from blasting operations.
Plant Species Assessment	Part of Terrestrial Biodiversity Impact Assessment.
Animal Species Assessment	Part of Terrestrial Biodiversity Impact Assessment.

Further studies that are not included in the GN 960 requirements, but were commissioned for the Rietkol Project, are:

- Hydropedological Assessment by Scientific Aquatic Services.
- Geohydrological Investigation by Groundwater Complete.
- Blasting Impact Assessment by Blast Management Consulting.
- Land Trade-off Study and Macro-Economic Impact Analysis by Mosaka Economic Consultants.
- Rehabilitation, Decommissioning and Closure Plan by Jacana Environmentals.

Where a specific environmental theme protocol has been prescribed by GN 320, the specialist assessment will adhere to such protocol. Where no protocol has been prescribed, the report will comply with Appendix 6 of the EIA Regulations.

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RIETKOL SILICA PROJECT: REPORT ON GEOHYDROLOGICAL INVESTIGATION AS PART OF THE EIA AND EMPR, MAY 2021

EXECUTIVE SUMMARY:

Groundwater Complete was contracted by Jacana Environmentals to conduct a geohydrological study and report on findings as specialist input to the Environmental Impact Assessment (EIA) and Environmental Management Programme (EMPr) for the Rietkol Silica Project (hereinafter referred to as Rietkol).

Silica is planned to be mined by means of conventional opencast methods to depths of between 30 to 50 meters below surface (mbs). The planned opencast mining will result in two individual opencast pits (i.e. North Block and South Block) separated by a ± 30 meters wide pillar.

The estimated life of mine (LOM) for the proposed Rietkol Project is 20 years and will include the following mining and related infrastructure:

- Two opencast pits;
- Processing plant (i.e. crushing, washplant, screening, etc.);
- Product stockpiles;
- Administration office facilities (i.e. security building, administration and staff offices, reception area, ablution facilities, etc.);
- Production facilities (i.e. locker rooms, laboratory, workshops, stores, explosives magazine, ablution facilities, etc.);
- Access roads; and
- Storm water management infrastructure.

The main aim or objective of this study was to determine the impact of the proposed new mining and related processing activities on both groundwater quality (contamination migration) and quantity (availability).

In order to successfully achieve this objective, the following methodology was followed:

- Firstly, a comprehensive and holistic conceptual model was developed for the geohydrological environment; and
- Secondly, the conceptual model formed the basis for the construction and calibration of numerical groundwater flow and contaminant transport models that were used to simulate/predict the impacts of the proposed new mining and related activities on both groundwater quality and water levels (availability).

The following conclusions and recommendations are based on the findings of the geohydrological investigation:

Conclusions – Geohydrological Environment:

- The topography of the project area can be described as being gently undulating with surface elevations (±4 km radius) varying from approximately 1 540 to 1 620 mamsl.
- A prominent watercourse, namely the Koffiespruit, is located ± 2.5 kilometers west of the MRA area and within the same catchment.
- The project area receives on average approximately 720 mm of rainfall annually, and the average annual evaporation rate is nearly 1 530 mm.
- Hydrocensus/groundwater user surveys were conducted by Aquatico Scientific on the MRA area and surrounding properties. A total of 86 boreholes, four dams and one cave were located. Most of the boreholes were used for domestic purposes, livestock watering and irrigation at the time of the surveys.
- Recharge to the dolomitic aquifer underlying the northern half of the MRA area was estimated with the Chloride Method to be approximately 13% of the mean annual rainfall.
- Stratigraphically, the project area occurs on the boundary between the Malmani Subgroup and the Pretoria Group of the Transvaal Supergroup *(SACS, 1980)*. The Malmani Subgroup consists of several hundred meters of cherty, stromatolitic dolostone of about 2.6 billion years old that was deposited on an intra-cratonic marine basin under tidal conditions *(Button, 1986)*. The Malmani Subgroup and the Pretoria Groups are disconformably overlain by late Carboniferous – Permian diamictite, shale and sandstone of the Karoo Supergroup.
- The Proterozoic and Permian strata are intruded by several generations of diabase and dolerite sills and dykes. A flat dipping dolerite sill of approximately 30 m thick cuts through the Rietkol quartzite deposit and divides it into an Upper and a Lower Quartzite band. Due to the thickness of the sill, mining will not cut through the sill and only the Upper Quartzite band will be mined to a depth of approximately 30 to 50 meters.
- A waste classification (i.e. total concentration digestion and distilled water leaching tests) was conducted on two composite samples (i.e. tailings material and waste rock) that were collected from the operational Thaba Chueu mine (previously known as SamQuarz). The tests concluded that both samples are a Type 4 or inert waste, requiring a Class D (or GSB-) disposal facility.
- Based on information gathered during the drilling of four monitoring boreholes, the unsaturated zone is predominantly composed of soil/clay and weathered bedrock (mostly chert and quartzite).
- The average transmissivity of the dolomitic aquifer that underlies the northern half of the MRA area was calculated to be in the region of 22 m^2/d. On the other hand, the Karoo aquifer underlying the southern half of the MRA area displayed a much lower transmissivity of nearly 6.5 m^2/d. The lowest transmissivities were calculated for the Rietkol quartzite deposit, which displayed an average of approximately 0.9 m^2/d.
- Groundwater levels in the project area generally vary between ± 9 and 100 mbs, with the average being ± 42 mbs.
- Numerous potential sources of groundwater contamination are planned for the MRA area. On the positive side, most of these potential source areas pose no real threat to the underlying aquifer in terms of impacts on groundwater quality. Both the target mineral and host rock that will be processed in the plant and then stockpiled/dumped

are chemically inert and will therefore not react with oxygen and water to create poor quality leachate (such as acid mine/rock drainage).
- Groundwater from most of the user and monitoring boreholes is considered to be of good quality and is suitable for human consumption if compared with the South African National Standards *(SANS 241:2015)*. Exceedances in terms of the groundwater nitrate content are, however, observed for some of the user boreholes.
- The dolomitic aquifer scored a groundwater vulnerability rating of 9 and is therefore regarded as being highly vulnerable.
- Three aquifer systems are present, namely a shallow, semi-confined or unconfined aquifer that occurs in the transitional soil and weathered bedrock zone or sub-outcrop horizon. A deeper secondary fractured rock aquifer that is hosted within the sedimentary rocks of the Karoo Supergroup, which underlies the southern half of the MRA area. A third, and major aquifer system that is associated with the Malmani Subgroup (Transvaal Supergroup) dolomite that underlies the northern half of the MRA area.
- The GQM rating for the project area calculates to 18, which means that no impact is allowed.

Note that the sensitive dolomitic aquifer will not be intersected by the proposed opencast pits. The sediment/sand (now quartzite after low grade metamorphism) was deposited into an ancient dolomite sinkhole. The proposed opencast pits are situated more or less in the center of this deposit – meaning that nearly at all times there will be a ± 90 to 300 meters buffer, or low transmissivity quartzite, between the pits and surrounding dolomite. The quartzite deposit in its entirety is expected to act as a buffer between the proposed mining activities and the surrounding and underlying dolomite.

Conclusions – Numerical Groundwater Modelling:

Flow model:

The main aim of the flow model was to simulate and predict the groundwater level impacts resulting from the planned opencast mining, i.e. simulation of groundwater depression cone. Two mining scenarios were simulated, namely **Scenario 1** where the depth of the pit floor is on average 30 meters below surface and **Scenario 2** where the average depth of the pit floor is 50 meters below surface. A summary of the model-simulated water level impacts **at mine closure** is provided below:
- The pit floor was simulated to intersect the water table from year one during both mining scenarios, resulting in groundwater flowing towards and eventually into the opencast pits.
- The groundwater influx for Scenario 1 was simulated to increase from approximately 20 m^3/d at the end of year one to a maximum of ± 90 m^3/d at mine closure. The influx simulated for Scenario 2 increased from ± 100 m^3/d to nearly 240 m^3/d at the end of the twentieth and final year.
- Dolerite dykes and sills, such as the one that cuts the Rietkol quartzite deposit into an Upper and a Lower Quartzite band, have the potential to yield significant volumes of

groundwater. Over and above the groundwater influx from the saturated aquifer host rock/s (fractured quartzite) that cannot be prevented, the risk of additional (and potentially high) groundwater influx from the abovementioned sill is high should mining cut into or through the structure (where below the groundwater level).

- An area of approximately 522 460 m^2 was simulated to be affected by the Scenario 1 pit dewatering activities, while a slightly larger area of ± 724 430 m^2 was simulated for Scenario 2.
- The water level impacts do extend beyond the MRA area, however no groundwater user boreholes are located within these affected areas.
- Fifty years after mining has ceased, the groundwater level (where the impact of pit dewatering was greatest) was simulated to have recovered by ± 91% for Scenario 1, while a ± 89% recovery was simulated for Scenario 2.

Contaminant transport model:

Throughout the following discussions reference is made to “contamination plumes“ instead of “pollution plumes”. Both contamination and pollution refer to any substance (either organic or inorganic) that may potentially enter the groundwater as a result of the planned mining and/or related activities. In light of this investigation, as long as this substance does not adversely affect the environment and groundwater user, it is referred to as contamination. The opposite holds true for pollution, meaning that it refers to any and all substances that affect the groundwater quality to such an extent that it is harmful to both the environment and groundwater user and it becomes unsuitable to apply to its original use.

The main aim of the contaminant transport model was to simulate and predict the groundwater quality-related impacts resulting from the planned mining and related activities, i.e. simulation of contaminant/plume migration. **Please refer to the waste classification results and note that the plumes referred to below will be leachate that formed through inert quartzite material and though salinities may be slightly elevated, groundwater quality of the plume is still expected to remain within drinking water guidelines**. A summary of the model-simulated water quality impacts at **mine closure** is provided below:

- Plume migration simulated for Scenario 1 is somewhat faster than for Scenario 2, i.e. a larger area was simulated to be affected in Scenario 1.
- The deeper mining depth simulated for Scenario 2 resulted in the opencast pits acting as sinks for both groundwater and contamination, which restricted plume migration – more so than for Scenario 1. Groundwater levels around the pits would firstly need to recover from the impacts of pit dewatering before groundwater and contamination can eventually migrate away and into the down gradient groundwater flow direction.
- The contamination plumes for both Scenario 1 and Scenario 2 were simulated to migrate towards the north-west and at rates of ± 5 and 3 meters per year respectively.
- At mine closure, an area of approximately 338 900 m^2 was simulated to be affected by the Scenario 1 contamination plumes, while a slightly smaller affected area of ± 268 500 m^2 was simulated for Scenario 2.
- Outside of the MRA area, only user borehole 278RR was simulated to be affected during both mining scenarios. That being said, the abovementioned borehole is located

barely 25 meters east of the MRA area on Holding 278, and the plume concentration was simulated to be between 5 and 8% of the original source concentration.

Following the mine closure simulation, the contaminant transport model was run for an additional 50 years to simulate/predict the post closure migration of residual contamination. A summary of the **post closure** contaminant transport model simulations is provided below:

- At 50 years post closure the Scenario 1 contamination plumes were simulated to have increased to 486 300 m^2 in size, while an area of 410 500 m^2 was simulated to be affected by the Scenario 2 plumes.
- Note that no user boreholes located outside of the MRA area were simulated to be adversely affected.
- Plume concentrations were simulated to increase over time, however, natural occurring processes such as dilution and dispersion caused concentrations to only reach ± 80% after 50 years from a source concentration of 100%.

Conclusions – Decant Predictions:

Tailings material from the plant will be dumped into the North Block during the operational phase of mining. This fine material will effectively “plug” the mine void, allowing for very little water infiltration and no decanting is therefore envisaged. Mining and related infrastructure will be demolished during the decommissioning phase and the resulting building rubble is planned to be disposed of into the South Block and the remainder of the void filled with water. Evaporation far exceeds rainfall in the project area and with the South Block being located on top of a local topographic high (resulting in limited surface water runoff into the pit), no decanting is expected to occur.

Recommendations:

- Four boreholes were drilled specifically for source monitoring purposes within the MRA area. At least four of the nearest user boreholes should also be included in the groundwater monitoring program.
- Groundwater monitoring (i.e. sampling and water level measurements) should be conducted at quarterly intervals and the schedule re-assessed by a qualified geohydrologist at a later stage in terms of stability of water levels and quality. If the sampling program requires changes, it should be done so in consultation with the appropriate authorities.
- Groundwater samples should be analysed at a SANAS accredited laboratory for a wide range of chemical and physical parameters.

1 INTRODUCTION AND OBJECTIVE

Groundwater Complete was contracted by Jacana Environmentals to conduct a geohydrological study and report on findings as specialist input to the Environmental Impact Assessment (EIA) and Environmental Management Programme (EMPr) for the Rietkol Silica Project (hereinafter referred to as Rietkol).

The Rietkol MRA covers an area of 221 ha in the Victor Khanye Local Municipality, Mpumalanga Province, consisting of:

- 16 Modder East Agricultural Holdings on the farm Olifantsfontein 196 IR;
- Portion 71 of the farm Rietkol 237 IR; and
- A portion of Remaining Extent (RE) of portion 31 of the farm Rietkol 237 IR.

The MRA area is situated in a mixed land use area approximately 9 km north-west of the town of Delmas and 5 km north of the Eloff hamlet as indicated in the locality map provided in Figure 1-1.

Silica is targeted for mining by means of conventional opencast methods to depths of between 30 to 50 meters below surface (mbs). The planned opencast mining will result in two individual opencast pits (i.e. North Block and South Block) separated by a ± 30 meters wide pillar.

The estimated life of mine (LOM) for the proposed Rietkol Project is 20 years and will include the following mining and related infrastructure:

- Two opencast pits;
- Processing plant (i.e. crushing, washplant, screening, etc.);
- Product stockpiles;
- Administration office facilities (i.e. security building, administration and staff offices, reception area, ablution facilities, etc.);
- Production facilities (i.e. locker rooms, laboratory, workshops, stores, explosives magazine, ablution facilities, etc.);
- Access roads; and
- Storm water management infrastructure.

The main aim or objective of this study was to determine the impact of the proposed new mining and related processing activities on both groundwater quality (contamination migration) and quantity (availability).

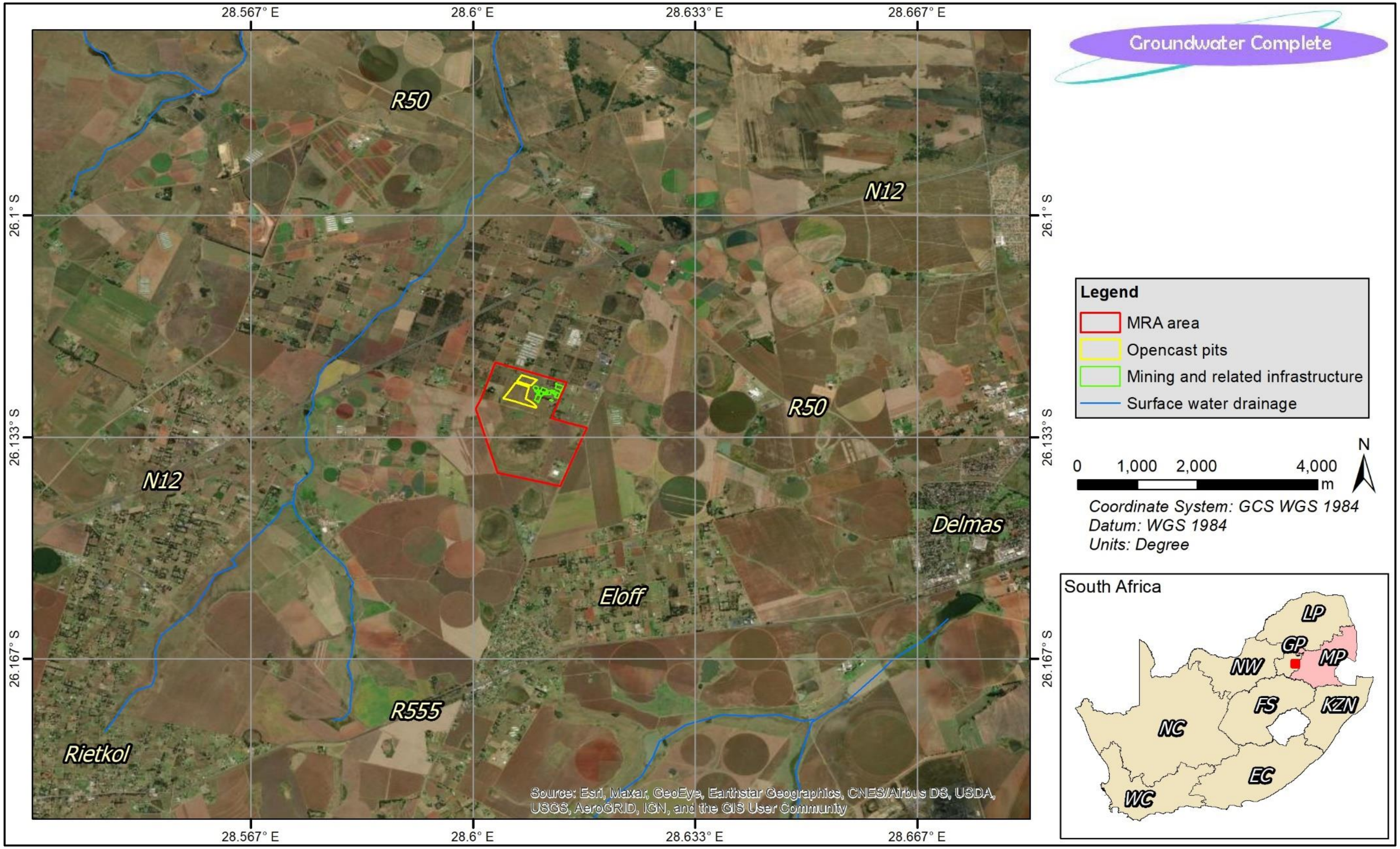


Figure 1-1: Locality map of the project area

2 GEOGRAPHICAL SETTING

2.1 SURFACE TOPOGRAPHY AND WATER COURSES

The topography of the project area can be described as being gently undulating with surface elevations (±4 km radius) varying from approximately 1 540 to 1 620 meters above mean sea level (mamsl). The highest surface elevations occur to the south and south-west and decrease towards the north/north-east in the flow direction of the Koffiespruit (Figure 2-1).

The project area is located within the B20B quaternary catchment, which covers an area of approximately 323 km^2. A prominent water course, namely the Koffiespruit, is located ± 2.5 kilometers west of the MRA area and within the same catchment. The Bronkhorstspruit is located approximately 9 kilometers east of the MRA area, but in the neighboring B20A catchment. Surface elevations and water courses for the project area are indicated in Figure 2-1.

Notes:

- *The Koffiespruit is regarded as a perennial river, however in its upper reaches and directly west of the MRA area this is not the case and it is therefore not believed to receive any significant baseflow.*
- *The Koffiespruit is therefore not considered to be an important receptor of any contamination that may potentially originate from the project area.*

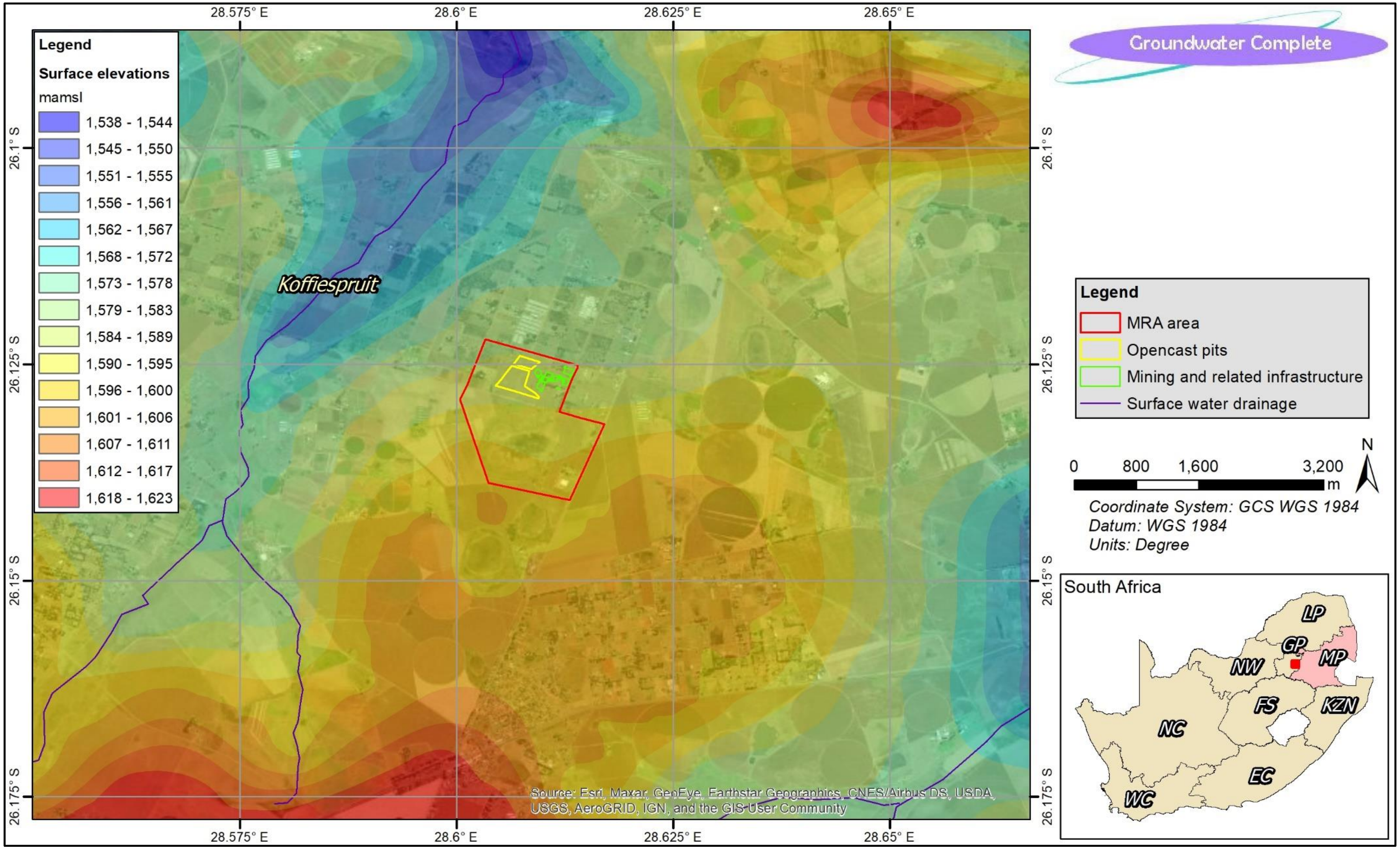


Figure 2-1: Surface elevations for project area (mamsl)

2.2 CLIMATIC CONDITIONS

Monthly rainfall and evaporation figures for the years 1967 to 2019 were obtained for the B2E001 meteorological station located approximately 28 kilometres north-east of the MRA area. The project area is located in a summer rainfall region and receives a mean annual rainfall of approximately 720 mm (Figure 2-2). The area is characterised by warm to hot summers and mild to cold winters with occasional frost.

The mean annual evaporation rate for the project area is nearly 1 530 mm, which far exceeds rainfall (Figure 2-3). The project area therefore has a net environmental moisture deficit when considering the annual rainfall and evaporation figures.

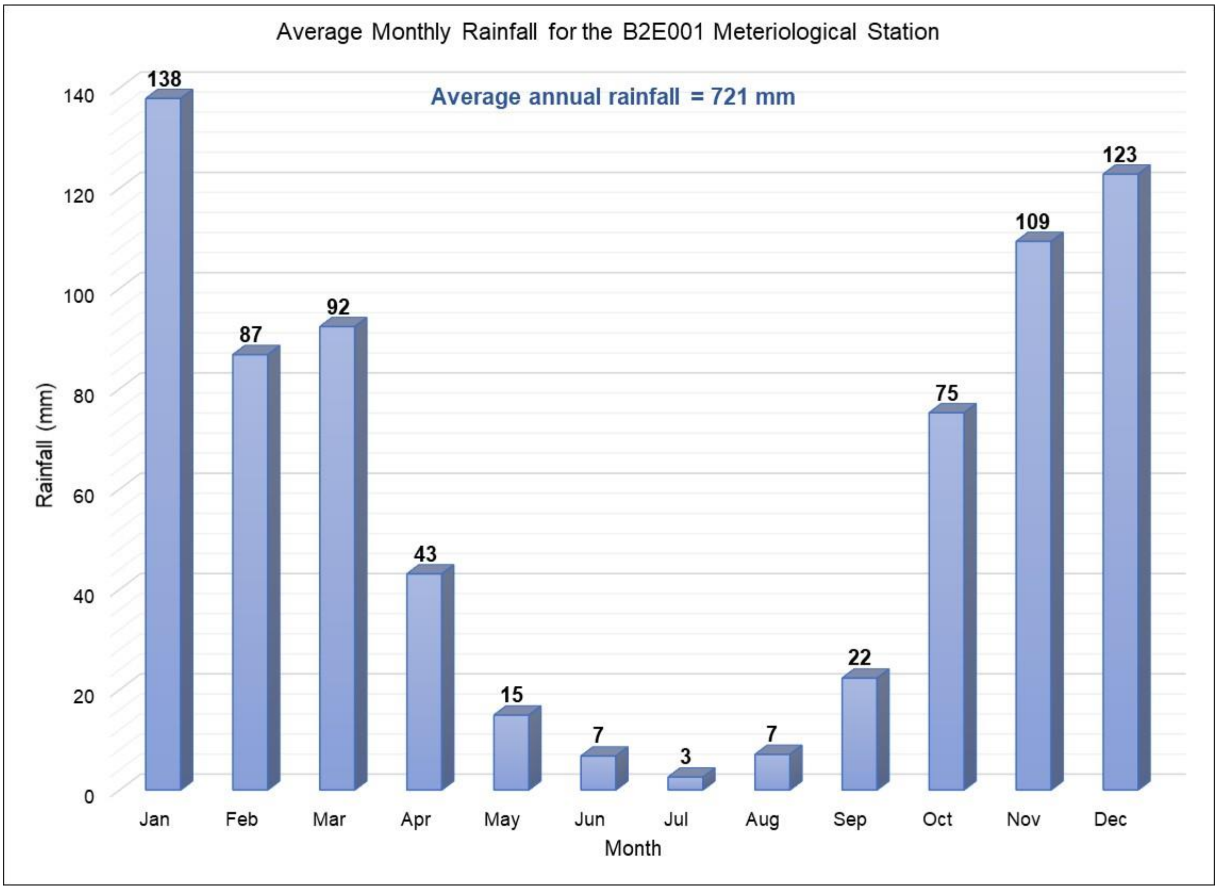


Figure 2-2: Mean monthly rainfall figure for meteorological station B2E001 *(DWS)*

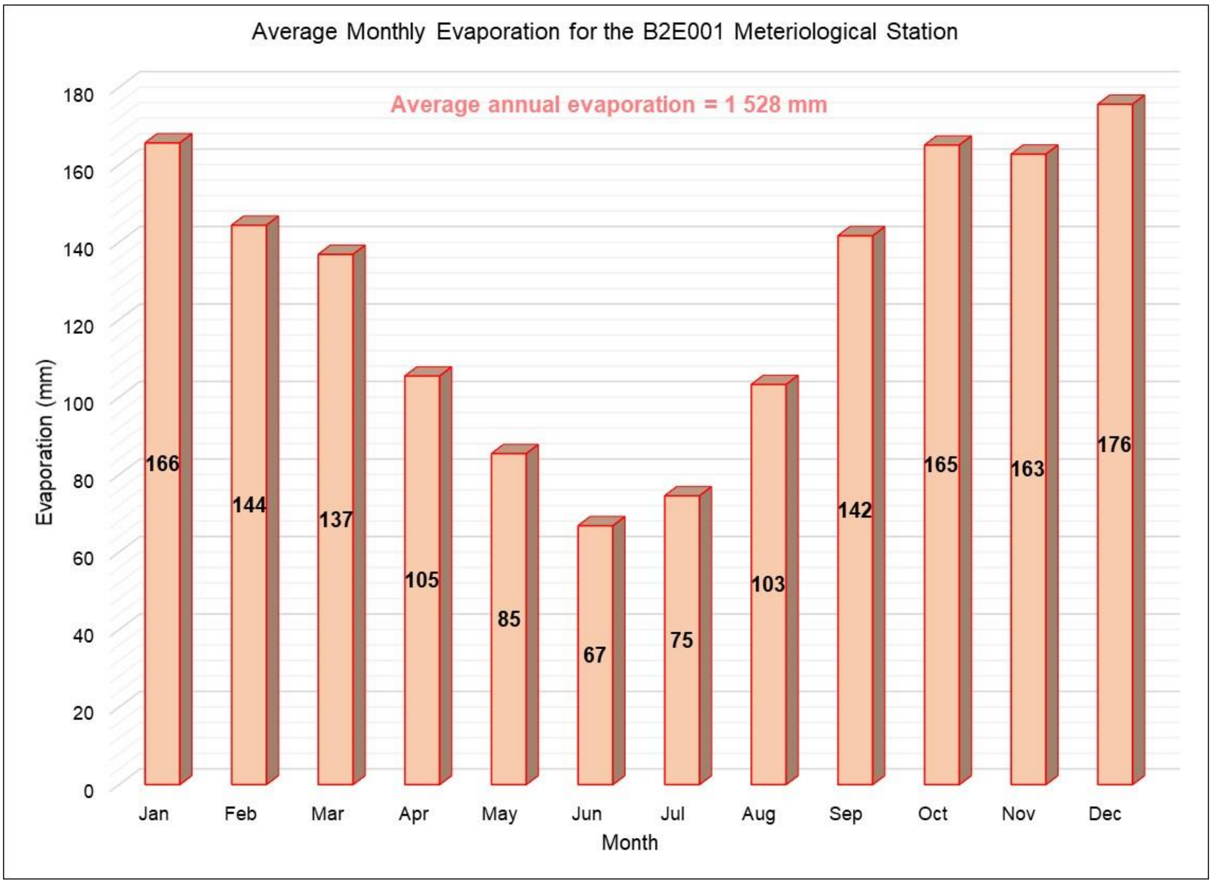


Figure 2-3: Mean monthly evaporation figures for meteorological station B2E001 *(DWS)*

3 SCOPE OF WORK AND REPORT STRUCTURE

The main objective of this study was to determine the potential impacts of the proposed mining and related activities on local groundwater quality conditions and water levels. In order to successfully achieve this objective, the following methodology was followed:

- Topographic maps were consulted and used in the general description of the surface topography and water courses located within the immediate vicinity of the project area *(Section 2.1)*.
- Climatic conditions were evaluated and discussed *(Section 2.2)*.
- All available groundwater and related studies and associated information were consulted and used accordingly throughout the investigation where applicable *(Section 4.1)*.
- Hydrocensus/groundwater user surveys were conducted by Aquatico Scientific on the MRA area and surrounding properties *(Section 4.2)*.
- A geophysical survey was conducted during which optimum drill positions were identified for several dedicated source monitoring localities/boreholes *(Section 4.3)*.
- A total of four boreholes were drilled for aquifer testing and groundwater monitoring purposes *(Section 4.4)*.

- Aquifer testing in the form of constant rate pumping tests were conducted on four monitoring boreholes situated within the MRA area and the results were applied in this investigation *(Section 4.5)*.
- The groundwater sampling protocol and chemical analysis of water samples were discussed *(Section 4.6).*
- Dedicated groundwater recharge studies were consulted in the assessment of the aquifer recharge rate, and the site-specific recharge was estimated using the Chloride Method *(Section 4.7)*.
- Numerical groundwater flow and contaminant transport models were constructed to simulate the potential groundwater quantity and quality impacts associated with the proposed new opencast mining and related activities *(Section 4.8)*.
- A groundwater availability assessment was conducted during which the model-simulated groundwater flow/discharge into the proposed opencast pits was compared with the General Authorised use and groundwater recharge over the MRA areas *(Section 4.9)*.
- Information interpreted from the 1:250 000 scale geological map of the project area and the Rietkol Mining Work Programme Report were used in the assessment and discussion of the underlying geology *(Section 5.1)*.
- A waste classification was conducted on tailings material and waste rock from the operational Thaba Chueu mine, and the results and consequent recommendations in terms of the requirements for a disposal facility/s at Rietkol are discussed *(Section 5.2)*.
- The geohydrology of the project area was assessed in terms of the unsaturated zone, saturated zone and aquifer hydraulic conductivity *(Section 5.3)*.
- Groundwater level measurements taken at hydrocensus/user boreholes and dedicated monitoring boreholes situated within the MRA area were used in the assessment of the groundwater level depths *(Section 5.4)*.
- Potential sources of groundwater contamination were identified and discussed in detail *(Section 5.5)*.
- Groundwater quality data obtained from user and monitoring boreholes was used in the assessment of the regional and site specific water quality conditions respectively *(Section 5.6)*.
- The *Groundwater Vulnerability Classification System* was used to determine the aquifer's vulnerability or susceptibility to groundwater contamination *(Section 6.1)*.
- Geological information combined with the drilling results of monitoring boreholes were used to identify and characterise the aquifers underlying the project area *(Section 6.2)*.
- The underlying aquifer was assessed in terms of the degree of protection it requires from contamination *(Section 6.3)*.
- With the numerical groundwater model only being a simplified representation of the very complex and highly heterogeneous aquifer system/s underlying the project area, certain model restrictions and limitations inevitably do exist and were discussed briefly *(Section 7.1)*.
- The choice of modelling software used to simulate the geohydrological environment was discussed in detail *(Section 7.2)*.

