Anglo Operations PTY Ltd

Der Brochen Amendment Project – Hydrogeological Study Pre-Feasibility B

Project Number: Delh.2018.49-6B

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1. INTRODUCTION

1.1. Background

Delta H (Delta-H Water System Modelling PTY Ltd) has been appointed by Anglo Operations Pty Ltd to conduct a groundwater specialist study for the purpose of the Environmental Impact Assessment for the proposed Der Brochen project, in Limpopo, South Africa. The Der Brochen Amendment Project Der Brochen Amendment Project is located approximately 35 km south-south-west of the town of Steelpoort, with the mining right consisting of the Helena, Richmond, Der Brochen, Hebron, Hermansdal and St George farms. Surface rights are held over portions of Helena, Der Brochen, Richmond and Mareesburg farms, all of which fall within the Groot- and Klein-Dwars River catchment (quaternary catchment B41G).

As part of the outcome of the Der Brochen Amendment Project Pre-Feasibility A (PFS) study completed in 2017, the following hydrogeological gaps were identified to be addressed in the PFS-B assessment:

- Determine potential water ingress (operational and post-closure phase)
- Further geochemical characterisation of potential pollution sources – specifically look at the groundwater versus surface water run-off infiltration to inform mitigation
    - Determine likely operational and post-closure water qualities
- Develop a groundwater management plan for the Der Brochen Amendment Project - i wanted engineering design costing, so now recommend that this is done – booster pumps, pipes, pumps, telemetry
    - Wellfield operational and monitoring plan
    - Post-closure water management
- Update of the Numerical Ground Water Flow and Transport Model

Delta H (Delta-H Water System Modelling PTY Ltd) developed a regional numerical groundwater flow and transport model in 2014 for the larger Der Brochen Amendment Project area in support of the Environmental Impact Assessment and Water Use Licence application. Since then, additional mining related infrastructure and activities were considered in the PFS-A study in 2017, known collectively as the Der Brochen Amendment Project. In terms of the Der Brochen Amendment Project, Anglo American will be required to apply for Environmental Authorisation from the Department of Mineral Resources (DMR) and from the Department of Water and Sanitation (DWS) respectively.

While the proposed investigation will inform the PFS-B assessment, the Geohydrology Report will also form part of the procedural requirements for Environmental Impact Assessments and Water Use Licence Applications and Appeals according to the Government Notice R. 267 (Government Gazette No. 40713, 27/03/2017) pertaining to the National Water Act, 1998 (Act No. 36 of 1998) and assess potential impacts of the Project on the ambient groundwater environment.

1.2. Project Description

The Der Brochen Mine is a platinum project owned by Rustenburg Platinum Mines Limited (RPM), a wholly owned subsidiary of Anglo-American Platinum (AAP), and is located approximately 25 km south-west of the town of Steelpoort and 40 km west of Mashishing (Lydenburg), in the Limpopo Province. The project area falls within the Greater Tubatse Local Municipality, under jurisdiction of the Greater Sekhukhune District Municipality. Der Brochen's mining right falls on the following farms:

- Richmond 370 KT;
- St George 2 JT;
- Hermansdal 3 JT;
- Hebron 5 JT;
- Helena 6 JT; and

- Der Brochen 7 JT.

In addition to the above farms, mining related infrastructure and activities are located on the farm Mareesburg 8 JT, such as the Mareesburg tailings storage facility (TSF), associated return water dams and tailings-return water pipeline. Current and planned activities and infrastructure (all approved by existing Environmental Management Programmes (EMPrs)) and Water Use Licences (WULs) at the Der Brochen Mine project are as follows:

Approved existing facilities and activities:

- Mototolo Concentrator;
- Helena TSF and two associated Return Water Dams (RWDs);
- Raising of the Helena TSF;
- Mine offices (old farm house) and access roads;
- Monitoring weirs (five) with four of the weirs up and downstream of the two authorised wellfields currently monitored;
- Prospecting activities comprising of site preparation, drilling of prospecting boreholes, site rehabilitation and monitoring;
- Trial mining area on the Richmond farm (activity is completed, and the soil stockpile and waste rock dump are well vegetated);
- Abstraction of groundwater in support of mining from the Helena and Richmond licenced wellfields;
- Abstraction from Der Brochen Dam based on an existing lawful industrial allocation; and
- Monitoring of surface and groundwater;

Activities previously authorised, but which have not yet commenced:

- The Helena and Richmond wellfields (only two of the authorised boreholes per wellfield are currently in use);
- Helena and Richmond shafts and associated waste rock dumps;
- Two Open Pits (Northern and Southern Pits) and associated waste rock/overburden dumps and pollution control dam;
- Re-routing of a 132-kV powerline; and

Authorised activities under construction:

- Mareesburg TSF and associated Return Water Dams (RWDs); and
- Mareesburg tailings-return water pipeline system to Mototolo Concentrator.

1.2.1. Proposed project overview

It is the intention of RPM to amend the Der Brochen Mine's approved EMPr and associated Environmental Authorisation (EA) including updating their WUL to include the following:

- The South Decline Shaft with associated infrastructure, i.e. water management infrastructure;
- The previously approved North Opencast Pit area with associated infrastructure as previously approved in 2015, i.e. water management infrastructure and waste rock stockpiles;
- Three up-cast ventilation shafts required for the underground workings associated with the South Decline Shaft;
- A Dense Medium Separation (DMS) Plant to be located within the existing footprint area of the Mototolo Concentrator area;
- A DMS Stockpile with associated water management infrastructure;
- The conversion of the existing Mototolo chrome plant from a final tailings' arrangement to an interstage arrangement
- Additional Run of Mine stockpiles and associated silos;
- Change houses and office complex to be located at the proposed South Decline Shaft area;
- An explosive destruction bay area to be located near the proposed South decline shaft;

- Staff accommodation facilities to be located near the Der Brochen Dam; and
- Additional linear infrastructure, i.e.:
    - Two conveyor systems. One conveyor belt system will be constructed to connect the proposed South Decline Shaft with the proposed DMS Plant that will be located in the existing footprint area of the Mototolo Concentrator Plant, for the purpose of transporting ore from the South Decline Shaft to the plant area. Another conveyor belt system will be required to transport DMS material from the proposed DMS Plant to the proposed DMS Stockpile area. It is currently anticipated that the DMS conveyor system will run along the existing Mareesburg tailings pipeline system.
    - Access and haul roads. New access roads to the proposed ventilation shafts will be required for maintenance purposes. Certain existing roads will also be required to be upgraded to provide sufficient access roads to the project related infrastructure such as the North Opencast Pit area, the South Decline Shaft and offices. The mine is also considering including a haul road within the proposed corridor associated with the ore conveyor belt system to transport ore from the proposed South Decline Shaft to the Mototolo Concentrator Plant area as an interim measure, whilst the conveyor belt system is being constructed.

See Figure 1 for the location of the Der Brochen Mine and the major infrastructure components listed above.

1.3. Data Sources and Deficiencies

The Der Brochen Amendment Project has been the focus of an intensive exploration programme on the Platinum Group Element (PGE) bearing horizons of the Bushveld Complex (BC) since 2001. It is understood that a number of environmental impact assessment reports (EIARs) and environmental management programmes (EMPs) have been submitted for the Der Brochen Amendment Project and Mototolo JV since 2002.

The development of the conceptual site and numerical groundwater flow and transport model was based on the following information and data made available to the project team:

- Underground mine layout and surface infrastructure.
- Geotechnical drilling.
- Hydrogeological (including geochemical) specialist reports for the site.
- Historical monitoring data for the site.
    - Quarterly water levels and quarterly sampling analysis from X to Y
- Published regional geological and hydrogeological maps.
    - Site specific geological information from Der Brochen Amendment Project geologist.
- Site walkover and hydrocensus

Figure 1-1: Der Brochen Mine's Expansion Project – Infrastructure layout.

1.4. Scope of Work

The scope of work entails the update of the conceptual model, the development of a numerical groundwater flow and transport model for the proposed Der Brochen Amendment Project and reporting according to Government Notice R.267.

The detailed scope of work comprises of the development of

- Updated conceptual model for site
    - Hydrogeological base maps and figures showing major structures, water table and any other relevant information
    - Geotechnical drilling information
- Determine potential water ingress (operational and post-closure phase)
- Further geochemical characterisation of potential pollution sources
- Determine likely operational and post-closure water qualities
- Develop a groundwater management plan for the Der Brochen Amendment Project
    - Wellfield operational and monitoring plan
- Post-closure water planning
- Update of the Numerical Ground Water Flow and Transport Model
    - Calibrated flow model describing the current "base case"
- Predictive Model Scenarios and Impact Assessment
    - Estimate the expected groundwater flow rates in the vicinity of the mine
    - Estimate the expected rebound of groundwater levels post closure
    - Evaluate the potential impacts of mining operations on the ambient groundwater quality using a conservative advective-dispersive transport model.
- Impact assessment on the ambient groundwater environment
- Recommended groundwater monitoring and management programmes

2. GEOGRAPHICAL SETTING

2.1. Topography and Drainage

The Der Brochen Amendment Project extends over three sub-catchments of the Dwars River quaternary catchment (B41G), namely the Klein-Dwars River, the Groot-Dwars River and the Mareesburg tributary. These rivers all drain to the north and are reportedly associated with major north / south striking fault zones. The Mareesburg stream flows into the Groot-Dwars River 1 200 m downstream of the northern boundary of Mareesburg Farm. Ultimately, the Dwars River flows into the Steelpoort River a further 25 km downstream. The topography of the study area is mountainous and characterised by steep valleys. The highest elevation of 2 300 mamsl is located to the extreme south of the project area, and the lowest elevation of 1 035 mamsl is located to the northern drainage path of the Groot-Dwars River (Figure 2-1).

2.2. Climate

The Der Brochen project area falls within the Highveld climatic region. This climatic region is associated with warm temperature and summer rainfall. The average daily maximum temperature for the region is 27°C in January and 17°C in July, with extreme averages of 38°C and 26°C respectively. Average daily minima for the region vary from 13ºC in January to 0ºC in July, while extremes reach 1ºC and minus13ºC, respectively.

The average annual rainfall for this climatic region varies from 900 mm in the east to 680 mm in the west. The average annual rainfall for the Der Brochen Amendment Project area is approximately 687 mm and occurs mostly in the summer (85%) from October to March, with a maximum in December. Average annual S-pan evaporation is 1 703 mm. Monthly data are presented in Table 2-1.

Table 2-1: Monthly rainfall data.

Month	Station WB 593419 (Maartenshoop) (1915-1999) [1]			Average for site stations	
	Average	**Maximum**	**Minimum**	**2017**	**2018[2]**
January	112.2	447.0	0	176.8	62.5
February	89.5	365.7	0	247.8	65
March	79.8	217.5	0	44	97.8
April	44.8	169.0	0	34	36.3
May	14.1	108.6	0	0	5.5
June	6.8	54.5	0	0	0
July	6.0	74.5	0	0	0
August	7.3	61.8	0	0	0
September	22.4	121.5	0	0	0
October	58.8	245.5	0	75	28.9
November	117.8	319.0	2.5	36	47.6
December	122.7	306.5	26.2	135,7	116
Totals	**682.1**			**749.3**	**459.6**

[1] Data based on the hydrological year commencing in October and ending September the following year. Data period simulated up to September 2017. Integrated Water Balance report, SRK 533247, 2018.
[2] Data received from Mr B Redmead of Anglo American, 24 January 2019.

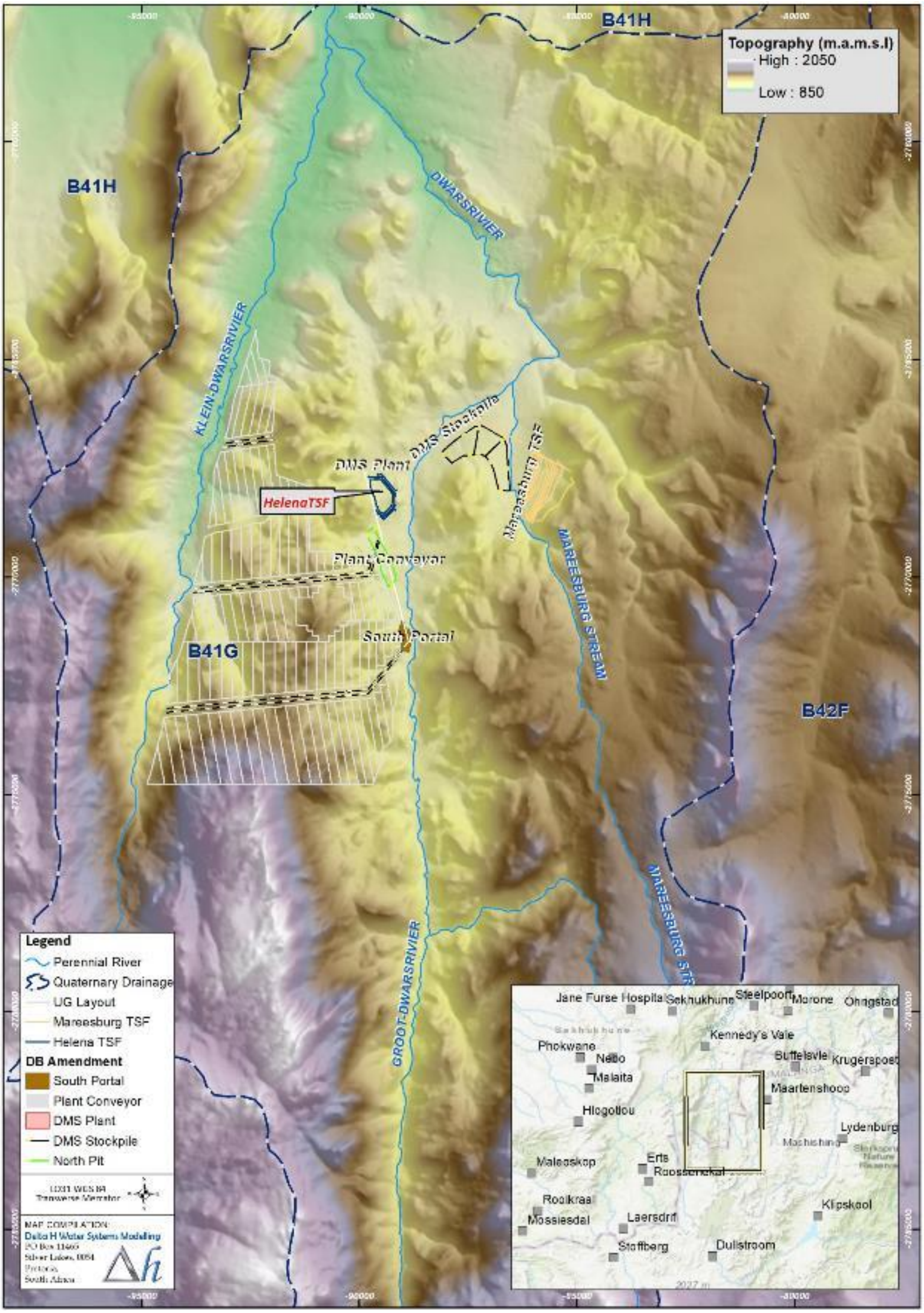


Figure 2-1: Locality and drainage of the Der Brochen Amendment Project area.

3. METHODOLOGY

3.1. Desktop study

The desktop study involved the collation and retrieval of exiting information as well as proposed mine layouts, which included amongst others:

- previous hydrogeological specialist reports,
- site layout as provided by the client,
- Der Brochen Amendment Project groundwater monitoring data

3.2. Hydrocensus

Previous hydrocensus and borehole information within the vicinity of the Der Brochen Amendment Project was augment with a hydrocensus to identify 3rd party private boreholes and characterise the main rivers/streams water quality, namely the Groot-, Klein-Dwars River and the Mareesburg River within the larger B41G catchment. Details pertaining to the hydrocensus are provided in Table 3-1, while the spatial distribution of the 32 hydrocensus geo-sites are shown in Figure 3-1 (details of the visited sites are given in Appendix A). Only a few groundwater levels could be obtained during the hydrocensus due to most boreholes being sealed off with no access point for water level measurements. The water levels measured during the hydrocensus in the area ranged between 2 metre below ground level (mbgl) and 25.7 mbgl.

The September 2018 hydrocensus identified borehole locations, status, depth, distribution and uses and included the measurement of groundwater levels as well as the collection of water samples as far as possible. The water samples were analysed for major and trace elements to provide an evaluation of the ambient (and regional) surface- and groundwater quality. A total of 32 sites were visited and 19 samples were collected. The quality results are discussed in section 4.4.1.

3.3. Geophysical survey and results

No geophysical surveys were done as part of this study. Previous geophysical studies included magnetic, electromagnetic and resistivity profiles. These surveys were largely used to identify sub-surface anomalies for optimal siting of water supply boreholes but also for seepage migration from the Helena Tailings Storage Facility (TSF) (Delta H, 2017A).

3.4. Drilling and siting of boreholes

Numerous boreholes were drilled for the previous authorisation applications. As a result, no new boreholes were required or drilled for this study.

3.5. Aquifer testing

Numerous aquifer tests (including infiltration tests) were completed for the site and hydraulic conductivity values of the aquifer are available for the site (section 4.2.3).

3.6. Sampling and chemical analysis

Selected samples were taken as part of the hydrocensus and submitted for major ions and selected trace elements for analysis (section 4.4).

3.7. Groundwater recharge calculations

The main source of recharge into the shallow primary aquifer is direct rainfall recharge that infiltrates the aquifer through the overlying unsaturated zone. Groundwater recharge takes place naturally, mainly in favourable locations such as areas with gentle slope, foothills or with good regolith cover. The interaction between groundwater and surface water (e.g. the Groot- and Klein-Dwars Rivers) is expected to be spatially and seasonally variable, changing from gaining to losing and disconnected conditions. A summary of the recharge estimates is provided in section 6.3.1.

Table 3-1: Summary of the hydrocensus for the Der Brochen Amendment Project.

Sample ID	Type	Latitude	Longitude	Elevation	GW Level (mbgl)	Sampled	Notes
Didi-BH1	Borehole	-24.98152	30.14095	1053.3	10.87		Boreholes next to small dam at hill top. Borehole equipped with submersible pump. Provides water supply to the Didingwe Lodge during summer rainfall months as back up.
HE01	Borehole	-24.93143	30.09936		7.96	Yes	
HE02	Borehole	-24.95700	30.09794		3.56		
HE04	Borehole	-25.02127	30.66812	982			Not possible to access locked borehole housing
HE07	Borehole	-24.99822	30.07803	953	14.74		Borehole was locked; not possible to obtain sample.
HE10	Borehole	-25.14647	30.17649	1756			Borehole was welded closed to prevent theft of pump. Will be necessary to drill hole through steel plate to allow for dipping to determine groundwater level.
HE12	Borehole	-25.12214	30.16826	1692			Old exploration borehole labelled SD1.
HE13	Borehole	-25.11331	30.17107	1673			Old borehole on abandoned farm house. Borehole blocked at 1.39 m bgl.
HE15	Borehole	-25.09684	30.16888	1624	25.77	Yes	Abandoned borehole on old farm house.
HE17	Borehole	-24.93950	30.14322	1025	6	Yes	Borehole on site of Old Miner Inn Accommodation.
HE18	Borehole	-24.98556	30.13222	1067	7.8	Yes	Recently drilled exploration borehole.
HE21	Borehole	-25.02245	30.14246	1106		Yes	Borehole pumping at time of visit therefore no groundwater level obtained.
HE22	Borehole	-25.01572	30.17324	1074			Borehole could not be accessed as it was covered with a heavy concrete block.
HE23	Borehole	-25.12935	30.08109	1902	12.58	Yes	Old borehole. Stagnant water. Brown colour.
HE25	Borehole	-25.16166	30.16603	1820			Borehole not accessible.
Thorn BH1	Borehole	-24.97694	30.13259	1034.5	3.38	Yes	Borehole is equipped with submersible pump. Supplies groundwater to Thorncliff Guesthouse. Groundwater is pumped to a 10 000L tank.
Thorn BH2	Borehole	-24.97502	30.13116	1025.1	3.21		Unequipped borehole next to stream.
Thorn BH3	Borehole	-24.97588	30.13453	1026.01	11.34	Yes	Equipped with submersible pump. Borehole was in use during site visit. Used for domestic and gardening purposes
Thorn BH4	Borehole	-24.97662	30.13341	1029.7	2.46		Equipped with submersible pump but not in use (not working). Old borehole.
HE26	Fountain	-25.17249	30.15774	1795	2	Yes	Fountain excavated into the hillside. Approximately 2 m bgl. Providing water to farm. Farm owner noted that they used to have a borehole but after "others" sampled it the borehole was backfilled with mud for some unknown reason.
HE11	Reservoir	-25.13177	30.17491	1702			Above ground reservoir
HE03	River	-24.94790	30.07860			Yes	
HE09	River	-24.95534	30.12794			Yes	Groot-Dwars River
HE05	Stream	-25.02181	30.06501	994		Yes	Stream sample was obtained because it was not possible to obtain a groundwater sample
HE06	Stream	-25.01327	30.07226				
HE08	River	-24.91194	30.10296	901		Yes	Dwars River. Confluence.
HE14	Stream	-25.11253	30.17641	1653		Yes	No boreholes in the area. Local farmer stated that water in area is obtained from fountains.
HE16	River	-25.06256	30.16218	1480		Yes	Mareesburg River. No boreholes in the area.
HE19	River	-24.99906	30.13239	1028		Yes	Groot-Dwars River
HE20	Stream	-25.00464	30.14243	1045		Yes	Possibly stagnant water.
HE24	Stream	-25.22888	30.08729	1875		Yes	Outside of catchment but sampled as it was not possible to gain access into the target area.
HE27	Stream	-25.17788	30.15001	1757		Yes	Stream leading to a dam.

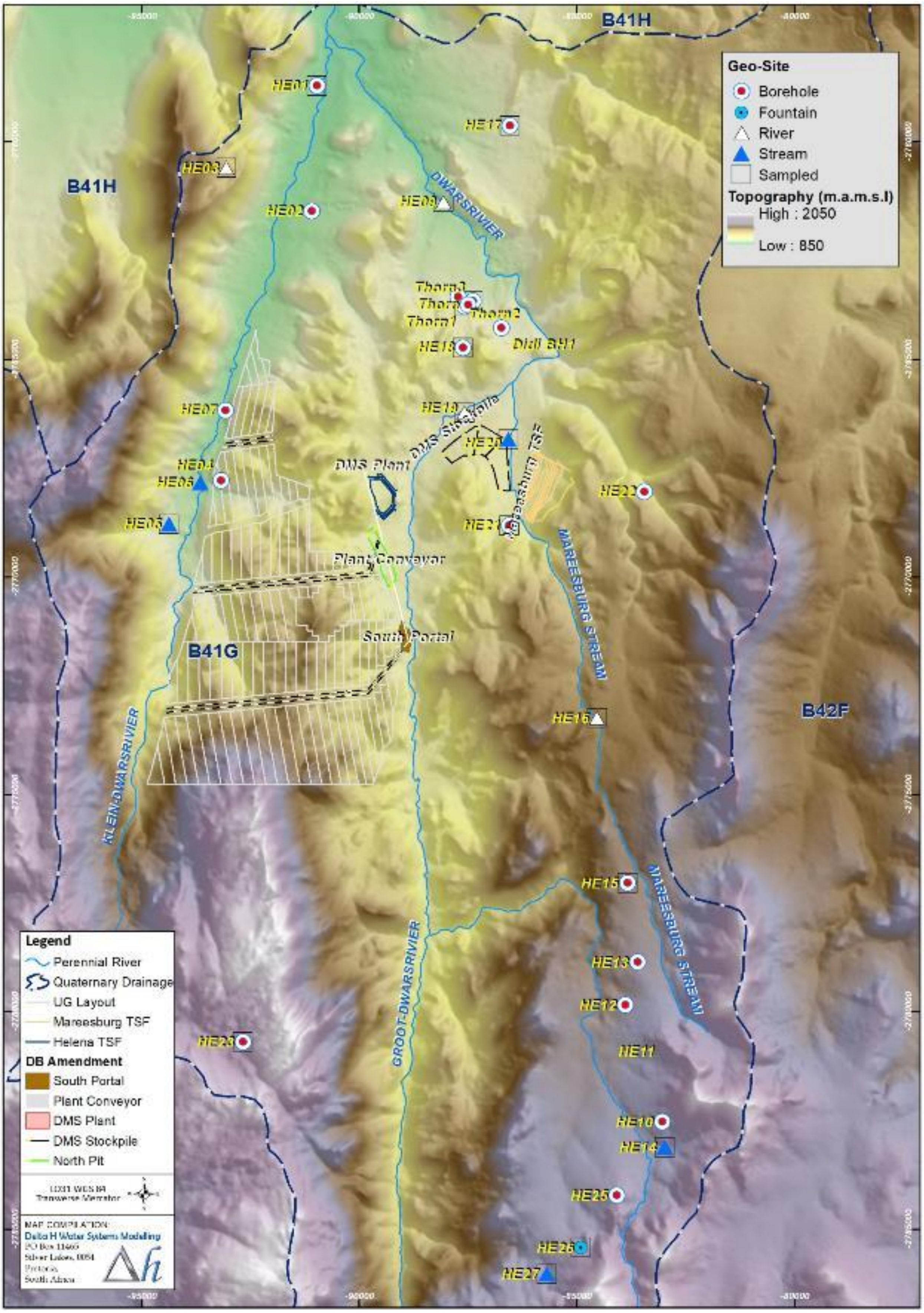


Figure 3-1: Locality of the groundwater hydrocensus.

3.8. GROUNDWATER MODELLING

A numerical model is a mathematical approximation of the real word aquifer system, and there are always errors associated with groundwater models due to uncertainty in the data, potential alternative conceptual models in describing the real-world system or the capability of numerical methods to describe natural physical processes. However, numerical groundwater models are considered the best tools available to quantify / estimate groundwater and contaminant transport, and the results can be used in management decisions. The chosen software code, model set-up, assumptions and results are described in detail in chapter 6.

3.9. GROUNDWATER AVAILABILITY ASSESSMENT

Groundwater abstractions will be undertaken for domestic water supply at the mine, in addition to the abstraction from the authorised Der Brochen and Richmond wellfields. The groundwater supply study commissioned during the Pre-feasibility A study remains relevant to the current study (Delta-H, 2017B). The study addressed the following:

- To confirm/verify whether the water resources potential of the authorized wellfield volumes could be met;
- To understand whether existing lawful groundwater use allocated to farm portion can further augment the water supply to the project.

A secondary objective was to assess alternative groundwater supply sources and to address hydrogeological water ingress and water quality impacts, towards identify knowledge gaps that need to be addressed during PFS-B technical studies.

4. PREVAILING GROUNDWATER CONDITIONS

4.1. GEOLOGY

The geological setting of the Der Brochen Amendment Project is shown in Figure 4-1.

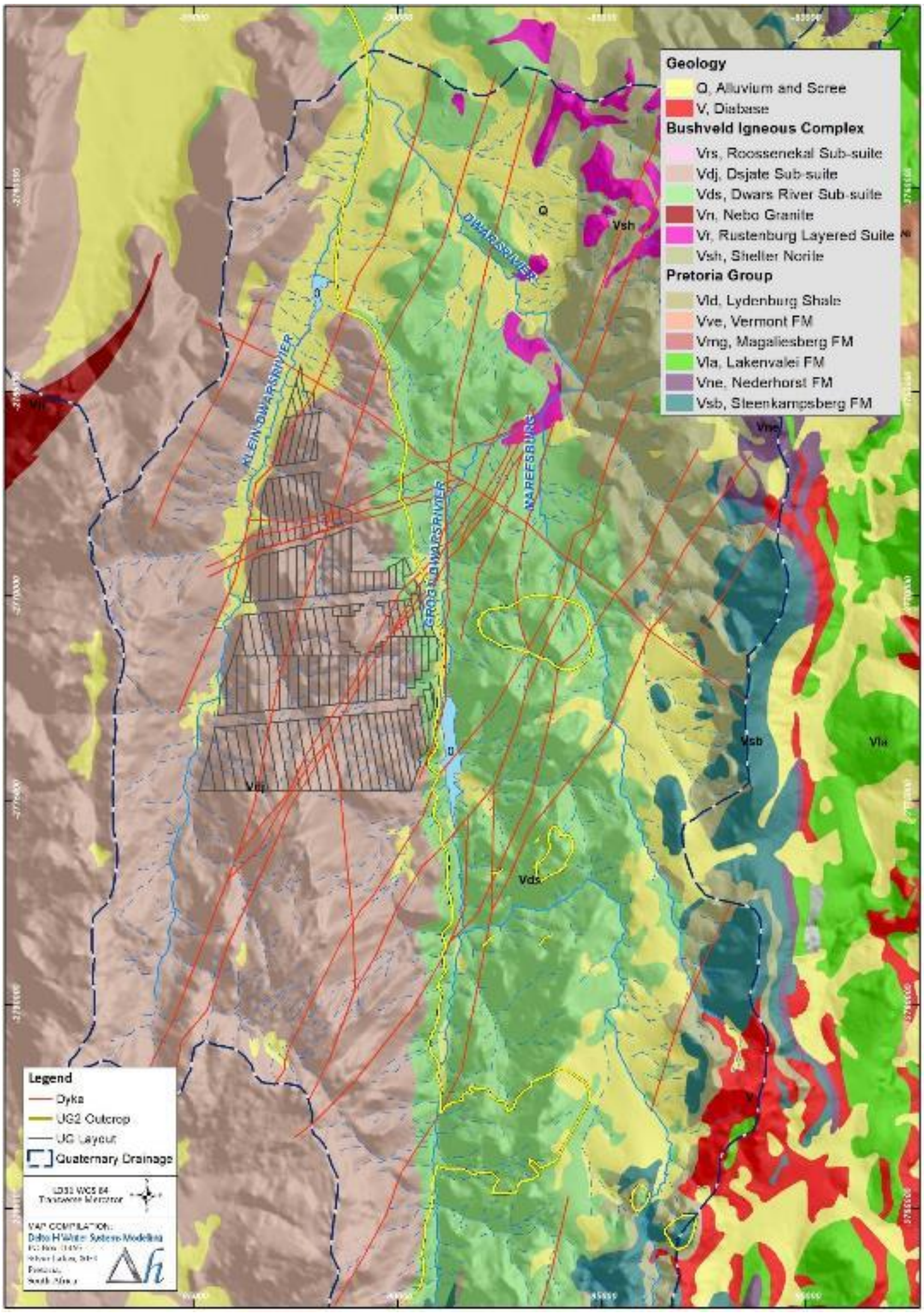


Figure 4-1: Regional geological setting.

