Groundwater Complete

STEAMBOAT GRAPHITE PROJECT

REPORT ON GEOHYDROLOGICAL INVESTIGATION AS INPUT TO THE ENVIRONMENTAL IMPACT ASSESSMENT AND WATER USE LICENSE APPLICATION

June 2021

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DECLARATION OF INDEPENDENCE AND SPECIALIST INFORMATION

I, Gerhard Steenekamp and Gerdes Steenekamp (Groundwater Complete) declare that:

- We act as independent specialists in this application to Diphororo Development (Pty) Ltd.;
- 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.

Gerhard Steenekamp
Pr.Sci.Nat. 400385/04

June 2021

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EXECUTIVE SUMMARY:

Groundwater Complete was contracted by Diphororo Development (Pty) Ltd to conduct a geohydrological study and report on findings as specialist input to the Environmental Impact Assessment (EIA) and Water Use License Application (WULA) for the Steamboat Graphite Project (hereinafter referred to only as Steamboat).

The projects are located on the farms Steamboat 306MR and Inkom 305MR, which is situated approximately 150km west of Louis Trichardt, Limpopo Province. The total extent of the two properties is 1453.6ha. The pit will be located on the border of the two properties.

Graphite is planned to be mined by means of conventional opencast methods to depths of approximately 60 meters below surface (mbs).

The estimated life of mine for the proposed Steamboat Project is 20 years.

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

- *The Mogalakwena River is located 250m downgradient from the proposed project site and will therefore be considered to be a possible receptor of any contamination that may potentially originate from the project area.*
- *Average annual rainfall is approximately 490mm.*
- *Average annual evaporation is between 2000 and 2200mm.*
- *The hydrocensus/user survey was conducted on the properties surrounding Steamboat.*
- *A total of six user boreholes were located within the hydrocensus area.*
- *Additionally, water levels could be measured in six of the old exploration boreholes.*
- *Six new boreholes were drilled on the proposed Steamboat mining area specifically for geohydrological testing and sampling.*
- *The effective recharge in the Steamboat area is estimated to be in the order of 4% of MAP.*
- *The area is underlain by quaternary sediments and metamorphic rock of the Limpopo Mobile Belt.*
- *The maximum on-site water requirement at full production is around 3 l/s.*
- *Water for the project can be provided using boreholes SBG03, SBG04 and SBG05 but additional water may be required initially.*
- *Static groundwater level depth in the Steamboat area range between 15 and 35 mbs.*
- *The waste classification concluded that both the ore material and waste rock that will be generated by the planned mining and related activities are inert and can be classified as a Type 3 (low risk) waste.*

- *It is concluded that a Class C (or GSB+) disposal facility would suffice for both the ore reserve and waste rock.*
- *Both samples have sufficient buffering capacity (base potential) to neutralize the small amount of acid that may form.*
- *Most potential surface source areas (discard dump, plant area, stockpiles) 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.*
- *Pre-mining (ambient/baseline) groundwater from five of the monitoring boreholes is considered to be of marginal to poor quality with numerous exceedances of the South African National Standards (SANS 241:2015).*
- *All the boreholes' groundwater is unsuitable for human consumption, except for borehole SBG03.*
- *The aquifer underlying the project area achieved a score of 5 (Table 6-1) and is therefore regarded as having a medium vulnerability.*
- *The aquifer underlying the Steamboat area classifies as a minor aquifer system according to the Parsons system.*
- *The fractured rock aquifer underlying the project area scored a GQM rating of 4, which means that a medium level of protection is required.*
- *The numerical flow model shows that simulated groundwater level impacts do not extend beyond the Steamboat MRA.*
- *The drawdown cone reached a maximum depth of 53 m and horizontal extent of about 720 m from the pit.*
- *Full recovery of the water level in the pit is expected to occur about 200 years after mining ends.*
- *The simulated groundwater quality impacts do not extend beyond the MRA area.*
- *The simulated contamination plume reached a maximum distance from the sources of about 200m in the down-gradient direction at 100 years after closure.*

The overall conclusion is that the proposed project poses no groundwater impacts that are of such magnitude or extent that it would cause a significant negative affect on the groundwater quality or availability of the region. Negative impacts are largely confined to the proposed mining and processing footprint area and are not expected to extend beyond the MRA. No nearby groundwater user or the nearest watercourse (Mogalakwena River) will be adversely affected in terms of quality or availability.

1 INTRODUCTION AND OBJECTIVE

Groundwater Complete was contracted by Diphororo Development (Pty) Ltd to conduct a geohydrological study and report on findings as specialist input to the Environmental Impact Assessment (EIA) and Water Use License Application (WULA) for the Steamboat Graphite Project (hereinafter referred to as Steamboat).

The project is located on the farm's Steamboat 306MR and Inkom 305MR, which is situated approximately 150km west of Louis Trichardt, Limpopo Province. The total extent of the two properties are 1453.6ha. The pit will be located on the border of the two properties.

Graphite is planned to be mined by means of conventional opencast methods to depths of approximately 60 meters below surface (mbs).

The estimated life of mine for the proposed Steamboat Project is 20 years.

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

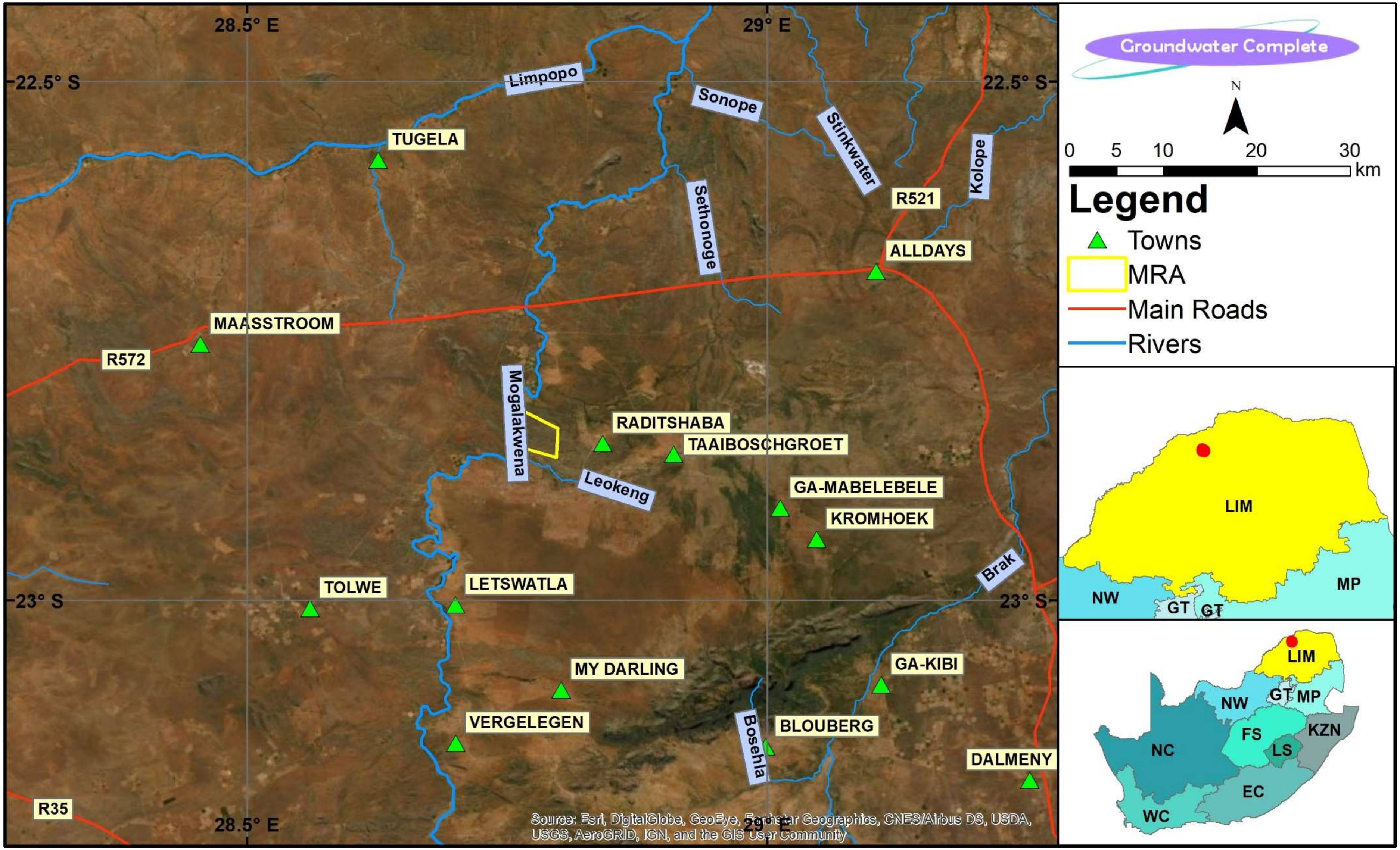

Figure 1-1: Locality map of the project area

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 760 to 880 meters above mean sea level (mamsl) **(Figure 2-1)**.

The project area is located within the A63B quaternary catchment, which covers an area of approximately 1505 km^2. A prominent water course, namely the Mogalakwena River, is located on the western border of the MRA **(Figure 1-1)**. The Mogalakwena flows northwards and joins the Limpopo River at the northern border of South Africa with Botswana. Surface elevations and water courses for the project area are indicated in **Figure 2-1**.

For the purposes of this study the Mogalakwena is considered to be a perennial river and located 250m east of the proposed project site. The Mogalakwena does not flow continuously and is thus not strictly perennial but alluvium below and around the river is recharged after run-off events and acts as a nearly constant storage volume (head) of shallow groundwater.

Notes:

- *The Mogalakwena is regarded as a perennial river for this report, though it is non-perennial per definition.*
- *The Mogalakwena is located 250m downgradient from the proposed project site and was therefore considered as a potential receptor of contamination from the project area.*

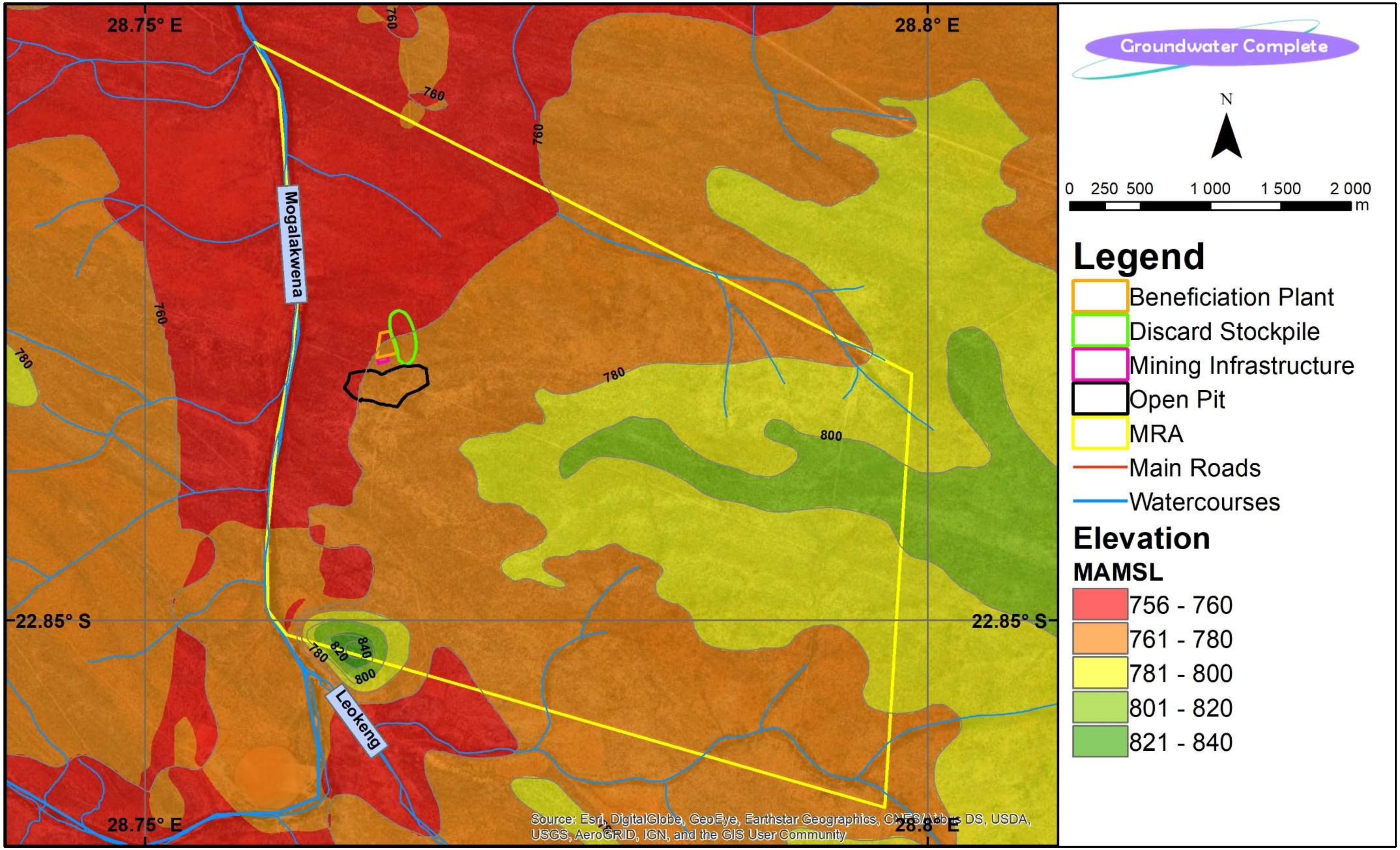

Figure 2-1: Surface elevations and water courses for project area (mamsl)

2.2 CLIMATIC CONDITIONS

Monthly rainfall and evaporation figures for the years 1968 to 2014 were obtained from the nearest DWS meteorological station (A6E004) located approximately 40 kilometres south of the MRA area. The project area is located in a summer rainfall region and receives mean annual rainfall of approximately 490 mm **(Figure 2-2)**. The area is characterised by warm to hot summers and mild winters with no frost.

The mean annual evaporation rate for the project area is between 2000 and 2200 mm, which far exceeds rainfall **(Figure 2-3)**. The project area therefore has a net environmental moisture deficit throughout the year when considering the annual rainfall and evaporation figures.

Notes:

- *Average annual rainfall is approximately 490mm.*
- *Average annual evaporation is between 2000 - 2200mm.*

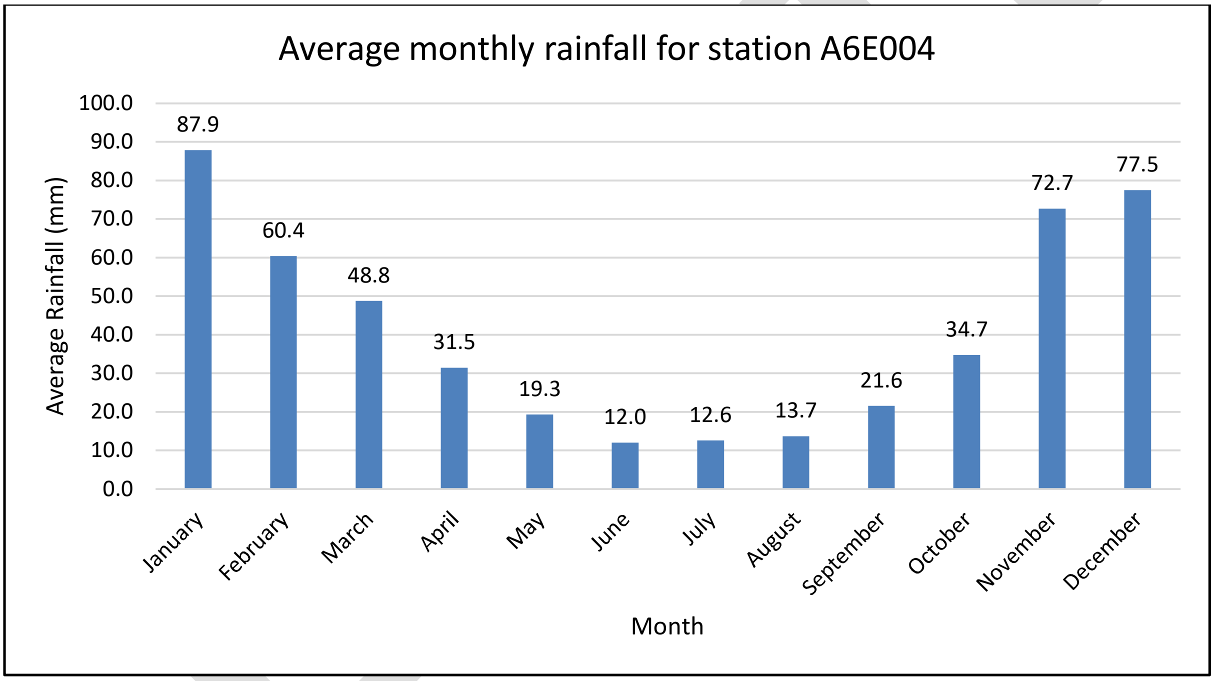

Figure 2-2: Average monthly rainfall figure for meteorological station A6E004 *(DWS)*

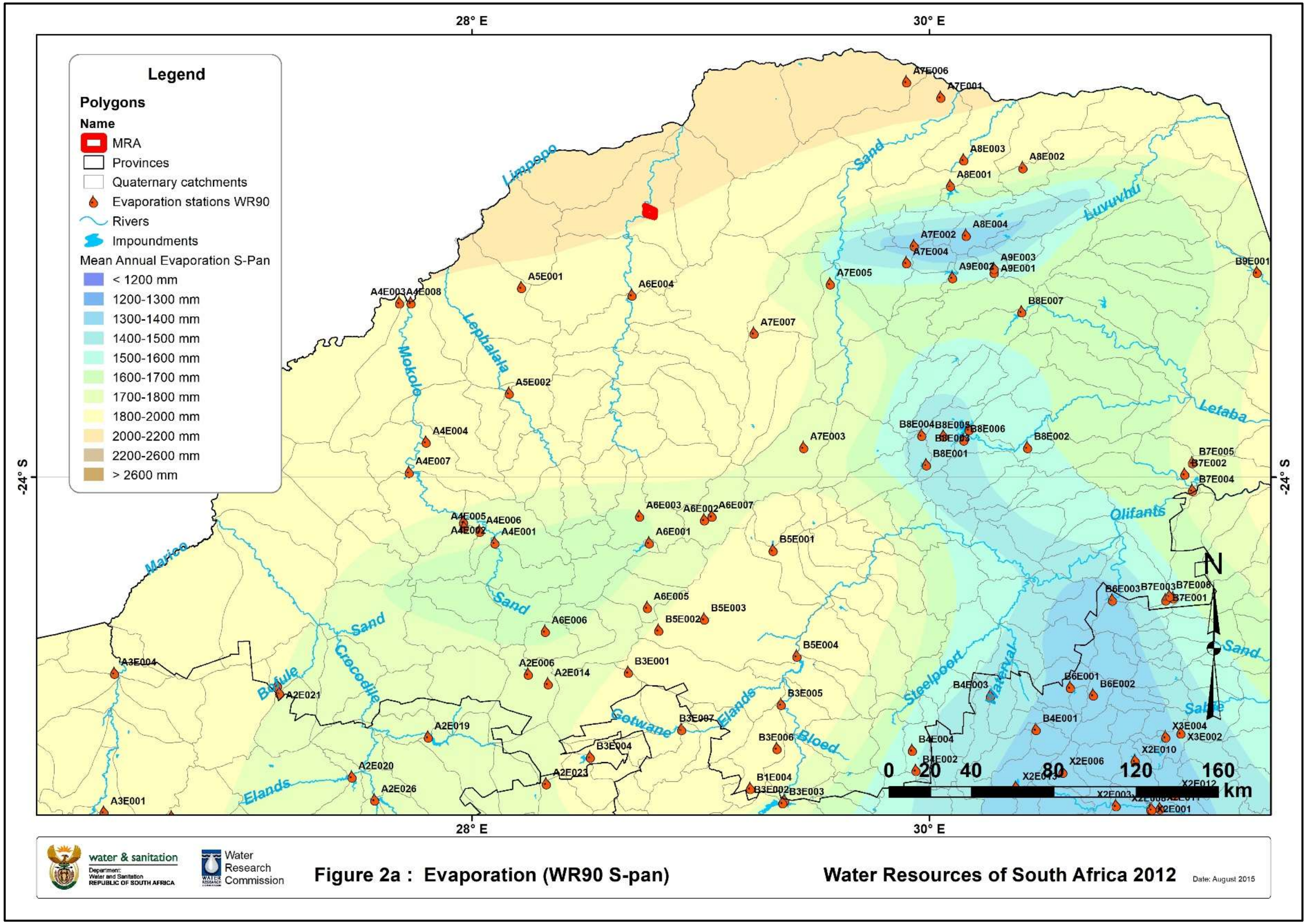

Figure 2-3: Mean monthly evaporation figures for meteorological station B2E001 *(DWS)*

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 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)*.
- A hydrocensus/groundwater user survey was 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 six boreholes were drilled for aquifer testing and groundwater monitoring purposes *(Section 4.4)*.
- Aquifer testing in the form of short duration constant rate pumping tests were conducted on the six monitoring boreholes situated within the Steamboat area and the results were applied in this investigation and numerical model *(Section 4.5)*.
- The hydrogeochemistry of water samples is discussed *(Section 4.6).*
- Dedicated groundwater recharge studies were consulted in the assessment of the aquifer recharge rate *(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 Steamboat area *(Section 4.9)*.
- Information interpreted from the 1:250 000 scale geological map of the project area and the *Project Description and alternatives Report* were used in the impact assessment and discussion of the underlying geology *(Section 5.1)*.
- A waste classification was conducted on Overburden and Ore Reserve samples collected from the boreholes, and the results and consequent recommendations in terms of the requirements for a disposal facility/s at Steamboat 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 the hydrocensus boreholes in the wider area and exploration boreholes as well as six dedicated monitoring boreholes situated within the Steamboat MRA were used in the assessment of the groundwater level depths *(Section 5.4)*.

