APPENDIX H: GEOHYDROLOGICAL STUDY

SLR Consulting PTY Ltd

Groundwater Impact Assessment for the Commissiekraal Coal Mine Project

Project Number: Delh.2013.018-5

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Table of Contents

List of Figures and Tables

EXECUTIVE SUMMARY

Delta-H Water Systems Modelling PTY (Ltd) has been appointed by SLR Consulting to provide groundwater specialist input for the assessment of the proposed Commisiekraal underground coal mine roughly 27 km west of Paulpietersburg. The specialist input consisted of the development of a site-specific numerical groundwater flow and contaminant transport model based on hydrogeological information gained from the drilling and testing of groundwater boreholes as well as exploration core holes drilled during the geological exploration phases.

The typical Karoo aquifer systems in the area of interest were conceptualised as a shallow weathered water table aquifer underlain by a deeper fractured semi-confined aquifer system. Vertical seepage of water from the more permeable weathered aquifer into the fractured aquifer is typically limited by low permeable layers of sediments below the weathered zone and especially by the presence of dolerite sills. Localised perched aquifers occur within colluvium or on weathered siltstone and feed seasonal hillside seeps and springs. Perennial springs in the area of interest occur predominantly as free draining contact springs associated with the dolerite sill at higher elevations of the catchment.

Forty five geosites were visited during the hydrocensus comprising of 12 surface water points, 7 exploration core holes, 21 springs, 3 hand pumps and 1 borehole. Water samples were collected from 11 surface water points, 3 boreholes (including hand pumps) and 3 springs. Due to the low groundwater potential of the underlying aquifers in the region, groundwater use is limited to domestic water supply and feedlots. Limited water supply occurs from borehole abstraction (apart from the hand pumps installed at schools). Usage of groundwater via capturing of spring discharges is more common. Based on the results the groundwater and surface water samples taken during the hydrocensus have a relatively low mineralisation with electrical conductivities of around 120 mS/m and a pH of around 7.5.

The geophysical survey conducted during May 2015 focussed specifically on the proposed underground mine section underlying the Pandana River. Due to the absence of a distinctive aquiclude (i.e. dolerite sill) overlying the mine workings in this section the risk for significant impacts on the river baseflow due to mining was considered high and needed an improved hydrogeological understanding. The objective of the survey was to investigate the sub surface for geological structures and deep weathering zones and to optimize the selection of drilling sites. Five (5) boreholes (2 deep and 3 shallow) were drilled as part of this investigation with the aim to improve the understanding the hydraulic link between the shallow and deeper aquifer system overlying the proposed underground coal mine. Pumping tests results indicate a limited extent respectively yield of the aquifer.

The conceptual hydrogeological model was converted into a three-dimensional numerical finite-element groundwater model. Using available groundwater data for the area of interest, a very satisfactory steady-state calibration of the numerical model was achieved and the model subsequently used to quantify the steady-state groundwater inflows into the underground mine workings for years 4, 10 and 20 (life of mine). The predictive modelling results of the mine inflows and groundwater contribution to the Pandana River was simulated under different recharge scenarios, namely average, low and high in order establish the impact on the water balance under different climate conditions.

The model estimates the average groundwater inflows into the final mine voids to around 660 572 m^3/a or around 20.1 L/s. The ensuing cone of dewatering due to mine inflows will capture groundwater, which would have otherwise contributed to spring discharges, leakages along hill slopes, wetlands, river baseflow or to deeper regional groundwater flow. Due to its generally low permeability, the cone of dewatering in the fractured aquifer is steeper and extends far further than the cone in the shallow aquifer.

Groundwater dependant eco-systems (i.e. wetlands) and yields of springs located within the significant zone of dewatering of the shallow aquifer, limited to the site boundaries, could be negatively impacted and some may dry up during the life of mine. However, not all wetlands are groundwater dependant and some of these wetlands might be supported by perched aquifers with a significant contribution from inter flow (in the vadose zone) and surface run-off in the rainy seasons.

