Environmental Management Assistance (PTY) Ltd.

BCR Minerals – Groundwater Impact Assessment

Project Number: Delh.2015.045-1

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1. INTRODUCTION

1.1. STUDY OBJECTIVE

Delta H (Delta-H Water System Modelling PTY Ltd) was appointed by Environmental Management Assistance (PTY) Ltd. on behalf of BCR Minerals (PTY) Ltd to conduct a groundwater assessment for a new open cast Chrome mine in the Steelpoort area, collectively called Spitsvale Project (SPV). It is understood that the mine recently commenced with exploration activities and is in the process of applying for a mining right, hence the requirement of a groundwater specialist study for the EIA and scoping study. The application is for a Mining Right over portions 24, 25, 26 and 28 of the farm Spitskop 333 KT and portions 8 and 22 of the farm Kennedy's Vale 361 KT. BCR Minerals recently acquired also a portion of portion 22 of the Farm Kennedy's Vale 361 KT from Rhodium Reefs Limited. The Life-of-Mine is dependent on the production rate that can be applied. If a rate of 360 000tpa ROM is maintained, the life of mine is estimated to about 35 years.

The groundwater study, initiated in October 2015, involved a hydrocensus and sampling of selected boreholes aimed at identifying potential groundwater users and to determine the status quo of the groundwater systems prior to mining. A site specific numerical groundwater flow model was developed based on available and determined aquifer parameters in order to:

- Estimate expected groundwater flow rates into the opencast mine workings during life of mine (to feed into overall water balance for the site).
- Investigate the impacts of mine inflows on the surrounding aquifers.
- Evaluate the potential impacts of mining operations (e.g. stockpiles) on the ambient groundwater quality.

1.2. DATA SOURCES

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

- Regional and local geological maps.
- Digital elevation model based on a 25 m x 25 m grid (National Geo-spatial Information (NGI)).
- Groundwater elevation data collected as part of this project in the vicinity of the open cast (Hydrocensus - October 2015).
- Regional groundwater level data from the National Groundwater Archive maintained by the Department of Water Affairs and earlier studies in the area.
- Inorganic chemical analysis of ten groundwater samples taken from production and other ad-hoc boreholes.
- Literature obtained from existing mining and related impact reports of the greater Steelpoort Valley.

2. GENERAL SETTING

2.1. Locality and Topography

BCR Minerals is situated on portions 24, 25, 26 and 28 of the farm Spitskop 333 KT and portions 8 and 22 of the farm Kennedy's Vale 361 KT in the Sekhukhune District, north of Tweefontein Chrome Mine and south of Spitzkop Platinum Mine (Figure 1). The BCR Minerals study area is located approximately 4 km south from the R555 and "Tweefontein" road intersection and approximately 17 km south west from Steelpoort. BCR Minerals lies on the north-western slopes of the foothills of the Schurinksberg and is situated in the primary catchment of the Olifants River. Locally, the site drains towards the Steelpoort River through various unnamed tributaries that originates in the surrounding mountains and hills. The relief changes by more than 600 m from the Steelpoort River (~ 750 metre above mean sea level) to the edge of the quaternary drainage (B41J) surface water divide (~ 1600 mamsl). These elevated areas slope steeply down to the flatter areas where the proposed Spitskop Mine infrastructure will be located.

2.2. Climate

The region is characterised by semi-arid temperatures with dry, warm winters and hot summers. Rainfall occurs mainly in summer, (i.e. October to April). A rainfall station operated by the Department of Water and Sanitation (DWS) is located at the Buffelskloof area, approximately 15 km southeast from BCR Minerals. The minimum, maximum and median monthly rainfall values for the Buffelskloof rainfall station data is presented in Table 1, while the rainfall trends are illustrated in Figure 2.

Table 1: Summary of rainfall data observed at Buffelskloof station.

Station Number	Coordinates (WGS1984)		Station	Date recorded	Annual Rainfall (mm/yr) *(and evaporation)*		
	Lat.	**Long.**			**Min.**	**Max.**	**Median**
B4E003	-24.9583	30.26367	Buffelskloof	1971 – 2015	321 *(921)*	2391 *(2621)*	701 *(1730)*

The mean annual rainfall varies between 321 mm/yr to about 2391 mm/yr (extraordinary high rainfall years in 2005 and 2006) with an average rainfall of 701 mm/yr. The mean annual evaporation varies between 921 mm/yr to about 2621 mm/yr with an average evaporation of 1730 mm/yr. In comparison, based on the Groundwater Resource Assessment (GRA II) data from the Department of Water and Sanitation (DWS) and Water Research -Commission (WRC), the mean annual precipitation is approximately 598 mm per year.

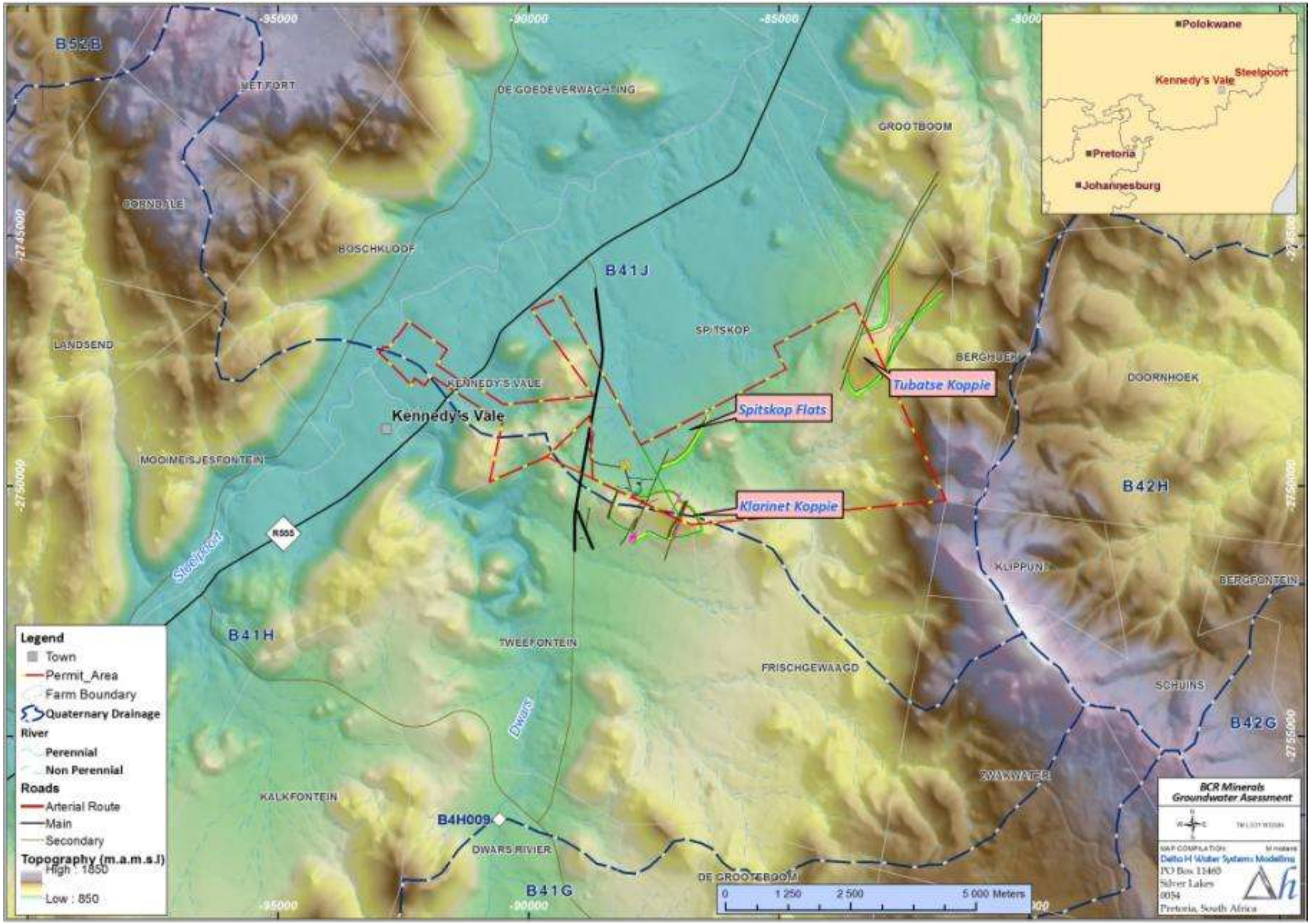

Figure 1: Locality Map of BCR Minerals.

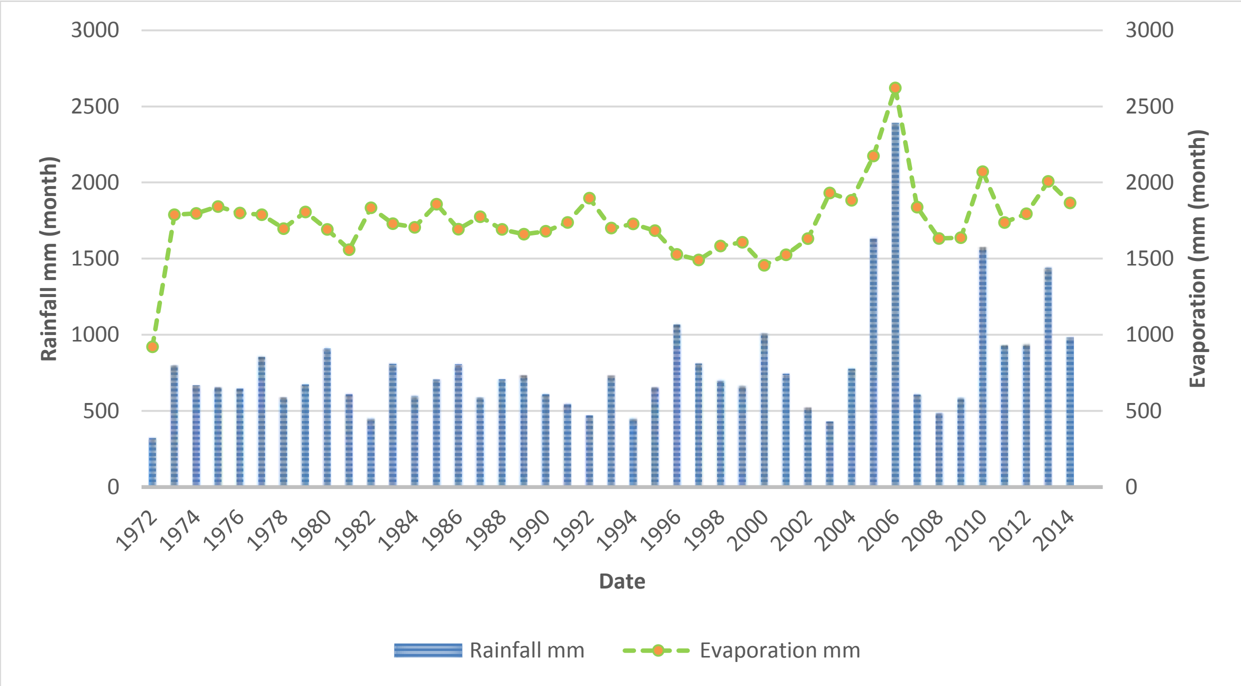

Figure 2: Rainfall and evaporation trends observed at Buffeslpoort Dam weather station.

2.3. GEOLOGY

The description of the geology is based on the existing knowledge and literature of the region as well as on the BCR Minerals Exploration Geology Report (McQuade, 2015).

The BCR Minerals mining area is underlain by the Rustenburg Layer Suite / Dwars River rocks of the Archaean age Bushveld Igneous Complex and lies south of the Steelpoort Fault trending in a northeast-southwest direction. The Bushveld Igneous Complex overlies the Transvaal Supergroup's Pretoria Group. Younger cover rocks (quaternary sedimentary deposits) occur throughout the area (Figure 3).

2.3.1. Bushveld Igneous Complex (BIC)

The Bushveld Igneous Complex (BIC) formed as massive crustal emplacements of predominantly mafic intrusive and extrusive rocks and comprises of suites of layered mafic complexes and sills that intruded the floor rocks of the Transvaal Supergroup. The BIC is divided into the Rustenburg Layered Suite, Lebowa Granite Suite, Rashoop Granophyre Suite and Rooiberg Group. BCR Minerals is underlain by rocks of the Rustenburg Layered Suite (BIC).

2.3.1.1. Rustenburg Layered Suite

The Rustenburg Layered Suite comprises rock types ranging from dunite, pyroxenite, norite, gabbro and anorthosite to magnetite and appatite rich diorite, demonstrating a complete differentiation sequence for basic magma. The Rustenburg Layered Suite is subdivided into different limbs and(or) zones, i.e. the Eastern Limb, Western Limb and Northern Limb with each limb further sub-divided into the Upper Zone, Main Zone, Critical Zone, Lower Zone and Marginal Zone. The limbs and zones are based on geographical location and stratigraphic /lithology units respectively. The farms associated with BCR Minerals are located in the Eastern Limb with associated rock units from the Main Zone and Critical Zone.

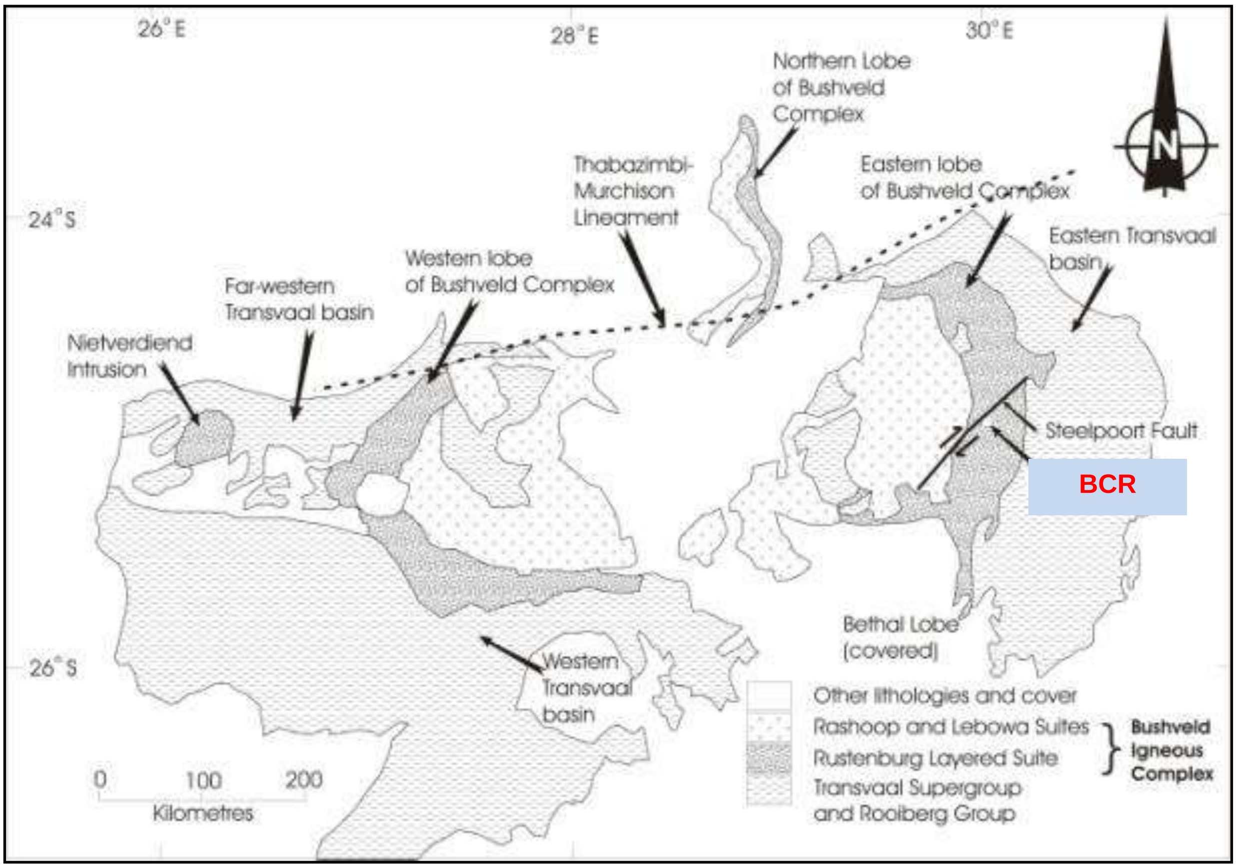

Figure 3: Approximate location of BCR Minerals and the Steelpoort Fault within the Bushveld Igneous Complex..

The Main Zone consists of medium-grained norite with minor pyroxenite. The rocks contain variable amounts of quartz and biotite. The Lower Zone consists of pyroxenite and olivine bearing rocks, such as Bronzinite and Harzburgite. The Critical Zone, known for its chromite deposits, consists of layered chromite, pyroxenite, norite and anorthosite. The Main Zone is a thick succession of norite and gabbronorite with minor anorthosite and pyroxenite layers. The BCR Minerals target area is underlain by rocks of the Lower Critical and Upper Critical Zones within the BIC, consisting of chromitite, pyroxenite, norite, anorthositic notire and mottled anothosite. The local geology associated with the BCR Minerals targeting the Critical Zone dips at 8° to 14° southwest.