The regional geology of the Der Brochen Amendment Project that forms the basis of the conceptual groundwater model is summarised below.

The Project area overlies intrusive rocks of Bushveld Complex (BC) which intruded into the Transvaal Supergroup on the Kaapvaal Craton at about 2 060 Ma. Of the various layers within the BC, the Project area is underlain by the upper portion of the Critical Zone (Dwars River Sub-suite) (Figure 4-1), which in this area consists of alternating layers of pyroxenites, norites and anorthosites. The igneous layering dips in the order of 9° to 12° to the west. Economic zones of interest include the platiniferous Merensky reef and the UG2 chromitite reef. The former outcrops with a N-S strike on the Der Brochen farm, occupying the mid-slope section west of the Groot-Dwars River. The UG2 lies some 180 to 210 m below the Merensky reef and outcrops in the gently sloping lower-slope section of the Groot-Dwars River valley.

West dipping quartzites, siltstones and shales of the Pretoria Group underlie the intrusive rocks of the BC and daylight 5 to 8 km east of the project area. The generally massive nature of the BC rocks underlying the Project area suggests that they are likely to be devoid of primary discontinuities. Secondary discontinuities such as joints, shear joints and fault surfaces in addition to intrusive dykes are therefore more likely to be an important control on the direction of groundwater flow. Unconsolidated alluvial sediment deposits are present along the lower reaches of the Groot-Dwars River, particularly on Helena, Mareesburg and Der Brochen Farms where they are moderately well developed, being up to 25 m thick. Scree deposits have developed at the base of the steep valley sides.

4.1.1. Structural geology

A series of prominent N-S to NNE-SSW trending lineaments, namely the St George and Helena Faults, dominate the structural setting of the Project area and provide the locus for the north flowing Klein-Dwars and Groot-Dwars Rivers (Figure 4-1). Other extensively developed structural features include NW-SE to NNW-SSE, as well as locally developed ENE-WSW, lineaments. The St. George fault, believed to be a first order sub-vertical fault zone, has a down-throw towards the east of approximately 50 m and an apparent left lateral horizontal displacement of 575 m. Using remote sensing and aeromagnetic images, several dyke swarms were delineated. Four of these dyke swarms are NNE trending, whilst the others have trends of NE, NW and N-S. All dykes are of a dolerite/diabase composition and vary in thickness from less than 15 m to up to 70 m. These dykes have generally a low permeability below the weathered zone and strongly influence the ground water flow.

4.2. HYDROGEOLOGY

4.2.1. Unsaturated zone

The thickness of the unsaturated zone ranges from 1 to 25 mbgl. The groundwater model considers flow and transport processes within the unsaturated zone, with a capillary pressure-saturation relationship (after van Genuchten) typically of a loamy sand assigned to the weathered aquifer and of a coarse sand assigned to the fractured Karoo rocks and dolerites.

4.2.2. Saturated zone

Based on the conceptual hydrogeological understanding of the site, the following hydro-stratigraphic zones are differentiated within the wider model area:

- **Overburden/weathered Zone Aquifer**
- **Deep Fractured (Structural) Bedrock Aquifer**

Overburden/weathered Zone Aquifer

Developed in the weathered bedrock profile and derived from prolonged in-situ decomposition of bedrock with a thickness ranging between negligible to circa 40 m. The overburden aquifer is poorly developed or absent on hill tops (or mid-slopes), but increases in thickness towards the valley bottom due to hillwash sediments adding to the weathering thickness along with the occurrence of deeper and more intense weathering along the drainage channels. Along the lower reaches of the Klein- and Groot-Dwars Rivers the overburden/weathered aquifer can be replaced or overlain by alluvial sediments, creating a distinct intergranular aquifer. Due to the topographical and geological setting there is a distinct difference between the sediments along these two river systems. The Klein-Dwars River is characterised by a broad alluvial plain composed of mixed clay, silt and sand (low permeability), while the Groot-Dwars River has a more incised alluvial valley composed of mixed boulders, cobbles, gravel and sand (with increased permeability). The alluvial, overburden and weathered sediments are in hydraulic continuity and are regarded as one aquifer system. They often contribute to the river baseflow.

Deep Fractured (Bedrock) Aquifer

The deeper fractured aquifer (Bushveld norites and anorthosites, as well as local diabase/dolerite dykes) outcrops along the hill tops and in the mid- and upper slopes of the valleys, and underlies the overburden/weathered aquifer in the valleys. The permeability of the aquifer is associated with secondary structural features (e.g. joints, fractures, fissures, dykes, faults etc.). Hydraulic connectivity between the overburden/weathered aquifer and the underlying deeper fractured bedrock aquifer is restricted to the topographic low (drainage) areas. Although it's expected that permeability would decrease significantly with depth in the bedrock aquifer, groundwater occurrence at greater depth (> 300 m) is associated with regional structures. The water volumes encountered at this depth are however expected to be limited.

4.2.3. Hydraulic conductivity

Due to the extensive groundwater exploration studies in the Groot- and Klein-Dwars River catchment, a large number of slug and pumping tests were conducted to establish recommended long-term yields and to determine aquifer permeability. Transmissivity values determined for the weathered- and upper fractured aquifer are high variable and range from 1 to > 100 m^2/day (Figure 4-3). Average transmissivity values for the overburden aquifer range from 20 to 30 m^2/d, while the fractured aquifer is generally less than 5 m^2/d.

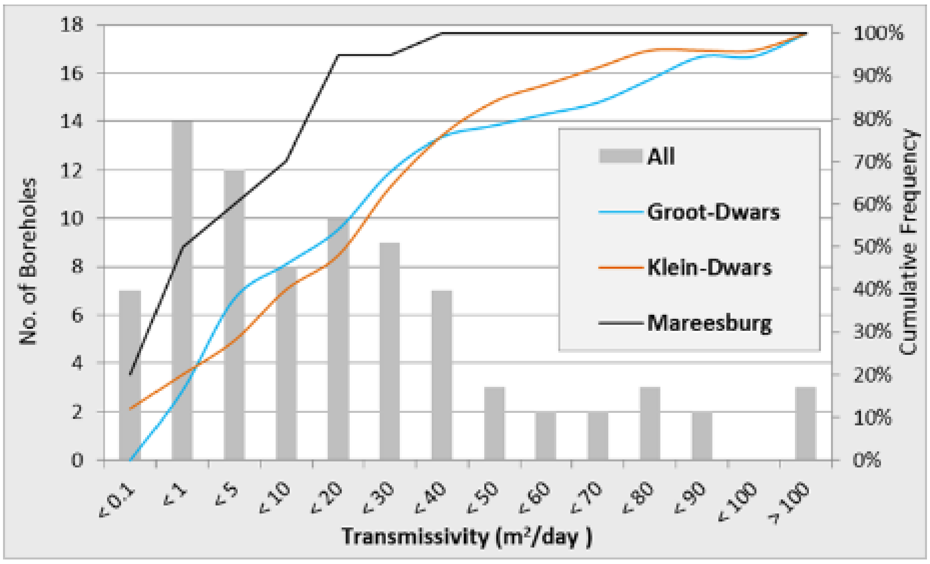


Figure 4-2: Distribution of transmissivity values for the Der Brochen Amendment Project.

4.2.1. Infiltration assessment (SRK, 2018)

SRKs hydrologists assessed the infiltration characteristics of selected sites of the Der Brochen Project. The assessment comprised of two sites, mainly within the proposed North- and South Portal footprints.

- Five positions at each site were chosen for the following:
  - Expose two levels of material as identified by colour and texture differences.
  - Conduct double ring infiltrometer tests at the two levels.
  - Conduct in-situ Guelph permeameter tests at the two levels.
  - Extract undisturbed soil core samples in thin-walled cylinders at the two levels for laboratory analysis.
  - Laboratory analysis of soil cores for bulk density and soil texture.

Double ring infiltrometer (DR) and Guelph permeameter (GP) tests yield the saturated hydraulic conductivity of materials, which is of value for the groundwater model development and calibration. The DR tests were performed on exposed flat surfaces, while the GP tests were conducted in augured holes. The tests reveal saturated hydraulic conductivities typical of Sand and Loamy Sand materials (1E-05 to 6E-05 m/s) at the surface, but lower saturated hydraulic conductivities, typical of Sandy Loams and Sandy Clay Loams, in the subsurface (1E-06 to 5E-06 m/s) (SRK, 2018).

Table 4-1: Results of the infiltration measurements undertaken at the Der Brochen sites.

Sample	Bulk density (g/cm3)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Ksat (GP) (m/s)	Ksat (DR) (m/s)
1A	1.66	0	86	13	1		6.10E-05
1B	1.48	2.3	63.7	14	20	1.30E-06	
1C							1.80E-05
2A	1.16	0	66	18	16		1.50E-05
2B	1.76	16.2	66.8	15	2	1.70E-06	
3A	1.58	5.4	57.6	23	14		5.20E-05
3B						1.20E-06	
4A	1.66	0.7	64.3	23	12		1.00E-05
4B	1.41	6.7	65.3	13	15	4.60E-06	
5A	1.71	1.7	66.3	18	14		4.20E-05
5B	1.77	0.8	65.2	15	19	9.20E-07	

4.3. GROUNDWATER LEVELS

The groundwater levels were collated from the Der Brochen monitoring programme as well as the hydrocensus. Average groundwater levels of around 6 mbgl in the area reflect shallow water levels within the upper weathered aquifer. Based on the distribution diagram (Figure 4-3), only a few deeper water levels within the fractured bedrock aquifer were observed.

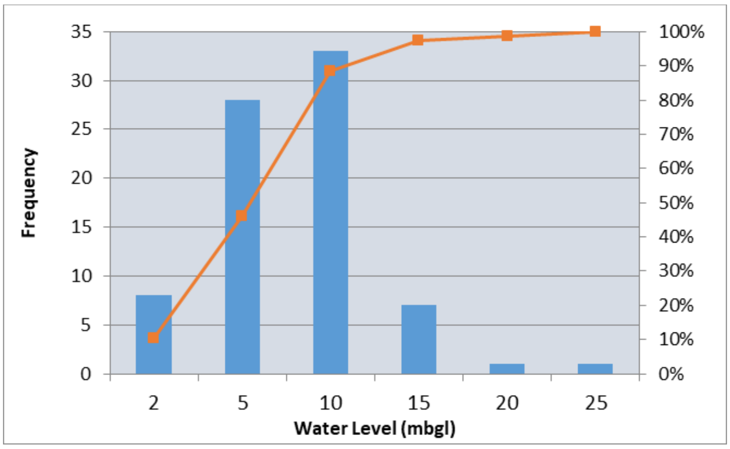


Figure 4-3: Frequency distribution of water levels within the project area.

A very good correlation (R^2=1.00) between absolute surface and hydraulic head elevations in meters above mean sea level (mamsl) is recognised for the Project area (Figure 4-4). The potentiometric surface therefore mimics surface topography, and regional groundwater flow is from higher lying ground towards lower lying valleys, where it accumulates in the alluvial deposits and contributes potentially to river baseflow. Note that local flow patterns may differ due to the fractured and partially compartmentalised nature of aquifers in the area.

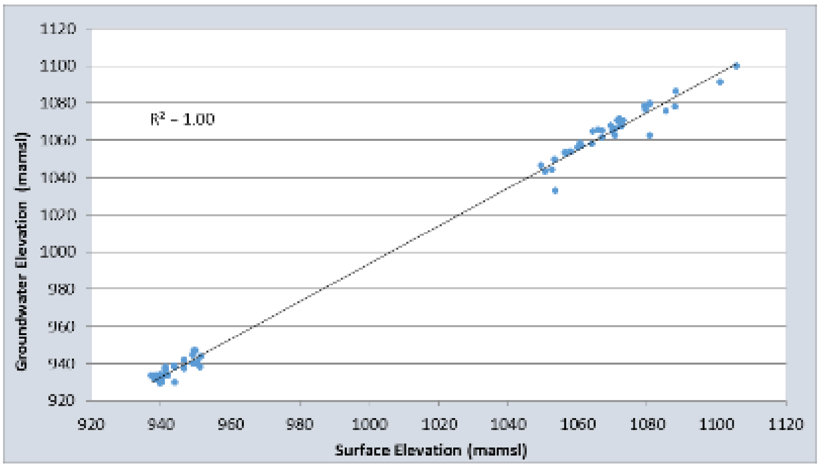


Figure 4-4: Correlation between surface topography and groundwater elevation.

The observed correlation is used to improve the interpolation of initial water levels for the numerical model in data scarce environments by applying co-kriging based on known topography (Bayesian interpolation). The Bayesian interpolation method uses correlated data to improve the spatial interpolation of the unknown variable, in this case the groundwater level. As a Universal Kriging algorithm, it relies on a mathematical description of the change (or variance) of a variable with distance, i.e. to what extent neighbouring observations are spatially correlated. Such correlation is expressed in a semi-variogram, as depicted in the empirical semi-variogram for the model area (Figure 4-5) with the fitted Bayesian model used for the interpolation. The semi-variogram model is then used in combination with the knowledge of the surface elevation and its correlation to the groundwater elevation as a qualified guess to improve the spatial interpolation of water levels.

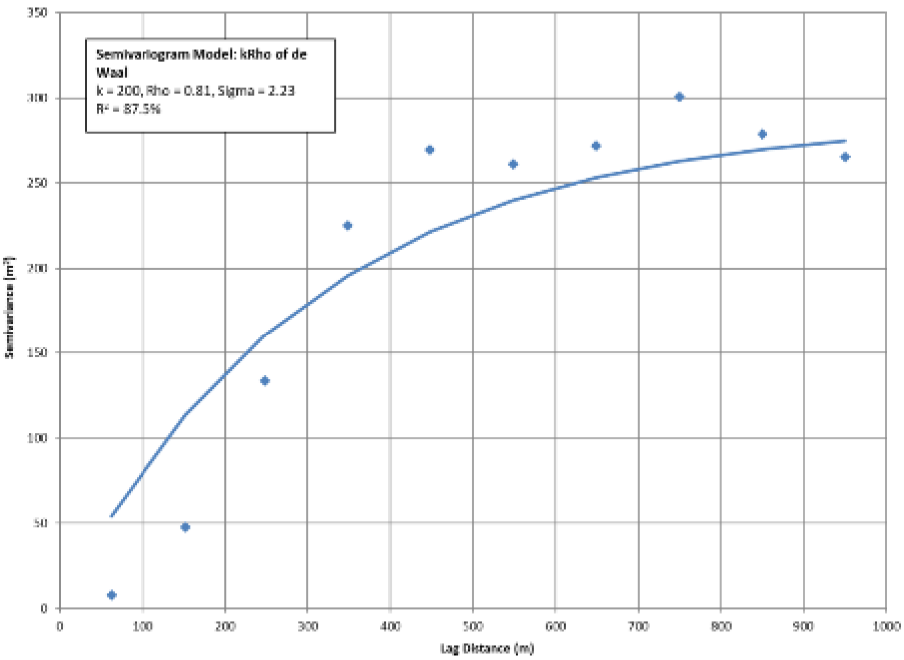


Figure 4-5: Empirical semi-variogram and fitted Bayesian model.

The interpolated (unconfined) groundwater piezometric map for the shallow weathered aquifer using Bayesian interpolation (with the model parameters given above) is shown in Figure 4-6 and was subsequently used as initial heads for the model (steady-state) calibration. The initial heads facilitate the mathematical convergence of a steady-state model, but do not change the outcome of the model i.e. the calculated steady-state heads.

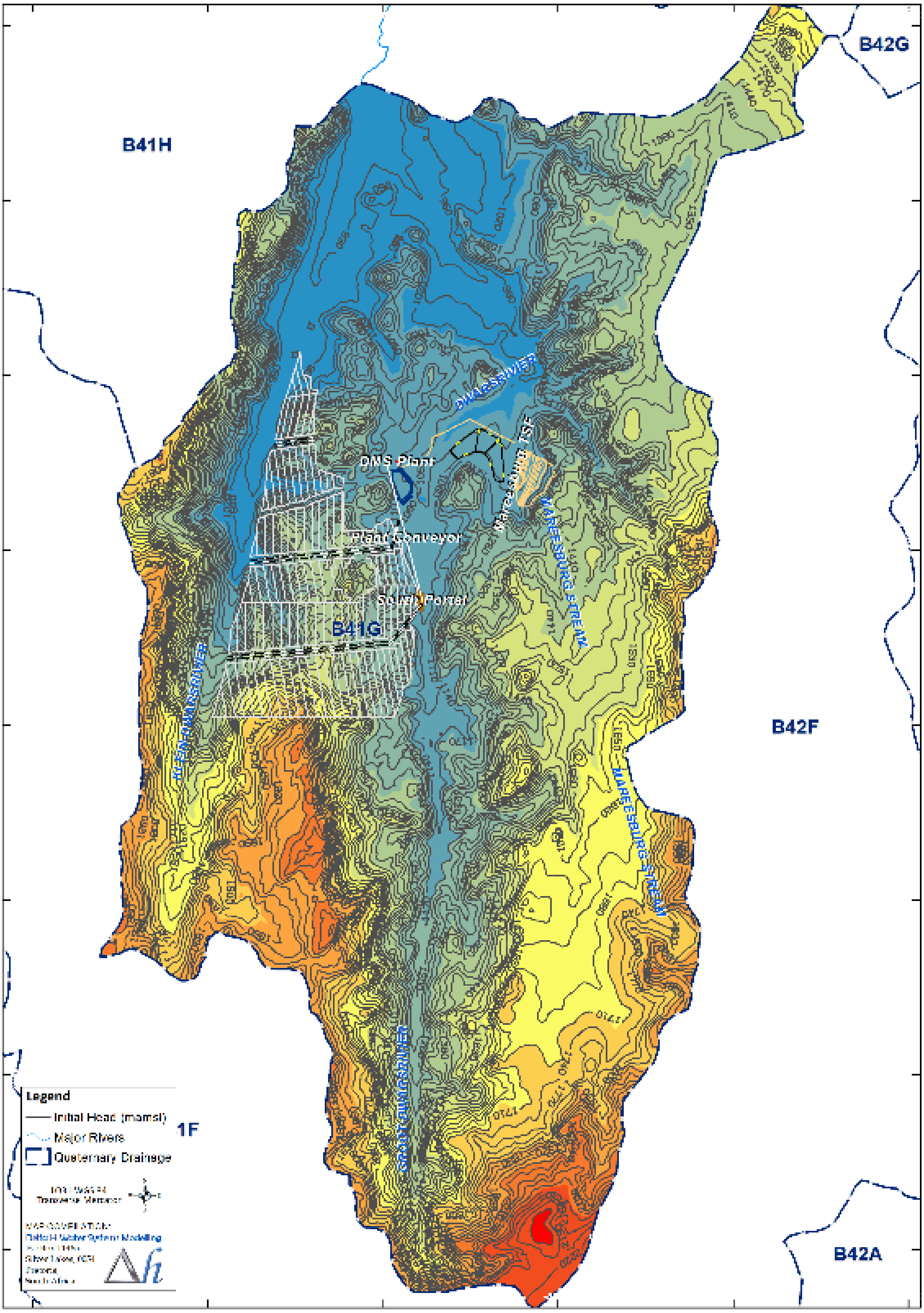


Figure 4-6: Interpolated shallow water table elevations for the model area.

4.4. SURFACE AND GROUNDWATER QUALITY

Box 1. WUL Quality Limits.

The quality of water containing waste was listed in the 2011 WUL (WUL TABLE 5) and amended in the 2016 WUL. The previous and amended water quality limits for waste water to be disposed into the return water dam are given in Table 4-2. Note that TABLE 8 of the WUL (2011) referred to the quality of water into the three settling ponds, which is similar to TABLE 5 of the WUL replicated below.

Table 4-2: Quality of waste water to be disposed into return water dams (all in mg/L).

	WUL (2011)	WUL amendment (May 2016)
pH Value	6.5-9.5	6.5-9.5
EC mS/m	59.2	268
TDS	780	1 710
Chloride, Cl	25	175
Sulphate, SO_4	90	611
Fluoride, F	1.25	1.25
Nitrate as N	1	139
Calcium, Ca	68	145
Magnesium, Mg	45	106
Sodium, Na	59	283
Potassium, K	4	40
Iron, Fe	2.6	2.6
Manganese, Mn	0.07	0.3

While no specific groundwater seepage (plume) quality is provided, reference is made to the Reserve and water resource protection. The WUL states that the impact of the activities of the mine on the Groot- and Klein Dwars River shall not exceed the following in-stream water quality limits or resource quality limits as stipulated in the water quality reserve for the area (WUL TABLE 7) (Table 4-3). While the table was re-referenced in the amendment of 2016, no parameters seem to have changed. There are no other surface or groundwater limits in the 2016 and 2017 (Licence No. 06/B41G/ABCFGIJ/5329) WULs. Table 4-3 can be regarded as interim limits for the receptor (Groot-Dwars River) and contributing streams (seepage/groundwater plume migration).

Table 4-3: Water quality limits or resource quality objectives (all in mg/L).

	WUL (2011)	WUL amendment (May 2016)	B41G (Groundwater Quality reserve) (2018)[3]
pH Value	6.5-9.5	6.5-9.5	8.5
TDS	520	520	-
Sulphate, SO_4	70	70	11
Chloride, Cl	62	62	18
Sodium, Na	9	9	25
Magnesium, Mg	25	25	32
Potassium, K	46	46	0.8
Calcium, Ca	25	25	56
Nitrate as N	6	6	0.4
Hexavalent Chrome as Cr^{6+}	0.014	0.014	-
Toxics	99% <TWQO	99% <TWQO	
	99% < CEV	99% < CEV	
	100% < AEV	100% < AEV	

[3] Government Gazette No. 41887 NO.932 7 September 2018 – Department of Water and Sanitation

The obtained hydrocensus results together with the existing monitoring data serves as a baseline for future developments as well as an indication of water qualities with the catchment (B41G).

4.4.1. Hydrocensus (water quality)

The water quality results obtained during the hydrocensus are presented in Table 4-4, while the laboratory certificates are provided in Appendix B. The sample locations were chosen to reflect the upstream and downstream surface and groundwater quality as well as the groundwater quality of the larger area. The latter is of importance to define the pre-development status-quo water quality prior to commencement of the Der Brochen Amendment Project. Note that a variety of trace elements were analysed, but concentrations were found to be in all samples below the analytical limit of detection. The results were for the sake of clarity therefore omitted from Table 4-4. The water quality is compared to the drinking water standards and the WUL Table 4-3 pre-scribing the resource quality limits (Refer to Box 1).

Based on the summary results, the surface and groundwater qualities are generally of good with slightly alkaline pH values of 8.1 and 7.4, electrical conductivity values of 29.3 and 38.7 mS/m and TDS concentrations of 208 mg/l and 265 mg/l, respectively (Table 4-5). Single elevated concentrations of EC, TDS, calcium, magnesium, sulphate and nitrate as N from samples obtained from HE18, Thorn 1 and Thorn 3 were excluded as outliers from the average calculations. These boreholes are generally highly mineralised with EC values more than 330 mS/m, which suggests a direct impact by mining activities. These boreholes are located down gradient of a number of mining operations. While the HE18 boreholes is a recently drilled exploration core hole, the other impacted boreholes (Thorn 1 and 3) are used for water supply to the Thorncliff lodge for domestic use and gardening. The quality is not fit for human consumption and should be flagged to the user as a matter of urgency.

Up-stream surface water qualities (i.e. HE 14, HE 16 and HE 27) show a lower mineralisation compared to the downstream catchment samples (i.e. HE 8, HE, 9, HE 19), with most major ions elevated and nitrate in sample HE8 exceeding the water quality limits. This higher mineralisation in the downstream surface water samples, especially in the slower flowing lower flowing streams, indicates a stronger contribution from groundwater baseflow with elevated calcium, magnesium and bicarbonate concentrations (i.e. HE15, HE 17 and HE21). A downstream increase in TDS and sulphate concentrations in surface water suggests impacts from mining activities. Elevated manganese (Mn) and iron (Fe) concentrations were recorded for a number of surface- and groundwater samples, and are considered naturally occurring within the groundwater system due to the weathering of iron and manganese bearing minerals. Similarly, the natural geogenic magnesium and calcium concentrations in groundwater from the Bushveld Complex are often elevated due to its mineralogical compositions.

Table 4-4: Water quality results (median) compared to the SANS water quality limits, from the hydrocensus for the Der Brochen Amendment Project (in mg/l).

Borehole ID			HE03 (SW)	HE05 (SW)	HE08 (SW)	HE09 (SW)	HE14 (SW)	HE16 (SW)	HE19 (SW)	HE20 (SW)	HE24 (SW)	HE27 (SW)	HE01	HE15	HE17	HE21	HE23	HE26	HE18	Thorn 1	Thorn 3
Parameters	**SAWQG Target**	**WUL (RQ) Limits**	**39434**	**39435**	**39436**	**39437**	**39438**	**39440**	**39443**	**39444**	**39447**	**39449**	**39433**	**39439**	**39441**	**39445**	**39446**	**39448**	**39442**	**42128**	**42129**
pH Value @ 20°C	6.0-9.0	6.5-9.5	8.2	7.9	8.2	8.4	7.6	7.8	8.2	8.2	7.8	7.4	8.0	7.3	7.5	7.2	7.0	6.4	6.4	6.2	6.3
EC mS/m @ 25°C	0-70		37.0	36.9	43.1	30.9	8.1	12.3	27.6	47.7	6.0	3.7	138.0	18.9	73.8	53.1	24.3	2.2	700	349	335
TD)	0-450	520	228.0	282.0	298.0	214.0	80.0	84.0	202.0	316.0	66.0	36.0	880.0	142	528	364.0	166.0	32.0	7028	2 412	2 512
Calcium, Ca	0-32	25	37	33	31	26	5	9	25	30	5	3	18	18	42	43	21	1	264	184	101
Magnesium, Mg	0-30	25	21	19	26	19	5	7	16	42	3	2	95	7	74	43	16	1	670	298	331
Sodium, Na	0-100	9	9	9	9	6	2	3	7	10	2	2	111	6	10	10	4	1	104	22	28
Potassium, K	0-50	46	< 0.5	< 0.5	0.8	0.8	0.5	< 0.5	0.8	0.6	< 0.5	< 0.5	2.0	0.6	0.8	0.6	1.1	0.1	6.2	2.8	2.9
Alkalinity as $CaCO_3$			204	192	156	136	40	60	120	252	28.0	16	324	92	408	280	120	8	112	176	104
Chloride, Cl	0-100	62	6.0	4.0	11.0	8.0	3.0	4.0	8.0	9.0	3.0	2.0	219.0	4.0	17.0	14.0	7.0	2.0	70.0	42.0	42.0
Sulphate, SO4	0-100	70	3.0	<2	25.0	18.0	<2	<2	18.0	13.0	<2	<2	122.0	2.0	40.0	16.0	<2	<2	271.0	167.0	175.0
Nitrate as N	0-6	6	<0.1	2.8	12.0	2.3	<0.1	<0.1	2.9	2.2	<0.1	<0.1	<0.1	0.7	<0.1	0.2	<0.1	<0.1	0.9	448	445
Fluoride, F			<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ammonia as NH_4			0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	<0.1	0.1	0.3	0.2	0.6	0.1	0.2	0.1	0.5	0.1	0.1
Iron, Fe	0.4		0.042	0.029	0.037	0.081	0.429	0.528	0.115	0.100	0.513	0.471	0.026	<0.025	0.071	<0.025	0.038	0.037	0.026	<0.025	<0.025
Manganese, Mn	0.4		<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	0.065	<0.025	<0.025	<0.025	0.242	<0.025	0.193	<0.025	<0.025
Zinc, Zn	5		0.048	0.042	0.040	0.041	0.046	0.048	0.042	0.042	0.044	0.056	0.044	0.055	0.045	0.052	0.042	0.049	0.047	0.047	0.029
Copper, Cu	0-1		<0.010	<0.010	<0.010	<0.010	<0.010	0.013	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.014	<0.010	<0.010	<0.010	<0.010	<0.010
Boron, B	2.4		<0.010	<0.010	<0.010	<0.010	<0.010	0.024	<0.010	0.028	<0.010	0.030	0.022	<0.010	0.030	0.034	<0.010	0.024	0.114	0.035	0.041
Silicon, Si			22	27	10.4	10.7	7.9	13.0	10.1	25	7.4	2.1	2.7	14.0	42	32	11.4	5.0	45	30.0	22.0

Table 4-5: Median water quality values for the surface and groundwater hydrocensus samples (in mg/l).

Parameter	SAWQG Target	WUL (RQ) Limits	B41G (Groundwater Quality reserve) (2018)[4]	Surface water	Groundwater
Nr of Samples				10	6
pH Value @ 20°C	6.0-9.0	6.5-9.5	8.5	8.1	7.3
Conductivity mS/m @ 25°C	70		65	29.3	38.7
Total Dissolved Solids	450	520	-	208.0	265.0
Calcium, Ca	32	25	56	25.5	19.9
Magnesium, Mg	30	25	32	17.3	29.6
Sodium, Na	100	9	25	6.7	8.1
Potassium, K	50	46	0.8	0.5	0.7
Total Alkalinity as $CaCO_3$	-	-	268	128	200
Chloride, Cl	100	62	18	5.0	10.5
Sulphate, SO_4	100	70	11	3.0	28.0
Nitrate as N	6	6	0.1	2.8	0.5
Iron Fe	0.1		-	0.06	0.03
Manganese Mn	0.05		-	0.03	0.03

* - excludes impacted boreholes HE18, Thorn 1 and Thorn 3.