- Potential sources of groundwater contamination were identified and discussed *(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 domain (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 *(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 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 DESKTOP 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 March 2021 by Aquatico Scientific within the mining right application area (MRA area) and the surrounding communities and 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.

Summaries of the findings are provided in **Table 4-1**. A total of six user boreholes 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 **(Table 4-1)**. Exploration boreholes drilled in the 1970's and 1980's were located and water level measurements could be obtained from six of the holes.

Notes:

- *The hydrocensus/user survey was conducted on the properties surrounding Steamboat.*
- *A total of six user boreholes are located within the hydrocensus area.*
- *Additionally, six of the old exploration boreholes were useful for water level measurement.*

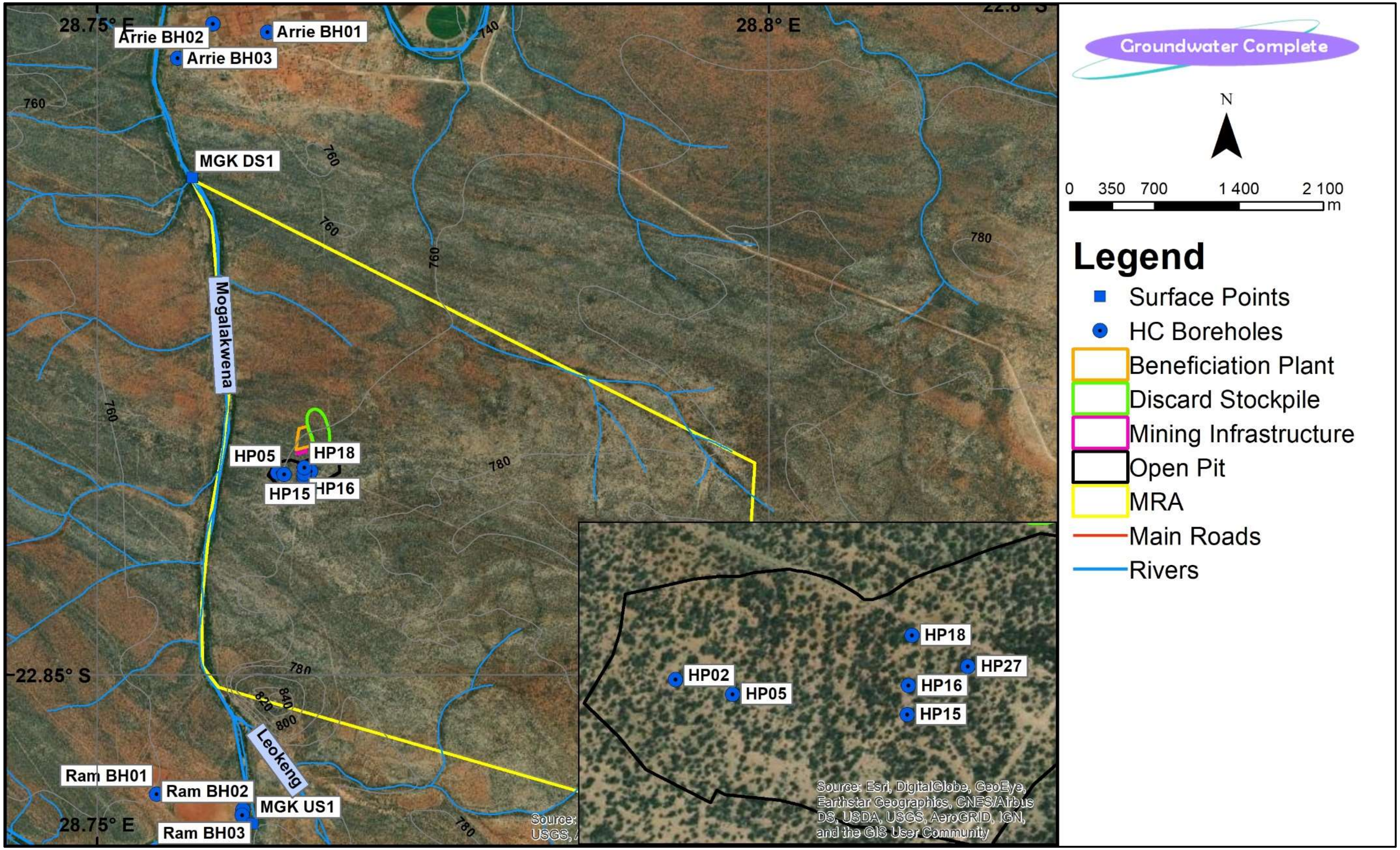

Figure 4-1: Positions of boreholes recorded during the hydrocensus and user surveys.

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

Steamboat Hydrocensus							
Locality	**Type**	**Water level**	**Uses**	**Pump inst.**	**Borehole Depth**	**Sampled**	**Coordinates**
Arrie BH01	Abstraction BH	NA	Community Water Provision	Yes	Unknown	No	S22.80204° E28.76272°
Arrie BH02	Abstraction BH	NA	Community Water Provision	Yes	Unknown	Yes	S22.80142° E28.75864°
Arrie BH03	Abstraction BH	7.8	Community Water Provision	Yes	100+	Yes	S22.80400° E28.75602°
Ram BH01	Abstraction BH	NA	Agricultural	Yes	Unknown	No	S22.85880° E28.75445°
Ram BH02	Abstraction BH	6.4	Agricultural	Yes	Unknown	No	S22.85997° E28.76087°
Ram BH03	Abstraction BH	5.8	Agricultural	Yes	Unknown	Yes	S22.86039° E28.76082°
HP27	Exploration	25.2	None	No	30	Yes	S22.83480° E28.76593°
HP02	Exploration	22.5	None	No	28	No	S22.83491° E28.76348°
HP05	Exploration	23.5	None	No	29	No	S22.83503° E28.76396°
HP15	Exploration	24	None	No	29	No	S22.83520° E28.76542°
HP16	Exploration	24.2	None	No	29	No	S22.83496° E28.76543°
HP18	Exploration	24.2	None	No	29	No	S22.83454° E28.76546°

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4.3 GEOPHYSICAL SURVEY AND RESULTS

A geophysical survey was conducted in March 2021 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). Several dykes were found (field observation of outcrop) present in the mining area though many of them did not show any magnetic susceptibility.

Six lines were traversed during which a total of seven anomalies were identified and their positions are indicated in **Figure 4-2**. 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 position
	(m)	South	East	South	East	
1	340	-22.8363	28.7659	-22.8344	28.7685	65
2	560	-22.8344	28.7685	-22.8295	28.7672	380
3	250	-22.8295	28.7672	-22.8296	28.7648	None
4	390	-22.8296	28.7648	-22.8331	28.7644	50
						100
						140
5	160	-22.8331	28.7644	-22.8333	28.7629	30
						70
6	250	-22.8333	28.7629	-22.8354	28.7621	None
7	130	-22.8354	28.7621	-22.8365	28.7627	None

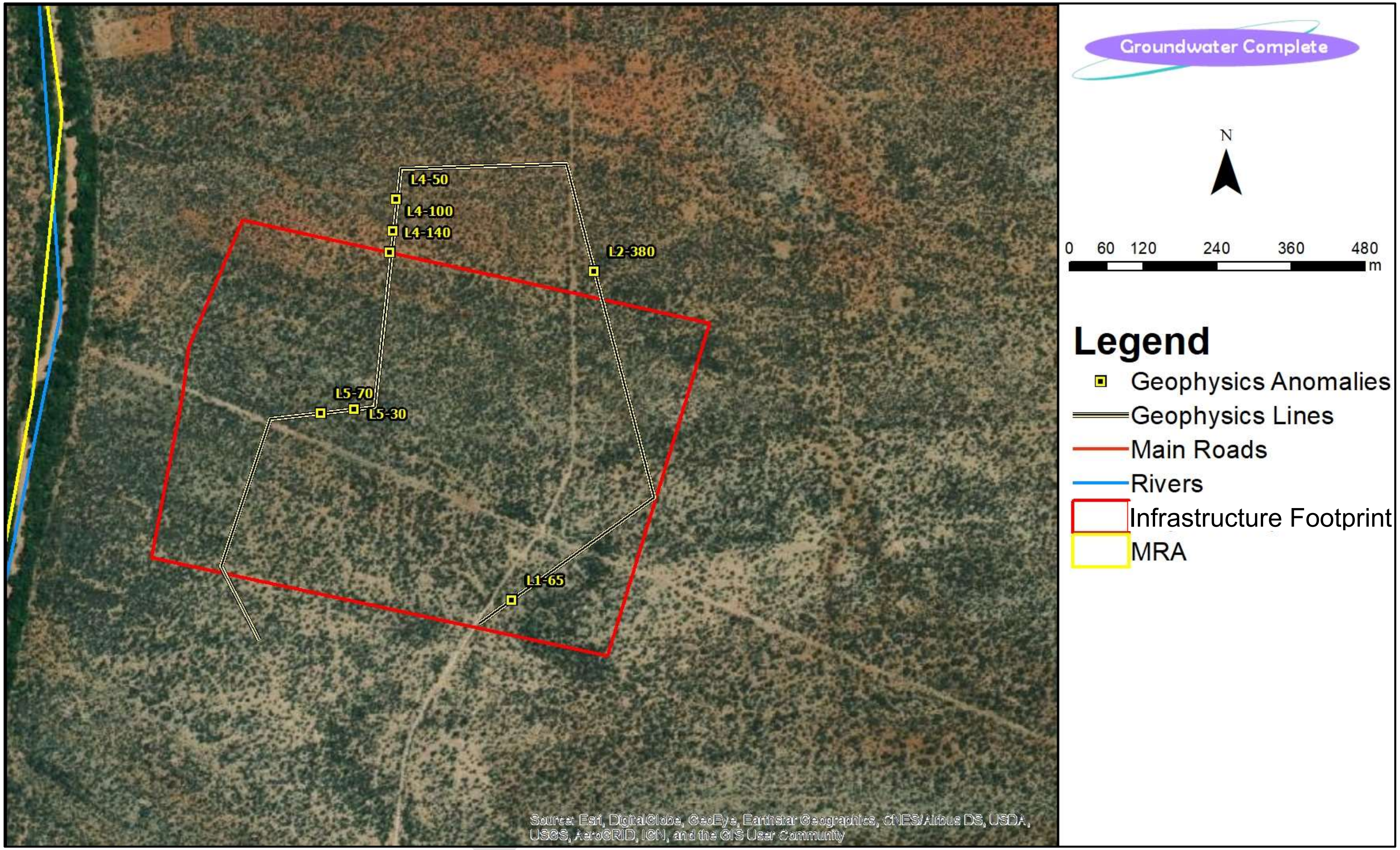

Figure 4-2: Positions of geophysical traverses and identified geological anomalies

4.4 SITING AND DRILLING OF BOREHOLES

Dedicated source monitoring boreholes were drilled at six of the seven locations identified by the geophysical survey **(Figure 4-2)** and their positions are indicated in **Figure 4-3**. The boreholes were drilled by Brewis Bore (Pty) Ltd in April 2021 and short descriptions of each borehole intersection are provided in the following paragraphs. Borehole logs are provided in **Appendix A**, while basic information is included in **Table 4-3**.

Notes:

- *Six new boreholes were drilled on the proposed Steamboat mining area for geohydrological testing and ongoing groundwater impact monitoring.*

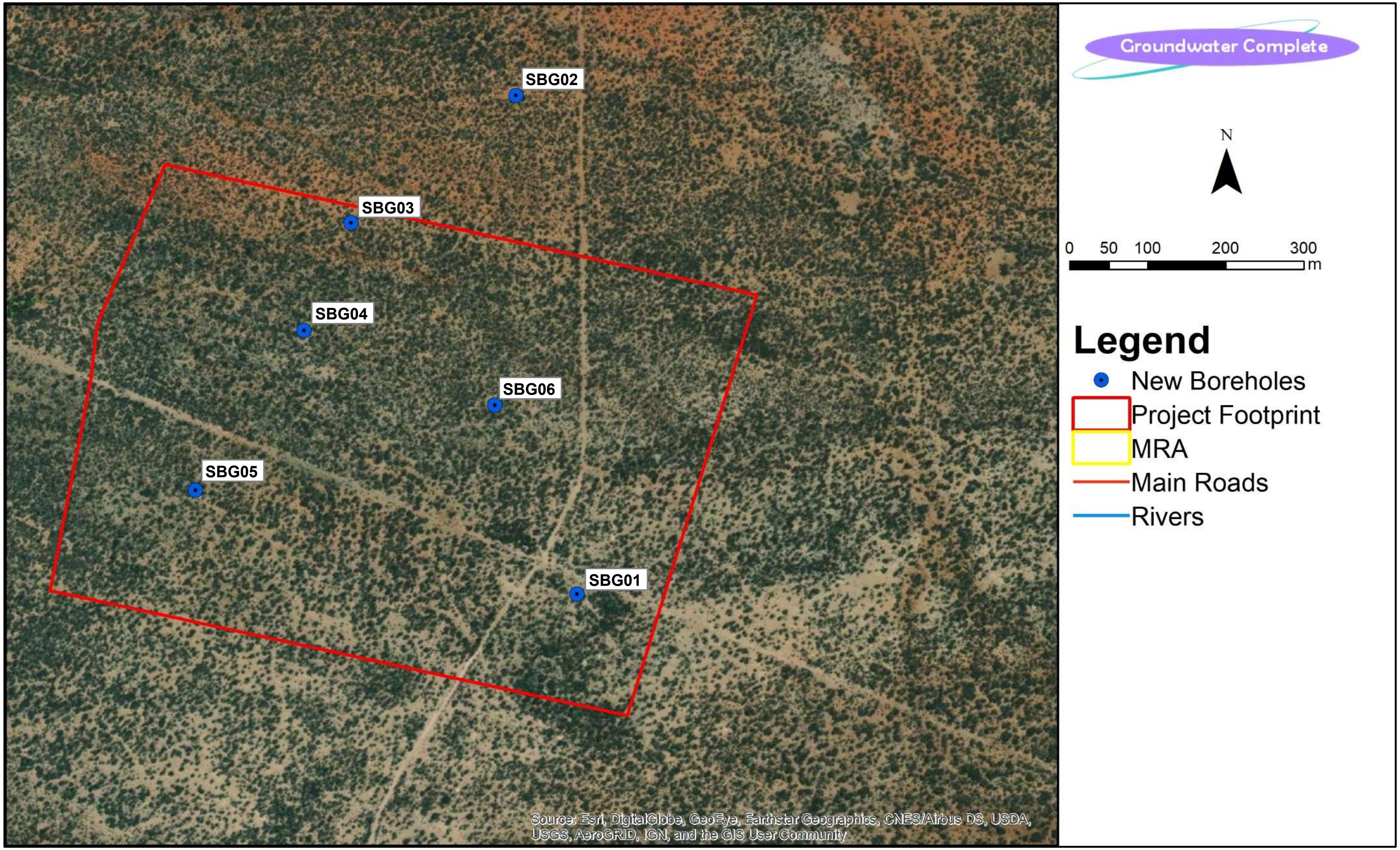

Figure 4-3: Locations of dedicated source monitoring boreholes drilled during study.

Table 4-3: Summary of new source monitoring boreholes.

BH	X	Y	Z	Final Depth	Water Strike Depth	Blow yield	Casing depth	Perforation	Geology
SBG01	**28.7672**	**-22.8353**	**774**	40	None	Dry	40	36-40	Gneiss
SBG02	**28.7665**	**-22.8295**	**763**	39	None	Dry	39	35-39	Gneiss
SBG03	**28.7646**	**-22.831**	**759**	30	28	4000	30	26-30	Gneiss + Quartz
SBG04	**28.764**	**-22.8323**	**760**	50	21 - 23	15000	50	19 (10")	Gneiss + Quartz
SBG05	**28.7628**	**-22.8341**	**760**	30	17 - 20	4000	21.5	17.5-21.5	Quartz + Gneiss
SBG06	**28.7662**	**-22.8331**	**765**	40	None	Dry	40	36-40	Gneiss + Weathering

4.5 AQUIFER TESTING

Aquifer tests (also referred to as pumping or slug tests) are 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.

Short duration constant rate pumping tests were conducted on all six purpose-drilled boreholes at Steamboat and their positions are indicated on **Figure 4-3**. The test results are discussed in **Section 5.3.3**.

4.6 GROUNDWATER SAMPLING AND CHEMICAL ANALYSIS

All groundwater quality testing 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.

Groundwater samples were collected from surrounding user boreholes as well as dedicated source monitoring boreholes and were analysed for a wide range of inorganic 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 sources/studies and can be summarized as follows:

- An Explanation for a set of National Groundwater Maps, Vegter (1995) – estimate recharge at 1% of MAP
- Groundwater Resource Assessment II, (GRAii, 2006) – estimate recharge at 2% of MAP

Another recharge estimation was developed by Van Tonder and Xu (2001), based on the geology of the aquifer **(Table 4-4)**. The abovementioned method estimates the recharge in the Steamboat area around 4-7% of the annual precipitation.

Table 4-4: 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

Based on the databases described above and the calibration of the modelling, the effective recharge is expected to be in the order of 4% of MAP.

Notes:

- *The effective recharge in the Steamboat area is expected to be in the order of 4% 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 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 A63B quaternary catchment and forms part of the Limpopo Water Management Area (WMA). The General Authorised groundwater use for this catchment is 45 m^3/ha/year *(Government Gazette (GGN), No. 40243)*. This amounts to 65 412 m^3/year.

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 pit to ensure dry and safe mining conditions was simulated/estimated with the numerical groundwater flow model to be approximately 440 m^3/d. Based on the DWS classification, this level of groundwater abstraction can be classified as **Category A** or **small scale**.

Table 4-5: Most salient parameters relevant to the mining rights areas

Description	***Unit***	**Value**	**Comment**
Catchment Area	*km^2*	1504	A63B
MRA area	*km^2*	14	1% of catchment
General Authorised Use (GA)	*m^3/ha/a*	45	Sourced from, "*Government Gazette, No. 40243"*
General Authorised Use	*m^3/a*	65 412	(45 m^3/ha/a * 1453 ha)
Mean Annual Rainfall	*mm/a*	490	Figure 2-2
Effective Annual Recharge	*mm/a*	19.6	Section 4.7
Annual Recharge Volume	*m^3/a*	285000	Recharge over MRA area
Groundwater use	*m^3/a*	158800	Maximum model simulated groundwater inflow to pit
Groundwater use as % GA	*%*	242	(Planned use/GA use) *100
Groundwater use as % recharge	*%*	55	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 *Steamboat Project Description and alternatives Report (Internal project report for Steamboat Mine, 2021)*.

5.1.1 SITE SPECIFIC GEOLOGY – RESULTS OF EXPLORATION DRILLING

The geology underneath the mining area consist of different formations of the Swazian erathem, which is some of the oldest geological formations in South Africa. The different formations (Gumbu, Malala Drift, Mount Dowe) belong to the Beitbridge Complex, which consists of different metamorphic rock like metaquartzites, calc-silicates and gneisses.

Much younger quaternary sediments have been deposited on top of the Beitbridge Complex. The Steamboat mining activities will take place mostly on the quaternary sediments underlain by gneisses.

The abovementioned rock types featured clearly in the drilling core samples which are displayed in **Appendix A**.

5.1.2 REGIONAL GEOLOGY

The Steamboat MRA is located on a geological region known as the Limpopo Mobile Belt. The Limpopo belt is an extensive ENE-trending linear zone of high-grade metamorphic tectonites which separates the Archaean nucleii of the Rhodesian Craton to the north from the Kaapvaal Craton to the south. The belt consists of reworked Archaean granite-greenstone terrain with an early Proterozoic cover sequence, the Messina Formation, in-folded and metamorphosed with the basement.

Two major zones of shearing and transcurrent dislocation separate marginal granulite zones from a central zone which consists of complexly in-folded cover rocks and reworked basement. The northern granulite zone appears to grade transitionally into the Rhodesian Craton to the north, whereas there is some evidence that the southern granulite zone is faulted against the Kaapvaal Craton to the south. The whole belt has behaved as a zone of crustal weakness throughout geological time, and is characterized by repeated shear deformation, igneous intrusion and extrusion, despite the cessation of major regional tectono-thermal reactivation about 1900 Ma ago.