- Model dimensions, boundaries and aquifer parameters used in the construction and calibration of the model were discussed in detail *(Section 7.3)*.
- Groundwater elevations and gradients achieved through the steady state calibration of the numerical groundwater flow model were discussed in detail *(Section 7.4)*.
- The groundwater sources and sinks were assessed and simulated in the numerical groundwater model *(Section 7.5)*.
- All relevant information was used in the formulation of a sound conceptual model of the geohydrological environment, which was discussed in detail and illustrated by means of a vertical cross-section through the project area *(Section 7.6)*.
- The model simulations and results were discussed in detail and indicated with the use of contour maps *(Sections 7.7 to 7.9)*.
- The potential groundwater related impacts were rated, aided largely by the findings of the numerical groundwater flow and contaminant transport models *(Section 8)*.
- A groundwater monitoring plan/protocol was proposed and discussed *(Section 9)*.
- The groundwater environmental management program was discussed *(Section 10)*.
- Conclusions and recommendations resulting from the geohydrological investigation are clearly stated *(Section 11)*.

4 METHODOLOGY

4.1 DESK TOP STUDY

All available groundwater and related studies, topographical and geological maps as well as satellite images and associated information were assessed and used accordingly throughout the groundwater investigation where applicable. Groundwater information was also obtained from various open sources as well as dedicated information gathering.

The relevant sources of information are listed as references in Section 12 of this report.

4.2 RESULTS OF HYDROCENSUS/USER SURVEY

A hydrocensus/groundwater user survey was conducted in April 2016 by Aquatico Scientific within the mining right application area (MRA area) and the immediate surrounding properties. The main aims of the hydrocensus field survey were as follow:

- To locate all interested and affected persons (I&APs) with respect to groundwater – thus groundwater users;
- To collect all relevant information from the I&APs (i.e. name, telephone number, address, etc.);
- Accurately log representative boreholes on the I&APs properties; and
- To collect all relevant information regarding the logged boreholes (i.e. yield, age, depth, water level etc.) but especially the use of groundwater from the borehole.

The MRA area was however extended towards the south, which prompted an update and expansion of the hydrocensus. A follow-up hydrocensus was consequently conducted by Aquatico Scientific in January 2017, specifically focusing on the areas to the south of the new MRA area. Some landowners could not be reached for appointments and were consequently excluded from the 2016 and 2017 surveys. These affected properties were visited in March 2018 and a number of additional boreholes were located and added to the database. Summaries of the findings are provided in Figure 4-2 and Table 4-1, while the complete hydrocensus report is included in Appendix A of this report. A total of 86 boreholes, four dams and one cave were located, and their positions are indicated in Figure 4-1. Most of these boreholes were used for domestic purposes, livestock watering and irrigation at the time of the surveys (Figure 4-2).

An important feature from a groundwater perspective that occurs in the area is an underground cave that is partly filled with groundwater. The cave opening/entrance occurs on Holding 138 of Modder East Orchards approximately 2.5 km north of the MRA boundary.

Apart from its presence and its rest water level, we could obtain very little concrete information on the cave structure and dimensions. One geotechnical study conducted by *Louis Kruger Geotechnics CC* in April 2008 was obtained. A gravity survey was conducted as part of the investigation, but the dimensions of the cave could not be determined accurately. It is recommended in the report that the dimensions of the cave be surveyed. Verbal communication with Mr. J. Coombie on whose property the cave is situated yielded, the following:

- An investigation was done (source unknown) to determine the extent of the cave. The purpose of this investigation was to follow the geotechnical report *(Louis Kruger Geotechnics CC, 2008)* that was conducted as specialist input for rezoning purposes. The property has in fact been rezoned from agricultural to residential and is in the process of being sold.
- Divers from Benoni Dive Club use the cave for recreational and training purposes on a regular basis.
- Indications are that the opening (roof) above the water table extends at least 200 m eastwards from the cave mouth, but that the cave floor continuously dips deeper from the mouth. The total extent could not be determined accurately.

A borehole is drilled into the cave through its roof and it was used until a few years ago for irrigation purposes. The water level in the borehole was measured in 2017 at 23.5 meters below surface.

Notes:

- *The hydrocensus/user surveys were conducted during the summer rainfall season – a time when groundwater elevations are generally slightly higher. The effect of increased aquifer recharge during this time of the year is however overshadowed by the large-scale groundwater abstraction in the project area. The time of season is therefore not expected to have any significant effect on the outcome of the geohydrological investigation.*

- *The main finding of the hydrocensus/user survey is that groundwater is used extensively throughout the project area, especially for irrigation (dolomitic aquifer) and domestic purposes (66% of all boreholes).*
- *A total of eight user boreholes are located within the MRA area, six of which were in use at the time of the survey. Groundwater abstraction from these boreholes will in all probability cease in the event of the mining application being approved. This will help to ease the impact of pit dewatering (if necessary) and groundwater abstraction for dust suppression, potable water and process water.*
- *A cave also occurs in the dolomitic aquifer some 2.5 km north of the Rietkol Project. The cave is recognized as an important feature in terms of environmental sensitivity as well as for heritage purposes. Although information on the cave is limited, it will follow from this study that the risk of negative impact as a result of the proposed mining and related activities on the cave is considered to be very low to negligible due to:*
    - *The more than 2.6 km distance between the cave's position and proposed mining and related activities;*
    - *The pit floor not penetrating the underlying* dolomitic *aquifer; and*
    - *The limited impact that the mining will have on the groundwater quality and water level conditions.*

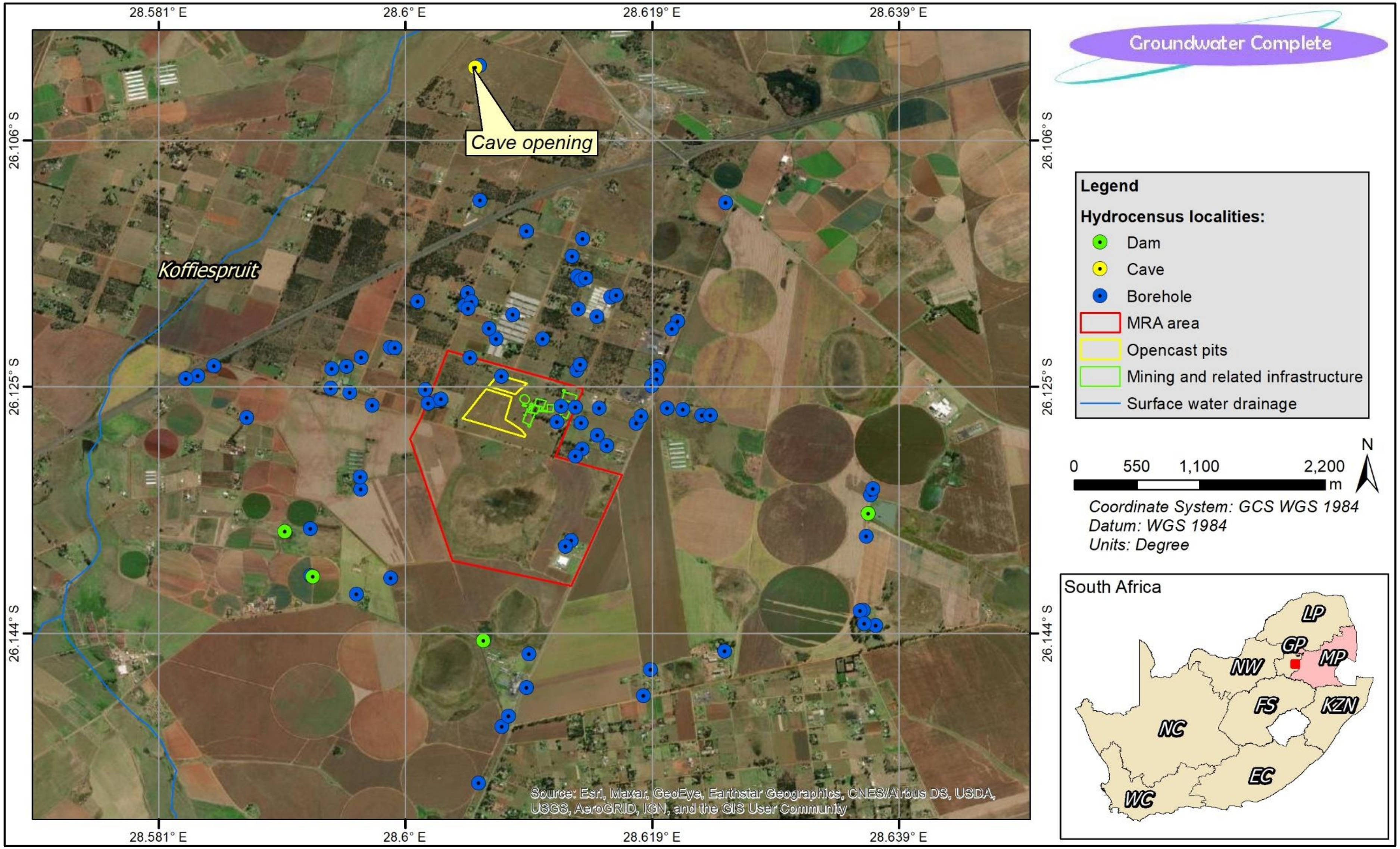


Figure 4-1: Positions of boreholes and surface water features recorded during the hydrocensus and user surveys

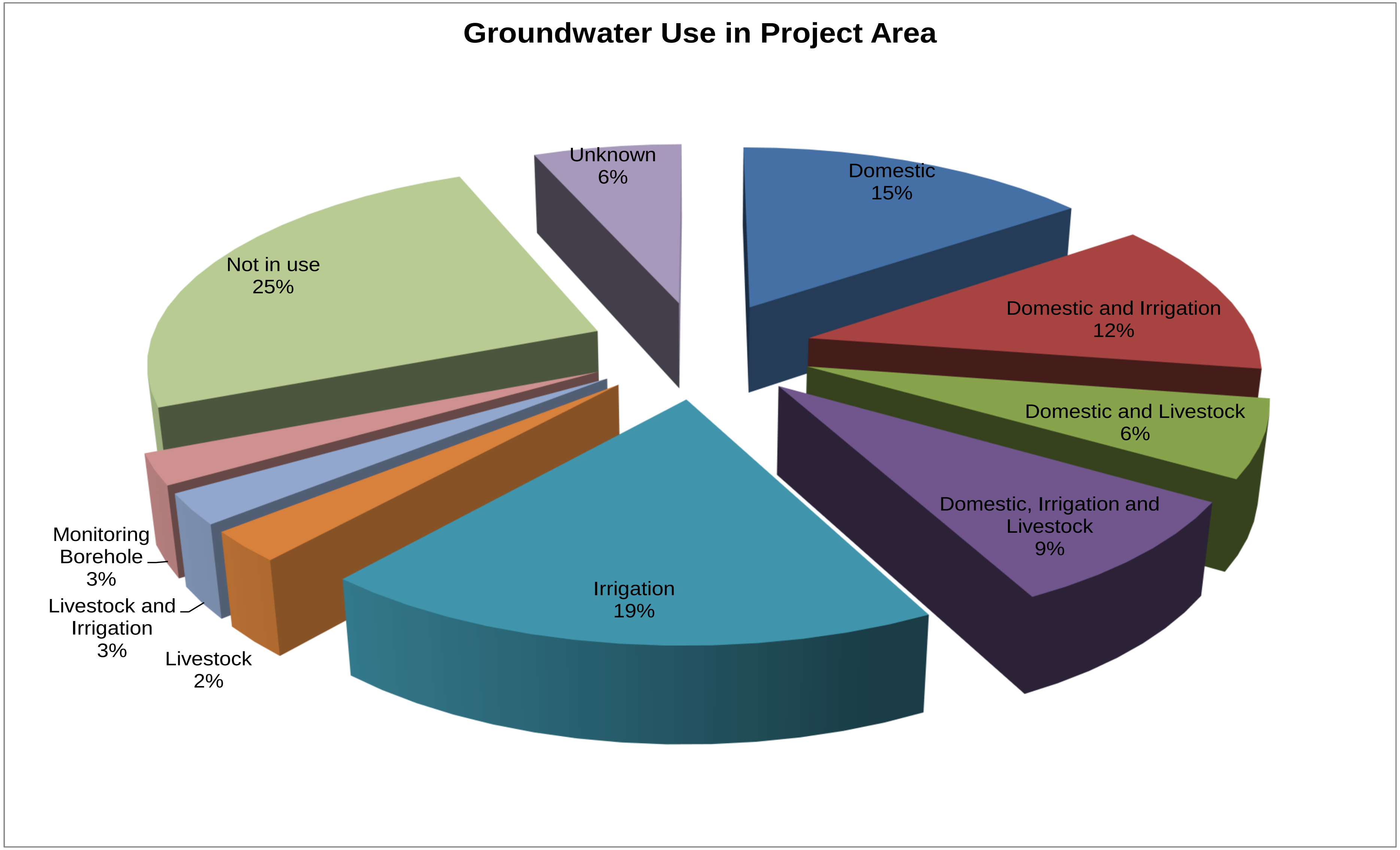


Figure 4-2: Proportional use of groundwater in the project area (% of all recorded boreholes)

Table 4-1: Summary results of hydrocensus/user surveys

Locality	Coordinates *(WGS 84)* South	Coordinates *(WGS 84)* East	Static WL (m)	Depth (m)	Sample	Use	Comments
143SM1	-26.1234	28.5954	-	20	Y	Domestic	Sample taken from storage tank, hole depth at 20.3 m (dry?) or blockage at 20.3 m
143SM2	-26.1236	28.5942	21.5	52	N	None	Hole not in use, not enough access space for bailer to take sample
143SM3	-26.1227	28.5966	-	-	N	Unknown	Old big borehole, can't open
144MBFI2	-26.1255	28.5956	-	70.0 Est.	Y	Irrigation	Borehole closed with concrete slab
144MBFI3	-26.1251	28.5941	-	70.0 Est.	Y	Domestic	Borehole closed with concrete slab
145MBFI1	-26.1265	28.5974	-	-	Y	Irrigation	Borehole closed with concrete slab
148PB1	-26.1253	28.6016	37.5	-	Y	None	Not in use
153MT01	-26.1220	28.5988	43.7	150	Y	Monitoring Borehole	None
153MT02	-26.1220	28.5992	-	-	Y	Domestic and Irrigation	Can't measure depth because of installed pump
158SK	-26.1176	28.6049	-	-	N	Domestic, Irrigation and Livestock	None
159AMB	-26.1186	28.6047	-	-	N	Not in use	No electricity or access (Not occupied)
160SK	-26.1183	28.6010	41.3	81.7	N	None	None
171HVR	-26.1103	28.6059	12	32	Y	Domestic, Irrigation and Livestock	None
199ID	-26.1128	28.6096	-	-	Y	Domestic	Can't measure depth because of installed pump
202Unex1	-26.1194	28.6085	-	-	Y	Irrigation of roses	None
202Unex2	-26.1213	28.6072	-		Y	Irrigation of roses	None
205MZ	-26.1183	28.6052	-	-	Y	Domestic	None
206JS	-26.1189	28.6050	-	83.0 Est.	Y	Irrigation	None
207NJ	-26.1204	28.6066	20.9	-	Y	Domestic, Irrigation and Livestock	None
208BM	-26.1228	28.6051	-	-	Y	Domestic	Can't measure depth because of installed pump
210HB	-26.1242	28.6076	-	80.0 Est.	N	Domestic, Irrigation and Livestock	None

Locality	Coordinates *(WGS 84)*		Static WL	Depth	Sample	Use	Comments
	South	East	(m)	(m)			
213JW1	-26.1261	28.6025	83.3	160.0 Est.	Y	Domestic, Irrigation and Livestock	None
213JW2	-26.1260	28.6028	-	87	N	None	Not in use
216ABM	-26.1263	28.6018	-	±200.0	N	Domestic	No electricity - Building house
219EW	-26.1278	28.6120	14.8	-	N	Domestic	None
222PK	-26.1266	28.6123	9.6	71	Y	Domestic and Livestock	None
226BKM	-26.1237	28.6135	-	-	Y	Domestic, Irrigation and Livestock	Can't measure depth because of installed pump
227JR	-26.1233	28.6138	-	-	N	None	Hole is covered by a bucket filled with concrete
229HDP	-26.1213	28.6109	-	115	Y	Domestic	None
234Geluk	-26.1267	28.6207	38.0 Est.	47.5 Est.	Y	Livestock (Chicken) and Irrigation	Depths estimated as depth meter did not register any depth/water. Installed pump provided challenges.
235LP1	-26.1189	28.6137	42.7 Est.	160.0 Est.	Y	Irrigation of roses	Depth meter got stuck at 26.8 m, WL estimated from other borehole depth. Sample is a composite sample with 235LP4
235LP2	-26.1195	28.6151	42.7	140.0 Est.	Y	Monitoring borehole	None
235LP3	-26.1180	28.6162	41.6	84	Y	Domestic	Water sample taken from tank
235LP4	-26.1178	28.6166	42	140.0 Est.	Y	Irrigation of roses	Sample is a composite sample with 235LP1
237JV1	-26.1163	28.6136	27.1	101.0 Est.	N	None	None
237JV2	-26.1166	28.6139	25.5	61	N	None	None
237JV3	-26.1165	28.6143	28.6	65	Y	Domestic	None
237LL1	-26.1234	28.5849	-	-	Y	Irrigation	Can't measure depth because of installed pump
237LL2	-26.1242	28.5837	-	-	N	Irrigation	Can't measure depth because of installed pump
237LL3	-26.1244	28.5827	-	-	N	Irrigation	Can't measure depth because of installed pump
237LL4	-26.1275	28.5875	-	-	N	Irrigation	Can't measure depth because of installed pump
237Vrede	-26.1331	28.5965	27.3	-	Y	Livestock (Chicken)	Can't measure depth because of installed pump
266IDW1	-26.1199	28.6215	-	57.0 Est	Y	Domestic and Irrigation	2 x Boreholes pumping to 1 tank (1 sample)
266IDW2	-26.1205	28.6210	-	90.0 Est.	Y	Domestic and Irrigation	2 x Boreholes pumping to 1 tank (1 sample)
271LFJ01	-26.1235	28.6200	-	-	Y	Domestic and Irrigation	Can't measure depth because of installed pump

Locality	Coordinates *(WGS 84)*		Static WL	Depth	Sample	Use	Comments
	South	East	(m)	(m)			
271LFJ02	-26.1237	28.6198	-	-	N	None	Not in use
272JR1	-26.1245	28.6198	-	65.0 Est.	Y	Domestic, Irrigation and Livestock	Can't measure depth because of installed pump
272JR2	-26.1250	28.6194	-	6	Y	None	Can't measure depth because of plate covering opening
276.1PF	-26.1279	28.6182	-	220 Est.	Y	Domestic	None
276.2PF	-26.1274	28.6186	20.2	75	Y	None	None
277KG	-26.1267	28.6153	-	-	Y	Domestic and Irrigation	Can't measure depth because of installed pump
278JDP02	-26.1289	28.6151	-	54	Y	Domestic and Livestock	Can't measure depth because of installed pump
278RR	-26.1267	28.6134	10.1	17	Y	None	Open borehole, rust coloured water
280EG	-26.1297	28.6159	-	43	Y	Domestic and Irrigation	None
281JDP01	-26.1279	28.6139	-	±180.0	Y	Domestic and Livestock	None
282.1RF	-26.1300	28.6140	46.8	150	Y	None	Planned future domestic use
282.2RF	-26.1305	28.6134	8.5	-	N	None	Caved in at 11.6 m
BBH01	-26.1105	28.6253	-	27	Y	Irrigation	Mud at 26.6 m (Dam sampled)
BBH02A	-26.1134	28.6140	-	50.0 Est.	Y	Domestic	None
BBH02B	-26.1147	28.6132	27.3	70.0 Est.	Y	Domestic and Irrigation	None
BH15.1	-26.1473	28.6193	-	-	N		Borehole
BH15.2	-26.1494	28.6188	50.0	-	Y	Domestic and livestock	Borehole
BH15.3	-26.1488	28.6096	15.9	-	Y	Not in use	Borehole
BH2.1	-26.1322	28.5965	22.1	-	Y	Livestock watering, Domestic	Borehole
BH24.03	-26.1273	28.6234	-	-	N	No - Borehole blocked	Borehole
BH24.11	-26.1336	28.6367	-	-	Y	Not in use	Borehole
BH24.12	-26.1331	28.6369	-	-	Y	Not in use	Borehole
BH24.13	-26.1459	28.6252	49.0	-	Y	Domestic	Borehole
BH24.2	-26.1269	28.6219	-	108.0	N	Domestic and irrigation	Borehole

Locality	Coordinates *(WGS 84)*		Static WL	Depth	Sample	Use	Comments
	South	East	(m)	(m)			
BH24.4	-26.1273	28.6240	52.3	-	N	Irrigation	Borehole
BH24.5	-26.1427	28.6361	74.5	95.0	Y	Irrigation, Domestic	Borehole
BH24.6	-26.1439	28.6371	92.0	-	Y	Not in use	Borehole
BH24.7	-26.1427	28.6358	83.3	202.0	Y	Not in use - New borehole	Borehole
BH24.8	-26.1437	28.6362	59.0	-	N	No - Borehole not in use	Borehole
BH24.9	-26.1368	28.6363	59.0	200.0	Y	Not in use	Borehole
BH31.1	-26.1563	28.6058	54.7	120.0	Y	Irrigation	Borehole
BH31.2	-26.1518	28.6076	48.3	68.0	Y	Irrigation	Borehole
BH31.3	-26.1510	28.6081	48.0	64.0	Y	Livestock watering	Borehole
BH63.1	-26.1362	28.5926	37.4	-	Y		Borehole
BH66.2	-26.1400	28.5926	92.4	-	N		Borehole
BH71.4	-26.1461	28.6098	-	-	Y	Domestic, Irrigation	Borehole
BH71.6	-26.1401	28.5989	36.6	-	Y	Not in use	Borehole
BH72.5	-26.1414	28.5962	100.0	160.0	Y	Irrigation, Livestock watering	Borehole
Cave	-26.0998	28.6055	23.5	N/A	Y	Recreational – cave diving	Cave
CaveBH	-26.0997	28.6059	23.5	-	N	Unknown	None
Dam237.1	-26.1451	28.6062	-	-	Y	Irrigation	Dam
Dam24.1	-26.1350	28.6365	-	-	Y	Irrigation	Dam
Dam63.2	-26.1365	28.5905	-	-	Y	Irrigation	Dam
Dam66.1	-26.1400	28.5927	-	-	Y	Irrigation	Dam
Res01	-26.1372	28.6131	8.9	-	Y	Not in use	Borehole
Res02	-26.1376	28.6126	-	-	Y	Irrigation, Livestock watering, Domestic	Borehole

Note: *WL = Water level.*

4.3 GEOPHYSICAL SURVEY AND RESULTS

A geophysical survey was conducted in April 2018 by *GeoRAY Geophysical Services* during which a combination of magnetic and electromagnetic methods was used to identify the optimum drill positions of dedicated boreholes for aquifer testing and later for ongoing source monitoring. Geological structures such as dykes/sills, faults and discontinuities in the underlying rocks are generally targeted when drilling for either water supply or source monitoring purposes as they are considered to act as preferred pathways for both groundwater flow and mass transport (contamination).

Three lines were traversed during which a total of seven anomalies were identified and their positions are indicated in Figure 4-3. The geophysical line survey graphs are provided in Appendix C, while a short summary of the geophysical investigation is provided in Table 4-2.

Table 4-2: Summary of geophysical survey

Line	Total length	Begin coordinate		End coordinate		Anomaly coordinate	
	(m)	South	East	South	East	South	East
1	270	-26.1280	28.6111	-26.1273	28.6086	1-1) -26.1277	28.6099
2	310	-26.1227	28.6098	-26.1253	28.6086	2-1) -26.1237 2-2) -26.1241 2-3) -26.1245	28.6093 28.6091 28.6090
3	200	-26.1270	28.6033	-26.1274	28.6053	3-1) -26.1271 3-2) -26.1273 3-3) -26.1273	28.6040 28.6047 28.6051

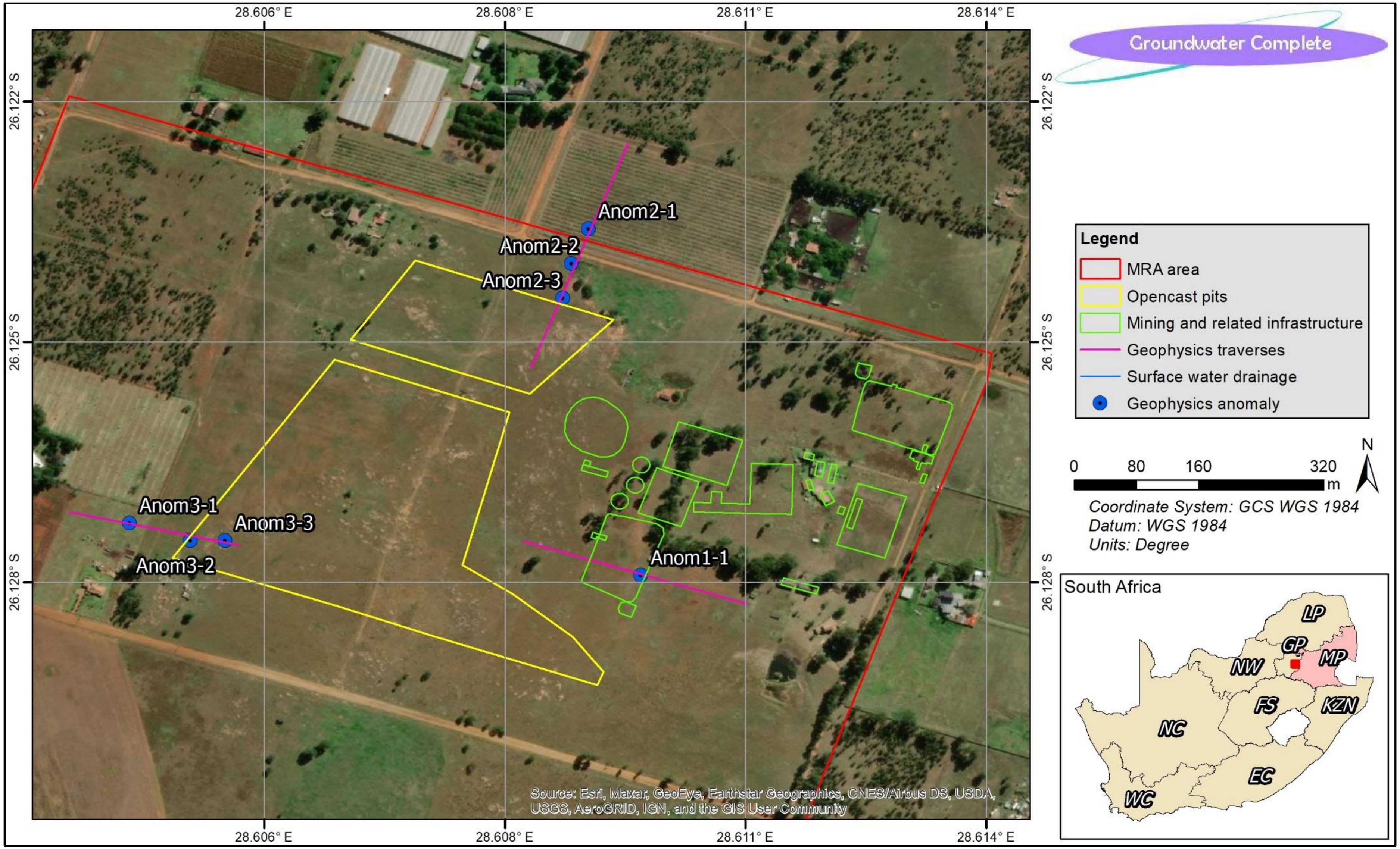


Figure 4-3: Positions of geophysical traverses and identified geological anomalies

4.4 SITING AND DRILLING OF BOREHOLES

Dedicated source monitoring boreholes were drilled at four (three shallow and one deep) of the seven locations identified by the geophysical survey (Figure 4-3) and their positions are indicated in Figure 9-1. The boreholes were drilled by a subcontractor *(Bennit Drilling)* in May 2018 and short descriptions of each are provided in the following paragraphs. Borehole logs are provided in Appendix D, while more information is included in Table 4-3.

RMBH01D:
Borehole RMBH01D was drilled to a maximum depth of 45 meters below surface (mbs). A water yielding fracture was intersected at a depth of 30 mbs with a blow yield of more or less 1 l/s. A steel casing was installed from surface to 36 mbs to ensure borehole stability as the lithology was soft and very clayey.

Soil covers the surface to a depth of 6 mbs, underlain by clay to more or less 13 mbs. Greyish white chert breccia was encountered between 13 and 45 mbs. A static water level of nearly 18 mbs was measured in May 2018.

RMBH02S:
Borehole RMBH02S was drilled to a maximum depth of 31 mbs and no significant water strike was encountered. A PVC casing was installed and perforated between 20 and 31 mbs to ensure that the borehole remains open and available for groundwater monitoring.

Soil covers the surface to a depth of 2 mbs and is underlain by light grey chert breccia from 2 to 31 mbs. A static water level of just over 24 mbs was measured in May 2018.

RMBH03S:
Borehole RMBH03S was drilled to a maximum depth of 31 mbs. No significant water strike was intersected, however, the lithology was slightly moist from 20 mbs onward. A PVC casing was installed and perforated between 20 and 31 mbs to ensure that the borehole remains open and available for groundwater monitoring.

Soil covers the surface to a depth of 2 mbs and is underlain by brownish clay from 2 to 31 mbs. A static water level of nearly 25 mbs was measured in May 2018.

RMBH04S:
Borehole RMBH04S was drilled to a maximum depth of 31 mbs. No significant water strike was intersected, however, the lithology was slightly moist from 20 to 31 mbs. A PVC casing was installed and perforated between 20 and 31 mbs to ensure that the borehole remains open and available for groundwater monitoring.

Metaquartzite was encountered from surface to nearly 3 mbs, followed by mudstone to a depth of 5 mbs. The mudstone is underlain by brownish clay between 5 and ± 24 mbs. Fresh dolerite was intersected from 24 to 31 meters below surface. A static water level of just over 18 mbs was measured in May 2018.

Table 4-3: Summary of new source monitoring boreholes

BH	Coordinates		Depth	Water strike	Construction	Water level	Lithology
	South	East					
RMBH01D	-26.1276	28.6098	45	1 l/s at 30 mbs	Steel to 36m (no perforation)	17.8	Soil, clay, chert
RMBH02S	-26.1273	28.6087	31	None	PVC to 31m (perforated from 20 to 31m)	24.1	Soil, chert
RMBH03S	-26.1244	28.6090	31	Moist from 20 mbs	PVC to 31m (perforated from 20 to 31m)	24.7	Soil, clay
RMBH04S	-26.1273	28.6047	31	Moist from 20 mbs	PVC to 31m (perforated from 20 to 31m)	18.3	Quartzite, mudstone, clay, dolerite

4.5 AQUIFER TESTING

An aquifer test (also referred to as a pumping or slug test) is conducted to determine aquifer parameters, especially transmissivity or hydraulic conductivity. Aquifer parameters play an important role in the conceptualisation of the project area (i.e. conceptual model), which ultimately forms the foundation of the numerical groundwater flow and contaminant transport models.

The test basically involves the abstraction of groundwater from a borehole by means of a pump (submersible or mono pump) at a known rate. Measurements of the decreasing water level within the borehole are taken at predetermined intervals, which are generally short at the start of the test and increase as the test progresses. After the test has been completed and the pump had been shut down, measurements are again taken of the water level as it starts to recover/rise in the borehole (i.e. recovery test). This water level vs. time data can then be analysed with analytical software developed specifically for pumping tests to determine aquifer parameters such as transmissivity/hydraulic conductivity and storage coefficient.

Constant rate pumping tests were conducted on four user boreholes and four purpose drilled monitoring boreholes and their positions are indicate on Figure 5-2. The test results are discussed in Section 5.3.3.

4.6 GROUNDWATER SAMPLING AND CHEMICAL ANALYSIS

All groundwater sampling was conducted by *Aquatico Scientific* and was done so based on the protocols and specifications, and code of practice contained in the SABS ISO 5667-1-15. These international standards address all aspects from the program design, sampling methods as well as sample preservation and many other aspects.
Sampling procedures are based on SABS standards namely:

- ISO 5667-1:1980 Part 1: Guidance on the design of sampling programs;
- ISO 5667-2: 1991 Part 2: Guidance on sampling techniques;
- ISO 5667-11: 1993 Part 11: Guidance on sampling of groundwater; and
- ISO 5667-3: 1994 Part 3: Guidance on preservation and handling of samples.

Aquatico Scientific maintains a state of the art and SANAS Accredited water laboratory in Pretoria *(Aquatico Laboratories, No T0685)* where the groundwater samples were also analysed for a wide range of chemical and physical indicator parameters. This analytical laboratory has been operational since July 2006 and takes part in the SABS Inter-laboratory Testing Scheme.

Groundwater samples were collected from surrounding user boreholes as well as dedicated source monitoring boreholes and were analysed for a wide range of chemical and physical parameters. The results of the analyses are discussed in detail in Section 5.6.

4.7 AQUIFER RECHARGE CALCULATIONS

Aquifer recharge figures for the project area were obtained from mainly two independent sources/studies and can be summarized as follows:

- An Explanation for a set of National Groundwater Maps, Vegter (1995) – 4.3%; and
- Groundwater Resource Assessment II, DWS (2005) – 6.7%.

Furthermore, recharge to the underlying aquifer was also estimated with the Chloride Method. The Chloride Method uses the chloride content of ambient/unaffected ground- and rainwater together with the mean annual rainfall to estimate the effective recharge. Groundwater chloride concentrations measured in 22 user boreholes and four dedicated source monitoring boreholes were used in the recharge estimations, while an average chloride concentration of 0.7 mg/l was used for the rainwater *(Van Wyk, 2010)*.