Groundwater contributes to baseflow throughout the upper Pandana River catchment via sub-surface seepage into surface water courses. Average groundwater contributions to the upper Pandana River are estimated at 17.3 L/s while a loss of 8 L/s was simulated at life of mine (20 years). While an obvious reduction of baseflow is expected towards the Pandana River due to the underground mine its flow is also largely dependent on surface water run-off and interflow (stored and transported) in the vadose zone

Post-closure, the mine voids represent a highly permeable flow path, which will result in new equilibrium water levels within the area of influence. Under the assumption of constant groundwater gradients towards and subsequent inflows into the mine it will take around 22 years for the mine void to fill and based on the post-closure modelling results it will take around 25 to 40 years for the aquifers above the mine to return to pre-mining conditions. The potential post closure impacts of decant from the underground mine voids on the groundwater quality are a distinct possibility. The decant predictions are burdened with substantial uncertainties and should be reviewed once inflow data from early mining operations become available.

If a constant source term of 100 % is assumed for the decant (seepage) water quality, a shallow pollution plume will develop downstream of the Pandana valley and downstream of the adit. Plume concentrations of between 30 and 60 % are likely to occur within the weathered aquifer underlying and contributing to a number of tributaries. However, the associated mass fluxes are likely to be small (compared to interflow and surface run-off) and likely to dilute quickly in the surface water.

While Delta H would classify the confidence in the conceptualisation of the aquifer system as well as the steady state model calibration alone as medium, the fact that the predictive time frame and stresses exceed the calibration timeframe and considered stresses pushes the overall model confidence back.

1. INTRODUCTION

1.1. Background and Modelling Objectives

Delta-H Water Systems Modelling PTY (Ltd) has been appointed by SLR Consulting to conduct a groundwater impact assessment for the Commissiekraal (Greenfields) coal mine project. The specialist input consisted of the development of a site-specific numerical groundwater flow and contaminant transport model based on the developed conceptual model. The study included the drilling of boreholes and hydraulic tests to determine the site specific hydraulic characteristics of the different aquifer systems potentially affected by the project by intrusive investigations. The numerical model has been used to assess potential impacts on the groundwater quantity (level) due to inflows into the proposed underground mine workings (cones of dewatering in the shallow weathered and deeper fractured aquifers), potential impacts of the mining operations on the ambient groundwater quality using an advective-dispersive transport model i.e. a conservative approach, and the potential for post-closure decant.

1.2. Scope of Work

The following scope of work was proposed for the Commissiekraal groundwater assessment:

- Establish current pre-mining groundwater quality and groundwater level baseline conditions.
- Advise client on hydrogeological characterising borehole locations and design (based on a detailed geophysical investigation).
- Oversee drilling and hydraulic testing of new boreholes.
- Characterise site specific aquifers.
- Develop a site-specific numerical groundwater flow and transport model to assess:
    - potential groundwater inflows into underground mine workings during life of mine;
    - the potential of post-closure decant from the mine voids;
    - potential pollution plumes developing from mine residue deposits; and
    - potential mitigation measures for identified impacts.

1.3. Data Sources and Deficiencies

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:

- Regional and local geological maps.
- 1:250 000 2730 Vryheid geological map (Council for Geoscience)
- Groundwater Resources Information (GRA II) Project (DWAF, 2006) – Quaternary Scale
- Vegter (1995) groundwater map set
- Digital elevation model (Survey and Mapping 5m contours).
- Digital mine layout (COMMUG_PPP-DEV_DOC_CASE01_REV01.Dxf) (16 April 2015).
- Groundwater level data from the National Groundwater Archive maintained by the Department of Water Affairs.
- Site-specific water level measurements and hydraulic tests on existing exploration coreholes and newly drilled boreholes.
- Water quality from samples collated during the hydrocensus and from the newly drilled boreholes.

1.4. Impact Assessment

The numerical groundwater flow and transport model has been used to predict and assess potential impacts of the proposed development on the groundwater environment. Such impacts might be related to (Saayman 2005):

- a change in the groundwater quality,
- a change in the volume of groundwater in storage or entering groundwater storage (recharge), or
- a change in the groundwater flow regime.

The impact ratings in Chapter 8 assess the significance of such changes following the recommendations by the Department of Environmental Affairs and Tourism (DEAT 2002). The applied ranking criteria and associated definitions are summarised in tabular form below.

Table 1.1: Ranking criteria for potential environmental impacts.