Notes:

- *The area is underlain by quaternary sediments and metamorphic rock.*
- *The Steamboat area is located on the Limpopo mobile belt, which caused the metamorphic rocks to form due to extreme pressure of in-folding.*

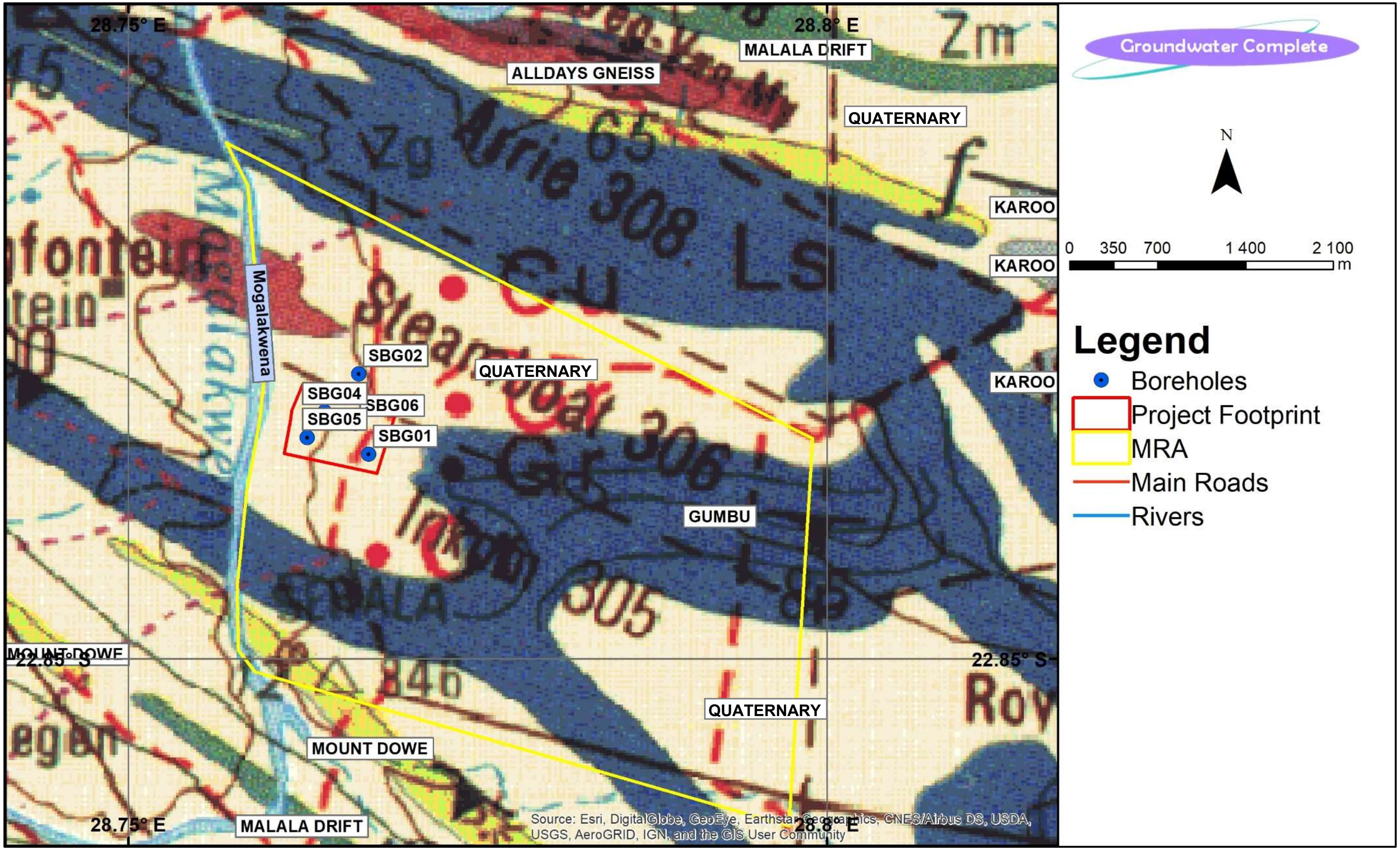

Figure 5-1: Geological map of the project area (1:250 000)

5.2 ACID GENERATING POTENTIAL AND WASTE CLASSIFICATION

5.2.1 ACID BASE ACCOUNTING (ABA)

ABA was conducted by the Aquatico laboratory and used to confirm that the geology in the steamboat area has minimal acid generating potential and such adequate buffering capacity that no Acid Rock Drainage (ARD) should form in any part of the mining process.

Two geochemistry samples were taken in the Steamboat area as composites from the drill chips from boreholes. The two samples are of the Overburden and the Ore Reserve. The results of the ABA are indicated in **Table 5-1**.

5.2.2 WASTE CLASSIFICATION

The same two composite samples used for the ABA were also used for waste classification. For the purpose of the investigation a Total Concentration Test (TCT) and a Leachable Concentration Test (LCT) was conducted in May 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. 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 rainwater infiltrates through the material under natural conditions when rain water (or recharge) percolates through the material.

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 results of the total concentration and leachable concentration analyses are provided in **Table 5-4** and **Table 5-5**, respectively. Neither of the samples exceeded any limit of the LCT. Both samples exceeded the TCT0 limits for barium and copper. **According to the waste classification described above, both the overburden and ore reserve can be regarded as a Type 3, or low risk 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 5-2**. **It is concluded that a Class C (or GSB+) disposal facility would suffice for both the overburden and ore reserve.**

Table 5-1: Results of the Steamboat ABA

Locality	Sample type	Sampled date	pH paste	Total Sulphur	Sulphide Sulphur	Sulphate Sulphur	Acid Potential AP (TS)	Acid Potential AP (SS)	Neutralization Potential NP	Net Neutralization Potential NNP	NP / AP (TS)	NP / AP (SS)
			pH	%	%	%	CaCO3 kg/t	CaCO3 kg/t	CaCO3 kg/t	CaCO3 kg/t		
Ore Reserve	Geochem	14-May-2021	9.18	0.025	0.008	0.017	0.781	-0.313	36	35.8	46.1	144
Overburden	Geochem	14-May-2021	9.52	0.02	0.009	0.011	0.625	-0.313	51.9	51.6	83	185

Acid Base Accounting (ABA) is a static test commonly conducted to determine the total amount of sulphur (sulphide sulphur + sulphate sulphur) present in a sample. The higher the sulphur content, the higher the potential to generate acid – more specifically sulphuric acid. This information is then used to determine the Neutralisation Potential (NP), Acid Potential (AP) and Net Neutralisation Potential (NNP).

The following criteria were used to assess the potential of each sample to generate acid:

- The difference between the neutralisation potential and acid potential is known as the net-neutralisation potential (NNP = NP – AP). Therefore, whenever the NNP is a negative value the acid potential exceeds the neutralisation potential, suggesting that water leaching through this material may potentially turn acidic; and
- The ratio of NP:AP is termed the Neutralising Potential Ratio (NPR).

Note:

*The results in **Table 5-1** indicate that the NNP is overwhelming positive and that the sulphur content is low, meaning that no acidic conditions are expected.*

Table 5-2: Classification of waste types

Waste Type	Risk	Description	Limits
Type 0	Very high risk	Waste with any element or chemical parameter concentration above the LCT3 or TCT2 limits	LC > LCT3 or TC > TCT2
Type 1	High risk	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
Type 2	Moderate risk	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
Type 3	Low risk	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
Type 4	Inert	Waste with element and chemical parameter concentrations for metal ions and inorganic anions below or equal to the LCT0 and TCT0 limits and with all chemical substance concentration level also below the total concentration limits for organics and pesticides	LC <= LCT0 and TC <= TCT0

Table 5-3: 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 5-4: Results of total concentration (TC) analyses

Total Concentration Solids				Overburden	Ore Reserve
VARIABLE	Guideline Limits (mg/kg)			Variable Concentration (mg/kg)	Variable Concentration (mg/kg)
	TCT0	TCT1	TCT2		
Paste pH (1:2) (pH Units)	-	-	-	9.52	9.18
Total Cyanide as CN	14	10500	42000	<10.00	<10.00
Redox	-	-	-	172	169
Arsenic as As	5.8	500	2000	<5.80	<5.80
Boron as B	150	15000	60000	<150	<150
Barium as Ba	62.5	6250	25000	170	192
Cadmium as Cd	7.5	260	1040	<7.50	<7.50
Cobalt as Co	50	5000	20000	<50.0	<50.0
Chromium as Cr	46000	800000	-	<1000	<1000
Copper as Cu	16	19500	78000	28.5	30.5
Mercury as Hg	0.93	160	640	<0.900	<0.900
Manganese as Mn	1000	25000	100000	<1000	<1000
Molybdenum as Mo	40	1000	4000	<10.0	10.7
Nickel as Ni	91	10600	42400	<50.0	51
Lead as Pb	20	1900	7600	<20.0	<20.0
Antimony as Sb	10	75	300	<10.0	<10.0
Selenium as Se	10	50	200	<10.0	<10.0
Vanadium as V	150	2680	10720	<100	<100
Zinc as Zn	240	160000	640000	<220	<220
Moisture %	-	-	-	0	0
Solid %	-	-	-	100	100

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

Leachable Concentrations - Distilled Water					Overburden	Ore Reserve
VARIABLE	Guideline Limits (mg/l)				Variable Concentration (mg/l)	Variable Concentration (mg/l)
	LCT0	LCT1	LCT2	LCT3		
Arsenic as As	0.01	0.5	1	4	<0.010	<0.010
Boron as B	0.5	25	50	200	<0.500	<0.500
Barium as Ba	0.7	35	70	280	<0.700	<0.700
Cadmium as Cd	0.003	0.15	0.3	1.2	<0.003	<0.003
Cobalt as Co	0.5	25	50	200	<0.400	<0.400
Chromium as Cr	0.1	5	10	40	<0.100	<0.100
Hexavalent chromium (Cr^{6+})	0.05	2.5	5	20	<0.020	<0.020
Copper as Cu	2	100	200	800	<1.00	<1.00
Mercury as Hg	0.006	0.3	0.6	2.4	<0.006	<0.006
Manganese as Mn	0.5	25	50	200	<0.500	<0.500
Molybdenum as Mo	0.07	3.5	7	28	<0.070	<0.070
Nickel as Ni	0.07	3.5	7	28	<0.070	<0.070
Lead as Pb	0.01	0.5	1	4	<0.010	<0.010

Antimony as Sb	**0.02**	**1**	**2**	**8**	<0.020	<0.020
Selenium as Se	**0.01**	**0.5**	**1**	**4**	<0.010	<0.010
Vanadium as V	**0.2**	**10**	**20**	**80**	<0.200	<0.200
Zinc as Zn	**5**	**250**	**500**	**2000**	<2.00	<2.00
Total Dissolved solids @ 180°C	**1000**	**12500**	**25000**	**100000**	<100	<100
Chloride as Cl	**300**	**15000**	**30000**	**120000**	<50.0	<50.0
Sulphate (SO_4)	**250**	**12500**	**25000**	**100000**	<50.0	<50.0
Nitrate (NO_3) as N	**11**	**550**	**1100**	**4400**	<10.0	<10.0
Fluoride as F	**1.5**	**75**	**150**	**600**	<1.00	<1.00
Total Cyanide as CN	**0.07**	**3.5**	**7**	**28**	<0.05	<0.05
pH @ 25°C	**-**	**-**	**-**	**-**	9.56	9.45

Table 5-6: Analytical analysis of chromium and fluoride

ANALYTICAL REPORT: Fluoride & Chromium (VI) Analysis

No unauthorised copies may be made of this report.

UIS analytical services

To:	**Aquatico Scientific (Pty) Ltd**	Date of Request: 2021-05-20	UIS Analytical Services
Attention:	**Theo Meyer**		Analytical Chemistry
order number	**PO105328**		Laboratories 4, 6
Tel:	012-349 1044		Fax: (012) 665 4294
Fax:	012- 349 2064		

Certificate of analysis: 38010

Lims ID	**Sample ID**	F mg/kg	Cr mg/kg
780730	9653/5BH6-D/Batch/no/104889/Lab/no/9653	655	<5
780730 QC	Duplicate	624	<5
780731	9654/5BH6-S/Batch/no/104889/Lab/no/9654	655	<5

		Chemical elements:	Cr6+, F
		Instrument:	Spectrophotometer, Fluoride Ion Selective Electrode
Date:	21/05/2021	Date:	28/05/2021
Analysed by:	RGM Rakoma	Authorised :	JJ Oberholzer

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Notes:

- *According to the waste classification described above, both the tailings material and waste rock can be regarded as a **Type 3** or **low risk waste**.*
- *It is concluded that a Class C (or GSB+) disposal facility would suffice for both the tailings material and waste rock.*
- *Both samples have sufficient buffering capacity to neutralize the small amount of acid formation.*

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 ± 15 and 35 meters below surface (average being ± 20 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 15 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 six purpose drilled boreholes in the mining area 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 six boreholes are indicated in **Figure 5-2**, while more information regarding these tests is provided in **Table 5-7**.

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 0.001 to 0.02 is taken as representative for the proposed mining area.

The pumping test data was analysed with the Fracture Characterisation (FC) program 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 *Cooper-Jacob (1946)* equation.

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 5-7: Summary of pumping tests.

BH	BH depth	Static WL	Pump duration	Pump rate	Drawdown	Recovery
Unit	***m***	***mbs***	***min***	***l/s***	***m***	***%***
SBG01	40	35.1	3	0.2	4.3	50% after 80 min
SBG02	39	18	12	0.33	16.4	25% after 72 min
SBG03	30	15.6	23	0.75	12	90% after 16 min
SBG04	50	14.2	30	1.6	5.3	70% after 67 min
SBG05	30	14.3	30	0.8	5.7	90% after 2 min
SBG06	40	20.4	16	0.35	16.6	25% after 68 min

Table 5-8: Summary of aquifer parameters calculated from pumping tests.

Borehole	T_m	T_f	S_m	S_f
SBG01	0.5	N/D	0.002	N/D
SBG02	0.2	0.7	0.003	0.0008
SBG03	2.5	9	0.016	0.005
SBG04	5	10	0.02	0.01
SBG05	2.8	9	0.016	0.005
SBG06	0.2	3	0.005	0.002

Tm - *Transmissivity of the aquifer matrix*
Tf - *Transmissivity of the fracture system*
Sm - *Storativity of the aquifer matrix*
Sf - *Storativity of the fracture system*
N/D - *Not determinable during the test*

Aquifer parameters and sustainable yield calculated from the pumping tests are provided in **Table 5-7** and **Table 5-8** respectively.

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 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 5-9** were therefore estimated with the lower matrix transmissivity and are indicated as liters per second for a 24-hour pump cycle.

Please note that the yields are indicative only since the purpose of the tests were for aquifer parameter estimation for use in the impact assessment. Test duration was too short to allow for long terms sustainable yield determination.

Table 5-9: Potential borehole yields

Borehole	Potential groundwater yield (l/s)				
	No boundary	1 Boundary	2 Boundaries	Closed	Average
SBG01	0.02	0.01	0.01	0.01	0.01
SBG02	0.05	0.02	0.02	0.01	0.02
SBG03	1.08	0.54	0.36	0.27	0.56
SBG04	1.07	0.53	0.35	0.27	0.55
SBG05	0.39	0.19	0.13	0.10	0.2
SBG06	0.58	0.29	0.19	0.14	0.3

Notes:

- *Although the borehole yields provided in Table 5-8 were calculated with tested and proven techniques, test duration was too short to apply for long term sustainable yield determination.*
- *The maximum on-site water requirement at full production is expected to be nearly 3 l/s.* ***Table 5-9*** *shows that the combined sustainable yield of the on-site tested boreholes is around 1.5 l/s.*
- *The on-site water can be provided using SBG03, SBG04 and SBG05.*

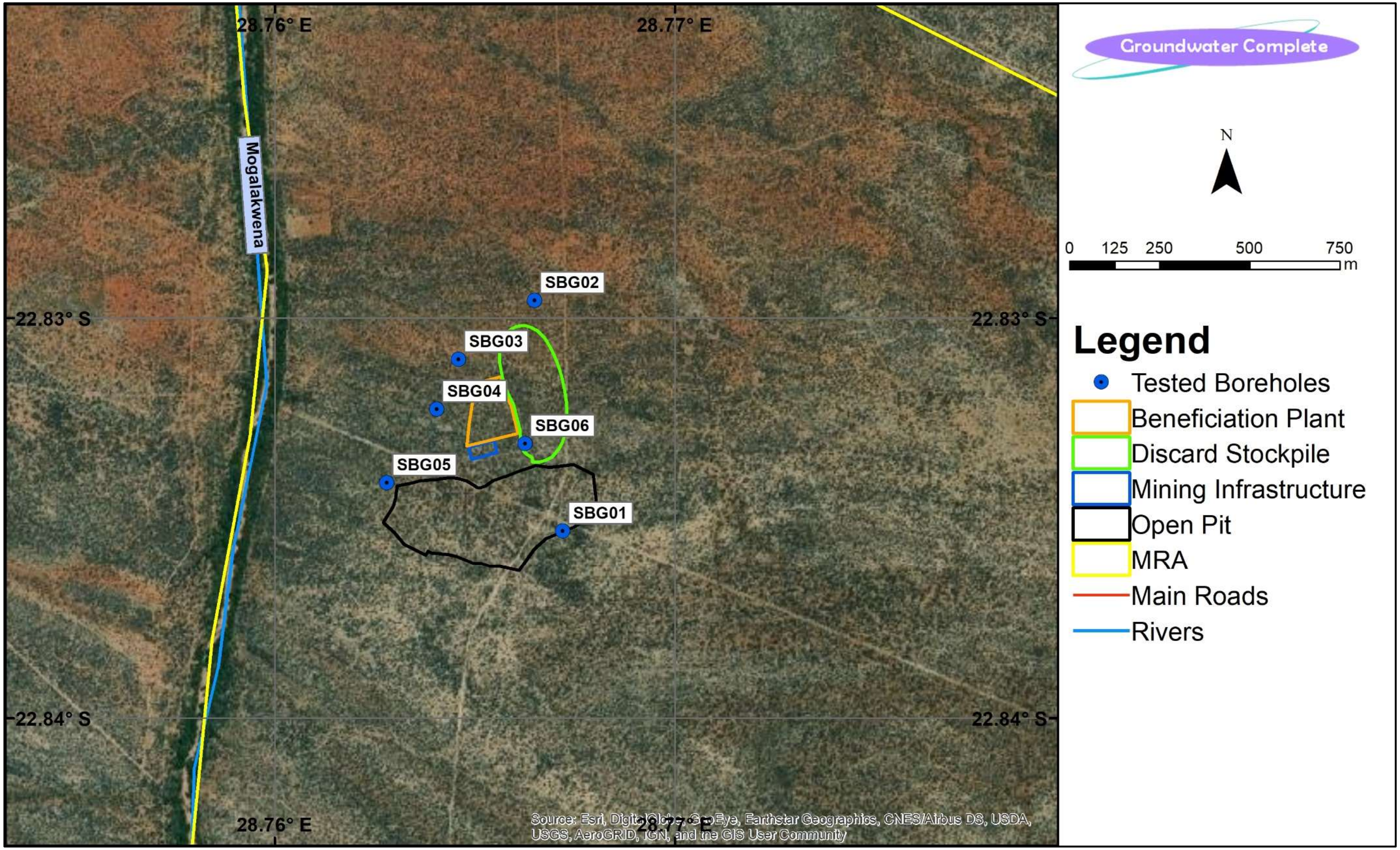

Figure 5-2: Positions of boreholes on which pumping tests were conducted

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 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 ± 15 and 35 meters below surface (mbs), with the average being ± 20 mbs.

A linear relationship often exists between the surface topography and groundwater elevation under natural conditions (i.e. groundwater follows surface topography). This natural relationship was not clearly represented by the measured boreholes due to the boreholes being very close to each other and not spread over a large area. There is also a definite influence of aquifer heterogeneity with different water levels in different geological layers in the metamorphic environment. It is however believed that groundwater level still mimics the topography in this area on a larger scale. A graph of borehole collar elevation versus groundwater level elevation is presented in **Figure 5-3**. This graph confirms that there exists no apparent correlation between the measured groundwater elevations and surface topography.