An average recharge figure of 13% was estimated (Table 4-4), which is typical of a dolomitic aquifer (Table 4-5). Recharge may even be higher in areas where the soil cover is thin and solution cavities better developed. In low-lying topographies, where discharge generally occurs and thicker sediment deposition, the effective recharge will be lower. This distribution of recharge based on the characteristics of the unsaturated zone explains the variance observed for the recharge figures estimated with the Chloride Method (Table 4-4).

Table 4-4: Aquifer recharge estimated with Chloride Method

BH	Average Cl in groundwater (mg/l)	Recharge (mm/a)	Recharge (%)
148PB1	14.9	34	4.7
153MT02	2.3	219	30.4
202Unex2	7.5	69	9.6
208BM	6.3	80	11.1
213JW1	1.8	280	38.9

BH	Average Cl in groundwater (mg/l)	Recharge (mm/a)	Recharge (%)
222PK	20.8	24	3.4
226BKM	7.7	66	9.1
229HDP	1.9	265	36.8
235LP3	4.2	120	16.7
276.1PF	5.4	94	13.0
276.2PF	6.4	78	10.9
277KG	9.2	55	7.6
278JDP02	13	39	5.4
282.1RF	85	6	0.8
BH15.2	3.9	129	17.9
BH2.1	7.4	68	9.5
BH24.13	10	50	7.0
BH24.5	10.1	50	6.9
BH63.1	20.6	24	3.4
BH71.4	9.1	55	7.7
BH72.5	14	36	5.0
Res02	17	30	4.1
RMBH01D	3.6	140	19.4
RMBH02S	13.5	37	5.2
RMBH03S	1.7	297	41.2
RMBH04S	5.4	94	13.0
Average =		**94**	**13.0**

Table 4-5: Typical recharge to different aquifer host rocks ***(Van Tonder & Xu, 2001)***

Geology	% Recharge (soil cover <5m)	% Recharge (soil cover >5 m)
Sandstone, mudstone, siltstone	5	2
Hard Rock (granite, gneiss etc.)	7	4
Dolomite	12	8
Calcrete	9	5
Alluvial sand	20	15
Coastal sand	30	20
Alluvium	12	8

On the quartzite reserve earmarked for mining at the Rietkol Project, the effective recharge is expected to be in the order of 3% of MAP.

4.8 GROUNDWATER MODELLING

Numerical groundwater flow and contaminant transport models were constructed to simulate the potential groundwater quantity and quality related impacts associated with the proposed new opencast mining and related activities. The conceptual model (as summarised in Section 7.6) formed the basis or foundation of the numerical models.

Model calibration was aided largely by groundwater level information obtained from user boreholes and dedicated source monitoring boreholes situated within the project area. Detailed discussions on the choice of modelling software, model setup, boundary conditions, etc. are provided in Section 7 of this report.

4.9 GROUNDWATER AVAILABILITY ASSESSMENT

A rapid reserve determination was conducted for the MRA area that falls within the B20B quaternary catchment and forms part of the Olifants Water Management Area (WMA). The General Authorised groundwater use for this catchment is 0 m^3/ha/year *(Government Gazette, No. 40243)*, which is the result of the underlying karst (dolomite) aquifer being under considerable stress from large scale groundwater abstraction for irrigation purposes and domestic use.

In a study conducted by Roger Parsons in 1994 for the Department of Water and Sanitation (DWS), “Groundwater Allocation” was defined as the rate at which groundwater can be withdrawn without resulting in a significant drop of regional groundwater levels in a catchment over the long-term, and without inducing a deterioration of groundwater quality or without causing any other detrimental impact on aquatic ecosystems *(Parsons, 1994)*.

The Department of Water and Sanitation (DWS) categorises the water use in three categories based on the amount of recharge that is used by the applicant in relation to the specified property:

- Category A: Small scale abstractions (<60% recharge on property);
- Category B: Medium scale abstractions (60-100% recharge on property); and
- Category C: Large scale abstractions (>100% recharge on property).

The maximum rate at which groundwater would need to be pumped from the proposed opencast pits to ensure dry and safe mining conditions was simulated/predicted with the numerical groundwater flow model to be approximately 90 m^3/d or 240 m^3/d – depending on the final depth of the pit. Based on the above DWS classification, this water abstraction can be classified as **Category A** or **small scale**.

Table 4-6: Most salient parameters relevant to the mining rights areas

Description	*Unit*	Value	Comment
Catchment Area	km^2	321	B20B
MRA area	km^2	2.2	None
General Authorised Use (GA)	m^3/ha/a	0	Sourced from, “*Government Gazette, No. 40243”*
General Authorised Use	m^3/a	0	Highly stressed aquifer

Description	***Unit***	**Value**	**Comment**
Mean Annual Rainfall	*mm/a*	720	Figure 2-2
Effective Annual Recharge	*mm/a*	94	Table 4-4
Annual Recharge Volume	m^3/a	207 720	Recharge over MRA area
Groundwater use	m^3/a	87 600	Maximum model-simulated groundwater inflow at 50m pit depth
Groundwater use as % GA	*%*	N/A	Zero is permitted under GA
Groundwater use as % recharge	*%*	42	Limited percentage of aquifer recharge

5 PREVAILING GROUNDWATER CONDITIONS

5.1 GEOLOGY

All geological information provided in this document was interpreted from the 1:250 000 scale geological map of the project area provided in Figure 5-1 and obtained from the Rietkol Mining Work Programme Report of 2019.

5.1.1 SITE SPECIFIC GEOLOGY – RESULTS OF EXPLORATION DRILLING

The Delmas silica deposit is referred to as a mega-sinkhole filled with beach sand during the Pretoria Group transgression. The deposit forms a kidney-shape of pure quartzite overlying agrillitic rock and chert breccia. The latter represents residual material left after dissolution of siliceous dolostone from the Malmani Subgroup of the Transvaal Supergroup during the pre-Pretoria Group karst event. The residual material and the quartzite are interpreted as the filling of a mega-sinkhole. From the sedimentological and structural relations between the residual material and the quartzite, it is suggested that the latter could be correlated with the basal, transgressive marine beds of the Pretoria Group. It is proposed that during this transgression, due to progressive subsidence, the mega-sinkhole was filled with pure arenitic quartz beach sand that had been washed and sorted by tidal action. The sand was later transformed into quartzite by low-grade metamorphism.

A flat dipping dolerite sill of approximately 30 m thick cuts through the deposit and divides it into an Upper and a Lower Quartzite band. Due to the thickness of the sill, mining will not cut through the sill and only the Upper Quartzite band will be mined to a depth of approximately 30 to 50 meters.

5.1.2 LOCAL GEOLOGY

Stratigraphically, the project area occurs on the boundary between the Malmani Subgroup and the Pretoria Group of the Transvaal Supergroup *(SACS, 1980)*. The Malmani Subgroup consists of several hundred meters of cherty, stromatolitic dolostone of about 2.6 billion years old that was deposited on an intra-cratonic marine basin under tidal conditions *(Button, 1986)*.

The Malmani Subgroup is unconformably overlain by a layer, informally known as the Giant Chert, of cryptically brecciated chert, grading into typical breccia, which is set in a black, silicified mudstone matrix. Its thickness varies along the strike from 0 to 20 m. The Giant Chert forms the base of the Pretoria Group and represents a palaeosol formed as a result of dissolution of the carbonate fraction of siliceous dolostone during a period of emersion and denudation. The cryptically brecciated chert formed as a result of small mechanical disturbances and where soil and alluvial movements were active; more typical breccia in silicified mudstone resulted. Sinkholes and cave systems, filled with residual material, which formed during this long period of denudation, have been described in detail outside the project area *(Martini, 1981)*.

The Bevets Conglomorate Member directly overlies the Giant Chert and consists of irregularly rounded chert pebbles, grading upward into pure quartzite. Both the Giant Chert and the Bevets Member form the Rooihoogte Formation. Conglomerate and quartzite are impersistent along the strike and are not more than a few meters thick. This stratigraphic unit marks the appearance of allochthonous terrigenous material, such as quartz, although variable amounts of autochthonous chert and clay are admixed in places. The Bevet's Member marks the transgression of a coast line *(Button, 1973: 1986)* and was followed by the deposition of shale, minor quartzite and ironstone of the Timeball Hill Formation.

The Bevets conglomerate and quartzite as well as the Timeball Hill formation are generally accepted as marine sediments *(Button, 1986)*. Nevertheless, a latchstring environment was recently proposed as an alternative, but without excluding the possibility of a marine environment *(Schreiber et al., 1991)*. Its age is not accurately established, but is probably 2.3 - 2.2 billion years old *(Burger &Coetzee, 1914)*. The Malmani Subgroup and the Pretoria Groups are disconformably overlain by late Carboniferous – Permian diamictite, shale and sandstone of the Karoo Supergroup. The Proterozoic and Permian strata are intruded by several generations of diabase and dolerite sills and dykes.

The Malmani Subgroup and the Pretoria Group underwent a mild static metamorphism, probably within the greenschist facies, which undurated the argillaceous rocks into slate and recrystallized the sandstone into quartzite. The Karoo strata are un-metamorphosed.

Notes:

- *The opencast mining of the silica rich quartzite will not cut into the underlying dolomitic aquifer, which will be separated from the overlying pits by a dolerite sill of approximately 30 meters thick and many more meters of quartzite (i.e. Lower Quartzite band).*
- *Dolerite dykes and sills, such as the one that cuts the Rietkol quartzite deposit into an Upper and a Lower Quartzite band, have the potential to yield significant volumes of groundwater. Over and above the groundwater influx from the saturated aquifer host rock/s (fractured quartzite) that cannot be prevented, the risk of additional (and potentially high) groundwater influx from the abovementioned sill is high should mining cut into or through the structure (where below the groundwater level).*

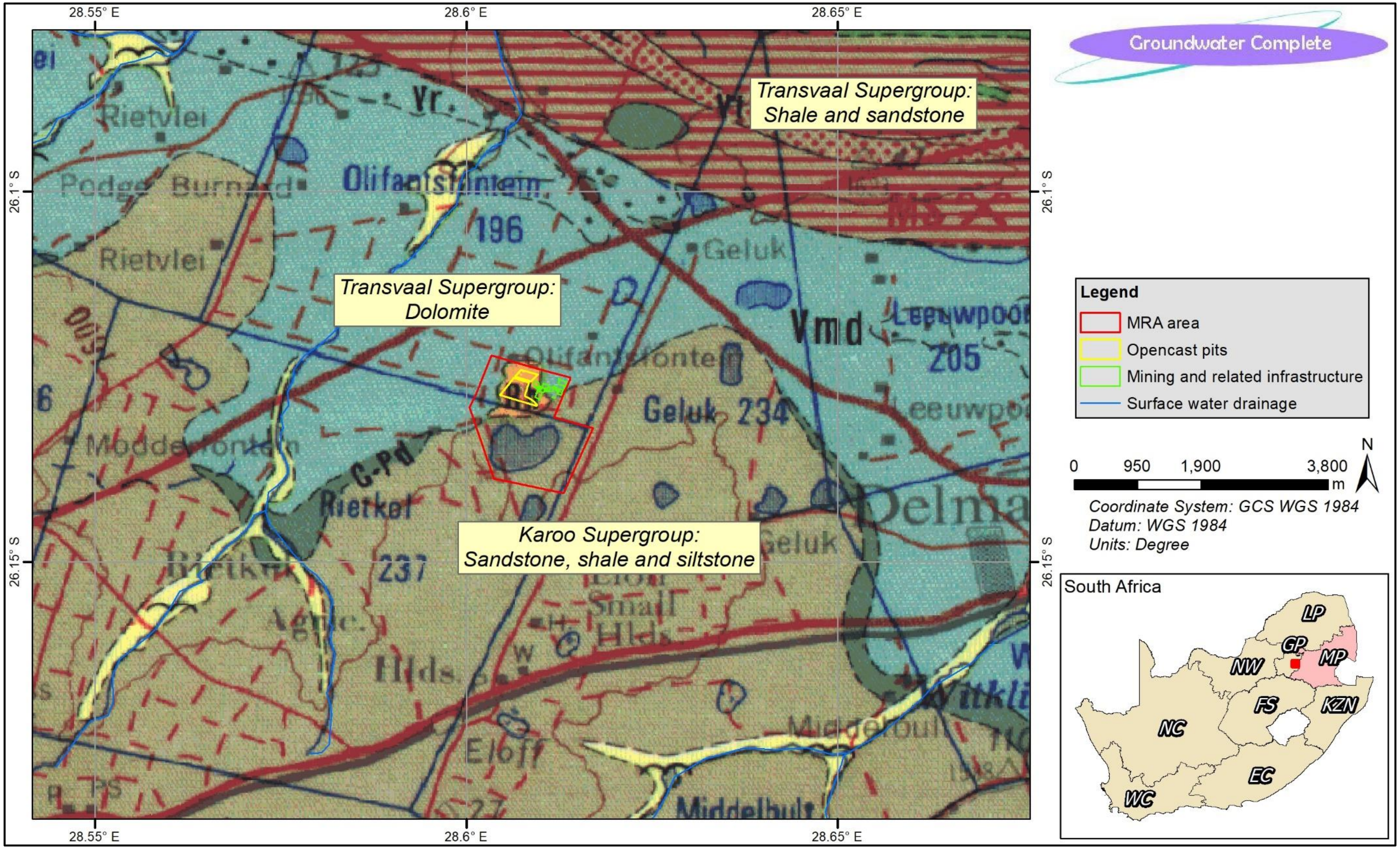


Figure 5-1: Geological map of the project area (1:250 000)

5.2 ACID GENERATING POTENTIAL AND WASTE CLASSIFICATION

5.2.1 ACID BASE ACCOUNTING

Exploration drilling in the project area found that the Rietkol quartzite deposit is exceptionally pure (Rietkol Mining Work Programme Report, 2019). No ABA was therefore deemed necessary for this investigation as the targeted quartzite is predominantly composed of inert silica (i.e. amount of metal sulphide minerals is negligible, if any).

5.2.2 WASTE CLASSIFICATION

Due to the pure quartzite nature of the Rietkol deposit, leachate from the pit itself, waste rock dumps, stockpiles and tailings is expected to be of acceptable quality. Leachates may, however, contain elevated nitrate concentrations as a result of remnants of nitrate-based explosives.

A groundwater study was conducted by WSM Leshika Consulting in 2015 for Silica Quartz located approximately 20 kilometers north-east of the Rietkol MRA area. For the purpose of the investigation a sample was collected of leachate originating from the tailings dam. This water sample was analysed for a wide range of chemical and physical parameters by a SANAS accredited laboratory. The analysis revealed that the leachate is in fact of relatively good quality and also suitable for human consumption with regards to the South African National Standards for drinking water *(SANS 241:2015)*. The iron content was however slightly elevated at nearly 1.8 mg/l, which is still below the maximum permissible SANS concentration of 2 mg/l. The Rietkol quartzite deposit has lower iron content than Silica Quartz and any potential leachate originating from the proposed mining and related activities is expected to be of acceptable quality.

A waste classification was conducted in April of 2021 by Aquatico Scientific and the aim was to chemically characterise the waste material that will be generated and stockpiled during the operational phase of the project. Mining is yet to commence, meaning that no silica ore or waste material was available for sampling and testing purposes. Two composite samples (i.e. tailings material and waste rock) were consequently collected from the operational Thaba Chueu mine (previously known as SamQuarz) situated approximately 17 kilometers east/north-east of the Rietkol MRA area. The ore deposit currently being mined at Thaba Chueu is chemically very similar to the Rietkol deposit, meaning that the results of the waste classification would be applicable to Rietkol.

Two types of tests or analyses were conducted, namely total concentration (TC) and leachable concentration (LC). A total concentration analysis, as the name suggests, determines the total inorganic composition of the sample. This is done by dissolving the sample in a strong acid (nitric acid-hydrochloric acid digestion) and then analysing the solution (ICP analysis). For the leachable concentration analysis, the sample is merely leached with distilled water and the resulting leachate analysed. The distilled water leach simulates the expected leachate quality when rain water infiltrates through the material under natural conditions.

The results of both the total concentration and leachable concentration analyses are compared with guideline limits developed specifically for the classification of the type of waste material. The type of waste, based on the leachable concentration and total concentration, is determined as follows:

- Waste with any element or chemical parameter concentration above the LCT3 or TCT2 (LC > LCT3 or TC > TCT2) limits are classified as **Type 0** Waste, i.e. **very high risk waste**.
- Waste with any element or chemical parameter concentration above the LCT2 but below or equal to the LTC3 limits, or above the TCT1 but below or equal to the TCT2 limits (LCT2 < LC <= LCT3 or TCT1 < TC <= TCT2) are classified as **Type 1** Waste, i.e. **high risk waste**.
- Waste with any element or chemical parameter concentration above the LCT1 but below or equal to the LTC2 limits **and** all concentrations below or equal to the TCT1 (LCT1 < LC <= LCT2 and TC <= TCT1) are classified as **Type 2** Waste, i.e. **moderate risk waste**.
- Waste with any element or chemical parameter concentration above the LCT0 but below or equal to the LTC1 limits **and** all TC concentrations below or equal to the TCT1 (LCT0 < LC <= LCT1 and TC <= TCT1) are classified as **Type 3** Waste, i.e. **low risk waste**.
- Waste with element and chemical parameter concentrations for metal ions and inorganic anions below or equal to the LCT0 and TCT0 limits (LC <= LCT0 and TC <= TCT0) and with all chemical substance concentration level also below the total concentration limits for organics and pesticides are **Type 4** Waste, i.e. **inert waste**.

The results of the total concentration and leachable concentration analyses are provided in Table 5-2 to Table 5-5, which show no exceedances of the TCT0 and LCT0 guideline limits. **According to the waste classification described above, both the tailings material and waste rock can be regarded as a Type 4 or inert waste.**

The requirements of a waste disposal facility (e.g. tailings storage facility, waste rock dump, etc.) are determined by the degree of risk posed by the material that requires disposal. The requirements as stated in the National Norms and Standards for Disposal of Waste to Landfill *(GN R. 636)*, based on the type of waste, are summarised in Table 5-1. **It is concluded that a Class D (or GSB-) disposal facility would suffice for both the tailings material and waste rock.**

The uranium and thorium concentrations (both leachable and total) are not considered during the waste classification process. These two radioactive elements, when present at high enough concentrations, do however pose a serious threat to public health. For this reason, the uranium and thorium content of both the waste rock and tailings samples were also determined, and the results are provided in Table 5-2 to Table 5-5. Both samples contain very low concentrations of the two elements and pose no real threat to human health in terms of harmful radiation. A dedicated radiological assessment of the waste material is therefore not required.

Table 5-1: Requirements of disposal facility based on type of waste

Waste Type	Disposal Facility Requirements
Type 0	Disposal is not allowed. The waste must be treated first and then re-assessed to determine Waste Risk Profile for disposal.
Type 1	Disposal only allowed at a Class A facility in terms of these draft regulations, or at a HH/Hh facility as specified in the Minimum Requirements Waste Disposal by Landfill (2nd Ed., DWAF, 1998).
Type 2	Disposal only allowed at a Class B facility in terms of these draft regulations, or a GLB+ facility as specified in the Minimum Requirements Waste Disposal by Landfill (2nd Ed., DWAF, 1998).
Type 3	Disposal only allowed at a Class C facility in terms of these draft regulations, or a GLB+ facility as specified in the Minimum Requirements Waste Disposal by Landfill (2nd Ed., DWAF, 1998).
Type 4	Disposal allowed at a Class D facility in terms of these draft regulations, or a GSB- facility as specified in the Minimum Requirements Waste Disposal by Landfill (2nd Ed., DWAF, 1998).

Table 5-2: Results of total concentration (TC) analyses – waste rock sample

Total Concentration - Acid Digestion					
Variable	Guideline Limits (mg/kg)			Variable Concentration (mg/l)	Variable Concentration (mg/kg)
	TCT0	TCT1	TCT2		
Paste pH (1:2) (pH Units)	-	-	-	-	7.47
Total Cyanide as CN	14	10500	42000	<0.100	<9.17
Redox	-	-	-	-	237
Arsenic as As	5.8	500	2000	<0.058	<5.32
Boron as B	150	15000	60000	<1.50	<138
Barium as Ba	62.5	6250	25000	<0.625	<57.3
Cadmium as Cd	7.5	260	1040	<0.075	<6.88
Cobalt as Co	50	5000	20000	<0.500	<45.9
Chromium as Cr	46000	800000	-	<10.0	<917
Copper as Cu	16	19500	78000	<0.160	<14.7
Mercury as Hg	0.93	160	640	<0.009	<0.826
Manganese as Mn	1000	25000	100000	<10.0	<917
Molybdenum as Mo	40	1000	4000	<0.100	<9.17
Nickel as Ni	91	10600	42400	<0.500	<45.9
Lead as Pb	20	1900	7600	<0.200	<18.3
Antimony as Sb	10	75	300	<0.100	<9.17
Selenium as Se	10	50	200	<0.100	<9.17
Vanadium as V	150	2680	10720	<1.00	<91.7
Zinc as Zn	240	160000	640000	<2.20	<202
Moisture %	-	-	-	-	0

Total Concentration - Acid Digestion					
Variable	Guideline Limits (mg/kg)			Variable Concentration (mg/l)	Variable Concentration (mg/kg)
	TCT0	TCT1	TCT2		
Solid %	-	-	-	-	100
Thorium as Th	-	-	-	0.001	-
Uranium as U	-	-	-	0.001	-

Table 5-3: Results of leachable concentration (LC) analyses – waste rock sample

Leachable Concentration - Distilled Water					
Variable	Guideline Limits (mg/l)				Variable Concentration (mg/l)
	LCT0	LCT1	LCT2	LCT3	
Arsenic as As	0.01	0.5	1	4	<0.010
Boron as B	0.5	25	50	200	<0.500
Barium as Ba	0.7	35	70	280	<0.700
Cadmium as Cd	0.003	0.15	0.3	1.2	<0.003
Cobalt as Co	0.5	25	50	200	<0.400
Chromium as Cr	0.1	5	10	40	<0.100
Hexavalent chromium (Cr^{6+})	0.05	2.5	5	20	<0.020
Copper as Cu	2	100	200	800	<1.00
Mercury as Hg	0.006	0.3	0.6	2.4	<0.006
Manganese as Mn	0.5	25	50	200	<0.500
Molybdenum as Mo	0.07	3.5	7	28	<0.070
Nickel as Ni	0.07	3.5	7	28	<0.070
Lead as Pb	0.01	0.5	1	4	<0.010
Antimony as Sb	0.02	1	2	8	<0.020
Selenium as Se	0.01	0.5	1	4	<0.010
Vanadium as V	0.2	10	20	80	<0.200
Zinc as Zn	5	250	500	2000	<2.00
Total Dissolved solids @ 180°C	1000	12500	25000	100000	<100
Chloride as Cl	300	15000	30000	120000	<50.0
Sulphate (SO_4)	250	12500	25000	100000	<50.0
Nitrate (NO_3) as N	11	550	1100	4400	<10.0
Fluoride as F	1.5	75	150	600	<1.00
Total Cyanide as CN	0.07	3.5	7	28	<0.05
pH @ 25°C	-	-	-	-	7.19
Thorium as Th	-	-	-	-	<0.001
Uranium as U	-	-	-	-	<0.001

Table 5-4: Results of total concentration (TC) analyses – tailings sample

Total Concentration - Acid Digestion					
Variable	Guideline Limits (mg/kg)			Variable Concentration (mg/l)	Variable Concentration (mg/kg)
	TCT0	TCT1	TCT2		
Paste pH (1:2) (pH Units)	-	-	-	-	7.92
Total Cyanide as CN	14	10500	42000	<0.100	<10.10
Redox	-	-	-	-	225
Arsenic as As	5.8	500	2000	<0.058	<5.86
Boron as B	150	15000	60000	<1.50	<152
Barium as Ba	62.5	6250	25000	<0.625	<63.1
Cadmium as Cd	7.5	260	1040	<0.075	<7.58
Cobalt as Co	50	5000	20000	<0.500	<50.5
Chromium as Cr	46000	800000	-	<10.0	<1010
Copper as Cu	16	19500	78000	<0.160	<16.2
Mercury as Hg	0.93	160	640	<0.009	<0.909
Manganese as Mn	1000	25000	100000	<10.0	<1010
Molybdenum as Mo	40	1000	4000	<0.100	<10.1
Nickel as Ni	91	10600	42400	<0.500	<50.5
Lead as Pb	20	1900	7600	<0.200	<20.2
Antimony as Sb	10	75	300	<0.100	<10.1
Selenium as Se	10	50	200	<0.100	<10.1
Vanadium as V	150	2680	10720	<1.00	<101
Zinc as Zn	240	160000	640000	<2.20	<222
Moisture %	-	-	-	-	20.1
Solid %	-	-	-	-	79.9
Thorium as Th	-	-	-	0.010	-
Uranium as U	-	-	-	0.004	-

Table 5-5: Results of leachable concentration (LC) analyses – tailings sample

Leachable Concentrations - Distilled Water					
Variable	Guideline Limits (mg/l)				Variable Concentration (mg/l)
	LCT0	LCT1	LCT2	LCT3	
Arsenic as As	0.01	0.5	1	4	<0.010
Boron as B	0.5	25	50	200	<0.500
Barium as Ba	0.7	35	70	280	<0.700
Cadmium as Cd	0.003	0.15	0.3	1.2	<0.003
Cobalt as Co	0.5	25	50	200	<0.400
Chromium as Cr	0.1	5	10	40	<0.100
Hexavalent chromium (Cr^{6+})	0.05	2.5	5	20	<0.020
Copper as Cu	2	100	200	800	<1.00
Mercury as Hg	0.006	0.3	0.6	2.4	<0.006

Leachable Concentrations - Distilled Water					
Variable	**Guideline Limits (mg/l)**				**Variable Concentration (mg/l)**
	LCT0	**LCT1**	**LCT2**	**LCT3**	
Manganese as Mn	0.5	25	50	200	<0.500
Molybdenum as Mo	0.07	3.5	7	28	<0.070
Nickel as Ni	0.07	3.5	7	28	<0.070
Lead as Pb	0.01	0.5	1	4	<0.010
Antimony as Sb	0.02	1	2	8	<0.020
Selenium as Se	0.01	0.5	1	4	<0.010
Vanadium as V	0.2	10	20	80	<0.200
Zinc as Zn	5	250	500	2000	<2.00
Total Dissolved solids @ 180°C	1000	12500	25000	100000	<100
Chloride as Cl	300	15000	30000	120000	<50.0
Sulphate (SO_4)	250	12500	25000	100000	<50.0
Nitrate (NO_3) as N	11	550	1100	4400	<10.0
Fluoride as F	1.5	75	150	600	<1.00
Total Cyanide as CN	0.07	3.5	7	28	<0.05
pH @ 25°C	-	-	-	-	9.28
Thorium as Th	-	-	-	-	0.001
Uranium as U	-	-	-	-	<0.001

Notes:

- *According to the waste classification described above, both the tailings material and waste rock can be regarded as a Type 4 or inert waste.*
- *It is concluded that a Class D (or GSB-) disposal facility would suffice for both the tailings material and waste rock.*

5.3 GEOHYDROLOGY

5.3.1 UNSATURATED ZONE

The unsaturated zone refers to the portion of the geological/soil profile that is located above the static groundwater elevation or water table. Based on information gathered during the drilling of four monitoring boreholes, the unsaturated zone is predominantly composed of soil/clay and weathered bedrock (mostly chert and quartzite).

The unsaturated zone affects both the quality and quantity of the underlying groundwater. The type of material forming the unsaturated zone as well as the permeability and texture thereof will significantly influence aquifer recharge as well as the transport of surface contamination to the underlying aquifer/s. Factors like ion exchange, retardation, bio-degradation and dispersion all play a role in the unsaturated zone.

The thickness of the unsaturated zone is obtained by subtracting the static groundwater level elevation from the surface elevation at the same location, or simply by measuring the distance to the groundwater level below surface. Based on water level measurements taken from user boreholes and dedicated source monitoring boreholes, the thickness of the unsaturated zone generally varies between ± 9 and 100 meters below surface (average being ± 42 mbs). Note that the deep water levels are caused by water level abstraction and do not represent steady state ambient levels.

5.3.2 SATURATED ZONE

The saturated zone, as the name suggests, is the portion of the geological/soil profile that is situated below the static groundwater level or water table and is therefore saturated with water. The saturated zone is therefore present from around 9 mbs to an infinite depth.

The saturated zone is important as it forms the groundwater zone or system on which groundwater users rely for their domestic/other water supply. The focus of this investigation is mainly on the saturated zone and its properties and characteristics, and potential impact of the proposed activities thereon.

5.3.3 HYDRAULIC PROPERTIES AND POTENTIAL YIELDS

As discussed in Section 4.5 of this report, aquifer tests in the form of constant rate pumping or discharge tests were conducted on eight boreholes (four user and four monitoring boreholes) to determine the hydraulic properties (more specifically conductivity/transmissivity) of the underlying aquifer. This information plays an important role in the conceptualisation of the project area (i.e. conceptual model), which ultimately forms the foundation for the numerical groundwater flow and contaminant transport models. The positions of these eight boreholes are indicated in Figure 5-2, while more information regarding these tests is provided in Table 5-6.

Aquifer transmissivity is defined as a measure of the amount of water that could be transmitted horizontally through a unit width of aquifer by the full-saturated thickness of the aquifer under a hydraulic gradient of 1. Transmissivity is the product of the aquifer thickness and the hydraulic conductivity of the aquifer, usually expressed as m^2/day (Length^2/Time).

Storativity (or the storage coefficient) is the volume of water that a permeable unit will absorb or expel from storage per unit surface area per unit change in piezometric head. Storativity (a dimensionless quantity) cannot be measured with a high degree of accuracy in slug tests or even in conventional pumping tests. It has been calculated by numerous different methods with the results published widely and a value of 0.002 to 0.01 is taken as representative for the proposed mining area – except to the north of the MRA area where the storativity of the underlying dolomitic aquifer is expected to be significantly higher.

The pumping test data was analysed with the AQTESOLV Professional software package, which offers a wide range of mathematical equations/solutions for the calculation of aquifer parameters. The time-water level data collected during the constant rate pumping test is plotted on a log-linear graph. A straight line or curve (depending on equation used) can then be fitted to the different flow stages on the graph (process known as curve matching) and the aquifer transmissivity and storativity are calculated in accordance with the preselected analytical equation. Aquifer parameters provided in this report were calculated with the *Theis (1935)* and *Cooper-Jacob (1946)* equations.

It is important to note that the abovementioned equations for pumping test analysis were designed for a primary porosity aquifer environment with the following assumptions:

- The aquifer is a homogeneous medium;
- Of infinite extent;
- No recharge is considered; and
- An observation borehole is used for water level recording at a distance from the pumped borehole.

Although few of these assumptions apply to the project area, the methods/equations could still be used as long as the assumptions and 'shortcomings' are recognized and taken into account.

Because aquifer hydraulic parameters (like most geological parameters) usually display a log-normal distribution it is an accepted approach to calculate the harmonic or geometric mean in preference to the arithmetic mean. A generally accepted approach for calculating a representative hydraulic conductivity for an aquifer is to take the average of the harmonic and geometric means.

Table 5-6: Summary of pumping tests

BH	BH depth	Static WL	Available drawdown	Pump duration	Pump rate	Drawdown	Recovery
Unit	***m***	***mbs***	***m***	***min***	***l/s***	***m***	***%***
213JW1	±160	83.3	-	159	1.0	11.0	99% after 159 min
219EW	-	14.8	-	20	1.0	4.0	81% after 20 min
226BKM	-	-	-	105	1.0	0.3	100% after 20 min
235LP1	±160	42.7	-	132	1.0	2.6	88% after 93 min
RMBH01D	45	17.8	16	60	0.8	4.8	100% after 10 min
RMBH002S	31	24.1	7	13	0.2	6.3	68% after 20 min
RMBH003S	31	24.7	3	10	0.1	2.4	4% after 90 min
RMBH004S	31	18.3	7	5	0.3	5.9	None

Aquifer parameters calculated from the pumping tests are provided in Appendix E. Please note that no accurate aquifer parameters could be calculated for boreholes 226BKM and

RMBH03S due to insufficient water level information collected during the tests. Based on the 1:250 000 scale geological map of the project area (Figure 5-1), boreholes 213JW1, 226BKM and 235LP1 are believed to be located within the Malmani dolomite. It follows that the average transmissivity of this dolomitic aquifer is in the region of 22 m^2/d. On the other hand, borehole 219EW displayed a much lower transmissivity of nearly 6.5 m^2/d, which is believed to be representative of the fractured Karoo Supergroup aquifer. The four monitoring boreholes were drilled into the Rietkol quartzite deposit and its associated contact zones and displayed an even lower average transmissivity of approximately 0.9 m^2/d.

The *Cooper-Jacob* equation was applied to calculate the potential yield of each tested borehole. Due to the extremely heterogeneous nature of the fractured rock aquifer system, yields were calculated for four main aquifer scenarios/systems, namely:

- An open aquifer system that is not restricted by any boundaries (never found in practice);
- An aquifer bounded by a single no-flow boundary e.g. an impervious dolerite dyke;
- An aquifer restricted by two no-flow boundaries; and
- A closed aquifer system (absolute worst-case scenario).

The borehole yield should preferably be based on the average yield calculated for the four aquifer scenarios, thus providing a conservative value should such boundaries exist. Furthermore, the sedimentary aquifer host rock/s is characterised by a double porosity, meaning that water is also present in pores throughout the rock. This pore/matrix water plays an important role in supplying the open fractures and discontinuities (and ultimately the borehole) with water. The potential abstraction rates provided below in Table 5-7 were therefore calculated with the lower matrix transmissivity and are indicated as liters per second for a 24-hour pump cycle.