The eastern margin of the study area is underlain by steeply dipping (floor) Pretoria Group sediments distributed around a north-south striking Steelpoort anticline. The Dwars River fragment in the southwest corner of the area is a floor inlier characterised by outcropping Steenkampsberg quartzite. The fragment probably represents a horst block of floor rocks with faulted contacts. Folding of quartzites and metamorphosed shale units occur on a variety of scales.

2.3.2. Transvaal Supergroup

The Transvaal Supergroup formed during the late Archaean to early Proterozoic eons and is preserved within three structural basins on the Kaapvaal Craton, one of which is the Transvaal and Griqualand West Basin. As described by Barnard (2000) and Foster (1984), this sequence consists mostly of volcanic rocks such as lava, tuff, andesite, basalt and rhyolite and sedimentary rocks which include quartzite, sandstone, shale, conglomerate and dolomite. Diabase sills and dykes form part of the Transvaal sequence as well. The Transvaal Supergroup underlies the Bushveld Igneous Complex.

2.3.2.1. Geological structures (faults and dykes)

The Steelpoort Valley is occupied by a large-scale NE-SW to NNE-SSW striking fault zone, known as the Steelpoort Fault, with up to 10 km of apparent right-handed faulting has occurred. The Steelpoort fault running the length of the Steelpoort Valley is found approximately 7 km north of BCR Minerals. The fault formed a fault zone ranging from 200-250 m in width and is likely to affect groundwater flow in the region. The presence of Steelpoort Fault splays have been interpreted from exploration boreholes, and show that the faults generally strike NE, NW and NNE, which may reflect imposed shear (Figure 4).

The Spitskope and Kennedy's Vale farms are intruded by several dolerite dykes, expected to be of several ages from the Waterberg and the Karoo Supergroup. These dykes are generally steeply dipping and have varying thickness but do not seem to exceed 20 metres in thickness.

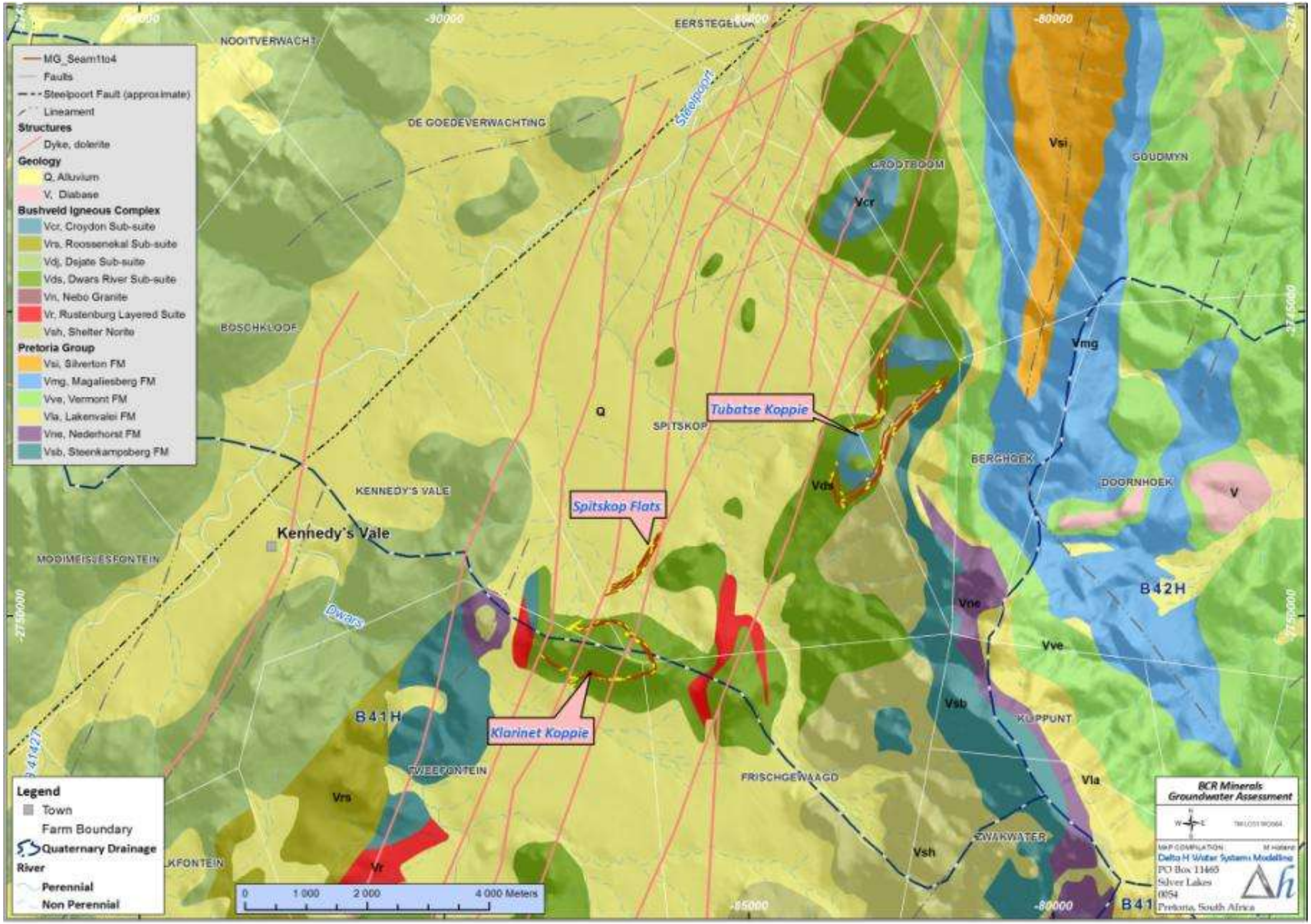

Figure 4: Regional geological map of BCR Minerals.

3. CONCEPTUAL MODEL

3.1. HYDROCENSUS

A (borehole) hydrocensus was initiated on the 19th of October 2015 to assess local groundwater levels and groundwater quality within the vicinity of the BCR Minerals study area. The hydrocensus identified borehole locations, status, depth, water levels, distribution, uses and owners. A total of 21 boreholes were visited in the field while ten water samples, including one surface water sample at an unnamed tributary were taken. The water samples were analysed for major and trace elements to provide an evaluation of the ambient groundwater quality that serves as a baseline for current and future groundwater developments. A summary of the boreholes identified is summarised in Table 2 and shown spatially in Figure 5. Photographs of the boreholes visited are given in appendix A. According to the limited water level measurements (nine water levels) the groundwater levels range from 7 metres to around 33 metres, with an average water level of 23 metre below ground level (mbgl). Some of these water levels reflect pumping water levels (Table 2).

Table 2: Summary of borehole hydrocensus.

Name	Latitude	Longitude	Elevation	Owner	Geomorphology	Geosite details	Water level (mbgl)
BCRSW1*	-24.8446	30.1553	916	Bushveld Chrome Mine	Valley Bottom	River	
BCR01	-24.8433	30.1549	830			Unequipped	
BCR03*	-24.8480	30.1292	891		Gently undulating surface	Equipped, in use	
BGR02	-24.8453	30.1549	843		Valley Bottom	Equipped, hand pump	
BH01*	-24.8684	30.1177	924	Industrial Steel	Gently undulating surface	Equipped, in use	
BH0	-24.8678	30.1154	939			Unequipped	32.62
BH03	-24.8749	30.1113	907	Chrome Valley Lodge	Low gradient hill slope	Equipped, not in use	25.64
BH04*	-24.8780	30.1090	886		Valley Bottom	Equipped, in use	
BH05	-24.8786	30.1140	895			Unequipped	
BH06	-24.8787	30.1141	893			Equipped, not in use	
BH07*	-24.8445	30.1209	890	Pierre Joubert	Low gradient hill slope	Equipped, in use	26.4
BH08*	-24.8680	30.1230	932	Sentula	Gently undulating surface	Equipped, in use	
BH09*	-24.8846	30.1532	1021	Private		Equipped, in use	
BH10	-24.8852	30.1525	1020			Unequipped	blocked
BH11	-24.8853	30.1487	1007			Equipped, in use	13.88
BH12*	-24.8663	30.1177	930	Jaco Malan		Equipped, not in use	20.57
BH13	-24.8653	30.1172	922			Equipped, in use	
BH14	-24.8665	30.1170	925			Equipped, in use	22.84
BH15	-24.8662	30.1166	925			Unequipped	24.08
DCM01*	-24.8432	30.1550	828	Community	Valley Bottom	Equipped, in use	
TWFBH01*	-24.9032	30.1076	896	Tweefontein Mine (Samancor)		Unequipped	8.23
TWFBH02	-24.8880	30.1118	887			Unequipped	6.85

* - Sample taken

The BCR Minerals study area users are supplied by both groundwater and a dedicated raw water pipeline for water use. Groundwater users range from small scale rural domestic use to larger scale domestic use at industrial and mine sites. A number of groundwater users were identified and are summarised below:

- BCR Minerals use one borehole, BCR03, for domestic water supply. The borehole is located within the mine office area. A second borehole (BH COMSUPPLY01), located approximately 2.6 km east of the mine office, supplies a community and school towards the east. Two boreholes in close vicinity of borehole DCM01 are equipped but not functional. Borehole BCR01 is blocked and borehole BCR02 is equipped with a broken hand pump. Two groundwater samples were collected from boreholes BCR03 and DCM01. One surface water sample was collected at an unnamed tributary flowing thought the mine lease area.

- Industrial Steel Park, located approximately 2.5 km southwest of BCR Minerals has two boreholes. One borehole, BH01 is currently equipped and in use, supplying the whole Industrial Steel Park with water for domestic, gardening and industrial use. The second borehole, BH02, is unequipped. Borehole BH01 was sampled for analysis.
- Chrome Valley Lodge is 3.5 km south west from BCR Minerals. A number of boreholes were identified at Chrome Valley Lodge. Two boreholes are currently in use and supply groundwater to the lodge for domestic and gardening use. A water level of 25.64 m bgl was recorded at borehole BH03. One groundwater samples was collected at Borehole BH04.
- Some minor groundwater users are scattered throughout the BCR Minerals Study, representing mostly private groundwater use for domestic and gardening purposes.

3.2. AQUIFER SYSTEMS

The geology of the BCR Minerals study area is characterised by the mafic rocks (pyroxenite, norite and anorthosites) of the Rustenburg Layered Suite of the Bushveld Igneous Complex. The rocks are overlain by weathered material, hillwash and alluvial deposits. Accordingly, the following aquifer systems can be distinguished for the area of interest:

- A shallow weathered aquifer
- An alluvial aquifer system replacing or overlying the weathered aquifer in the vicinity of river courses
- A deeper fractured aquifer system within the Bushveld Igneous Complex.

The shallow unconfined or water table aquifer is generally found in the regolith/saprolite (formed as a result of intensive and in-situ weathering processes) to saprock (differentially weathered and fractured bedrock underlying the saprolite) zone (Figure 6). The saprolite zone is poorly developed or absent on hill tops or mid-slopes but increases in thickness towards the valley bottom due to hill wash sediments adding to the weathering thickness along with the occurrence of deeper and more intense weathering along the drainage channels. The saprolite (where present) and saprock are treated as a single weathered aquifer unit, referred to as the weathered overburden. The weathered overburden (referring here mainly to the saprolite) is considered to have low to moderate transmissivity but high storativity.

Along the reaches of the Dwars- and Steelpoort River and some unnamed tributaries, the weathered aquifer is replaced or overlain by alluvial sediments creating a distinct intergranular aquifer. The alluvial and weathered sediments are in good hydraulic contact, as well as interacting and contributing to the river baseflow and are regarded as one aquifer system.

Outcropping along the hill tops and in the mid- and upper slopes of the valleys, and underlying the overburden/weathered aquifer is fresh bedrock (Bushveld pyroxenite, norites and anorthosites, as well as local diabase/dolerite dykes). Crystalline material are characterised by an unweathered rock matrix with negligible matrix porosity and permeability, and planes of discontinuity in the rock matrix, including both faults, joints and other geological contact zones (for the sake of simplicity collectively referred to as fractures). These fractures are often filled by precipitates from late phase fluids. The intact bedrock has a very low matrix hydraulic conductivity and its effective hydraulic conductivity is determined by fractures and mine openings. Groundwater flow through interconnected fracture systems allow potentially for vertical groundwater flow from the weathered overburden as well as surface water bodies to greater depths. Although it's expected that permeability would decrease significantly with depth in the bedrock aquifer, groundwater occurrence at greater depths (~ 150 m) may be associated with regional structures. The permeability and water encountered at this depth however is expected to be of limited quantities.

Figure 5: Position of hydrocensus sites.

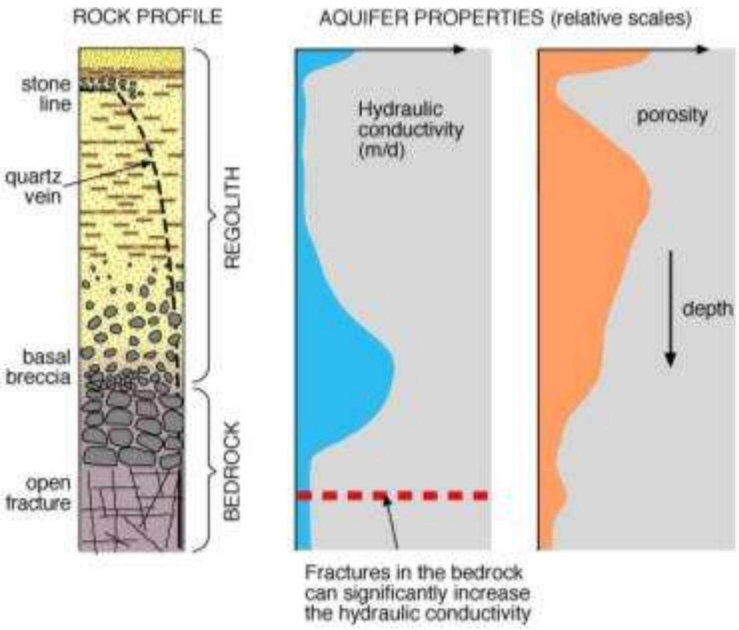

Figure 6: Conceptual cross-section through a weathered aquifer in Basement rocks (Chilton and Foster, 1995).

Fractured crystalline rocks are characterized by extreme heterogeneity in their hydraulic properties and the hydraulic conductivity can vary, within the same rock mass, by orders of magnitude and over short distances. Furthermore the structural features are also extremely variable in nature with regard to frequency, spatial extent, aperture or interconnectedness within the relatively impervious crystalline rock mass.

According to the Hydrogeological Map (2430 1:500 000) the regional hydrogeology is characterized by an 'intergranular and fractured aquifer' systems. The fractured aquifer, attributed to the presence of the Rustenburg Layered Suite has a potential yield of 2 to 5 litres per second. A micro-fractured matrix in these aquifers provide the storage capacity with limited groundwater movements while secondary features such as fractures / faults and bedding planes enhance the groundwater flow. The intergranular aquifer is associated with the river alluvial and quaternary sand deposits.

Based on the aquifer classification map (Parsons and Conrad, 1998), the aquifer system underlying the BCR Minerals study area is regarded a "minor aquifer". A summary of the classification scheme is provided in Table 3. 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.

Therefore, based on the 1:500 000 hydrogeological map sheets, the BCR Minerals study area is located on an aquifer classed as a minor, intergranular and fractured aquifer system with potential groundwater yields up to 5 litres a second (i.e. a moderately yielding aquifer of acceptable quality water).

Table 3: 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

3.3. Hydraulic Properties

To obtain an idea of the permeabilities of the underlying aquifer, five slug tests were conducted on the boreholes identified during the hydrocensus, namely; BH02, BH11, BH15, TWFBH1 and TWFBH2. The slug tests were analysed with the software package AQTESOLV Pro version 4.5. The aquifer and well parameters were obtained by inverse curve-fitting procedure using automatic and manual curve fitting with appropriate analytical solutions/conceptual model (i.e. confined or unconfined). The following process was followed for estimating aquifer parameters based on the Slug Test data:

1) Slug Test interpretation was based on the either the falling-head data or rising-head data, depending on the quality of the data extracted from the automatic logger.
2) Head data were displayed as normalized head. In general, over damped responses of the aquifer to the slug tests were observed (i.e. the water-level response is characterized by exponential decay or recovery to equilibrium level).
3) The Cooper et al. (1967) method for confined aquifers was used to screen the data and determine initial aquifer parameters.
4) Datasets were also fitted with unconfined models, to see if the water-table boundary has an effect on the results. The Hyder et al. (1994) solution (KGS Model) for an over damped slug test in an unconfined aquifer for fully and partially penetrating wells was applied.
5) Finally the datasets were also analysed with the Bouwer-Rice (1976) solution for a confined aquifer. The Bouwer-Rice solution is based on the quasi-steady-state slug test model that ignores elastic storage in the aquifer. K-values were determined by matching the straight line to the data within the recommended head range (the range of normalized head recommended by Butler (1998)) for matching the Bouwer-Rice solution.