Notes:

- *Static groundwater level depth in the Steamboat area range between 15 and 35 mbs.*

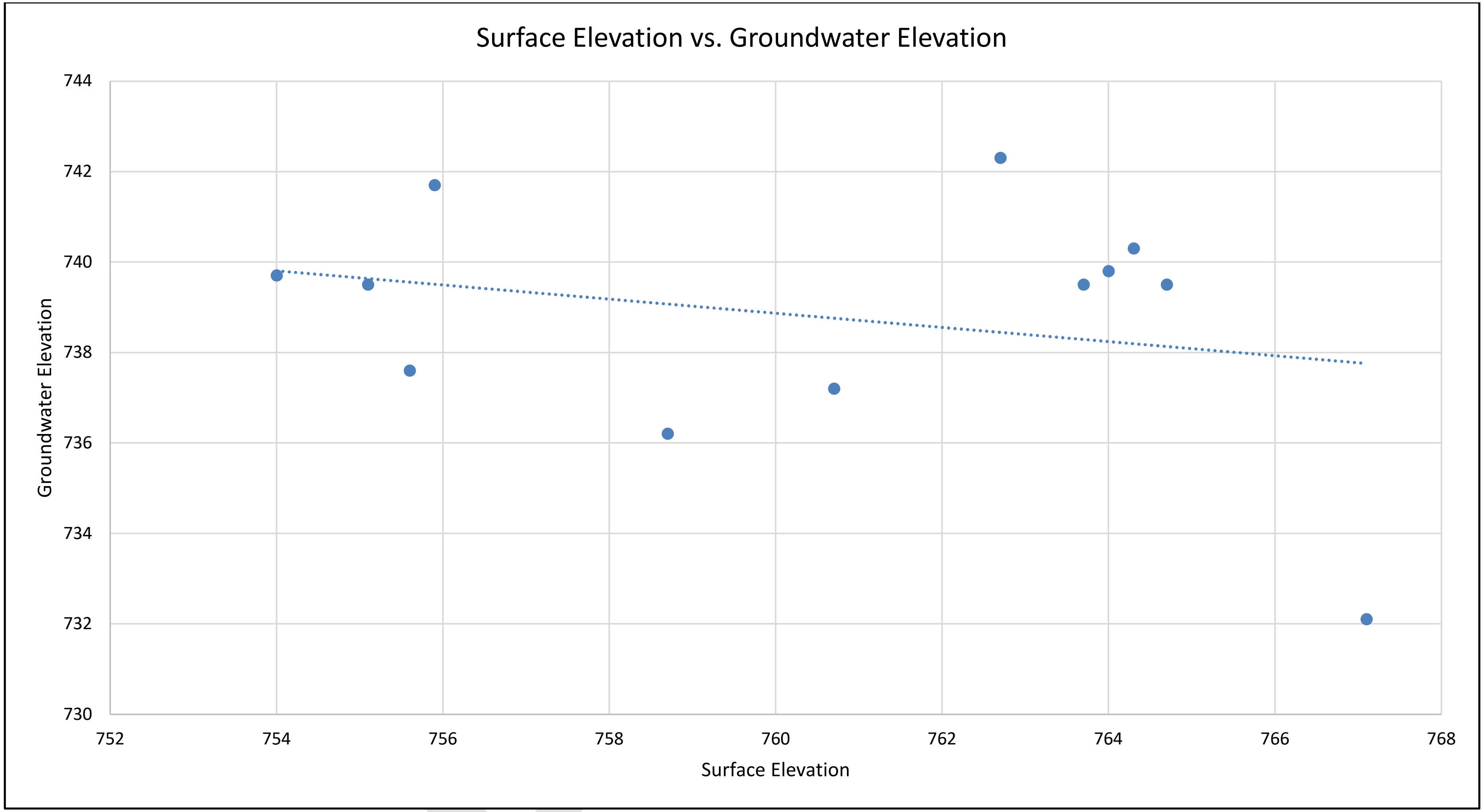

Figure 5-3: Relationship between surface and groundwater elevation

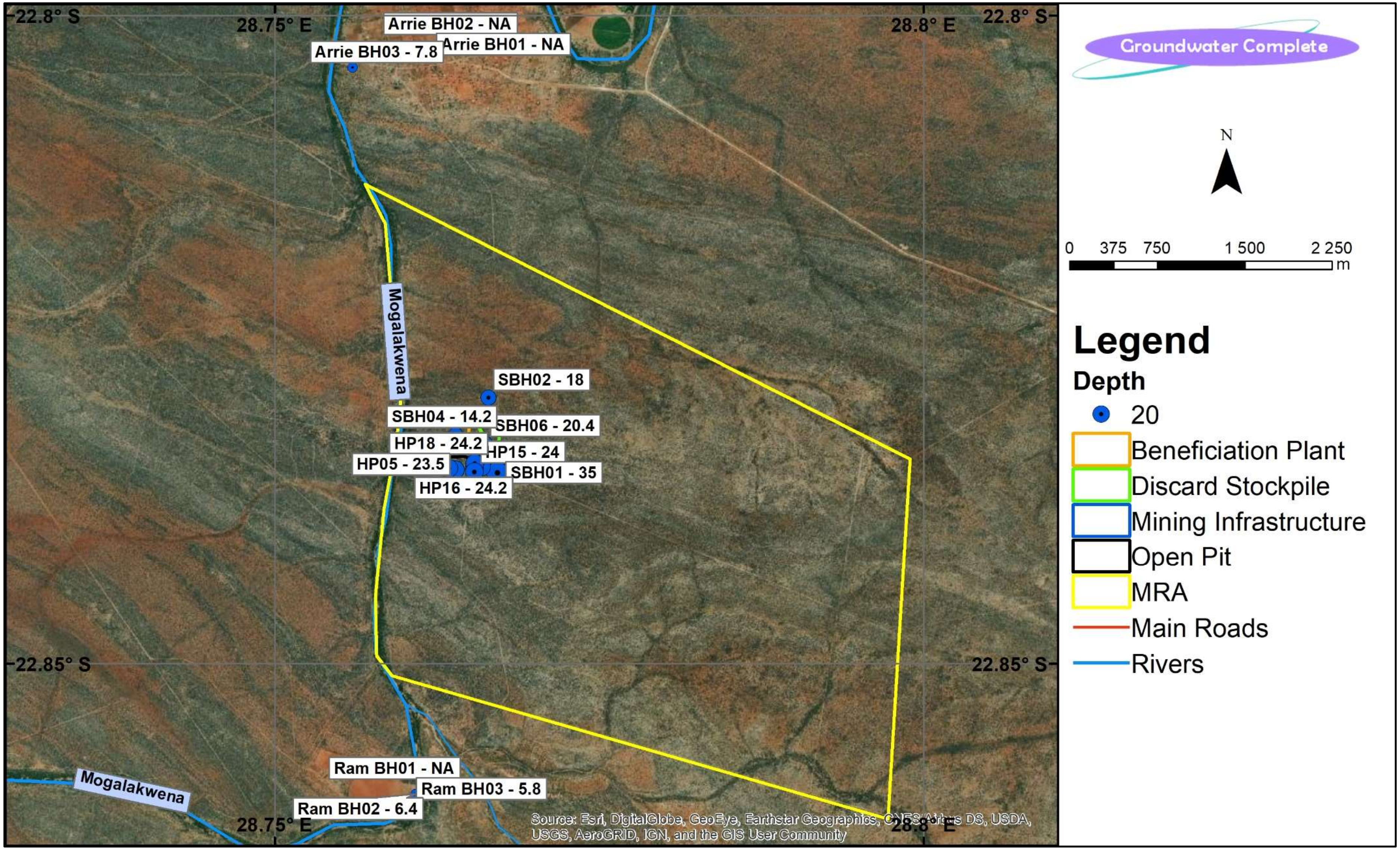

Figure 5-4: Thematic contour map of the groundwater level depths (mbs)

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 5-10**.

Table 5-10: Potential sources of groundwater contamination

Source	Contamination risk	Comments
1) Beneficiation 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. - The mined material proved to be a low risk waste in die geochemical assessment.
2) Discard stockpile	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 eventual in-pit disposal thereof is considered to be more environmentally friendly. - The ore reserve as well as the overburden material proved to be a low risk waste in die geochemical assessment.
3) Water and Waste Management Infrastructure	Low	- 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

Source	Contamination risk	Comments
		have the potential to contaminate the underlying groundwater.
4) Pit	Low	- Impact on the groundwater only occurs through leachate formation from surface. - The groundwater flow gradient is towards the pit and will remain so for nearly 2 centuries after closure – no contamination will thus affect downstream groundwater, even from the low risk waste. - 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 ore material and waste rock that will be generated by the planned mining and related activities are inert and can be classified as a Type 3 low risk waste.*
- *Most potential source areas listed in Table 5-10 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.*
- *Backfilling the waste rock to the pit after mining will result in prevention of any leachate effects (however minimal given the low risk nature of the material) from the mine because the pit will remain a groundwater sink for nearly 200 years.*

5.6 GROUNDWATER QUALITY

Groundwater quality data is available for six dedicated source monitoring boreholes, three hydrocensus boreholes and two surface water samples from the Mogalakwena River and their positions are indicated in **Figure 4-1**. 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 5-11).** 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:

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

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

<u>Field 3:</u>
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.

<u>Field 4:</u>
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.

<u>Field 5:</u>
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.

<u>Field 6:</u>
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.

<u>Field 7:</u>
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.

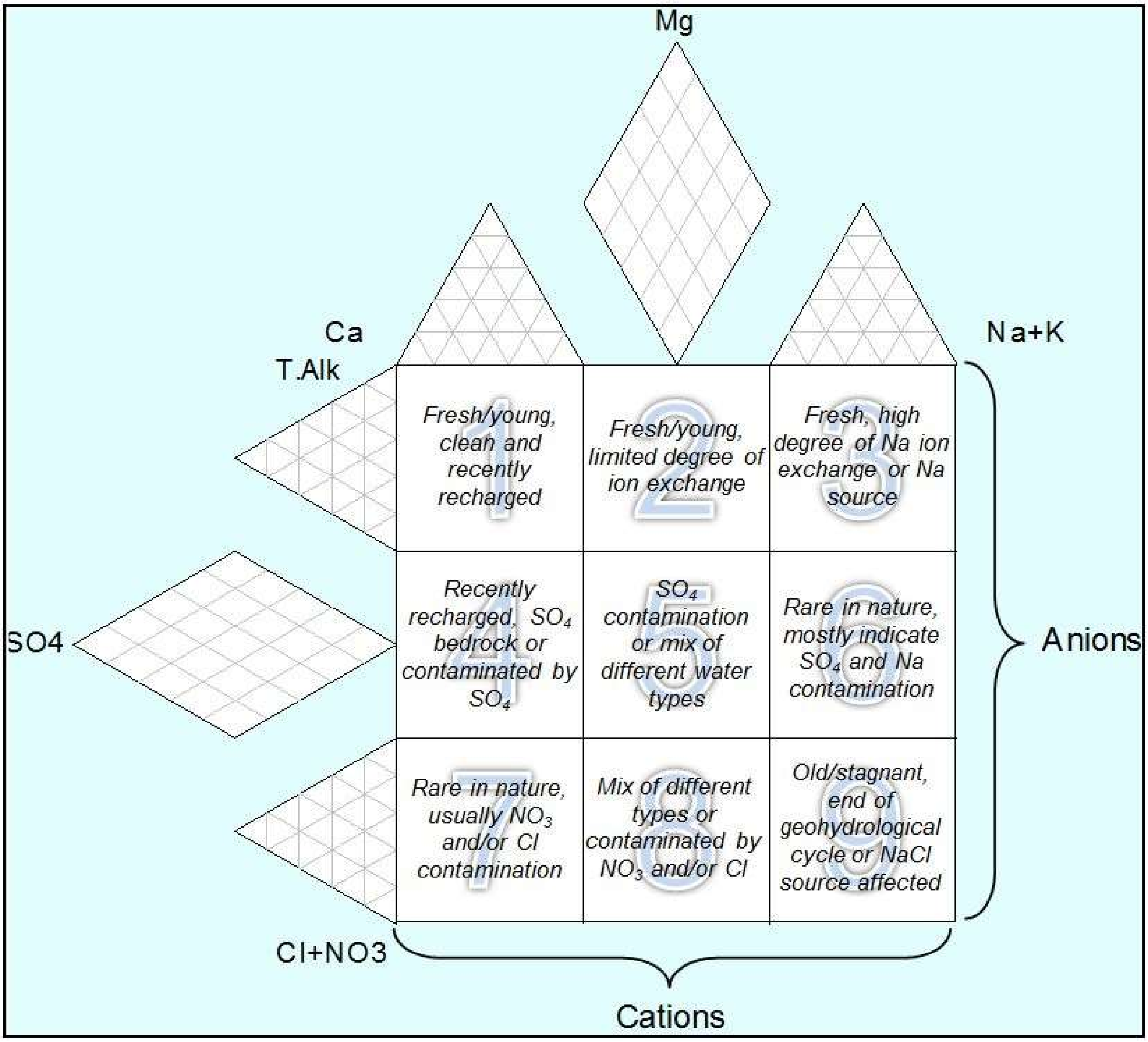

Figure 5-5: Layout of fields of the Expanded Durov diagram

Table 5-11: 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

Six dedicated source monitoring boreholes were drilled within the MRA area and their positions are indicated in **Figure 5-2**. The results of the chemical and physical analyses are provided in **Table 5-12**.

Groundwater within the Steamboat project area is considered to be of marginal or poor quality for domestic use if compared to the South African National Standards for drinking water purposes *(SANS 241:2015)* and still representative of the ambient or unaffected environment. Groundwater TDS concentrations vary between 770 mg/l and 2600 mg/l **(Table 5-12)**. The high salinity of the ambient groundwater is considered to be a result of the following contributing factors:

- The very hot and dry climate resulting in high evapotranspiration and salinity increase;
- Salinity contribution by the underlying geological formations due to natural salinity in the aquifer host rock as exacerbated by the metamorphic processes which included late stage fluids after re-crystallization.

The groundwater quality in the user boreholes around Steamboat indicate somewhat better quality as they are located closer to the Mogalakwena River in a primary aquifer. The river provides fresh water recharge to the primary aquifers around it. The hydrocensus boreholes are situated in close proximity to the river and the groundwater is therefore of better quality. The diagnostic plots clearly show that the hydrocensus boreholes (Arrie BH3 and RAM BH3) have very similar water type (macro element parameter ratios) than the Mogalakwena River upstream (MGK US1) and downstream (MGK DS1).

In **Figure 5-6** and **Figure 5-7** it is clear that the groundwater in the Steamboat area is dominated by three types:

- Relatively young freshly, recharged groundwater that has only started undergoing ion exchange with magnesium. The groundwater is therefore dominated by **magnesium** cations and **alkaline** anions.
- Groundwater that is usually a mix of different types – either clean water from fields 1 and 2 of the EDD that has undergone sulphate and chloride mixing/contamination, or old stagnant sodium chloride dominated water that has mixed with water richer in magnesium. Groundwater is consequently dominated by **magnesium** cations and **chloride** anions.
- Groundwater that is usually a mix of different types – either clean water from fields 1 and 2 of the EDD that has undergone sulphate and chloride mixing/contamination, or old stagnant sodium chloride dominated water. Groundwater is consequently dominated by **sodium** cations and **chloride** anions.

Summary:

- *Groundwater from five of the monitoring boreholes is considered to be of poor marginal to quality with numerous exceedances of the South African National Standards (SANS 241:2015).*
- *All the boreholes' groundwater is unsuitable for human consumption, except for borehole SBG03.*

- *User boreholes are of better groundwater quality due to freshwater recharge from the Mogalakwena River.*

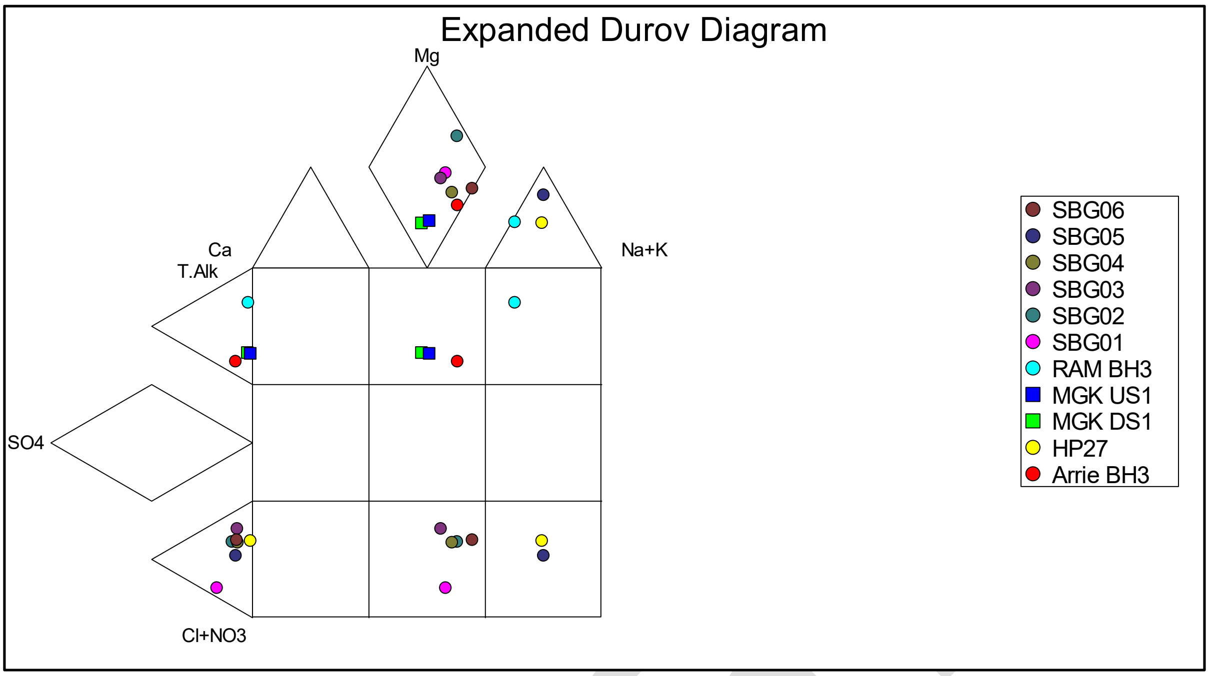

Figure 5-6: Expanded Durov diagram of Steamboat groundwater chemistries.

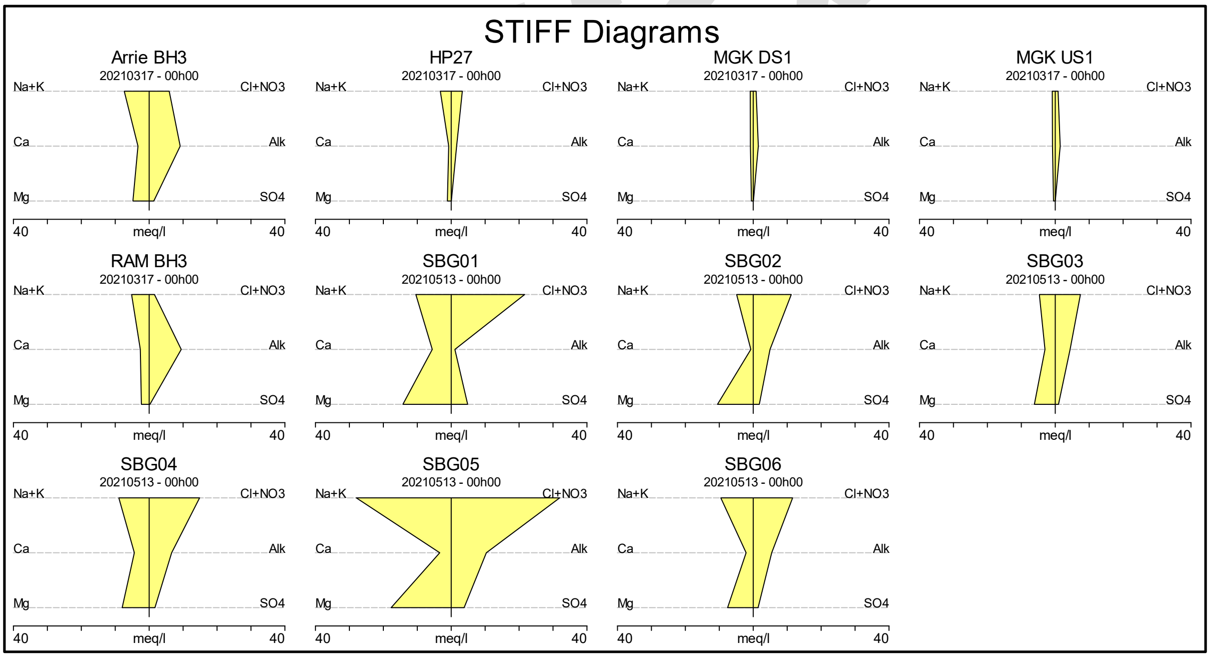

Figure 5-7: Stiff diagram of Steamboat groundwater chemistries.