LOW	MEDIUM	HIGH
Extent (spatial scale)		
Impact is localized within site boundary	Widespread impact beyond site boundary; Local	Impact widespread far beyond site boundary; Regional/national
Duration		
Quickly reversible, less than project life, short term (0-5 years)	Reversible over time; medium term to life of project (5-15 years)	Long term; beyond closure; permanent; irreplaceable or irretrievable commitment of resources
Probability of occurrence		
Unlikely; low likelihood; seldom. No known risk or vulnerability to natural or induced hazards.	Possible, distinct possibility, frequent Low to medium risk or vulnerability to natural or induced hazards.	Definite (regardless of prevention measures), highly likely, continuous. High risk or vulnerability to natural or induced hazards.

Table 1.2: Ranking criteria for the intensity (severity) of potential environmental impacts.

Type of Criteria	Negative			Positive		
	HIGH-	MEDIUM-	LOW-	LOW+	MEDIUM+	HIGH+
Qualitative	Substantial deterioration, death, illness or injury, loss of habitat/ diversity or resource, severe alteration or disturbance of important processes.	Moderate deterioration, discomfort, Partial loss of habitat/biodiversity/resource or slight or alteration	Minor deterioration, nuisance or irritation, minor change in species/habitat/ diversity or resource, no or very little quality deterioration.	Minor improvement, restoration, improved management	Moderate improvement, restoration, improved management, substitution	Substantial improvement, substitution
Quantitative	Measurable deterioration. Recommended level will often be violated (e.g. pollution)	Measurable deterioration. Recommended level will occasionally be violated	No measurable change; Recommended level will never be violated	No measurable change; Within or better than recommended level.	Measurable improvement	Measurable improvement
Community response	Vigorous	Widespread complaints	Sporadic complaints	No observed reaction	Some support	Favourable publicity

2. GENERAL SETTING

2.1. LOCALITY AND DRAINAGE

The project area is located approximately 27 km west of Paulpietersburg within the Emadlangeni (Utrecht) Local Municipality of the Amajuba District Municipality, in the province of KwaZulu-Natal (Figure 2.1). The site falls within the upper reaches of quaternary catchment W42A, which lies immediately east of the regional water divide between the Thukela River catchment and the Usutu-, Pongola and Mhlatuze River catchment. As a result the site falls along the western edge of the Usutu to Mhlathuze Water Management Area which drains in a general eastward direction. The morphology is characterised by Kruger (1983) as low mountain terrain with a medium drainage density. The low mountains are separated from the undulating hills and low lands by a distinct escarpment, which crosses the area in a north - south direction, turning east - west near Wakkerstroom. Along the south-western edge of the project area the topographic watershed (of quaternary catchment W41A) rises to 2000 metres above mean sea level (mamsl) and reduces to approximately 1400 mamsl towards the north-east. The Pandana River flows in a northern direction through the centre of the Commissiekraal Project Area where it eventually turns east towards the confluence with the Phongolo River, approximately 17 km downstream.

2.2. REGIONAL GEOLOGY

The site is dominated by the Karoo Supergroup sediments comprising of shale, mudstone, sandstone, dolerite and coal of the Vryheid Formation. Just south of the proposed mining area the Vryheid Formation is overlain by similar rocks of the Volksrust Formation and Normandien Formation. The sediments of the Karoo Supergroup were intruded by doleritic magma from a southerly direction to form thick sills and dykes (Figure 2.2). In general, the higher lying elevated hills are characterised by resistant / hard, slightly weathered to un-weathered dolerite sills covering the softer / less resistant, weathering prone sedimentary rocks of the Vryheid Formation (e.g. sandstone and siltstones) that usually form deep valleys or depressions when exposed in areas not covered by interconnected dolerite sills and dykes. The springs in the area are due to groundwater flowing in the interbedded sedimentary rock (aquifers) covered and/or underlain by aquitards (dolerite) forming distinct surface discharge points / spring lines. Most of these springs form tributaries that flow into the main river systems. Quaternary sands (alluvium) are observed across the central and northern extents of the study area and are associated with the deposition of sands alongside the Pandana- and Phongolo River.

2.2.1. Site geology

The Gus seam is considered economically minable in the Commissiekraal area and occurs between 20 and 400 m below surface dipping in a south-westerly direction. The Lower Gus Seam is on average 2.7 m thick and, despite its depth from surface, is of economic interest because of its overall good coal qualities (ECMA, 2014). The coal seam will be accessed through a three-entrance box cut directly into the Gus lower seam from the side of the mountain/hill (Figure 2.2).The Life of Mine (LOM) is 20 years.