Table 5-7: Potential borehole yields

Borehole	**Potential groundwater yield (l/s)**				
	No boundary	**1 Boundary**	**2 Boundaries**	**Closed**	**Average**
213JW1	5.5	2.7	1.8	1.4	2.8
219EW	1.3	0.6	0.4	0.3	0.7
226BKM	Test inconclusive				
235LP1	9.4	4.7	3.1	2.3	4.9
RMBH01D	0.9	0.5	0.3	0.2	0.5
RMBH02S	0.04	0.02	0.01	0.01	0.02
RMBH03S	Test inconclusive				
RMBH04S	0.04	0.02	0.01	0.01	0.02

Notes:

- *Although the borehole yields provided in Table 5-7 were calculated with tested and proven techniques, uncertainties still exist (especially with regards to the available drawdown) and are therefore first order approximations only.*

- *The maximum on-site water requirement at full production is expected to be nearly 4 l/s. This water is planned to be abstracted from on-site boreholes and the deficit (if any) sourced from the proposed opencast pits.*
- *The long-term sustainable groundwater yields of such boreholes first need to be accurately determined through pumping tests and analytical analyses before pumping can successfully go ahead.*

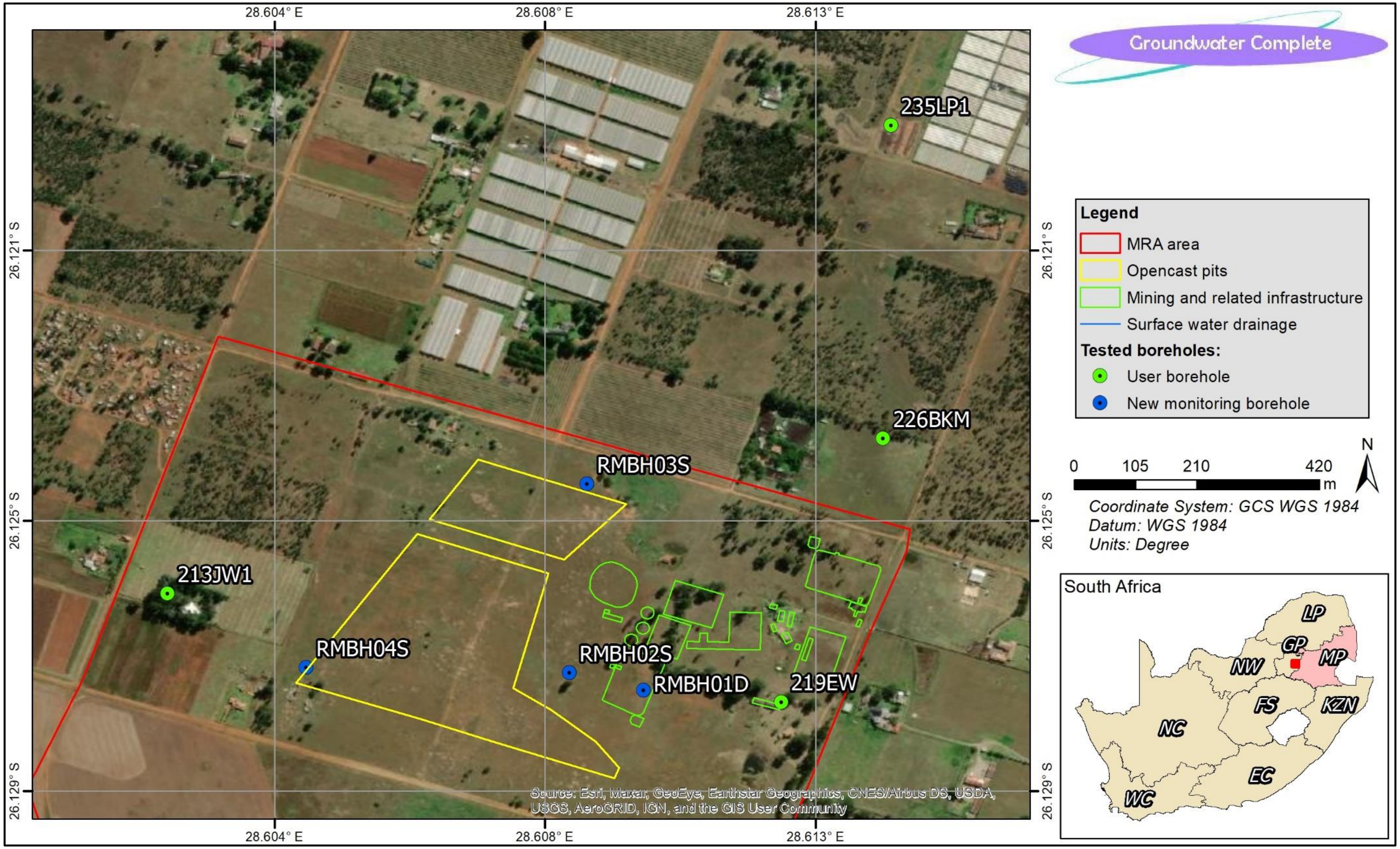


Figure 5-2: Positions of boreholes on which pumping tests were conducted

5.4 GROUNDWATER LEVEL DEPTHS

Groundwater level information was collected during the hydrocensus/user surveys that were conducted within the MRA area and on the surrounding properties. Water level measurements were also taken at the newly drilled source monitoring boreholes. A thematic contour map indicating groundwater level depths in the project area is provided in Figure 5-4. The blue circles indicated on the abovementioned figure represent the positions of the boreholes, while the sizes of the circles are proportional to the groundwater level depth (i.e. the largest circle represents the deepest water level).

Groundwater levels in the project area generally vary between ± 9 and 100 meters below surface (mbs), with the average being ± 42 mbs. Under ambient conditions, the deeper groundwater levels would generally be associated with the dolomitic aquifer, while water levels in the Karoo aquifer/s generally do not exceed 10 mbs. Approximately 66% of all boreholes were being pumped for mainly domestic and/or irrigation purposes at the time of the water level measurements. Not all groundwater levels are therefore representative of the ambient or unaffected conditions, making it difficult to distinguish between the dolomitic aquifer and Karoo aquifer solely based on differing groundwater levels. The groundwater level contour map provided in Figure 5-4 clearly shows the groundwater depression cones resulting from the groundwater abstraction.

A linear relationship often exists between the surface topography and groundwater elevation under natural conditions (i.e. groundwater follows surface topography). This natural relationship is destroyed when the aquifer is stressed (groundwater abstraction) or receives artificial recharge. Some dolomitic aquifers are characterised by very high transmissivities and storativities, which are also known to interfere with this relationship, i.e. causing a very flat water table. A graph of borehole collar elevation versus groundwater level elevation is presented in Figure 5-3. This graph confirms that there exists no meaningful correlation between the measured groundwater elevations and surface topography. This lack of correlation is believed to be the result of groundwater abstraction and/or the intrinsic characteristics of the dolomitic aquifer underlying most of the project area to the north. A further influencing factor is the occurrence in some areas of a shallower aquifer (in the Karoo sedimentary rocks) on top of the deeper dolomitic aquifer.

Notes:

- *Groundwater abstraction for domestic purposes and/or farming related activities has already caused a lowering of the local groundwater levels and is also believed to have affected the natural groundwater flow patterns and velocities around Rietkol.*

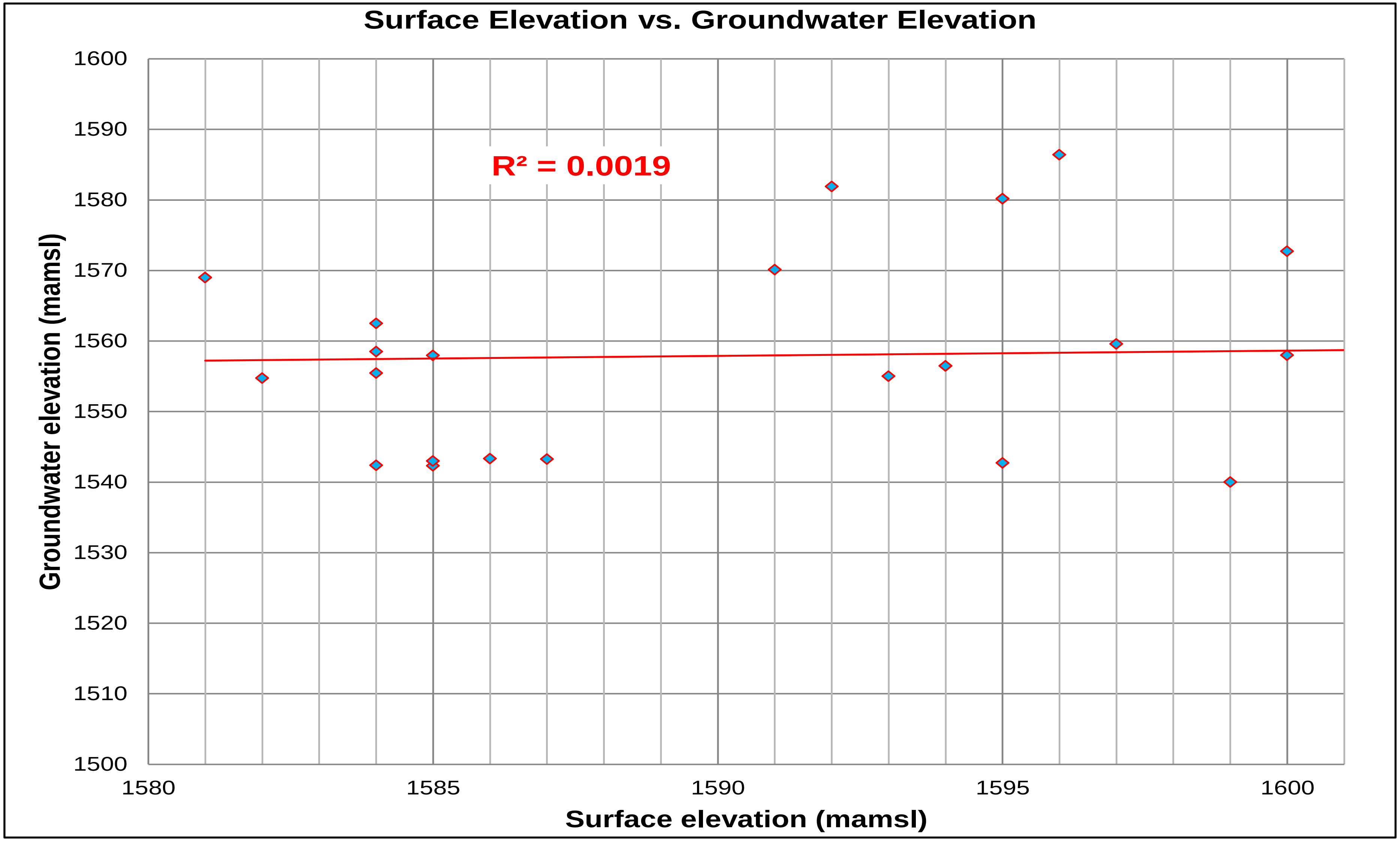


Figure 5-3: Relationship between surface and groundwater elevation

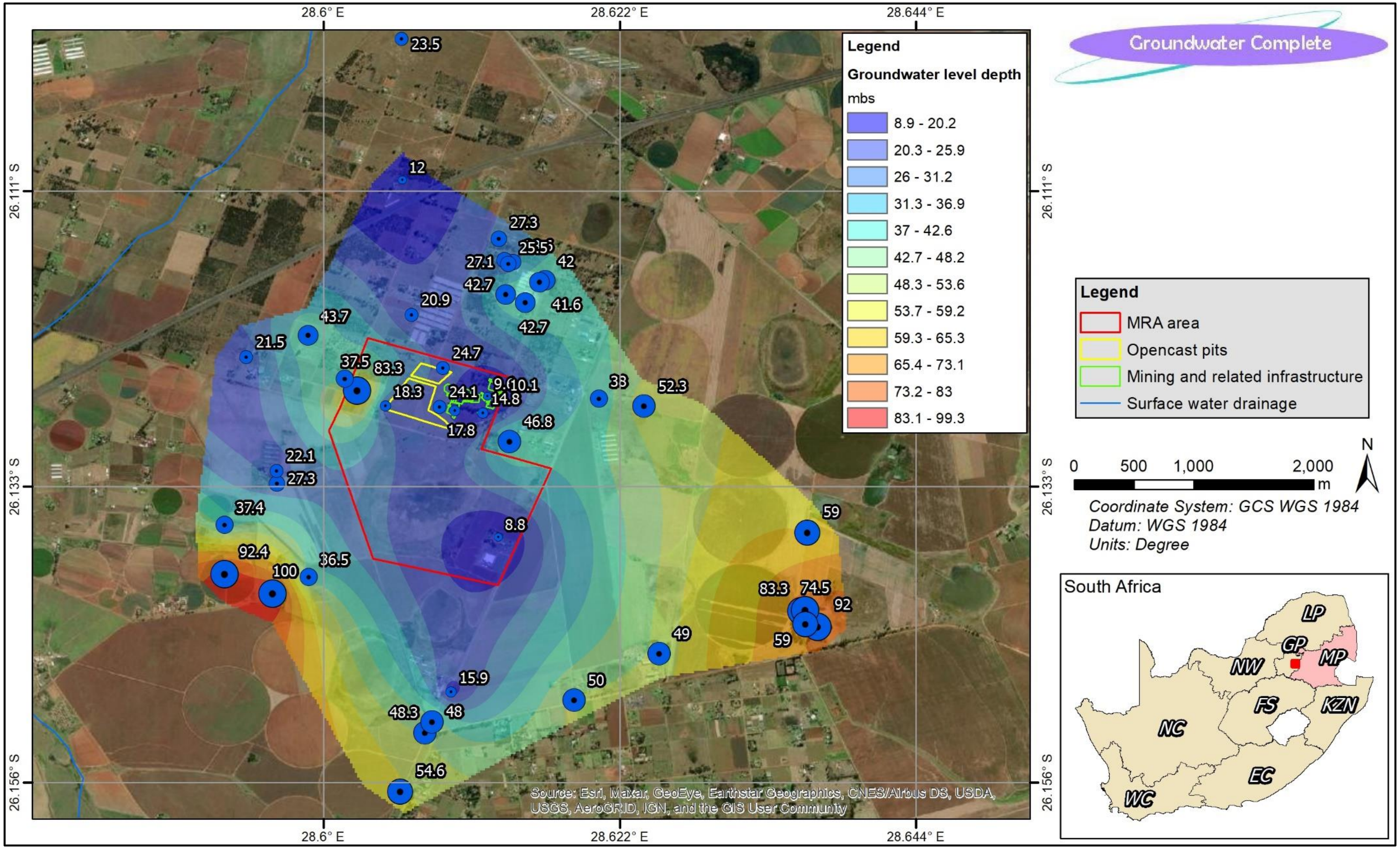


Figure 5-4: Thematic contour map of the groundwater level depths (mbs)

5.5 POTENTIAL SOURCES OF GROUNDWATER CONTAMINATION

A groundwater source area is defined as an area in which groundwater contamination is generated or released from as seepage or leachate. Source areas are subdivided into two main groups:

- Point sources where the contamination can easily be traced back to the origin; and
- Diffuse sources where the contamination is typically associated with poor quality leachate formation through numerous surface sources.

An evaluation of the project description revealed numerous potential source areas, which are listed and briefly discussed in Table 5-8.

Table 5-8: Potential sources of groundwater contamination

Source	Contamination risk	Comments
1) Plant area	Low	- Impact on the groundwater only occurs through leachate formation from surface. Impacts thus only occur as a result of rainfall recharge or when water is introduced in some form where leachate can form that seeps to the groundwater.
2) Waste rock dumps/stockpiles and in-pit tailings	Low	- Effective recharge through waste rock dumps and stockpiles is much higher than the natural recharge of the area due to lower evaporation rates. - Surface water run-off originating from these source areas, toe-seeps and seepage through the base could contaminate the groundwater if the seepage is of poor quality. - Compared to the standard aboveground disposal of tailings material, the alternative in-pit disposal thereof is considered to be more environmentally friendly.
3) Dirty water retaining facilities (water treatment plant, pollution control dam, sewage, etc.)	Low/Medium	- These facilities are developed and constructed for the sole purpose of containing dirty/affected water and therefore minimising the risk of it contaminating the groundwater. Mismanagement of these facilities may however lead to spills and/or leakages that have the potential to contaminate the underlying groundwater.

Source	Contamination risk	Comments
4) Workshops and washing/cleaning bays	Low/Medium	- Impact on the groundwater only occurs through leachate formation from surface. Impacts thus only occur as a result of rainfall recharge or when water is introduced in some form where leachate can form that seeps to the groundwater. - Organic contaminants are usually the main pollutants of concern (e.g. oil, grease, diesel, petrol, hydraulic fluid, solvents, etc.).

Notes:

- *The waste classification (Section 5.2.2) concluded that both the tailings material and waste rock that will be generated by the planned mining and related activities are inert and can be classified as a Type 4 inert waste.*
- *Most potential source areas listed in Table 5-8 therefore pose no real threat to the underlying aquifer in terms of impacts on groundwater quality, i.e. leachate generated by the activities/sources is expected to be of reasonably good quality in terms of the inorganic content.*
- *Explosives will be used in the opencast mining process, which in all likelihood will be nitrate-based. Remnants of the explosives still contain high concentrations of nitrate adsorbed to the blasted rock material. Nitrate dissolves readily in water, resulting in nitrate enriched leachate being generated whenever water is available for dissolution (usually during and directly after a rainfall event). Waste rock dumps and stockpiles are therefore regarded as potential sources of nitrate contamination.*
- *The in-pit disposal of tailings material is considered to be more environmentally friendly for the following main reasons:*
    - *The tailings material is effectively enclosed by mostly quartzite that is characterised by low hydraulic properties. This will greatly reduce the rate of contaminant migration (if present).*
    - *The tailings material (or a portion thereof at least) will be deprived of oxygen in the event of the pit being flooded, which will reduce oxidation and the formation of potentially poor quality leachate.*

5.6 GROUNDWATER QUALITY

Groundwater quality data is available for 22 user boreholes and four dedicated source monitoring boreholes and their positions are indicated in Figure 5-7 and Figure 9-1 respectively. The data was evaluated with the aid of diagnostic chemical diagrams and by comparing the inorganic concentrations to the South African National Standards for drinking water (Table 5-9). The once-off sampling data does not allow for any statistical analyses or trend identification.

The four main factors usually influencing groundwater quality are:

- **Annual recharge** to the groundwater system,
- **Type of bedrock** where ion exchange may impact on the hydrogeochemistry,
- **Flow dynamics** within the aquifer(s), determining the water age and
- **Source(s) of pollution** with their associated leachates or contaminant streams.

Where no specific source of groundwater pollution is present up gradient from the borehole, only the other three factors play a role.

One of the most appropriate ways to interpret the type of water at a sampling point is to assess the plot position of the water quality on different analytical diagrams like a Piper, Expanded Durov and Stiff diagrams. Of these three types, the Expanded Durov diagram probably gives the most holistic water quality signature. The layout of the fields of the Expanded Durov diagram (EDD) is shown in Figure 5-5.

Although never clear-cut, the general characteristics of the different fields of the diagram could be summarized as follows:

Field 1:
Fresh, very clean recently recharged groundwater with HCO_3 and CO_3 dominated ions.

Field 2:
Field 2 represents fresh, clean, relatively young groundwater that has started to undergo mineralization with especially Mg ion exchange.

Field 3:
This field indicates fresh, clean, relatively young groundwater that has undergone Na ion exchange (sometimes in Na - enriched granites or felsic rocks) or because of contamination effects from a source rich in Na.

Field 4:
Fresh, recently recharged groundwater with HCO_3 and CO_3 dominated ions that has been in contact with a source of SO_4 contamination or that has moved through SO_4 enriched bedrock.

Field 5:
Groundwater that is usually a mix of different types – either clean water from fields 1 and 2 that has undergone SO_4 and NaCl mixing / contamination or old stagnant NaCl dominated water that has mixed with clean water.

Field 6:
Groundwater from field 5 that has been in contact with a source rich in Na or old stagnant NaCl dominated water that resides in Na rich host rock/material.

Field 7:
Water rarely plots in this field that indicates NO_3 or Cl enrichment or dissolution.

Field 8:
Groundwater that is usually a mix of different types – either clean water from fields 1 and 2 that has undergone SO_4, but especially Cl mixing/contamination or old stagnant NaCl dominated water that has mixed with water richer in Mg.

Field 9:
Old or stagnant water that has reached the end of the geohydrological cycle (deserts, salty pans etc.) or water that has moved a long time and / or distance through the aquifer or on surface and has undergone significant ion exchange because of the long distance or residence time in the aquifer.

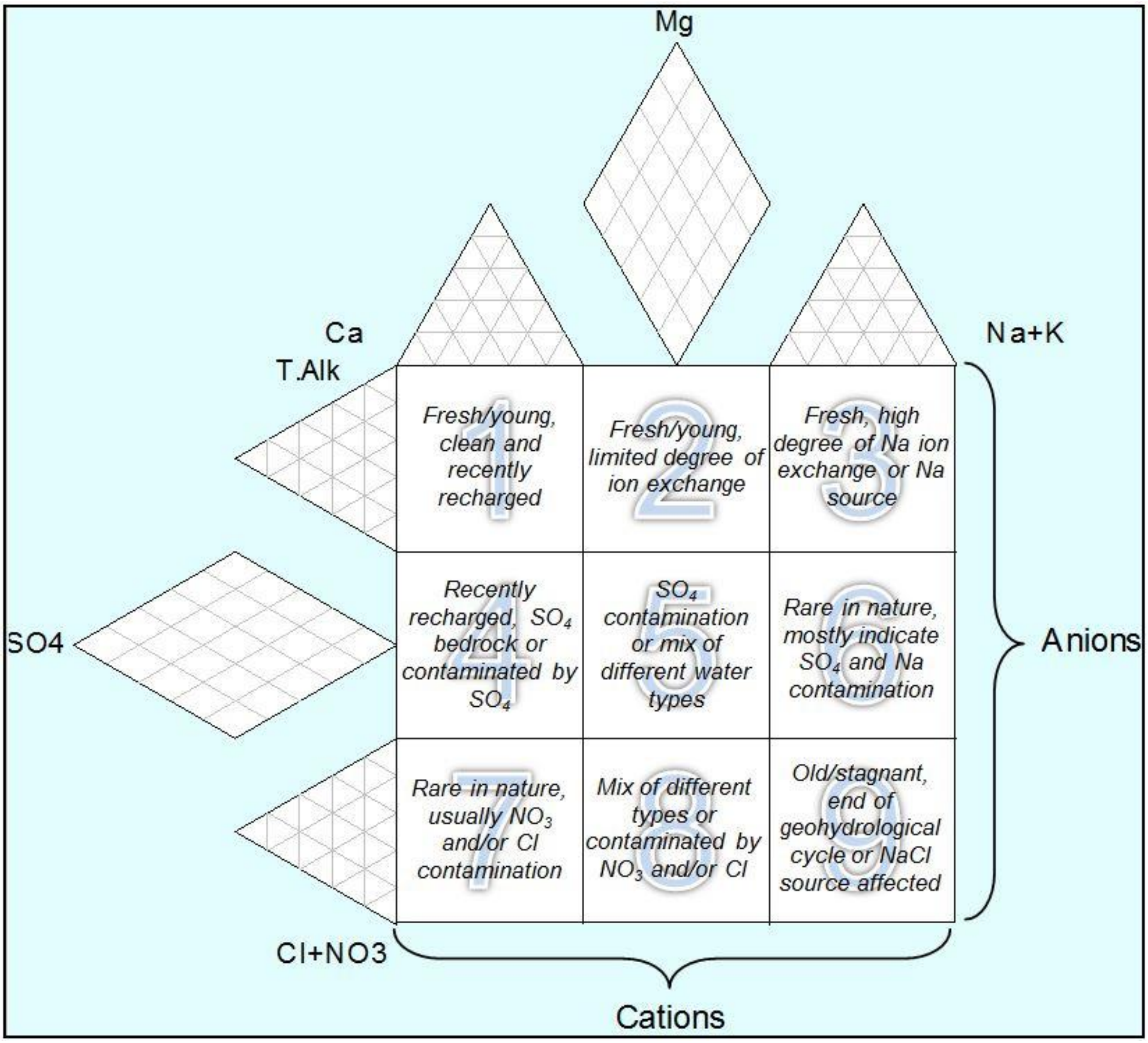


Figure 5-5: Layout of fields of the Expanded Durov diagram

Table 5-9: South African National Standards for drinking water *(SANS 241:2015)*

Determinant	Risk	Unit	Standard limits
Physical and aesthetic determinants			
Free chlorine	Chronic health	mg/l	≤ 5
Monochloramine	Chronic health	mg/l	≤ 3
Conductivity at 25 °C	Aesthetic	mS/m	≤ 170
Total dissolved solids	Aesthetic	mg/l	≤ 1 200
Turbidity	Operational	NTU	≤ 1
	Aesthetic	NTU	≤ 5
pH at 25 °C	Operational	pH units	≥ 5 to ≤ 9.7
Chemical determinants - macro-determinants			
Nitrate as N	Acute health – 1	mg/l	≤ 11
Nitrite as N	Acute health – 1	mg/l	≤ 0.9
Sulfate as SO_4^{2-}	Acute health – 1	mg/l	≤ 500
	Aesthetic	mg/l	≤ 250
Fluoride as F^-	Chronic health	mg/l	≤ 1.5
Ammonia as N	Aesthetic	mg/l	≤ 1.5
Chloride as Cl^-	Aesthetic	mg/l	≤ 300
Sodium as Na	Aesthetic	mg/l	≤ 200
Zinc as Zn	Aesthetic	mg/l	≤ 5
Chemical determinants - micro-determinants			
Aluminium as Al	Operational	µg/l	≤ 300
Antimony as Sb	Chronic health	µg/l	≤ 20
Arsenic as As	Chronic health	µg/l	≤ 10
Barium Ba	Chronic health	µg/l	≤ 700
Boron B	Chronic health	µg/l	≤ 2 400
Cadmium as Cd	Chronic health	µg/l	≤ 3
Total chromium as Cr	Chronic health	µg/l	≤ 50
Cobalt as Co	Chronic health	µg/l	≤ 500
Copper as Cu	Chronic health	µg/l	≤ 2 000
Cyanide (recoverable) as CN^-	Acute health – 1	µg/l	≤ 70
Iron as Fe	Chronic health	µg/l	≤ 2 000
	Aesthetic	µg/l	≤ 300
Lead as Pb	Chronic health	µg/l	≤ 10
Manganese as Mn	Chronic health	µg/l	≤ 400
	Aesthetic	µg/l	≤ 100
Mercury as Hg	Chronic health	µg/l	≤ 6
Nickel as Ni	Chronic health	µg/l	≤ 70
Selenium as Se	Chronic health	µg/l	≤ 40
Uranium as U	Chronic health	µg/l	≤ 15
Vanadium as V	Chronic health	µg/l	≤ 200
Organic determinants			
Total organic carbon	Acute health – 1	mg/l	≤ 10

5.6.1 REGIONAL USER BOREHOLES

A total of 22 user boreholes were sampled during the hydrocensus/user surveys and their positions are indicated in Figure 5-7. The groundwater samples were analysed at the SANAS accredited Aquatico Laboratories for a wide range of chemical and physical indicator parameters. Although only five parameters (TDS, SO_4, NO_3, Cl and pH) will be discussed, all inorganic parameters will be assessed, and anomalies will be discussed where necessary.

The **total dissolved solids (TDS)** content of groundwater is a good indicator of the overall quality of the water, as it provides a measurement of the total amount/weight of salts that are present in solution. An increase in TDS will therefore also indicate an increase in the total inorganic content of the groundwater. Groundwater TDS concentrations of user boreholes vary between 120 mg/l and 416 mg/l (Table 5-10), which are well below the maximum permissible SANS value of 1 200 mg/l.

The **sulphate** content of groundwater is low and vary from below the detection limit of 0.452 mg/l to nearly 45 mg/l, which are well below the maximum permissible SANS value of 500 mg/l.

In a farming environment, **nitrate** contamination is generally associated with seepage from pit latrines and animal feedlots/kraals or fertilisers, while where mining occurs the usage of nitrate-based explosives is mainly responsible for high levels of nitrate contamination. Health effects associated with high nitrate intake are impaired concentration, lack of energy and the formation of methahemoglobin in blood cells. Groundwater nitrate concentrations measured in most user boreholes are well below the maximum permissible SANS value of 11 mg/l (Table 5-10). Exceptions do however occur and a concentration of approximately 12 mg/l was measured in both boreholes 148PB1 and 202Unex2. The once-off analyses do not allow for accurate source identification, however the nitrate contamination affecting the abovementioned two boreholes is likely to originate from pit latrines and/or feedlots.

The groundwater **pH** conditions are more or less neutral with values varying between 7.0 and 8.8. The neutral pH conditions restrict the mobilisation of metals, which are also sensitive to groundwater redox conditions.

User boreholes display groundwater **chloride** concentrations of between 2 mg/l and 85 mg/l, which are well below the maximum permissible SANS value of 300 mg/l (Table 5-10).

According to the Expanded Durov diagram (Figure 5-6), most user boreholes are dominated by fresh, clean, relatively young groundwater that has started to undergo mineralization, i.e. magnesium ion exchange. The groundwater is therefore dominated by **magnesium** cations, while **bicarbonate alkalinity** dominates the anion content. This is typical of a dolomitic aquifer, which is mainly composed of calcium and magnesium carbonates.

As mentioned above, borehole 202Unex2 is affected by nitrate contamination, which explains its plot position in field 8 of the EDD. The groundwater is therefore dominated by **magnesium** cations and **nitrate** anions.

Summary:

- Groundwater from most of the user boreholes is considered to be of good quality and is suitable for human consumption with regards to the South African National Standards *(SANS 241:2015)*.
- Exceptions do however occur as the groundwater nitrate content measured in user boreholes 148PB1 and 202Unex2 exceeds the maximum permissible SANS value of 11 mg/l.
- The nitrate contamination is likely to originate from pit latrines or feedlots.
- The groundwater is mainly dominated by magnesium cations and bicarbonate alkalinity, which is typical of an unpolluted dolomitic aquifer.