Table 5-12: Results of chemical and physical analyses for site specific monitoring boreholes

Locality	pH	EC	TDS	MALK	Cl	SO_4	NO_3	NH_4	PO_4	F	Ca	Mg	Na	K	Al	Fe	Mn	Thard - cal
		mS/m	mg/l	mgCaCO3/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mgCaCO3/l
SBH1	7.5	304	1597	54	766	233	-0.2	0.8	0.0	0.3	112	173	207	55	0.0	0.0	0.4	991
SBH2	8.6	149	924	247	375	86	8.8	5.0	1.4	0.6	14	128	103	16	0.0	0.0	0.0	562
SBH3	7.8	138	773	219	254	46	3.5	0.4	0.4	0.8	61	75	102	10	0.0	0.0	0.1	460
SBH4	7.4	200	1286	331	514	81	5.0	0.1	0.4	1.1	88	97	200	10	0.0	0.0	0.0	617
SBH5	7.9	439	2634	518	1125	183	3.0	0.1	1.9	1.4	68	215	623	33	0.0	0.0	0.3	1057
SBH6	7.7	194	1025	272	411	69	-0.2	3.5	0.1	1.0	42	92	210	17	0.0	0.0	0.1	483
Arrie BH3	8	150	897	457	146	66	25	0	1.9	1.1	66	58	166	5	-0	-0	-0	-0.003
HP27	7	61.2	289	80.1	116	2.3	0.2	4.9	0.4	0.4	15	14	58	28	-0	-0	0.3	-0.003
MGK DS1	8	24.3	125	75.1	28.3	2.7	0.7	0.1	0.2	-0.3	17	6.5	19	3.2	0.5	0.2	-0	-0.003
MGK US1	8	24	122	72.9	27.8	1.1	0.8	0.1	0.1	-0.3	17	6.3	18	3.2	0.4	0.2	-0	-0.003
RAM BH3	8	89.4	571	472	43.8	11	4.5	2.5	0.2	0.4	53	28	113	11	-0	-0	0.2	-0.003

***Note: Red** - Value exceeds the maximum permissible SANS concentration allowed in drinking water (Table 5-11).*

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 aquifer underlying the project area achieved a score of 5 **(Table 6-1)** and is therefore regarded as having a medium 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 medium vulnerability.

Table 6-1: Groundwater vulnerability rating for project area

	Rating
Depth to groundwater level	1
Groundwater quality	2
Aquifer type	2
Total score:	**5**

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 two 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.**

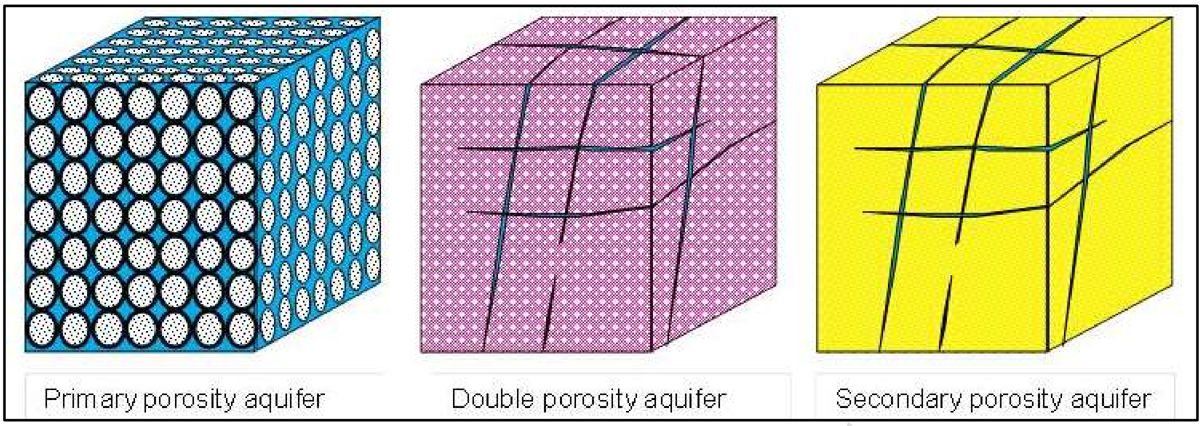

Figure 6-1: Types of aquifers based on porosity.

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 4, which means that a **medium level of protection is required.**

Notes:

- *The aquifer underlying the project area achieved a score of 5* ***(Table 6-1)*** *and is therefore regarded as having a medium vulnerability.*
- *The aquifer underlying the Steamboat area is considered to be a minor aquifer system.*
- *The fractured rock aquifer underlying the project area scored a GQM rating of 4, which means that a* ***medium level of protection is required.***

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.

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.

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 20 meters thick and represents the shallow weathered zone aquifer. The second layer (confined) represents the deeper fractured rock type aquifer hosted within the Swazian erathem rocks.

Table 7-1: Model dimensions and aquifer parameters

General information	
Grid size	Easting = 5920 m Northing = 4720 m
Rows and Columns	Rows = 472, Columns = 592
Cell size	10m by 10m
Number of layers	2
Grid Tilt	19º clockwise
Transmissivity layer 1	
- Quaternary Sedimentary deposits - Gumbu Formation - Fracture zones around boreholes with significant blow yield	1.5 m^2/day 1.2 m^2/day 5-10 m^2/day
Transmissivity layer 2	
- Fractured Metamorphic aquifer	0.29 m^2/day
Specific yield layer 1	
- Quaternary Sedimentary deposits - Gumbu Formation	0.08 0.08
Storage coefficient layer 2	
- Fractured Metamorphic aquifer	0.025
Recharge layer 1	
- Riparian Zone - Medium elevations - Higher elevations	0% of MAP 3% of MAP 4% of MAP

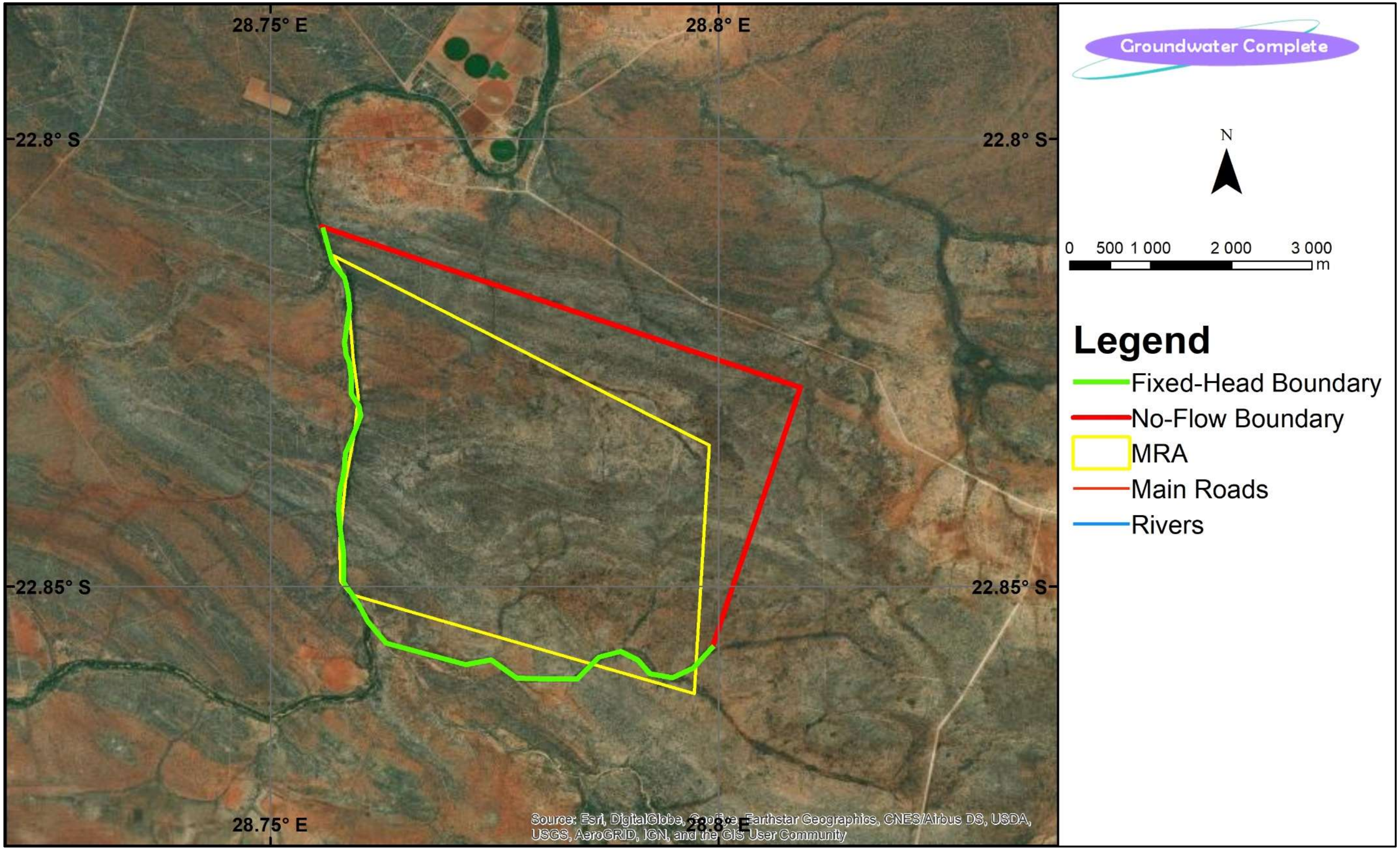

Figure 7-1: Numerical model area

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. 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 7-2**. Groundwater flow from the Steamboat area was simulated to be towards the west as indicated in the abovementioned figure. The average groundwater gradient in this direction was simulated to be approximately 1º.

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.

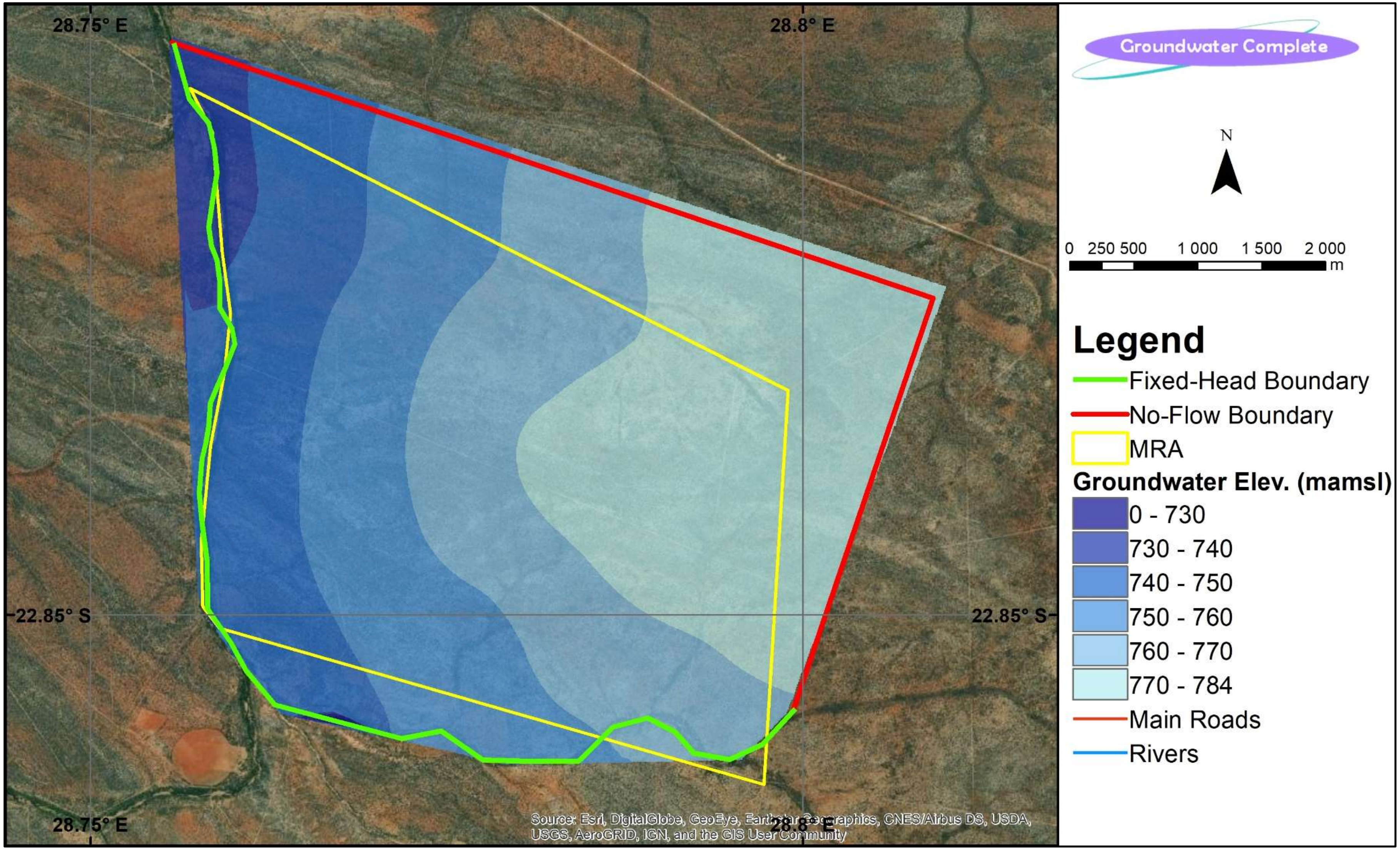

Figure 7-2: Steady state calibrated groundwater elevations

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 pit was included in the transient state model simulations as a drain node, 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 mining area was drawn and is provided in **Figures 7-3** to **7-5**. Based on the assessment of all groundwater related aspects and previous groundwater studies, the hydrogeological system underlying the Steamboat area was conceptualised as follows:

- The topography of the project area can be described as being relatively flat sloping gently from east to west, varying from approximately 810 to 760 mamsl.
- A prominent water course, namely the Mogalakwena River, is located ± 370 meters west of the planned pit.
- The project area receives on average approximately 490 mm of rainfall annually, and the average annual evaporation rate is nearly 2100 mm.
- Hydrocensus/groundwater user surveys were conducted by Aquatico Scientific on the MRA area and surrounding properties. A total of six boreholes were located on the surrounding farms as well as six of the old exploration boreholes from which water levels were measured.
- Recharge to the aquifer underlying the Steamboat area was estimated by means of different measures to be in the order of 4% of the mean annual rainfall.
- The Steamboat MRA is located on a geological region known as the Limpopo Mobile Belt.
- The different formations (Gumbu, Malala Drift, Mount Dowe) belong to the Beitbridge complex, which consists of different metamorphic rock like metaquartzites, calc-silicates and gneisses.
- A waste classification (i.e. total concentration digestion and distilled water leaching tests) was conducted on two samples (i.e. Overburden and Ore Reserve) that were collected from the boreholes drilled on the Steamboat area. The tests concluded that

both samples are a Type 3 or low risk waste, requiring a Class C (or GSB+) disposal facility.

- Based on information gathered during the drilling of six monitoring boreholes, the unsaturated zone is predominantly composed of soil/sand and weathered bedrock (mostly Gneiss).
- The average transmissivity of the quaternary sediment aquifer that underlies the steamboat area was calculated to be in the region of 1.5 m^2/d. The transmissivity of the Gumbu formation is slightly lower at around 1.2 m^2/d.
- Groundwater levels in the project area generally vary between ± 15 and 35 mbs, with the average being ± 20 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 are non-acid forming with high buffering capacities.
- Groundwater from purpose drilled monitoring boreholes is considered to be of poor quality and is mostly unsuitable for human consumption if compared with the South African National Standards *(SANS 241:2015)*.
- The aquifer scored a groundwater vulnerability rating of 5 and is therefore regarded as being of medium vulnerability.
- Two 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.
- The GQM rating for the project area calculates to 4, which means that a medium level of aquifer protection is necessary.