A massive dolerite sill overlies a large part of the coal-bearing sequence but is more prominent towards the south-east of the proposed underground mine workings (Figure 2.3) (Adapted from Copper Leaf, 2013). The area is dominated by northeast-southwest trending structures which can manifest as faults, dolerite dykes and fracture zones. It is acknowledged that there was some discrepancy between the interpretation and positioning of these structures, emphasizing the structural complexity (Refer to Copper Leaf, 2011). Figure 2.3 shows the more recent structural interpretation from ECMA (2014) that will be used for the groundwater investigation. The underground mine workings is based on the delineated structural blocks.

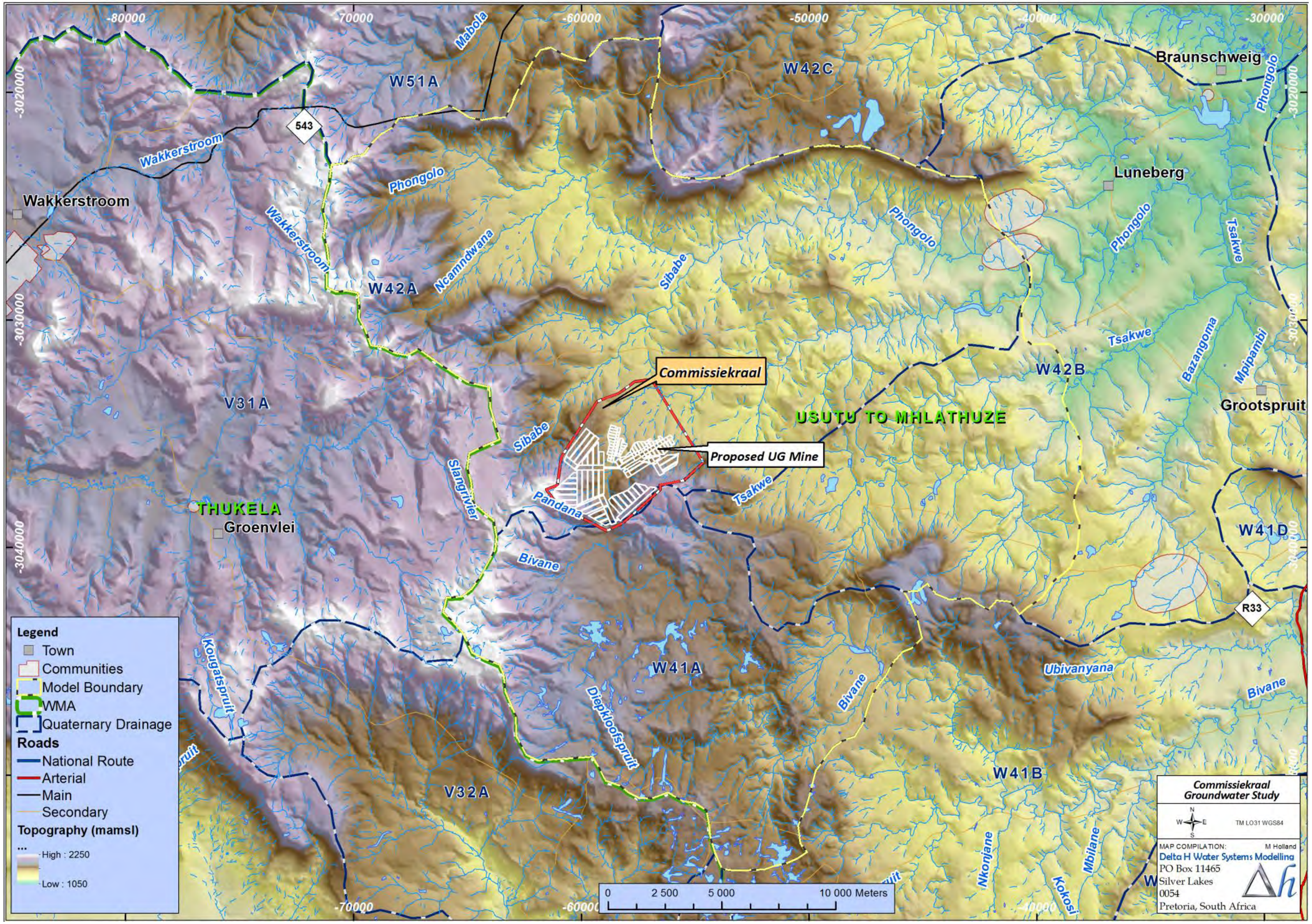


Figure 2.1: Locality map of the Commisiekraal Project area.