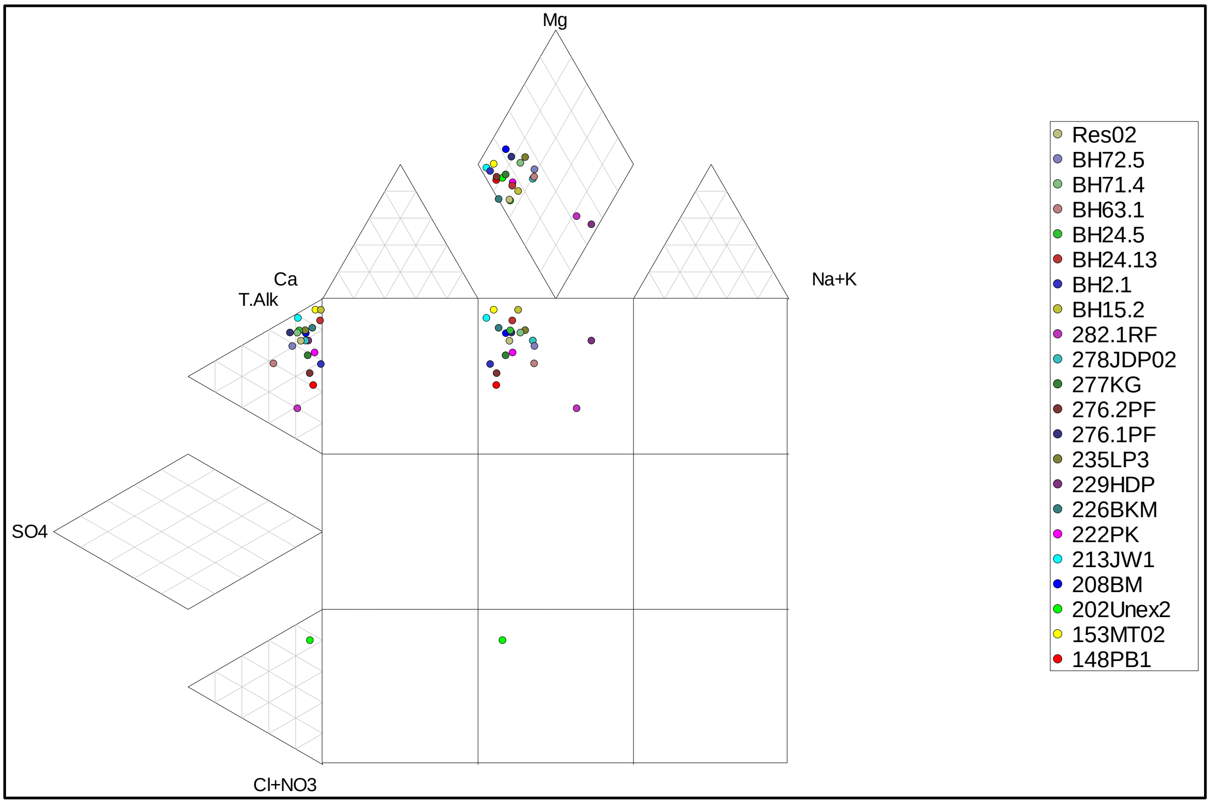


Figure 5-6: Expanded Durov diagram of regional groundwater chemistries

Table 5-10: Results of chemical and physical analyses for regional user boreholes

BH	pH	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Cl mg/l	SO_4 mg/l
148PB1	7.4	264.0	48.7	27.6	9.5	2.8	14.9	7.0
202Unex2	7.3	120.0	17.6	10.7	4.6	0.7	7.5	3.9
208BM	8.0	216.0	35.8	31.5	6.7	0.9	6.3	12.0
153MT02	7.5	211.0	42.0	28.4	5.4	0.9	2.3	4.7
213JW1	7.9	173.0	35.0	21.5	2.7	0.9	1.8	14.7
229HDP	8.8	127.0	11.6	7.8	25.8	0.6	1.9	5.6
222PK	7.0	209.0	36.3	22.5	13.7	2.0	20.8	5.1

BH	pH	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Cl mg/l	SO_4 mg/l
226BKM	8.1	167.0	35.2	15.8	10.5	1.0	7.7	5.4
235LP3	8.2	133.0	18.9	18.0	8.6	1.3	4.2	7.7
276.1PF	8.2	200.0	29.6	25.0	7.6	2.1	5.4	23.0
276.2PF	7.1	177.0	30.8	18.2	5.9	1.5	6.4	6.9
277KG	8.1	202.0	33.0	21.4	8.9	1.9	9.2	9.8
278JDP02	8.6	196.0	29.1	22.4	18.8	2.0	13.0	10.9
282.1RF	7.7	416.0	44.5	29.5	74.4	4.6	85.0	33.7
Res02	7.9	265.0	46.2	22.1	18.3	2.4	17.0	19.9
BH15.2	7.7	182.0	29.4	16.9	12.8	3.5	3.9	<0.452
BH2.1	8.3	182.0	30.7	18.6	3.4	1.4	7.4	<0.452
BH24.13	7.9	219.0	36.2	21.4	12.7	4.1	10.0	1.3
BH24.5	7.9	246.0	42.8	20.3	16.6	3.7	10.1	20.0
BH63.1	8.5	261.0	32.2	25.8	21.4	2.1	20.6	44.5
BH71.4	8.3	205.0	28.7	24.3	11.9	1.4	9.1	18.5
BH72.5	8.3	209.0	25.9	23.0	17.0	1.5	14.0	22.2

BH	NO_3 mg/l	F mg/l	Al mg/l	Fe mg/l	Mn mg/l	NH_3 mg/l	THardness mg/l	PO_4 mg/l
148PB1	**11.7**	<0.466	<0.005	<0.009	<0.001	<0.005	235.0	0.06
202Unex2	**12.1**	0.18	<0.005	<0.009	<0.001	<0.005	88.0	<0.002
208BM	2.6	0.20	<0.005	<0.009	<0.001	<0.005	219.0	<0.002
153MT02	0.7	0.23	<0.005	<0.009	<0.001	<0.005	222.0	<0.002
213JW1	0.3	0.17	<0.005	<0.009	<0.001	<0.005	176.0	<0.002
229HDP	3.0	<0.142	<0.005	<0.009	<0.001	<0.005	61.0	<0.002
222PK	1.3	0.49	<0.005	<0.009	<0.001	<0.005	183.0	<0.002
226BKM	0.6	0.18	<0.005	<0.009	<0.001	<0.005	153.0	<0.002
235LP3	1.1	0.20	<0.005	<0.009	<0.001	<0.005	121.0	<0.002
276.1PF	0.9	<0.263	0.01	<0.004	<0.001	0.19	177.0	<0.005
276.2PF	7.6	<0.263	<0.002	<0.004	0.04	0.19	152.0	<0.005
277KG	5.2	<0.263	<0.002	<0.004	<0.001	0.04	171.0	<0.005
278JDP02	0.6	0.22	<0.005	<0.009	<0.001	<0.005	165.0	<0.002
282.1RF	0.3	0.3	<0.002	<0.004	0.19	0.14	232.0	<0.005
Res02	0.8	<0.466	<0.005	<0.009	<0.001	0.10	206.0	0.05
BH15.2	0.5	<0.466	<0.005	<0.009	<0.001	0.08	143.0	0.04
BH2.1	7.7	<0.466	<0.005	<0.009	<0.001	0.05	153.0	0.04
BH24.13	0.6	<0.466	<0.005	<0.009	<0.001	0.05	179.0	0.11
BH24.5	<0.459	<0.466	<0.005	<0.009	<0.001	0.05	191.0	0.07
BH63.1	0.7	<0.466	<0.005	<0.009	<0.001	0.10	187.0	0.04
BH71.4	<0.459	<0.466	<0.005	<0.009	<0.001	0.05	172.0	0.05
BH72.5	0.5	<0.466	<0.005	<0.009	<0.001	0.06	159.0	0.04

***Note: Red** - Value exceeds the maximum permissible SANS concentration allowed in drinking water (Table 5-9).*

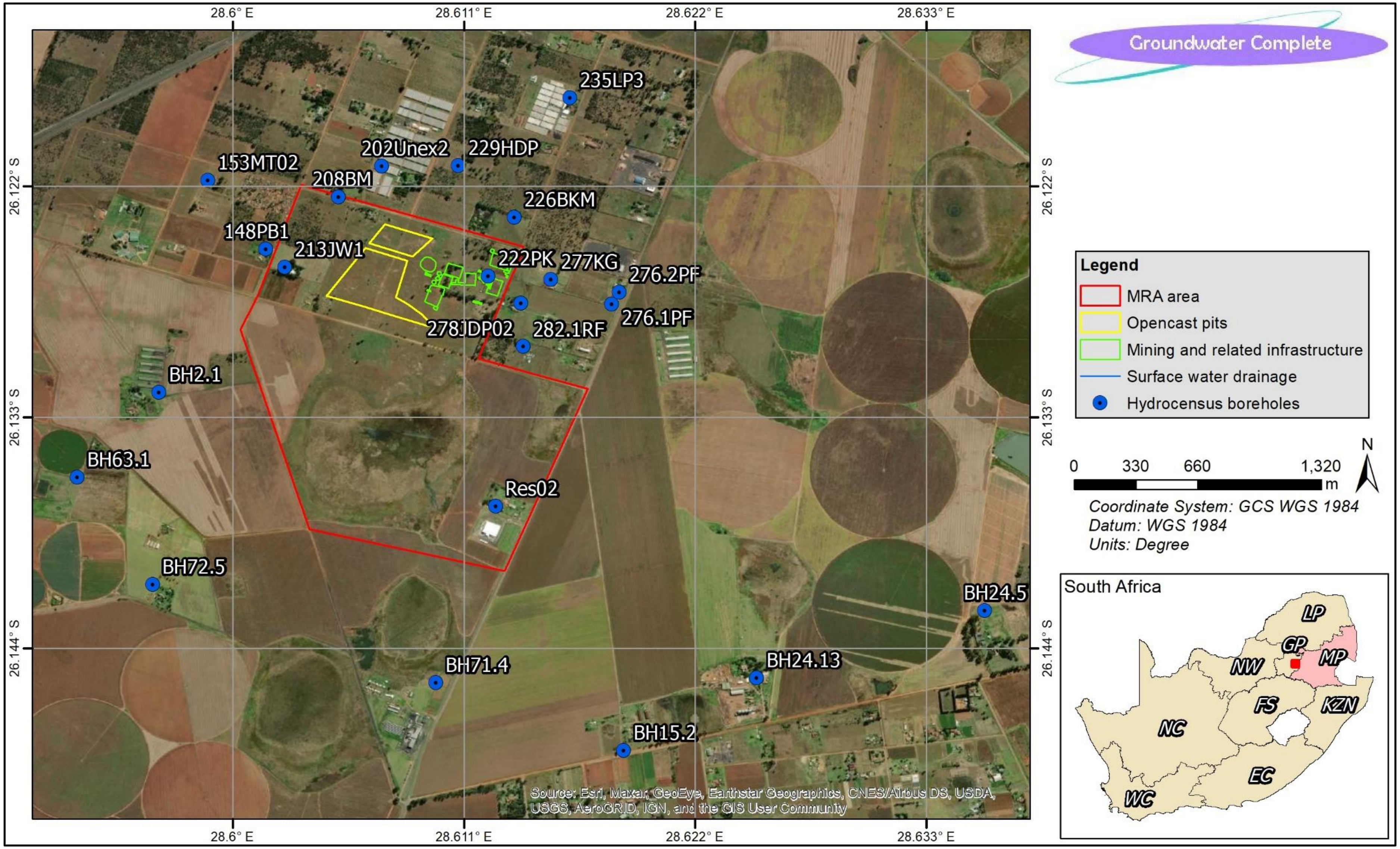


Figure 5-7: Distribution of regional groundwater quality data

5.6.2 GROUNDWATER QUALITY IN SITE-SPECIFIC SOURCE MONITORING BOREHOLES

Four dedicated source monitoring boreholes were drilled within the MRA area and their positions are indicated in Figure 9-1. The results of the chemical and physical analyses are provided in Table 5-11.

Groundwater within the MRA area is considered to be of good quality according to the South African National Standards for drinking water purposes *(SANS 241:2015)* and also representative of the ambient or unaffected environment. The TDS content of groundwater is a very effective indicator of inorganic type contamination. Groundwater TDS concentrations vary between 20 mg/l and 84 mg/l (Table 5-11), which are low and perfectly suitable for human consumption.

The groundwater manganese content in borehole RMBH01D did however exceed the maximum permissible SANS value of 0.4 mg/l. The only explanation for the elevated manganese content is the fact that the borehole was drilled into the dolomitic aquifer and the weathering in the borehole was very deep. The chemical weathering in dolomite terrains in South Africa often leaves a black to coffee-brown residue which is very light and is named manganese earth or wad *(Dowding, 2004)*. Since RMBH01 is the only site borehole drilled into the weathered dolomite and sampled shortly thereafter the elevated manganese in the groundwater is likely to originate from the manganese earth. It is unlikely to be the result of any nearby farming or human related activities.

The four groundwater samples plot in four different fields of the Expanded Durov diagram (Figure 5-8). Fields four (RMBH02S) and seven (RMBH04S) generally represent impacts associated with sulphate and/or nitrate type contamination, which however in this situation is not the case. Concentrations of both these chemical parameters are very low and representative of the ambient or unaffected groundwater environment (Table 5-11).

Boreholes RMBH01D and RMBH03S plot in fields two and one of the EDD respectively, which represent groundwater dominated by calcium and magnesium cations. The anion content on the other hand is dominated by bicarbonate alkalinity.

Summary:

- Groundwater from the four monitoring boreholes is considered to be of good quality and is suitable for human consumption with regards to the South African National Standards *(SANS 241:2015)*.
- The groundwater manganese content in borehole RMBH01D did however exceed the maximum permissible SANS value of 0.4 mg/l. The elevated manganese content is expected to originate from wad formed due to weathered dolomite/chert.

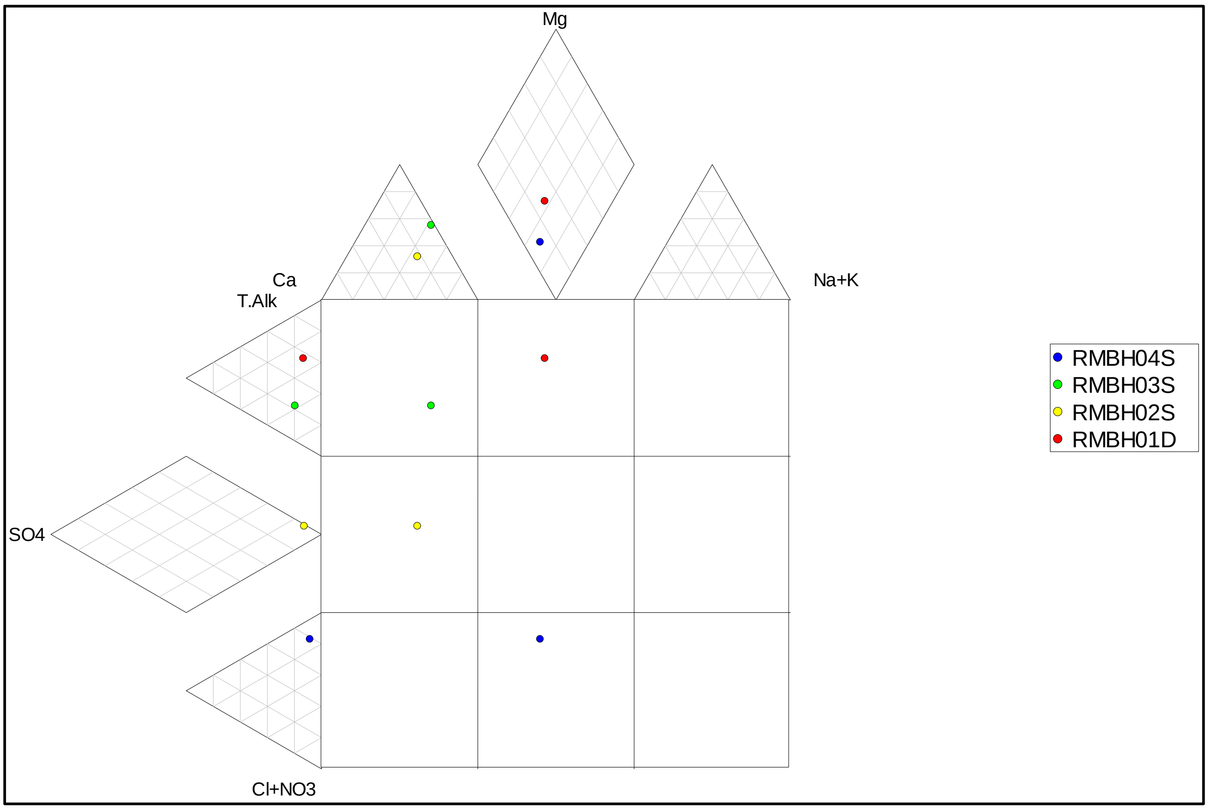


Figure 5-8: Expanded Durov diagram of site specific groundwater chemistries

Table 5-11: Results of chemical and physical analyses for site specific monitoring boreholes

Parameter	***Unit***	**RMBH01D**	**RMBH02S**	**RMBH03S**	**RMBH04S**
pH	*pH units*	8.0	6.9	6.1	6.1
EC	*mS/m*	6.9	13.9	3.6	5.8
TDS	*mg/l*	40.0	84.0	20.0	36.0
Alkalinity	*mg $CaCO_3$/l*	30.3	34.8	10.6	11.3
Cl	*mg/l*	3.6	13.5	1.7	5.4
SO_4	*mg/l*	2.4	4.2	1.6	1.1
NO_3	*mg/l*	0.3	3.5	0.8	2.5
NH_4	*mg/l*	1.2	0.1	<0.008	<0.008
PO_4	*mg/l*	<0.005	<0.005	<0.005	<0.005
F	*mg/l*	<0.263	<0.263	<0.263	<0.263
Ca	*mg/l*	4.4	17.4	3.8	5.3
Mg	*mg/l*	2.7	2.7	1.2	1.5
Na	*mg/l*	2.5	4.7	1.5	4.2
K	*mg/l*	2.7	4.8	0.6	0.9
Al	*mg/l*	<0.002	<0.002	<0.002	<0.002
Fe	*mg/l*	<0.004	0.1	<0.004	<0.004
Mn	*mg/l*	**2.04**	0.36	0.02	0.08
Cr	*mg/l*	<0.003	<0.003	<0.003	<0.003

Parameter	*Unit*	RMBH01D	RMBH02S	RMBH03S	RMBH04S
Cu	*mg/l*	<0.002	<0.002	<0.002	<0.002
Ni	*mg/l*	<0.002	<0.002	<0.002	<0.002
Total hardness	*mg $CaCO_3$/l*	22.0	55.0	14.0	19.0

***Note: Red** - Value exceeds the maximum permissible SANS concentration allowed in drinking water (Table 5-9).*

6 AQUIFER CHARACTERISATION

6.1 GROUNDWATER VULNERABILITY

The *Groundwater Vulnerability Classification System* used in this investigation was developed as a first order assessment tool to aid in the determination of an aquifer's vulnerability/susceptibility to groundwater contamination. This system incorporates the well-known and widely used *Parsons Aquifer Classification System* (Table 6-4) as well as drinking water quality guidelines as stated by the *Department of Water and Sanitation*. This system is especially useful in situations where limited groundwater related information is available and is explained in Table 6-2 and Table 6-3. The dolomitic aquifer underlying the project area achieved a score of 9 (Table 6-1) and is therefore regarded as having a high vulnerability.

According to the *Aquifer Vulnerability Map of South Africa* that was first published by the CSIR in 1999, the underlying aquifer is considered to have a high vulnerability.

Table 6-1: Groundwater vulnerability rating for project area

	Rating
Depth to groundwater level	1
Groundwater quality	4
Aquifer type	4
Total score:	**9**

Table 6-2: Groundwater vulnerability classification system

Rating	*4*	*3*	*2*	*1*
Depth to groundwater level	0 – 3 m	3 – 6 m	6 – 10 m	>10 m
Groundwater quality *(Domestic WQG*)*	Excellent (TDS < 450 mg/l)	Good (TDS > 450 < 1 000 mg/l)	Marginal (TDS > 1 000 < 2 400 mg/l)	Poor (TDS > 2 400 mg/l)
Aquifer type *(Parsons Aquifer Classification)*	Sole aquifer system	Major aquifer system	Minor aquifer system	Non-aquifer system

** WQG = Water Quality Guideline.*

Table 6-3: Groundwater vulnerability rating

Vulnerability	Rating
Low vulnerability	≤ 4
Medium vulnerability	> 4 ≤ 8
High vulnerability	≥ 9

6.2 AQUIFER CLASSIFICATION

Information from geological maps, drilling results and experience gained from numerous studies conducted in similar geohydrological environments suggest that three different types of aquifers may be present in the project area. For the purpose of this study an aquifer is defined as a geological formation or group of formations that can yield groundwater in economically useable quantities. Aquifer classification according to the Parsons Classification system is summarised in Table 6-4.

The **first aquifer** is a shallow, **semi-confined or unconfined aquifer** that occurs in the transitional soil and **weathered bedrock zone** or sub-outcrop horizon. Yields in this aquifer are generally low (less than 0.5 l/s) and the aquifer is usually not fit for supplying groundwater on a sustainable basis. Consideration of the shallow aquifer system becomes important during seepage estimations from pollution sources to receiving groundwater and surface water systems. The shallow weathered zone aquifer plays the most important role in contaminant transport simulations from process and mine induced contamination sources because the lateral seepage component in the shallow weathered aquifer often dominates the flow. **According to the Parsons Classification system, this aquifer is usually regarded as a minor- and in some cases a non-aquifer system.**

Due to the mainly lateral flow and sometimes phreatic nature of the weathered zone aquifer, it is usually only affected by opencast mining, high extraction or shallow underground mining where subsidence occurs and the entire roof strata above the mined area is destroyed.

The **second aquifer** system is the deeper **secondary fractured rock aquifer** that is hosted within the sedimentary rocks of the Karoo Supergroup, which underlies the southern half of the MRA area (Figure 6-1). Groundwater yields, although more heterogeneous, can be higher. This aquifer system usually displays semi-confined or confined characteristics with piezometric heads often significantly higher than the water-bearing fracture position. Fractures may occur in any of the co-existing host rocks due to different tectonic, structural and genetic processes. **According to the Parsons Classification system, the aquifer could be regarded as a minor aquifer system, but also a sole aquifer system in some cases where groundwater is the only source of domestic water.**

The **third, and major aquifer** system is associated with the Malmani Subgroup (Transvaal Supergroup) dolomite that underlies the northern half of the MRA area (Figure 5-1). Dolomite is generally considered to be an excellent host rock for aquifers due to the formation of solution cavities and their ability to store vast volumes of groundwater. However, water needs to penetrate the rock for any dissolution to occur, meaning that the dolomite must have undergone some significant fracturing for any significant cavities to have formed over the years. **According to the Parsons Classification System, this aquifer could be regarded as a major aquifer system, but also a sole aquifer system in some cases where groundwater is the only source of domestic water.**

Notes:

- *Mining will technically only intersect the shallow weathered zone aquifer to gain access to the underlying Rietkol quartzite that was deposited in an ancient sinkhole structure – leaving both the Karoo Supergroup and Transvaal Supergroup (i.e. Malmani dolomite) aquifers intact. The quartzite deposit may be regarded as a* ***fourth aquifer****, however, its crystalline structure and small size are characteristic of a* ***minor- or even a non-aquifer system****.*
- *The underlying* dolomitic *aquifer will be separated from the overlying opencast pits by a dolerite sill of approximately 30 meters thick and many more meters of quartzite (i.e. Lower Quartzite band). The quartzite deposit in its entirety is expected to act as a buffer between the proposed mining activities and the surrounding and underlying dolomite.*

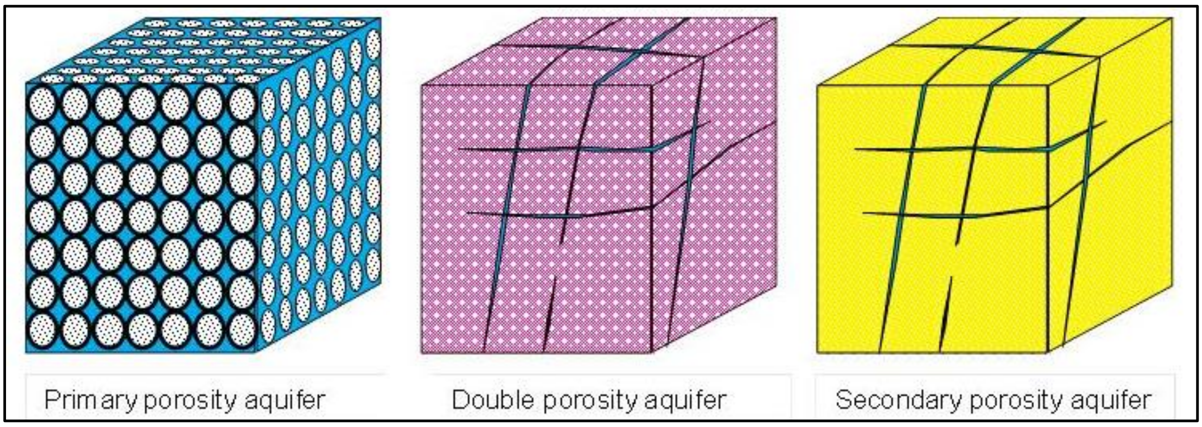


Figure 6-1: Types of aquifers based on porosity

Table 6-4: Parsons Aquifer Classification *(Parsons, 1995)*

Sole Aquifer System	An aquifer that 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 formation, 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 (less than 150 mS/m).
Minor Aquifer System	These can be fractured or potentially fractured rocks that do not have a primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large volumes of water, they are important both for local suppliers and in supplying base flow for rivers.

Non-Aquifer System	These are formations with negligible permeability that are generally 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 impermeable, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.
Special Aquifer System	An aquifer designated as such by the Minister of Water Affairs, after due process.

6.3 AQUIFER PROTECTION CLASSIFICATION

In 1995 Roger Parsons prepared a report for the Water Research Commission and the Department of Water and Sanitation titled, "*A South African Aquifer System Management Classification*". Amongst other things, he described how the need or importance to protect groundwater led to the development of a Groundwater Quality Management classification system, or GQM. The level of protection depends on the aquifer vulnerability (Section 6.1), and aquifer classification (Section 6.2).

Table 6-5: Groundwater Quality Management classification ratings

Aquifer vulnerability		**Aquifer classification**	
Class	**Points**	**Class**	**Points**
		Sole source aquifer	6
High	3	Major aquifer	4
Medium	2	Minor aquifer	2
Low	1	Non-aquifer	0
		Special aquifer	0 - 6

The GQM (or level of protection) is calculated by multiplying aquifer vulnerability with aquifer classification (Table 6-5) and the results can be interpreted as follows:

GQM	**Level of protection**
<1	Limited protection
1 – 3	Low protection
3 – 6	Medium protection
6 – 10	High protection
>10	Strictly non-degradation (i.e. no impact is allowed)

The fractured rock aquifer underlying the project area scored a GQM rating of 18, which means that **no impact is allowed.**

7 NUMERICAL GROUNDWATER MODELLING

7.1 MODEL RESTRICTIONS AND LIMITATIONS

The numerical groundwater model, despite all efforts and advances in software and algorithms, remains a very simplified representation of the very complex and heterogeneous interacting aquifer systems underlying the project area. The integrity of a numerical model depends strongly on the formulation of a sound conceptual model and the quality and quantity (distribution, length of records etc.) of input data. Nonetheless, a numerical model can still be used quite successfully to assess the effectiveness of various management and remediation options/techniques, especially if the shortcomings in information and assumptions made in the construction and calibration of the model are clearly listed and kept in mind during modelling.

The main purpose is thus not to try and predict what the exact groundwater level or concentration of a certain element will be at a certain position at a specific moment in future. The heterogeneity of the natural groundwater system, especially the secondary fractured rock aquifer environment underlying the project area, is simply too great to accurately incorporate and simulate accurately in the model. The purpose is therefore to rather evaluate what the relative magnitude or contribution of certain impacts or different pollution sources will be on the larger groundwater regime and then to determine which remediation options would have the most beneficial effects.

Although relatively good borehole coverage occurs in many parts of the modelled area, the significant heterogeneity of the aquifer still makes the assigning of representative geohydrological flow or contaminant transport parameters to the entire model grid problematic.

No detailed structural geological information was available at the time of submission of this report, therefore modelling (i.e. updating of the model) should be an ongoing process as new information becomes available over time. Because the aquifer underlying the project area is of a secondary fractured rock type, groundwater flow and contaminant migration are fully restricted to open fractures and discontinuities associated with geological structures. These structures therefore have the ability to significantly affect the outcome of a model.

7.2 MODEL SOFTWARE

The Processing Modflow 8 modelling package was used for the model simulations, which is a finite difference type model capable of performing multi-layered (3-dimensional) flow and contaminant transport simulations. It uses the MODFLOW algorithm for the flow modelling, while the MT3DMS algorithm was used for contaminant transport modelling.

7.3 MODEL SET-UP, BOUNDARIES AND GEOMETRIC STRUCTURE

Model dimensions and aquifer parameters used in the construction and calibration of the flow model are provided in Table 7-1, while the model area is indicated on Figure 7-1.

The following model boundaries are generally used to define a model area:

- **No-flow boundaries** in a model, as in nature, are groundwater divides (topographic high or low areas/lines) and geological structures (dykes) across which no groundwater flow is possible.
- **Constant head boundaries** are positions in the model grid where the groundwater elevation always remains fixed and unchanged. Such a boundary typically represents a perennial surface water body in nature (e.g. dam, river, ocean, etc.). Depending on the surrounding groundwater elevations, such a boundary may be an infinite source of groundwater or sink.
- **General head boundaries** are boundaries through which groundwater movement is possible. The rate at which the groundwater moves through the boundary depends on the groundwater gradients as well as the hydraulic conductivities on opposite sides of the boundary position.

No-flow and general head boundaries were used to define the model area and were set at sufficient distances that would ensure they do not interfere with the flow and contaminant transport model simulations. A three-dimensional model (i.e. two layers) was constructed in which the first model layer (confined/unconfined) is 15 meters thick and represents the shallow weathered zone aquifer. The second layer (confined) represents the deeper fractured rock type aquifer hosted within the Transvaal- and Karoo Supergroup rocks.

The model grid is composed of 649 rows and 461 columns, which divide the model area into a total of 598 378 cells (299 189 cells per layer). The conceptual model, as summarised in Section 7.6, formed the basis for the numerical groundwater model.

Table 7-1: Model dimensions and aquifer parameters

General information	
Grid size	Easting = 8 298 m Northing = 11 682 m
Rows and Columns	Rows = 649, Columns = 461
Cell size	18m by 18m
Number of layers	2
Transmissivity layer 1	
- Weathered Transvaal aquifer	1.5 m^2/day
- Weathered Karoo aquifer	1.3 m^2/day
- Weathered Dolomitic aquifer	20 m^2/day
Transmissivity layer 2	
- Fractured Transvaal aquifer	0.45 m^2/day
- Fractured Karoo aquifer	0.35 m^2/day

- Dolomitic aquifer	20 m^2/day
Specific yield layer 1	
- Weathered Transvaal aquifer	0.06
- Weathered Karoo aquifer	0.06
- Weathered Dolomitic aquifer	0.12
Storage coefficient layer 2	
- Fractured Transvaal aquifer	0.003
- Fractured Karoo aquifer	0.003
- Dolomitic aquifer	0.05
Recharge layer 1	
- Weathered Transvaal aquifer	4% of MAP
- Weathered Karoo aquifer	2% of MAP
- Weathered Dolomitic aquifer	6% of MAP

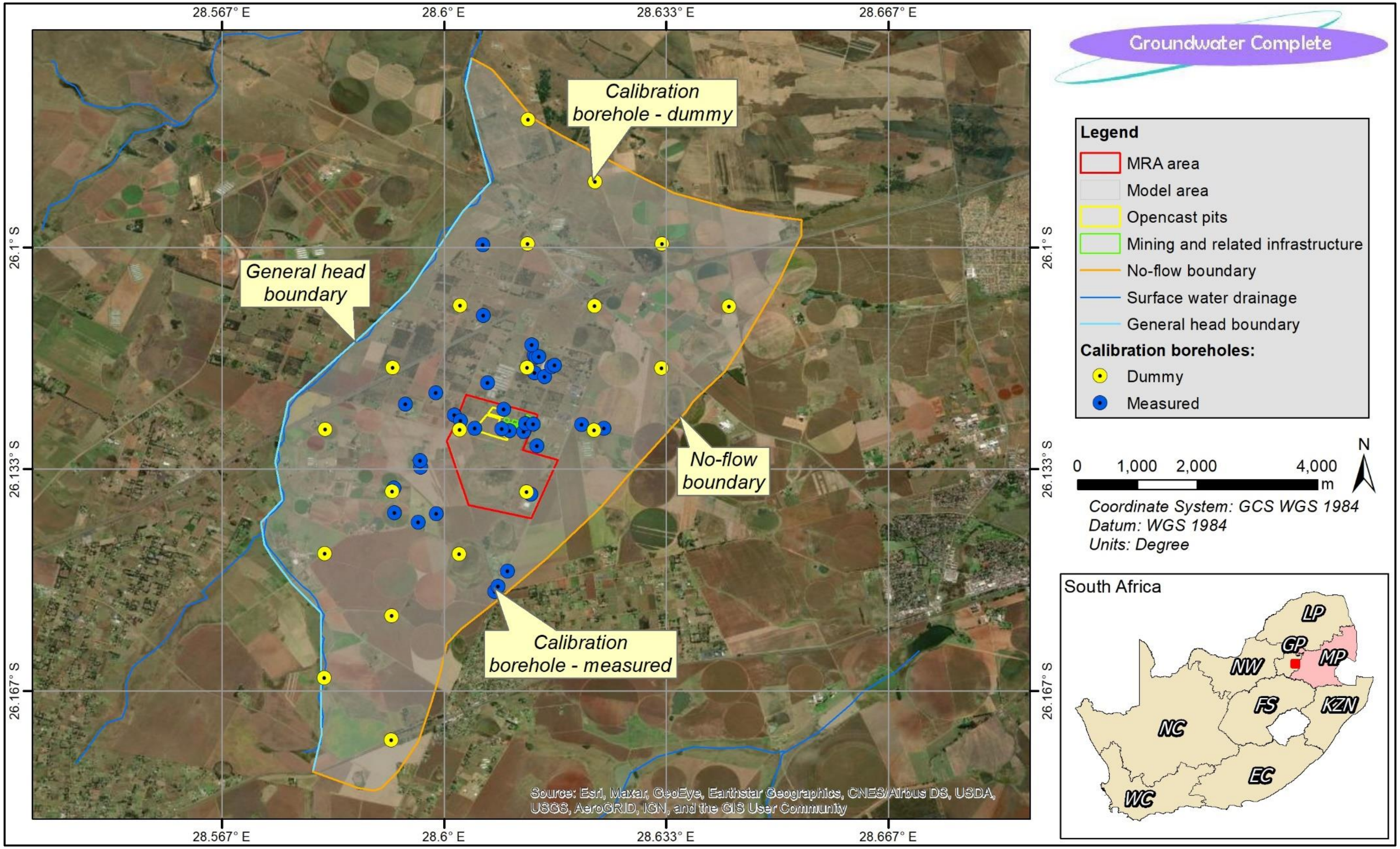


Figure 7-1: Numerical model area

7.4 GROUNDWATER ELEVATIONS, GRADIENTS AND FLOW DIRECTIONS

During the steady state calibration of a flow model, changes are made to mainly the hydraulic properties (transmissivity) of the aquifer host rock and effective recharge (Table 7-1) until an acceptable correlation is achieved between the measured/observed groundwater elevations and those simulated by the model. These model-simulated groundwater elevations are then specified as initial groundwater levels and form the basis for the transient state model simulations to follow.

Groundwater level information used in the calibration of the flow model was collected from user boreholes as well as dedicated source monitoring boreholes. Most user boreholes were in use at the time of the surveys, therefore filtering of the water level information was necessary and water levels believed to be affected by groundwater abstraction were identified and excluded from the model calibration process.

A good correlation (i.e. root mean square error or RMSE of ±3.3) was achieved with the calibration of the flow model and the results are provided in Figure 7-2. The good correlation suggests that the simulated water levels in the simplified model simulation closely resemble the actual water levels. Model predictions in reasonable time frames should therefore provide results to an acceptable level of confidence. However, it should be noted that areas do exist where very little or even no water level data is available which, combined with the heterogeneous nature of the underlying aquifer, are bound to result in over- and/or underestimations of the groundwater elevations.

The calibrated groundwater elevations were exported from the flow model and used to construct a contour map of the steady state groundwater elevations presented in Figure 7-3. Groundwater flow from the MRA area was simulated to be towards the west/north-west as indicated in the abovementioned figure. The average groundwater gradient in this direction was simulated to be approximately 1.8% or nearly 6.5°.

During a steady state simulation, the model runs until groundwater levels reach a state of equilibrium, i.e. total groundwater inflow from natural sources is equal to the total volume of groundwater outflow through natural sinks. On the other hand, in transient state the model runtime is predetermined according to a desired scenario and groundwater levels can now also be affected by artificial sinks and sources as simulated by the modeller.