3.3.1. Slug tests results

A slug test involves the instantaneous injection or withdrawal of a volume of water or solid cylinder of known volume. The cylinder displaces its own volume of water within the borehole, thus increasing or reducing the pressure in the borehole. As the equilibrium of the groundwater level is changed, it will recover or stabilise to its initial level over time as a function of the aquifer parameters. If the rate of recovery or recession of the water level is measured, the transmissivity or hydraulic conductivity of the borehole can be determined.

The diagnostic plots of the slug tests are provided in Appendix D, while a summary of the determined hydraulic conductivity (K) values are given in Table 4.

Table 4: Summary of hydraulic conductivity obtained from the slug tests.

Borehole ID	Bouwer-Rice		KGS Model	Cooper et al	Average K-value (m/day)	Average K-value (m/sec)
	Early time	Late time				
BH02		0.067	0.069	0.05	0.062	7.2E-7
BH11	4.69	1.47	4.97	3.69	3.705	4.3E-5
BH15	No fit	0.001	No fit	No fit	0.001	1.2E-8
TWF BH01	1.14	0.01	0.46	0.14	0.438	5.1E-6
TWF BH02	No fit	0.001	No fit	No fit	0.001	1.2E-8
Average					**0.841**	**9.7E-6**

3.4. GROUNDWATER LEVELS AND FLOW DIRECTIONS

Utilising a total of 55 measured groundwater table elevations in the wider area of interest (approximately 6 km radius) from:

- 37 water levels obtained from previous hydrogeological studies by Water Geosciences Consulting (2007) and Delta-H (2012),
- nine (9) water levels from the National Groundwater Achieve obtained by Department of Water and Sanitation and
- nine (9) water levels from the 2015 hydrocensus.

Based on the larger regional water level data, groundwater levels range from 1 mbgl to 33 mbgl, with an average depth to groundwater of 14 mbgl. Delta H established the correlation between surface topography and elevation of the hydraulic head (Figure 7) for the wider BCR Minerals study area.

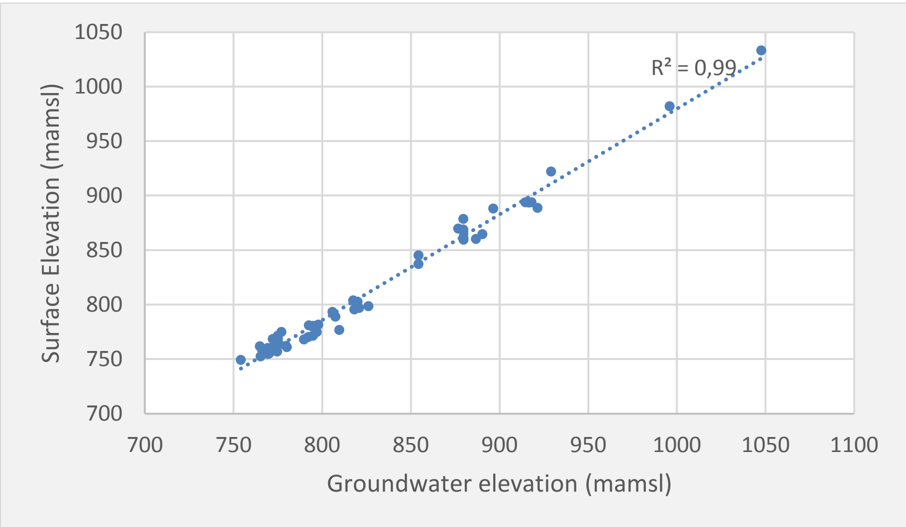

Figure 7: Correlation between surface topography and potentiometric heads, BCR Minerals area

An excellent correlation (R^2=0.98) between absolute surface and hydraulic head (water level) elevations in m above mean sea level (mamsl) is recognised for the wider area of interest. The potentiometric surface therefore mimics surface topography, and regional groundwater flow is from higher lying ground towards lower lying valleys, where it accumulates or surfaces in the alluvial and hill wash deposits and discharges ultimately into the Steelpoort River. Note that local flow patterns may differ due to the fractured nature of the aquifer in the Bushveld Rocks or the presence of dykes.

BCR Minerals is located approximately 6 km upstream of the Steelpoort River on the crest of a large hill forming part of the Schurinksberg mountainous area. A regional northerly groundwater flow direction from higher lying ground in the south and east towards the Steelpoort River dominates the groundwater flow. At the BCR Minerals site itself, groundwater is expected to follow the topography and flow from a north-westerly direction following the unnamed tributary.

A groundwater piezometric map was interpolated from the collated measured shallow water levels using Bayesian interpolation, based on the established correlation between surface topography and groundwater levels. 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 (Figure 8) 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 (with its correlation to the groundwater elevation used as a qualified guess) to improve the spatial estimation of water levels.

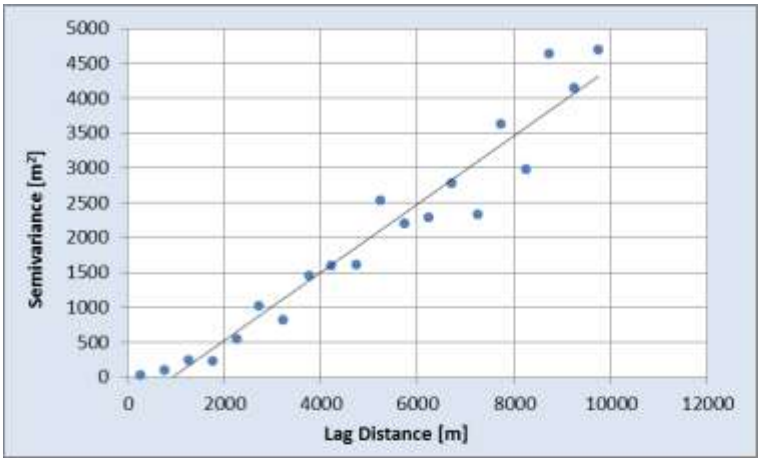

Figure 8: Empirical semi-variogram and fitted Bayesian model.

The interpolated (unconfined) groundwater piezometric map using Bayesian interpolation is shown in Figure 9 and was subsequently used as initial heads for the model calibration. It must be noted that initial heads only accelerate the mathematical convergence of a steady-state model, but do not change the outcome of the model i.e. the calculated steady-state heads.

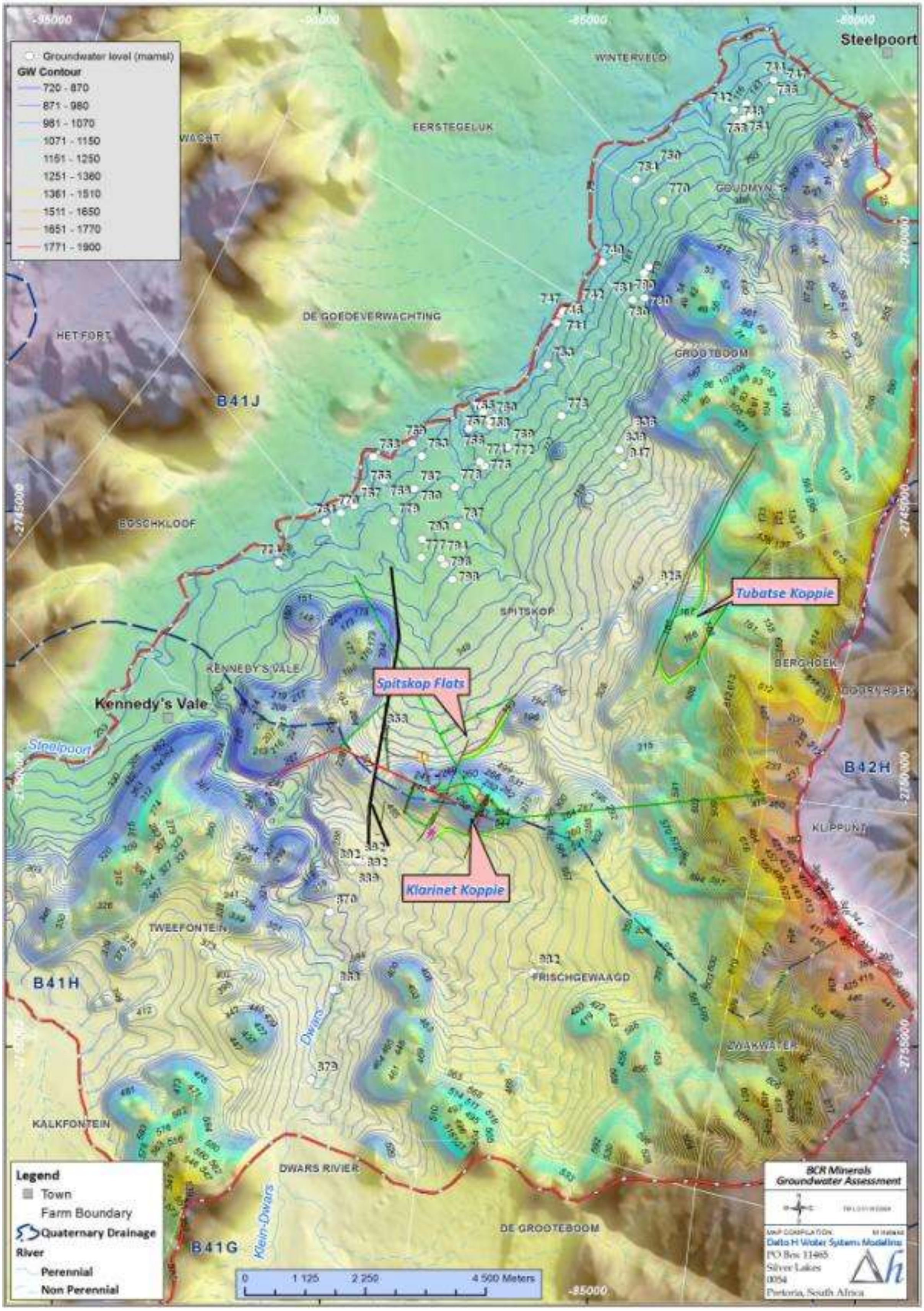

Figure 9: Groundwater piezometric map shown with the water level measurement locations.

3.5. GEOPHYSICAL SURVEY

The geophysical survey was conducted from the 7th to the 10th of December 2015, specifically focusing on the proposed mine workings to identify potential drilling targets for aquifer characterisation and monitoring boreholes. The objective of the survey was to investigate the subsurface for geological structures and deep weathering zones, which could act as potential preferential flow paths. Ultimately a total of four geophysical traverses comprising of electromagnetic (EM) and magnetic methods were conducted with a total length of 3 100 m (Figure 10).

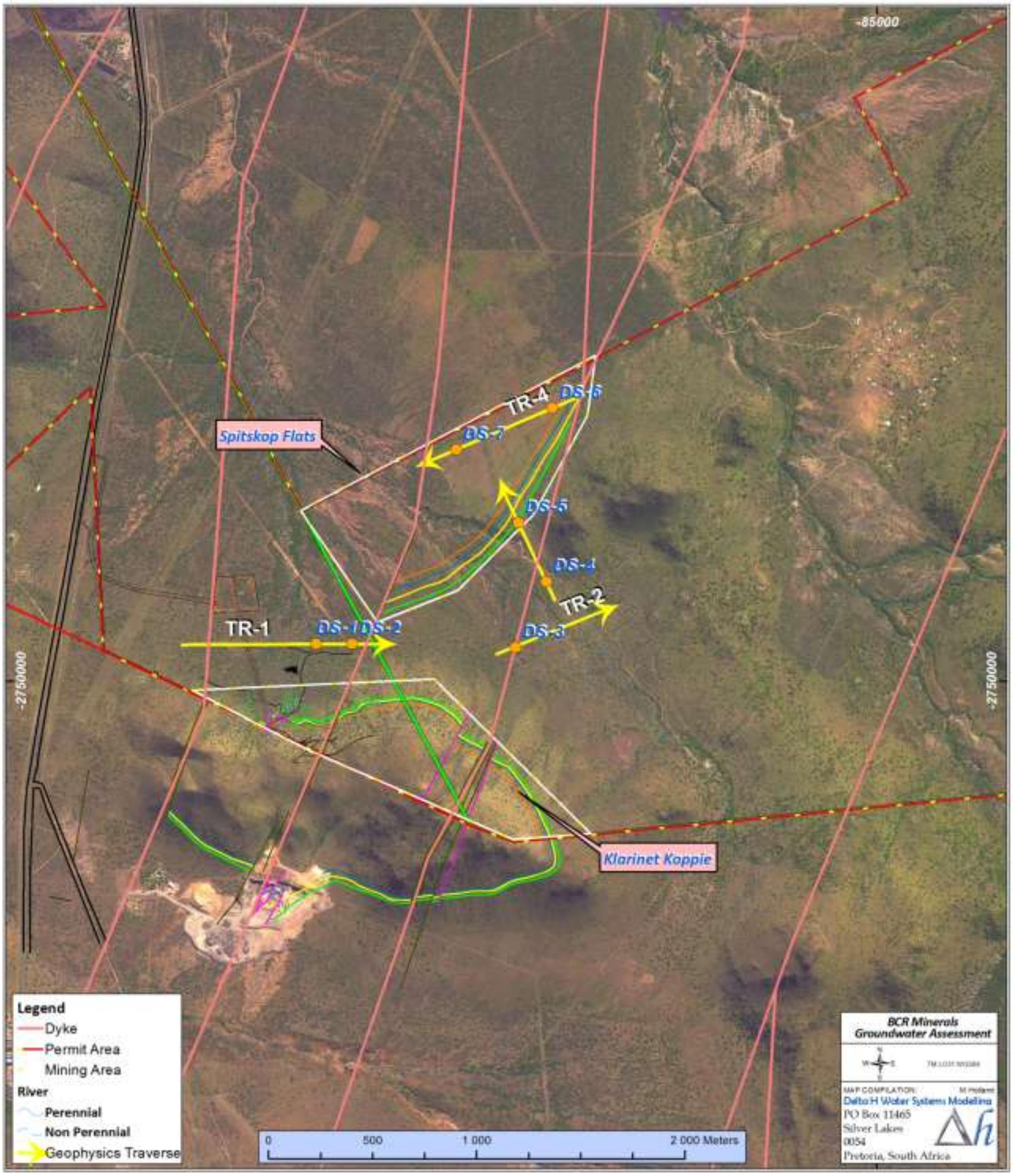

Figure 10: BCR 2015 geophysical survey traverses.

A brief summary of the applied methods is provided below, while the geophysical traverses are provided in Appendix B:

- Magnetic Method
    - The aim of the magnetic method is to investigate sub surface geology on the basis of anomalies in the earth's magnetic field resulting from the varying magnetic properties of underlying rocks. Different rock types have different magnetic susceptibilities, which may have remnant magnetism. The contrast in magnetic susceptibility and/or remnant magnetism gives rise to anomalies related to structures like intrusive dykes, faults, lithological contacts and weathered/fractured bedrock.
- Electromagnetic Method
    - The Geonics EM-34 electromagnetic method was used for rapid measurements of terrain conductivity in milliSiemens/m (mS/m) with a maximum effective penetration depth of approximately 60 m. Vertical and horizontal coil orientation was used with a 20m and 40m coil separation. The EM-34 is applied for its effectiveness to detect remnant and non-magnetic dykes and to determine the dip of dykes or geological structures.

3.5.1. Geophysical Survey

Seven proposed drill sites were selected based on geophysical results and to inform the future groundwater monitoring network (marked as DS1 to DES7 in Figure 10). The geophysics was also used to confirm the position of the dykes inferred from the regional aeromagnetic data.

3.6. GROUNDWATER QUALITY

The description of the site specific groundwater quality is based on the boreholes sampled during the hydrocensus (October 2015). These samples were submitted to the SANAS accredited laboratory Waterlab PTY Ltd. in Pretoria. The borehole sample localities are shown in Figure 5.

The resulting parameters have been compared against the South African National Standards (SANS:241, 2011) drinking water quality limits, the South African Water Quality Guidelines by the Department of Water Affairs and Forestry (1996) for domestic use and the World Human Organisation (2011) water quality guidelines . Guideline values have been determined for those chemical components that are considered to have significant potential to harm human health at concentrations above the specified limits. Guideline values should not be exceeded in public water supplies, but exceeding the guideline values may not always be a matter for immediate concern, but rather a trigger for follow-up action. It must furthermore be noted that the application of drinking water guidelines does not suggest that drainage from mine activities will be used for drinking purposes.

Based on the results in Table 5, the local groundwater quality is classified as slightly alkaline (pH in the range of 7.6 to 8.5) with generally elevated Total Dissolved Solids (TDS) contents ranging from around 464 to 924 mg/l, exceeding the (DWAF 1996) recommended drinking water limit of 450 mg/l. Analysed inorganic chemical parameters not shown in Table 5 are either below detection limit or the concentration levels did not trigger major health risks. The laboratory certificates are provided in Appendix B.

Table 5. Groundwater chemical results (selected parameters).