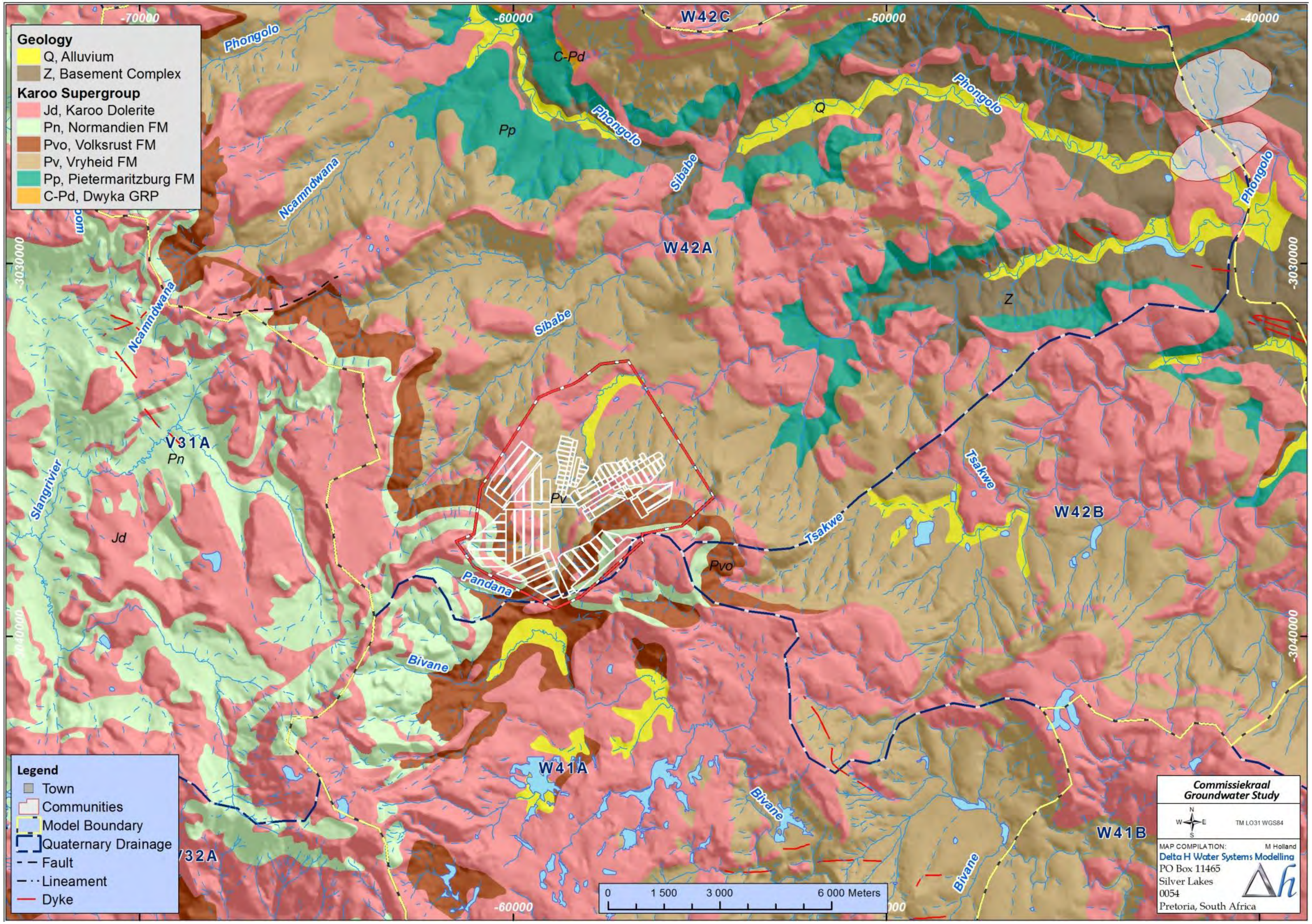


Figure 2.2: Regional geological setting.

Figure 2.3: Local geological setting in relation to the proposed mine workings.