[4] Government Gazette No. 41887 NO.932 7 September 2018 – Department of Water and Sanitation

4.4.2. Monitoring water quality

To further establish the status quo water quality and to determine operational water qualities for the Der Brochen Amendment Project, the available Mototolo, Mareesburg and Der Brochen monitoring network data have been reviewed. Surface monitoring stations are sampled on a monthly basis, while the monitoring boreholes are sampled and analysed quarterly. The current monitoring locations are presented in Figure 4-7.

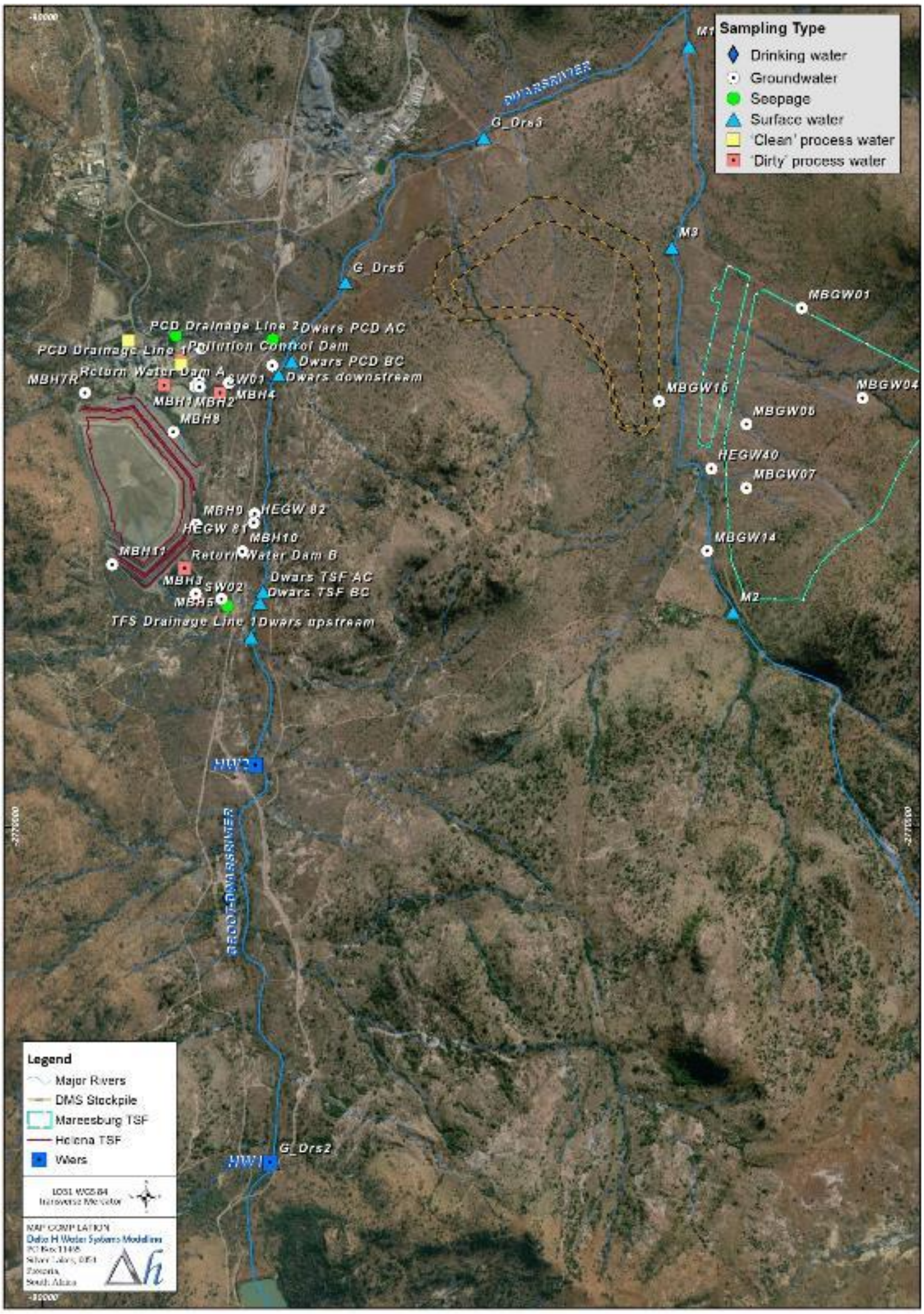


Figure 4-7: Existing Der Brochen monitoring network.

4.4.2.1. *Process water*

To establish operational and post-closure water qualities for the Der Brochen Amendment Project, the existing Mototolo monitoring data have been assessed. Deposition on the Tailings Storage Facility started in October 2006. For an overview of the process water quality results, the median values for selected parameters of each of the monitoring areas (i.e. Return Water Dams (RWD), Seepage Sump (SW) and Pollution Control Dams (PCD) types) are shown in Table 4-7.

Table 4-6: Mototolo process surface water quality results compared to the WUL limits (in mg/l).

	WUL limit	RWD A	RWD B	SW01	SW02	PCD	Tailings Slurry	
							27-Jun-2018	30-Jul-2018
N (samples)		113	113	107	107	110	1	1
pH	6.5-9.5	7.7	8.1	8.1	8.3	7.9	8.2	8.7
EC (mS/m)	268	199	165	153	157	146	172	211
TDS	1 710	1 363	1 120	1 078	1 144	1 075	1 094	1 278
Ca	145	69	84	135	106	128	28	28
Mg	106	56	54	75	89	71	46	49
Na	283	217	188	114	122	75	196	251
K	40	27.0	13.4	1.8	1.2	4.9	23.0	28.0
HCO_3	-	255	228	534	343	255	289	201
Cl	175	112	142	116	143	98	115	170
SO_4	611	351	419	275	363	307	341	418
NO_3 as N	6	9.4	1.8	1.6	0.4	25.8	<0.1	42.0
F	1.25	0.3	0.1	0.23	0.2	0.2	<0.2	<0.2
NH_4	-	20.4	2.2	0.2	0.1	7.7	26.0	35.0
Fe	2.6	0.01	0.04	0.03	0.004	0.04	< 0.025	1.14
Mn	0.3	0.030	0.01	0.05	0.01	0.01	< 0.025	< 0.025
Cr	-	0.008	0.01	0.01	0.01	0.01	< 0.010	< 0.010

The recently (June and July 2018) sampled tailings liquor (separate analysis of the fluid phase of the tailings slurry) results were compared to the water quality of the Return Water Dam (RWD) A, Return Water Dam (RWD) B and the Pollution Control Dam (PCD) and seepage sumps. These facilities are classified as 'dirty' process water dams. As expected for source monitoring points, a number of constituents are elevated, but within WUL limits for waste water. However, seepage from the unlined TSF and RWD have resulted in groundwater impacts and the migration of a contaminant plume towards the southern tributary of the Groot-Dwars River and the tributary east of the RDW B (Delta H, 2017). The process water quality is generally characterised by its elevated sodium/chloride/alkalinity content. Sulphate concentrations have increased over time from around 300 mg/l to 600 mg/l (Figure 4-8). The major environmental concern associated with the tailings and process water stream is the overall elevated expected salt load and nitrate concentration.

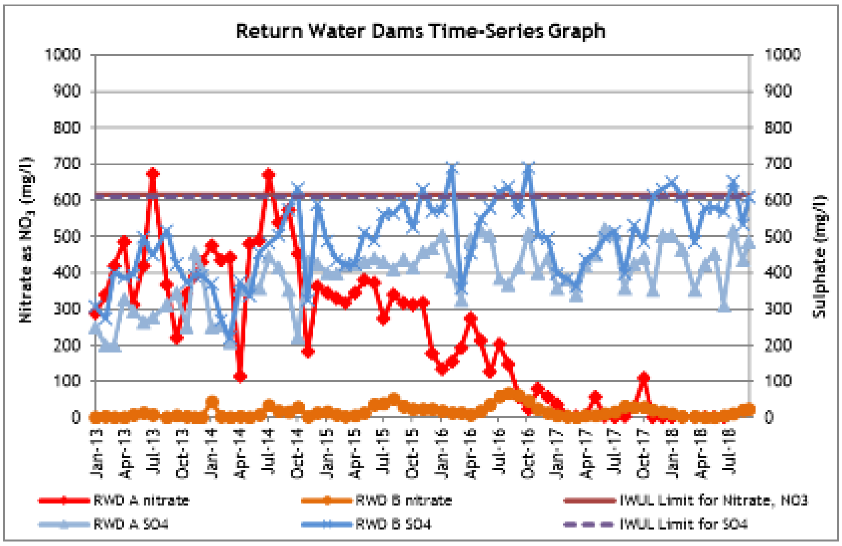


Figure 4-8: Nitrate and sulphate concentrations time series graph for the RWDs.

4.4.2.2. Groundwater

The median concentrations for selected parameters of the Mototolo monitoring boreholes are given in Table 4-7. The Mototolo monitoring borehole qualities show similar chemical signatures as observed in the TSF process water (Table 4-6). Major elements (chloride, sulphate nitrate, calcium, magnesium, sodium and potassium) exceed applicable WUL, RQO in almost all of the groundwater quality samples. The groundwater is generally classified as alkaline (pH in the range of 7.6 to 8.2) with a magnesium and calcium dominance, and elevated sulphate and chloride concentrations due to mining influences. Exceedances of the WUL limits for major elements like calcium, magnesium and potassium are not considered a human health risk (as evident in the higher South African Drinking Water Guideline) and are geogenic (natural) for the Bushveld Complex.

The median concentrations for selected parameters of the Der Brochen and Mareesburg background monitoring boreholes are given in Table 4-7. Based on the results, the groundwater quality is classified as slightly alkaline (pH in the range of 7.6 to 8.2), with Total Dissolved Solids (TDS) contents ranging from 142 to 538 mg/L. The groundwater quality is generally within drinking water limits. Exceedances of the WUL and the higher South African Drinking Water Guideline limits for some boreholes with a strong dominance of calcium and magnesium are noted, but can be directly linked to the underlying geology with magnesium and calcium rich pyroxenites, norites and anorthosites.

4.4.2.3. Surface water

The sample number and median concentrations of surface water samples from the Groot-Dwars River (receptor monitoring) samples up- and down-stream of the Helena TSF site and the background (pre-Mareesburg TSF deposition) are given in Table 4-8. Compared to the Groot-Dwars River, the Mareesburg Stream (M1, M2 and M3) water qualities show an overall higher mineralisation, a strong magnesium dominance and lower sulphate concentrations.

Smaller tributaries along the mining areas are likely to gain water from the upper shallow overburden/weathered aquifer, which in turn receives seepage from the Mine Residue Facilities (MRD) (excluding direct releases of mine water into these channels). An obvious increasing trend in sulphate concentrations can therefore be observed for the Groot-Dwars River up- and downstream of the TSF (Figure 4-9).

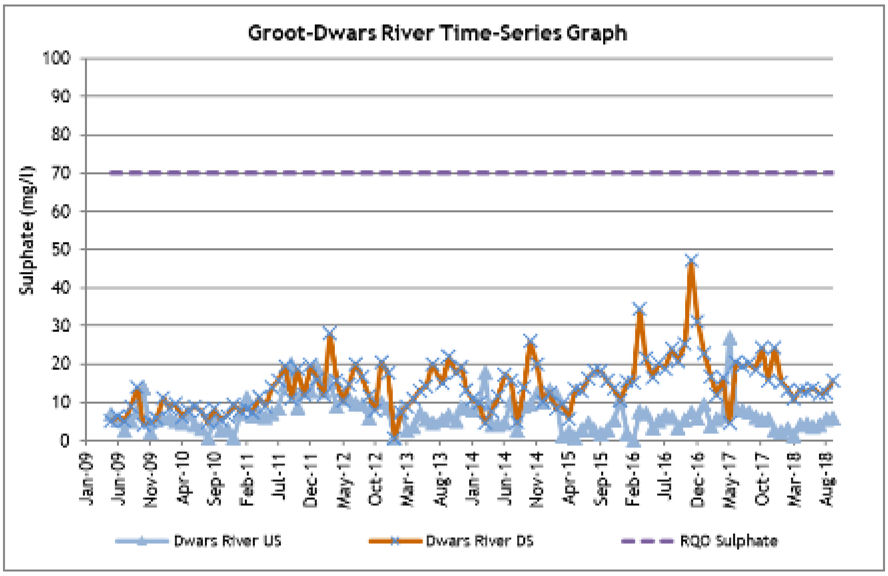


Figure 4-9: Time series of sulphate concentrations in the Groot-Dwars River (up and downstream of current Der Brochen mining activities).

Table 4-7: Mototolo groundwater quality results compared to the WUL RQO limits (in mg/l).

	SAWQG	WUL limits (RQ)	MBH 1R	MBH 2	MBH 7R	MBH 3	MBH 4	MBH 5	MBH 6	MBH 7	MBH 8	MBH 9	MBH 10	MBH 11	MBH 12	MBH 13	MBH 14	MBH 15	MBH 18	HEGW 78	HEGW 81	HEGW 82	HEGW 88
N (samples)			8	47	18	47	30	30	29	11	14	17	17	17	1	1	1	2	2	10	10	10	10
pH	6.0-9.0	6.5-9.5	7.7	8.1	7.5	8.1	7.9	7.8	7.6	7.8	7.8	7.4	7.3	7.6	7.1	7.5	7.6	7.7	7.7	7.8	7.7	7.8	7.7
EC (mS/m)	70		162	117	133	158	123	99	147	159	160	106	48	137	109	165	137	195	181	130	54	64	132
TDS	450	520	1 181	714	930	1 032	812	642	1 104	1 124	1 136	737	302	1 051	788	1 239	1 036	1 454	1 338	947	370	443	954
Ca	32	25	176	113	175	78	78	93	146	144	145	139	69	196	176	165	148	163	129	137	68	79	150
Mg	30	25	87	41	78	75	59	48	78	74	50	57	19	77	36	71	83	98	96	84	27	29	84
Na	100	9	91	85	31	164	91	43	82	75	178	33	13	31	26	133	55	159	158	42	23	29	41
K	50	46	0.7	3.5	0.3	2.7	0.6	1.1	0.9	2.2	4.0	2.2	0.3	0.7	0.5	0.8	0.9	1.6	0.5	0.5	0.4	0.5	0.6
HCO_3	NS		571	576	570	549	472	263	326	469	448	519	288	489						304	330	423	316
Cl	100	62	104	89	72	120	104	109	101	102	151	53	9	92	86	123	116	142	134	86	4	7	98
SO_4	200	70	376	35	183	231	172	131	354	258	342	123	20	241	159	345	426	659	507	320	22	24	358
NO_3 as N	6	6	0.3	0.5	6.1	0.6	0.7	0.4	10.6	1.6	0.9	1.1	0.7	5.8	0.5	0.5	0.3	5.9	0.3	4.6	0.4	0.5	0.9
F	1		0.28	0.20	0.25	0.40	0.20	0.20	0.20	0.30	0.20	0.25	0.16	0.22						0.19	0.22	0.21	0.19
NH_4	-																						
Fe	0.1			0.07	0.02	0.04	0.08	0.09	0.02	0.07	0.04	0.06	0.03	0.01								0.09	
Mn	0.05		1.18	0.45	0.00	0.78	0.05	0.15	0.21	0.10	1.09	0.16	0.01	0.12	0.00	0.00	0.00	0.01	0.55	0.00	0.13	1.68	0.01

Table 4-8: Mareesburg and Der Brochen background groundwater quality results compared to the WUL RQO limits (in mg/l).

	SAWQG	WUL limits (RQ)	MBGW01	MBGW02	MBGW04	MBGW05	MBGW07	MBGW14	MBGW15	HEGW40	HEGW15	HEGW98	RMGW38	RMGW51
N (samples)			9	5	7	11	7	20	21	11	14	14	14	14
pH	6.0-9.0	6.5-9.5	7.7	7.7	7.8	7.8	8.0	8.2	7.6	7.9	7.7	7.7	7.7	7.8
EC (mS/m)	70		88.5	49.0	83.6	83.7	74.3	23.1	56.1	74.7	60.6	56.7	54.9	49.4
TDS	450	520	538.0	274.0	512.0	535.0	493.0	142.0	306.0	488.0	385.0	339.0	300.5	291.5
Ca	32	25	75.8	39.2	53.2	57.9	55.6	10.2	30.5	58.4	69.9	55.1	57.3	56.1
Mg	30	25	72.2	31.9	82.2	90.1	80.8	25.1	58.1	83.3	36.5	38.3	33.2	30.1
Na	100	9	26.1	15.5	19.2	18.1	16.9	8.2	9.6	11.4	16.2	17.6	16.7	13.7
K	50	46	1.0	3.2	0.9	1.0	1.0	2.7	1.4	0.5	0.5	0.3	1.1	0.6
HCO_3			601.2		606.7	617.0	562.7	172.9	355.3	548.5	380.0	351.0	339.0	328.4
Cl	100	62	8.5	6.8	11.0	14.3	9.7	5.3	6.0	11.7	6.7	6.5	5.4	4.9
SO_4	200	70	46.5	1.8	40.6	32.0	40.8	1.4	19.5	35.2	18.2	10.4	1.3	3.1
NO_3 as N	6	6	0.6	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2
F	1		0.33		0.32	0.32	0.31	0.28	0.27	0.30	0.25	0.20	0.20	0.20
NH_4	-		0.06		0.08	0.09	0.13	0.08	0.07	0.06	0.07	0.03	0.81	0.17
Fe	0.1			0.80					0.02		0.04	0.05	0.71	0.27

Table 4-9: Mototolo surface water quality results compared to the WUL RQO limits (in mg/l).

	WUL limits (RQ) Limits	M1	M2	M3	G_Drs 2	G_Drs 3	G_Drs 4	G_Drs 5	Dwars River US	Dwars River DS
N (samples)		135	21	21	136	137	137	130	113	113
pH	6.5-9.5	8.3	8.4	8.3	8.0	8.1	8.2	8.2	8.2	8.1
EC (mS/m)		35	38	19	18	27	29	25	21	25
TDS	520	240	222	124	123	188	198	174	144	169
Ca	25	26	31	19	18	26	26	25	21	25
Mg	25	28	38	15	11	16	19	15	13	15
Na	9	8	8	6	5	7	7	7	6	7
K	46	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.8
HCO_3		210	233	150	110	138	152	134	126	133
Cl	62	5	5	4	3	6	6	6	3	5
SO_4	70	8	9	4	3	14	12	13	6	13
NO_3 as N	6	1.0	1.2	1.5	1.5	6.0	4.2	2.3	1.9	2.3
F		0.1	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.1
NH_4		0.04	0.04	0.04	0.08	0.06	0.05	0.05	0.10	0.10
Fe		0.07	0.004	0.004	0.03	0.03	0.04	0.02	0.02	0.02
Mn									0.001	0.001

Total dissolved solids (TDS) concentrations, an indicator of the overall water mineralisation, have been assessed over the long term (May 2009 – September 2018) for the existing operations, with the time series up- and downstream of the existing Mototolo Concentrator and Helena TSF shown in Figure 4-10. The TDS values fluctuate around 170 mg/l, with downstream TDS concentrations slightly higher (~ 25 mg/l) than upstream concentrations.

The long-term trends for the nitrate, sulphate and chloride concentrations at the downstream DWS B4H009 gauging station are shown in Figure 4-11. The deterioration of the water quality over time observed at the B4H009 gauging station is most likely attributable to a number of mining related sources within the catchment. Elevated nitrate and sulphate concentrations are associated with contaminants emanating from MRDs, PCDs and process water facilities, which also tend to increase chloride (evaporative and/or due to discharge of deeper, higher mineralised mine inflows).

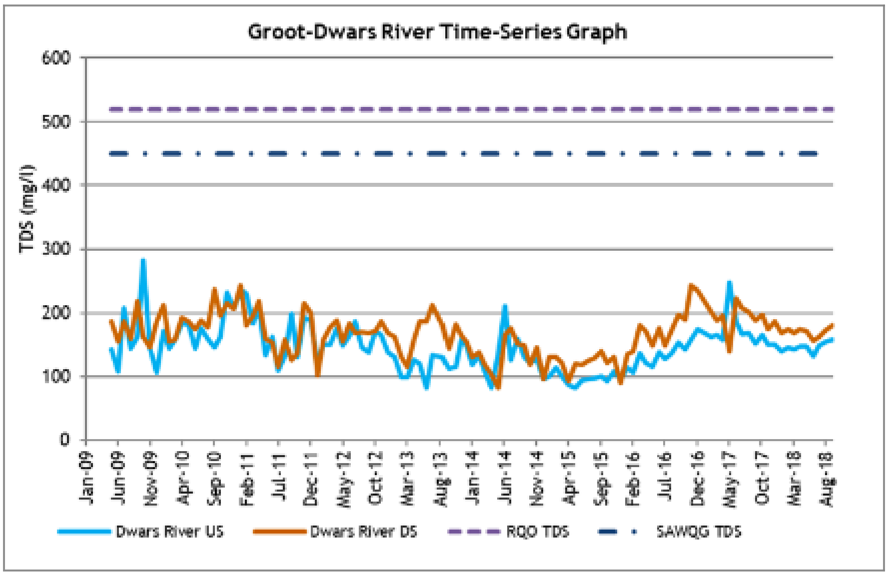


Figure 4-10: Time series of TDS in the Groot-Dwars River (up and downstream of current Der Brochen mining activities).

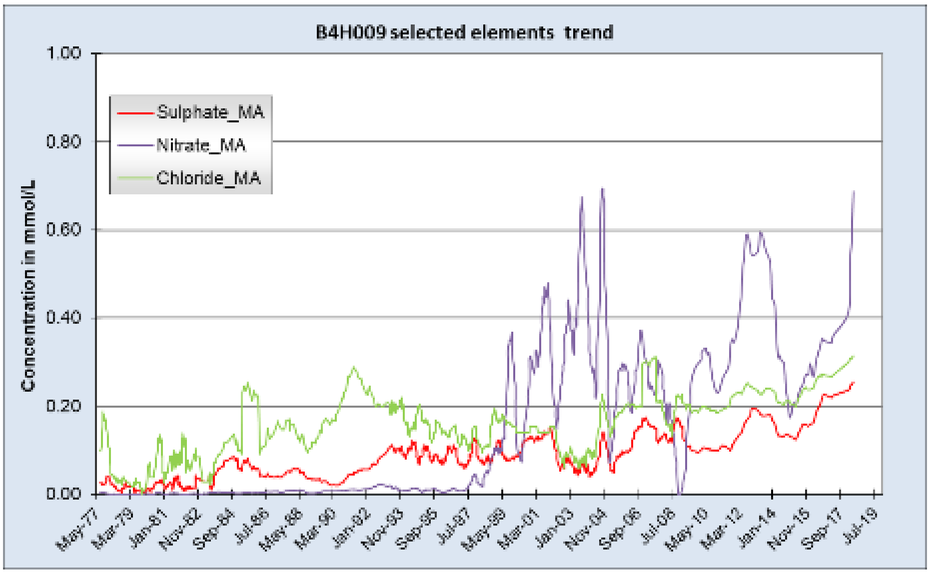


Figure 4-11: Long term trend for nitrate, sulphate and chloride downstream of the B41G catchment (annual moving averages).

4.4.2.4. Lebowa/Borwa Water Quality

The water quality results obtained from the January to June 2018 Mototolo mine monitoring report[5] were used to present the median water qualities for the Process Water Dams and Pollution control Dam of the Lebowa and Borwa shafts (Table 4-10). The process water qualities of the Lebowa and Borwa underground shafts provide an indication of operational water qualities of the Der Brochen North and South Portal and indicate alarmingly high levels of nitrate as well as elevated ammonium, calcium, sodium, sulphate and chloride concentrations. The elevated nitrate (and ammonium) concentrations in the mine process water facilities are due to the use of nitrogen-based explosives in the underground mining activities. After blasting, ammonium and nitrate residues are transported with the ore to the processing facilities, where it is incorporated into the mine process water circuit. As the reticulation system is a closed loop, the concentrations increase over time unless treated or intermittently flushed out.

Table 4-10: Mototolo mine process water quality results (in mg/l).

Parameter	WUL limit*	PWDMS	PWDMN	PCDMN
N (samples)		6	5	5
pH	6.5-9.5	7.45	7.7	7.3
EC (mS/m)	268	387	473	319
TDS	1 710	3450	3654	2872
Ca	145	464	468	405
Mg	106	131	83	64
Na	283	176.5	209	172
K	40	44	31	29
HCO_3	-	110	160	123
Cl	175	212	225	169
SO_4	611	314	383	269
NO_3 as N	6	459	438	371
F	1.25	0.6	0.65	0.61
NH_4 as N	-	65.5	84	41.4
Fe	2.6	0.004	0.004	0.004
Mn	0.3	0.272	0.084	0.071
Nil	-	0.283	0.1795	0.142

* - Mototolo (concentrator WUL)

[5] Exigo Quarterly Water Monitoring Reports: Mototolo Borwa (E-R-2018-06-22) and Lebowa (E-R-2018-06-25)

4.4.3. Water signatures/summary

An overview of the median concentrations of selected elements for the various monitoring sites (areas) since monitoring commenced is given in Table 4-11.

Table 4-11: Median concentrations for selected elements of the Der Brochen monitoring sites (highest values highlighted in red, lowest in green) (in mg/l).

Monitoring Site	Mon. Type	pH	EC	TDS	Ca	Mg	Na	K	HCO_3	Cl	SO4	NO_3
RWDA	Process Water	7.7	199	1363	69	56	217	27	255	112	351	339
RWDB		8.1	165	1120	84	54	188	13	228	142	419	7.8
SW01		8.1	154	1078	135	75	114	2	534	116	275	7.6
SW02		8.3	157	1144	106	89	122	1	343	143	363	1.5
PCD		7.9	146	1075	128	71	75	5	255	98	307	128
PCD Drainage Line 1	Tributaries	8.2	141	1028	139	88	74	2	309	95	350	55.6
PCD Drainage Line 2		8.3	134	946	124	78	78	1	285	96	355	27.4
TSF Drainage Line 1		8.3	144	1057	175	87	52	1	279	118	457	6.0
Mototolo BH	Groundwater	7.9	131	884	117	63	81	1	476	98	151	3.1
Mareesburg BH		7.8	59	340	39	62	11	1	550	7	25	1.5
Der Brochen BH		7.7	55	320	58	35	16	1	348	6	9	1.0
Mareesburg River	Surface Water	8.3	25	156	24	21	7	1	174	5	7	1.2
Klein Dwars River		8.2	27	193	30	16	7	0	178	2	3	1.3
Groot Dwars River		8.2	26	182	24	16	7	1	138	5	9	2.4
Dwars River US		8.2	21	144	21	13	6	1	126	3	6	2.0
Dwars River DS		8.1	25	169	25	15	7	1	133	5	13	2.4
Dwars River PCD BC		8.3	27	185	28	16	7	1	158	6	16	2.3
Dwars River PCD AC		8.3	27	196	29	17	8	1	160	7	21	2.8
Dwars River TSF BC		8.3	23	160	24	14	6	1	145	4	7	2.2
Dwars River TSF AC		8.3	26	187	29	16	7	1	152	7	19	2.3

The summary median concentration collated in Table 4-11 indicate the following:
The groundwater type is generally calcium / magnesium – bicarbonate (Ca/Mg-HCO3) rich, which is typical of shallow groundwater in the Bushveld Complex (BC). The magnesium and calcium dominance for the cations can be directly linked to the underlying geology (with magnesium and calcium rich gabbroic norites), while the bicarbonate anion dominance of the samples indicates relatively young or fresh groundwater in equilibrium with carbon-dioxide in the atmosphere and soil zone.

Compared to the Klein- and Groot-Dwars River catchments, the Mareesburg catchment is characterised by a higher contribution of magnesium, which can be distinguished on a Piper Diagram (Figure 4-8Figure 4-12). A more sodium (Na) rich water type is observed in a few boreholes in the Groot-Dwars sub-catchment, where the sodium replaces the calcium and magnesium in solution.