Comments	pH Value at 25˚C	Electrical Conductivity	TDS	Turbidity NTU	Alkalinity as $CaCO_3$	Chloride as Cl	Sulphate as SO_4	Nitrate as N	Fluoride as F	Ortho phosphate	Ammonia as N	As	Ca	K	Mg	Na
		mS/m	mg/L	NTU	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
WHO Standard for Drinking Water (2011)	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**11**	**1.5**	**N/A**	**N/A**	**0.01**	**N/A**	**N/A**	**N/A**	**N/A**
DWAF (1996) Domestic	**6-9**	**N/A**	**450**	**N/A**	**N/A**	**<100**	**<200**	**<6**	**<1**	**N/A**	**<1**	**N/A**	**N/A**	**N/A**	**N/A**	**<100**
SANS 241 (2011) Operational	**5 - 9.7**	**N/A**	**N/A**	**1**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
SANS 241 (2011) Aesthetic	**N/A**	**170**	**1200**	**5**	**N/A**	**300**	**250**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**200**
SANS 241 (2011) Acute Heath	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**500**	**11**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
SANS 241 (2011) Chronic Health	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**1.5**	**N/A**	**N/A**	**0.01**	**N/A**	**N/A**	**N/A**	**N/A**
BCR Surface 1	8.5	83.1	**506**	**8.1**	408	29	49	0.1	<0.2	<0.1	0.2	<0.010	45.01	0.737	80.02	24.82
BH01	8.1	139	**766**	**1.8**	512	**157**	44	**9.3**	<0.2	<0.1	0.2	**0.013**	53.33	3.97	131.8	31.76
BH04	8.3	114	**732**	0.1	436	51	49	**29**	<0.2	<0.1	0.1	<0.010	24.32	1.637	100.5	69.29
BH07	7.7	140	**860**	0.1	424	**168**	102	4.7	<0.2	<0.1	0.1	**0.022**	99.44	3.534	109.1	39.46
BH08	8.2	93.3	**606**	0.2	472	36	25	**6.8**	<0.2	<0.1	0.1	<0.010	49.24	2.202	79.51	51.15
BH09	8.2	90.6	**548**	0.1	500	20	37	3.3	<0.2	<0.1	0.2	<0.010	22.97	2.006	97.18	28.65
BH12	7.9	110	**678**	0.1	500	56	43	**9.4**	<0.2	<0.1	0.2	**0.011**	40.28	3.024	92.9	50.22
BRC03	8.1	151	**924**	0.1	640	**128**	78	4.2	<0.2	<0.1	0.2	**0.014**	44.76	4.016	136.5	89.56
DCM 1	7.9	117	**736**	0.2	444	72	68	**20**	<0.2	<0.1	0.2	**0.015**	75.3	0.837	97.23	27.55
TWFBH01	7.6	75.6	**464**	**143**	400	14	30	0.2	<0.2	<0.1	0.4	**0.014**	73.78	0.392	44.98	22.91

Of the analysed constituents, the highly elevated nitrate concentration for boreholes BH01, BH04, BH08, BH12 and DCM 1 are of major concern due to potential acute health implications as well as ecological considerations (nutrient). However, the source of the generally elevated nitrate concentrations are not fully understood and might also be influenced by upstream waste rock dumps (e.g. residues from explosives), mining activities or clearing of vegetation ("natural" sources from root zone). In other words, in the absence of a properly established baseline of the ambient groundwater chemistry, neither apportionment of nitrate sources on the site nor the consideration of a potentially regionally elevated background concentration is possible. Further investigations in this regard are recommended, preferably aided by the drilling of upstream monitoring boreholes.

Chloride concentrations exceed the DWAF drinking water quality guidelines of 100 mg/L for boreholes BH01, BH07 and BRC03. However, the exceedances are considered to be a combined result of low recharge values in conjunction with intense water-rock interaction as expected in the Bushveld Igneous Complex (BIC). Arsenic concentrations in most of the water samples exceed the WHO and SANS water quality guideline standards of 0.01 mg/l.

The data, as presented in the Piper Diagram (Figure 11) suggest that the groundwater type is generally magnesium/bicarbonate (Mg-HCO_3) rich which is typical of shallow groundwater in the Bushveld Igneous Complex (with boreholes BH01, BH07 and BRC03 showing a slight trend in the dominant anion towards chloride, indicative of the influence of deeper groundwater or evaporative effects). The bicarbonate anion dominance of the samples indicates relatively young or fresh groundwater, which typically evolves along the flow path (i.e. with depth and age) towards sodium-chloride dominance. The magnesium and calcium dominance for the cations can be directly linked to the underlying geology with magnesium and calcium rich gabbroic norites.

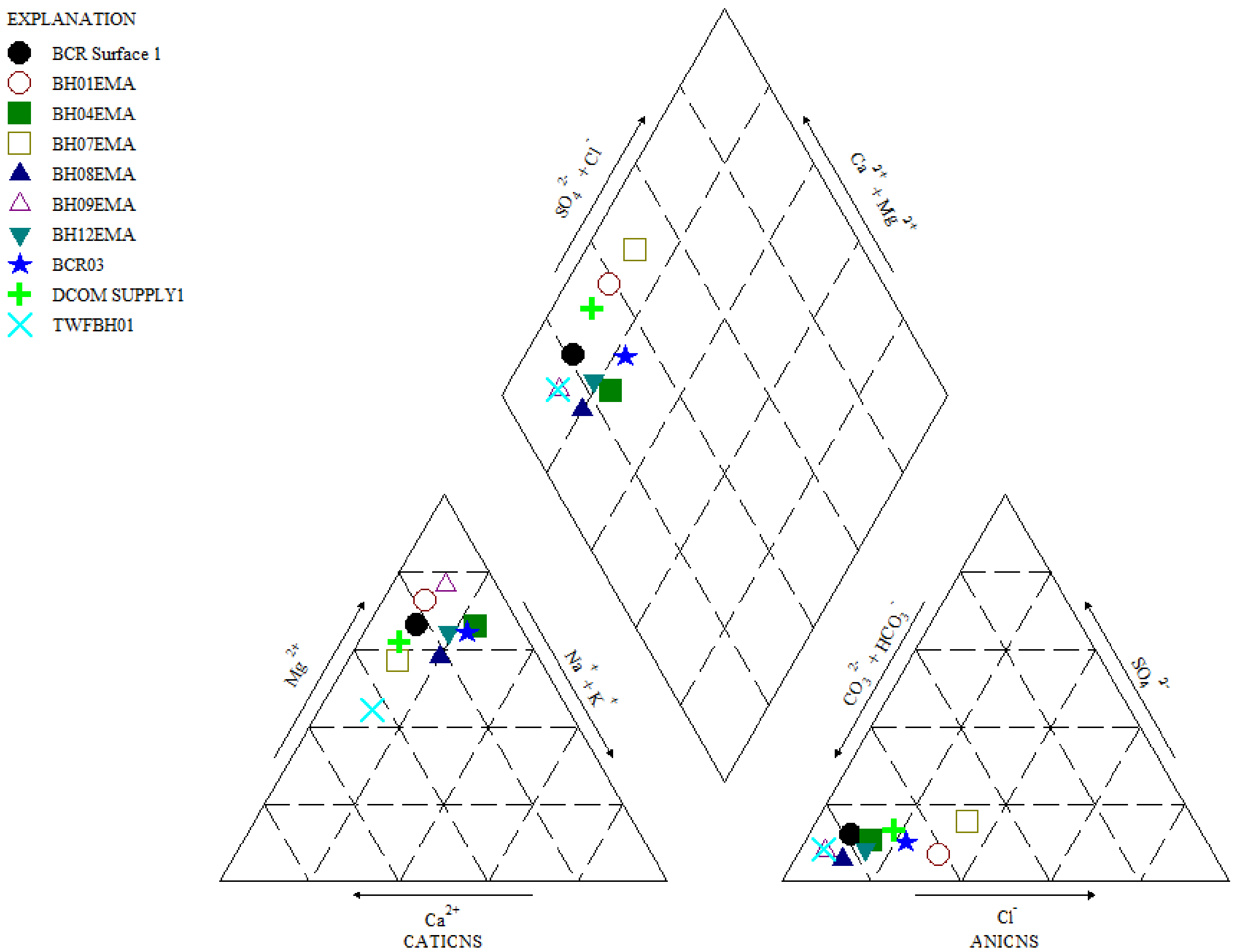

Figure 11: Piper diagram of borehole samples in the BCR Minerals area.

4. MODEL CONSTRUCTION

4.1. COMPUTER CODE

The software code chosen for the numerical finite-element modelling work was the 3D groundwater flow model SPRING, developed by the delta h Ingenieurgesellschaft mbH, Germany (König, 2011). The program was first published in 1970, and since then has undergone a number of revisions. 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 solves the stationary flow equation independent of the density for variable saturated media as a function of the pressure according to:

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

∇	$\left(\frac{\partial}{\partial x},\frac{\partial}{\partial y},\frac{\partial}{\partial z}\right)$
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 $1-(1/\mathrm{n})$
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.

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 Hydrodynamic 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.

While SPRING allows the consideration of sorption as well as chemical or biological decay processes, the current model assumes according to the precautionary principle (and in the absence of measured geochemical parameter an ideal), non-retarded transport behaviour of the simulated solutes.

4.2. MODEL DOMAIN

The model domain covers a surface area of almost 235 km^2 and straddles quaternary catchments B41J and B41H. The boundaries follow accordingly mostly topographic highs, which are considered to also define groundwater divides (Figure 7) and therefore outer no-flow model boundaries. Exemptions are the SW and NE boundaries across the Steelpoort River valley, which exploits the Steelpoort Fault. The chosen model domain ensures a dependable water balance for the model with recharge being the main driver of groundwater flow. The model mesh was spatially discretised into 116 116 nodes on 5 node layers, which make up 4 element layers with 125 862 elements of variable (triangles and quadrangles) geometry and sizes (Figure 12).

The horizontal element size (side length) varies from a minimum of 10 m along surface water drainages, 20 m along mapped dykes, to a maximum side length of 50 m for the remainder model area. The chosen model discretisation allows a sufficiently accurate representation of discrete physical features (drainages, dykes and open cast mine) 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. The generally fine discretisation enables furthermore future model updates should it be required.

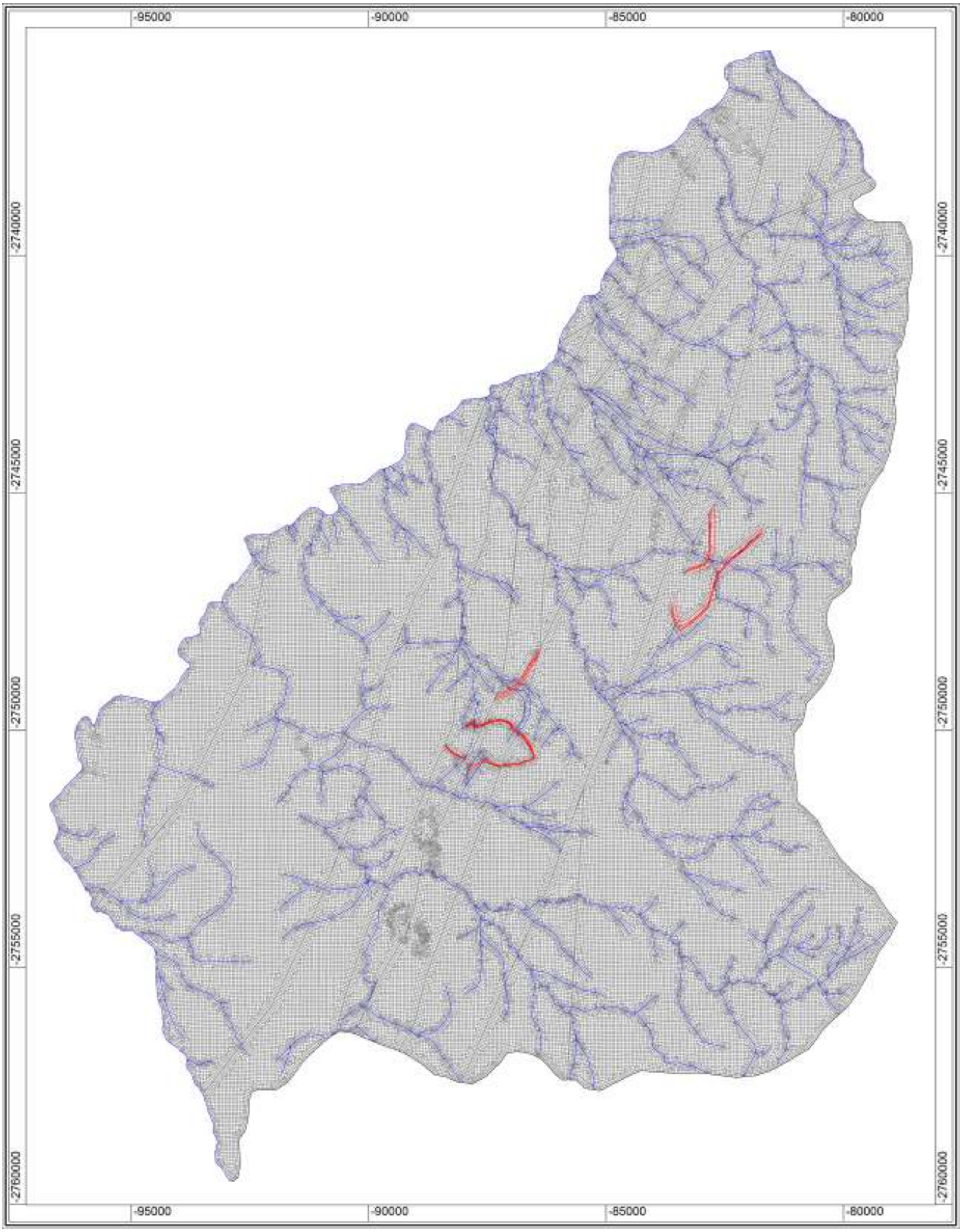

Figure 12: Finite element mesh for the model (proposed open cast indicated in red).

The finite-element model was set-up as a three-dimensional three element layer, steady-state groundwater model. In accordance with the conceptual model, the uppermost model layer I represents the weathered and alluvial aquifers. Different hydraulic conductivities were assigned to the weathered aquifer in areas with topographic gradients lower 20°, i.e. from the lower reaches of the mountain slopes towards the Steelpoort River to account for hillwash. It is assumed that the weathered zone is absent or of insignificant thickness on the steeper dipping slopes due to erosion and the same hydraulic conductivities as for the deeper layer were assigned. The lower model layers represent the BIC and Pretoria Group rocks in the western edge of the model domain. The layer arrangement is described in Table 6.

Table 6: BCR Minerals model layer arrangement.

Node Layer	Element layers	Aquifer feature	Data used for interpolation
I, top	I, top	Surface elevation	Digital Elevation Model (DEM) (25 m)
II, bottom	1	Soil Zone	2 m
III and IV, bottom	2	Weathered Zone	Thickness 2 to 20 m (Inferred from BH logs)
IV, bottom	3	Fractured bedrock aquifer	Thickness ~ 20 to 50 m
V, bottom	4	Bedrock aquifer (largely impermeable)	Thickness ~ 75 m

In accordance with the developed conceptual model, a thin upper layer represents the soil layer that overlies the overburden/weathered aquifer, while the underlying layers represent the deeper fractured aquifer in the pyroxenite and norites. The active groundwater flow system is considered to occur within the upper 75 mbgl of the BC, while most groundwater strikes are generally encountered at depths less than 50 mbgl. The deeper fractured aquifer was sub-divided into two element layers, representing an upper more permeable aquifer compared to a deeper, less fractured aquifer/aquitared (layer 4) which forms the base of the flow system and model domain. The layer arrangement is shown in a cross-section in Figure 13.

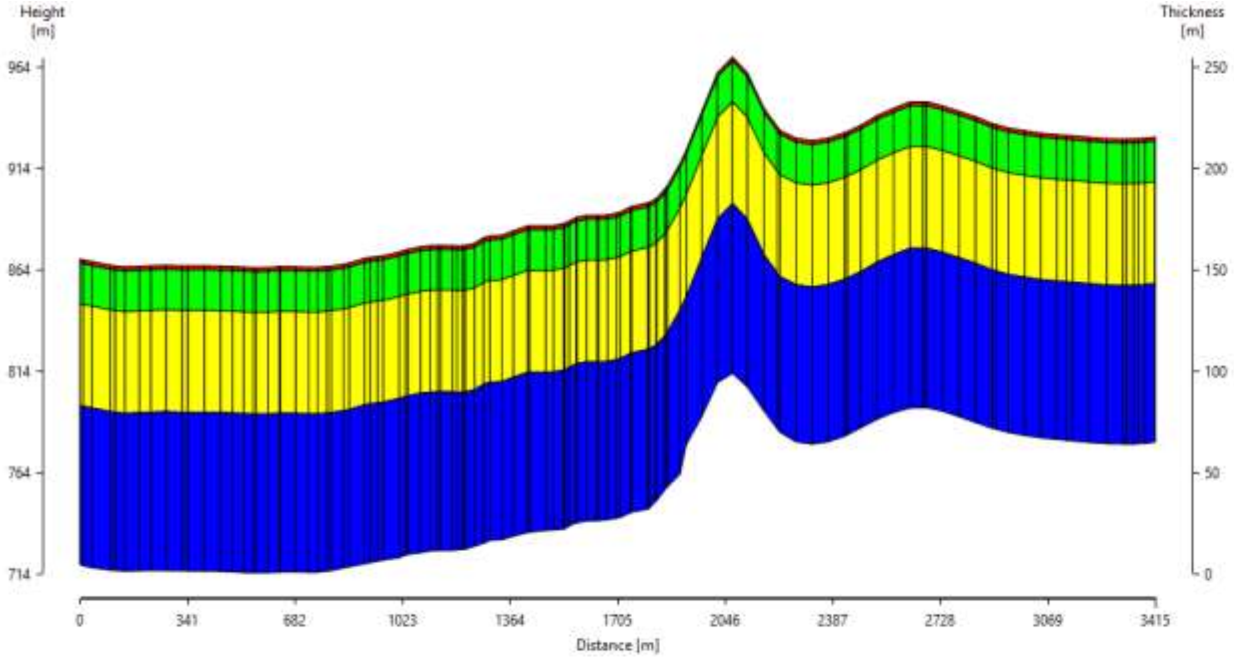

Figure 13: Example of the vertical grid layout across the site.