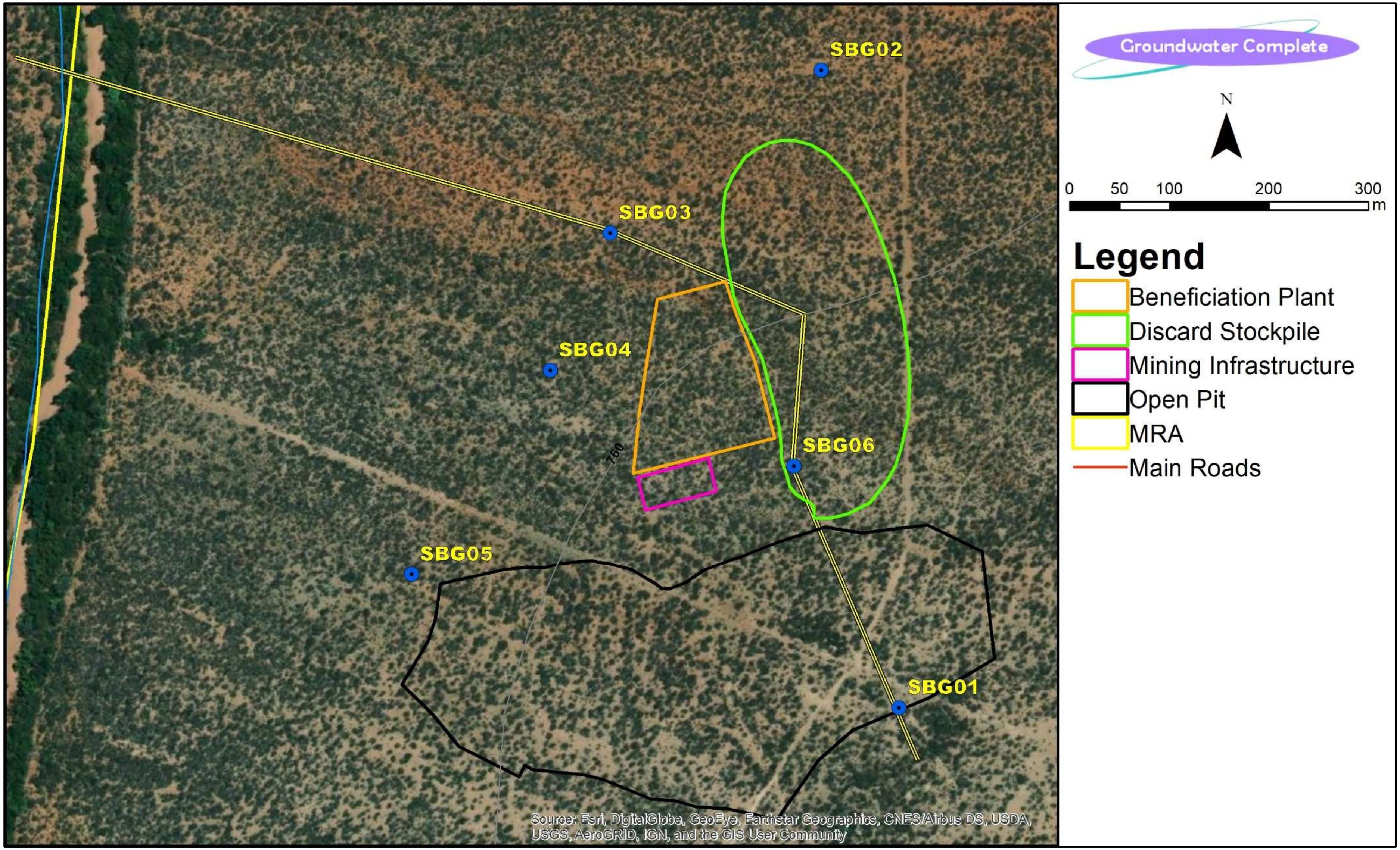

Figure 7-3: Position of the cross section across the mining area

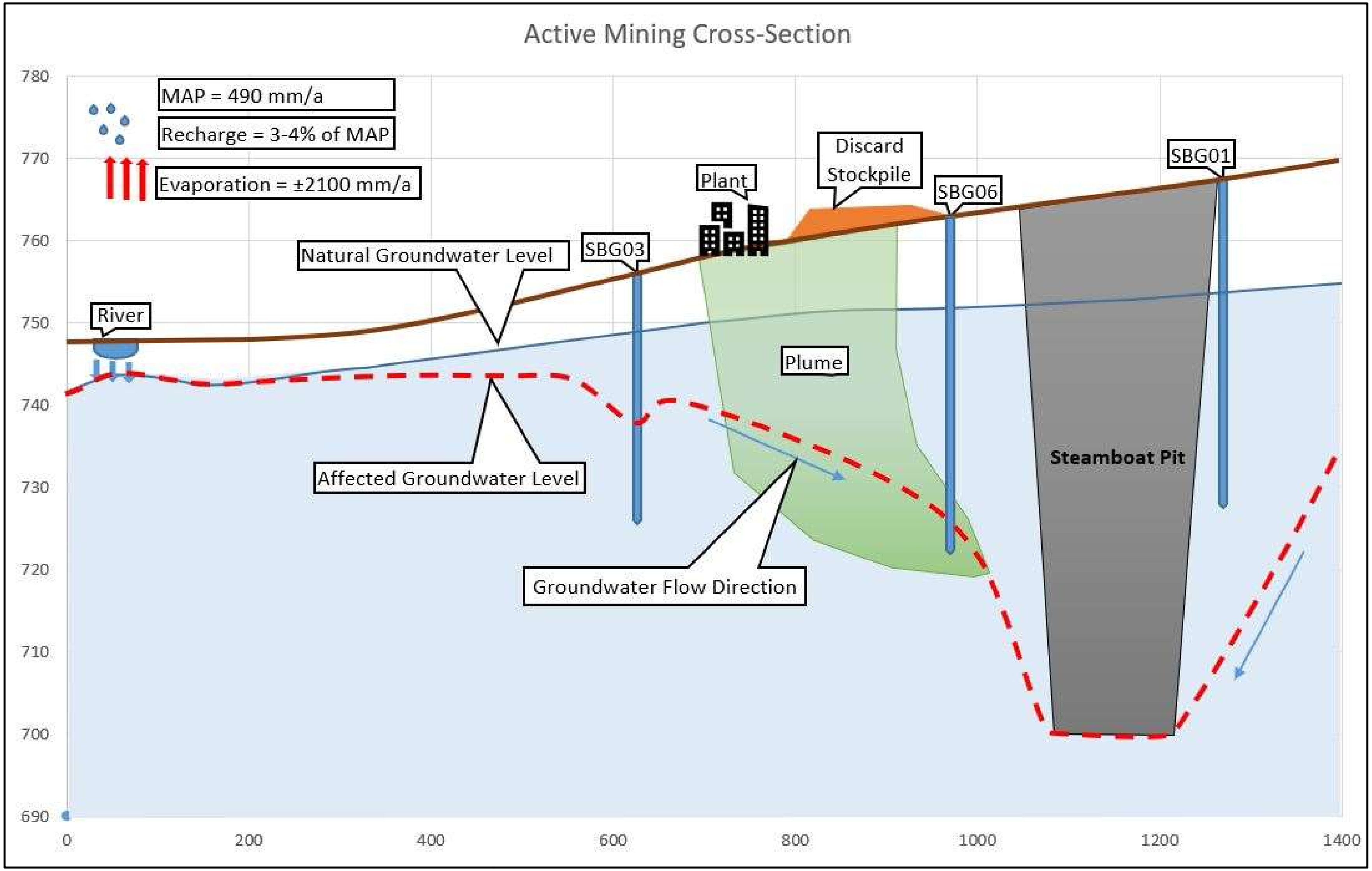

Figure 7-4: Vertical cross section during active mining

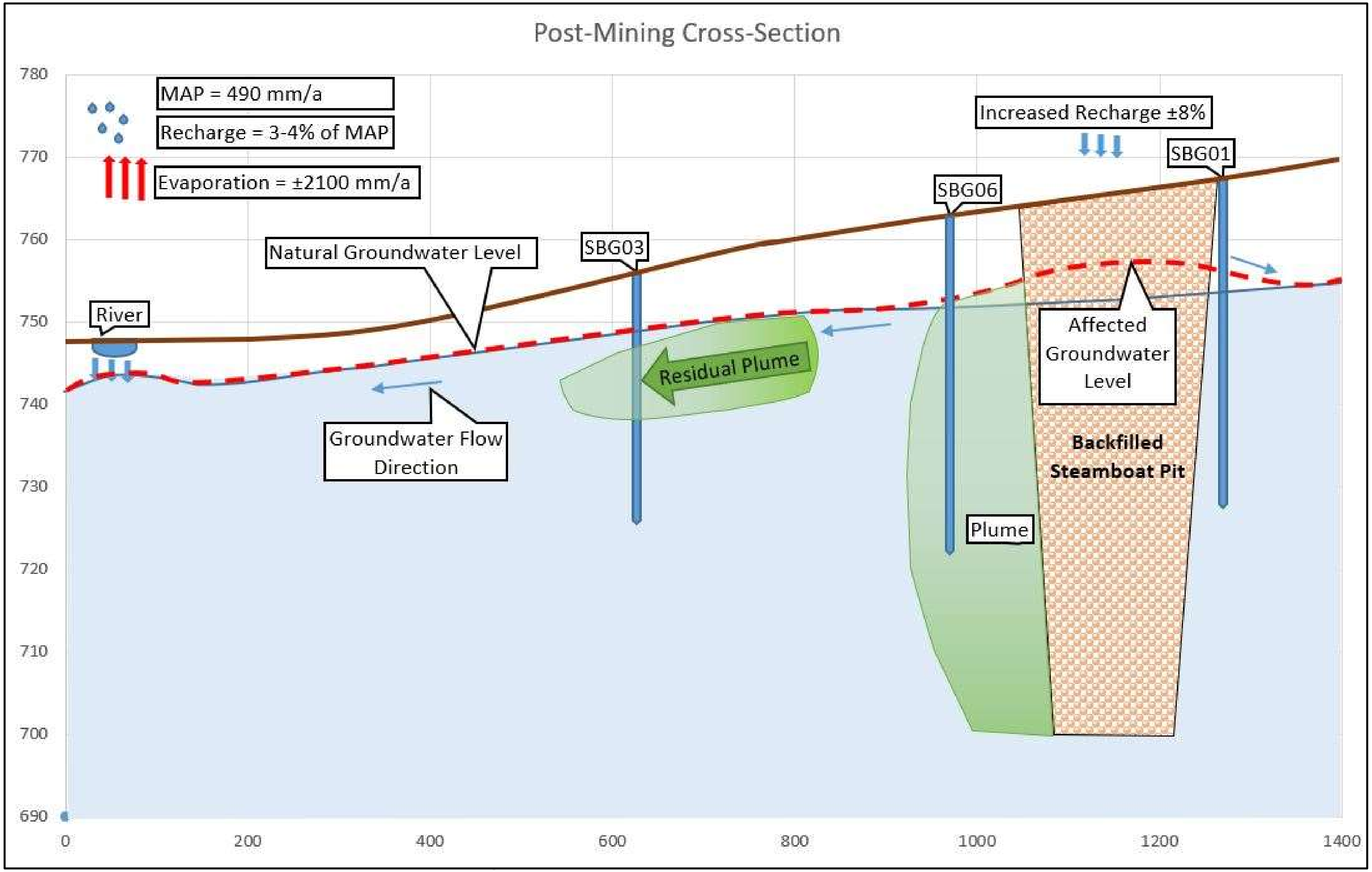

Figure 7-5: Vertical cross section after mining when groundwater levels have recovered

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)*:

Equation 1: Calculation of radius of influence (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.

Also simulated in the model, are three boreholes which will be used during the first few years of mining. These boreholes are SBG03, SBG04 and SBG05. The use from the boreholes is very limited when compared to the dewatering of the pit and they were overshadowed by the drawdown cone from the pit.

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 120 years was subdivided into 15 individual stress periods:

Stress period	Simulation time	Comments
1	1 Year	Simulates pre-mining (ambient) groundwater levels
2 - 20	19 Years	Simulate operational phase activities, i.e. active opencast mining and utilization of mining and related infrastructure.
15	100 Years	Simulate post-closure impacts on especially groundwater quality conditions.

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).

Notes:

- *The model was used to simulate groundwater flow and mass transport conditions for 20 years of mining and 100 years after mining has ceased.*

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 100-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 existing groundwater users.*
- *Most of the potential source areas (e.g. plant footprint, stockpiles and overburden rock) will be removed after the 20 years of mining and backfilled to the mine void.*

7.9 MODEL RESULTS

7.9.1 FLOW MODEL

The results of the numerical groundwater flow model simulations are summarised in **Table 7-2** and **7-3**. The pit floor only intersected the water table from year two of mining. The groundwater influx for Steamboat was simulated to increase to a maximum of ± 440 m^3/d at mine closure. An area of approximately 460 000 m^2 was simulated to be affected by the pit dewatering activities **(Figure 7-6)**.

Figures 7-7 to **7-8** display the model simulated drawdown recovery. 100 years after mining has concluded, the drawdown will have recovered to within a meter of the original water level. A time-to-fill estimation was also conducted and the results can be viewed in Table 7-4. It is estimated that under the most likely conditions (void porosity 25% and recharge of 8%) the pit should fill up and decant in around 210 years post closure.

Table 7-2: Extent of drawdown at LOM

	Extents of drawdown
Simulated drawdown	53 meters at LOM
Area affected	460 000 m^2 at LOM
Maximum radius	720 m at LOM

Table 7-3: Influx into pit at different stages of mining

Stress Period	Influx (m3/d)	Influx (l/s)	annual influx (m3)
2	0	0	0
3	25	0.3	9500
4	30	0.3	10200
5	120	1.4	42700
6	140	1.6	51500
7	170	1.9	60200
8	240	2.7	86500
9	240	2.8	87200
10	320	3.6	115000
11	340	3.9	122300
12	400	4.6	145600
13	440	5.0	158800
14	410	4.8	150700

Table 7-4: Time-to-fill estimations

General information		
	Units	**Pit**
Pit surface area	m^2	106 480
Total void volume	m^3	3 500 000
Mean annual rainfall	m/a	0.49
Backfilled void volume		
20% Porosity	m^3	700 000
25% Porosity	m^3	875 000
30% Porosity	m^3	1 050 000
Recharge/Decant rate		
6% Recharge	m^3/y	3 131
8% Recharge	m^3/y	4 174
10% Recharge	m^3/y	5 218
Time to fill		
Most probable scenario (25% Ø and 8% RCH)	**Years**	**210**

Notes:

- *The simulated groundwater level impacts do not extend beyond the MRA area.*
- *The drawdown cone reached a maximum depth of 53 m and horizontal extent of about 720 m from the pit.*
- *The backfilled pit is expected to fill with water at approximately 210 years after mining ends.*
- *100-years after mining has concluded, the drawdown will have recovered to within a meter of the original water level*

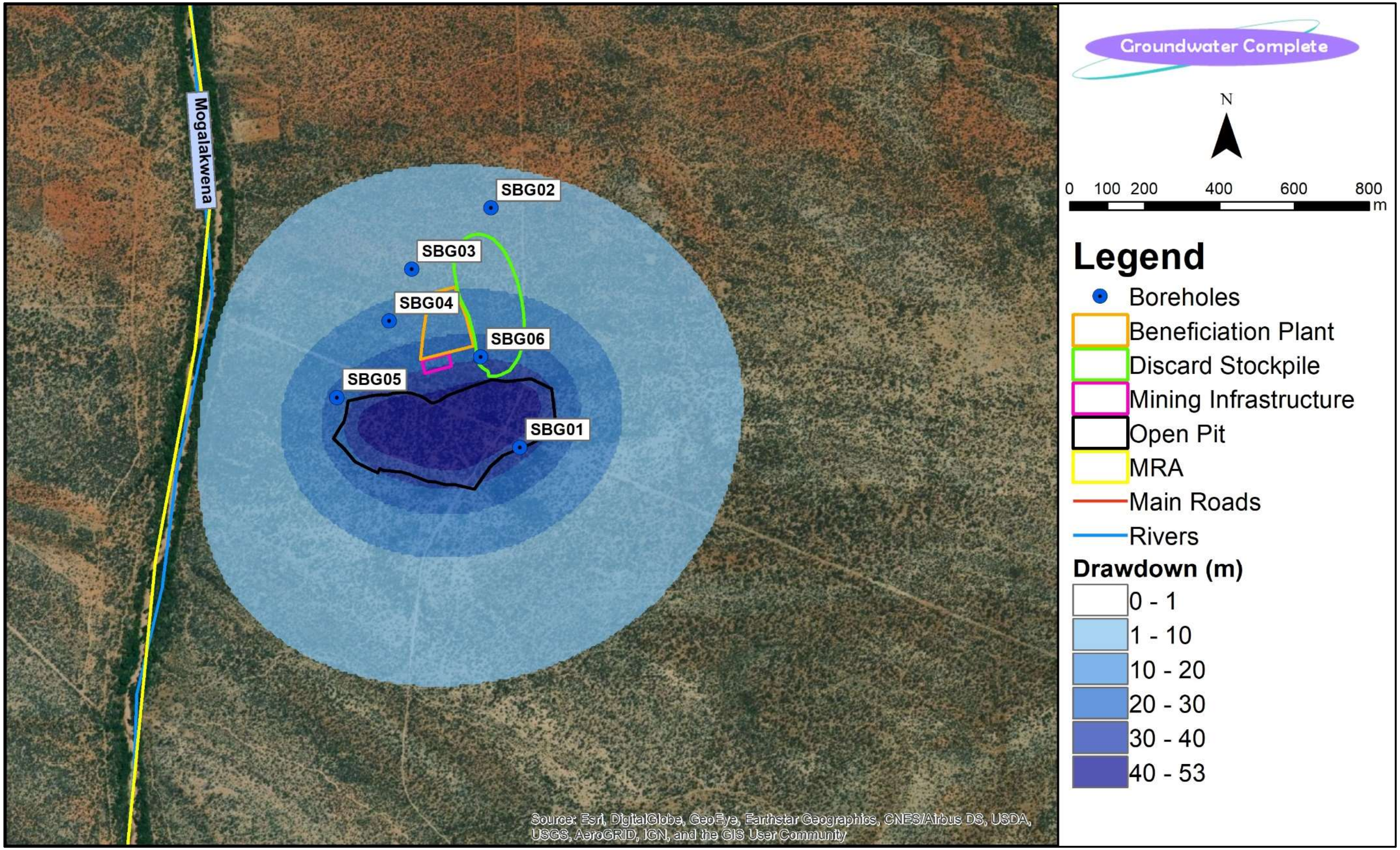

Figure 7-6: Groundwater drawdown cone at mine closure

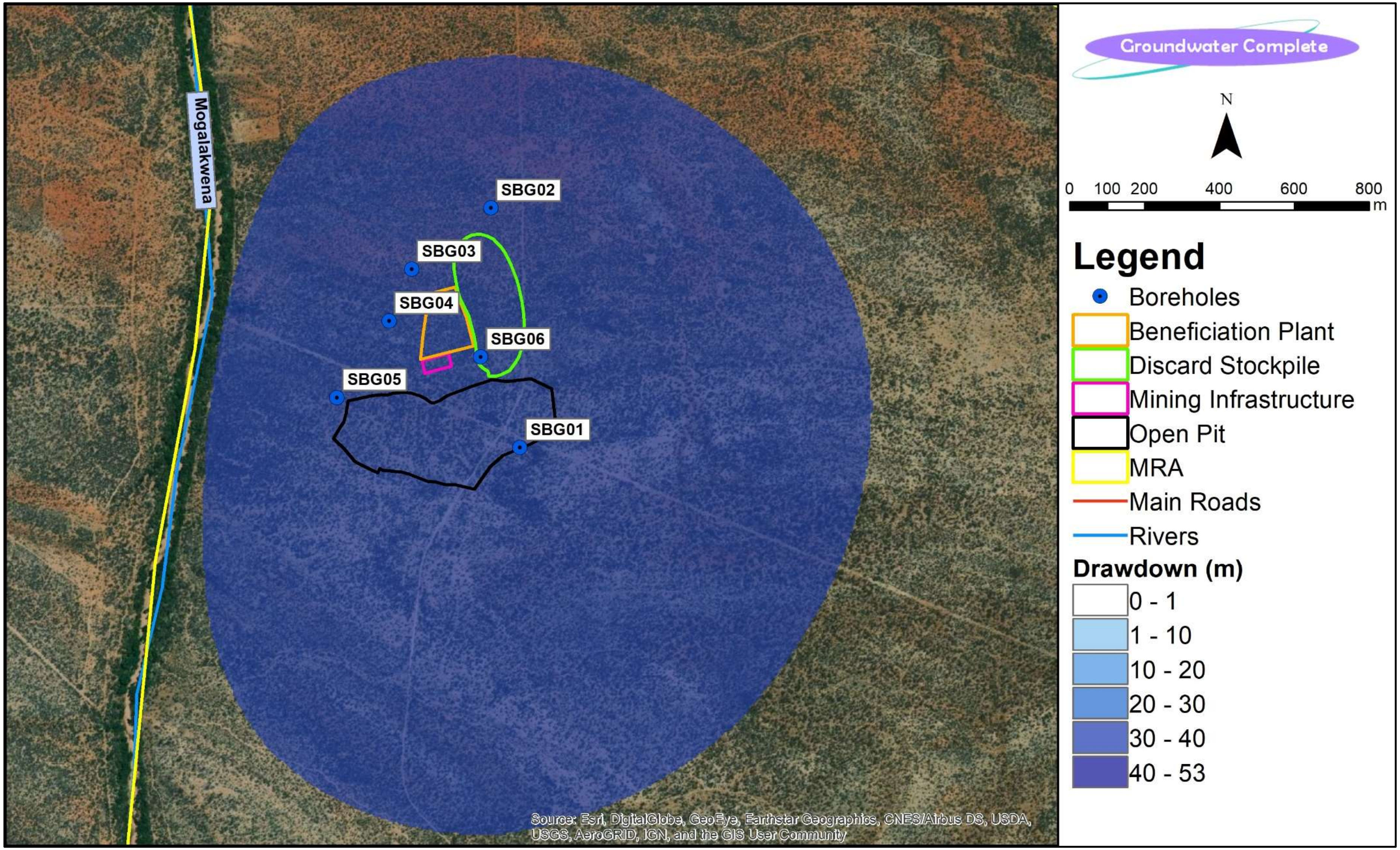

Figure 7-7: Groundwater drawdown cone 20-years after mine closure

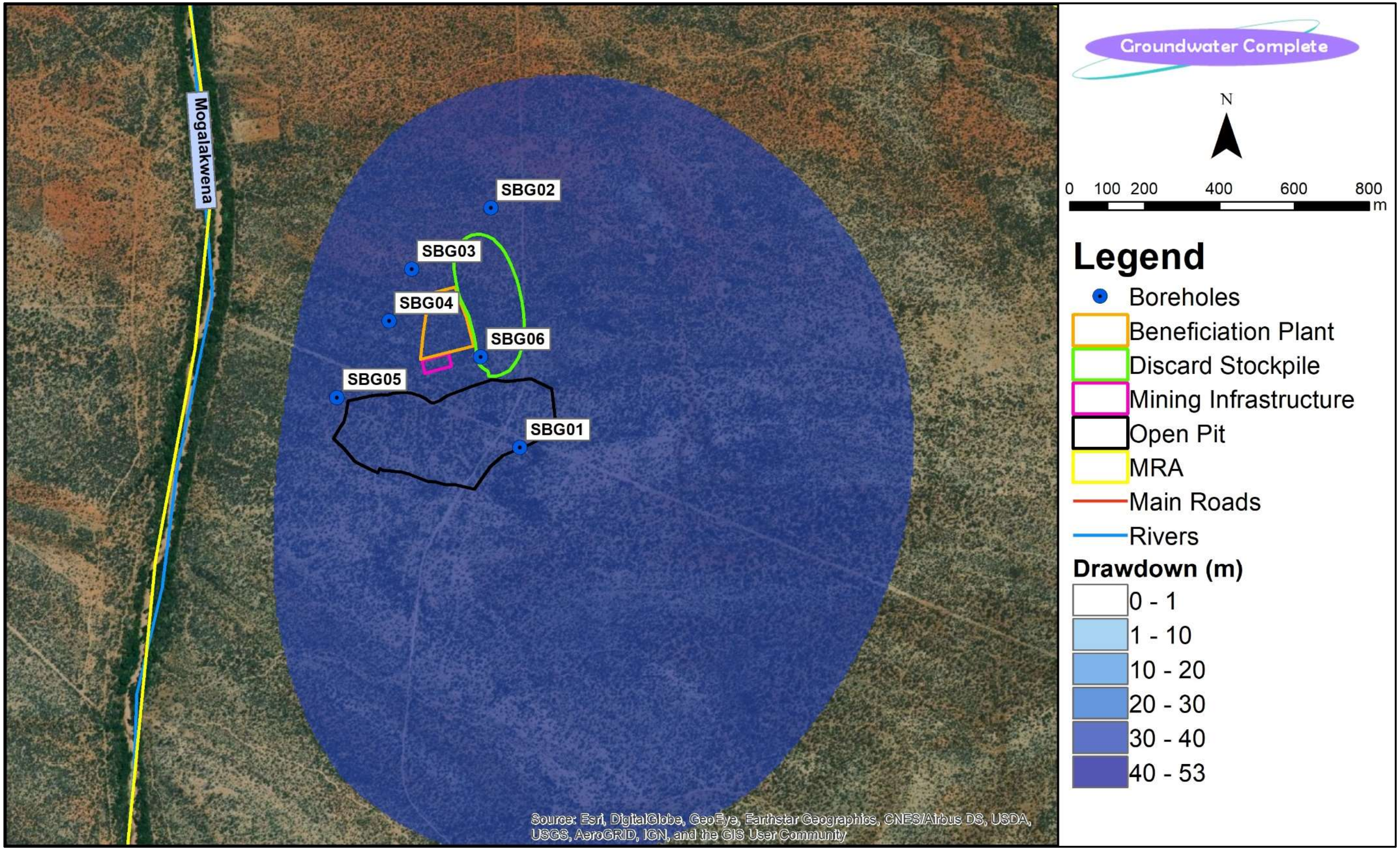

Figure 7-8: Groundwater drawdown cone 50-years after mine closure

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 mining related infrastructure and Discard Stockpile 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.

Mine closure:

The model simulated groundwater contamination plumes for the Steamboat area are provided in **Figure 7-9** and **7-10**. Plume migration simulated for Steamboat remained very limited during the pit acting as a groundwater sink. All of the contamination will flow towards the pit. Thus, contamination should not have spread more than a few meters from any source by LOM.

The contamination plume for Steamboat was confined to the mining footprint area for the entire active mining period and was simulated to be between 5 and 8% of the original source concentration at most.