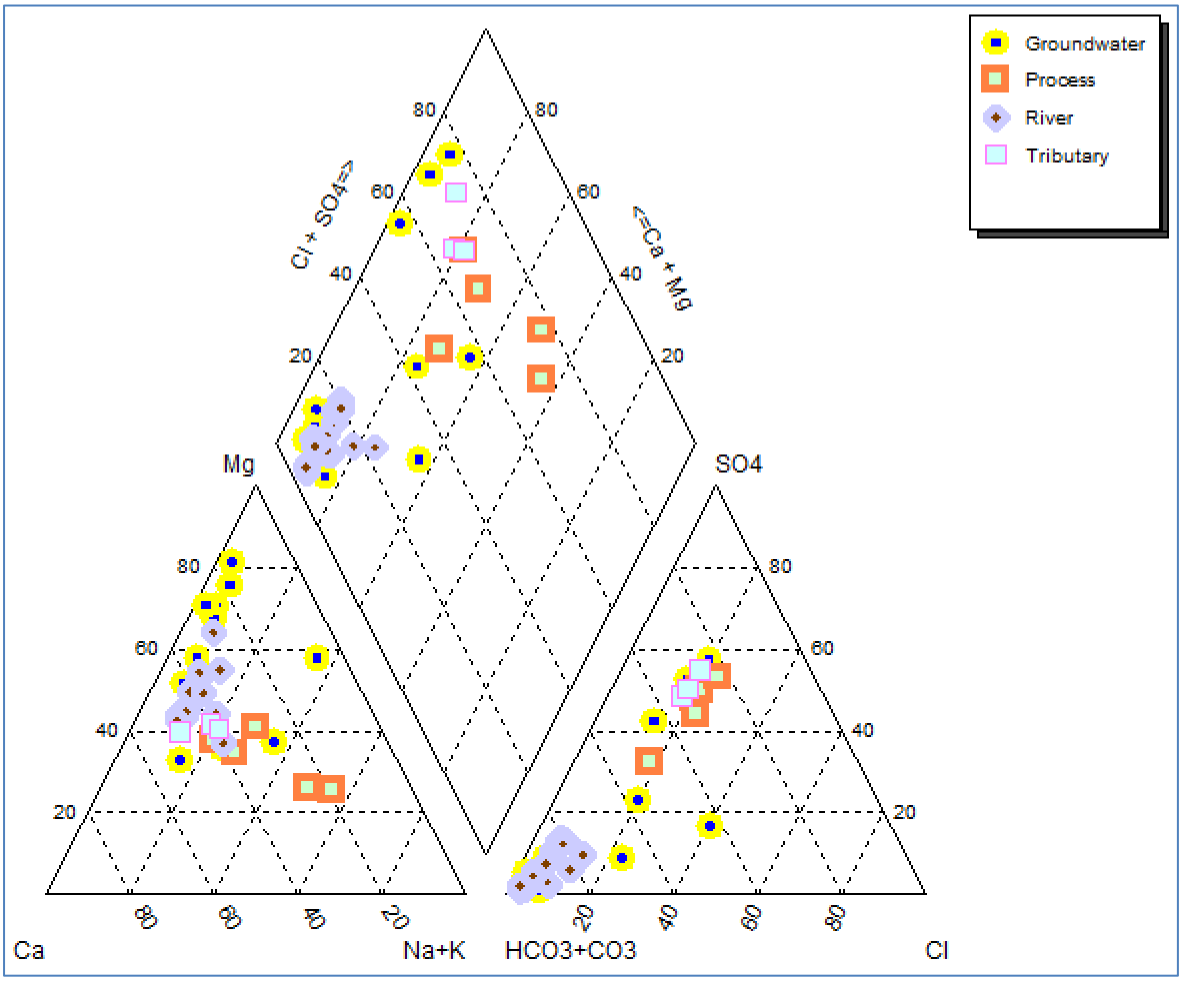


Figure 4-12: Piper Diagram for groundwater samples collected during the hydrocensus and the summarised median concentrations for the Der Brochen monitoring data.

4.5. CONCEPTUALISATION

4.5.1. Surface- groundwater interaction

Groundwater contributes to baseflow throughout the lower Dwars River catchment via sub-surface seepage into surface water courses. The Groot- and Klein-Dwars River floodplain is characterised by a relatively thick alluvial layer either replacing the upper overburden/weathered aquifer or overlying the upper overburden/weathered aquifer. The alluvial and overburden/weathered aquifer is largely in hydraulic continuity, while the regional (deeper fractured) aquifer only exchanges water with the river indirectly via the alluvial and/or the weathered aquifer. Where the alluvium/weathered aquifers are lacking, surface-groundwater exchange may occur directly from the regional aquifer via discrete fault or fracture zones linking it to the river. Recharge in the alluvial aquifer is primarily from the rivers during high flow periods and direct rainfall. Recharge of the shallow overburden/weathered aquifer is from the alluvium, interflow along the interface between overburden and weathered bedrock in the lower and mid-slopes of the valley side, as well as groundwater flow along the upper weathered portion of the bedrock across the catchment. A conceptual illustration of the hydrogeological setting of the Der Brochen underground workings is shown in Figure 4-13.

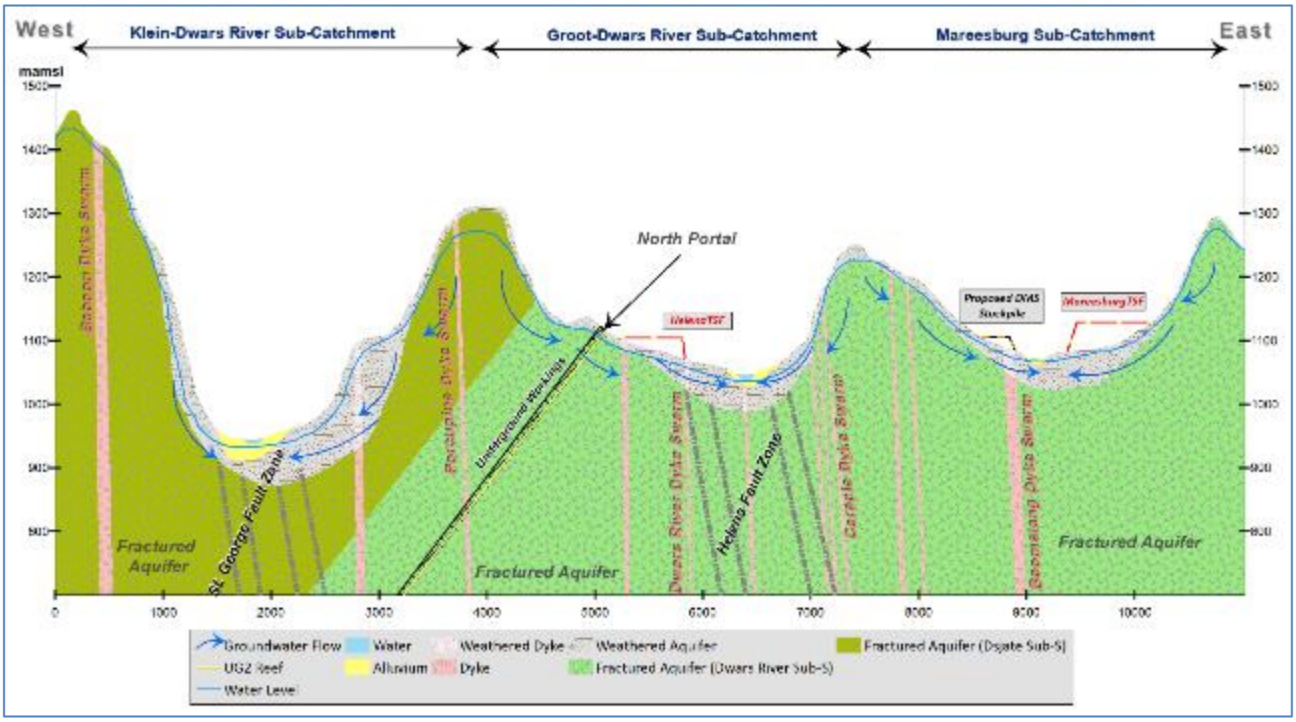


Figure 4-13: Conceptual regional groundwater flow model for the Der Brochen Project.

The surface-groundwater exchange between the alluvium and the Groot- and Klein-Dwars River occurs on a far shorter time scale in comparison to the interaction between the regional and alluvial/weathered aquifers. Surface-groundwater interaction is strongly seasonal, as both effluent / influent conditions can occur depending on the recharge period of the alluvium. This is illustrated in the weir hydrographs for both the Helena (HW1, HW2) gauging stations. The flow monitoring weirs have been installed to assess the impact on flow due to the Helena wellfield development for the Der Brochen Project which has not been yet been fully developed[6]. The average flow volume 2018 (oct-12 to Sep-18) is estimated as 4.9 Mm^3/a at HW1 and 4.2 Mm^3/a at HW2, which is slightly lower compared to the long-term median of 5.6 Mm^3/a and 4.5 Mm^3/a, respectively. This is largely in response to the lower rainfall for the year.

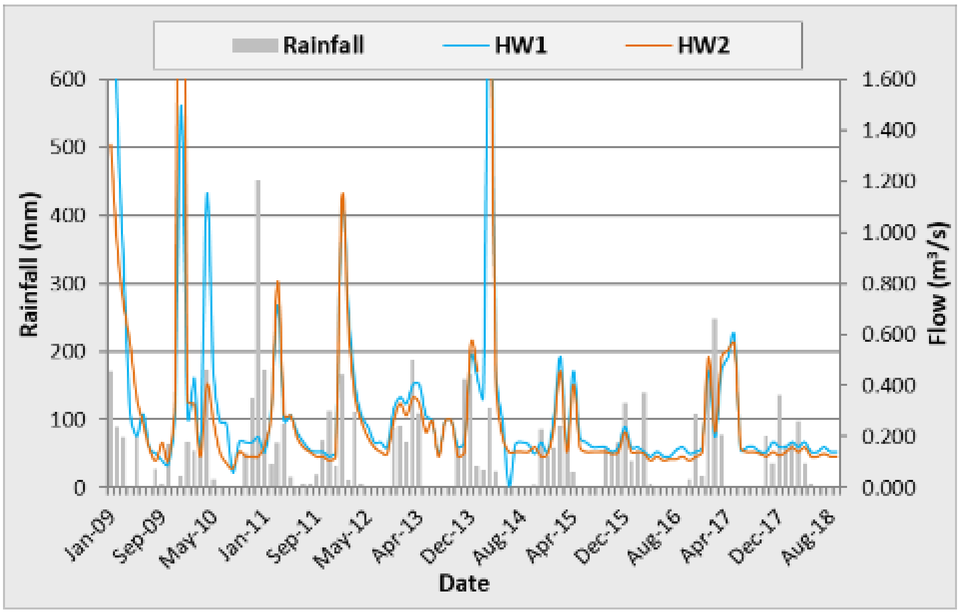


Figure 4-14: Average monthly flow rates for the Groot-Dwars River (Helena) weirs HW1 and HW2.

[6] Groundwater abstraction is currently limited to "pilot scale" of one borehole.

The total discharge volumes measured at the DWS B4H009 gauging station downstream of the B41G catchment are shown in Figure 4-15. Assuming that the gauging station remained in good condition since the 1960s, an increase in discharge, especially since the middle to late 2000s, is notable. Over the last decade, the average flow volume was measured at around 24 Mm^3/a, compared to a long-term average of 18 Mm^3/a. The increase is not necessarily attributable to an increase in rainfall or dam releases, but more likely to drought cycles, the contribution of mine water return flow into the Dwars-River system and/or sealing of land surface due to developments. Lower discharges post 1989 can also be correlated to the completion (and filling) of the Der Brochen dam.

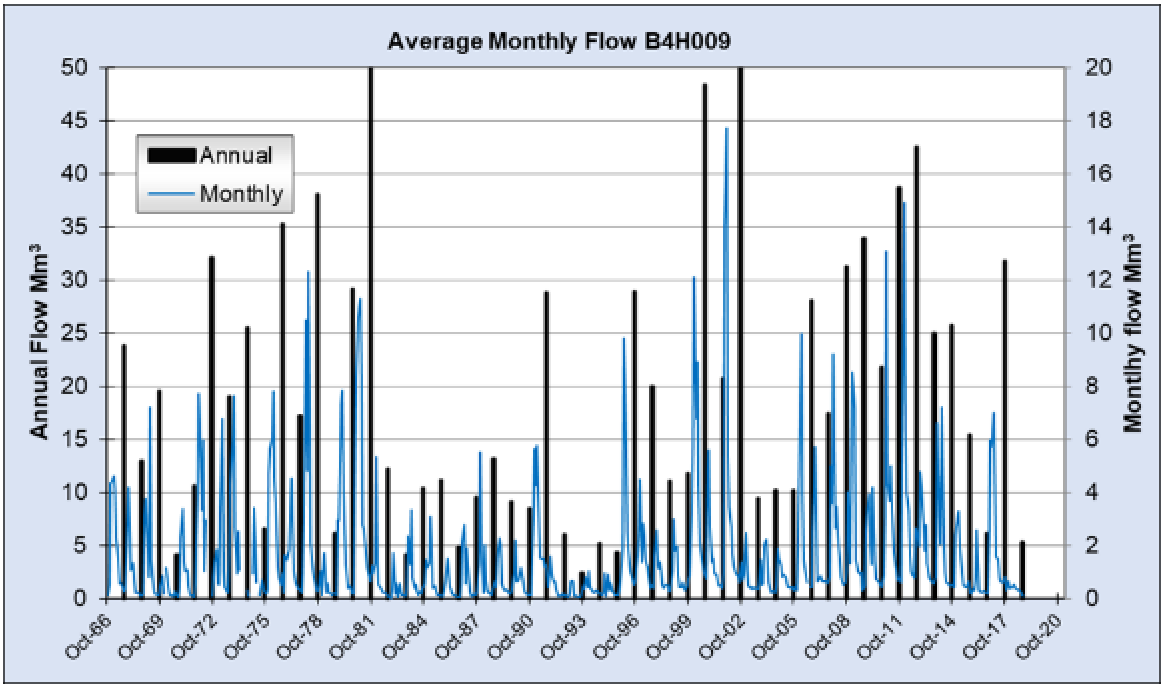


Figure 4-15: Monthly and annual measured flow volumes at gauging station B4H009.

4.5.2. Near-surface Hydrology Concept Model (SRK, 2018)

The near-surface hydrological conceptual model of the site was represented by SRK (2018) in a typical hillslope section (Figure 4-16). The key hydrological mechanisms in the conceptual model comprise of:

- Rapid initial infiltration into the top surface due to the high hydraulic conductivities on the surface, but water ingress is likely to be limited and surface runoff generated due to the low conductivity, high clay content, subsurface layers;
- Low diffuse recharge, evident from the soil/bedrock interface hydropedological observations;
- Discontinuous hydromorphic zones throughout the landscape formed by topographic depressions and exposed bedrock.

Recharge into the lower vadose zone and groundwater is possible. This is likely to occur:

- During very low intensity rain events followed by low evaporative demands
- During rain storms following long periods of droughts where shrinking clays provide extensive macropore networks (desiccation cracks) or
- At geological discontinuities and isolated areas where fractured rocks are on the surface.

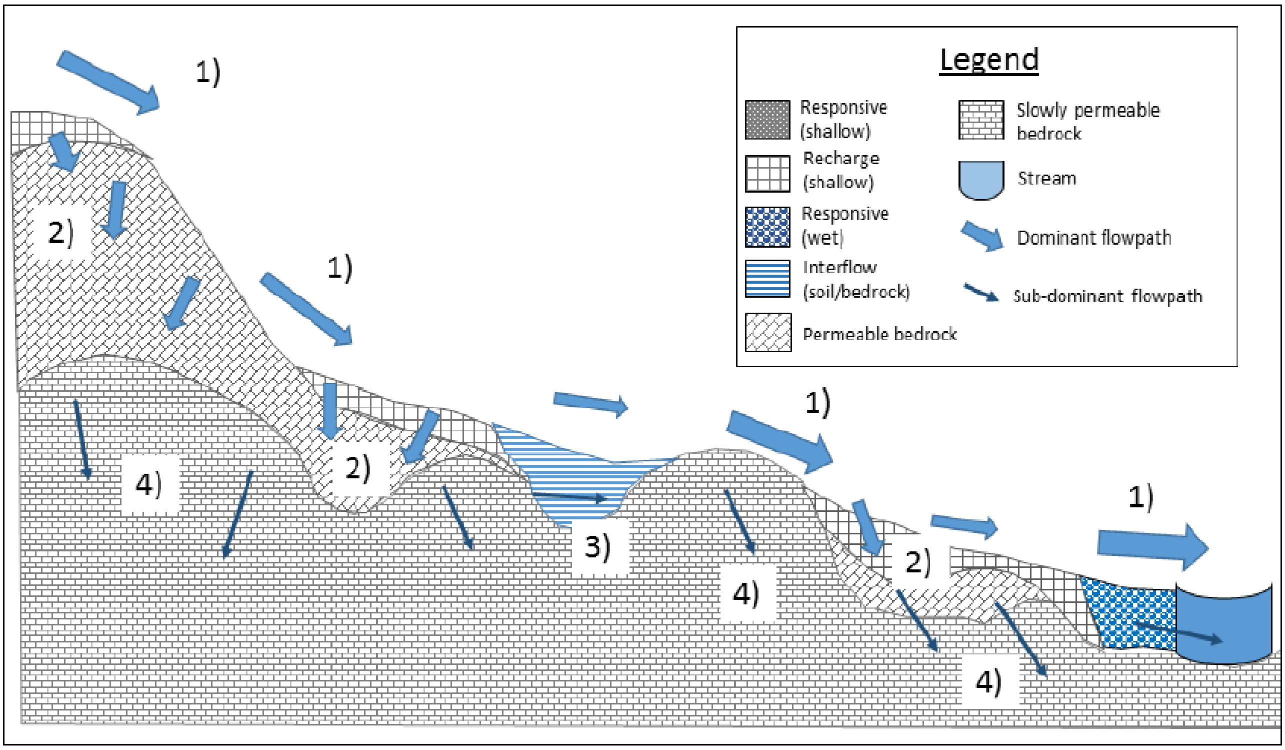


Figure 4-16: Near-surface hydrology conceptual model: 1) Overland flow is dominant, 2) infiltration into fractured rock occurs but at slow rates, 3) localized depressions and impermeable rock can result in hydromorphic properties, but these are not connected through the landscape and 4) drainage through the soils to regional water tables is limited.

4.6. Potential Pollution sources

Apart from the existing approved mining surface infrastructure (i.e. the Helena and Mareesburg TSFs and RWDs), the only other major potential pollution sources are the proposed DMS stockpile and the underground workings (including associated shafts). Water management infrastructure such as pollution control dams etc. will be sized to contain storm events and lined. Therefore, it is not expected that there will be any significant contamination from these surface sources. The geochemical assessment (Appendix C) was based on material retrieved from the Booysendal (Northam Platinum) DMS stockpile as well as core samples retrieved from the newly drilled North Portal exploration 16-degree hole and showed rather inert leaching behaviour of the tested materials.

DMS Stockpile

The tested DMS plant samples are classified as non-acid generating, with excess buffer capacity to neutralise potential acidity. Based on the static leachate quality tests conducted, only leached total chromium concentrations in one of the three samples at a 1: 4 leach ratio (and not in the prescribed 1:20 leach tests) exceeds the LCT0 threshold. All samples exceed on the other hand the TCT0 threshold for total concentrations of copper, two DMS samples the TCT0 threshold for nickel and one sample the TCT0 threshold for fluoride; rendering all samples therefore formally as Type 3 wastes. However, as the total metal concentrations are mostly non-leachable (less than 0.1 percent of the total concentrations are actually leachable), potentially leached metal concentrations are likely to represent a low environmental risk. The abundance of metal in the materials is furthermore highly variable and dependent on the geology of the processed material. Kinetic leach tests of samples DMS plant showed a constant neutral pH during the 20-week leach period with a lower sulphate production rate compared to NP consumption. If this relationship is maintained over the long term, the DMS stockpile sample are unlikely to become acidic. In addition, the salt load potential released from weathering of the material remained low during kinetic leaching from the DMS stockpile sample.

Underground Workings

The earlier (Delta-H, 2014) as well as current assessments classify the majority of waste rock and ore/reef samples as non-acid generating. All leach test assessments indicate limited leachability of elements from the waste rock (floor and roof material) and the ore/reef, suggesting a limited impact of seepage from waste rock dumps and ore stockpiles on the ambient groundwater quality.

4.7. Groundwater Pathway

The pathway through which contaminants could move in the subsurface environment would generally involve a combination of one or more of the following:

- Movement through the vadose (unsaturated) zone, and
- Movement through an aquifer.
- Movement through mining voids (underground or opencast),

The major flow paths in the study area are within the upper shallow overburden/weather aquifer, while the fracture zones and dykes across the site act as preferential flow paths for contaminants to travel. It is expected that contamination of the deeper aquifer will be limited due to limited hydraulic connectivity between the shallow and deep aquifers. Flow and transport are furthermore compartmentalized by the more competent dyke structures at depth.

Surface water can be impacted or via baseflow contributions from groundwater.

4.7.1. Process water spillages and overflows

Groundwater can be impacted by impacted by surface runoff and spills from the operational areas through recharge/infiltration. All areas with wet operations (tailings facilities and dirty water dams) or where ponding of contaminated water can occur pose a risk to groundwater via seepage.

4.8. Receptors

Receptors in the context of the water resource would be users of the water resource itself, including:

- Groundwater abstracted through a borehole for domestic, livestock watering or irrigation use,
- Aquatic fauna and flora in a receiving water course, and
- Any water user abstracting water from a watercourse.

Apart from the mine offices and houses that are using borehole supply no other so 'third party domestic' use occurs within the lease area. However, a number of potential downstream groundwater uses were identified during the hydrocensus (section 3.2). Although these users are located beyond the Der Brochen mine lease area, they are situated downstream of numerous mining activities, leading to potential cumulative impacts. As a result, the main receptor for contamination will be the Groot-Dwars River and the Mareesburg Stream with their associated ecosystems and users abstracting from the water course (if any).

5. AQUIFER CHARACTERISATION

5.1. GROUNDWATER VULNERABILITY

Groundwater vulnerability gives an indication of how susceptible an aquifer is to contamination. Aquifer vulnerability is used to represent the intrinsic characteristics that determine the sensitivity of various parts of an aquifer to being adversely affected by a contaminant load imposed from surface. Figure 5-1 shows the national groundwater vulnerability ratings underlying the project area, indicating the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some surface location above the uppermost aquifer.

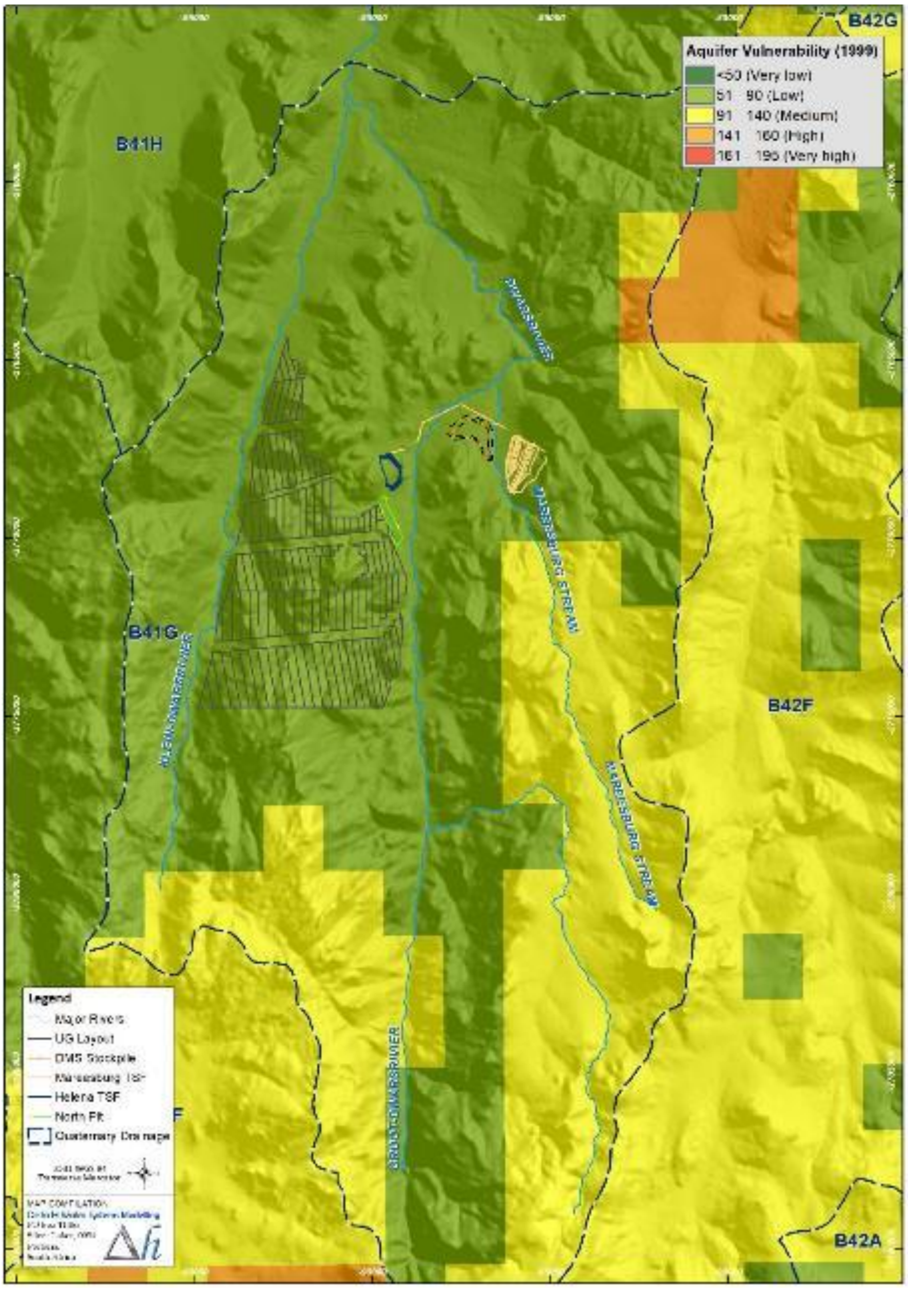


Figure 5-1: Groundwater vulnerability map for the project area.

The method is based on the DRASTIC method which includes the following parameters: Depth to water table; Recharge (net); Aquifer media; Soil media; Topography; Impact of the vadose (unsaturated) zone; Conductivity (hydraulic). Based on the national scale results, the aquifer underlying the project area has a low vulnerability rating. However, is should be noted that medium to high vulnerability rating areas occur towards the west (high), north (medium) and far south (medium).

5.2. AQUIFER CLASSIFICATION

According to the Hydrogeological Map (1:500 000) series, the regional hydrogeology is characterized as an 'intergranular and fractured aquifer' with a typical potential yield of 0.1 to 2.0 litres per second (Figure 5-2).

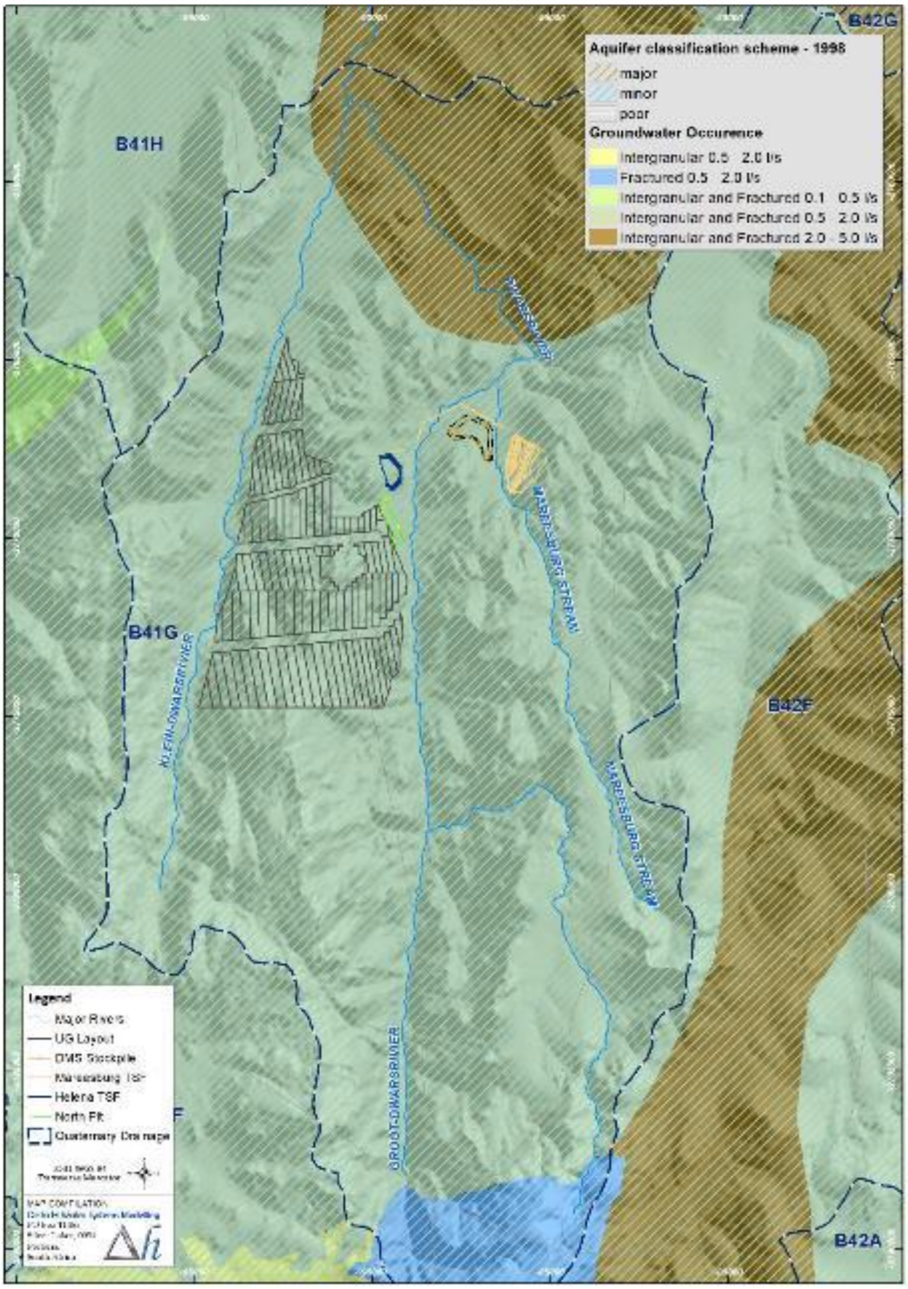


Figure 5-2: Aquifer classification map for the project area.

A micro-fractured matrix in the fractured aquifers provides the storage capacity with limited groundwater movements, while secondary features such as fractures / faults and bedding planes enhance groundwater flow. The intergranular aquifer is associated with the weathered zone, river alluvial and quaternary sand deposits. Despite a relatively low groundwater potential classification for the region, the extensive drilling programmes throughout the Upper Dwars-River catchment achieved median and average blow yields of 1.8 and 3.6 l/s respectively (Delta-H, 2014). Based on the aquifer classification map (Parsons and Conrad, 1998), the aquifer system underlying the site is regarded mainly a "minor aquifer" (Figure 5-2). A summary of the classification scheme is provided in Table 5-1. In this classification system, it is important to note that the concepts of Minor and Poor Aquifers are relative and that yield is not quantified. Within any specific area, all classes of aquifers should therefore, in theory, be present.