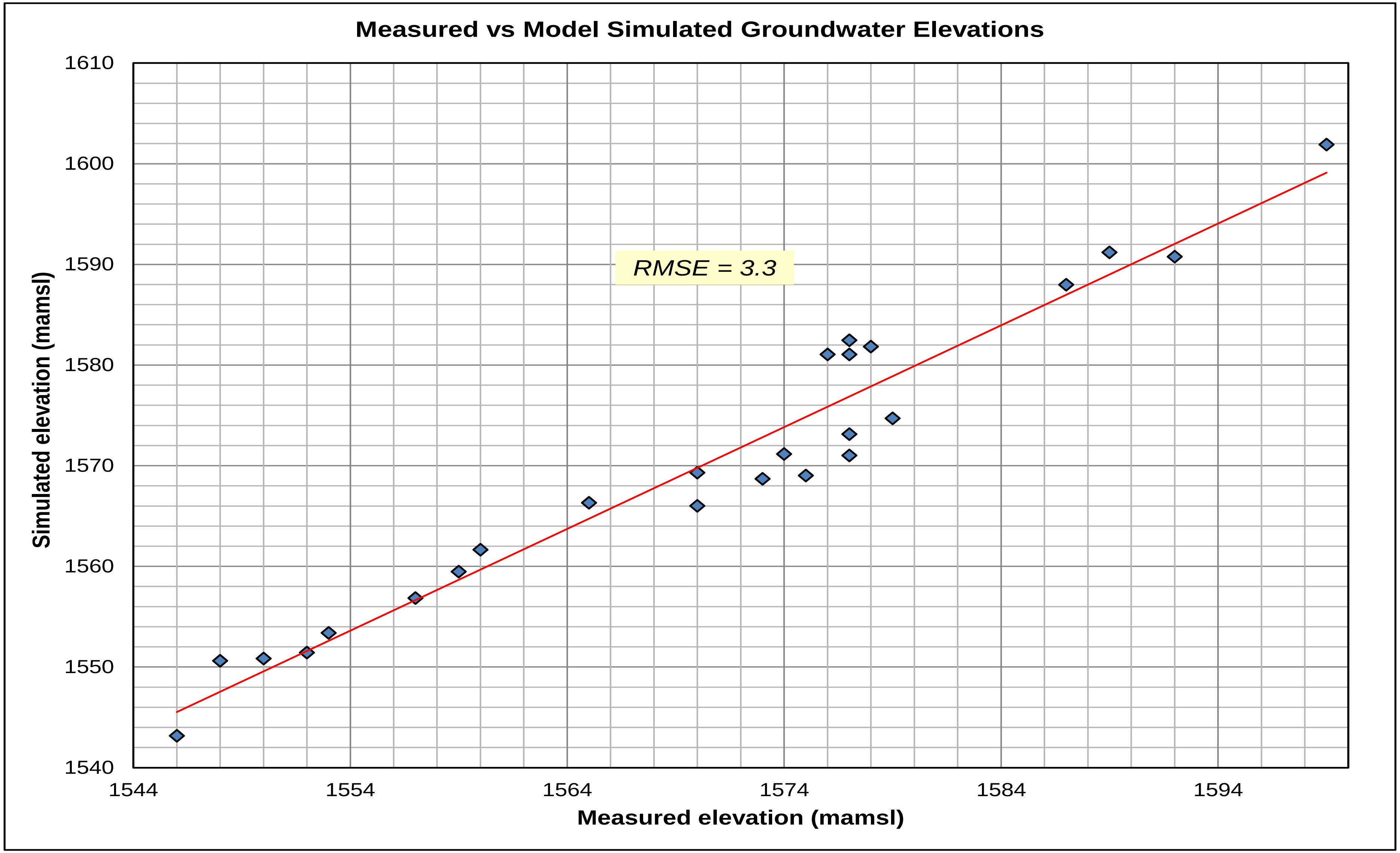
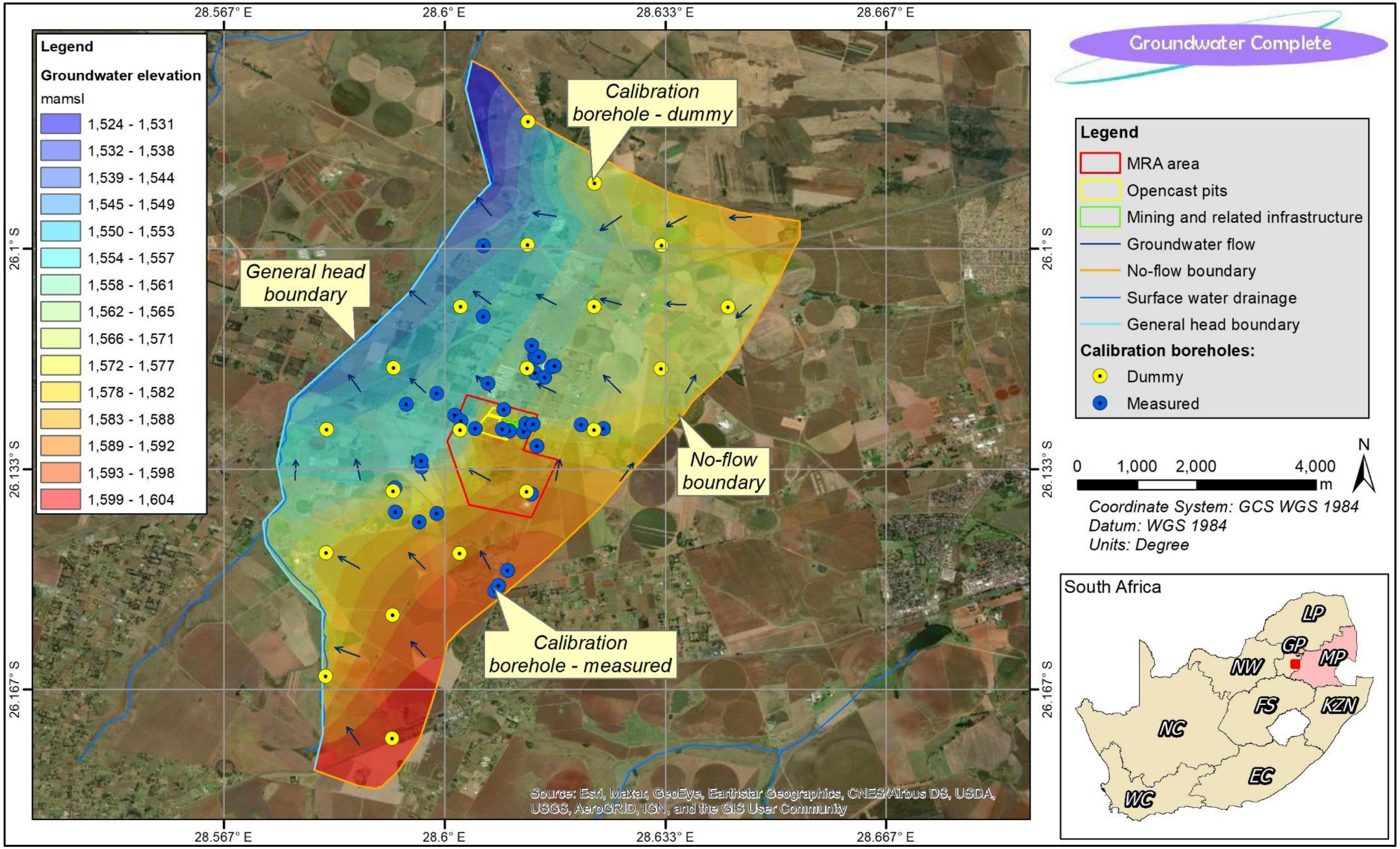


Figure 7-2: Steady state calibration results of the flow model



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 7-3: Steady state calibrated groundwater elevations

7.5 GROUNDWATER SOURCES AND SINKS

Groundwater sources and sinks, in modelling terms, refer to features that either add or remove water from the model area. Only natural sources (e.g. surface water features such as influent rivers and dams and rainfall) and sinks (e.g. effluent rivers and dams and evapotranspiration) are simulated during the steady state calibration of the flow model. Artificial sources (e.g. recharge boreholes) and sinks (e.g. abstraction boreholes and opencast/underground mine voids) are included in the transient state model simulations.

The proposed opencast pits were included in the transient state model simulations as drain nodes, and the volumes of groundwater removed from the model area were simulated/predicted and discussed in Section 7.9.1.

7.6 CONCEPTUAL MODEL

A conceptual model brings together and describes all groundwater and related components that make up the geohydrological environment underlying the project area. A good understanding of the geohydrological environment is central to the accurate assessment of potential future groundwater related impacts associated with the proposed opencast mining and related activities.

A vertical cross section through the proposed opencast pits from north to south is provided in Figure 7-4. Based on the assessment of all groundwater related aspects and previous groundwater studies, the hydrogeological system underlying the Rietkol mining right application area was conceptualised as follows:

- The topography of the project area can be described as being gently undulating with surface elevations (±4 km radius) varying from approximately 1 540 to 1 620 mamsl.
- A prominent water course, namely the Koffiespruit, is located ± 2.5 kilometers west of the MRA area and within the same catchment.
- The project area receives on average approximately 720 mm of rainfall annually, and the average annual evaporation rate is nearly 1 530 mm.
- Hydrocensus/groundwater user surveys were conducted by Aquatico Scientific on the MRA area and surrounding properties. A total of 86 boreholes, four dams and one cave were located. Most of the boreholes were used for domestic purposes, livestock watering and irrigation at the time of the surveys.
- Recharge to the dolomitic aquifer underlying the northern half of the MRA area was estimated with the Chloride Method to be approximately 13% of the mean annual rainfall.
- Stratigraphically, the project area occurs on the boundary between the Malmani Subgroup and the Pretoria Group of the Transvaal Supergroup *(SACS, 1980)*. The Malmani Subgroup consists of several hundred meters of cherty, stromatolitic dolostone of about 2.6 billion years old that was deposited on an intracratonic marine basin under tidal conditions *(Button, 1986)*. The Malmani Subgroup and the Pretoria Groups are disconformably overlain by late Carboniferious – Permian diamictite, shale and sandstone of the Karoo Supergroup.

- The Proterozoic and Permian strata are intruded by several generations of diabase and dolerite sills and dykes. A flat dipping dolerite sill of approximately 30 m thick cuts through the Rietkol quartzite deposit and divides it into an Upper and a Lower Quartzite band. Due to the thickness of the sill, mining will not cut through the sill and only the Upper Quartzite band will be mined to a depth of approximately 30 to 50 meters.
- A waste classification (i.e. total concentration digestion and distilled water leaching tests) was conducted on two composite samples (i.e. tailings material and waste rock) that were collected from the operational Thaba Chueu mine (previously known as SamQuarz). The tests concluded that both samples are a Type 4 or inert waste, requiring a Class D (or GSB-) disposal facility.
- Based on information gathered during the drilling of four monitoring boreholes, the unsaturated zone is predominantly composed of soil/clay and weathered bedrock (mostly chert and quartzite).
- The average transmissivity of the dolomitic aquifer that underlies the northern half of the MRA area was calculated to be in the region of 22 m^2/d. On the other hand, the Karoo aquifer underlying the southern half of the MRA area displayed a much lower transmissivity of nearly 6.5 m^2/d. The lowest transmissivities were calculated for the Rietkol quartzite deposit, which displayed an average of approximately 0.9 m^2/d.
- Groundwater levels in the project area generally vary between ± 9 and 100 mbs, with the average being ± 42 mbs.
- Numerous potential sources of groundwater contamination are planned for the MRA area. On the positive side, most of these potential source areas pose no real threat to the underlying aquifer in terms of impacts on groundwater quality. Both the target mineral and host rock that will be processed in the plant and then stockpiled/dumped are chemically inert and will therefore not react with oxygen and water to create poor quality leachate (such as acid mine/rock drainage).
- Groundwater from most of the user and monitoring boreholes is considered to be of good quality and is suitable for human consumption if compared with the South African National Standards *(SANS 241:2015)*. Exceedances in terms of the groundwater nitrate content are, however, observed for some of the user boreholes.
- The dolomitic aquifer scored a groundwater vulnerability rating of 9 and is therefore regarded as being highly vulnerable.
- Three aquifer systems are present, namely a shallow, semi-confined or unconfined aquifer that occurs in the transitional soil and weathered bedrock zone or sub-outcrop horizon. A deeper secondary fractured rock aquifer that is hosted within the sedimentary rocks of the Karoo Supergroup, which underlies the southern half of the MRA area. A third, and major aquifer system that is associated with the Malmani Subgroup (Transvaal Supergroup) dolomite that underlies the northern half of the MRA area.
- The GQM rating for the project area calculates to 18, which means that no impact is allowed.

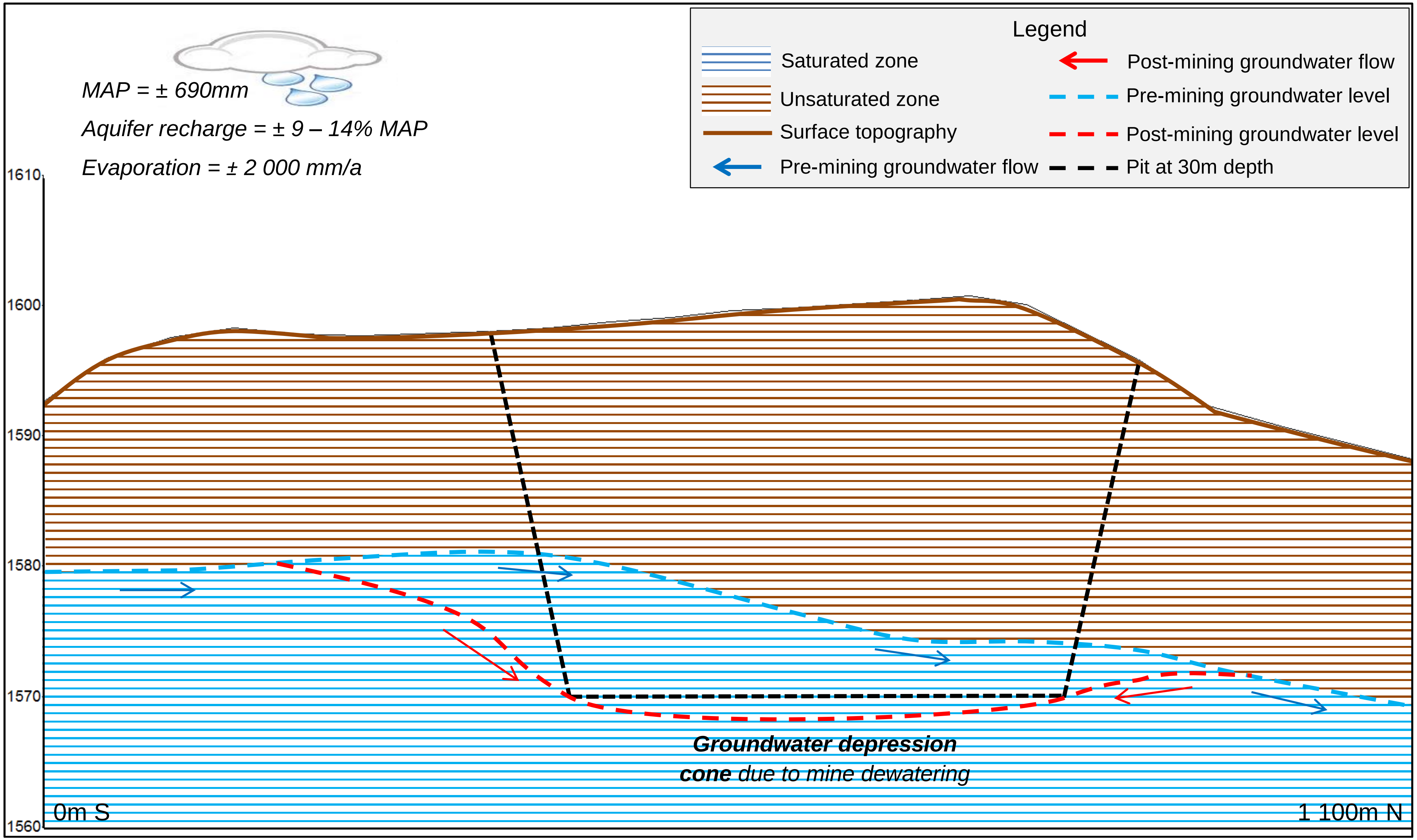


Figure 7-4: Vertical cross section from south to north through the proposed opencast pits

7.7 FLOW MODEL

Impacts on groundwater levels are expected to occur as a result of pit dewatering. The flow model was therefore used to simulate this potential impact. The extent of the groundwater level impacts is governed by the hydraulic properties (transmissivity) of the aquifer host rock, storativity and time. The influence of transmissivity on the radius/extent of the cone of depression (water level impact) is explained by means of the following equation *(Bear, 1979)*:

$$R(t) = 1.5(Tt/S)^{1/2}$$

Where R = *Radius (m),*
T = *Aquifer transmissivity* (m^2/d)*,*
t = *Time (days),*
S = *Storativity.*

From the equation it is clear that an increase in transmissivity will lead to an increase in the radius of influence (extent of depression cone). Impacts on groundwater levels are therefore expected to extend along transmissive geological structures, which is why structural geological information plays such an important role in the construction of an accurate flow model. Furthermore, such structures may also greatly increase groundwater discharge into the mine void.

A stress period in the model is a period where groundwater flow and contaminant transport conditions are constant. All time dependent parameters in the model, like drains, rivers, aquifer recharge, contaminant sources, sinks and contaminant concentrations remain constant during the course of a stress period. The total model simulation time of 70 years was subdivided into 15 individual stress periods:

Stress period	Simulation time	Comments
1 - 13	20 Years	Simulate operational phase activities, i.e. active opencast mining and utilisation of mining and related infrastructure.
14 - 15	50 Years	Simulate post-closure impacts on especially groundwater quality conditions.

Two mining scenarios were simulated, namely:

- **Scenario 1**: Depth of pit floor is on average 30 meters below surface; and
- **Scenario 2**: Average depth of pit floor is 50 meters below surface.

In order to better indicate the impact of the planned opencast mining activities on the surrounding groundwater levels, initial groundwater elevations were subtracted from the simulated groundwater elevations at the time of mine closure (i.e. year 20).

The difference between these two data sets therefore represents the total decrease in water level experienced over the simulation time. This data was used to construct contour maps of the model-simulated groundwater depression cones for both mining scenarios, which are indicated in Figure 7-6 and Figure 7-7 respectively. Groundwater user boreholes located within the MRA area are also indicated in the abovementioned figures.

Notes:

- *The increase in mining depth from 30 to 50 mbs will affect the outcome of both the groundwater flow (water levels) and contaminant transport (plume migration) models.*

7.8 CONTAMINANT TRANSPORT MODEL

The calibrated flow model was used as a basis for the contaminant transport model, which was constructed to simulate the post closure migration of contaminants in the aquifer system underlying the MRA area. The proposed opencast pits and entire surface area of the mining operation were simulated in the contaminant transport model.

In order to better indicate the impact of the potential sources on the surrounding groundwater quality conditions, contamination contours were exported from the contaminant transport model at mine closure, but also after a 25- and 50-years post closure simulation.

The contamination was simulated by applying contaminated recharge to the entire surface areas of the potential sources. The source areas were assigned theoretical concentrations of 100%, therefore the results of the model simulations are regarded as being qualitative rather than quantitative.

Notes:

- *Throughout the discussions reference is made to “contamination plumes“ instead of “pollution plumes”. Both contamination and pollution refer to any substance (either organic or inorganic) that may potentially enter the groundwater as a result of the planned mining and/or related activities. In light of this investigation, as long as this substance does not adversely affect the environment and groundwater user, it is referred to as contamination. The opposite holds true for pollution, meaning that it refers to any and all substances that affect the groundwater quality to such an extent that it is harmful to both the environment and groundwater user and it becomes unsuitable to apply to its original use.*
- *Most of the potential source areas will be covered by concrete or lined with some form of a clay or synthetic liner to prevent contamination from entering the underlying aquifer and eventually contaminating the groundwater. Sources were however simulated without any such form of surface cover or lining, therefore the model results represent a worst-case scenario.*

7.9 MODEL RESULTS

7.9.1 FLOW MODEL

The results of the numerical groundwater flow model simulations are summarised below:

	Scenario 1 – Maximum pit depth of 30 meters	**Scenario 2 – Maximum pit depth of 50 meters**
Simulated drawdown	20 meters at LOM	40 meters at LOM
Area affected	522 460 m^2 at LOM	724 430 m^2 at LOM
Simulated groundwater influx	90 m^3/d at LOM	240 m^3/d at LOM

The pit floor was simulated to intersect the water table from year one during both mining scenarios, which resulted in the following model-simulated groundwater influx volumes:

Year	**Scenario 1 - 30m mining depth**		**Scenario 2 - 50m mining depth**	
	Influx (m^3/d)	**Influx (l/s)**	**Influx (m^3/d)**	**Influx (l/s)**
1	20	0.2	97	1.1
2	19	0.2	102	1.2
3	18	0.2	95	1.1
4	36	0.4	138	1.6
5	35	0.4	133	1.5
6	34	0.4	127	1.5
7	35	0.4	128	1.5
8	36	0.4	128	1.5
9	40	0.5	136	1.6
10	44	0.5	145	1.7
11	45	0.5	145	1.7
12	46	0.5	145	1.7
13	58	0.7	171	2.0
14	69	0.8	196	2.3
15	76	0.9	210	2.4
16	83	1.0	223	2.6
17	86	1.0	228	2.6
18	89	1.0	232	2.7
19	90	1.0	235	2.7
20	90	1.0	237	2.7

The groundwater influx for Scenario 1 was simulated to increase from approximately 20 m^3/d at the end of year one to a maximum of ± 90 m^3/d at mine closure. The influx simulated for Scenario 2 increased from ± 100 m^3/d to nearly 240 m^3/d at the end of the twentieth and final year.

An area of approximately 522 460 m^2 was simulated to be affected by the Scenario 1 pit dewatering activities, while a slightly larger area of ± 724 430 m^2 was simulated for Scenario 2. The model-simulated groundwater depression cones for Scenario 1 and Scenario 2 are indicated in Figure 7-6 and Figure 7-7 respectively.

Model-simulated head-time curves are provided below in Figure 7-5, which give an indication of the time it would take groundwater levels to recover. Fifty years after mining has ceased, the groundwater level (where the impact of pit dewatering was greatest) was simulated to have recovered by ± 91% for Scenario 1, while a ± 89% recovery was simulated for Scenario 2. The degree of water level recovery depends on the post closure backfilling of the pit. The closer the pit is backfilled to the pre-mining groundwater elevation, the higher the degree of water level recovery.

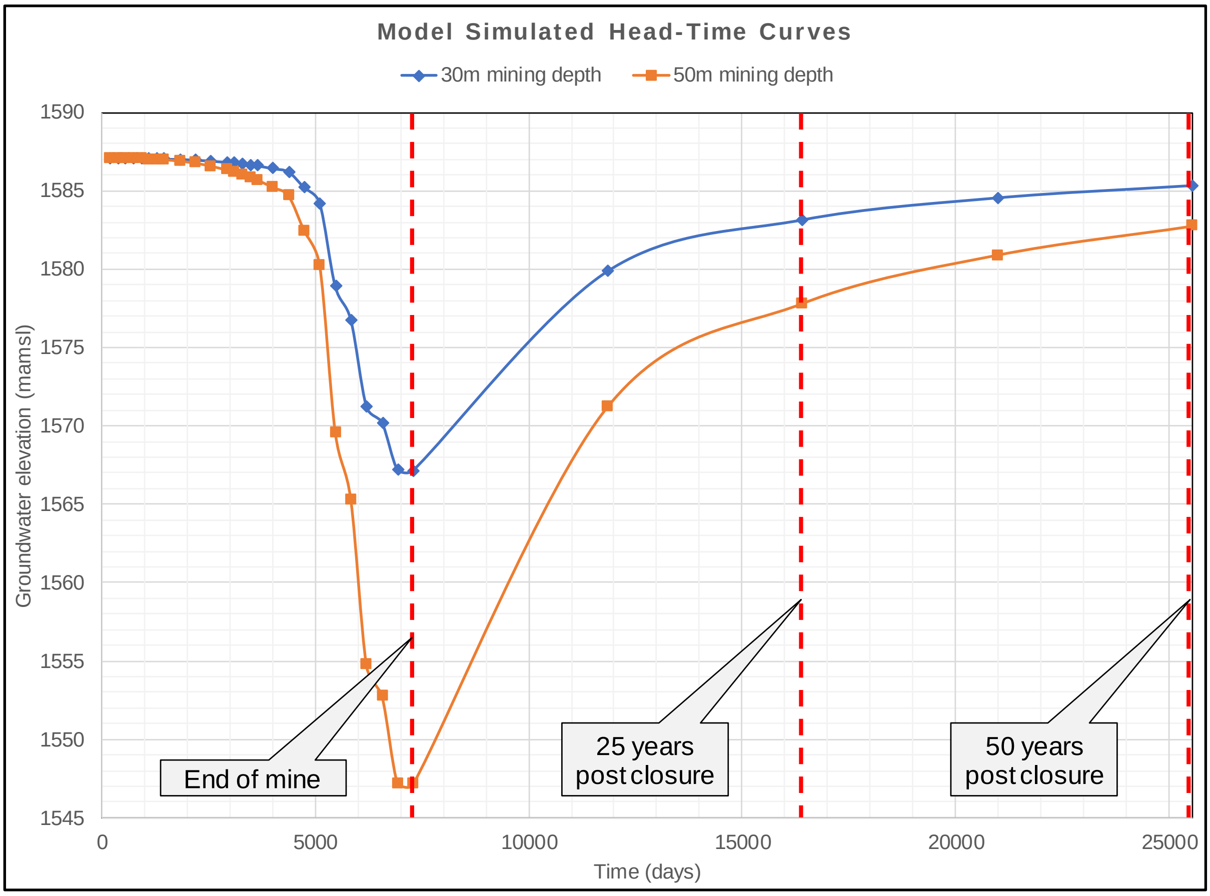


Figure 7-5: Model-simulated head-time curves

Notes:

- *The water level impacts do extend beyond the MRA area, however no groundwater user boreholes are located within these affected areas.*
- *The sensitive dolomitic aquifer will not be intersected by the proposed opencast pits. The sediment/sand (now quartzite after low grade metamorphism) was deposited into an ancient dolomite sinkhole. The proposed opencast pits are situated more or less in the center of this deposit – meaning that nearly at all times there will be a ± 90 to 300*

meters buffer, or low transmissivity quartzite between the pit and surrounding dolomite. The quartzite deposit in its entirety is expected to act as a buffer between the proposed mining activities and the surrounding and underlying dolomite.

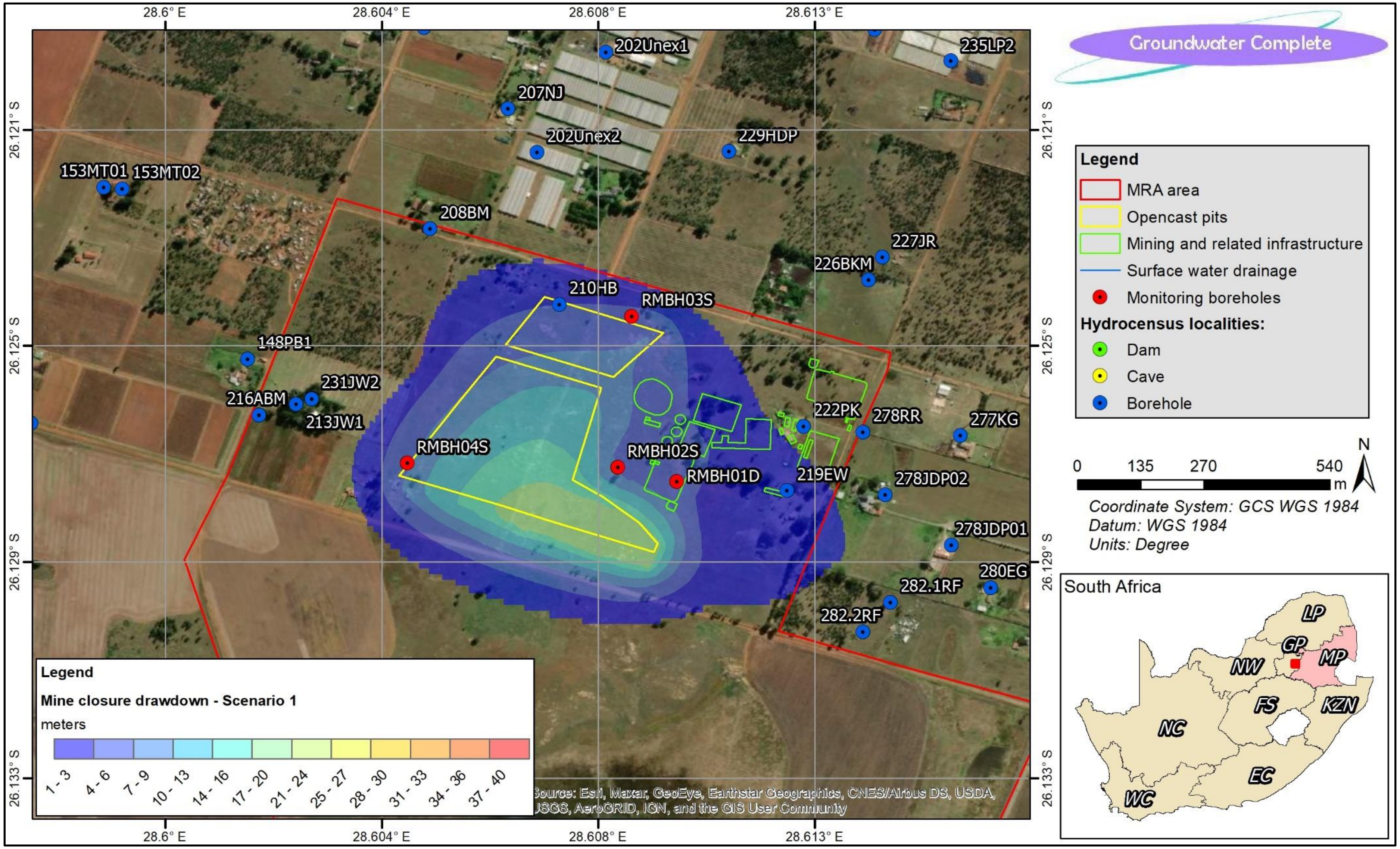


Figure 7-6: Groundwater drawdown cone at mine closure - Scenario 1

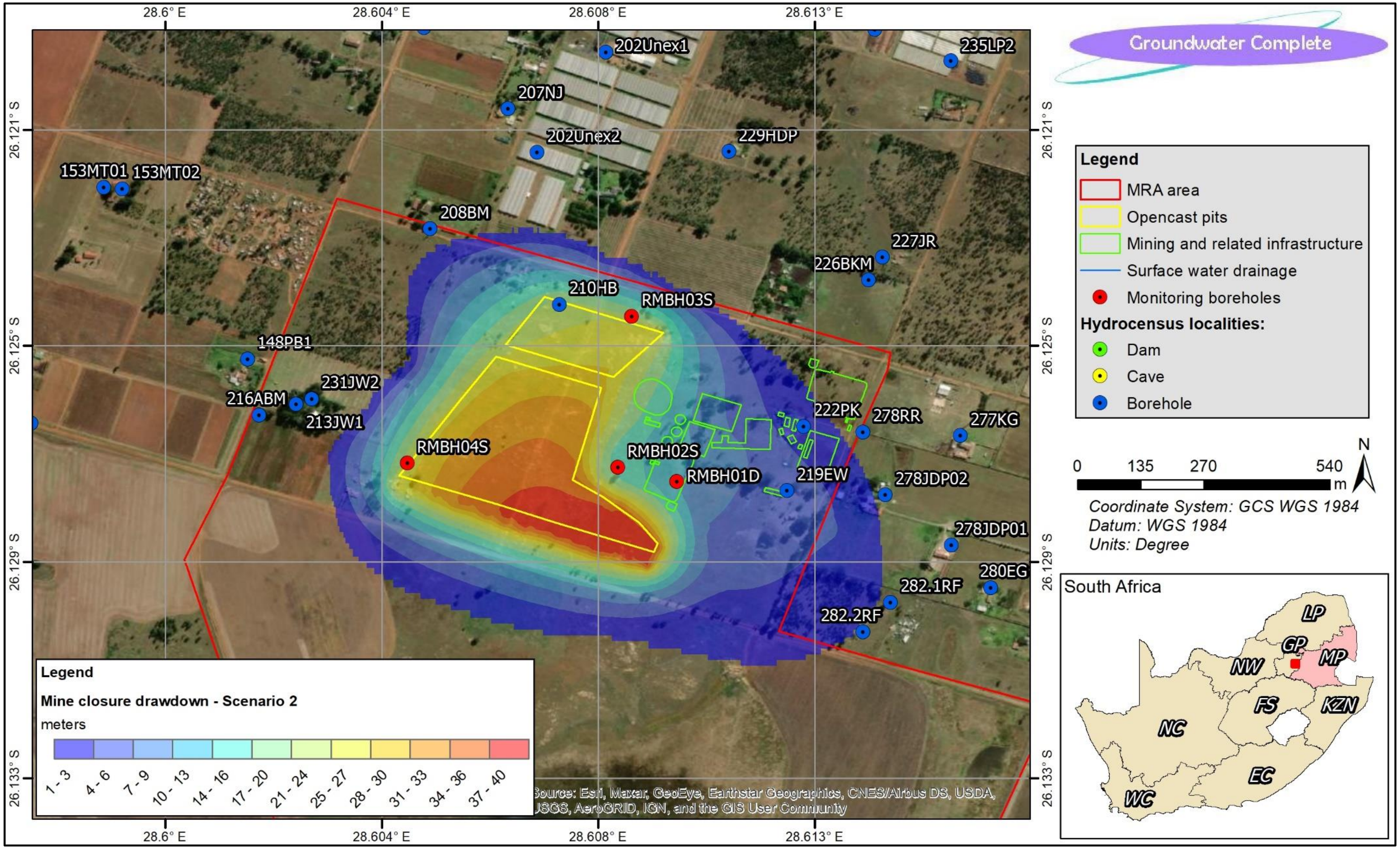


Figure 7-7: Groundwater drawdown cone at mine closure - Scenario 2

7.9.2 CONTAMINANT TRANSPORT MODEL

The proposed opencast pits were gradually included in the model simulations as source areas as mining progressed over a 20-year period, while the entire footprint of the mining and related infrastructure area was included from year one. The rehabilitated opencast pits were also included in the post closure simulations, while all mining and related infrastructure were removed after mine closure.