2.3. GROUNDWATER OCCURRENCE AND AQUIFERS

From a regional and conceptual point of view the aquifer is characterised as an unconfined, intergranular and fractured rock aquifer. Typical boreholes yields expected in the intrusive dolerite rocks vary between 0.1 and 0.5 L/s and in the sedimentary Vryheid Formation vary between 0.5 and 2.0 L/s. Water strikes are mostly encountered in fractured rock, however weathering at the contact between the sandstone and shale within the Formation also yields groundwater. The groundwater yield potential is considered to be low since the probability of obtaining a yield of 2 l/s is between 10 and 30 % (Vegter, 1995), while the median borehole yields in the aranaceous Vryheid Formation rocks is 0.6 l/s (King, 2003).

Hodgson and Krantz (1998) differentiate three superimposed aquifer systems in the northern Kwazulu-Natal coal fields, namely the upper weathered Karoo, the fractured Karoo and the fractured pre-Karoo aquifer below the Ecca sediments.
In the study area the pre-Karoo aquifer is not applicable and only the upper weathered Karoo and the fractured Karoo aquifers will be discussed. The upper weathered Karoo aquifer is associated with this weathered zone and varies in depth between 5 and 20 mbgl. Water levels are often shallow (a few mbgl) and the water quality good due to direct rainfall recharge and dynamic groundwater flow through the unconfined aquifer in weathered sediments, which also makes it vulnerable to pollution. Localised perched aquifers may occur on clay layers or lenses. Vertical infiltration of water in the weathered aquifer is typically limited by impermeable layers of sediments below the weathered zone, with subsequent lateral movement following topographical gradients. Generally the sandstone and coal layers are normally reasonable aquifers, while the shales and intruded dolerite sill's serves as aquitards. Several layered aquifers perched on the relative impermeable shale are common in such sequences. Groundwater daylights at springs where the flow path is obstructed by dolerite dykes (contact spring) or paleo-topographic highs in the bedrock or where the surface topography cuts into the groundwater level at, for example, drainage lines (free draining springs).

Groundwater flow is governed by secondary porosities like faults, fractures, joints, bedding planes or other geological contacts, while the rock matrix itself is considered impermeable. Not all secondary structures are water bearing due to compressional forces by the neo-tectonic stress field overburden closing the apertures. While fractured Karoo aquifers have typically a low hydraulic conductivity (<0.001 m/d), they are highly heterogeneous with yields ranging from 0.1 to 2 L/sec. Higher yields are typically associated with higher hydraulic conductivities along shallow coal seams (±0.1 m/d) and at dyke/sill contacts. The contact zones of dolerite dykes and sills with the host rock provide preferential flow paths, while the dolerite itself is rather impermeable or semi-permeable. This setting promotes groundwater flow along, but not across the dykes or sills. Based on the exploration drilling at Commisiekraal water was found in medium to coarse sandstone as well as at lithological contacts[1] (sandstone-shale), suggesting that the groundwater flow is therefore considered predominantly down-dip (horizontal) with local variations due to (sub-vertical) fracture intersections.

[1] Personal Communication – Digby Gold [Copperleaf Consulting] 23 April 2015

3. SITE INVESTIGATION

3.1. HYDROCENSUS

As part of the hydrogeological impact assessment a hydrocensus was conducted during the first and second week of May 2015 to identify existing groundwater users and to establish the baseline water quality conditions of both groundwater and surface water. The gathered geosite information is summarised in Appendix A and the locations are shown spatially in Figure 2.2. According to best practice the hydrocensus covered different percentages of the area of interest, starting from 80 to 100 % coverage in the immediate vicinity of the proposed development to 20 % coverage in the wider area of interest (up to 11 km radius). Specific sampling sites included the Kemplust and Makatees Kop historical mine (area). However, during the survey the mines were essentially dry and the samples were taken from downstream streams, springs or boreholes (see map insert Figure 3.3).

Forty five geosites were visited comprising of 12 surface water points, 7 exploration coreholes, 21 springs, 3 hand pumps and 1 borehole. Water samples were collected from 11 surface water points, 3 boreholes (including hand pumps) and 3 springs and submitted to Waterlab (Pty) Ltd, a SANAS (South African National Accreditation System) accredited laboratory, for chemical analyses. A further 3 samples were collected on the 27^{th} of May 2015 and again on the 10th of September 2015 from the fountain and streams downstream (Mpipambi River) of the abandoned mine (residue dumps) of Makatees Kop, including a farm borehole.