4.3. Sources and Sinks

4.3.1. Recharge

Groundwater enters the model domain as direct recharge from rainfall, with an estimated regional recharge rate of around 3 to 5% of a mean annual precipitation of 598 mm (section 2.2). 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. The regional recharge rate was split up into 18 mm/a for the lower lying areas and 30 mm/a for the higher lying areas comprising of the Pretoria Group and Dwars River Sub-suite of the BIC.

4.3.2. River courses

Water leaves the model domains via a number of non-perennial and perennial (Steelpoort River) rivers (blue lines in Figure 12). The non-perennial rivers or drainage lines were generally classified within the model domain as continuously gaining rivers (i.e. groundwater is only allowed to discharge into them). The rivers were therefore described within the model using SPRING's 'river package', with no exfiltration of surface water allowed. The Steelpoort and Dwars River were on the other hand classified as gaining or loosing rivers, with exfiltration of surface water allowed. The stage of each river node was carefully aligned with the height of the Digital Elevation Model (DEM) at that point and an incision the river bottom of 3 m below topography assumed. A river bed conductance of 1E-7 m/s was assumed.

4.3.3. Groundwater abstraction

While numerous water supply boreholes do occur in the wider area, in the absence of construction details and pumping schedules/rates no groundwater abstraction from the aquifer were simulated.

4.3.4. Open cast mine working

The proposed open cast mine workings (pits), namely Klarinet-, Tubatse Koppie resource area and the Spitskop flat lying resource area, were integrated into the model domain for the predictive simulations by updating the digital elevation model for the pit areas and assigning free seepage boundaries to the pit areas. It is assumed that any groundwater entering the pit is removed (pumped out) and that the pit bottom represents therefore the lowest drainage elevation. In other words, groundwater is allowed to seep freely into the pit with a subsequent development of a cone of dewatering. It must be noted that the computation of the free groundwater table and pit inflows consider partially saturated flow conditions using the van Genuchten equation to calculate the relative permeability as a function of the capillary pressure, saturation residual saturation and entry pressure.

4.3.5. Seepage from infrastructure (i.e. stockpiles)

Based on other geochemical assessments for mines in the larger Spitskop area, stockpiles and waste rock dumps are likely to be non-acid generating due to a very low sulphur content with a likely neutral to alkaline leachate quality (Delta-H, 2014 and 2015). As a result, seepage from the stockpiles is not expected to significantly impact on the ambient groundwater quality beyond a general increase in mineralisation. However, it is expected that during the feasibility assessment more detailed geochemical analysis will inform the site-specific pollution potential together with the appropriate measures to minimise seepage.

4.4. Selection of Calibration Targets and Goals

The collated groundwater level measurements used for the derivation of the regional groundwater flow directions (section 3.3) are within the model domain and were used as optimisation targets for the steady state model calibration. The more regional groundwater levels used for the calibration were observed infrequently over a number of years and represent therefore by no means a single or average snapshot of water levels in time. Furthermore, several of the water levels retrieved from earlier studies by Water Geosciences Consulting (2007) and the earlier hydrocensus were measured in boreholes used for water supply and are therefore potentially influenced by preceding abstractions. However, considering the regional extent of the model and the coverage with groundwater monitoring points, it appeared reasonable to use these water levels to constrain the calibration process regionally. No discharge measurements from the underground mines or in the river courses were available for calibration purposes.

Since the modelled groundwater levels are directly related to the assigned recharge rates and hydraulic conductivities, an independent estimate of one or the other parameter is required to arrive at a potentially unique solution of the model. The estimated recharge rates were therefore considered fixed for the calibration and only hydraulic conductivities considered variable, i.e. adjusted within reasonable boundaries to represent the observed flow system

4.5. Numerical Parameters

SPRING uses an efficient preconditioned conjugate gradient (PCG) solver for the iterative solution of the flow 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 0.3 and was limited to 10 iterations. The mean difference between computed potential heads or capillary pressures for the last two iterations was generally below an acceptable 0.1 m.

4.6. Initial Conditions

The initial conditions specified in numerical model were as follows:

- Starting heads were interpolated from measured water levels using Bayesian interpolation, i.e. co-kriging using the established correlation between surface topography and groundwater elevation.
- Hydraulic conductivities of 5E-07 m/s for the weathered and of 3E-08 m/s for the fractured aquifer.
- Vertical hydraulic conductivities were set at 10% of the horizontal conductivities.
- Effective porosity values were specified as 10% for the weathered and 2 to 5% for the fractured aquifer.

5. MODEL CALIBRATION

5.1. Steady State Calibration

The model was run with the initial conditions described in section 4.6 and the permeabilities adjusted using sensible boundaries until a best fit between initial and computed potential heads was observed. An excellent correlation coefficient R^2 between modelled and observed values of 98% with no obvious bias towards too high or low modelled heads (Figure 14) was achieved for the steady-state calibration. It must be noted that an almost 100 % correlation does not mean that each measured head is exactly replicated by the model, but that the sum of (normalised) squared differences between observed and simulated heads is just below unity.

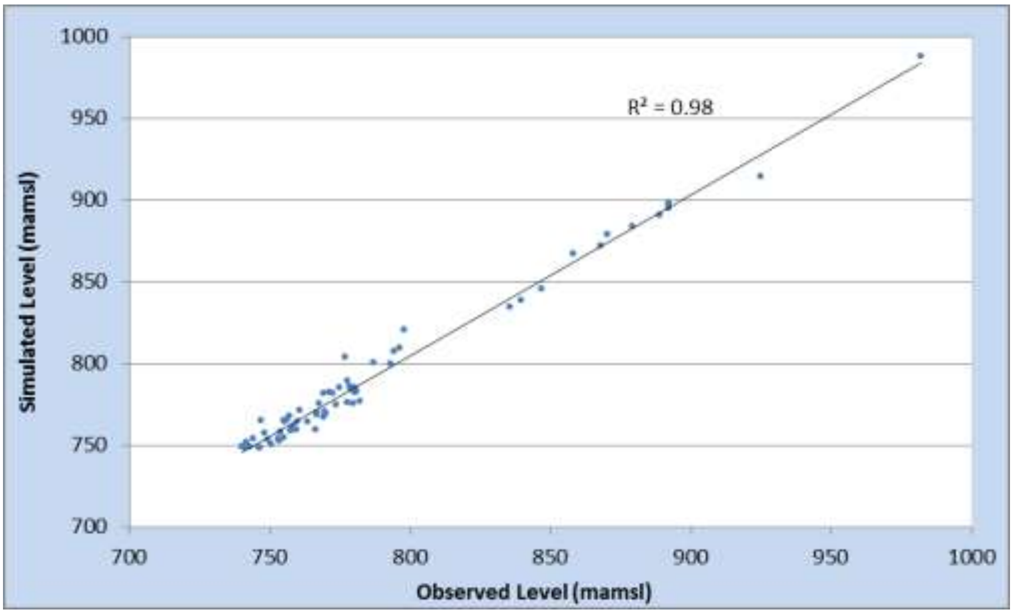

Figure 14: Steady state calibration of the groundwater model.

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 55 (=*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 $h_{max} - h_{min}$ =980 mamsl - 740 mamsl = 240 m), with values lower than 10% considered acceptable. The corresponding normalised root mean square error of 3.6 % (and a RMSE of 7.6) for the observed heads are considered more than acceptable for the model.

The calibrated conductivity values (Table 7) appear plausible and correlate well with literature values and more importantly with the site specific hydraulic parameters obtained during intrusive investigations of the site (Table 4). The subsequently simulated steady-state head contours of the regional BCR groundwater model is shown in Figure 15.

Table 7: Calibrated hydraulic conductivities.

Aquifer	Hydraulic conductivity	
	[m/s]	[m/d]
Layer 1 – Soil zone	3.0E-06	0.2592
Layer 2 – Overburden/weathered aquifer	2.0E-06	0.1728
Layer 3 – Fractured bedrock aquifer	2.0E-07	0.0173
Layer 4 – Bedrock Aquifer	7.0E-09	0.0006
Dyke	8.0E-09	0.0007

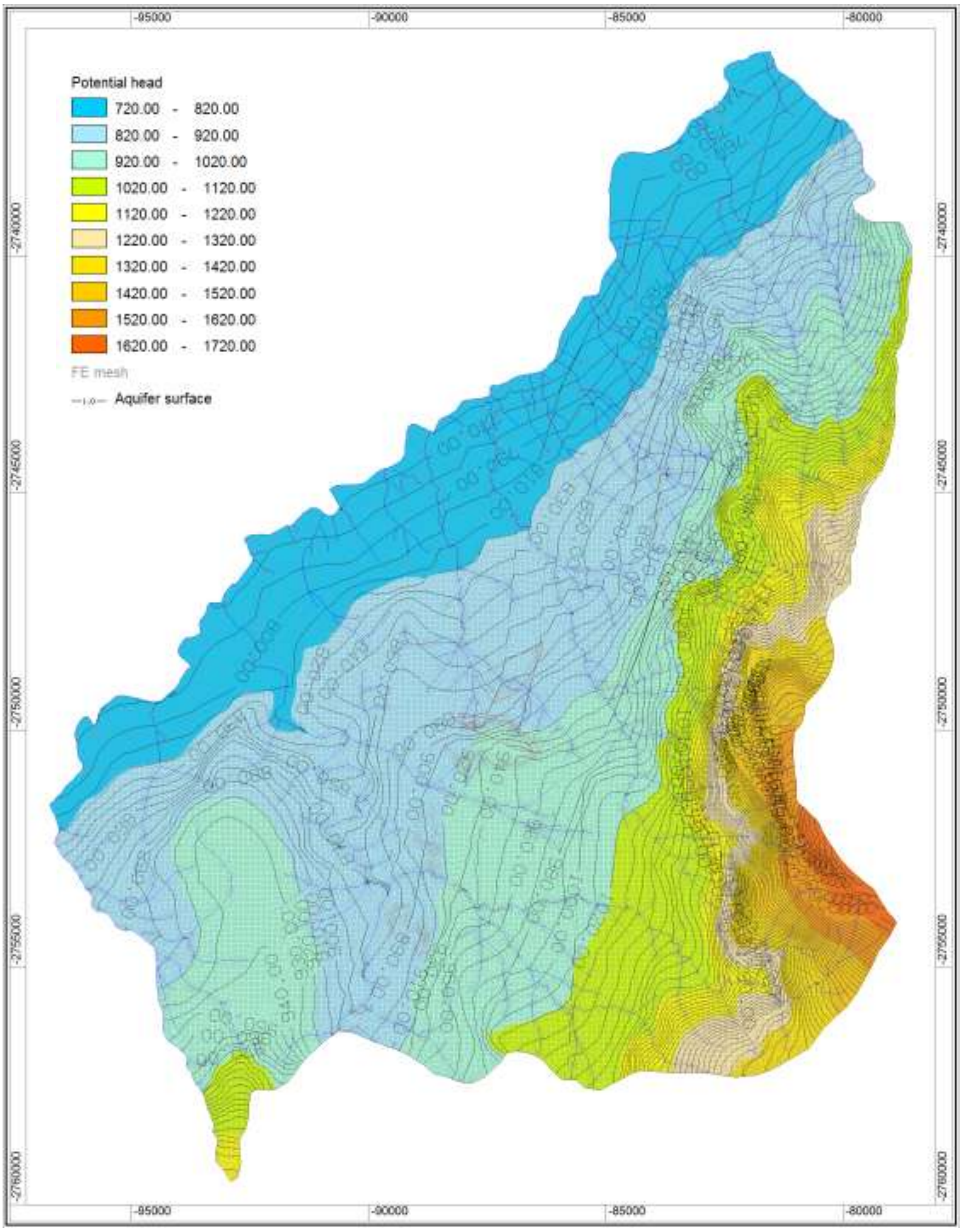

Figure 15: Simulated steady state heads (10 m) (mining areas shown as red lines).

Expectedly, the modelled groundwater contours are closely related to the topography, and groundwater flows from higher lying ground towards lower lying valleys (drainage lines). The influence of the dykes with assumed lower permeabilities on the simulated heads are clearly visible in the steep gradients across the dykes (accumulation of contour lines).

5.2. Sensitivity Analysis

No formal sensitivity analysis with regard to modelled groundwater levels was performed, though the model proved during the calibration process most sensitive to hydraulic conductivity values of the alluvial aquifer system (with assumed fixed recharge values) due to the predominance of groundwater levels close to the Steelpoort River.

5.3. Model Verification

Model verification entails a comparison of simulated heads against observed heads, preferably taken under different hydraulic conditions (e.g. drought years), which have not been used for the model calibration. In view of the data scarcity and subsequent steady-state nature of the model, no model verification was done

6. PREDICTIVE SIMULATION

6.1. SIMULATED DEPTH TO GROUNDWATER (MINING AREAS)

The depth to groundwater was based on the simulated steady state groundwater levels and is shown in Figure 16. The depth to groundwater over the mining area at the Tubatse and Klarinet Koppies is generally more than 50 m below surface while the towards the valleys and drainage channels groundwater levels are much shallower with simulated depths of between 5 and 15 m in the proposed Spitskop Flats open cast mine. The open cut along the Koppies mining footprint will be above the groundwater level and inflows from groundwater seepage are expected to be minimal. The inflow of water into the open cut area will be mainly from surface runoff and direct rainfall. However, groundwater is likely to be intercepted at the proposed Spitskop Flats open cast area and will be addressed in the following section.

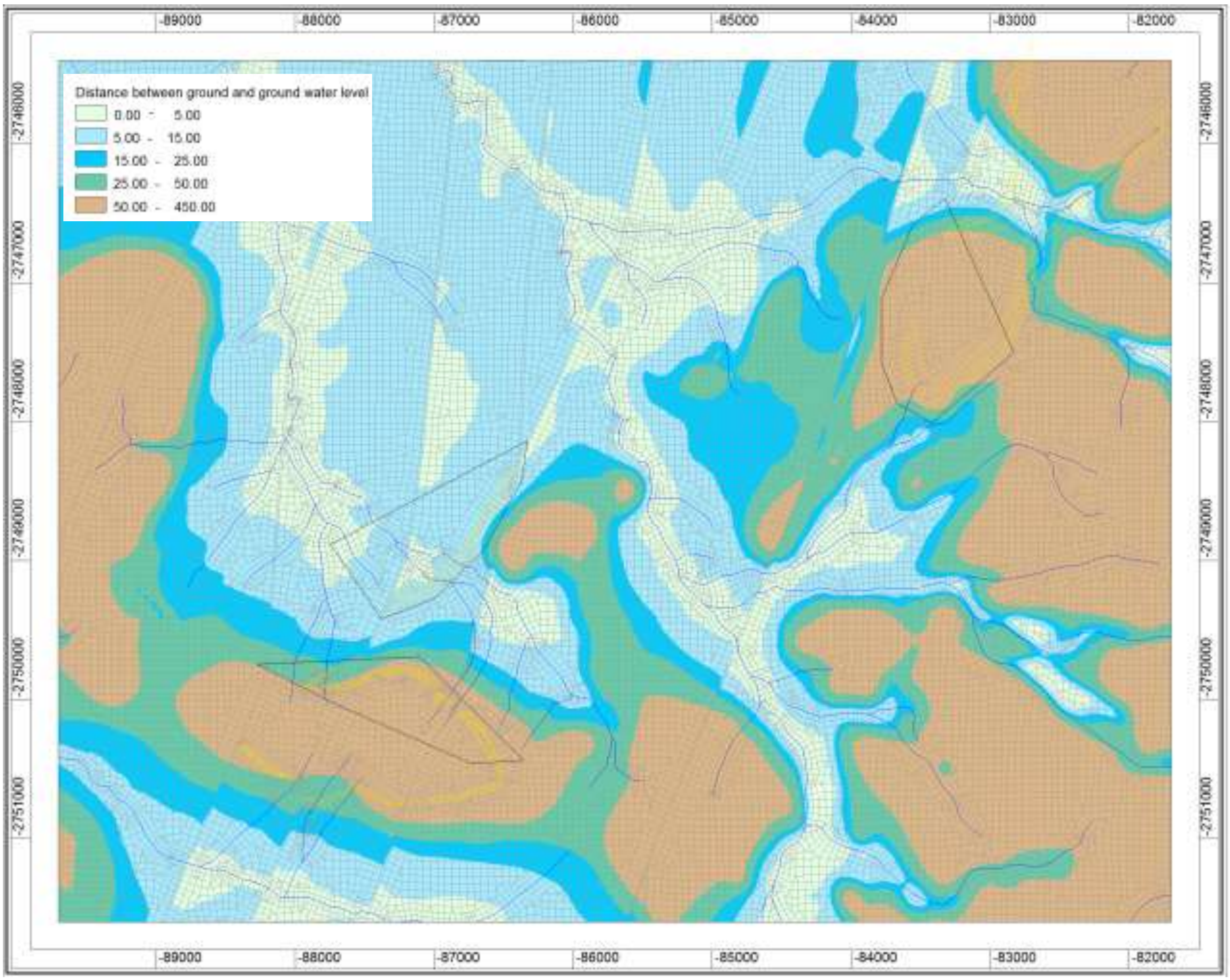

Figure 16: Depth to groundwater based on the simulated (steady-state) heads.