Post closure:

At 100 years post closure, the Steamboat contamination plumes were simulated to have increased in size and concentration. With the pit no longer acting as a sink for the groundwater, the plumes have started to migrate west towards the river. The maximum plume movement was about 170m downgradient from the pit. Plume concentrations were simulated to increase over time, however, natural occurring processes such as dilution and dispersion caused concentrations to only reach ± 50% after 100 years.

The concentration of any leachate from the plant of overburden dump or pit is unknown. The geochemical assessment showed that all the material represents a low risk waste. For modelling purposes, the source concentration was applied as 100, which represents 100% of the source. The concentration contours thus indicate how the plumes will dilute with distance away from source until the concentration zero, thus not influence of the source remains.

Notes:

- *The simulated groundwater quality impacts do not extend beyond the MRA area.*
- *The simulated contamination plume reached a maximum distance from the sources of about 170m in the down-gradient direction.*

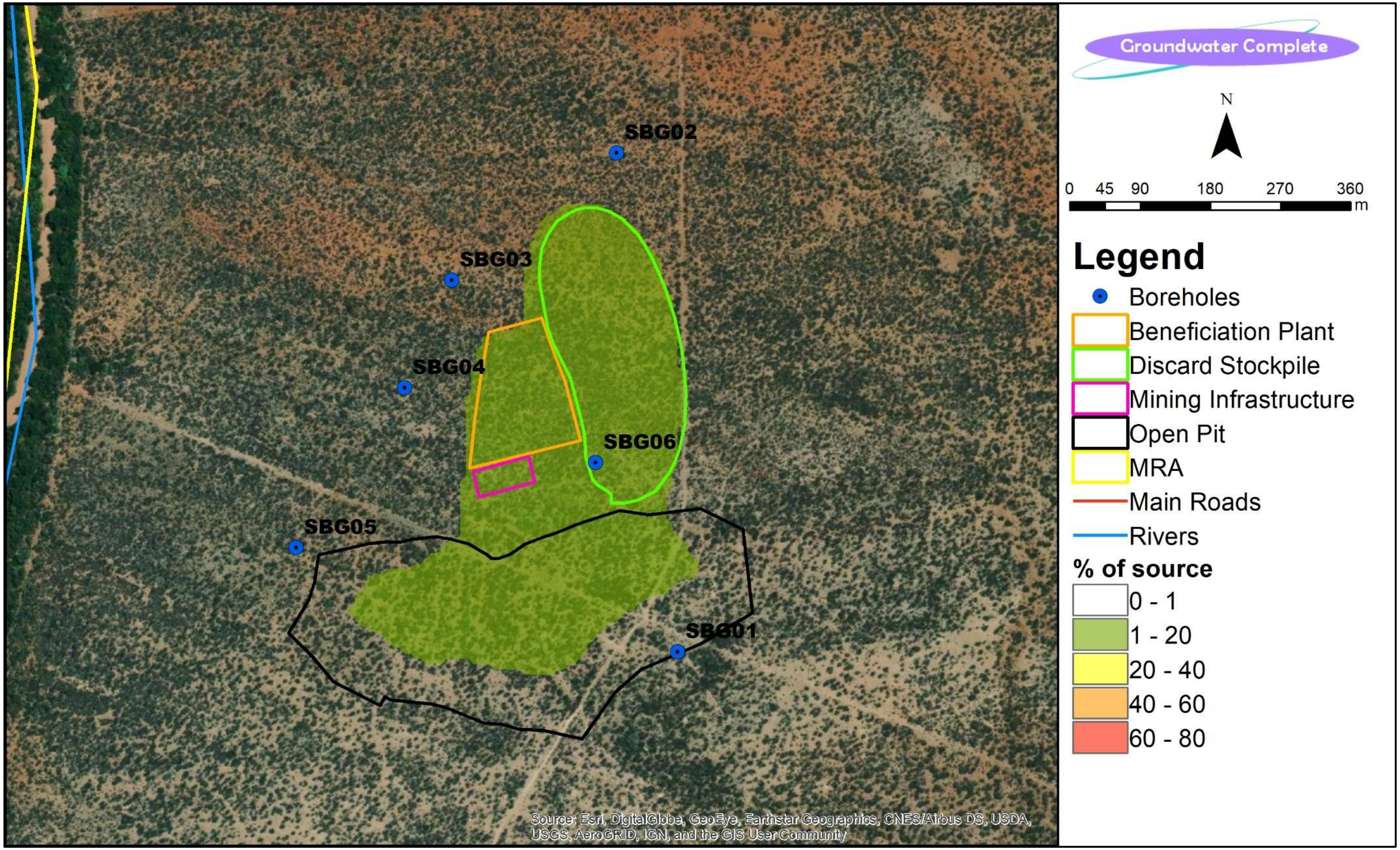

Figure 7-9: Groundwater contamination plumes at mine closure

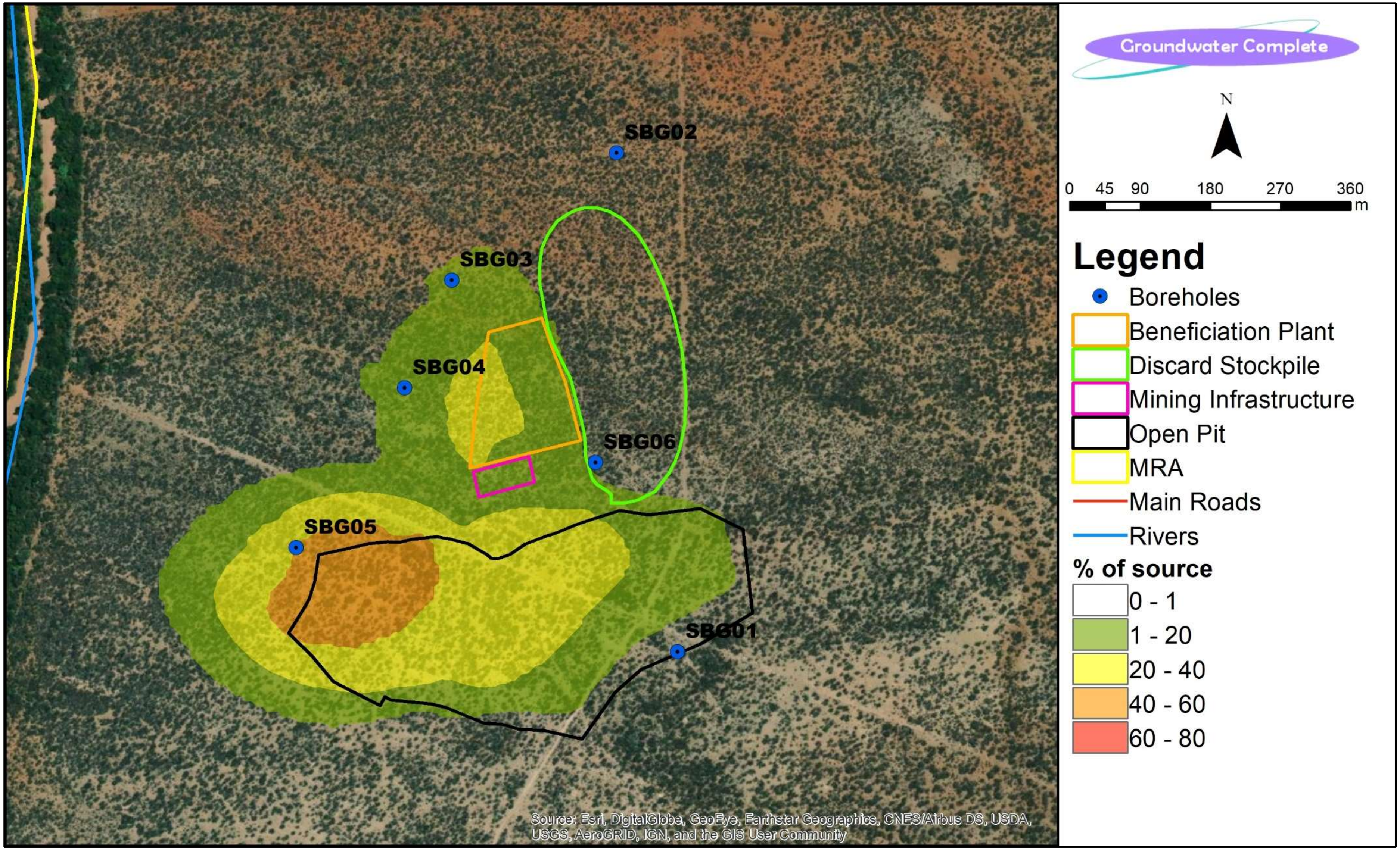

Figure 7-10: Groundwater contamination plumes at 100 years post closure

8 GEOHYDROLOGICAL IMPACT ASSESSMENT

This part of the geohydrological input to the EMP report describes and evaluates the potential impact of the Steamboat Graphite 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 Diphororo Development (Pty) Ltd and is discussed in **Section 8.1** below. The expected groundwater impacts during the various project phases with possible mitigation alternatives are discussed in **Section 8.2**, after which the rating table with significance before and after mitigation is presented in **Table 8-4**.

Impact assessment is 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 holistic and balanced way, thus supporting the aim of minimising adverse impacts on the environment.

8.1 METHODOLOGY

The various aspects that add up to the significance of the impact are listed below.

Status of Impact (S)
The impacts are assessed as either having a:

- Negative effect (i.e. at a `cost' to the environment),
- Positive effect (i.e. a `benefit' to the environment), or
- Neutral effect on the environment.

Extent of the Impact (E)

- (1) Site (site only),
- (2) Local (site boundary and immediate surrounds),
- (3) Regional,
- (4) National, or
- (5) International.

Duration of the Impact (D)
The length that the impact will last for is described as either:

- (1) Immediate (<1 year)
- (2) Short term (1-5 years),
- (3) Medium term (5-15 years),
- (4) Long term (ceases after the operational life span of the project),
- (5) Permanent.

Magnitude of the Impact (M)
The intensity or severity of the impacts is indicated as either:
- (0) None,
- (2) Minor,
- (4) Low,
- (6) Moderate (environmental functions altered but continue),
- (8) High (environmental functions temporarily cease), or
- (10) Very high / unsure (environmental functions permanently cease).

Probability of Occurrence (P)
The likelihood of the impact actually occurring is indicated as either:
- (0) None (the impact will not occur),
- (1) Improbable (probability very low due to design or experience)
- (2) Low probability (unlikely to occur),
- (3) Medium probability (distinct probability that the impact will occur),
- (4) High probability (most likely to occur), or
- (5) Definite.

Significance of the Impact without Mitigation (SWOM)
Based on the information contained in the points above, the potential impacts are assigned a significance rating (S). This rating is formulated by adding the sum of the numbers assigned to extent (E), duration (D) and magnitude (M) and multiplying this sum by the probability (P) of the impact.

SWOM = (E+D+M) x P

The significance ratings are as follow;
- **(<60) low** (i.e. where this impact would not have a direct influence on the decision to develop in the area),
- **(60-100) medium** (i.e. where the impact could influence the decision to develop in the area unless it is effectively mitigated),
- **(>100) high** (i.e. where the impact must have an influence on the decision process to develop in the area).

8.2 Impact Rating

Discussion of the potential impacts on groundwater of various project activities and during the main project phases are provided below

8.2.1 Construction Phase

Table 8-1: Potential impact of activities in the Construction phase

Activity	Potential impact	Mitigation
Vegetation and land clearance	Clearing of vegetation of topsoil from footprint areas (pit, plant discard dump) can increase infiltration rates of water to the groundwater system, ultimately leading to a (very slight) increase in groundwater levels. This potential impact is a slightly positive one.	Mitigation is not possible.
Waste/Hydrocarbon handling	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.	Waste should be stored/managed/contained in allocated waste areas. Spills should be cleaned up immediately. Domestic waste must either be stored in an approved waste site or removed by credible contractors.

8.2.2 OPERATIONAL PHASE

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

Table 8-2: Potential impact of activities in the Operational phase

Activity	Potential impact	Mitigation
Opencast mining	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.	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.
Extraction of groundwater for mining	Localized lowering of the water level will occur	Boreholes should only be pumped at sustainable yields. More boreholes spread over a larger area and pumped at lower rates should decreased the drawdown effect.
Waste rock, topsoil, waste water and product stockpiling (plant area)	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.	Stockpiles, plant footprint and the overburden dump should be kept as small as practically possible. Any run-off from these areas should be contained.
Dirty water facilities	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.	All water and effluent 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. Proper management and regular inspections for leakages are strongly recommended.
Workshops and washing/cleaning bays	Impacts on the groundwater only occur through leachate formation from dirty surface areas. Impacts	Surface areas below workshops and wash bays should be lined to prevent

	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.).	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.

8.2.3 DECOMMISSIONING AND POST CLOSURE PHASE

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. The long-term effect in terms of groundwater quantity will be positive in that the effective recharge will be higher to the backfilled pit with more groundwater being available on a sustainable basis.

All the potential 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 potential source of contamination is the backfilled and rehabilitated opencast pit. The pit will in fact remain a groundwater sink for 200 years or longer. After groundwater levels have recovered and a new groundwater level equilibrium has been established, contamination from the rehabilitated pit will begin to migrate in the down gradient groundwater flow direction. Waste assessment results however show that the backfill material is of low contamination risk and the leachate will probably be of similar quality than the ambient groundwater.

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

Table 8-3: Potential impact of activities in the Decommissioning phase

Activity	Potential impact	Mitigation
Rehabilitation and backfill of pit	The water level will recover in the backfilled void. Recharge will be higher than pre-mining and the eventual effect will be positive.	None necessary. The effect is positive. Recharge can, however, be further promoted by leaving the final surface as a slight depression and use the pit as source of water supply.
Migration of residual contamination away from the rehabilitated surface source areas	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.	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	Backfill material is expected to be relatively inert and in itself poses	Dedicated plume monitoring boreholes should be drilled in the

away from rehabilitated opencast pit	no significant threat to groundwater quality. It may, however, contain remnants of the nitrate-based explosives used during mining. These nitrates dissolve readily in water, meaning that the migrating plume may contain nitrate.	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 8-4: Impact ratings for various activities for all project phases

Specialist Area	Activity	Status	Extent	Duration	Magnitude	Probability	Significance without Mitigation	Mitigation Efficiency	Significance without Mitigation
Construction Phase									
Groundwater	Vegetation and land clearance	Positive	Site	Medium term	Low	High probability	**Medium**	Low	**Medium**
Groundwater	Waste/Hydrocarbon handling	Negative	Site	Medium term	Moderate	Medium probability	**Low**	Medium	**Low**
Operational Phase									
Groundwater	Opencast mining	Negative	Site	Medium term	High	Definite	**Medium**	Low	**Medium**
Groundwater	Extraction of groundwater for mining	Negative	Site	Medium term	Low	Definite	**Medium**	Medium	**Medium**
Groundwater	Waste rock, topsoil, waste water and product stockpiling	Negative	Site	Long term	Low	Low probability	**Low**	Low	**Low**
Groundwater	Dirty water facilities	Positive	Site	Long term	Low	Definite	**Medium**	High	**Low**
Groundwater	Workshops and washing/cleaning bays	Negative	Site	Long term	Low	Low probability	**Low**	High	**Low**
Decommissioning and Post Closure									
Groundwater	Rehabilitation and backfill of pit	Positive	Site	Permanent	Low	Definite	**Medium**	Low	**Medium**
Groundwater	Migration of residual contamination away from the rehabilitated surface source areas	Negative	Site	Long term	Low	Medium probability	**Low**	Low	**Low**
Groundwater	Migration of contamination away from rehabilitated opencast pit	Negative	Site	Permanent	Moderate	Medium probability	**Medium**	Low	**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). The boreholes described in **Section 4.4** were drilled with this purpose in mind.

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 over time to evaluated how and to what extent the aquifer is affected.

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 pit (dewatering volume); and
- Volumes of contaminated water used for dust suppression.
- Volumes extracted from boreholes to use in the mining activities.

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

Six boreholes were drilled specifically for groundwater monitoring purposes and their positions are indicated in **Figure 4-3**. Over time, more boreholes may be drilled if it is deemed necessary by a groundwater specialist.

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.

10 GROUNDWATER 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 ± 15 and 35 mbs, with the average being ± 20 mbs.

10.1.2 GROUNDWATER QUALITY CONDITIONS

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

Groundwater from most user boreholes is considered to be of marginal to poor quality and is unsuitable for human consumption with regards to the South African National Standards *(SANS 241:2015)*. It is believed that the poor quality of the groundwater represents ambient conditions and is due to low recharge and high evaporation rates.

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.

Note:

- *Although all care was taken to follow scientific methodology in the processing and assessment of results, diligent following of a groundwater monitoring protocol is crucial to verify, update and refine the estimations, predictions and conclusion made in this report.*
- *The groundwater monitoring program itself also needs to be reviewed and updated, expanded and/or refined if necessary due to changes in the process and infrastructure simulated in this study or if anomalous results are measured that require additional information.*

11 CONCLUSIONS AND RECOMMENDATIONS

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

- *The Mogalakwena River is located 250m downgradient from the proposed project site and will therefore be considered to be a possible receptor of any contamination that may potentially originate from the project area.*
- *Average annual rainfall is approximately 490mm.*
- *Average annual evaporation is between 2000 and 2200mm.*
- *The hydrocensus/user survey was conducted on the properties surrounding Steamboat.*
- *A total of six user boreholes were located within the hydrocensus area.*
- *Additionally, water levels could be measured in six of the old exploration boreholes.*
- *Six new boreholes were drilled on the proposed Steamboat mining area specifically for geohydrological testing and sampling.*
- *The effective recharge in the Steamboat area is estimated to be in the order of 4% of MAP.*
- *The area is underlain by quaternary sediments and metamorphic rock of the Limpopo Mobile Belt.*
- *The maximum on-site water requirement at full production is around 3 l/s.*
- *Water for the project can be provided using boreholes SBG03, SBG04 and SBG05 but additional water may be required initially.*
- *Static groundwater level depth in the Steamboat area range between 15 and 35 mbs.*
- *The waste classification concluded that both the ore material and waste rock that will be generated by the planned mining and related activities are inert and can be classified as a Type 3 (low risk) waste.*
- *It is concluded that a Class C (or GSB+) disposal facility would suffice for both the ore reserve and waste rock.*
- *Both samples have sufficient buffering capacity (base potential) to neutralize the small amount of acid that may form.*
- *Most potential surface source areas (discard dump, plant area, stockpiles) 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.*
- *Pre-mining (baseline) groundwater from five of the monitoring boreholes is considered to be of poor quality with numerous exceedances of the South African National Standards (SANS 241:2015).*
- *All the boreholes' groundwater is unsuitable for human consumption, except for borehole SBG03.*
- *The aquifer underlying the project area achieved a score of 5 (Table 6-1) and is therefore regarded as having a medium vulnerability.*

- *The aquifer underlying the Steamboat area classifies as a minor aquifer system according to the Parsons system.*
- *The fractured rock aquifer underlying the project area scored a GQM rating of 4, which means that a medium level of protection is required.*
- *The numerical flow model shows that simulated groundwater level impacts do not extend beyond the Steamboat MRA.*
- *The drawdown cone reached a maximum depth of 53 m and horizontal extent of about 720 m from the pit.*
- *Full recovery of the water level in the pit is expected to occur about 200 years after mining ends.*
- *The simulated groundwater quality impacts do not extend beyond the MRA area.*
- *The simulated contamination plume reached a maximum distance from the sources of about 200m in the down-gradient direction at 100 years after closure.*
- *A groundwater monitoring protocol was proposed for the project. Diligent application of a groundwater monitoring protocol is crucial to verify, update and refine the estimations, predictions and conclusion made in this report.*
- *The groundwater monitoring program itself also needs to be reviewed and updated, expanded and/or refined if necessary if changes occur to the process and infrastructure simulated in this study or if anomalous results are measured that require additional information.*

The overall conclusion is that the proposed project poses no groundwater impacts that are of such magnitude or extent that it would cause a significant negative affect on the groundwater quality or availability of the region. Negative impacts are largely confined to the proposed mining and processing footprint area and are not expected to extend beyond the MRA. No nearby groundwater user or the nearest watercourse (Mogalakwena River) will be adversely affected in terms of quality or availability.