Due to the low groundwater potential of the underlying aquifers in the region, groundwater use is limited to domestic water supply and feedlots. Limited water supply occurs from borehole abstraction (apart from the hand pumps installed at schools). Usage of groundwater via capturing of spring discharges is more common. Springs mark the termination of the underground flow path and capturing of spring discharges for domestic or livestock watering purposes can for all practical purposes be seen as groundwater use. Springs/seepages in the area are due to groundwater flowing in the interbedded sedimentary rock (aquifers) covered and/or underlain by aquitards (dolerite) forming distinct surface discharge points / spring lines. A typical setting of such a spring is shown in Photo 1. Many springs are also the source of many surface drainage channels. Spring '11' feeds into the Pandana River 250 m downstream of its origin.

Based on a review of available data in the Water Use Authorisation and Registration Management System (WARMS) it appears that there are no registered groundwater users of the Department of Water and Sanitation (DWS) within the vicinity of the Commisiekraal Project.

Photo 1. Spring '11' situated 70 m from exploration borehole MCK11 (Figure 2.3).

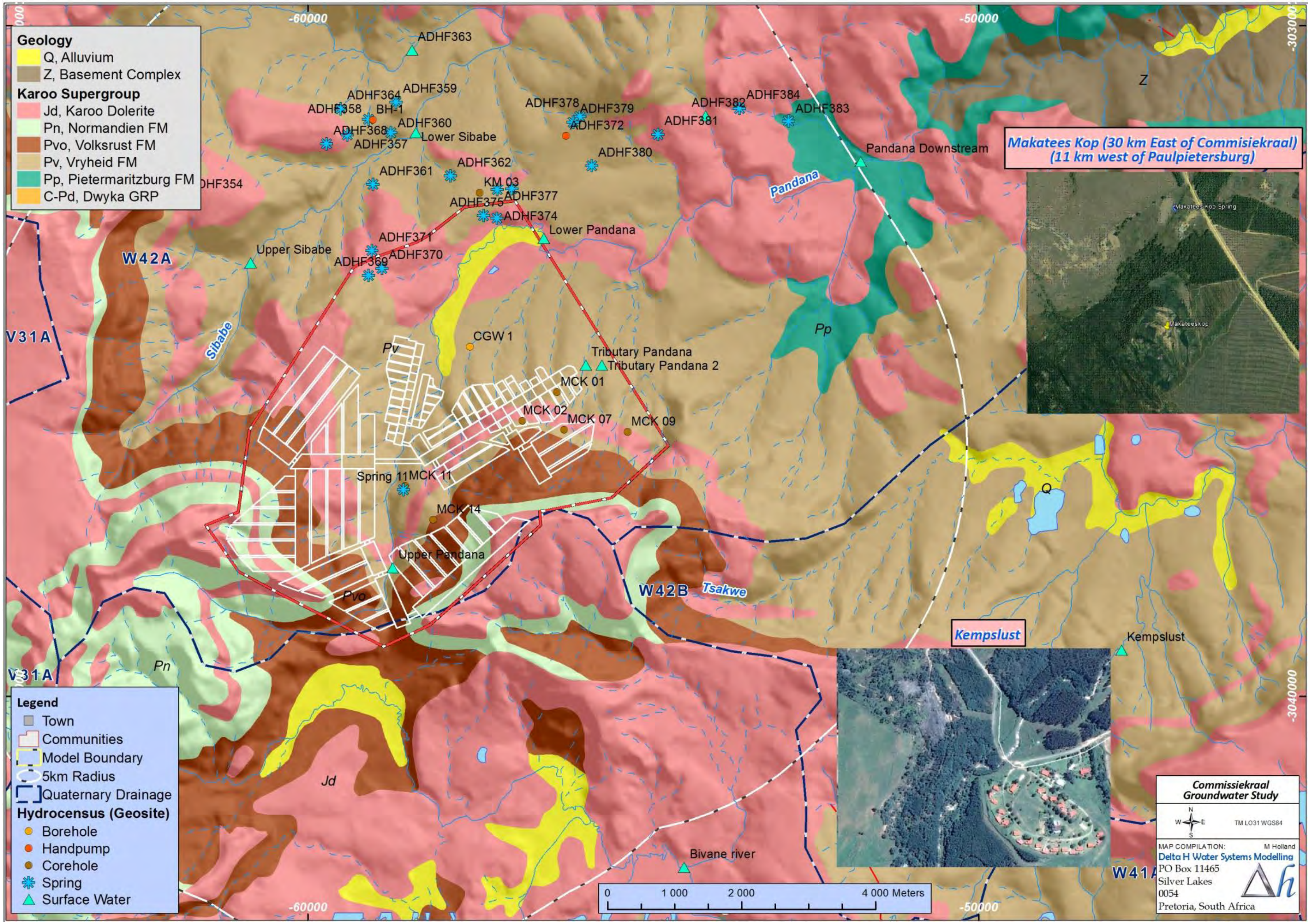


Figure 3.1: Hydrocensus survey positions.

3.2. GEOPHYSICAL SURVEY

The geophysical survey conducted during May 2015 focussed specifically on the proposed underground mine section underlying the Pandana River. Due to the absence of a distinctive aquiclude (i.e. dolerite sill) overlying the mine workings in this section the risk for significant impacts on the river baseflow due to mining was considered high and needed an improved hydrogeological understanding. The objective of the survey was to investigate the sub surface for geological structures and deep weathering zones and to optimize the selection of drilling sites. A total of five geophysical traverses were conducted which comprised of electromagnetic, magnetic and earth resistivity imaging methods:

- 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 meters. 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.
- Earth Resistivity Imaging Method (ERI)