Table 5-1: Aquifer classification scheme after Parsons and Conrad (1998).

Aquifer	Description
Sole source aquifer	An aquifer used to supply 50% or more of urban domestic water for a given area, for which there are no reasonably available alternative sources, should this aquifer be impacted upon or depleted.
Major aquifer region	High-yielding aquifer of acceptable quality water.
Minor aquifer region	Moderately yielding aquifer of acceptable quality or high yielding aquifer of poor-quality water.
Poor aquifer region	Insignificantly yielding aquifer of good quality or moderately yielding aquifer of poor quality, or aquifer that will never be utilised for water supply and that will not contaminate other aquifers.
Special aquifer region	An aquifer designated as such by the Minister of Water

5.3. AQUIFER PROTECTION CLASSIFICATION

As part of the aquifer classification, a Groundwater Quality Management (GQM) Index is used to define the level of groundwater protection required (Parsons 1995). The point scoring system and classification of the site-specific project area are presented in Table 5-2.

Table 5-2: Groundwater Quality Management (GQM) Classification System.

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

The recommended level of groundwater protection based on the Groundwater Quality Management Classification is calculated as follows: GQM Index = Aquifer System Management x Aquifer Vulnerability = 2 x 1 = 2.

A Groundwater Quality Management Index of 2 was estimated for the project area from the ratings for the Aquifer System Management Classification (Table 5-3). According to this estimate, a low-level groundwater protection is required for the intergranular and fractured aquifer. Reasonable groundwater protection measures are recommended to ensure that no cumulative pollution affects the aquifer, even in the long term. DWSs water quality management objectives are to protect human health and the environment. Therefore, the significance of this aquifer classification is that if any potential risk exists, measures must be taken to limit the risk to the environment, which in this case is the protection of the underlying aquifer.

Table 5-3: GQM index for the project area.

Index	Level of Protection	Project area
<1 1 - 3 3 - 6 6 - 10 >10	Limited Low Level Medium Level High Level Strictly Non-Degradation	**2**

6. GROUNDWATER MODELLING

6.1. SOFTWARE MODEL CHOICE

The software code chosen for the numerical finite-element modelling work was the 3D groundwater flow and transport model SPRING, developed by the delta h Ingenieurgesellschaft mbH, Germany (König, 2011). The program, formerly known as SICK 100, was first published in 1970, and since then has undergone a number of revisions. The current saturated and unsaturated program module SPRING-SITRA is based on the well-known SUTRA model (Voss, 1984). SPRING is widely accepted by environmental scientists and associated professionals. SPRING uses the finite-element approximation to solve the groundwater flow equation. This means that the model area or domain is represented by a number of nodes and elements. Hydraulic properties are assigned to these nodes and elements and an equation is developed for each node, based on the surrounding nodes. A series of iterations are then run to solve the resulting matrix problem utilising a pre-conditioning conjugate gradient (PCG) matrix solver for the current model. The model is said to have "converged" when errors reduce to within an acceptable range. SPRING is able to simulate steady and non-steady flow, in aquifers of irregular dimensions.

SPRING solves the stationary flow equation independent of the density for variable saturated media as a function of the pressure according to:

$$-\nabla(K_{ij}\nabla h) = -\nabla\left(K_{perm}\frac{\rho g}{\mu}\nabla h\right) = q = -\nabla\left[\frac{K_{perm}\cdot k_{rel}}{\mu}(\rho g\nabla z + \nabla p)\right]$$

$$\nabla \qquad \left(\frac{\partial}{\partial x},\frac{\partial}{\partial y},\frac{\partial}{\partial z}\right)$$

q	Darcy flow
K_{ij}	Hydraulic conductivity tensor
ρg	Density $\cdot$ gravity
K_{perm}	Permeability
μ	Dynamic viscosity
k_{rel}	Relative permeability
p	Pressure

The relative hydraulic conductivity is hereby calculated as a function of water saturation, which in turn is a function of the saturation:

$$k_{rel}(S_r) = (S_e)^l\left[1-\left(1-(S_e)^{\frac{1}{m}}\right)^m\right]^2$$

$$S_e = \frac{S_r(p)-S_{res}}{S_s-S_{res}} = \left[1+\left(\frac{p_c}{p_e}\right)^n\right]^{\frac{1-n}{n}}$$

$S_r(p)$	Relative saturation dependent on pressure
S_e	Effective saturation
l	Unknown parameter, determined by van Genuchten to 0.5
m	equal to $1-(1/n)$
n	Pore size index
S_{res}	Residual saturation
S_s	Maximum saturation
p_c	Capillary pressure
p_e	Water entry pressure

Solving these equations for the relative saturation as a function of the capillary pressure $S_r(p_c)$ results in the capillary pressure- saturation function according to the Van Genuchten (1980) model as used in SPRING:

$$S_r(p_c) = S_{res} + (S_s - S_{res})\cdot\left[1+\left(\frac{p_c}{p_e}\right)^n\right]^{\frac{1-n}{n}}$$

The water entry pressure is a soil specific parameter and defined as the inverse of a = $1/p_e$ in the saturation parameters. Figure 6-1 shows examples of the pressure-saturation functions according to van Genuchten for different soil types

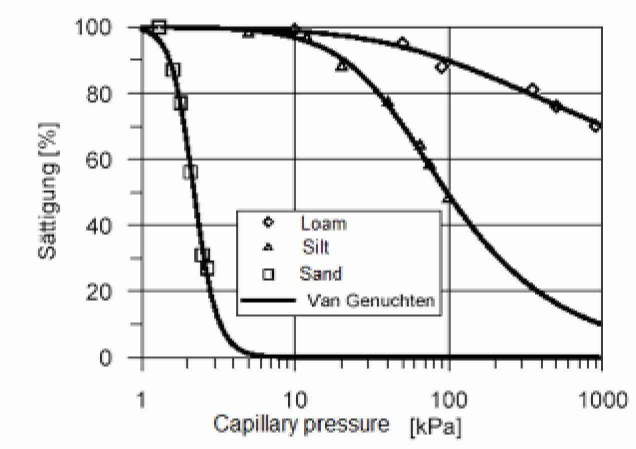


Figure 6-1: Examples of capillary pressure- saturation functions (König, 2011).

The density independent, instationary flow equation for variable saturated media as a function of the capillary pressure is given as follows:

$$\rho\left(S_r(p_c)S_{sp}+\theta\frac{\partial S_r(p_c)}{\partial p}\right)\frac{\partial p}{\partial t}+\theta S_r(p_c)\frac{\partial \rho}{\partial t}-\nabla\left[\rho\frac{K_{perm}k_{rel}}{\mu}(\nabla p+\rho g\nabla z)\right]=q$$

The specific pressure dependent storage coefficient S_{sp} is hereby given as

$$S_{sp}=\alpha(1-\theta)+\beta\theta$$

α Compressibility of porous media matrix
β Compressibility of fluid (water)
θ Aquifer porosity

The transport equation for a solute in variably saturated aquifers is given as follows:

$$\theta S_r(p_c)\frac{\partial c}{\partial t}+\theta S_r(p_c)v\nabla c-\nabla\left(\theta S_r(p_c)\left(D_m\bar{\bar{1}}+D_d\right)\nabla c\right)=qc^*+R_i$$

qc^* Volumetric source/sink term with concentration c *
D_m Molecular diffusion
$\bar{\bar{1}}$ Unit matrix
D_d Hydromechanic dispersion
R_i Reactive transport processes (sorption, decay, etc.)

The software is therefore capable to derive quantitative results for groundwater flow and transport problems in the saturated and unsaturated zones of an aquifer.

SPRING uses an efficient preconditioned conjugate gradient (PCG) solver for the iterative solution of the flow and transport equation. The closure criterion for the solver, i.e. the convergence limit of the iteration process was set at a residual below 1e-06. The Picard iteration, used for the iterative computation of the relative permeability for each element as a function of the relative saturation respectively capillary pressure, used a damping factor of 0.5 and was limited to 8 iterations. The relative difference between the two computed potential heads or capillary pressures after 8 iterations was generally below an acceptable 0.05 m.

6.2. MODEL SET-UP AND BOUNDARIES

The model domain covers a surface area of 443 km^2 and coincides with the B41G quaternary catchment boundaries, so as to ensure a dependable water balance for the model with recharge being the main driver of groundwater flow. The boundaries follow accordingly mostly topographic highs, which are considered to also define groundwater divides (chapter 4.3) and therefore outer no-flow model boundaries. The model domain was spatially discretised into 78 141 nodes on eight node layers, which make up seven finite-element layers with 89 530 elements (triangles and quadrangles) each. The horizontal element size (side length) varies from a minimum of 30 to 50 m (average) along surface drainages and mapped dykes (as provided by the Der Brochen Amendment Project geologist), to a maximum side length of 100 m further away from the area of interest The chosen model discretisation allows a sufficiently accurate representation of discrete physical features (dykes, drainages, proposed infrastructure layouts) in a regional groundwater flow model, employed to ensure a justifiable water balance and natural upstream boundaries of the flow system for the area of interest (Figure 6-2).

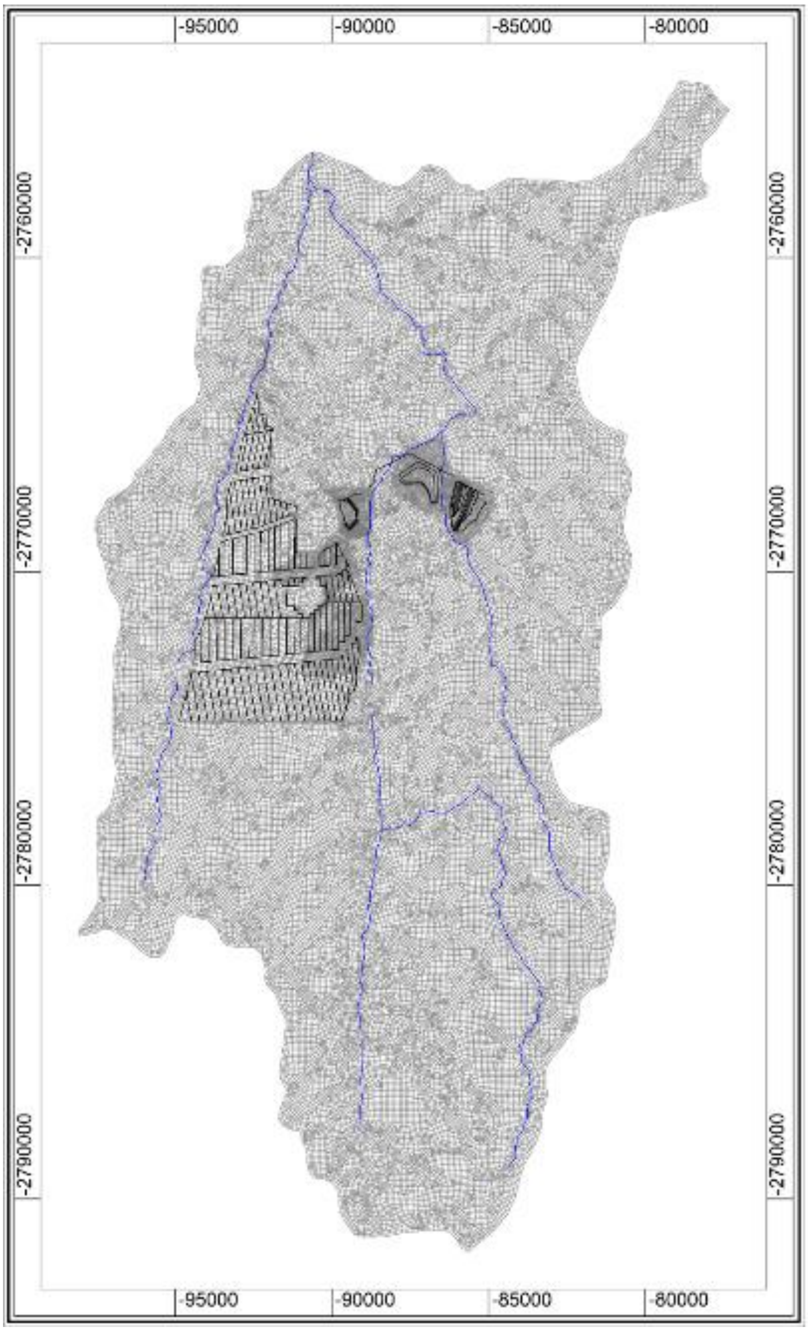


Figure 6-2: Finite element mesh of the groundwater model (mining areas indicated black, surface drainages in blue).

The different data sources used to define the elevations of the different model layers are given in Table 6-1. The layers were arranged to represent the conceptual model as well as the UG2 reef targeted over the life of mine. Not all layers used to represent the mine layout are therefore present throughout the model domain (Figure 6-3). The upper layer (discretised into two layers to account for the unsaturated zone calculations and increase numerical stability) simulates the shallow weathered and alluvial aquifers, while the underlying layers represent the deeper fractured aquifer in the BC. The active groundwater flow system occurs within the upper 100 mbgl of the BC, while groundwater strikes are generally less than 50 mbgl (see section 3.4). As a result, the deeper bedrock aquitard was sub-divided into two layers for numerical reasons above and below the UG2 reef layer 5. The layer arrangement is shown in a cross-section in Figure 6-3.

Table 6-1: Arrangement of model layers in the Der Brochen groundwater model.

Element layer	Node layer	Aquifer feature	Data used for interpolation
I, top	1	Surface elevation	Digital Elevation Model (DEM) 25x25m
I, bottom	2	Weathered aquifer	DEM – 5 to 25 m
II, bottom	3	Fractured aquifer (upper)	DEM – 96 m
III, bottom	4	Bedrock (aquitard) (upper split)	Split for numerical accuracy
IV, bottom	5	Bedrock (aquitard) (up to Reef elevation)	
VI, bottom	6	UG2 Reef Elevation	Final2016tr_reef.csv linearly interpolated
VII, bottom	7	Bedrock (aquitard)	Split for numerical accuracy
VII, bottom	8	Bedrock (aquitard)	Minus 400 mamsl

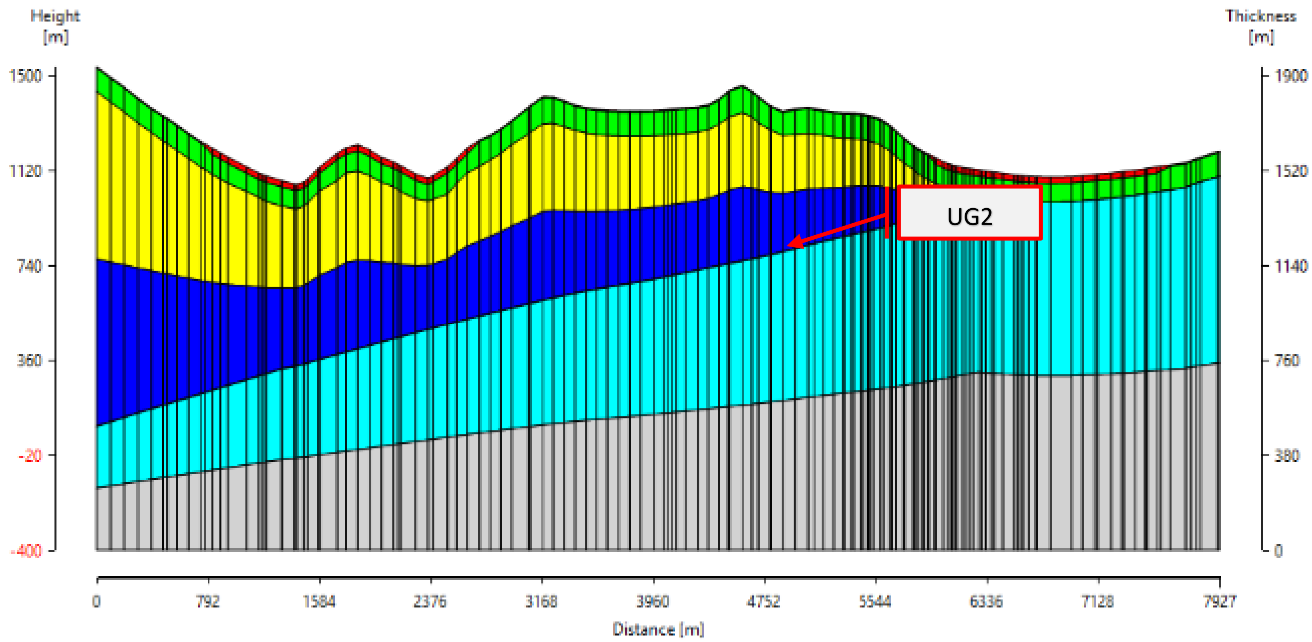


Figure 6-3: Example of the vertical grid layout across the mining area (E-W cross section, colours indicate numerical model layers only).

6.3. GROUNDWATER SOURCES AND SINKS

6.3.1. Groundwater Recharge

Groundwater enters the model domains as direct recharge from rainfall. It was therefore implied that certain areas may have greater recharge potential and may thus contribute a larger proportion of recharge towards the aquifer systems. Based on the conceptual understanding of the larger B41G groundwater system, the higher lying areas (above 1400 mamsl) were assigned a mean annual recharge rate of 30 mm (4.5 % of MAP), while the remainder of the sub-catchment was assigned a recharge rate of 24 mm/annum (3.6 %).

6.3.2. Seepage from Mine Residue Deposits

Seepage or "recharge" rates applied to the existing and proposed infrastructure are shown in Table 2-1. Seepage (fluxes) from the existing mine residue deposits (Helena TSF including the RWDs) associated with the Mototolo JV concentrator were taken from previous studies (Delta H, 2018) and incorporated into the Der Brochen Amendment Project Model. The deposition from the DMS plant is scheduled to start in 2022. The DMS stockpile design is shown in Figure 6-4 and scheduled in the following phases[7]:

- Phase 1 (2037) – 7 .1Mm^3
- Phase 2 (2049) – 12.6 Mm^3
- Phase 3 (2067) – 20.2 Mm^3

Table 6-2: Seepage rates applied in the groundwater model.

Source	Estimated current seepage rate [mm/a]	% of MAP
TSF (Beach and Pool)	100	15
TSF (Wall)	55	8.3
RWD A (un-lined)	80	12
RWD B (un-lined)	60	9
'new' DMS Stockpile (lined)	15	2.2
'new' DMS Stockpile (unlined)	45*	6.8

[7] E-mail correspondence 29 October 2018 – Albertus du Plessis (Principal Civil) Engineer Knight Piésold (Pty) Ltd.

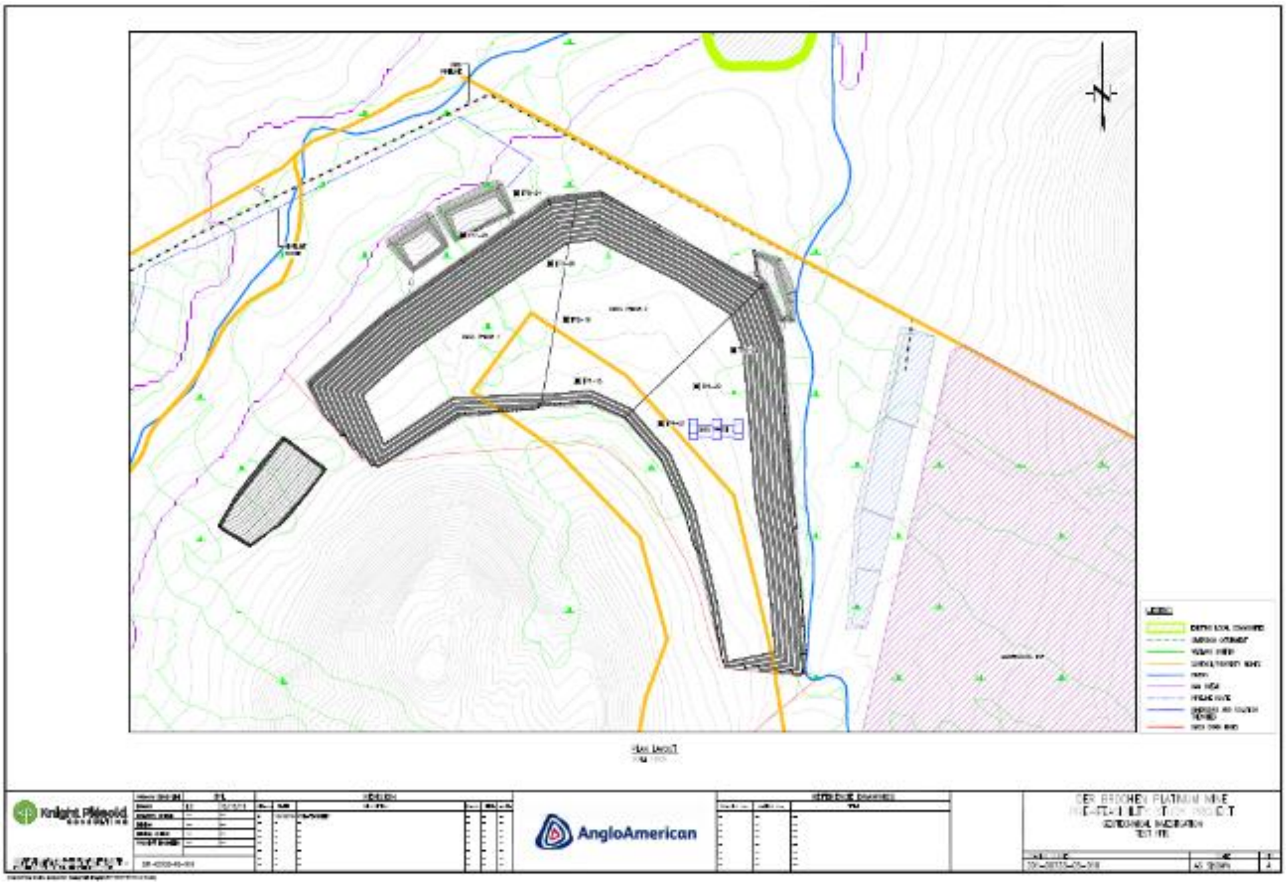


Figure 6-4: DMS stockpile drawing (client data).

6.3.3. Surface water

Water leaves the model domain via numerous perennial and non-perennial rivers. Notwithstanding the type, all surface water drainages were classified as continuously gaining river courses. A river or 3rd type (Cauchy) boundary condition was assigned to the streams and river courses within the model domain whereby the leakage of groundwater into the river (or vice versa) depends on the prevailing gradient. Based on estimated baseflow rates for the catchments of interest, the streams/rivers were generally classified as potentially gaining streams/rivers and no leakage of surface water into the aquifer respectively the model domain allowed. With the chosen approach, no water losses occur from the perennial and non-perennial rivers into the model domain, but groundwater on either side of the river/drainage might discharge into it as a function of the calculated gradients. The streams act therefore only as groundwater sinks. In the absence of site-specific data, leakage of groundwater into the rivers/streams is assumed to be not constricted by semi-pervious layers in the riverbed and a leakage coefficient equivalent to the aquifer permeability assigned to the river. An incision of 5 metres below the surrounding topography is assumed for the hydraulic active riverbed.

6.3.4. Underground mine workings

At this project phase the future underground mine workings were represented in the numerical model by a node layer aligned to the UG2 reef elevation for the LOM workings (Ore production) at the various shafts/portals (Figure 6-5). Mining will continue from the Borwa and Leboa shafts until production from Der Brochen South portal will commence around 2022, which will increase the Run of Mine (ROM) to around 320 kt/month. Der Brochen's North portal is expected to commence once the Borwa extension has reached full development around 2039. The spatial setting of the underground workings and reef elevation is shown in Figure 6-6.

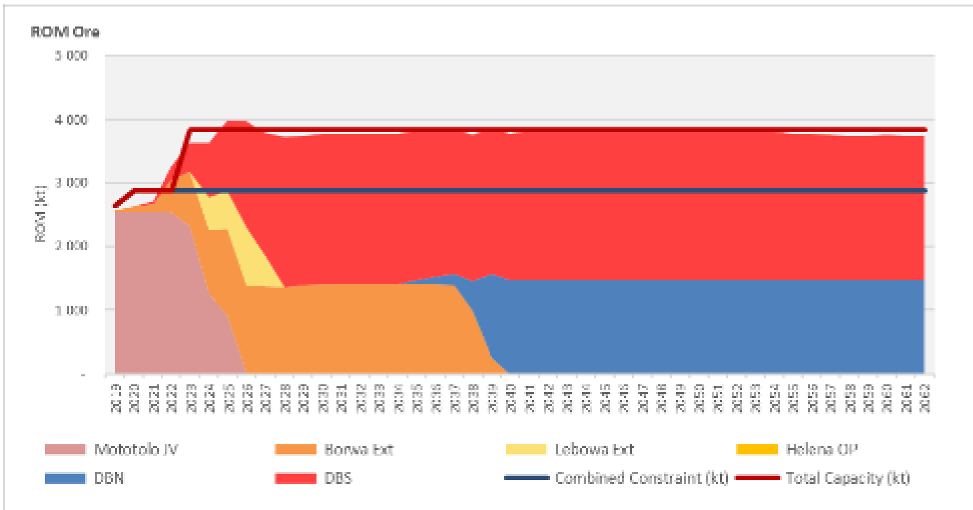


Figure 6-5: Run of mine (ROM) production profile (client data).

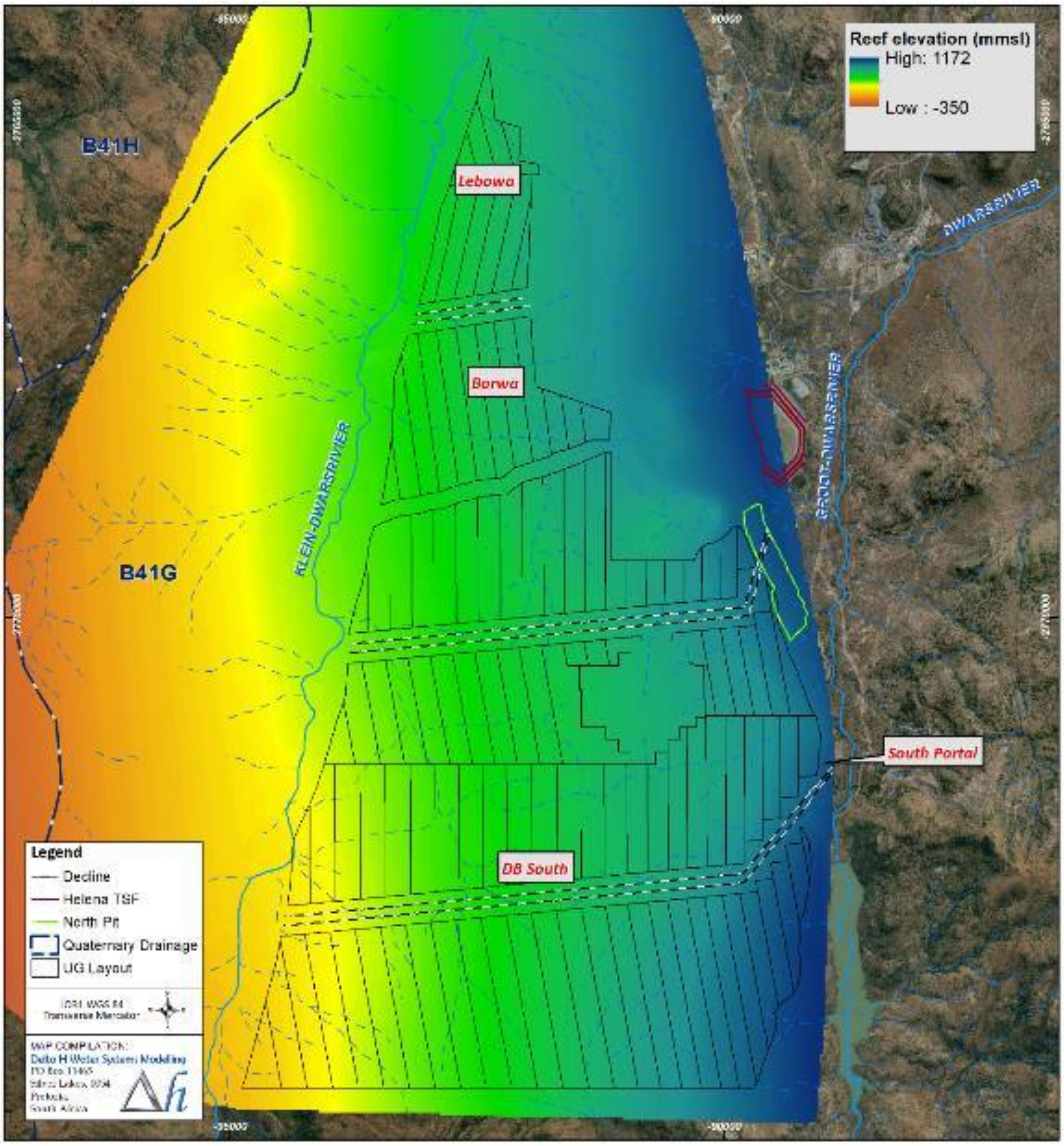


Figure 6-6: Future underground workings and south portal.

In order to estimate groundwater inflows into the future underground mine workings, a leakage boundary (with no losses or flow of water into the model domain allowed) was assigned to the UG2 reef (floor) elevation. The chosen approach assumes that any groundwater entering the underground workings is removed immediately and no groundwater storage or flow within the mine workings or return flows into the aquifer is considered. In other words, it is assumed that the entire mine workings are dry due to continuous dewatering of any water ingress.

6.4. NUMERICAL MODEL

6.4.1. Initial Conditions

The initial conditions specified in the steady state flow model were as follows:

- Starting heads for the aquifers were interpolated from measured shallow water levels using Gaussian interpolation and used as initial heads for the steady-state simulations (Chapter 4.3).
- Horizontal hydraulic conductivities of 5E-06 m/s and 1E-07 m/s for the weathered and fractured aquifer respectively.
- Vertical hydraulic conductivities were set at 10% of the horizontal conductivities.