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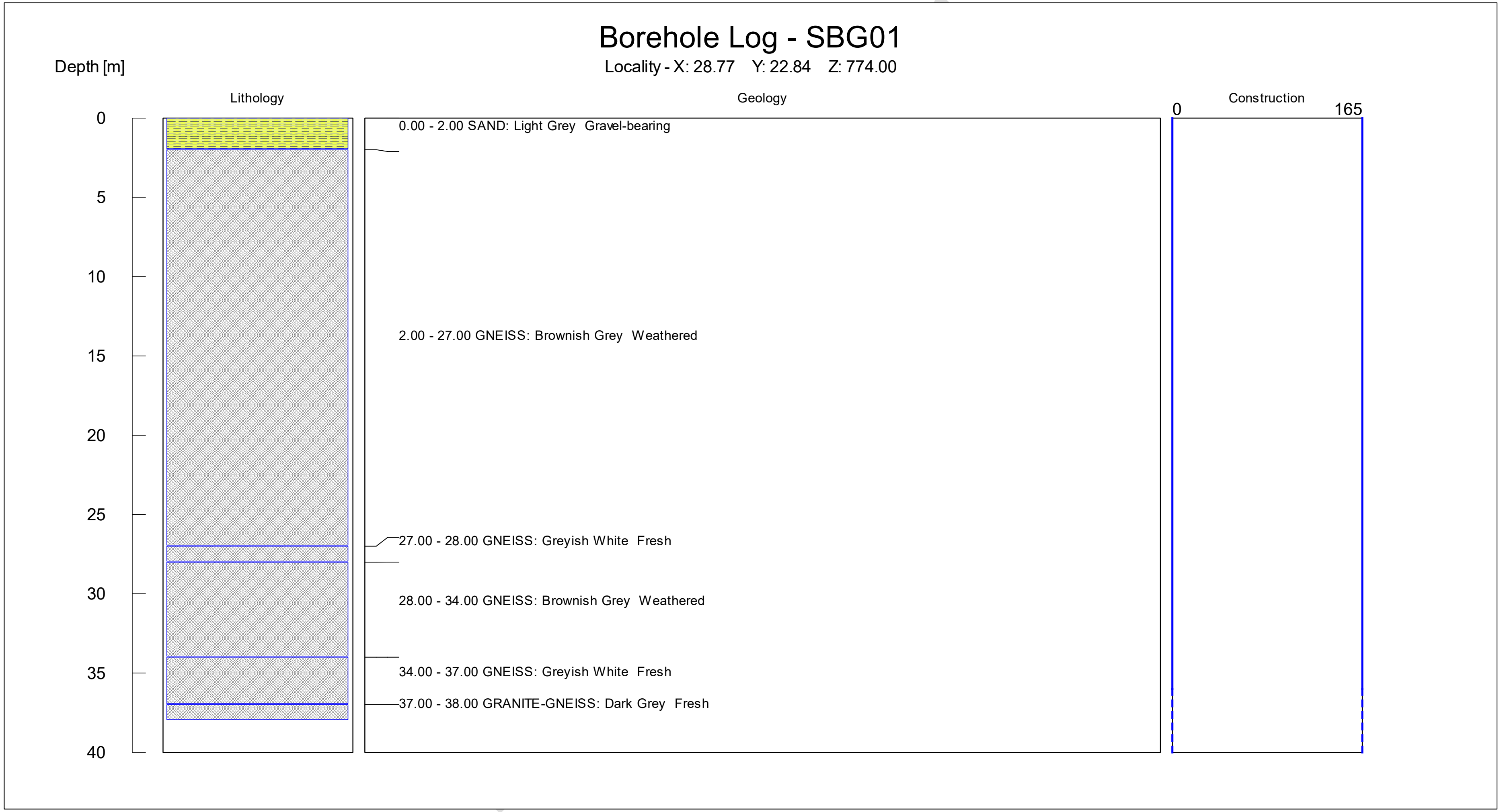
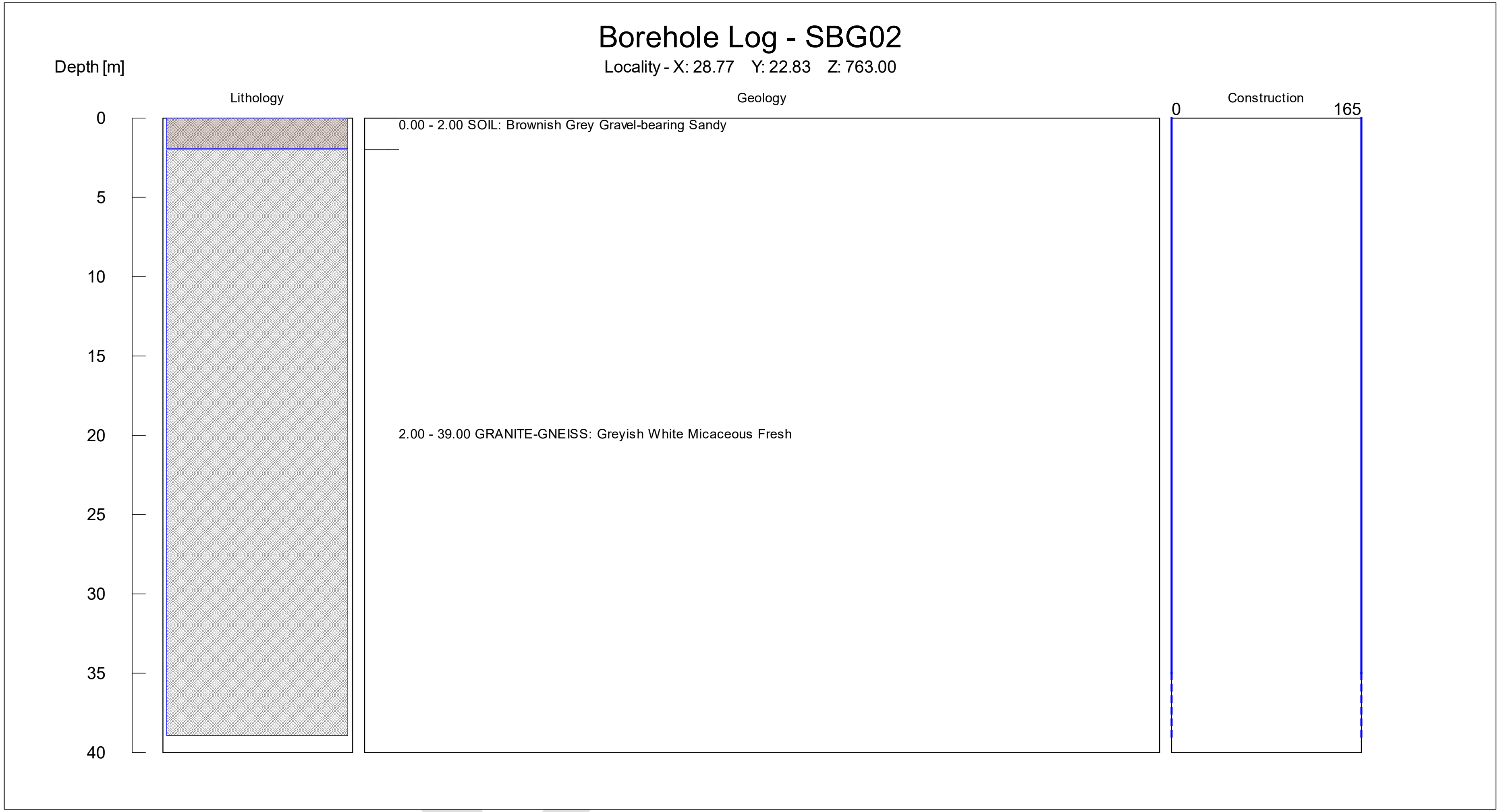
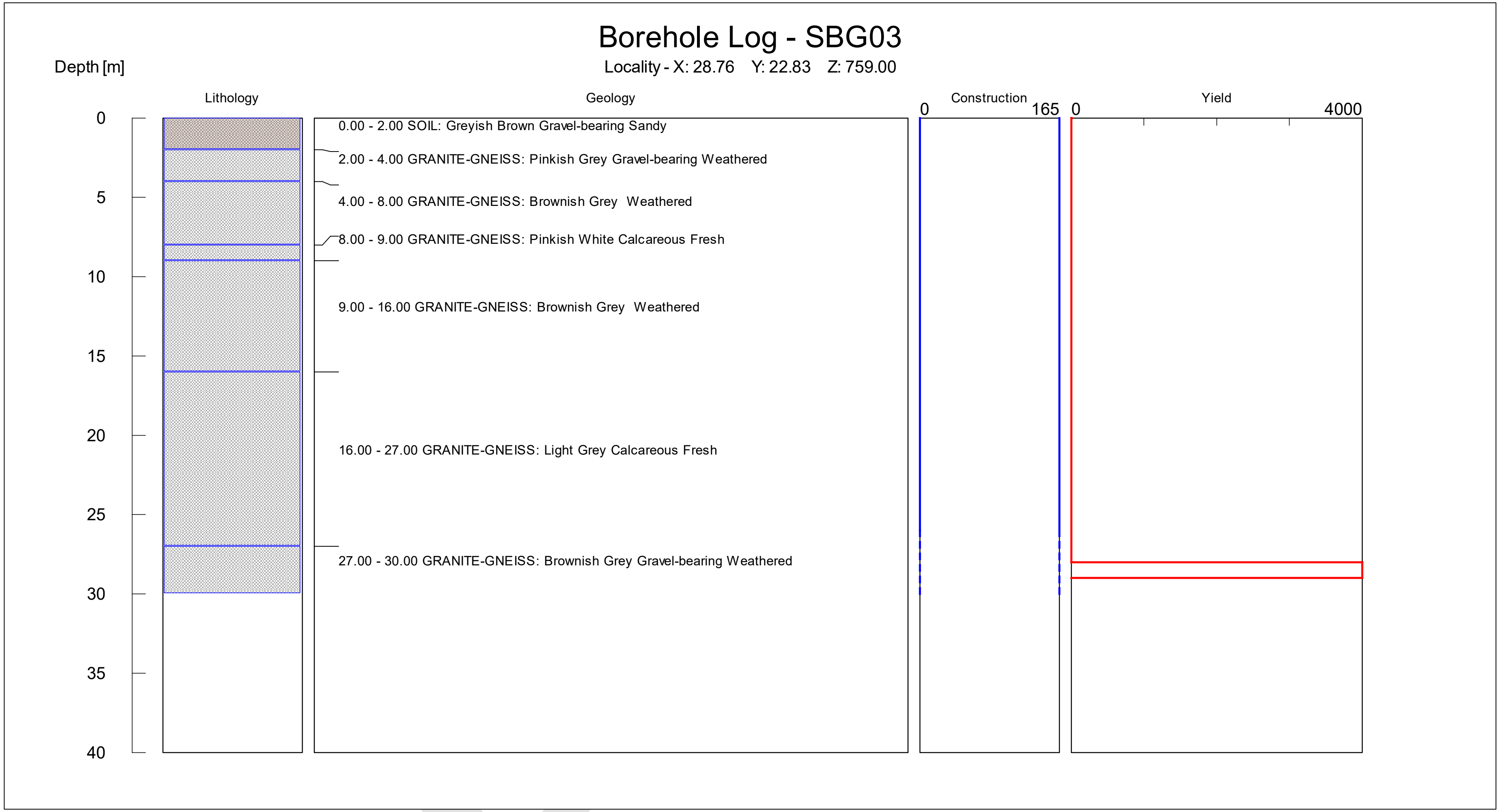
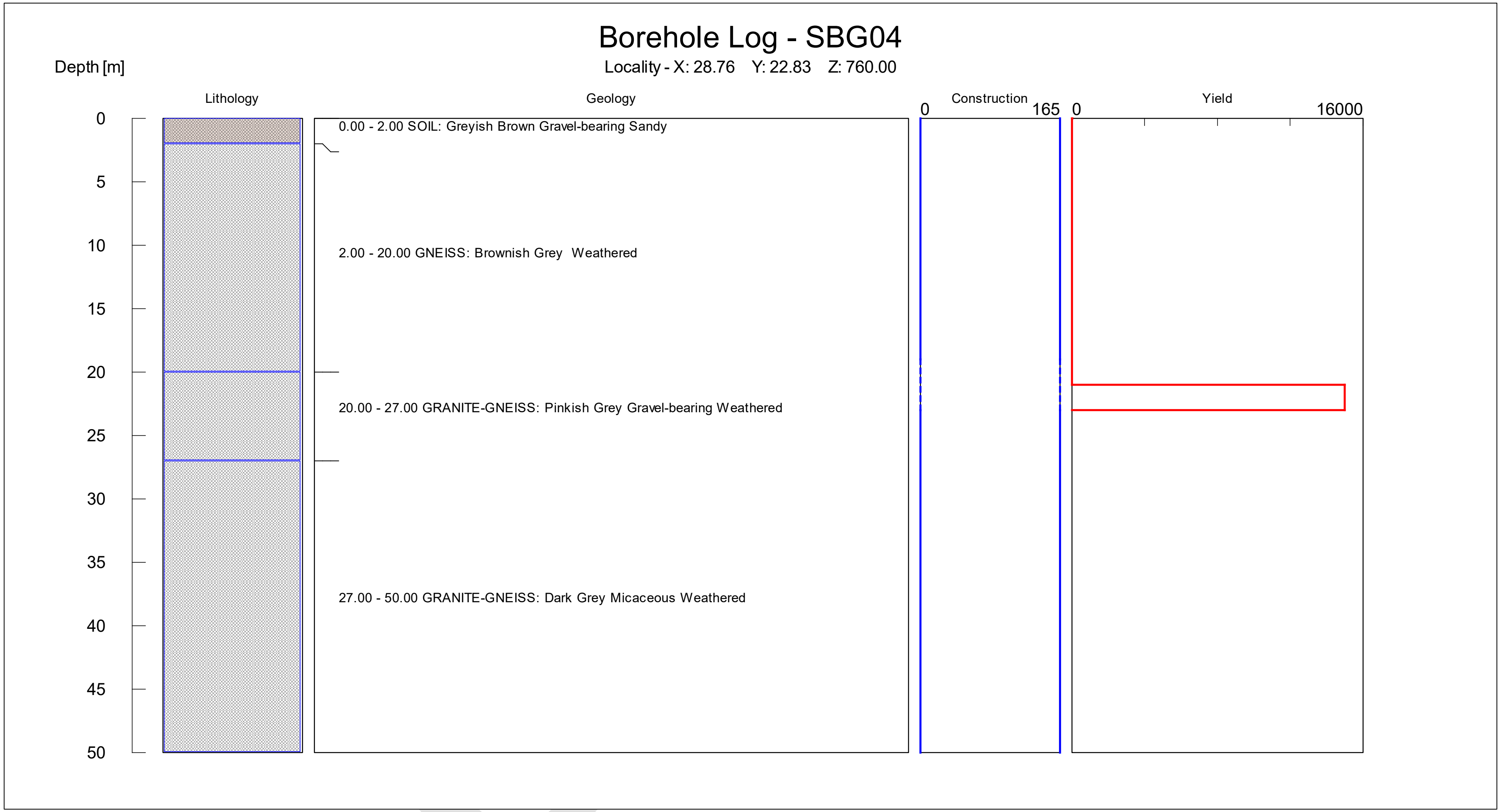
13 APPENDIX A: MONITORING BOREHOLE LOGS

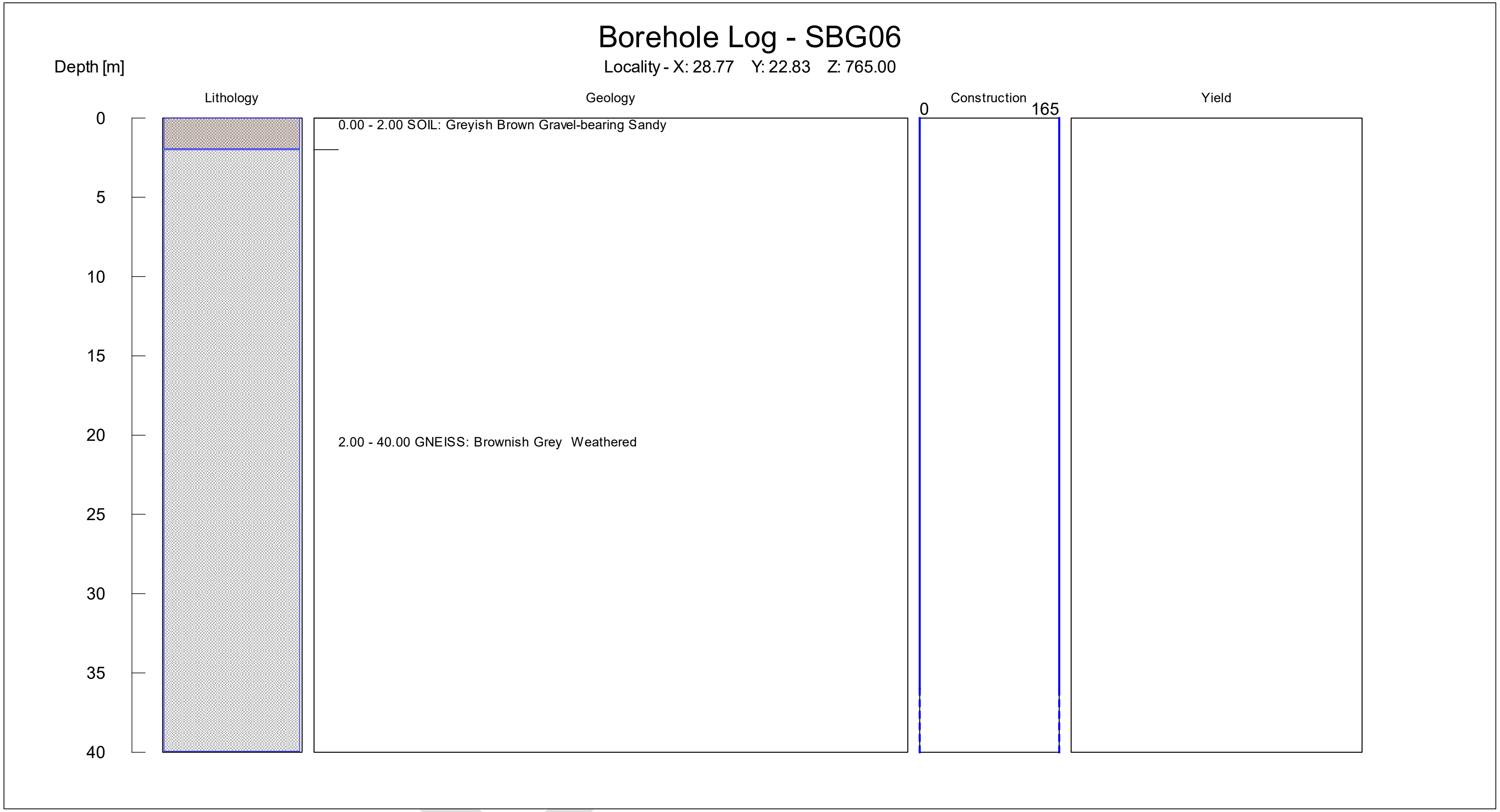



Borehole Log - SBG02
Locality - X: 28.77 Y: 22.83 Z: 763.00
Depth [m]
Lithology
Geology
Construction
0
165
0
5
10
15
20
25
30
35
40
0.00 - 2.00 SOIL: Brownish Grey Gravel-bearing Sandy
2.00 - 39.00 GRANITE-GNEISS: Greyish White Micaceous Fresh


Borehole Log - SBG03
Locality - X: 28.76 Y: 22.83 Z: 759.00
Depth [m]
Lithology
Geology
Construction
Yield
0
165
0
4000
0
5
10
15
20
25
30
35
40
0.00 - 2.00 SOIL: Greyish Brown Gravel-bearing Sandy
2.00 - 4.00 GRANITE-GNEISS: Pinkish Grey Gravel-bearing Weathered
4.00 - 8.00 GRANITE-GNEISS: Brownish Grey Weathered
8.00 - 9.00 GRANITE-GNEISS: Pinkish White Calcareous Fresh
9.00 - 16.00 GRANITE-GNEISS: Brownish Grey Weathered
16.00 - 27.00 GRANITE-GNEISS: Light Grey Calcareous Fresh
27.00 - 30.00 GRANITE-GNEISS: Brownish Grey Gravel-bearing Weathered


Borehole Log - SBG04
Locality - X: 28.76 Y: 22.83 Z: 760.00
Depth [m]
Lithology
Geology
Construction
0
165
Yield
0
16000
0
5
10
15
20
25
30
35
40
45
50
0.00 - 2.00 SOIL: Greyish Brown Gravel-bearing Sandy
2.00 - 20.00 GNEISS: Brownish Grey Weathered
20.00 - 27.00 GRANITE-GNEISS: Pinkish Grey Gravel-bearing Weathered
27.00 - 50.00 GRANITE-GNEISS: Dark Grey Micaceous Weathered

Borehole Log - SBG05
Locality - X: 28.76 Y: 22.83 Z: 760.00
Depth [m]
Lithology
Geology
Construction
Yield
0
165
0
4000
0
5
10
15
20
25
30
35
40
0.00 - 3.00 SOIL: Brownish Grey Silty Sandy
3.00 - 15.00 GNEISS: Brownish Grey Weathered
15.00 - 18.00 GNEISS: Brownish White Micaceous Weathered
18.00 - 30.00 GRANITE-GNEISS: Brownish Grey Weathered


Borehole Log - SBG06
Locality - X: 28.77 Y: 22.83 Z: 765.00
Depth [m]
Lithology
Geology
Construction
Yield
0
165
0
5
10
15
20
25
30
35
40
0.00 - 2.00 SOIL: Greyish Brown Gravel-bearing Sandy
2.00 - 40.00 GNEISS: Brownish Grey Weathered