6.2. SIMULATED MINE INFLOWS

6.2.1. Klarinet- and Tubatse Koppies resource area

The calibrated groundwater flow model was used to determine the impact of the opencast of the Koppie resource areas (namely Klarinet and Tubatse) on the regional groundwater levels. The modelling results confirmed that no groundwater seepage is to be expected into the open cut along the Klarinet- and Tubatse Koppie resource areas due to groundwater levels being below the pit bottom. A north-south cross-section for the Klarinet Koppie and Tubatse Koppie resource area is shown in Figure 17.

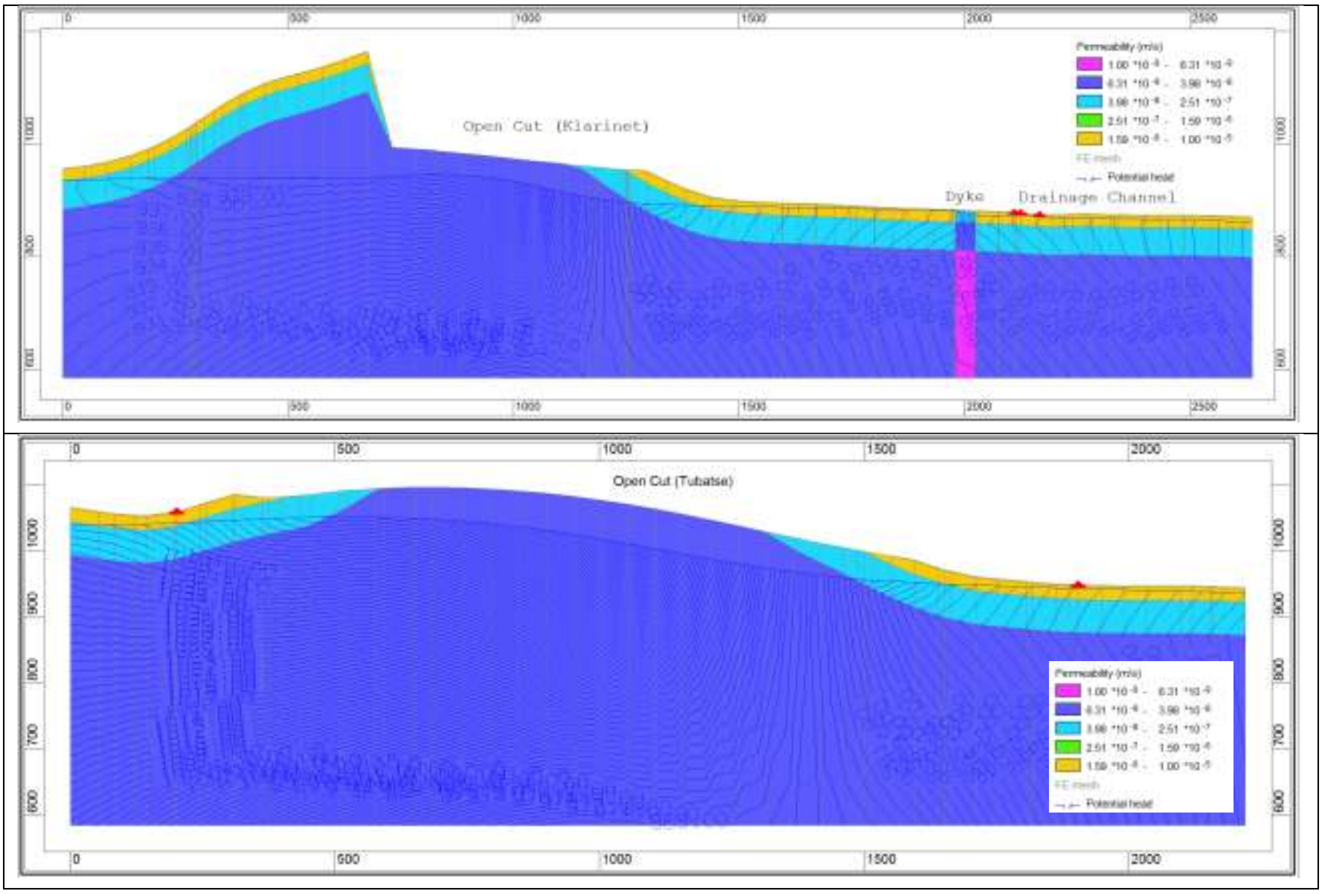

Figure 17: Simulated heads in relation to the Klarinet (top) and Tubatse (bottom) open cut.

6.2.2. Spitskop Flats resource area

Unlike the Koppie resource areas, the open cast mine targeting the Spitskop Flats chrome seams will extend below the groundwater level and groundwater seepage into the mine workings is foreseen. The proposed box cut is therefore represented in the digital elevation model by aligning the surface elevation of the respective cut to the floor of the targeted seams (expected to be between around 40 mbgl). It is assumed that any groundwater entering the pit is removed (pumped out) and that the pit bottom represents therefore the lowest drainage elevation.

The open pit will develop to below the groundwater level and groundwater would have to be removed during mining. A north-south cross-section for the Klarinet and Tubatse Koppie resource area is shown in Figure 18. The simulated steady-state pit inflow for the open cast development is 2.8 L/s (~89 500 m^3/a).

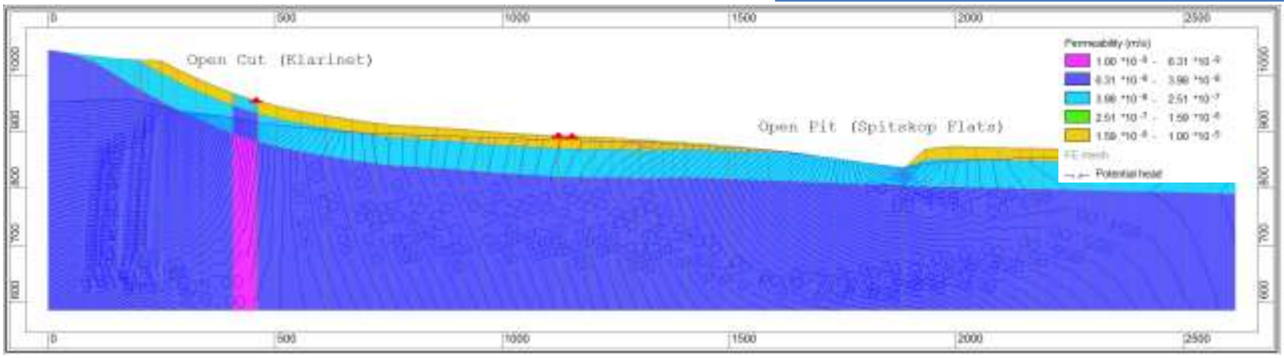

Figure 18: Simulated heads in relation to the Spitskop Flats open pit.

6.3. IMPACTS ASSOCIATED WITH DEWATERING

Assuming re-use or other environmentally acceptable disposal practices of the groundwater entering the pit, the environmental impacts associated with the pit inflows are primarily associated with:

- the partial dewatering of the aquifer in the vicinity of the mine and subsequent impacts on groundwater users or groundwater dependant eco-systems
- the interception of ambient groundwater flow, which would have under natural conditions discharged into the alluvial aquifer providing baseflow to the Steelpoort River, or contributed to deeper regional groundwater flow.

The simulated impact of the partial dewatering of the aquifer due to pit inflows is depicted in Figure 19 as contours of drawdown from the pre-mining groundwater table in meters, i.e. the lowering of the water table due to the proposed mining operations. The contour classes were chosen to differentiate the severity of associated impacts:

- 2 - 5 m drawdown – regarded as minor to moderate impact.
- 5 – 10 m drawdown – moderate to significant impact.
- >10 m – significant impact.

Drawdown values below 2 meters are considered to be within the seasonal variability of water levels respectively the accuracy of the model predictions and therefore not visualised.

It is expected that the potential impacts of the pit inflows on the regional groundwater flow and groundwater contribution to baseflow towards the River systems are:

- Unlikely for the Koppies resource area but highly likely to occur for the Spitskop Flats resource area.
- Localised within the site boundaries with negligible impacts beyond the site boundaries.
- An insignificant reduction of groundwater baseflow towards the river systems.
- A minor reduction of BH yields within the zone of influence depending on location.
- Reversible over time once pit dewatering stops (and the pit is backfilled).
- Of moderate severity with a drawdown of the water table in the vicinity of the open cast mine and a partial loss of borehole yields in the affected area.

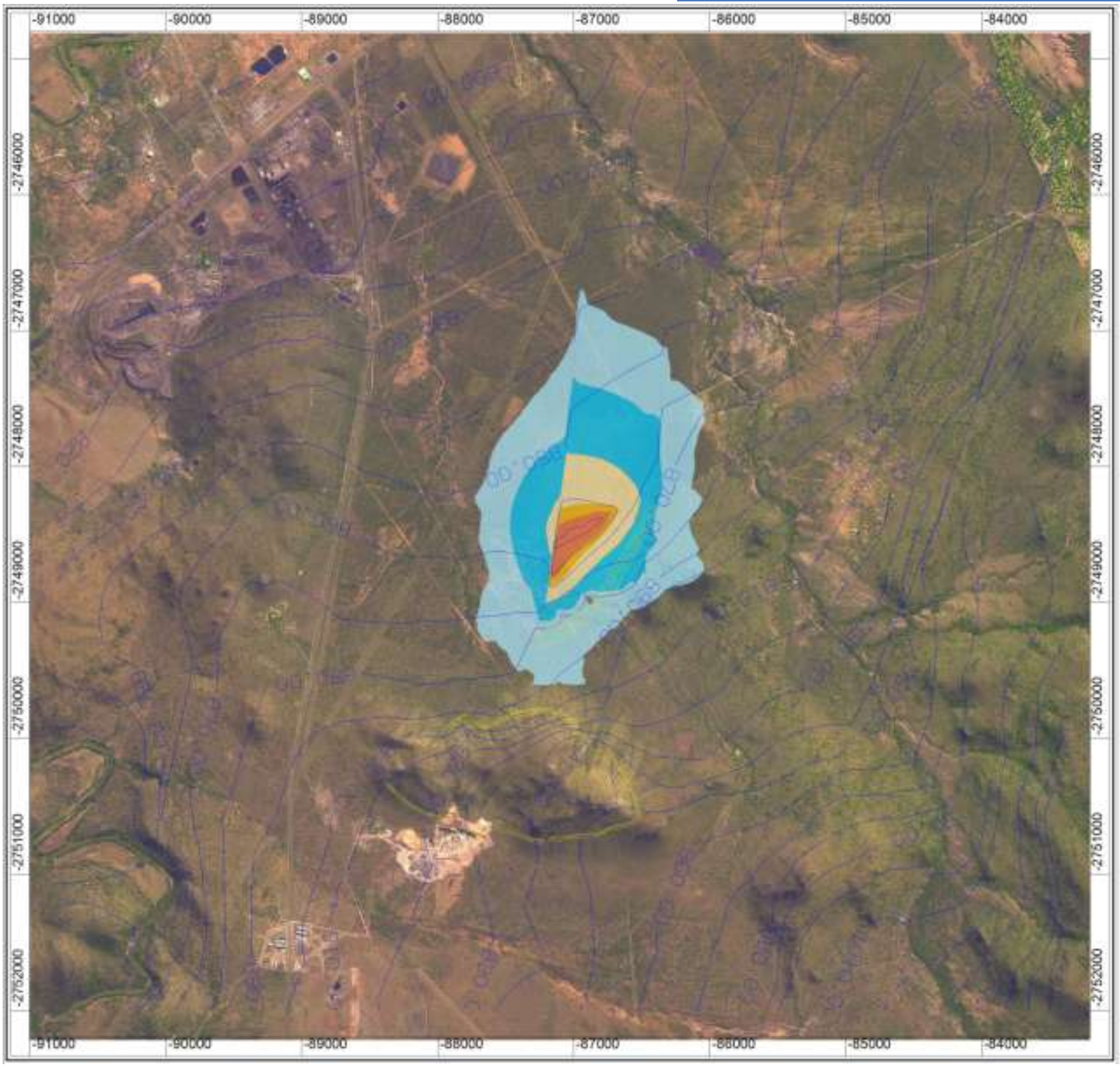

Figure 19: Simulated (steady-state) cone of dewatering [m] due to groundwater inflows into the Spitskop Flats open pit (chrome seam shown in yellow).

6.4. CONFIDENCE IN MODEL PREDICTIONS

6.4.1. Methodology

In the absence of other internationally accepted standard, 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 according to this guideline are given in Appendix C, and depend 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 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) in Appendix E, 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.

6.4.2. 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 8).

Table 8: Criteria specific and overall model confidence level classification.

Criteria	Confidence level classification	Key indicators
Data	1	No available records of metered groundwater extraction or evapotranspiration rates of wetlands Single water level measurements spread over a decade (2007 – 2015)
Calibration	1	Calibration is based on an inadequate temporal distribution of data. Calibration only to datasets (water levels) other than that required for prediction (inflows)
Prediction	1	Model predictive time frame is more than 10 times longer than transient calibration period
Overall	1	All criteria fall into a Class 1, model to be updated once more data become available

6.4.3. Recommendations to improve model confidence

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

1. Continuous (quarterly) monitoring of groundwater levels in the existing and newly proposed (refer to recommendations in sub-sequent section) monitoring boreholes.
2. Independent estimation of recharge rates.
3. Independent estimation of baseflow in the perennial Steelpoort River.

Once more data, especially groundwater level data over a full hydrological year or initial pit inflow rates become available, a transient calibration of the model should be performed and the model predictions reviewed.

Predicted mine inflow rates and associated impacts for later years of mine development can significantly be improved by observation data from earlier years and subsequent updates of the groundwater model.

7. SUMMARY AND RECOMMENDATIONS

7.1. SUMMARY

The aquifers in the model area were conceptualised as a shallow weathered and alluvial aquifer underlain by a deeper fractured aquifer system within the Bushveld Igneous Complex, dissected by numerous discontinuities (fractures and dykes) in the area. Utilising data from boreholes sampled during a hydrocensus, the site specific groundwater quality is described as a magnesium-bicarbonate water facies, typical of shallow groundwater in the Bushveld Igneous Complex. Elevated concentrations of chromium and nitrate are noted and could be of natural and/or anthropogenic origin. While elevated chromium concentrations are often related to groundwater contact with the ore body itself, elevated nitrate concentrations might represent blasting residues from upstream mining activities or, as in many cases in the Bushveld Igneous Complex, naturally occurring nitrogen presence in the soil and rock formations. Additional investigations in this regard are recommended.

The conceptual hydrogeological model was converted into a three-dimensional (four-layer) numerical finite-element groundwater model using the modelling software SPRING. Using available data, a satisfactory steady-state calibration of the model was achieved. The proposed BCR open cast mine workings was incorporated into the calibrated groundwater flow model by updating the digital elevation model for the pit area and assigning a free seepage boundary to the pit, assuming that any groundwater entering the pit is pumped out. The model was then used to estimate the steady-state inflow rates into the fully developed pit based on annual average groundwater recharge rates.

The modelling results confirmed that no groundwater seepage is to be expected into the open cut along the Klarinet- and Tubatse Koppie resource areas due to the deeper groundwater levels below the bottom of the proposed pits. However, groundwater flow into the Spitskop Flats open pit have to be dewatered at a rate of around 2.8 l/s The dewatering rates are relatively low because of the low conductivity of the host rocks and small drainage area upstream of the pit. The reduction of groundwater baseflow is predicted to be insignificant (based on the low inflow rates).

No significant impact on the water quality is expected due to the low sulphur content in waste material from other mines in the area and a likely neutral to alkaline leachate quality with slightly elevated mineralisation in comparison to the ambient groundwater. The potential plume emanating from the stockpiles and/or waste rock dumps will be limited in extent and expected to diminish post-closure.