The results of the numerical contaminant transport model simulations are summarised below:

	Scenario 1 – Maximum pit depth of 30 meters	**Scenario 2 – Maximum pit depth of 50 meters**
Area affected at closure	338 900 m^2	268 500 m^2
Area affected at 25 years post closure	462 600 m^2	340 100 m^2
Area affected at 50 years pot closure	486 300 m^2	410 500 m^2
Plume direction	North-west	North-west
Plume migration rate at closure	5 meters per year	3 meters per year
Plume migration rate post closure	9 meters per year	7 meters per year

<u>Mine closure:</u>

The model-simulated groundwater contamination plumes for Scenario 1 and Scenario 2 (at mine closure) are provided in Figure 7-8 and Figure 7-9 respectively. Plume migration simulated for Scenario 1 is somewhat faster than for Scenario 2, i.e. a larger area was simulated to be affected in Scenario 1. The deeper mining depth simulated for Scenario 2 resulted in the opencast pits acting as sinks for both groundwater and contamination, which restricted plume migration – more so than for Scenario 1. Groundwater levels around the pits would firstly need to recover from the impacts of pit dewatering before groundwater and contamination can eventually migrate away and into the down gradient groundwater flow direction.

The contamination plumes for both Scenario 1 and Scenario 2 were simulated to migrate towards the north-west and at rates of ± 5 and 3 meters per year respectively. At mine closure, an area of approximately 338 900 m^2 was simulated to be affected by the Scenario 1 contamination plumes (Figure 7-8), while a slightly smaller affected area of ± 268 500 m^2 was simulated for Scenario 2 (Figure 7-9).

Outside of the MRA area, only user borehole 278RR was simulated to be affected during both mining scenarios. That being said, the abovementioned borehole is located barely 25 meters east of the MRA area on Holding 278, and the plume concentration was simulated to be between 5 and 8% of the original source concentration.

Post closure:

At 50 years post closure, the Scenario 1 (Figure 7-12) contamination plumes were simulated to have increased to 486 300 m^2 in size, while an area of 410 500 m^2 was simulated to be affected by the Scenario 2 plumes (Figure 7-13). Note that no user boreholes located outside of the MRA area were simulated to be adversely affected.

Plume concentrations were simulated to increase over time, however, natural occurring processes such as dilution and dispersion caused concentrations to only reach ± 80% after 50 years from a source concentration of 100%.

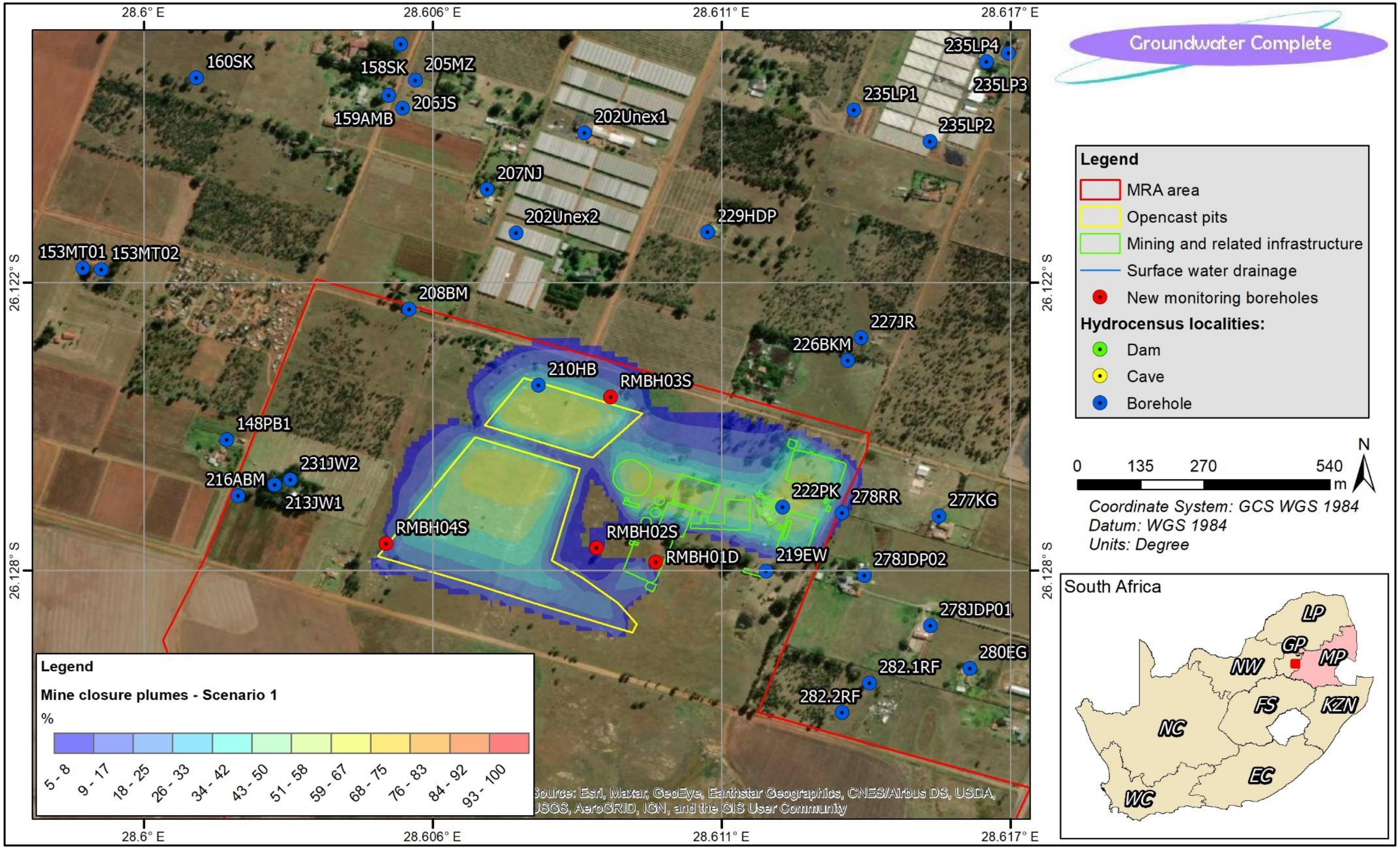


Figure 7-8: Groundwater contamination plumes at mine closure - Scenario 1 (percentage of source)

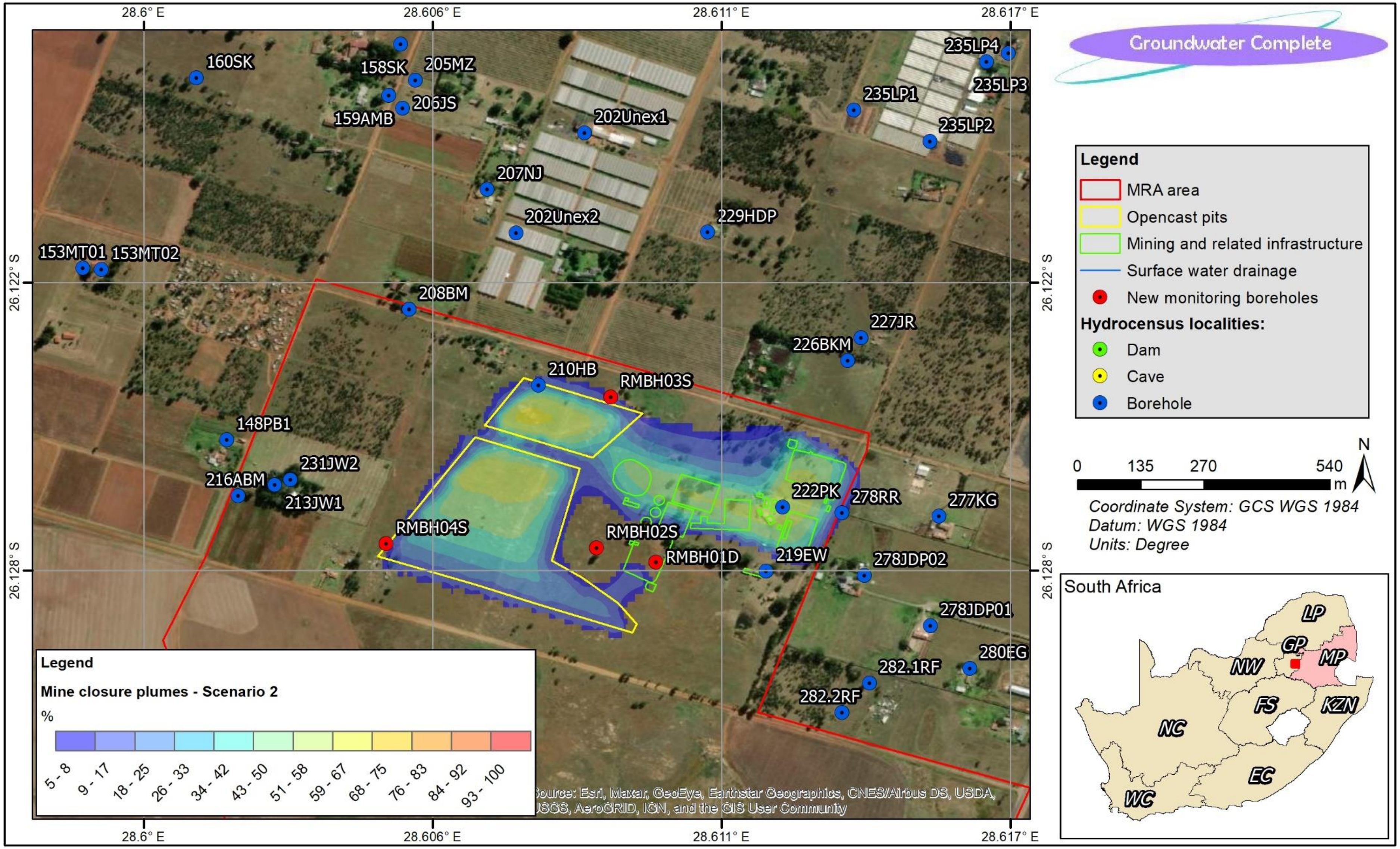


Figure 7-9: Groundwater contamination plumes at mine closure - Scenario 2 (percentage of source)

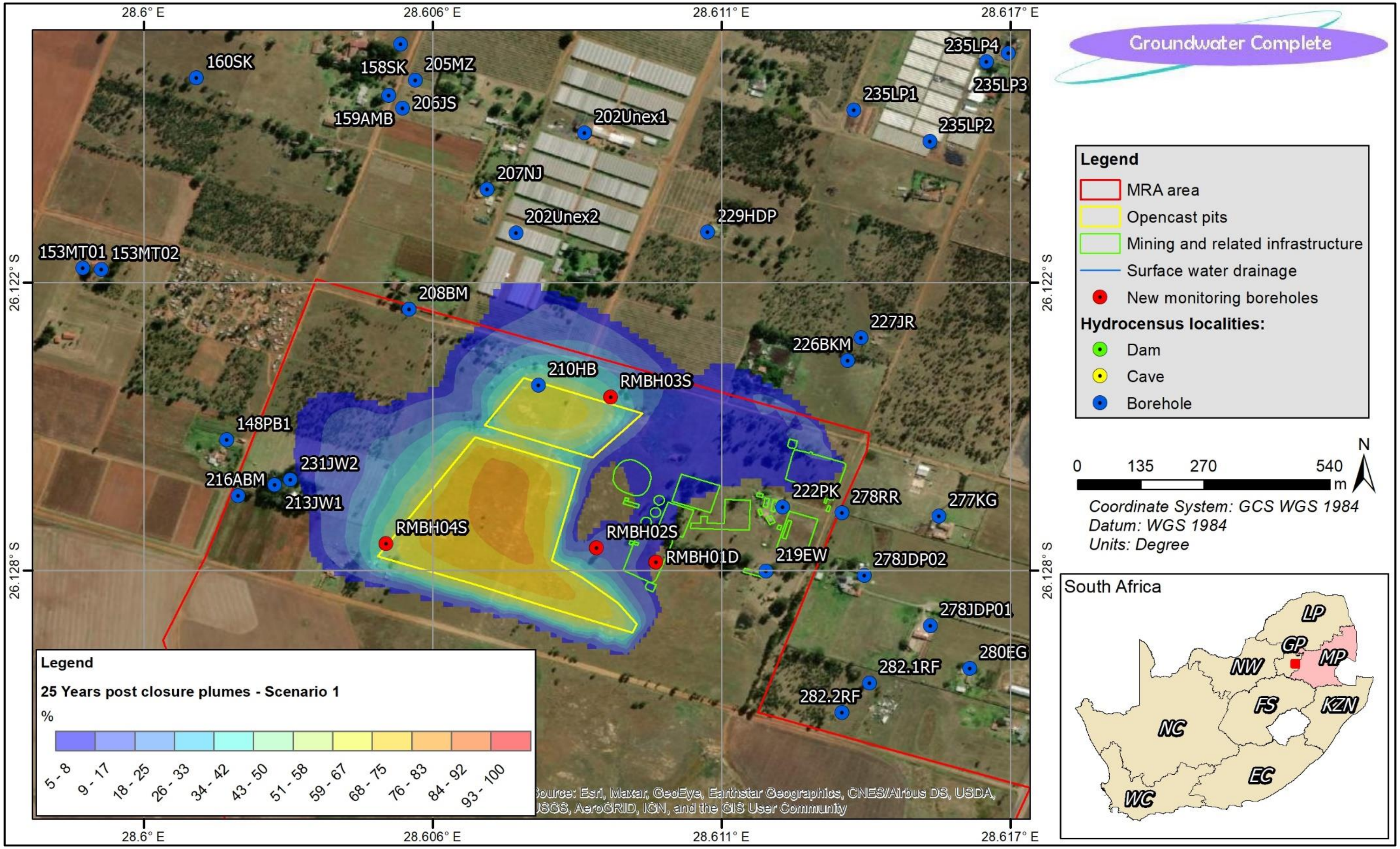


Figure 7-10: Groundwater contamination plumes at 25 years post closure - Scenario 1 (percentage of source)

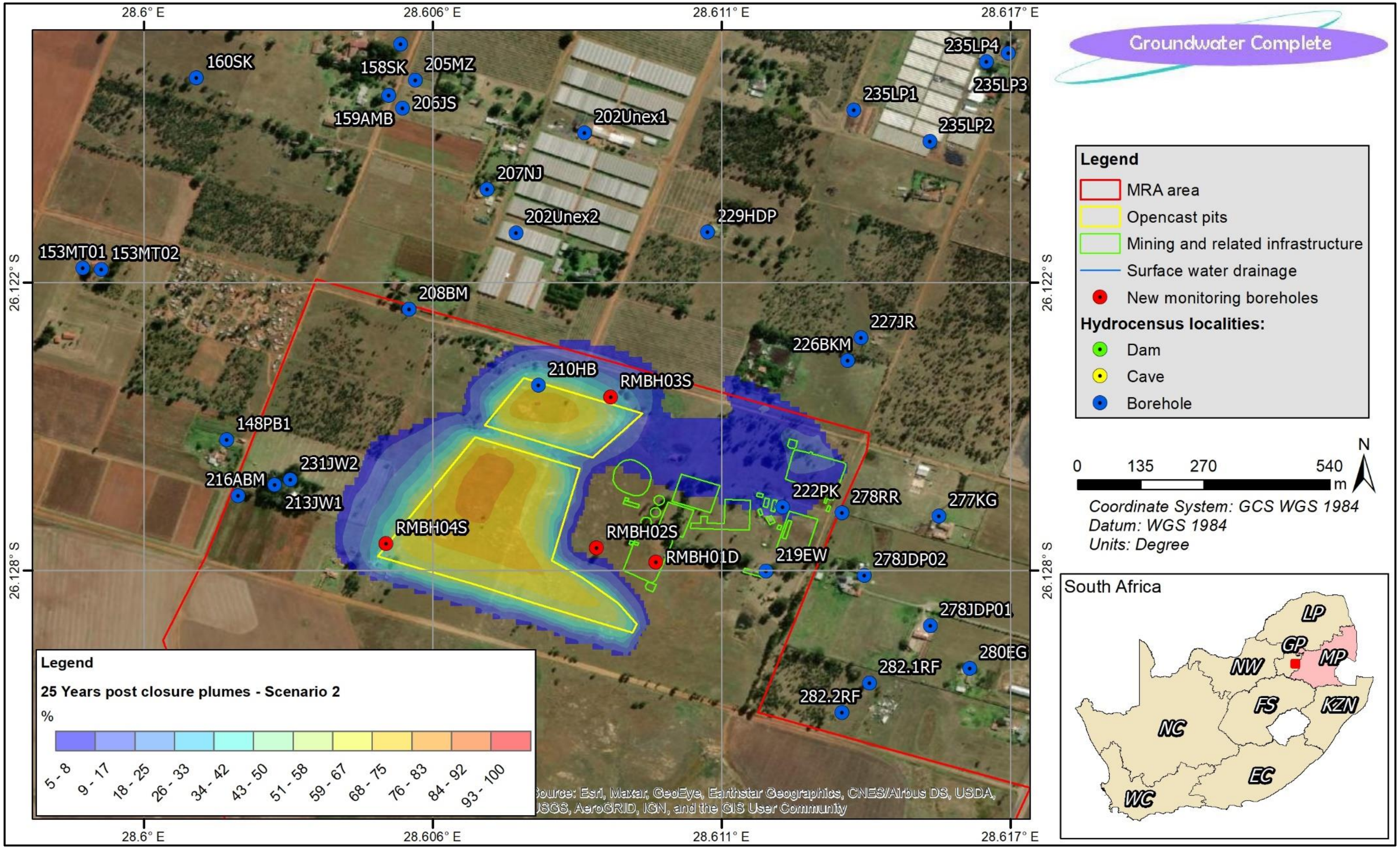


Figure 7-11: Groundwater contamination plumes at 25 years post closure - Scenario 2 (percentage of source)

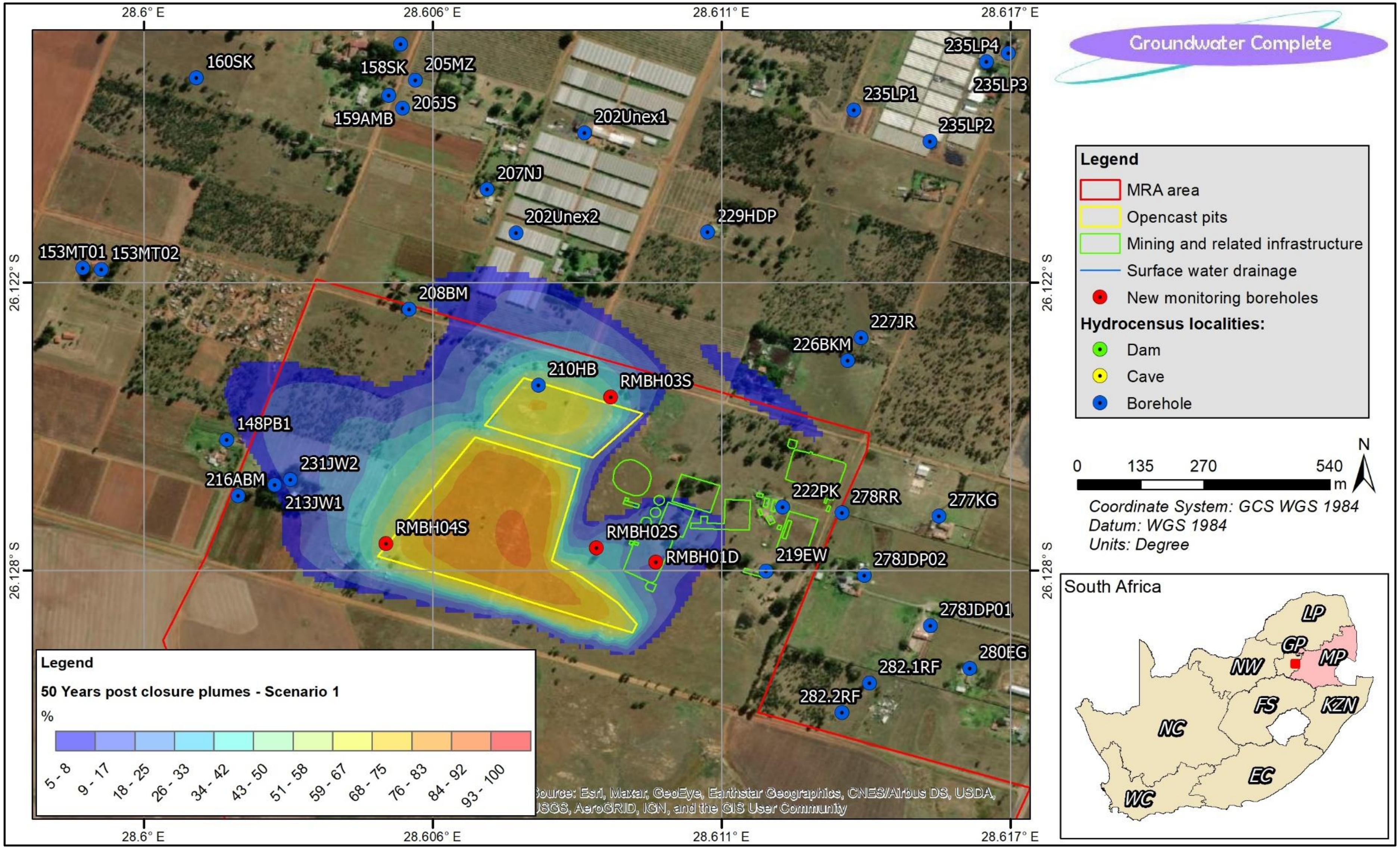


Figure 7-12: Groundwater contamination plumes at 50 years post closure - Scenario 1 (percentage of source)

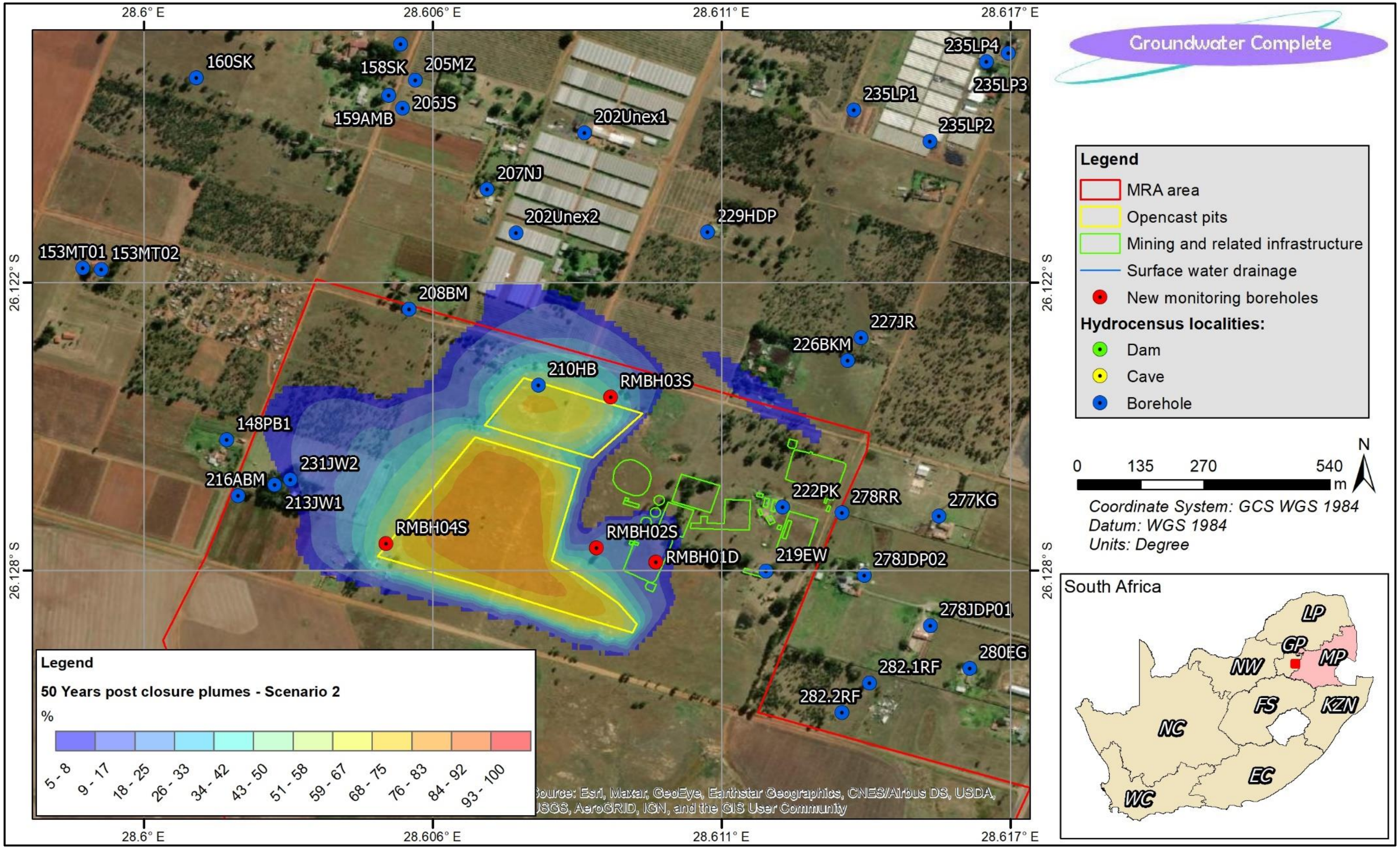


Figure 7-13: Groundwater contamination plumes at 50 years post closure - Scenario 2 (percentage of source)

8 GEOHYDROLOGICAL IMPACT ASSESSMENT

This part of the geohydrological input to the EMP report describes and evaluates the potential impact of the Rietkol Project on the receiving environment. The management program and mitigation measures proposed for the proposed new mining activities from a geohydrological perspective will also be discussed in this section. Generic aspects will be discussed together, but aspects pertaining to one project or source area specifically will be discussed as such with the specific areas. The impact assessment methodology was provided by Jacana Environmentals and is discussed in the following paragraphs.

According to the Information Series 5: Impact Significance of the Integrated Environmental Management Information Series *(Department of Environmental Affairs and Tourism, 2002)*: *'The concept of significance is at the core of impact identification, prediction, evaluation and decision-making. Deciding whether a project is likely to cause significant environmental effects is central to the practice of EIA.'*

Impact assessment is therefore based on the description of an impact, the significance of this impact, and how the impact can be managed and/or mitigated. It must be noted that many of the potential negative consequences can be mitigated successfully. It is however necessary to make a thorough assessment of all possible impacts in order to ensure that environmental considerations are taken into account in a balanced way, thus supporting the aim of minimising any adverse impacts on the environment.

8.1 METHODOLOGY

8.1.1 IMPACT SIGNIFICANCE

Nature and Status

The 'nature' of the impact describes what is being affected and how. The 'status' is based on whether the impact is positive, negative or neutral.

Spatial Extent

'Spatial Extent' defines the spatial or geographical scale of the impact.

Table 8-1: Rating criteria for spatial extent of impact

Category	Rate	Descriptor
Site	1	Site of the proposed development
Local	2	Limited to site and/or immediate surrounds (500m zone of influence)
District	3	Local Municipal Areas
Region	4	District Municipal Areas
Provincial	5	Mpumalanga Province
National	6	South Africa

Category	Rate	Descriptor
International	7	Beyond South African borders

Duration

'Duration' gives the temporal scale of the impact.

Table 8-2: Rating criteria for duration of impact

Category	Rate	Descriptor
Temporary	1	0 – 1 years
Short term	2	1 – 5 years
Medium term	3	5 – 15 years
Long term	4	Where the impact will cease after the operational life of the activity either because of natural process or by human intervention
Permanent	5	Where mitigation either by natural processes or by human intervention will not occur in such a way or in such a time span that the impact can be considered as transient

Probability

The 'probability' describes the likelihood of the impact actually occurring.

Table 8-3: Rating criteria for probability of impact

Category	Rate	Descriptor
Rare	1	Where the impact may occur in exceptional circumstances only
Improbable	2	Where the possibility of the impact materialising is very low either because of design or historic experience
Probable	3	Where there is a distinct possibility that the impact will occur
Highly probable	4	Where it is most likely that the impact will occur
Definite	5	Where the impact will occur regardless of any prevention measures

Intensity

'Intensity' defines whether the impact is destructive or benign, in other words the level of impact on the environment.

Table 8-4: Rating criteria for intensity of impact

Category	Rate	Descriptor
Insignificant	1	Where the impact affects the environment is such a way that natural, cultural and social functions and processes are not affected. Localised impact and a small percentage of the population is affected

Category	Rate	Descriptor
Low	2	Where the impact affects the environment is such a way that natural, cultural and social functions and processes are affected to a limited extent
Medium	3	Where the affected environment is altered in terms of natural, cultural and social functions and processes continue albeit in a modified way
High	4	Where natural, cultural or social functions or processes are altered to the extent that they will temporarily or permanently cease
Very High	5	Where natural, cultural or social functions or processes are altered to the extent that they will permanently cease and it is not possible to mitigate or remedy the impact

Ranking, Weighting and Scaling

The weight of significance define the level or limit at which point an impact changes from low to medium significance, or medium to high significance. The purpose of assigning such weights serves to highlight those aspects that are considered the most critical to the various stakeholders and ensure that the element of bias is taken into account. These weights are often determined by current societal values or alternatively by scientific evidence (norms, etc.) that define what would be acceptable or unacceptable to society and may be expressed in the form of legislated standards, guidelines or objectives.

The weighting factor provides a means whereby the impact assessor can successfully deal with the complexities that exist between the different impacts and associated aspect criteria.

Table 8-5: Rating criteria for weighting factor

Spatial Extent	Duration	Intensity / Severity	Probability	Weighting factor	Significance Rating (SR - WOM) Pre-mitigation	Mitigation Efficiency (ME)	Significance Rating (SR-WM) Post Mitigation
Site (1)	Short term (1)	Insignificant (1)	Rare (1)	Low (1)	Low (0 – 19)	High (0.2)	Low (0 – 19)
Local (2)	Short to Medium term (2)	Minor (2)	Unlikely (2)	Low to Medium (2)	Low to Medium (20 – 39)	Medium to High (0.4)	Low to Medium (20 – 39)
District (3)							
Regional (4)	Medium term (3)	Medium (3)	Possible (3)	Medium (3)	Medium (40 – 59)	Medium (0.6)	Medium (40 – 59)
Provincial (5)	Long term (4)	High (4)	Likely (4)	Medium to High (4)	Medium to High (60 – 79)	Low to Medium (0.8)	Medium to High (60 – 79)
National (6)							
International (7)	Permanent (5)	Very high (5)	Almost certain (5)	High (5)	High (80 – 110)	Low (1.0)	High (80 – 110)

Impact significance without mitigation (WOM)

Following the assignment of the necessary weights to the respective aspects, criteria are summed and multiplied by their assigned weightings, resulting in a value for each impact (prior to the implementation of mitigation measures).

Equation 1:

Significance Rating (WOM) = (Extent + Intensity + Duration + Probability) x Weighting Factor

Effect of Significance on Decision-making

Significance is determined through a synthesis of impact characteristics as described in the above paragraphs. It provides an indication of the importance of the impact in terms of both tangible and intangible characteristics. The significance of the impact "without mitigation" is the prime determinant of the nature and degree of mitigation required.

Table 8-6: Significance of impact

Rating	Rate	Descriptor
Negligible	0	The impact is non-existent or insignificant, is of no or little importance to decision making.
Low	1 – 19	The impact is limited in extent, even if the intensity is major; the probability of occurrence is low and the impact will not have a significant influence on decision making and is unlikely to require management intervention bearing significant costs.
Low to Medium	20 – 39	The impact is of importance, however, through the implementation of the correct mitigation measures such potential impacts can be reduced to acceptable levels. The impact and proposed mitigation measures can be considered in the decision-making process
Medium	40 – 59	The impact is significant to one or more affected stakeholder, and its intensity will be medium or high; but can be avoided or mitigated and therefore reduced to acceptable levels. The impact and mitigation proposed should have an influence on the decision.
Medium to High	60 – 79	The impact is of major importance but through the implementation of the correct mitigation measures, the negative impacts will be reduced to acceptable levels.
High	80 – 110	The impact could render development options controversial or the entire project unacceptable if it cannot be reduced to acceptable levels; and/or the cost of management intervention will be a significant factor and must influence decision-making.

8.1.2 MITIGATION

"Mitigation" is a broad term that covers all components of the 'mitigation hierarchy' defined hereunder. It involves selecting and implementing measures, amongst others, to conserve biodiversity and to protect, the users of biodiversity and other affected stakeholders from potentially adverse impacts as a result of mining or any other land use. The aim is to prevent adverse impacts from occurring or, where this is unavoidable, to limit their significance to an acceptable level. Offsetting of impacts is considered to be the last option in the mitigation hierarchy for any project.