6.4.2. Transport Parameter

One of the uncertainties encountered during transport modelling of pollutants is the kinetic or effective porosity of the aquifer. Effective (transport) porosity values were specified as 10% for the weathered and 5 to 3% (decreasing with depth) for the fractured aquifer. In the absence of site-specific data, values of dispersivity were inferred from literature values, with a uniform longitudinal dispersion length of 100 m assigned to all aquifer's units and the transversal dispersivity set at 10 % of the longitudinal dispersivity (NRC, 1990).

6.4.3. Steady State Calibration

The groundwater levels (in metres above mean sea level) measured in 89 boreholes were used as targets for the steady-state model calibration. The model was run with the initial conditions and the conductivities adjusted within sensible boundaries until a best fit between measured and computed heads and pit inflows was achieved (Figure 6-7).

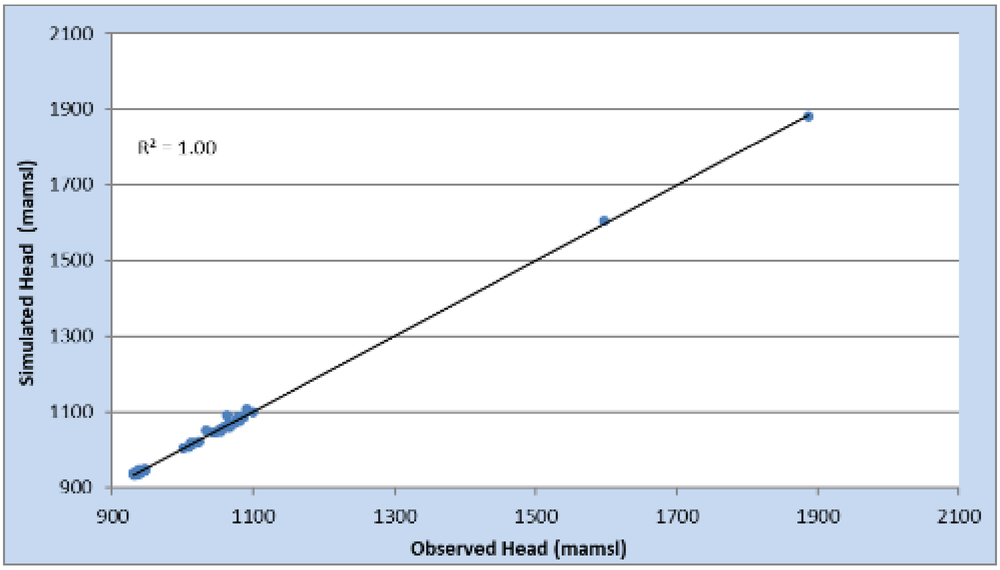


Figure 6-7: Steady-state calibration of the Der Brochen groundwater flow model.

The root mean square error (RMSE) respectively the normalised root mean square error (NRMSE) were used as quantitative indicators for the adequacy of the fit between the 89 (=n) observed (h_{obs}) and simulated (h_{sim}) water levels:

$$RMSE = \sqrt{\frac{\sum(h_{obs} - h_{sim})^2}{n}}$$

$$NRMSE = \frac{RMSE}{h_{max} - h_{min}}$$

The normalised root mean square error scales the error value to the overall range of observed heads within a model domain (here approximately $h_{max} - h_{min}$ = 1882 mamsl – 933 mamsl = 948 m), with values lower than 10% considered acceptable.

A very good correlation (essentially 100%) between observed and modelled water levels (Figure 6-7) was achieved for the steady-state calibration. The corresponding root mean square error of RMSE = **5.7** and normalised root mean square error of NRMSE = **0.6 %** of the steady-state calibration of the groundwater flow model are considered very good and more than adequate for the purpose of the study. The calibrated hydraulic conductivity values as given in Table 6-3 were subsequently used for the predictive model simulations.

Table 6-3: Calibrated hydraulic conductivity values for the groundwater model.

Aquifer	Hydraulic conductivity [m/s]	
	Min	max
Overburden/weathered zone aquifer	6E-7	5E-6
Fractured aquifer	1E-7	9E-7
Deep bedrock aquitard	5E-9	1e-8

6.5. RESULTS OF THE MODEL

6.5.1. Baseline 2018

The simulated average (steady-state), pre-mining water levels are shown in Figure 6-8 and represent the current status quo or baseline against which mining impacts are assessed.

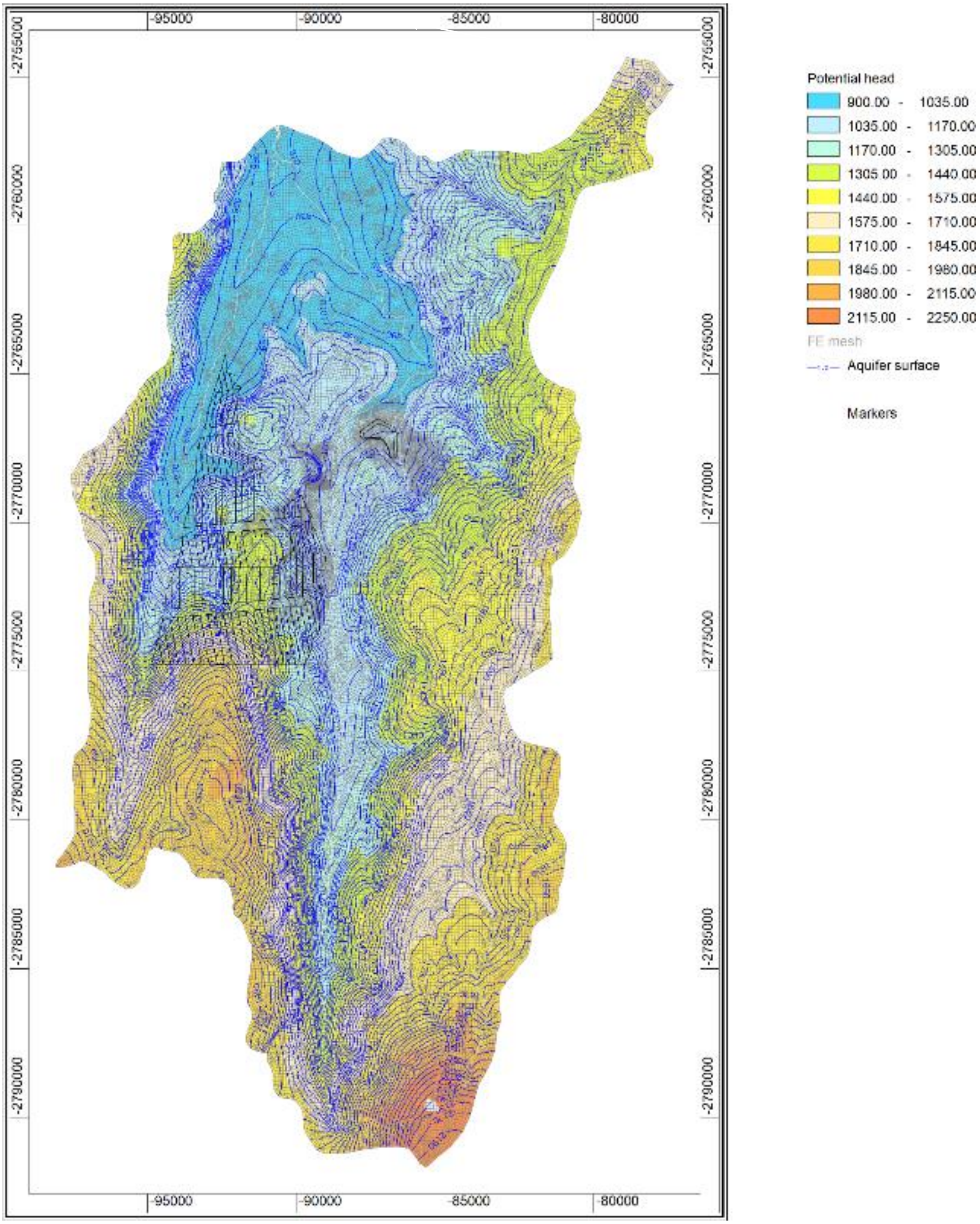


Figure 6-8: Simulated steady state free water table elevations (2018) for the model area (mining area indicated in black).

6.5.1. Decline areas

Daily inflow rates (averaged per month) into the south decline areas for a distance of 1400 m for the South portal, are shown in Figure 6-9. The detailed 3D-phases of the box-cut design were not available for the model simulation. To provide a first guesstimate of potential inflows the spatial portal/UG decline area was used (refer to Figure 6-6). Groundwater inflows into the decline area are expected to decrease after the initial portal development (breaching the weathered aquifer) from around 350 m^3/d to around 150 m^3/day for the South decline. The location of the south portal is associated with a deeper weathered zone that extends to approximately 25 mbgl and 32 mbgl and is associated by high conductivity zones proven by hydraulic testing. Excavations of the portal sites will breach the permeable zones at relatively shallow groundwater levels, which will pose a challenge to construction, grouting and water ingress management. The feasibility of upfront dewatering of the area should be assessed during the feasibility phase.

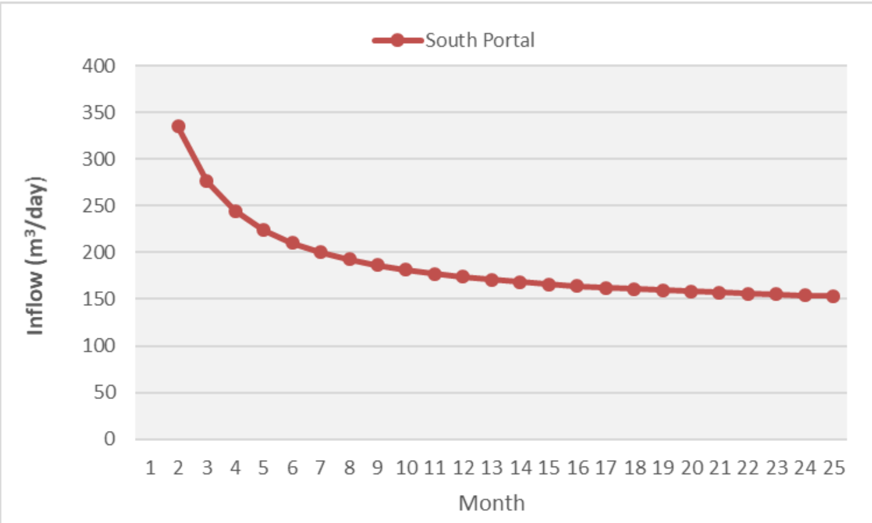


Figure 6-9: Simulated South decline inflows.

6.5.2. Life of Mine (2022 to 2062)

The calibrated groundwater flow model was used to estimate the average groundwater inflow rates into the underground workings based on the provided ROM profile for the Mototolo Mine (Lebowa/Borwa) expansion and Der Brochen's South-Portal development. It must be noted that no annual schedules for the underground mine expansions were provided by the client and the different mining areas (Lebowa/Borwa expansion, Der Brochen's South Portal) are therefore not gradually incorporated into the model, but only based on the ROM profiles. In other words, each mining area was incorporated into the model in its entirety at their commissioning date and not sequentially over time. This obviously results in overestimated inflows during the early years of each development, as the final mine extents are in reality only reached at the end of life for each mining area. The simulated inflows should therefore be seen as an estimate of maximum inflow rates per mining area at full development. The simulated groundwater inflow rates over the different ROM periods are shown in Figure 6-10, while the average and cumulative (for all expansion projects) LoM inflow rates are summarised in Table 6-4. Simulated groundwater inflow rates increase progressively as the mining areas are developed but will start to decrease as the surrounding deep aquifers/aquitards are dewatered and less water is released from storage. Again, these simulated inflow rates represent maximum inflow rates per mining area at full development and the inflow rates should be re-visited once annual mining schedules become available.

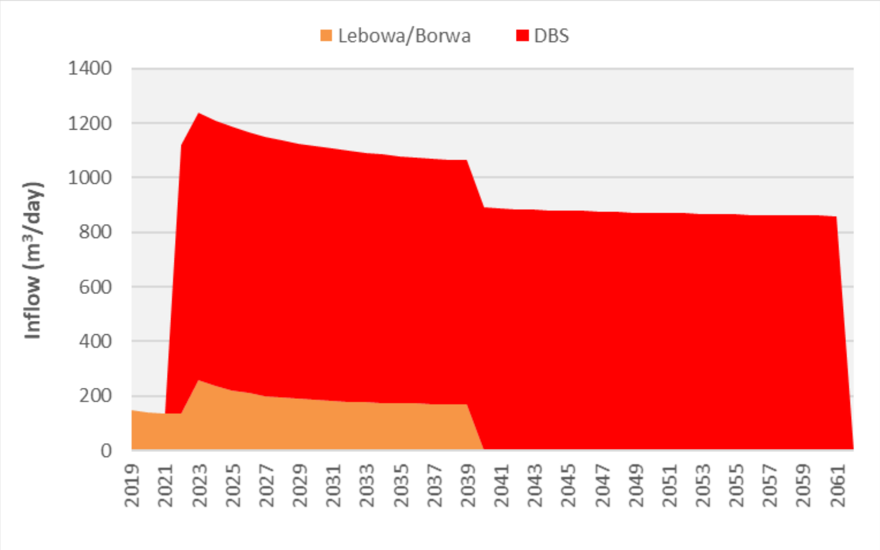


Figure 6-10: Simulated underground mine inflows.

Table 6-4: Estimated inflow rates based on the LoM schedule.

Mining Area	Average Inflows (m^3/day)	Cumulative Inflows (m^3/day)
Lebowa/Borwa (Expansion)	180	180
DBS	900	1080 (2021 to 2039)
DBS (only)	-	860 (2039 to 2062)

6.5.2.1. Impacts associated with mine inflows

Assuming re-use or other environmentally acceptable disposal practices of the groundwater entering the declines and underground mine voids, the environmental impacts associated with the mine inflows are primarily associated with

- the dewatering of the aquifer above and in the vicinity of the underground mine voids with potential impacts on the receiving groundwater environment, and
- the interception of ambient groundwater flow, which would have under natural conditions discharged into the surface drainages, provided baseflow to the rivers, or contributed to deeper regional groundwater flow.

The simulated impact of the partial dewatering of the weathered aquifer due to mine inflows is depicted in Figure 6-11 as contours of drawdown (in metres) for LoM. A cross section, showing the simulated separation of the deeper and shallow aquifer free surfaces (water levels) due to mine dewatering, is presented in Figure 6-13. The split of the free water tables within the weathered and fractured aquifer, as observed in nature, results in limited impacts of mine inflows on the water table in the shallow weathered aquifer. The very low hydraulic conductivity of the fractured aquifer at the depth of mining results furthermore in a very steep but spatially limited zone of dewatering, which does not affect the surrounding aquifers significantly. The drawdown in groundwater levels around the South portals is expected to be around 25 to 30 m (see Figure 6-11), with the extent of the dewatering cone (with a drawdown > 5m) calculated to up to 100 m from the underground workings. The numerical modelling results show furthermore that the drawdown in groundwater levels along the Groot-Dwars River will be limited and no induced losses of surface water from the river to the aquifer (due to a reversal of gradients) are expected.

Based on the balance nodes immediately adjacent the Groot-Dwars River the contribution to baseflow for the base case is less than 5.0 % of the total baseflow for the catchment (Figure 6-12). The estimated average loss of the total groundwater contribution towards the baseflow is less than 1 %. Groundwater contribution to the non-perennial drainage lines are limited due to groundwater levels being well below the base of the drainage bed for most parts of the year.

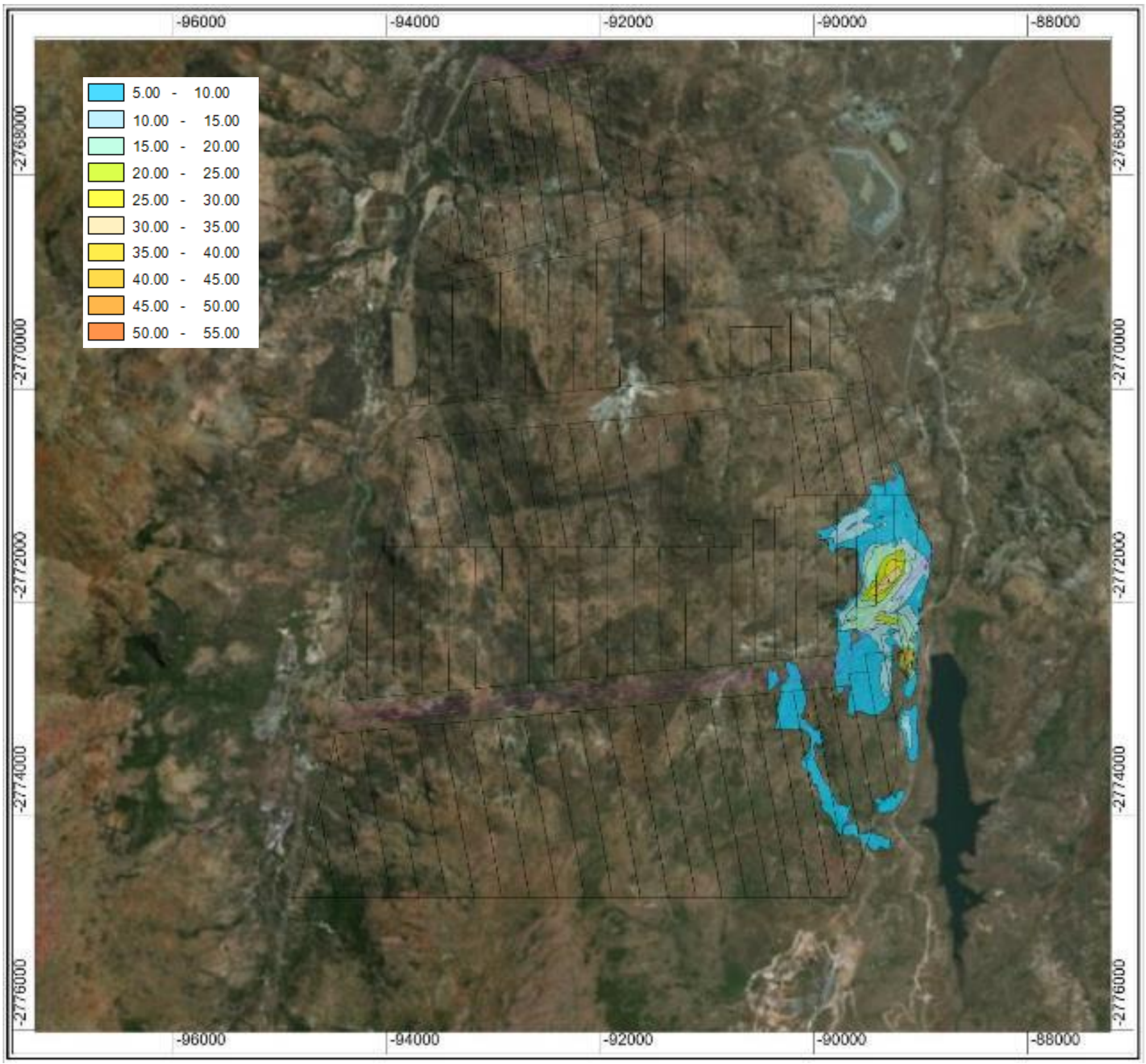


Figure 6-11: Simulated groundwater table drawdown in the weathered aquifer at the end of LoM (mining areas indicated by black lines).

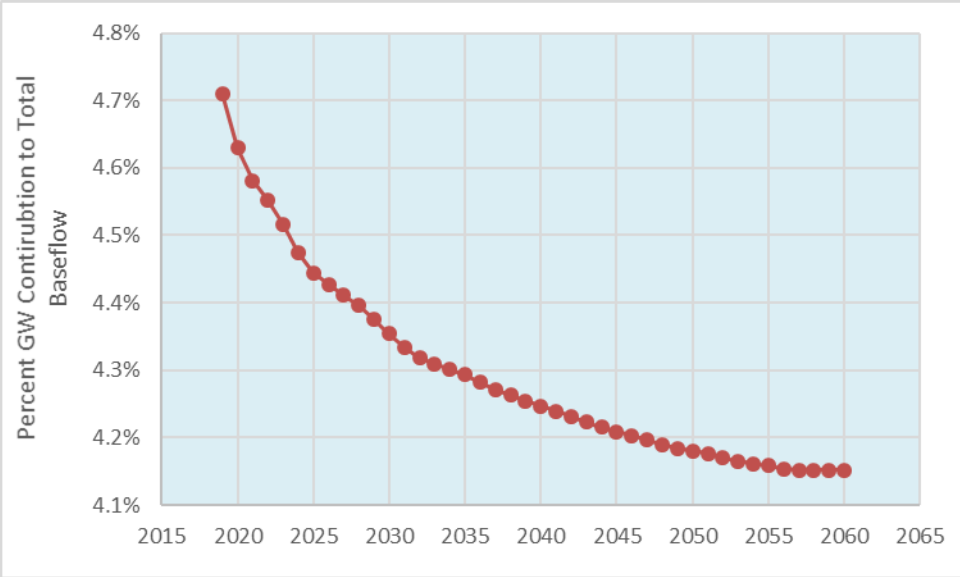


Figure 6-12: Change in groundwater contribution to the Groot-Dwars River for the LoM scenario.

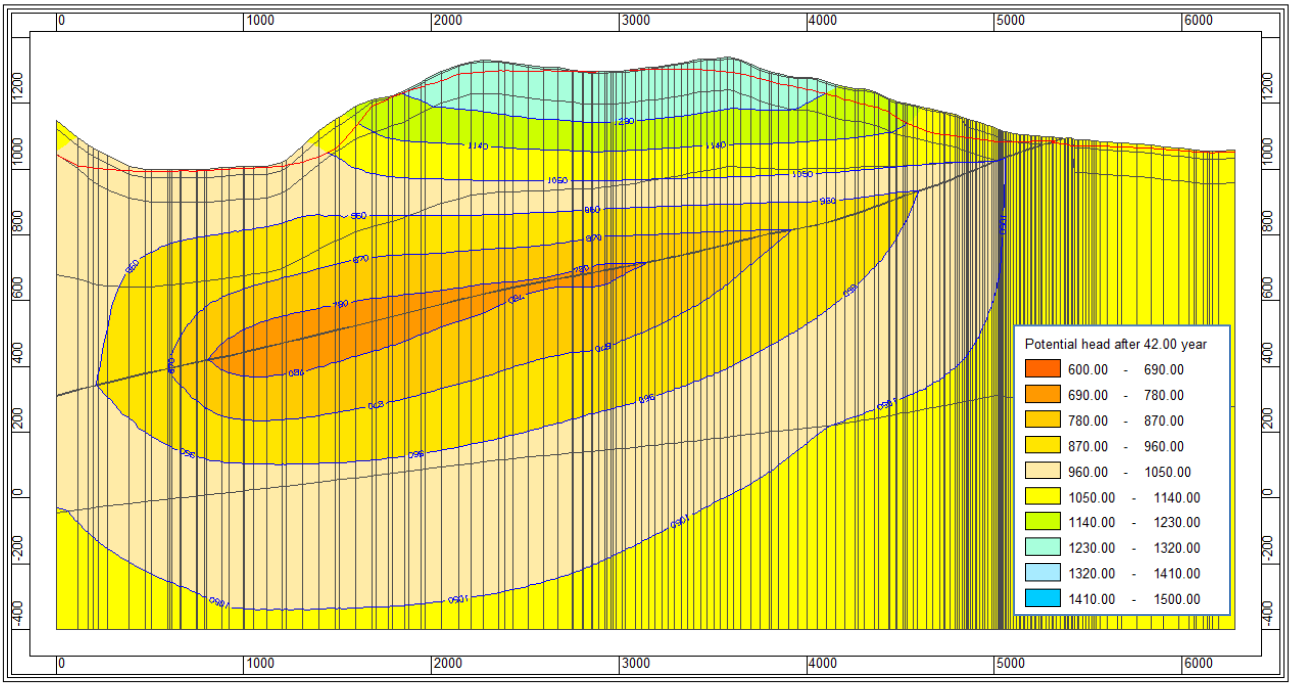


Figure 6-13: Cross section for the simulated potential head (LoM).

The cumulative impact of the North Pit and underground workings on the water level is shown in Figure 6-14. Groundwater inflows into the northern pit will necessitate continuous dewatering of the pits during life of mine. Delta-H (2014) long-term dewatering estimates was between 1.2 and 4.6 L/s while the updated cumulative model showed similar ranges of inflows of around 2.6 to 3.5 L/s (Figure 6-15). The averaged estimated inflows of around 225 m^3/d to 302 m^3/d is in range with the existing WUL (2017) (License no. 27/2/2/B741/9/9) authorised northern pit volume of 86 436 m^3/ a (or 237 m^3/d). As a result, no need for an amendment is required at this stage until further detailed mine development schedules are made available.

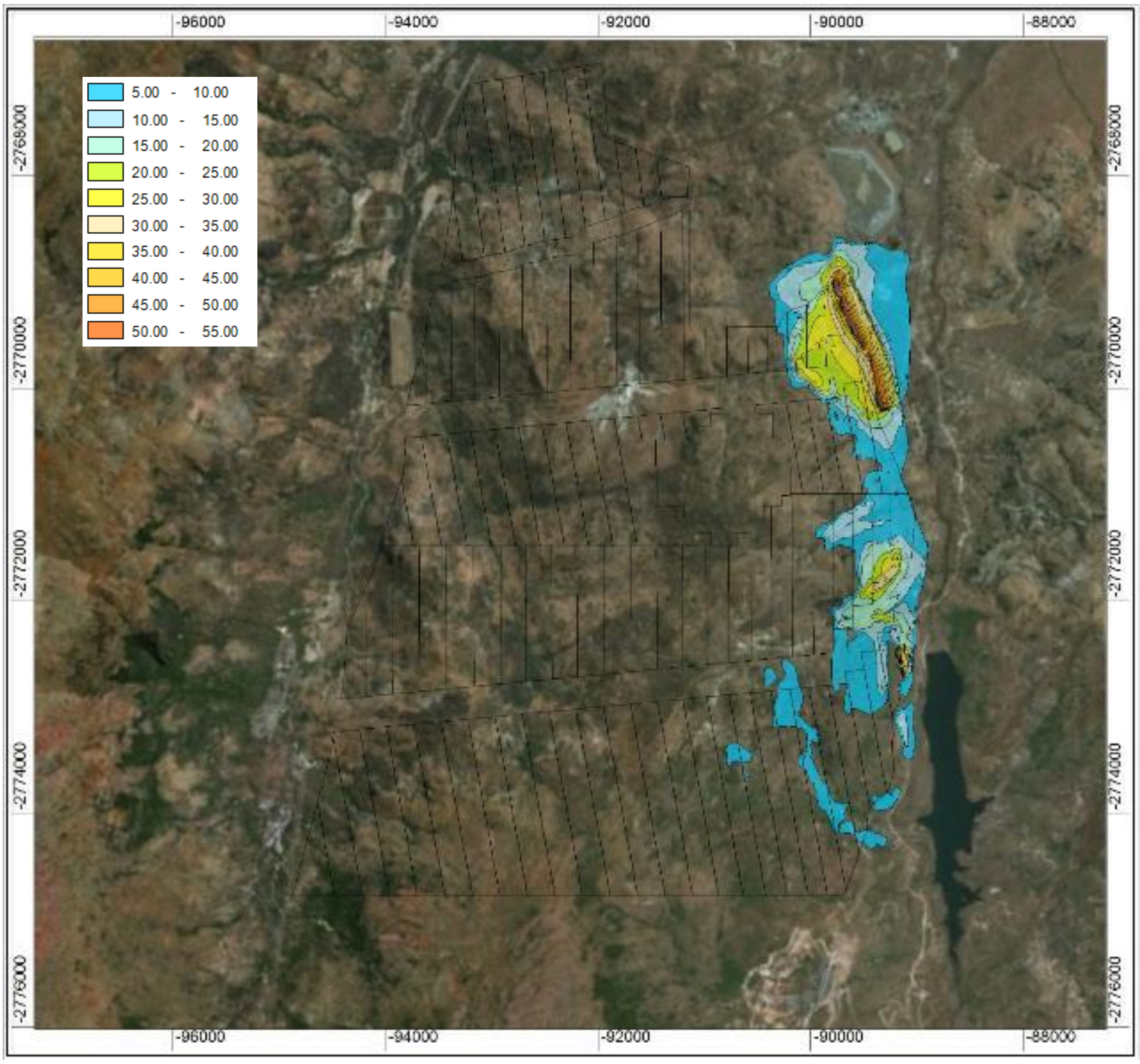


Figure 6-14: Simulated (cumulative) groundwater table drawdown in the weathered aquifer at LoM (mining areas indicated by black lines).

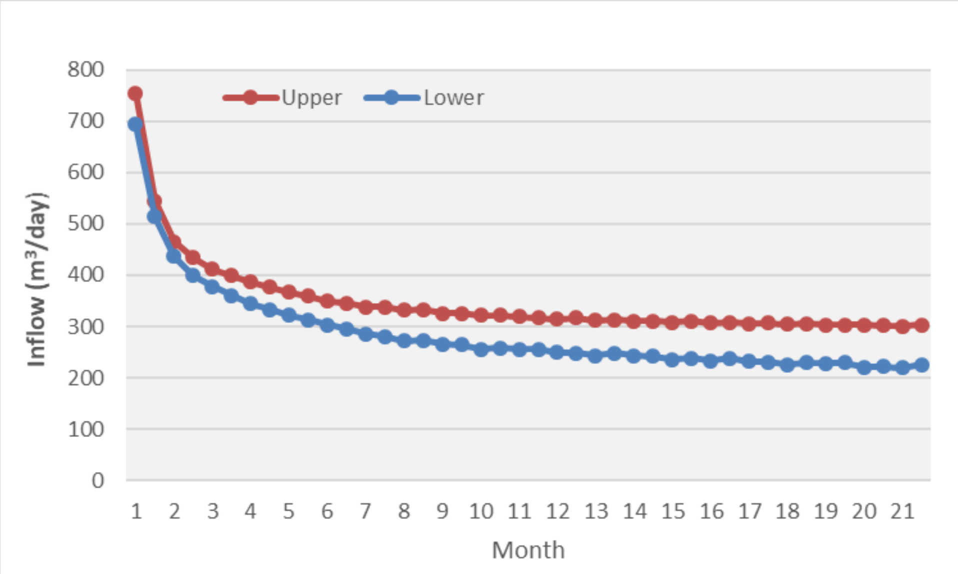


Figure 6-15: Simulated North Pit inflows.