7.2. RECOMMENDATIONS

The following recommendations are proposed to monitor and minimise potential impacts on the receiving groundwater environment:

- An environmental monitoring programme should be established in order to monitor groundwater quality and groundwater level changes up- and downstream of the proposed open cast mine workings. Collected monitoring data (quarterly) may be used for future model updates (e.g. every second year).
    - A number of geosites (i.e. boreholes, springs and surface water drainages) and newly proposed boreholes were identified (refer to fig) to be included into a monthly/quarterly monitoring programme for the BCR Minerals operation.
    - The parameters to be analysed should comprise the following:
        - Physico-chemical parameters (pH, EC, TDS);
        - Major anions (F, Cl, NO_3, SO_4, HCO_3, NH_4, PO_4,);
        - Major cations (K, Na, Mg, Ca, NH_4,); and
        - Other elements/metals (Fe, Mn, Zn, Pb, Co, Cr, Cr (VI),).

- Emphasis should be placed on monitoring of groundwater levels prior mining and during the operation phase as well as to establish the origin of the elevated nitrate concentrations in the project area.
- Recording of pit dewatering rates.
  - Initial monthly (and later quarterly) sampling and analysis (major and trace elements) of pumped water.

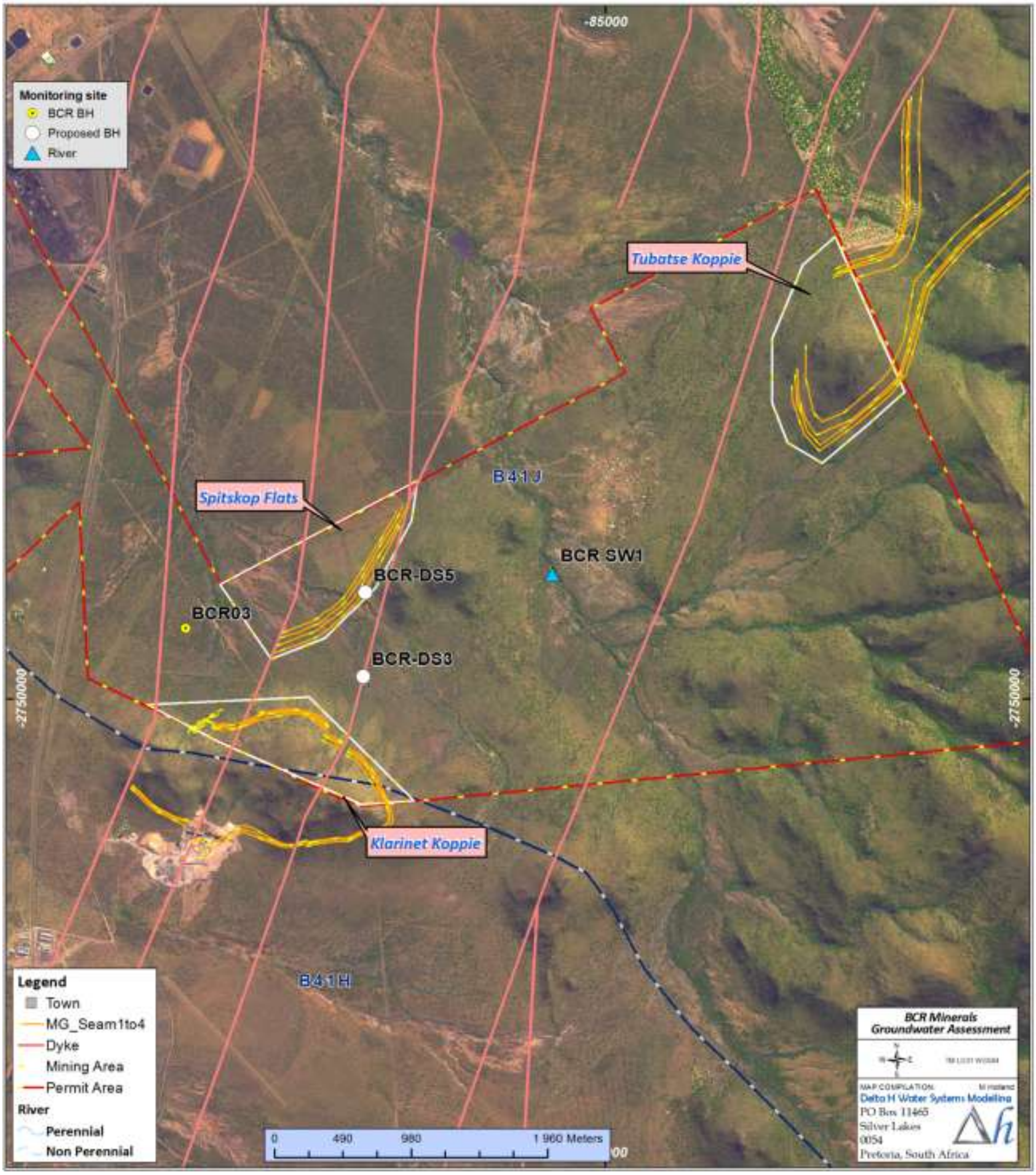

Figure 20: BCR Minerals proposed monitoring sites.

Await final mine layout

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9. DISCLAIMER

Delta-H Water System Modelling Pty Ltd (Delta H) has executed this study along professional and thorough guidelines, within their scope of work. The model development is in large parts based on aquifer data provided by others. Delta H does not accept any liability for the accuracy or representivity of the data provided by others.

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APPENDIX A– BOREHOLES VISITED (PHOTO'S)

Borehole BCR02

Borehole BCR02

Surface Water BCR01

Borehole DCM01

Borehole BH01

Borehole BH02

Borehole BH03

Borehole BH04

Borehole BH05

Borehole BH06

Borehole BH07

Borehole BH08

Borehole BH09

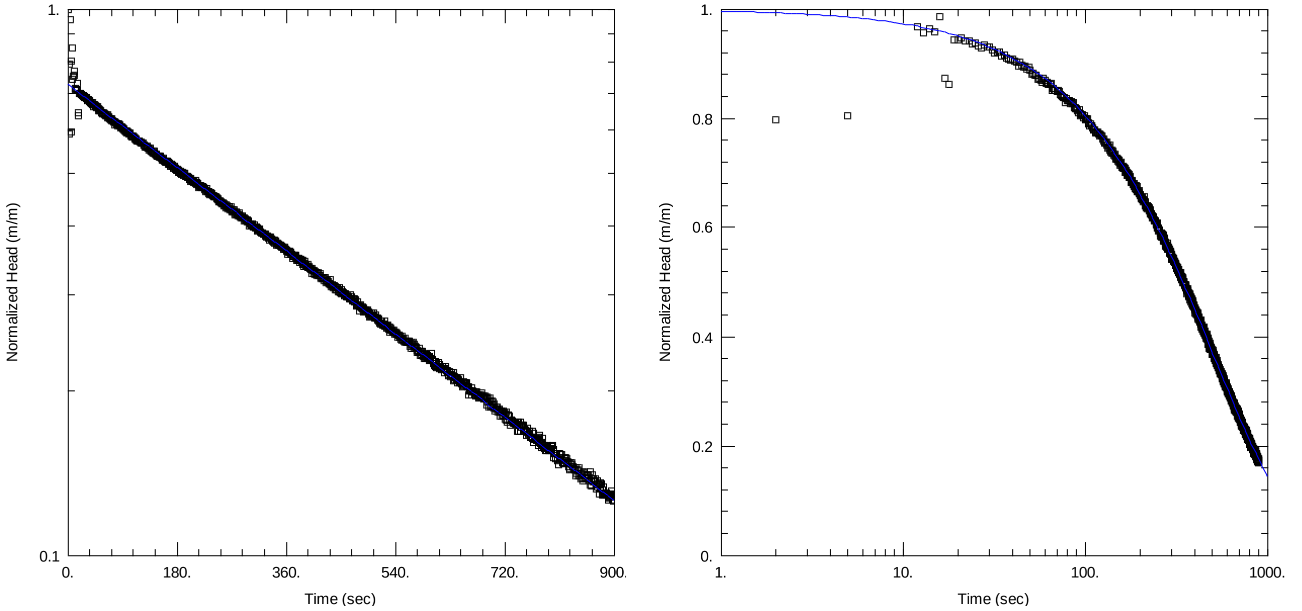
Borehole BH11

Borehole BH10	Borehole TWFBH01
	
Borehole TWFBH02	

APPENDIX B – DIAGNOSTIC PLOTS

BH02 – Slug Test

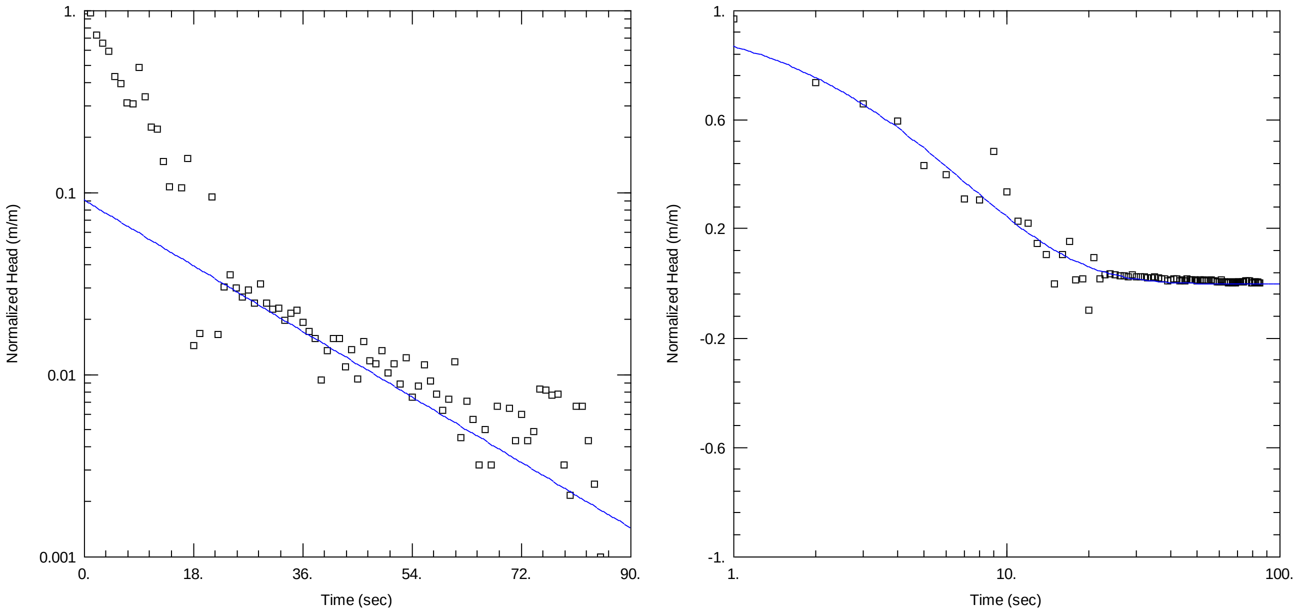
Parameter	Value	
Slug volume/size	100 mm	
Time	900 seconds	
Static WL	31.6 mbgl	
Displacement (water level)	0.81 m	
BH Depth		
Hydraulic parameter	**Value**	**Aquifer Model / Solution**
Hydraulic Conductivity	0.067 m/d	Bouwer-Rice (late time)
Hydraulic Conductivity	0.069 m/d	KGS model
Transmissivity	5.052 m^2/d ()	Cooper et al



Normalised head plot based on groundwater level displacement for Borehole BH02 and fitted Bouwer-Rice and KGS Model for slug in.

BH11 – Slug Test

Parameter	Value	
Slug volume/size	100 mm	
Time	85 seconds	
Static WL	14 mbgl	
Displacement (water level)	0.6 m	
BH Depth		
Hydraulic parameter	**Value**	**Aquifer Model / Solution**
Hydraulic Conductivity	4.69 m/d	Bouwer-Rice (early time)
Hydraulic Conductivity	1.47 m/d	Bouwer-Rice (late time)
Hydraulic Conductivity	4.97 m/d	KGS model
Transmissivity	369 m^2/d ()	Cooper et al



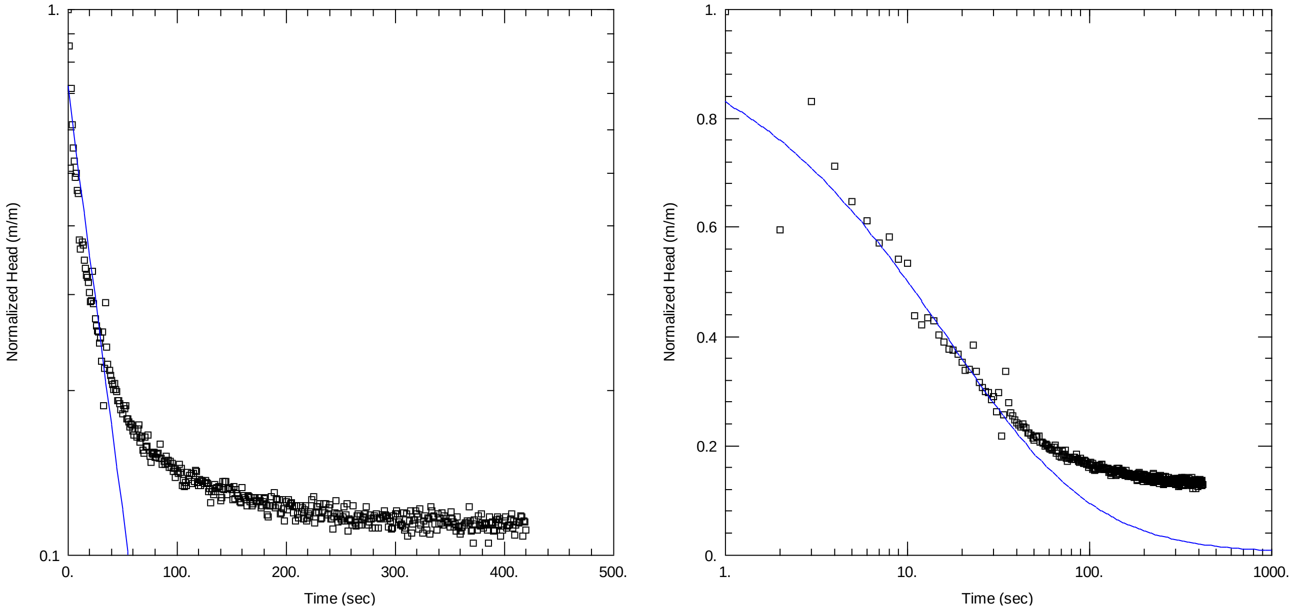
Normalised head plot based on groundwater level displacement for Borehole BH11 and fitted Bouwer-Rice and KGS Model for slug in.

BH15 – Slug Test

Parameter	Value	
Slug volume/size	100 mm	
Time	240 seconds	
Static WL	24 mbgl	
Displacement (water level)	1.2 m	
BH Depth		
Hydraulic parameter	**Value**	**Aquifer Model / Solution**
Hydraulic Conductivity	0.001 m/d	Bouwer-Rice (late time)

TWF BH01 – Slug Test

Parameter	Value	
Slug volume/size	100 mm	
Time	420 seconds	
Static WL	8.3 mbgl*	
Displacement (water level)	0.43 m	
BH Depth		
Hydraulic parameter	**Value**	**Aquifer Model / Solution**
Hydraulic Conductivity	1.14 m/d	Bouwer-Rice (early time)
Hydraulic Conductivity	0.01 m/d	Bouwer-Rice (late time)
Hydraulic Conductivity	0.46 m/d	KGS model
Transmissivity	13.75 m^2/d ()	Cooper et al



Normalised head plot based on groundwater level displacement for Borehole TWFBH01 and fitted Bouwer-Rice and KGS Model for slug in.