The mitigation hierarchy in general consists of the following in order of which impacts should be mitigated:

- Avoid/prevent impact: can be done through utilising alternative sites, technology and scale of projects to prevent impacts. In some cases if impacts are expected to be too high the “no project” option should also be considered, especially where it is expected that the lower levels of mitigation will not be adequate to limit environmental damage and eco-service provision to suitable levels.
- Minimise (reduce) impact: can be done through utilisation of alternatives that will ensure that impacts on biodiversity and eco-services provision are reduced. Impact minimisation is considered an essential part of any development project.
- Rehabilitate (restore) impact is applicable to areas where impact avoidance and minimisation are unavoidable where an attempt to re-instate impacted areas and return them to conditions which are ecologically similar to the pre-project condition or an agreed post project land use, for example arable land. Rehabilitation can however not be considered as the primary mitigation toll as even with significant resources and effort rehabilitation that usually does not lead to adequate replication of the diversity and complexity of the natural system. Rehabilitation often only restores ecological function to some degree to avoid ongoing negative impacts and to minimise aesthetic damage to the setting of a project. Practical rehabilitation should consist of the following phases in best practice:
  - Structural rehabilitation which includes physical rehabilitation of areas by means of earthworks, potential stabilisation of areas as well as any other activities required to develop a long terms sustainable ecological structure;
  - Functional rehabilitation which focuses on ensuring that the ecological functionality of the ecological resources on the subject property supports the intended post closure land use. In this regard special mention is made of the need to ensure the continued functioning and integrity of wetland and riverine areas throughout and after the rehabilitation phase;
  - Biodiversity reinstatement which focuses on ensuring that a reasonable level of biodiversity is re-instated to a level that supports the local post closure land uses. In this regard special mention is made of re-instating vegetation to levels which will allow the natural climax vegetation community of community suitable for supporting the intended post closure land use; and
  - Species reinstatement which focuses on the re-introduction of any ecologically important species which may be important for socio-cultural reasons, ecosystem functioning reasons and for conservation reasons. Species re-instatement need only occur if deemed necessary.
- Offset impact: refers to compensating for latent or unavoidable negative impacts on biodiversity. Offsetting should take place to address any impacts deemed to be unacceptable which cannot be mitigated through the other mechanisms in the mitigation hierarchy. The objective of biodiversity offsets should be to ensure no net

loss of biodiversity. Biodiversity offsets can be considered to be a last resort to compensate for residual negative impacts on biodiversity.

According to the DMR (2013) "Closure" refers to the process for ensuring that mining operations are closed in an environmentally responsible manner, usually with the dual objectives of ensuring sustainable post-mining land uses and remedying negative impacts on biodiversity and ecosystem services.

The significance of residual impacts should be identified on a regional as well as national scale when considering biodiversity conservation initiatives. If the residual impacts lead to irreversible loss or irreplaceable biodiversity the residual impacts should be considered to be of very high significance and when residual impacts are considered to be of very high significance, offset initiatives are not considered an appropriate way to deal with the magnitude and/or significance of the biodiversity loss. In the case of residual impacts determined to have medium to high significance, an offset initiative may be investigated. If the residual biodiversity impacts are considered of low significance no biodiversity offset is required.

Impact significance with mitigation measures (WM)
In order to gain a comprehensive understanding of the overall significance of the impact, after implementation of the mitigation measures, it is necessary to re-evaluate the impact.

Mitigation Efficiency (ME)
The most effective means of deriving a quantitative value of mitigated impacts is to assign each significance rating value (WOM) a mitigation effectiveness (ME) 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. Thus, the lower the assigned value the greater the effectiveness of the proposed mitigation measures and subsequently, the lower the impacts with mitigation.

Equation 2:
Significance Rating (WM) = Significance Rating (WOM) x Mitigation Efficiency (ME)

Mitigation Efficiency is rated out of 1 as explained in the table below.

Table 8-7: Rating criteria for mitigation efficiency

Category	Rate	Descriptor
Not Efficient (Low)	1	Mitigation cannot make a difference to the impact
Low to Medium	0.8	Mitigation will minimize impact slightly
Medium	0.6	Mitigation will minimize impact to such an extent that it becomes within acceptable standards
Medium to High	0.4	Mitigation will minimize impact to such an extent that it is below acceptable standards
High	0.2	Mitigation will minimize impact to such an extent that it becomes insignificant

Significance Following Mitigation (SFM)

The significance of the impact after the mitigation measures are taken into consideration. The efficiency of the mitigation measure determines the significance of the impact. The level of impact is therefore seen in its entirety with all considerations taken into account.

8.2 IMPACT RATING

8.2.1 CONSTRUCTION PHASE – GROUNDWATER QUANTITY

The following construction phase activities have the potential to affect the underlying groundwater:

Activity	Potential impact and mitigation
Land clearance	**Impact:** Clearing of topsoil from footprint areas can increase infiltration rates of water to the groundwater system, ultimately leading to an increase in groundwater levels. This potential impact is not necessarily a negative one. **Mitigation:** Mitigation is not possible.

8.2.2 CONSTRUCTION PHASE – GROUNDWATER QUALITY

The following construction phase activities have the potential to affect the underlying groundwater:

Activity	Potential impact and mitigation
Waste/Hydrocarbon handling	**Impact:** Handling of waste and the transport of building material can cause various types of spills (especially hydrocarbons) that may potentially infiltrate and contaminate the underlying groundwater system. **Mitigation:** Waste should to be discarded in the allocated waste area. The waste area should be bunded. Spills should be cleaned up immediately. The relevant authorities should be notified in the event of a significant spill. Solid waste must either be stored on-site in an approved waste disposal area or removed by credible contractors.

Table 8-8: Impact ratings for construction phase

Activity	Nature of impact	Duration	Extent	Probability	Intensity	Weighting factor	Pre-mitigation impact significance	Mitigation efficiency	Post-mitigation impact significance
Groundwater Quantity									
Land clearance	Positive	Short term	Site specific	Highly probable	Insignificant	Low	Low	Low	Low
Groundwater Quality									
Waste/Hydrocarbon handling	Negative	Short term	Site specific	Highly probable	Low	Low to medium	Low	Medium to high	Low

8.2.3 OPERATIONAL PHASE – GROUNDWATER QUANTITY

The following operational phase activities have the potential to affect the underlying groundwater:

Activity	Potential impact and mitigation
Opencast mining	**Impact:** Opencast mining, when occurring below the water table, results in an influx of groundwater. Pit dewatering is then required to ensure dry and safe mining conditions, which ultimately leads to a lowering of the local groundwater levels. **Mitigation:** No mitigation measures are available for when mining occurs below the local water table. Only by remaining above the water table can this impact be avoided.

The hydrocensus/user survey found that groundwater is used extensively throughout the project area, especially for irrigation and domestic purposes (66% of all boreholes). Groundwater levels are in most instances therefore no longer representative of the ambient/unaffected conditions.

8.2.4 OPERATIONAL PHASE – GROUNDWATER QUALITY

The following operational phase activities have the potential to affect the underlying groundwater:

Activity	Potential impact and mitigation
Tailings disposal, topsoil, waste rock and product stockpiling (plant area)	**Impact:** The soil and ROM material are chemically inert, meaning that any leachate originating from these stockpile areas is expected to be of acceptable quality. However, leachate from these stockpiles may contain remnants of the nitrate-based explosives used in the mining process. **Mitigation:** Surface areas should be lined to prevent potentially poor quality leachate from contaminating the underlying groundwater. Surface areas should be bunded to prevent clean surface water runoff from being contaminated by dirty surface areas. Stockpiles and dirty footprint areas should be kept as small as practically possible.
Dirty water retaining	**Impact:** Water retaining facilities such as the planned pollution control/recycling dam are designed and constructed with the objective to prevent any poor quality water from entering the underlying aquifer and contaminating the groundwater. Poor

	management and maintenance of such facilities may however lead to spills and/or leakages that could contaminate the groundwater. **Mitigation:** All water retaining facilities should be lined with an impervious liner to prevent dirty water from reaching the underlying aquifer and contaminating the groundwater. Spills should be cleaned up immediately. Authorities should be notified of all spills. Proper management and regular inspections for leakages are strongly recommended.
Workshops and washing/cleaning bays	**Impact:** Impacts on the groundwater only occur through leachate formation from dirty surface areas. Impacts thus only occur as a result of rainfall recharge or when water is introduced in some form where leachate can form that seeps to the groundwater. Organic contaminants are usually the main pollutants of concern (e.g. oil, grease, diesel, petrol, hydraulic fluid, solvents, etc.). **Mitigation:** Surface areas should be lined to prevent poor quality seepage from reaching the aquifer and contaminating the underlying groundwater. Surface areas should be bunded to prevent clean surface water runoff from being contaminated by dirty surface areas. Spills should be cleaned up immediately. Relevant authorities should be notified of all spills.

Table 8-9: Impact ratings for operational phase

Activity	Nature of impact	Duration	Extent	Probability	Intensity	Weighting factor	Pre-mitigation impact significance	Mitigation efficiency	Post-mitigation impact significance
Groundwater Quantity									
Opencast mining at 30 m max depth	Negative	Long term	Local	Definite	Medium	Medium	Medium	Not efficient	Medium
Opencast mining at 50 m max depth	Negative	Long term	Local	Definite	Medium	Medium	Medium	Not efficient	Medium
Groundwater Quality									
Tailings disposal, topsoil, waste rock and ROM stockpiling	Negative	Long term	Local	Highly probable	Low	Low to medium	Low to medium	Low to medium	Low
Dirty water handling and retaining	Negative	Long term	Local	Probable	High	Medium to high	Medium	Medium to high	Low to medium
Workshops and washing/cleaning bays	Negative	Long term	Local	Probable	Medium	Medium	Low to medium	Medium to high	Low

8.2.5 DECOMMISSIONING AND POST CLOSURE PHASE – GROUNDWATER QUANTITY

During this phase it is assumed that active mining has ceased and that the mine void has been rehabilitated. Groundwater levels will slowly start to recover from the impacts of pit dewatering and will tend to return to pre-mining elevations. No additional adverse impacts on groundwater quantity are therefore expected to occur.

Tailings material from the plant will be dumped into the North Block during the operational phase. This fine material will effectively “plug” the mine void, allowing for very little water infiltration and no decanting is therefore envisaged.

Mining and related infrastructure will be demolished during the decommissioning phase and the resulting building rubble is planned to be disposed of into the South Block and the remainder of the void filled with water. Evaporation far exceeds rainfall in the project area (Section 2.2) and with the South Block being located on top of a local topographic high (resulting in limited surface water runoff into the pit), no decanting is expected to occur.

8.2.6 DECOMMISSIONING AND POST CLOSURE PHASE – GROUNDWATER QUALITY

All the surface contaminant sources (plant area and associated infrastructure, pollution control dam and stockpiles) have been decommissioned and no longer pose a threat to the underlying groundwater.

The only remaining sources of contamination are the two rehabilitated opencast pits. No further adverse impacts on groundwater levels are envisaged as groundwater levels are allowed to recover from the impacts of pit dewatering after the decommissioning/closure phase. After groundwater levels have recovered and a new groundwater level equilibrium has been established, contamination from the rehabilitated pits will begin to migrate in the down gradient groundwater flow direction. During this project phase the emphasis is therefore placed on groundwater quality impacts rather than quantity.

The following decommissioning and post-closure phase activities have the potential to affect the underlying groundwater:

Activity	Potential impact and mitigation
Migration of residual contamination away from rehabilitated surface source areas	**Impact:** Even though all mining related surface infrastructure/areas have been removed and rehabilitated, the down gradient movement of residual contamination will continue for some time after closure. **Mitigation:** Dedicated plume monitoring boreholes should be drilled in the down gradient groundwater flow direction and sampled at quarterly intervals to monitor plume migration. Should the monitoring program indicate significant plume migration,

	interception trenches and/or rehabilitation boreholes may be considered.
Migration of contamination away from rehabilitated opencast pits	**Impact:** Building rubble in the South Block is expected to be relatively inert and in itself poses no significant threat to groundwater quality. Tailings material in the North Block should also be inert, however it may contain remnants of the nitrate-based explosives used during mining. These nitrates dissolve readily in water, meaning that the migrating plume may contain nitrate. **Mitigation:** Dedicated plume monitoring boreholes should be drilled in the down gradient groundwater flow direction and sampled at quarterly intervals to monitor plume migration. Should the monitoring program indicate significant plume migration, interception trenches and/or rehabilitation boreholes may be considered.

Table 8-10: Impact ratings for post closure phase

Activity	Nature of impact	Duration	Extent	Probability	Intensity	Weighting factor	Pre-mitigation impact significance	Mitigation efficiency	Post-mitigation impact significance
Groundwater Quality									
Migration of residual contamination from rehabilitated source areas	Negative	Long term	Local	Highly probable	Medium	Medium	Low to medium	Low to medium	Low to medium
Migration of contamination from rehabilitated pits	Negative	Permanent	Local	Highly probable	Low	Low to medium	Low to medium	Low to medium	Low to medium

9 GROUNDWATER MONITORING SYSTEM

9.1 GROUNDWATER MONITORING NETWORK

9.1.1 SOURCE, PLUME, IMPACT AND BACKGROUND MONITORING

Boreholes located close to potential sources of groundwater contamination are generally referred to as **source monitoring boreholes**. The main aim of such a borehole is to detect a contamination breakthrough long before it reaches and adversely affects a groundwater user or sensitive surface water feature (receptors). Note that four dedicated source monitoring boreholes were drilled specifically for the purpose of this investigation and their positions are indicated on Figure 9-1.

Plume monitoring refers to the groundwater quality monitoring points that have been committed specifically for determining the extent, geometry, concentration and migration rate of a groundwater contamination plume downgradient from a source. In the event of a source monitoring borehole detecting a contamination breakthrough, additional plume monitoring boreholes should be developed to ensure that the concentration distribution and extent of the contamination plume are well understood and accurately definable.

9.1.2 SYSTEM RESPONSE MONITORING (GROUNDWATER LEVEL)

The aquifer's response to the expected pit dewatering (Section 7.9.1) should be monitored closely, especially given the high vulnerability of the dolomitic aquifer underlying the northern half of the MRA area. Note that three of the four boreholes that were drilled for source monitoring purposes are also ideally situated for groundwater level monitoring purposes (Figure 9-1).

In terms of flow, all water uses and discharges should be measured on an ongoing basis. The flows include:

- Volumes of groundwater seepage into the opencast pits (dewatering volume); and
- Volumes of contaminated water used for dust suppression.

9.1.3 MONITORING FREQUENCY

Groundwater monitoring (i.e. sampling and water level measurements) should be conducted at quarterly intervals, and the schedule re-assessed by a qualified geohydrologist at a later stage in terms of stability of water levels and quality. If the sampling program requires changes, it should be done so in consultation with the appropriate authorities.

Monitoring in all boreholes (including pit dewatering volumes during the operational phase) should commence prior to any construction/mining. This background information will play an invaluable role in future impact assessments.

9.2 MONITORING PARAMETERS

Groundwater samples should be analysed at a SANAS accredited laboratory for chemical and physical constituents normally affected by the planned mining and related activities (Table 9-1). Laboratory results should be evaluated against the target water quality guidelines for domestic use (i.e. the South African National Standards for drinking water; *SANS 241:2015*).

Monitoring results should be entered into an electronic database as soon as results are available, and at no less than one quarterly interval, allowing:

- Data presentation in tabular format;
- Time-series graphs with comparison abilities;
- Graphical presentation of statistics;
- Linear trend determination;
- Presentation of data, statistics and performance on diagrams and maps; and
- Comparison and compliance with the South African National Standards for drinking water *(SANS 241:2015)*.

Table 9-1: Groundwater constituents for routine analysis

Monitoring	Variable
Quarterly	EC, pH, TDS, total hardness, total alkalinity, calcium, magnesium, sodium, potassium, chloride, sulphate, fluoride, nitrate, iron, manganese, aluminium and turbidity.

Regular assessment and reporting on the monitoring results are recommended to investigate trends and non-compliance over the geohydrological year.

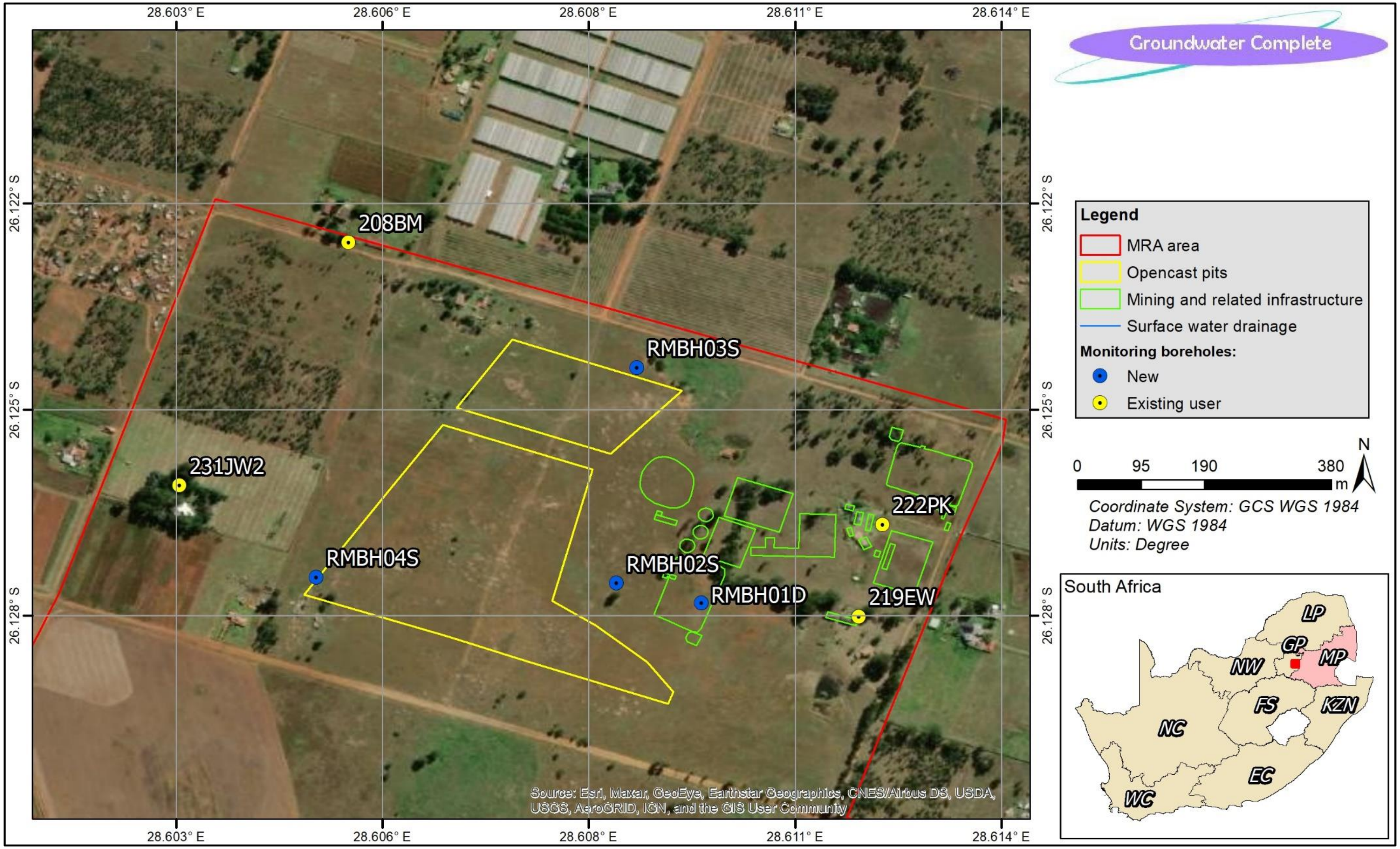
9.3 MONITORING BOREHOLES

Four boreholes (three shallow and one deep) were drilled specifically for groundwater monitoring purposes and their positions are indicated in Figure 9-1. In addition to these boreholes, four of the nearest existing user boreholes should also be included in the monitoring program and their positions are indicated in the abovementioned figure.

As far as possible, the same monitoring points should be used from the construction phase through the operational and decommissioning phases to after mine closure to develop a long data record, which will enable trend analysis and recognition of progressive impacts with time.

The following maintenance activities should be adhered to:

- Monitoring boreholes should be capped and locked at all times;
- Borehole depths should be measured quarterly, and the boreholes blown out with compressed air (if required); and
- Vegetation around the boreholes should be removed on a regular basis and the borehole casings painted, when necessary, to prevent excessive rust and degradation.



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 9-1: Positions of groundwater monitoring boreholes

10 GROUNDWATER ENVIRONMENTAL MANAGEMENT PROGRAM

10.1 CURRENT GROUNDWATER CONDITIONS

10.1.1 GROUNDWATER LEVEL CONDITIONS

Groundwater level depths measured in the project area are discussed in detail in Section 5.4.

Groundwater levels in the project area generally vary between ± 9 and 100 mbs, with the average being ± 42 mbs. Under ambient conditions, the deeper groundwater levels would generally be associated with the dolomitic aquifer, while water levels in the Karoo aquifer/s generally do not exceed 10 mbs.

Approximately 66% of all boreholes were being pumped for mainly domestic and/or irrigation purposes at the time of the water level measurements. Not all groundwater levels are therefore representative of the ambient or unaffected conditions.

10.1.2 GROUNDWATER QUALITY CONDITIONS

A detailed discussion on the groundwater quality conditions is provided in Section 5.6.

Groundwater from most of the user boreholes is considered to be of good quality and is suitable for human consumption with regards to the South African National Standards *(SANS 241:2015)*. Exceptions do however occur as the groundwater nitrate content of some boreholes exceeds the maximum permissible SANS value for drinking water purposes.

The site-specific groundwater quality is mostly good if compared with drinking water standards *(SANS 241:2015)*.

10.2 IMPACTS ON GROUNDWATER QUALITY AND QUANTITY

The potential groundwater quality and quantity (i.e. water level) impacts associated with the proposed new opencast mining and related activities were simulated/predicted with numerical groundwater flow and contaminant transport models and the results are provided and discussed in detail in Section 7.9 of this report. The geohydrological impact rating is provided in Section 8.

10.3 MITIGATION MEASURES

Groundwater mitigation refers to measures that are put in place to help ease or reduce adverse impacts on groundwater users and the geohydrological environment. Mitigation measures, where possible, are discussed in Section 8 of this report.

11 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are based on the findings of the geohydrological investigation:

Conclusions – Geohydrological Environment:

- The topography of the project area can be described as being gently undulating with surface elevations (±4 km radius) varying from approximately 1 540 to 1 620 mamsl.
- A prominent water course, namely the Koffiespruit, is located ± 2.5 kilometers west of the MRA area and within the same catchment.
- The project area receives on average approximately 720 mm of rainfall annually, and the average annual evaporation rate is nearly 1 530 mm.
- Hydrocensus/groundwater user surveys were conducted by Aquatico Scientific on the MRA area and surrounding properties. A total of 86 boreholes, four dams and one cave were located. Most of the boreholes were used for domestic purposes, livestock watering and irrigation at the time of the surveys.
- Recharge to the dolomitic aquifer underlying the northern half of the MRA area was estimated with the Chloride Method to be approximately 13% of the mean annual rainfall.
- Stratigraphically, the project area occurs on the boundary between the Malmani Subgroup and the Pretoria Group of the Transvaal Supergroup *(SACS, 1980)*. The Malmani Subgroup consists of several hundred meters of cherty, stromatolitic dolostone of about 2.6 billion years old that was deposited on an intracratonic marine basin under tidal conditions *(Button, 1986)*. The Malmani Subgroup and the Pretoria Groups are disconformably overlain by late Carboniferious – Permian diamictite, shale and sandstone of the Karoo Supergroup.
- The Proterozoic and Permian strata are intruded by several generations of diabase and dolerite sills and dykes. A flat dipping dolerite sill of approximately 30 m thick cuts through the Rietkol quartzite deposit and divides it into an Upper and a Lower Quartzite band. Due to the thickness of the sill, mining will not cut through the sill and only the Upper Quartzite band will be mined to a depth of approximately 30 to 50 meters.
- A waste classification (i.e. total concentration digestion and distilled water leaching tests) was conducted on two composite samples (i.e. tailings material and waste rock) that were collected from the operational Thaba Chueu mine (previously known as SamQuarz). The tests concluded that both samples are a Type 4 or inert waste, requiring a Class D (or GSB-) disposal facility.
- Based on information gathered during the drilling of four monitoring boreholes, the unsaturated zone is predominantly composed of soil/clay and weathered bedrock (mostly chert and quartzite).
- The average transmissivity of the dolomitic aquifer that underlies the northern half of the MRA area was calculated to be in the region of 22 m^2/d. On the other hand, the Karoo aquifer underlying the southern half of the MRA area displayed a much lower transmissivity of nearly 6.5 m^2/d. The lowest transmissivities were calculated for the Rietkol quartzite deposit, which displayed an average of approximately 0.9 m^2/d.

- Groundwater levels in the project area generally vary between ± 9 and 100 mbs, with the average being ± 42 mbs.
- Numerous potential sources of groundwater contamination are planned for the MRA area. On the positive side, most of these potential source areas pose no real threat to the underlying aquifer in terms of impacts on groundwater quality. Both the target mineral and host rock that will be processed in the plant and then stockpiled/dumped are chemically inert and will therefore not react with oxygen and water to create poor quality leachate (such as acid mine/rock drainage).
- Groundwater from most of the user and monitoring boreholes is considered to be of good quality and is suitable for human consumption if compared with the South African National Standards *(SANS 241:2015)*. Exceedances in terms of the groundwater nitrate content are, however, observed for some of the user boreholes.
- The dolomitic aquifer scored a groundwater vulnerability rating of 9 and is therefore regarded as being highly vulnerable.
- Three aquifer systems are present, namely a shallow, semi-confined or unconfined aquifer that occurs in the transitional soil and weathered bedrock zone or sub-outcrop horizon. A deeper secondary fractured rock aquifer that is hosted within the sedimentary rocks of the Karoo Supergroup, which underlies the southern half of the MRA area. A third, and major aquifer system that is associated with the Malmani Subgroup (Transvaal Supergroup) dolomite that underlies the northern half of the MRA area.
- The GQM rating for the project area calculates to 18, which means that no impact is allowed.

Note that the sensitive dolomitic aquifer will not be intersected by the proposed opencast pits. The sediment/sand (now quartzite after low grade metamorphism) was deposited into an ancient dolomite sinkhole. The proposed opencast pits are situated more or less in the center of this deposit – meaning that nearly at all times there will be a ± 90 to 300 meters buffer, or low transmissivity quartzite between the pits and surrounding dolomite. The quartzite deposit in its entirety is expected to act as a buffer between the proposed mining activities and the surrounding and underlying dolomite.

Conclusions – Numerical Groundwater Modelling:

Flow model:

The main aim of the flow model was to simulate and predict the groundwater level impacts resulting from the planned opencast mining, i.e. simulation of groundwater depression cone. Two mining scenarios were simulated, namely **Scenario 1** where the depth of the pit floor is on average 30 meters below surface and **Scenario 2** where the average depth of the pit floor is 50 meters below surface. A summary of the model-simulated water level impacts **at mine closure** is provided below:

- The pit floor was simulated to intersect the water table from year one during both mining scenarios, resulting in groundwater flowing towards and eventually into the opencast pits.

- The groundwater influx for Scenario 1 was simulated to increase from approximately 20 m^3/d at the end of year one to a maximum of ± 90 m^3/d at mine closure. The influx simulated for Scenario 2 increased from ± 100 m^3/d to nearly 240 m^3/d at the end of the twentieth and final year.
- Dolerite dykes and sills, such as the one that cuts the Rietkol quartzite deposit into an Upper and a Lower Quartzite band, have the potential to yield significant volumes of groundwater. Over and above the groundwater influx from the saturated aquifer host rock/s (fractured quartzite) that cannot be prevented, the risk of additional (and potentially high) groundwater influx from the abovementioned sill is high should mining cut into or through the structure (where below the groundwater level).
- An area of approximately 522 460 m^2 was simulated to be affected by the Scenario 1 pit dewatering activities, while a slightly larger area of ± 724 430 m^2 was simulated for Scenario 2.
- The water level impacts do extend beyond the MRA area, however no groundwater user boreholes are located within these affected areas.
- Fifty years after mining has ceased, the groundwater level (where the impact of pit dewatering was greatest) was simulated to have recovered by ± 91% for Scenario 1, while a ± 89% recovery was simulated for Scenario 2.

Contaminant transport model:

Throughout the following discussions reference is made to “contamination plumes“ instead of “pollution plumes”. Both contamination and pollution refer to any substance (either organic or inorganic) that may potentially enter the groundwater as a result of the planned mining and/or related activities. In light of this investigation, as long as this substance does not adversely affect the environment and groundwater user, it is referred to as contamination. The opposite holds true for pollution, meaning that it refers to any and all substances that affect the groundwater quality to such an extent that it is harmful to both the environment and groundwater user and it becomes unsuitable to apply to its original use.

The main aim of the contaminant transport model was to simulate and predict the groundwater quality related impacts resulting from the planned mining and related activities, i.e. simulation of contaminant/plume migration. **Please refer to the waste classification results and note that the plumes referred to below will be leachate that formed through inert quartzite material and though salinities may be slightly elevated, groundwater quality of the plume is still expected to remain within drinking water guidelines**. A summary of the model-simulated water quality impacts at **mine closure** is provided below:

- Plume migration simulated for Scenario 1 is somewhat faster than for Scenario 2, i.e. a larger area was simulated to be affected in Scenario 1.
- The deeper mining depth simulated for Scenario 2 resulted in the opencast pits acting as sinks for both groundwater and contamination, which restricted plume migration – more so than for Scenario 1. Groundwater levels around the pits would firstly need to recover from the impacts of pit dewatering before groundwater and contamination can eventually migrate away and into the down gradient groundwater flow direction.

- The contamination plumes for both Scenario 1 and Scenario 2 were simulated to migrate towards the north-west and at rates of ± 5 and 3 meters per year respectively.
- At mine closure, an area of approximately 338 900 m^2 was simulated to be affected by the Scenario 1 contamination plumes, while a slightly smaller affected area of ± 268 500 m^2 was simulated for Scenario 2.
- Outside of the MRA area, only user borehole 278RR was simulated to be affected during both mining scenarios. That being said, the abovementioned borehole is located barely 25 meters east of the MRA area on Holding 278, and the plume concentration was simulated to be between 5 and 8% of the original source concentration.

Following the mine closure simulation, the contaminant transport model was run for an additional 50 years to simulate/predict the post closure migration of residual contamination. A summary of the **post closure** contaminant transport model simulations is provided below:

- At 50 years post closure the Scenario 1 contamination plumes were simulated to have increased to 486 300 m^2 in size, while an area of 410 500 m^2 was simulated to be affected by the Scenario 2 plumes.
- Note that no user boreholes located outside of the MRA area were simulated to be adversely affected.
- Plume concentrations were simulated to increase over time, however, natural occurring processes such as dilution and dispersion caused concentrations to only reach ± 80% after 50 years from a source concentration of 100%.

Conclusions – Decant Predictions:

Tailings material from the plant will be dumped into the North Block during the operational phase of mining. This fine material will effectively "plug" the mine void, allowing for very little water infiltration and no decanting is therefore envisaged. Mining and related infrastructure will be demolished during the decommissioning phase and the resulting building rubble is planned to be disposed of into the South Block and the remainder of the void filled with water. Evaporation far exceeds rainfall in the project area and with the South Block being located on top of a local topographic high (resulting in limited surface water runoff into the pit), no decanting is expected to occur.

Recommendations:

- Four boreholes were drilled specifically for source monitoring purposes within the MRA area. At least four of the nearest user boreholes should also be included in the groundwater monitoring program.
- Groundwater monitoring (i.e. sampling and water level measurements) should be conducted at quarterly intervals and the schedule re-assessed by a qualified geohydrologist at a later stage in terms of stability of water levels and quality. If the sampling program requires changes, it should be done so in consultation with the appropriate authorities.
- Groundwater samples should be analysed at a SANAS accredited laboratory for a wide range of chemical and physical parameters.

12 REFERENCES

Bredenkamp et al. 1995. Manual on Quantitative Estimation of Groundwater Recharge and Aquifer Storativity, Water Research Commission.

Dennis et al. 2012. Climate Change Vulnerability Index for South African Aquifers, Water SA.

Dowding, C.E., 2004: Morphology, mineralogy and surface chemistry of manganiferous oxisols near Graskop, Mpumalanga Province, South Africa.

Groundwater Resource Assessment II, DWS (2005).

Groundwater Resource Directed Measures (GRDM) v4.0.0.0 software developed by Department of Water Affairs (DWA), 2010.

Hydrogeological Map Series of the Republic of South Africa, 2002.

Louis Kruger *Geotechnics CC,* 2008. Report on the Engineering Geological Investigation of Portion 1 of Holding 138 of Modderfontein East Orchards Agricultural Holdings.

Lynch, S.D., 2004: Development of a Raster Database of Annual, Monthly and Daily Rainfall for Southern Africa. WRC Report No. 1156/1/04.

Parsons, R. (1995). A South African Aquifer System Management Classification. WRC Report KV 77/95, Water Research Commission, Pretoria.

Rietkol Mining Work Programme Report, 2019.

The South African Bureau of Standards (SABS), ISO 5667-1 to 5667-15, First Edition, 1999.

Van Tonder G, Bardenhagen I, Riemann K, van Bosch J, Dzanga P, Xu, Y,. 2001. Manual on pumping test analysis in fractured-rock aquifers, Part A3, IGS.

Van Tonder, G.J. and Kirchner, J. (1990). Estimation of Natural Groundwater Recharge in the Karoo Aquifers of South Africa. J. Hydrol., Vol. 121, pp 395-419.

Van Tonder, G.J. and Xu, Y. (2001). Estimation of Recharge Using a Revised CRD Method.

Van Wyk, E., 2010. Estimation of Episodic Groundwater Recharge in Semi-Arid Fractured Hard Rock Aquifers.

Vegter, J.R., 1995. An explanation of a set of National Groundwater Maps. Water Research Commission. Report No TT 74/95.

WSM Leshika Consulting, 2015. Specialist Groundwater Report for the Quarry on Portion 22 of the Farm Groenfontein 206 IR, Delmas Municipality, Mpumalanga Province.

https://en.climate-data.org/