6.5.3. Post Closure

Groundwater levels in the mining areas will start to recover or rebound once mine dewatering stops. Groundwater will start to accumulate at the lowest levels of the mining area and inundate the open mine voids over time. The previously assigned leakage boundaries for the mining areas were removed and the predictive post-closure simulation performed as a transient simulation over a period of 200 years to provide an estimation of the post-closure rebound of the water level. Using the mine area of 18.2 Mm^2, a stoping height of 2 m and a void space of 70 % (or 30% pillars), it is estimated that the Der Brochen underground mining area has approximately 25.5 Mm^3 of final void space to be flooded. Using an average inflow rate of 328 500 m^3/a into the final underground area, it can be estimated that the mining area will be flooded 77 years after mine closure. The predicted post-closure water level rebound in the shallow aquifer and the potential head of the deep aquifer are shown in Figure 6-16 and Figure 6-17, respectively.

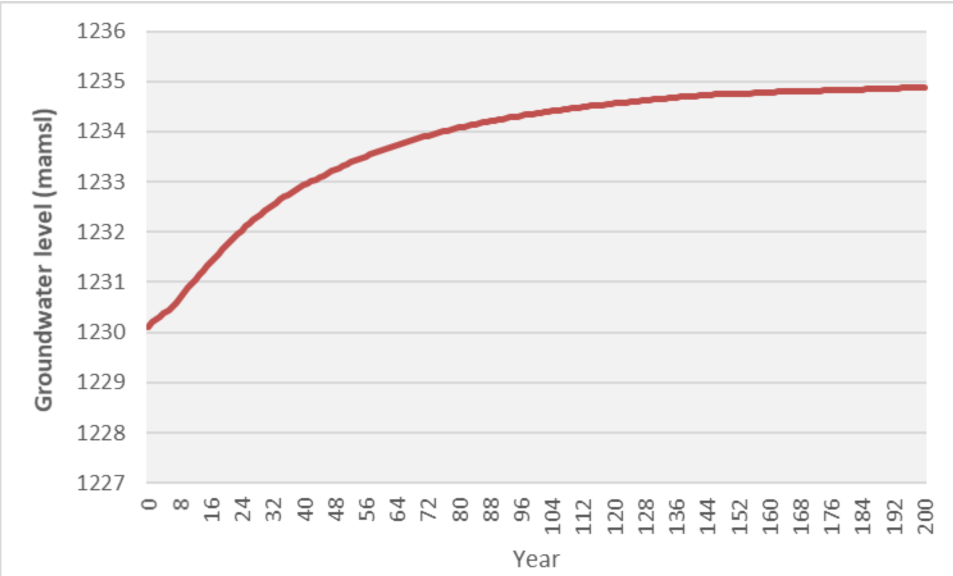


Figure 6-16: Simulated post-closure water level rebound of the upper weathered aquifer.

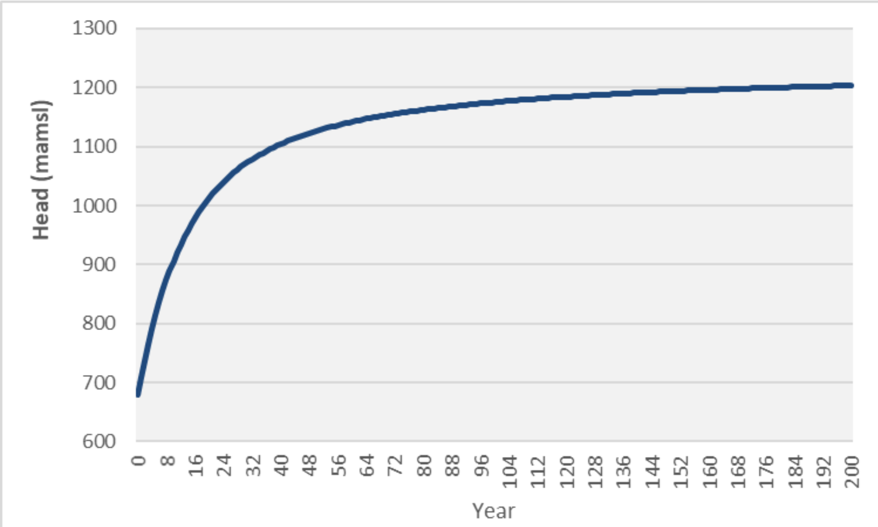


Figure 6-17: Simulated post-closure potential head rebound in the deeper fractured aquifer.

While the model simulation shows that the water level rebound within the upper weathered aquifer occur within 50 years, the recovery of the deeper aquifer's piezometric head to pre-mining levels may well be beyond 100 years once active dewatering is stopped (assuming no other changes in the environment). Although the mine floor elevation of workings is below surface, decant will be driven by the elevation of the box-cuts. Should the rebounding groundwater level in the underground area rise above the elevations of these box cuts decant can occur. The shaft portals should be sealed-off to avoid any direct surface decant from the workings.

6.6. NON-REACTIVE TRANSPORT MODEL

6.6.1. Stability criteria

In order to simulate the solute transport accurately and to comply with applicable numerical stability criteria (Courant Criteria), a time step width of 10 days was used for the predictive scenarios.

$$C_r = \left|\frac{v\Delta t}{L}\right| \leq 1$$

The geometry of the mesh can have an undesirable effect (numerical dispersion) on the simulated spreading of solutes, if the elements are too large in relation to the dispersion length. The mesh was therefore designed to comply with the Peclet criteria:

$$L < 2\alpha_l$$

v Flow velocity
Δt Discrete time step
L Longest dimension of an element in the direction of flow
α_l Longitudinal dispersion coefficient

A measure of this ratio is the Peclet number P_e, which should be less than 2 so that the proportion of the non-hyperbolic part of the transport equation dominates:

$$P_e = \left|\frac{v\Delta l}{D}\right| < 2$$

It describes the ratio of the advective part to the dispersion part (D) with respect to a characteristic length (side length of the elements, Δl). The lower the Peclet number, the less iterations are necessary to achieve a pre-defined maximum value of the residuals. Once this dimensionless number exceeds the value of 10, it is no longer guaranteed that the solution converges. An optimal discretization in space results for a Peclet number < 2.

The steady-state heads as simulated by the calibrated flow model were used for the transient transport simulations. The source concentrations of the DMS stockpile (see section 6.3.2) were implemented into the model using a second type boundary condition, i.e. specified seepage/recharge concentrations over the respective footprint areas. Different seepage/recharge rates were assigned to the DMS stockpile to simulate a lined and unlined scenario (see Table 6-2).

6.6.2. DMS Stockpile (42-year LoM)

During the operational phase of the mine DMS material will be deposited onto the stockpile. This will potentially cause vertical leakage of rainwater in contact with the material towards the underlying aquifers. The quality of this leachate will determine along with the seepage rate the impact on the underlying aquifers. DMS stockpile samples were characterised as rather benign with limited leachability of its constituents. A unit concentration of the DMS stockpile was specified as 100% using a first type boundary condition over the respective footprint areas of the stockpile area. In other words, a constant concentration of 100% was assigned to any seepage over the footprint areas and since no element specific retardation or transformation is simulated, concentrations for individual elements of concern (Table 6-5) can be easily derived by multiplying given percentages with the respective source concentration of an element. Calculated leaching rates for all metals tested suggest a low risk for metal contamination, while the salt load potential released from weathering of the material remained low during kinetic leaching. As a result, the source concentration of the DMS stockpile sample is largely within guideline limits (Table 6-5).

Table 6-5: Source percentages in relation to concentrations of constituents flagged from the leachate quality results.

Source Concentration	CrTotal	TDS	Sulphate	Al#	Fe*
100%* -	**0.17**	**186**	**69**	0.237	0.163
90%	0.15	28.5	62.1	0.213	0.147
80%	0.14	25.3	55.2	0.190	0.130
70%	0.12	22.1	48.3	0.166	0.114
60%	0.10	19.0	41.4	0.142	0.098
50%	0.09	15.8	34.5	0.119	0.082
40%	0.07	12.6	27.6	0.095	0.065
30%	0.05	9.5	20.7	0.071	0.049
20%	0.03	6.3	13.8	0.047	0.033
10%	0.02	3.2	6.9	0.024	0.016
Background Groundwater (PFS-B regional assessment)	**< 0.01**	**265**	**28**	**0.15**	**0.05**
SANS 241-1 (2015)	***0.05***	**-**	***250***	***0.3***	***2***
B41G (Groundwater Quality reserve) (2018)[8]			***11***	**-**	**-**

* - maximum leachate quality results retrieved from 20-week kinetic test
# - average of highest 3 leachate quality results retrieved from 20-week kinetic test

Unlined Scenario

Figure 6-18 shows the extent of the simulated seepage plume migration from the (unlined) DMS footprint area for Phase 1 to Phase 3 of its expansion.

- Phase 1 – The plume movement is limited in extent but predominately down-gradient towards the Groot-Dwars River.
- Phase 2 – The plume movement continues migrating down-gradient towards the Groot-Dwars River, but also starts to migrate towards the Mareesburg Stream. The plume (with a cut-off limit of 10 %) does not reach the river within this simulation time period and as a result will not impact negatively on the surface water quality of the river.

[8] Government Gazette No. 41887 NO.932 7 September 2018 – Department of Water and Sanitation

- Phase 3 – The LoM plume extends approximately 420 m down-gradient from the DMS stockpile towards the Groot-Dwars River. To the west, the simulated plume migrated approximately 100 m from the DMS stockpile. Seepage is likely to discharge into the river as groundwater baseflow, but at significantly lower volumes compared to the river interflow and rainfall-run-off component. The associated concentrations reaching the river are less than 10 % of the source concentration and are therefore unlikely to impact the water quality significantly.

Lined Scenario

Figure 6-19 shows the extent of the simulated seepage plume migration from the (lined) DMS footprint area for Phase 1 to Phase 3 of its expansion.

- Phase 1 – The plume movement is limited to the foot print area itself.
- Phase 2 – The plume starts to migrate down-gradient towards the Groot-Dwars River, but at lower concentrations and to a lesser extent compared to the unlined scenario. The plume does not reach any surface drainage system within this simulation time period.
- Phase 3 – The LoM plume extends approximately 320 m down-gradient from the DMS stockpile towards the Groot-Dwars River. To the west, the simulated plume migrated approximately 50 m from the DMS stockpile. Compared to the unlined scenario, simulated concentrations over the footprint area and further downstream are approximately 30 % lower. The plume (with a cut-off limit of 10 %) does not reach the river within the simulation time period and as a result will not impact negatively on the surface water quality of the river.

Mitigated Scenario

Figure 6-20 shows the extent of the simulated seepage plume migration from the unlined DMS footprint area for Phase 1 to Phase 3 of its expansion. The mitigated scenario accounts for the commissioning of 2 hydraulic containment (scavenger wells) to intercept the seepage plume emanating from the unlined DMS stockpile and limit its migration towards the Groot Dwars River. Pumping rates of 0.5 L/s, which is within the groundwater potential of the underlying aquifer, were assigned to each borehole.

- Phase 1 – The plume movement is limited in extent, but down-gradient migration towards the Groot-Dwars River is noted.
- Phase 2 – The scavenger wells limits the migration from DMS footprint and the simulated plume does not reach either river systems within the simulation time period.
- Phase 3 – For this phase a seepage interception trench parallel to the DMS stockpile and Mareesburg Stream was introduced for the mitigation (containment) scenario. The plume extends approximately 290 m down-gradient from the DMS stockpile towards the Groot-Dwars River. Based on the results, the trench largely limits the plume migration from the DMS stockpile towards the Mareesburg Stream. The plume (with a cut-off limit of 10 %) does not reach either river within the simulation time period and as a result will not impact negatively on the surface water qualities of the rivers.

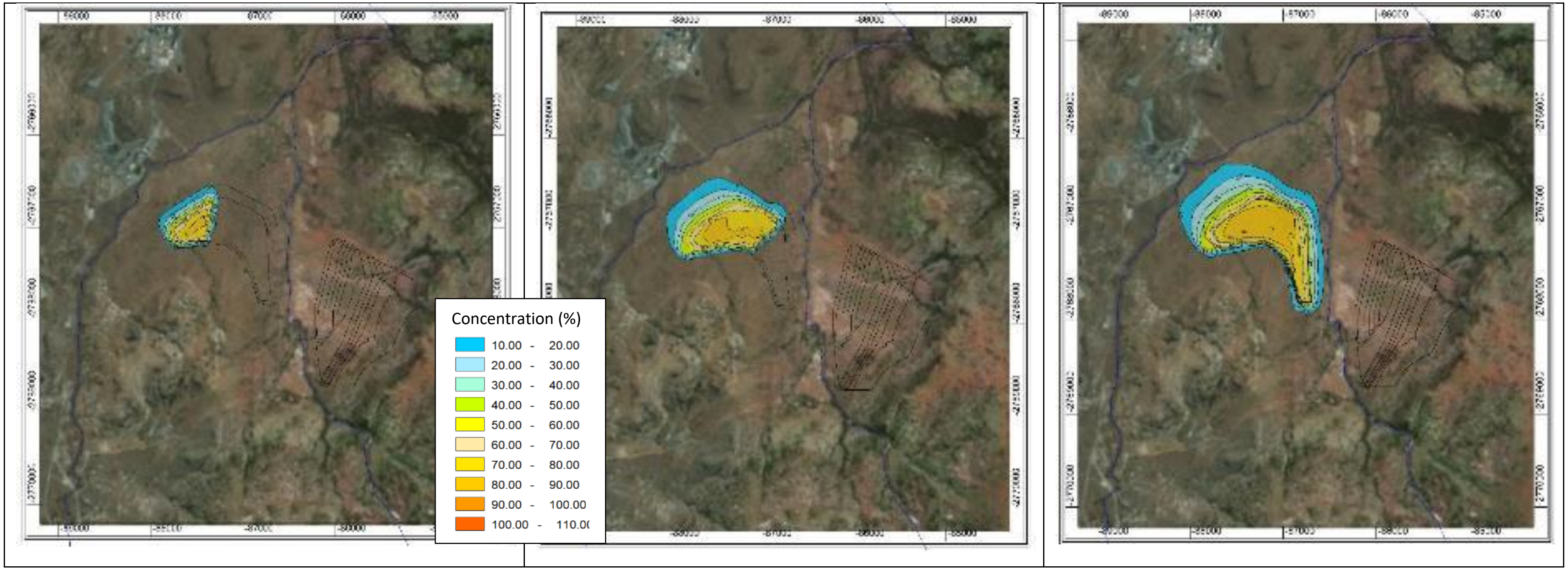


Figure 6-18: Simulated plumes for the unlined DMS stockpile scenario.

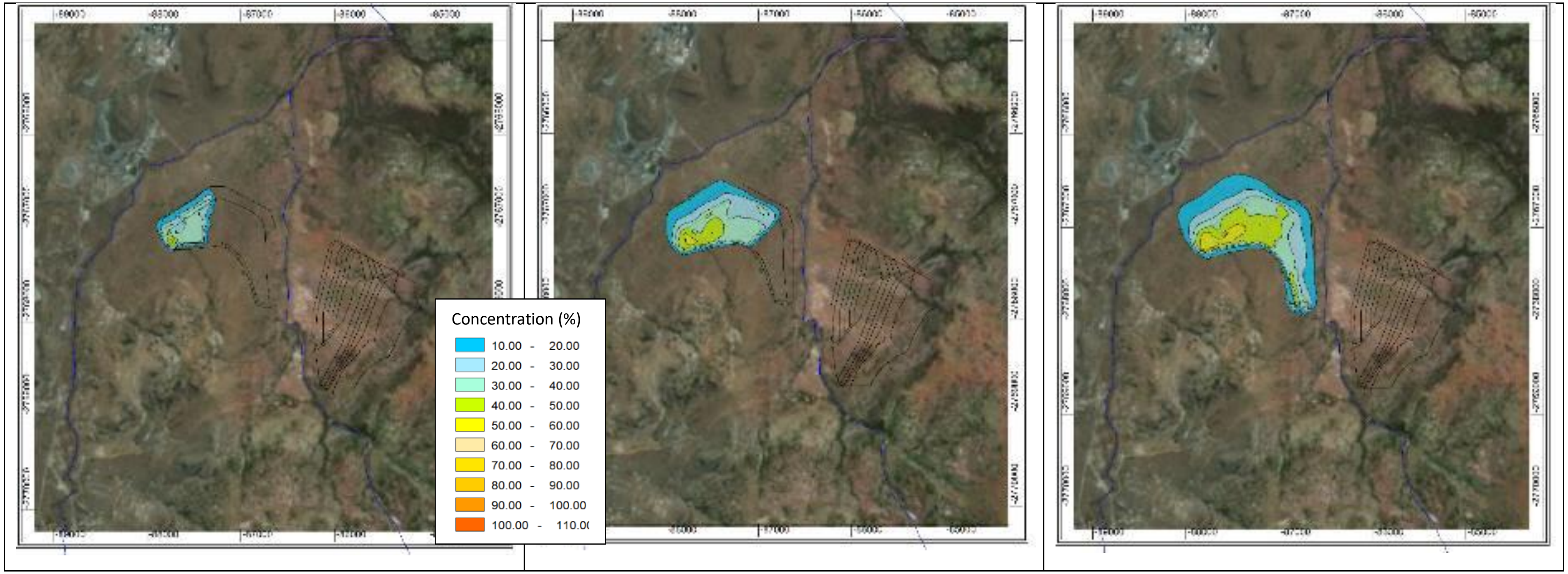


Figure 6-19: Simulated plumes for the <u>lined</u> DMS stockpile scenario.

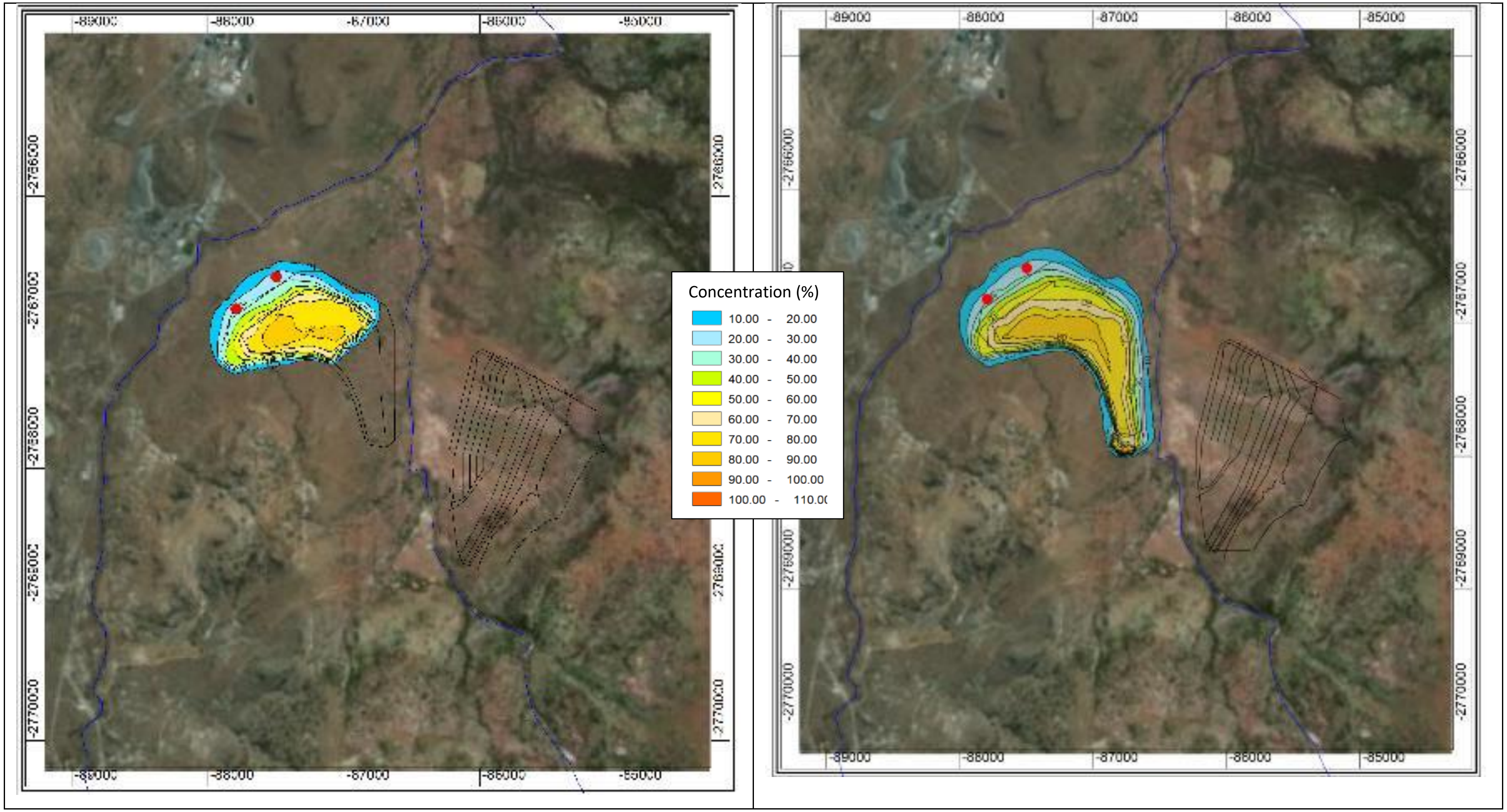


Figure 6-20: Simulated plumes for the <u>unlined interception</u> DMS stockpile scenario.

6.6.3. DMS Stockpile (post-closure)

The predictive post closure simulations are based on the following criteria:

- The DMS stockpile be covered with overburden and/or growth material and vegetated. The model simulation assumes a reduction in seepage/infiltration and quality over time.

Unlined post-closure scenario

Figure 6-21 shows the extent of the simulated seepage plume emanating from the unlined DMS 25- and 50 years post-closure. While the plume reaches the Groot-Dwars River, associated concentrations are less than 20 % of source concentrations (refer to Table 6-5) and are unlikely to impact the water quality significantly.

Lined post-closure scenario

Figure 6-22 shows the extent of the simulated seepage plume emanating from the lined DMS 25- and 50 years post-closure. While the plume migrates towards the Groot-Dwars River, the plume (with a cut-off limit of 10 %) does not reach the river within the simulation time period and as a result will not impact negatively on the surface water quality of the river.

Mitigated post-closure scenario

Figure 6-23 shows the extent of the simulated seepage plume emanating from the unlined DMS, but mitigated by hydraulic containment 25- and 50 years post-closure. The mitigated post-closure scenario assumes the cessation of hydraulic containment (pumping) at mine closure with subsequent natural attenuation of the remaining (initially contained) plume. Due to active hydraulic containment during the operational phase of the mine, the plume is limited in extent compared to the unlined post-closure simulation, but the concentration within the footprint area is on the other hand around 20 % higher compared to the lined DMS scenario.

6.6.4. Summary

The DMS stockpile may result in higher infiltration of precipitation through the stockpiles (due to increased permeabilities and reduced evaporation) and mounding of water within the stockpile, causing an increase of seepage/recharge to the groundwater system beneath and affecting the groundwater levels and flow patterns in the surrounding aquifer. The DMS material has the potential to generate elevated concentrations of several constituents of concern in contact water (leachate), and therefore the potential to negatively influence the groundwater quality beneath the stockpiles and along the downstream flow paths. However, the tested DMS stockpile samples are non-acid generating and due to limited elemental concentrations in its leachate, a low risk to the groundwater quality is expected.

Monitoring of mine effluent and seepage forms part of the Der Brochen IWWMP to assure protection of the environment. Monitoring and field testing are proposed for the early detection of potential environmental issues, allowing evaluation and, if necessary, adaptive management interventions (e.g. hydraulic containment or water quality treatment) for the DMS facility.

Box (Scavenger Horizontal Well System at Helena TSF) (example)

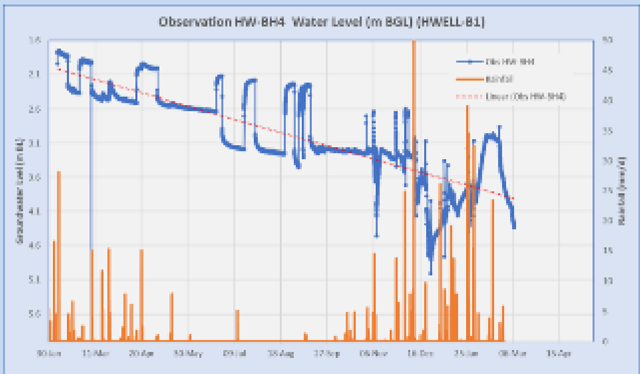
The distribution of the horizontal wells in relation to the observation/monitoring boreholes are shown in the figure below.

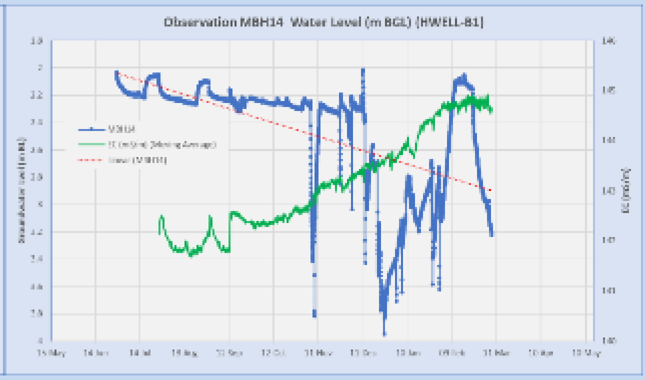
Pumping rates measured from the flow meters are shown in the table below:

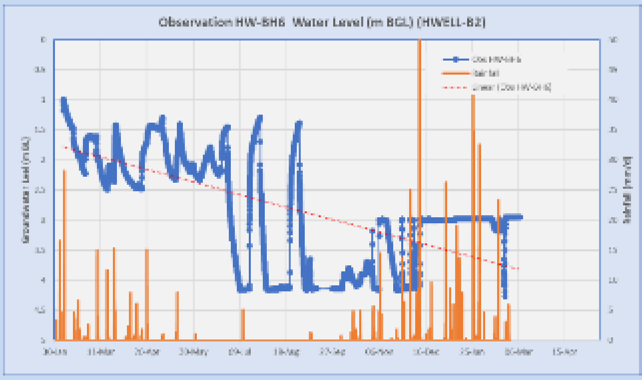
Well Number	Discharge m³/a	Discharge L/s	Commissioned	Flow rate (in L/s) (22 Feb. 2019)	Volume in m³ (since commissioning)
HWELL-B1	12 663	0.4	2018/02/06	1.1	25 280
HWELL-B2	7 330	0.23	2018/02/06	< 0.5	6 356

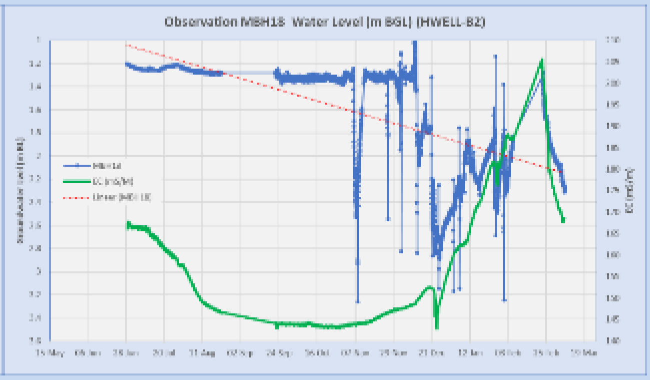
During the testing and commissioning phase continuous water level loggers were installed in the observation boreholes (HW-BH4 and HW-BH6) along the horizontal wells. These loggers have been in operation since 2 February 2018, and is used to determine the drawdown of the aquifer in the immediate vicinity of the pumping well. Level and EC logging have commenced on the 26 June 2018 from MBH14 and MBH18 with the main purpose to monitoring the effectiveness of pumping downstream of the horizontal well.

The water level retrieved from the data loggers from the four observation boreholes is shown in the figures below:









Pumping from the horizontal wells has desirable decline on the water levels as planned but requires a considerate period with optimal pumping rates to reverse the flow gradient and as a result a decrease in overall mineralisation of water qualities.