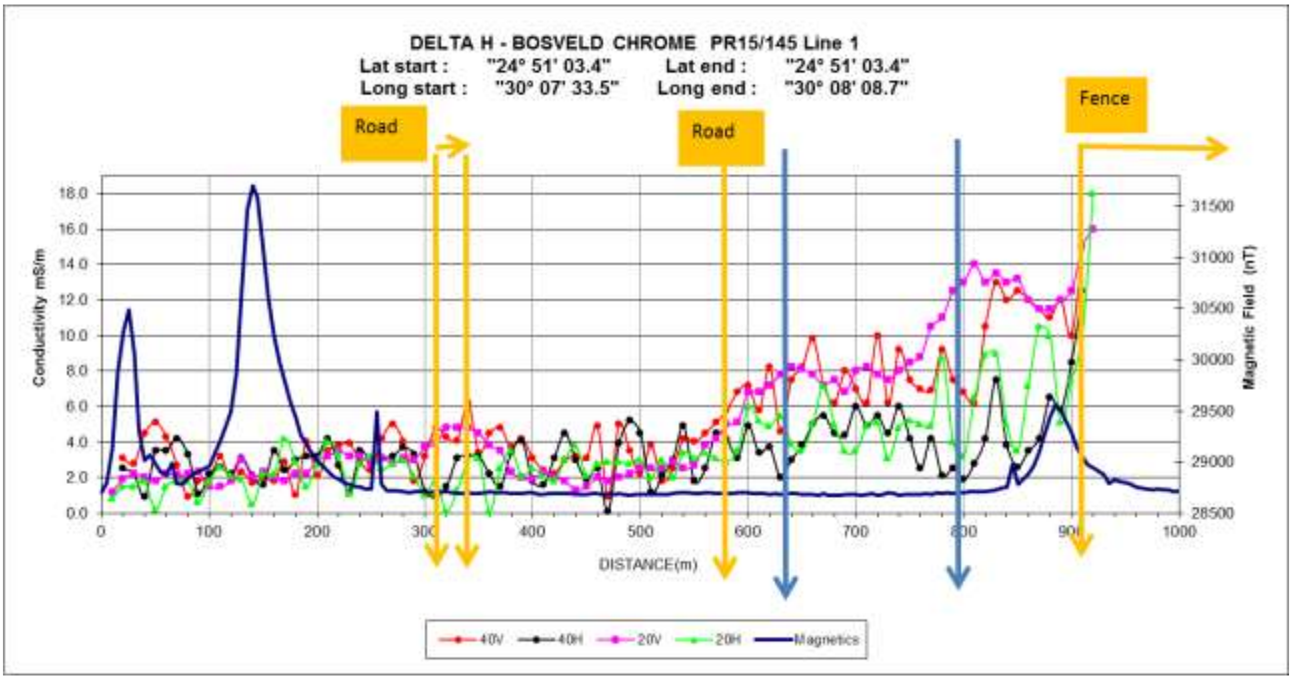
TWF BH02 – Slug Test

Parameter	Value
Slug volume/size	100 mm
Time	260 seconds
Static WL	6.6 mbgl*
Displacement (water level)	0.8 m

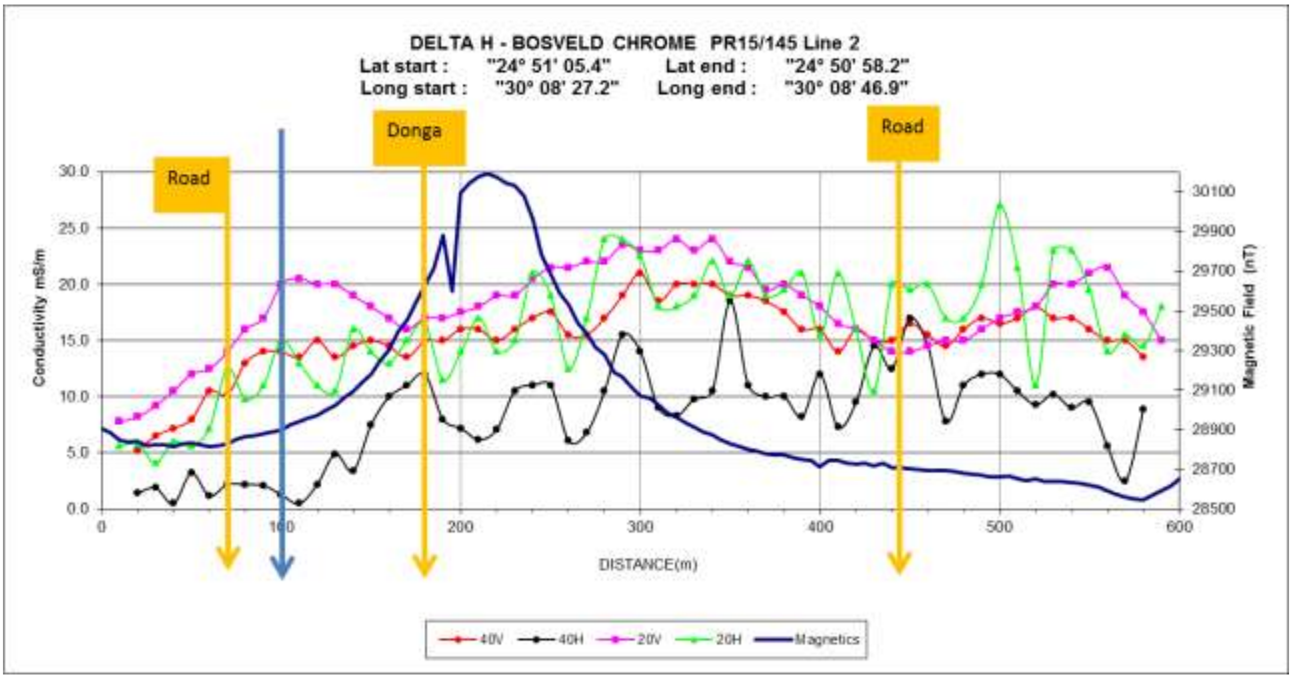
BH Depth		
Hydraulic parameter	**Value**	**Aquifer Model / Solution**
Hydraulic Conductivity	0.001 m/d	Bouwer-Rice (late time)

APPENDIX C – GEOPHYSICS

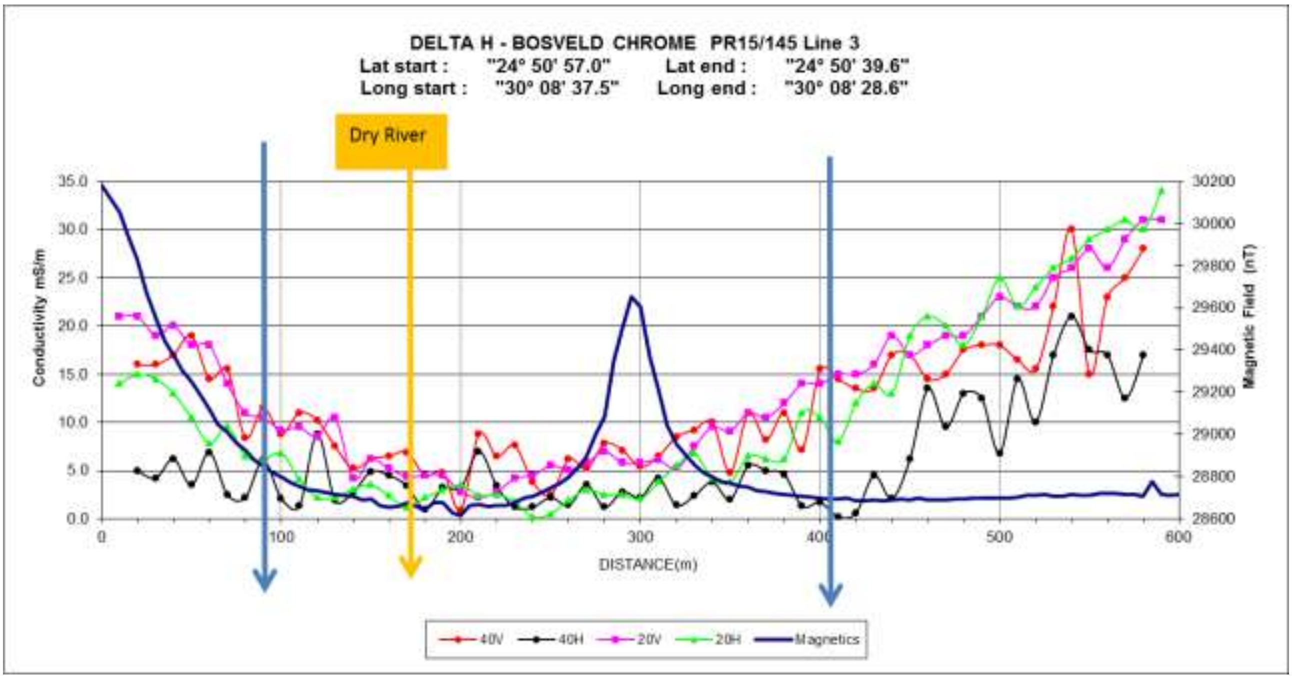
Traverse-1



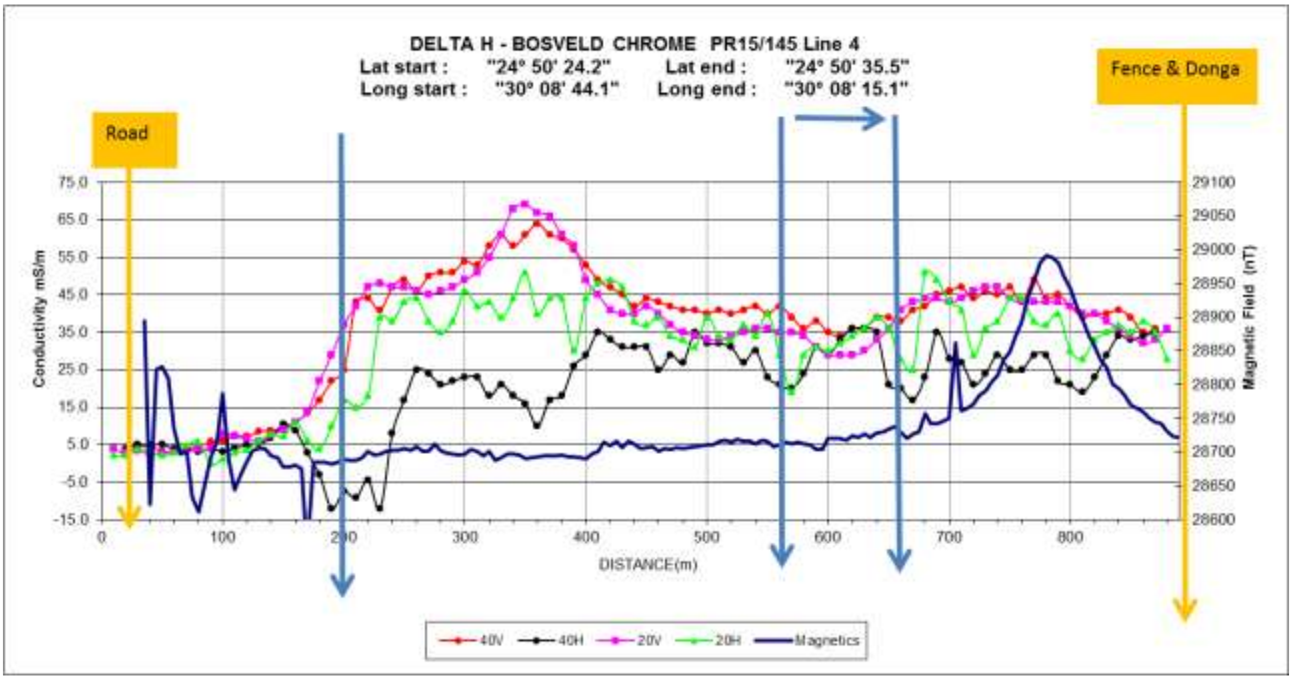
Traverse-2



Traverse-3



Traverse-4


DELTA H - BOSVELD CHROME PR15/145 Line 4
Lat start : "24° 50' 24.2" Lat end : "24° 50' 35.5"
Long start : "30° 08' 44.1" Long end : "30° 08' 15.1"
Road
Fence & Donga
Conductivity mS/m
Magnetic Field (nT)
DISTANCE(m)
40V
40H
20V
20H
Magnetics

APPENDIX D– LABORATORY CERTIFICATES

APPENDIX E – MODEL CLASSIFICATION

Model confidence level classification—characteristics and indicators (Barnett et al. 2012).

Confidence level classification	*Data*	*Calibration*	*Prediction*	*Key indicator*	*Examples of specific uses*
Class 3	• Spatial and temporal distribution of groundwater head observations adequately define groundwater behaviour, especially in areas of greatest interest and where outcomes are to be reported. • Spatial distribution of bore logs and associated stratigraphic interpretations clearly define aquifer geometry. • Reliable metered groundwater extraction and injection data is available. • Rainfall and evaporation data is available. • Aquifer-testing data to define key parameters. • Streamflow and stage measurements are available with reliable baseflow estimates at a number of points. • Reliable land-use and soil-mapping data available. • Reliable irrigation application data (where relevant) is available. • Good quality and adequate spatial coverage of digital elevation model to define ground surface elevation.	• Adequate validation* is demonstrated. • Scaled RMS error (refer Chapter 5) or other calibration statistics are acceptable. • Long-term trends are adequately replicated where these are important. • Seasonal fluctuations are adequately replicated where these are important. • Transient calibration is current, i.e. uses recent data. • Model is calibrated to heads and fluxes. • Observations of the key modelling outcomes dataset is used in calibration.	• Length of predictive model is not excessive compared to length of calibration period. • Temporal discretisation used in the predictive model is consistent with the transient calibration. • Level and type of stresses included in the predictive model are within the range of those used in the transient calibration. • Model validation* suggests calibration is appropriate for locations and/or times outside the calibration model. • Steady-state predictions used when the model is calibrated in steady-state only.	• Key calibration statistics are acceptable and meet agreed targets. • Model predictive time frame is less than 3 times the duration of transient calibration. • Stresses are not more than 2 times greater than those included in calibration. • Temporal discretisation in predictive model is the same as that used in calibration. • Mass balance closure error is less than 0.5% of total. • Model parameters consistent with conceptualisation. • Appropriate computational methods used with appropriate spatial discretisation to model the problem. • The model has been reviewed and deemed fit for purpose by an experienced, independent hydrogeologist with modelling experience.	• Suitable for predicting groundwater responses to arbitrary changes in applied stress or hydrological conditions anywhere within the model domain. • Provide information for sustainable yield assessments for high-value regional aquifer systems. • Evaluation and management of potentially high-risk impacts. • Can be used to design complex mine-dewatering schemes, salt-interception schemes or water-allocation plans. • Simulating the interaction between groundwater and surface water bodies to a level of reliability required for dynamic linkage to surface water models. • Assessment of complex, large-scale solute transport processes.
Class 2	• Groundwater head observations and bore logs are available but may not provide adequate coverage throughout the model domain. • Metered groundwater-extraction data may be available but spatial and temporal coverage may not be extensive. • Streamflow data and baseflow estimates available at a few	• Validation* is either not undertaken or is not demonstrated for the full model domain. • Calibration statistics are generally reasonable but may suggest significant errors in parts of the model domain(s). • Long-term trends not replicated in all parts of the model domain.	• Transient calibration over a short time frame compared to that of prediction. • Temporal discretisation used in the predictive model is different from that used in transient calibration. • Level and type of stresses included in the predictive model are outside the	• Key calibration statistics suggest poor calibration in parts of the model domain. • Model predictive time frame is between 3 and 10 times the duration of transient calibration. • Stresses are between 2 and 5 times greater than those included in calibration. • Temporal discretisation in predictive model is not the same	• Prediction of impacts of proposed developments in medium value aquifers. • Evaluation and management of medium risk impacts. • Providing estimates of dewatering requirements for mines and excavations and the associated impacts.

Confidence level classification	*Data*	*Calibration*	*Prediction*	*Key indicator*	*Examples of specific uses*
	points. • Reliable irrigation-application data available in part of the area or for part of the model duration.	• Transient calibration to historic data but not extending to the present day. • Seasonal fluctuations not adequately replicated in all parts of the model domain. • Observations of the key modelling outcome data set are not used in calibration.	range of those used in the transient calibration. • Validation* suggests relatively poor match to observations when calibration data is extended in time and/or space.	as that used in calibration. • Mass balance closure error is less than 1% of total. • Not all model parameters consistent with conceptualisation. • Spatial refinement too coarse in key parts of the model domain. • The model has been reviewed and deemed fit for purpose by an independent hydrogeologist.	• Designing groundwater management schemes such as managed aquifer recharge, salinity management schemes and infiltration basins. • Estimating distance of travel of contamination through particle-tracking methods. Defining water source protection zones.
Class 1	• Few or poorly distributed existing wells from which to obtain reliable groundwater and geological information. • Observations and measurements unavailable or sparsely distributed in areas of greatest interest. • No available records of metered groundwater extraction or injection. • Climate data only available from relatively remote locations. • Little or no useful data on land-use, soils or river flows and stage elevations.	• No calibration is possible. • Calibration illustrates unacceptable levels of error especially in key areas. • Calibration is based on an inadequate distribution of data. • Calibration only to datasets other than that required for prediction.	• Predictive model time frame far exceeds that of calibration. • Temporal discretisation is different to that of calibration. • Transient predictions are made when calibration is in steady state only. • Model validation* suggests unacceptable errors when calibration dataset is extended in time and/or space.	• Model is uncalibrated or key calibration statistics do not meet agreed targets. • Model predictive time frame is more than 10 times longer than transient calibration period. • Stresses in predictions are more than 5 times higher than those in calibration. • Stress period or calculation interval is different from that used in calibration. • Transient predictions made but calibration in steady state only. • Cumulative mass-balance closure error exceeds 1% or exceeds 5% at any given calculation time. • Model parameters outside the range expected by the conceptualisation with no further justification. • Unsuitable spatial or temporal discretisation. • The model has not been reviewed.	• Design observation bore array for pumping tests. • Predicting long-term impacts of proposed developments in low-value aquifers. • Estimating impacts of low-risk developments. • Understanding groundwater flow processes under various hypothetical conditions. • Provide first-pass estimates of extraction volumes and rates required for mine dewatering. • Developing coarse relationships between groundwater extraction locations and rates and associated impacts. • As a starting point on which to develop higher class models as more data is collected and used.