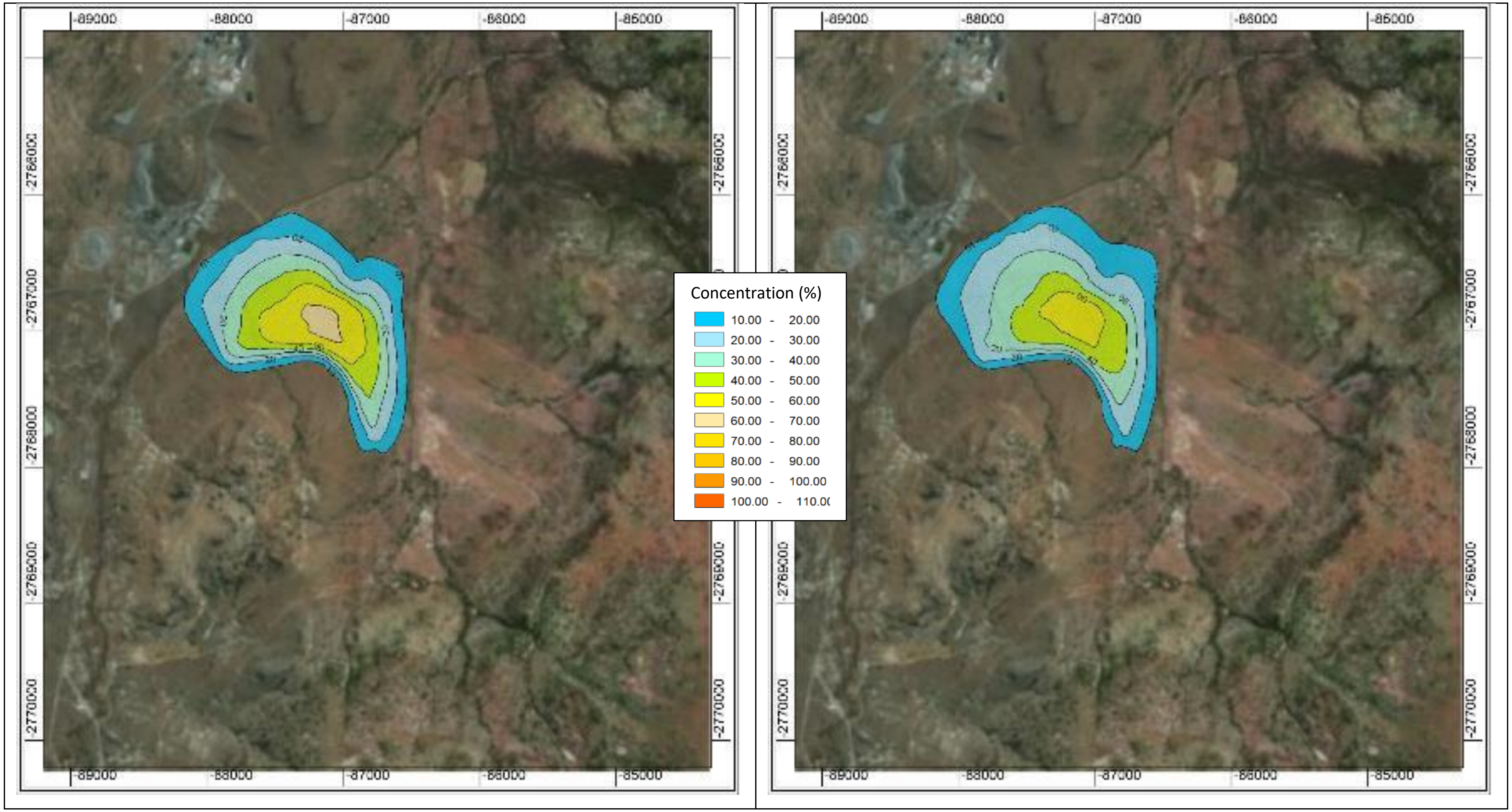


Figure 6-21: Simulated plumes for the unlined DMS stockpile 25- and 50-years post-closure.

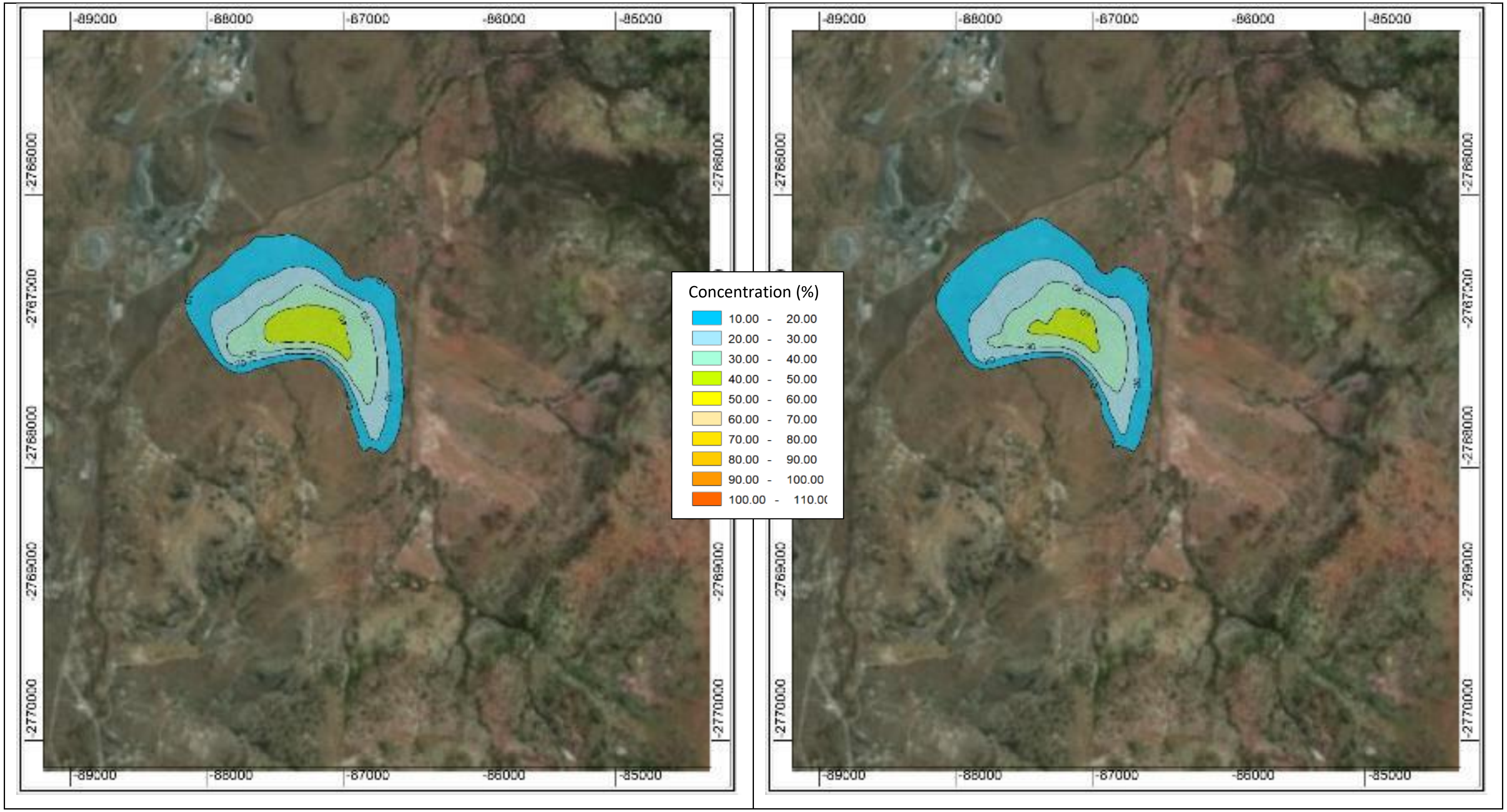


Figure 6-22: Simulated plumes for the <u>lined</u> DMS stockpile 25- and 50-years post-closure.

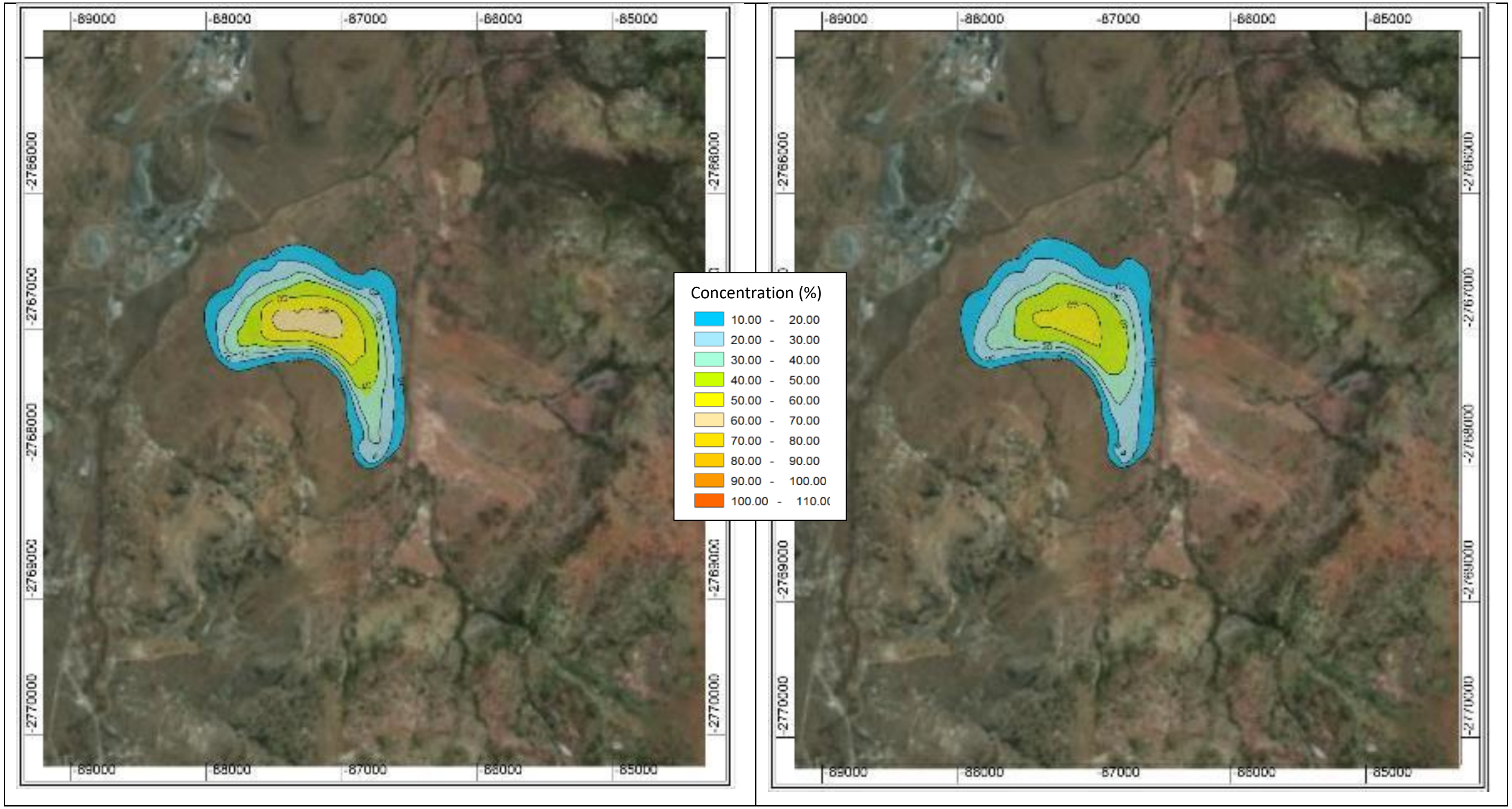


Figure 6-23: Simulated plumes for the <u>unlined interception</u> DMS stockpile 25- and 50-years post-closure.

6.7. CONFIDENCE IN MODEL PREDICTIONS

Preamble: "A decision often must address the fact that something bad may happen. We may be willing to pay a price to reduce the likelihood of its occurrence. How much we are prepared to pay depends on the cost of its occurrence and the amount by which its likelihood can be reduced through pre-emptive management. The role of modelling in this process is to assess likelihood. This must not be confused with predicting the future." (Australian groundwater modelling guidelines, Barnett et al. 2012). Delta H shares this view, specifically for long-term predictions beyond the model calibration timeframe.

6.7.1. Methodology

In the absence of other internationally accepted standards, Delta H follows the Australian groundwater modelling guidelines (Barnett et al. 2012) to distinguish the confidence-levels (Class 1, Class 2 or Class 3 in order of increasing confidence) of a model. The factors used for the classification depends foremost on

- the available data, including their spatial and temporal coverage to fully characterise the aquifer and the historic groundwater behaviour,
- the calibration procedures, including types and quality of data used as calibration targets,
- the consistency between the calibration and predictive analysis, e.g. a steady state calibration is bound to produce transient predictions of low confidence and a transient prediction is expected to have a high level of confidence if the time frame of the predictive model is of less or similar to that of the calibration model (e.g. a 25-year transient calibration period would be required for a high confidence prediction over 25 years), and
- the level of stresses applied in the predictive model in relation to the stresses included in the calibration (e.g. if a model was calibrated without major abstractions, simulations of significant abstractions or mine inflows will be of low confidence).

While a model may fall into different classes for the various criteria (data, calibration and prediction), it should be classified as Class 1 if any of the criteria fall into a Class 1 classification irrespective of all other ratings. A class 1 or low confidence model is often used for an initial assessment of a project if insufficient data are available to support a full conceptualisation of the aquifer(s) and subsequently improved to higher confidence classes as additional data from e.g. an associated monitoring programme become available.

6.7.2. Classification

In accordance with the guideline, Delta H provides a classification for each of these criteria as well as an overall model classification that reflects their importance with regard to the model objectives (Table 6-6).

Table 6-6: Criteria specific and overall model confidence level classification.

Criteria	Confidence level classification	Key indicators
Data	2	Observations and measurements are available and distributed in areas of interest Gauge data available on river flows
Calibration	1	Steady-state calibration statistics are very good, but no transient calibration performed No calibration against mine inflows was possible, as this is a proposed and not yet existent underground mine
Prediction	1	Transient predictions in excess of 10 years are made, when the model was only calibrated in steady-state
Overall	1	Two criteria fall into a Class 1, model to be updated once more data become available

While the model must formally be classified as a class 1, a 'low' model confidence does not mean that the model is not fit for purpose. A class 1 model is for example sufficient for (Barnett et al. 2012):

- Predicting long-term impacts of proposed developments in low-value aquifers.
- Understanding groundwater flow processes under various hypothetical conditions.
- Provide first-pass estimates of extraction volumes and rates required for mine dewatering.

6.7.3. Recommendations to improve Model Confidence

In order to increase the formal classification of the model confidence from Class 1 to Class 2, the following steps should be undertaken (in decreasing priority):

1. Update of groundwater ingress simulation once detailed (feasibility) mine (and box-cut) designs and profiles become available.
2. Re-calibration of groundwater flow model against observed mine inflows once new mining areas become operational.
3. Once data of water levels and concentrations of constituents of concern (downstream of the DMS and existing TSF sources) become available, a transient re-calibration of the model should be done and the model predictions reviewed.

7. GEOHYDROLOGICAL IMPACTS

7.1. Methodology

This methodology complies with Regulation 31(2)(l) of the National Environmental Management Act (Act 107 of 1998) as amended (NEMA[9]), which states the following:

(2) An environmental impact assessment report must contain all information that is necessary for the competent authority to consider the application and to reach a decision …, and must include –

(l) an assessment of each identified potentially significant impact, including –

(i) cumulative impacts;

(ii) the nature of the impact;

(iii) the extent and duration of the impact;

(iv) the probability of the impact occurring;

(v) the degree to which the impact can be reversed;

(vi) the degree to which the impact may cause irreplaceable loss of resources; and

(vii) the degree to which the impact can be mitigated.

Based on the above, the EIA Methodology will require that each potential impact identified is clearly described (providing the nature of the impact) and be assessed in terms of the following factors:

- extend (spatial scale) - will the impact affect the national, regional or local environment, or only that of the
- duration (temporal scale) - how long will the impact last;
- magnitude (severity) - will the impact be of high, moderate or low severity; and
- probability (likelihood of occurring) - how likely is it that the impact may occur.

To enable a scientific approach for the determination of the environmental significance (importance) of each identified potential impact, a numerical value has been linked to each factor. In order to comply with best practice principles, the evaluation of impacts will be conducted in terms of the criteria presented in Table 7.1.

Table 7.1: Impact assessment criteria.

Duration:	**Probability:**
5 – Permanent	5 – Definite/don't know
4 - Long-term (ceases with the operational life)	4 – Highly probable
3 - Medium-term (5-15 years)	3 – Medium probability
2 - Short-term (0-5 years)	2 – Low probability
1 – Immediate	1 – Improbable
	0 – None
Extent/scale:	**Magnitude:**
5 – International	10 - Very high/uncertain
4 – National	8 – High
3 – Regional	6 – Moderate
2 – Local	4 – Low
1 – Site only	2 – Minor
0 – None	

[9] NEMA (1998): National Environmental Management Act (Act107 of 1998)

Once the above factors had been ranked for each identified potential impact, the environmental significance of each impact can be calculated using the following formula:

Significance = (duration + extend + magnitude) x probability

The maximum value that can be calculated for the environmental significance of any impact is 100. The environmental significance of any identified potential impact is then rated as either: high, moderate or low on the following basis:

- More than 60 significance value indicates a high (H) environmental significance impact;
- Between 30 and 60 significance value indicates a moderate (M) environmental significance impact; and
- Less than 30 significance value indicates a low (L) environmental significance impact.

In order to assess the degree to which the potential impact can be reversed and be mitigated, each identified potential impact will need to be assessed twice.

- Firstly, the potential impact will be assessed and rated prior to implementing any mitigation and management measures; and
- Secondly, the potential impact will be assessed and rated after the proposed mitigation and management measures have been implemented.

The purpose of this dual rating of the impact before and after mitigation is to indicate that the significance rating of the initial impact is and should be higher in relation to the significance of the impact after mitigation measures have been implemented. In order to assess the degree to which the potential impact can cause irreplaceable loss of resources, the following classes (%) will be used and will need to selected based on your informed decision and discretion (Table 7.2):

Table 7.2: Loss of resources impact classes.

5	100% - Permanent loss
4	75% - 99% - significant loss
3	50% - 74% - moderate loss
2	25% - 49% - minor loss
1	0% - 24% - limited loss

Note: The Loss of Resources aspect will not affect the overall significant rating of the impact.

7.2. ENVIRONMENTAL ASPECTS

Impacts on the local and regional ambient groundwater environment may consist of changes in the groundwater quantity (i.e. groundwater levels), changes in the ambient groundwater quality, or both. Altered groundwater conditions will most likely impact on other aspects of the environment such as river baseflow, in-stream water quality or vegetation types (for e.g. groundwater dependent wetlands). Note: Existing approved mining infrastructure does not form part of this impact assessment.

Although the impact of surface clearing for portal (box-cuts) will be evident, no groundwater impacts during the construction phase are expected and where therefore not assessed. Groundwater impacts associated with the north pit was assessed during the groundwater impact assessment by Delta-H (2014). The portal development will be discussed as part of the operational phase. Further, contaminant prevention measures will most likely be implemented during the construction and operational phases (i.e. lining of PCDs). The PCDs are lined facilities and no significant impacts on the groundwater regime is expected from these facilities. All contaminated surface water runoff from haul road areas will be collected in the dirty water management system, infiltration of contaminated water will be minimized.

It is considered that the most significant groundwater impacts could arise from the following activities / infrastructure:

- Operational
    - Contamination of groundwater caused by spillage (i.e. hydrocarbons)
    - Influx of groundwater into north-pit and south portal decline shaft void (i.e. lowering of groundwater levels due to dewatering) (refer to section 6.5.2)
    - Change of groundwater quality due to north pit and underground mine workings (refer to section 4.4)
    - Seepage and run-off from DMS stockpile (refer to section 6.6)
    - Spillage and overflows of PCDs, stormwater management

The potential groundwater impacts identified during the operational project phase and rated according to the environmental significance is summarised in Table 7.3.

- Closure/Post-closure
    - Flooding of mine workings (groundwater quality deterioration)
        - gradual recovery of groundwater levels (refer to section 6.5.3)
        - rehabiliation of the open pit will lead to gradual recovery of groundwater levels. This will lead to the re-establishment of groundwater levels, flow directions and flow gradients to near pre-mining levels.
        - potential decant due to potential head rebound
            - The quality of this groundwater may be affected by explosives residues and other contaminants from the mining operation. However, the residues dissolve easily and once leached away in a period of years or less, no significant impacts are predicted. In addition, the leachate quality presents no risk due to the inert nature of the ore and host rocks.
    - Seepage and run-off from DMS stockpile (refer to section 6.6.3)

The potential groundwater impacts identified during the closure project phase, and rated according to the environmental significance, are summarised in Table 7.4.

Table 7.3: Risk assessment for the operation phase impacts.

Nature of the impact		Significance of potential impact BEFORE mitigation							Mitigation Measures	Significance of potential impact AFTER mitigation							degree of mitigation (%)
		Probability	Duration	Extent	Magnitude	Loss of Resources (%)		Significance		Probability	Duration	Extent	Magnitude	Loss of Resources (%)		Significance	
Operational Phase																	
Potential contamination of shallow groundwater resources due to accidental hydrocarbon or other chemical spillages, vehicles and operational activities. Spillages are commonly minor and localised.	-	2	3	2	6	2	22	Low	*Develop and maintain a Standard Operating Procedure to contain and remediate any accidental hydrocarbon or other chemical spillages. Spill kits should be made available and used in the event of a spill. Contain spillage, excavated and dispose of contaminated material/soil required at accredited disposal site. If properly contained and/or excavated quickly impacts are reversible and unlikely to occur.*	2	3	1	4	2	16	Low	27.3
Localized lowering of the water level within the shallow weathered aquifer due to dewatering of the north-pit in addition to the box-cut and shaft	-	3	4	2	4	2	30	Moderate	*No 3rd party groundwater users exist within 1Km of the Underground workings* *Continuous monitoring of water levels in monitoring boreholes in the shallow weathered aquifer* *Monitoring of piezometric head from installed piezometers for the shallow and deep aquifer (limited hydraulic connection between the shallow- and deep aquifer)* *Excess water must be pumped to the surface water storage facilities for re-use*	3	4	1	4	2	27	Low	10.0
Change of the ambient water quality due to open pit and underground mine workings	-	3	4	1	4	2	27	Low	*Geochemical results indicate that the material to be exposed is non-acid generating* *Leach test results suggest limited impacts of seepage from the exposed underground mine material* *Dewatering qualities must be measured at the transfer and pollution control dams*	3	4	1	2	1	21	Low	22.2
Change of the ambient groundwater quality due to seepage and run-off from DMS stockpile	-	3	4	2	4	2	30	Moderate	*Geochemical results indicate that the DMS material to be stockpiled is non-acid generating* *Leach test results suggest limited impacts of seepage from the DMS stockpile* *Monitoring of seepage an groundwater should be performed to assure protection of the environment* *Monitoring and field testing provide early detection of potential environmental issues, allowing evaluation and, if necessary, adaptive management interventions*	3	4	1	2	1	21	Low	30.0
Nature of the impact		Significance of potential impact BEFORE mitigation							Mitigation Measures	Significance of potential impact AFTER mitigation							degree of mitigation (%)
		Probability	Duration	Extent	Magnitude	Loss of Resources (%)		Significance		Probability	Duration	Extent	Magnitude	Loss of Resources (%)		Significance	

Table 7.4: Risk assessment for the closure phase impacts.

Post-Closure Phase																
Rebound of the water level within the shallow weathered aquifer due rebound/flooding of open pit and underground workings (potential decant)	-	3	4	2	4	2	30	**Moderate**	*Continuous monitoring of water levels in monitoring boreholes in the shallow weathered aquifer* *Monitoring of piezometric head from installed piezometers for the shallow and deep aquifer (limited hydraulic connection between the shallow- and deep aquifer)* *Seal off box cuts* *Polluted decant water must be pumped to the surface water storage facilities until within accepted discharge qualities*	1	4	1	2	2	7	**Low**	76.7
Impact on groundwater quality due to the flooding of mine workings	-	3	4	1	4	2	27	**Low**	*Sealing of shafts should be considered to (isolate certain areas if needed)* *Geochemical results indicate that the material to be exposed is non-acid generating* *Leach test results suggest limited impacts of seepage from the exposed underground mine material* *Post-closure monitoring of water qualities until acceptable levels have been reached*	3	4	1	2	1	21	**Low**	22.2
Impact on groundwater quality due to seepage and run-off from DMS stockpile	-	3	4	2	4	2	30	**Moderate**	*Geochemical results indicate that the DMS material to be stockpiled is non-acid generating* *Leach test results suggest limited impacts of seepage from the DMS stockpile* *Post-closure monitoring of seepage and groundwater qualities until acceptable levels have been reached* *Monitoring and field testing provide early detection of potential environmental issues, allowing evaluation and, if necessary, adaptive management interventions*	3	4	1	2	1	21	**Low**	30.0

8. GROUNDWATER MONITORING

The initial groundwater monitoring points listed in Table 7 of the April 2011 WUL (16/2/7/8400/C100/1) related to the Richmond and Helena wellfields (refer to Appendix D). Specification to the frequency of monitoring was not set specific for the list. The updated WUL of March 2016 (04/841G/Cl/4141) included the Helena Tailings Storage Facility (TSF) monitoring boreholes (Table 5 of WUL) with a specified quarterly sampling/analysis frequency (Appendix D). The amendment of WUL April 2011 issued in May 2016 (B07224) substituted (WUL Table 7) with the reduced number of monitoring points and specified monitoring type (i.e. water level or quality) (refer to Appendix D) for the Richmond and Helena wellfields. The recent Water Use Licence (WUL) of May 2017 (Licence Number: 06/B41G/ABFGGIJ/5329) included a number of new points (Table 8 of the WUL) based on the Environmental Impact Assessments (EIA) for the Der Brochen Project in 2014. The list comprises of 80 existing boreholes and 10 proposed boreholes to monitor future authorised infrastructure (i.e. open cast and Mareesburg TSF) (Appendix D).

The current Der Brochen (including the Mareesburg TSF and Helena TSF) groundwater monitoring points have been reviewed and correlated with the issued WULs and amendments (2011, 2016, 2017). It must be noted that the future WUL amendment should clearly list groundwater level monitoring boreholes and groundwater quality (and groundwater level) monitoring boreholes to prevent unnecessary sampling points. The Der Brochen reviewed and proposed amendment to the WUL is added to Appendix D.

9. GROUNDWATER MANAGEMENT (RECOMMENDATIONS)

9.1.1. Predicted Impacts from facility (mining)

The environmental impacts associated with the mine are discussed in chapter 7.

9.1.2. Mitigation measures

Selected management and mitigation measures are summarised below:

- From a water loss point of view, it is recommended that alternative means of containing the seepage from below the DMS be investigated during the feasibility stage and be incorporated into the risk study. The losses are not as substantive as in the TSF and alternative measures to intercept and contain the groundwater plume may be beneficial. These should entail a simplified (in comparison to a class C liner) liner system, interception trenches and/or scavenger boreholes.
- During the operational phase, mine water must be re-used or pumped to dirty water dams or pollution control facilities in order to avoid deterioration of the mine water quality.
- Monitoring of mine effluent and seepage should be performed to assure protection of the environment. Monitoring and field testing provide early detection of potential environmental issues, allowing evaluation and, if necessary, adaptive management interventions
- It recommended that the numerical model and geochemical study is updated biennially during the life of the mine in order to validate its results and to inform effective water management and closure planning.

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APPENDICES

Appendix A – Hydrocensus Info.

Date	ID	Brief Description	Notes/Photograph
22/09/18	HE01	Borehole	
22/09/18	HE02	Borehole	
22/09/18	HE03	River	
22/09/18	HE04	Borehole	Not possible to access borehole housing due to it being locked and the farm worker not being able to open it.
22/09/18	HE05	Stream	Stream sample was obtained because it was not possible to obtain a groundwater sample in the area. 

Date	ID	Brief Description	Notes/Photograph
22/09/18	HE06	Stream	
22/09/18	HE07	Borehole	Borehole was locked; not possible to obtain sample.
22/09/18	HE08	Stream	Elevation is that of the bridge.
22/09/18	HE09	River	
23/09/18	HE10	Borehole	Borehole was welded closed to prevent theft of pump. Will be necessary to drill hole through steel plate to allow for dipping to determine groundwater level.
23/09/18	HE11	Reservoir	Above ground reservoir
23/09/18	HE12	Borehole	Old exploration borehole labelled SD1.
23/09/18	HE13	Borehole	Old borehole on abandoned farm house. Borehole blocked at 1.39 m bgl.
23/09/18	HE14	Stream	No boreholes in the area. Local farmer stated that water in area obtained from fountains.
23/09/18	HE15	Borehole	Abandoned borehole on old farm house. 

Date	ID	Brief Description	Notes/Photograph
23/09/18	HE16	Stream	No boreholes in the area. Stream popular with cows. 
23/09/18	HE17	Borehole	Borehole on site of Old Miner Inn Accommodation.
23/09/18	HE18	Borehole	Recently drilled exploration borehole. 
23/09/18	HE19	Stream	
23/09/18	HE20	Stream	Possibly stagnant water.

Date	ID	Brief Description	Notes/Photograph
			
23/09/18	HE21	Borehole	Borehole pumping at time of visit therefore no groundwater level obtained. 
23/09/18	HE22	Borehole	Borehole could not be accessed as it was covered with a heavy concrete block. 
28/09/18	HE23	Borehole	Old borehole. Stagnant water. Brown colour.
28/09/18	HE24	Stream	Outside of catchment but samples as it was not possible to gain access into the target area.
28/09/18	HE25	Borehole	Borehole on mine site land. Not accessible.
28/09/18	HE26	Fountain	Fountain excavated into the hillside. Approximately 2 m below general ground level. Providing water to farm. Farm owner noted that they used to have a borehole but after "others" sampled it the borehole was backfilled with mud for some unknown reason.

Date	ID	Brief Description	Notes/Photograph
28/09/18	HE27	Stream	Stream leading to a small dam.
17/09/18	DIDI-BH1	Borehole	Boreholes next to small dam at hill top. Borehole equipped with submersible pump. Provides water supply to the Didingwe Lodge during summer rainfall months as back up. 
17/09/18	THORN BH1	Borehole	Borehole is equipped with submersible pump. Supply groundwater to Thorncliff Guesthouse. Groundwater is pumped to a 10 000L tank. (Sampled) 
17/09/18	THORN BH2	Borehole	Unequipped borehole next to stream.

Date	ID	Brief Description	Notes/Photograph
			
17/09/18	THORN BH3	Borehole	Equipped with submersible pump. Borehole was in use during site visit. Used for domestic and gardening purposes. (Sampled) 

APPENDIX B –LABORATORY CERTIFICATES INFO

APPENDIX C – GEOCHEMICAL CLASSIFICATION

Appendix D – Groundwater Monitoring Programme