  - The ERI was conducted with the Abem Lund 2D resistivity system. The most common minerals forming soils and rocks have very high resistivity in a dry condition, and the resistivity of soils and rocks is therefore normally a function of variations in water content and the concentration of dissolved ions in the groundwater. Resistivity investigations are thus used to identify zones with different electrical properties, which can then be referred to different geological strata. The electrode separation and survey protocol used, determines the depth of investigation. The measuring protocols used were Wenner array with an investigation depth of approximately 60 m, using 100 meter cables with 10 meter spacing intervals.

The geophysical traverses were surveyed at 10 m station intervals, with all stations marked in the field. The traverse positions are indicated in Figure 3.2 and the profiles are shown in Appendix B.

3.2.1. Geophysical results

The average weathering depth of these formations as defined by the ERI method is ~25 mbgl, and drilling targets are mainly deep weathering and fracture zones in the Karoo sediments. Ten provisional drilling sites were selected based on the anomalies identified from the geophysical profiles. A prominent positive magnetic anomaly (inferred dolerite dyke Figure 3.2) is present at site DS-6 on Traverse 3 and corresponds with a positive anomaly on Traverse 5 at site DS-9. The inferred dolerite dyke strike is approximately northeast-southwest which is similar to the structural trend. An inferred deep weathering and potential fracture zone was delineated based on the ERI results at site DS-2 on Traverse 1 and DS-4 on Traverse 2. This deep weathering and fracture zone could act as a possible preferred groundwater flow paths.

Table 3.1: Provisional drill sites.

Drill Site	Latitude	Longitude	Traverse/ station	Drilling Target	Geophysical Method	Proposed Depth(m)
DS1	-27.43127	30.40548	1/110	Weathering and possible fracture zone	Magnetic, ERI	40
DS2	-27.43147	30.40767	1/330	Deep weathering and possible fracture zone	Magnetic, EM-34, ERI	40
DS3	-27.43134	30.40732	2/130	Weathering and possible fracture zone	Magnetic, EM-34, ERI	40
DS4	-27.43097	30.40777	2/190	Deep weathering and possible fracture zone	ERI	40
DS5	-27.43018	30.41128	3/305	Dolerite dyke contact and fracture zone	Magnetic, EM-34, ERI	40
DS6	-27.43011	30.41141	3/330	Confirm dolerite dyke	Magnetic, EM-34, ERI	15
DS7	-27.42997	30.41167	3/360	Dolerite dyke contact and fracture zone	Magnetic, EM-34, ERI	40
DS8	-27.43633	30.40845	4/170	Deep weathering and possible fracture zone	Magnetic, EM-34, ERI	40
DS9	-27.43113	30.41135	5/10	Confirm dolerite dyke	Magnetic, EM-34, ERI	15
DS10	-27.43203	30.41124	5/110	Deep weathering and possible fracture zone	Magnetic, EM-34, ERI	40

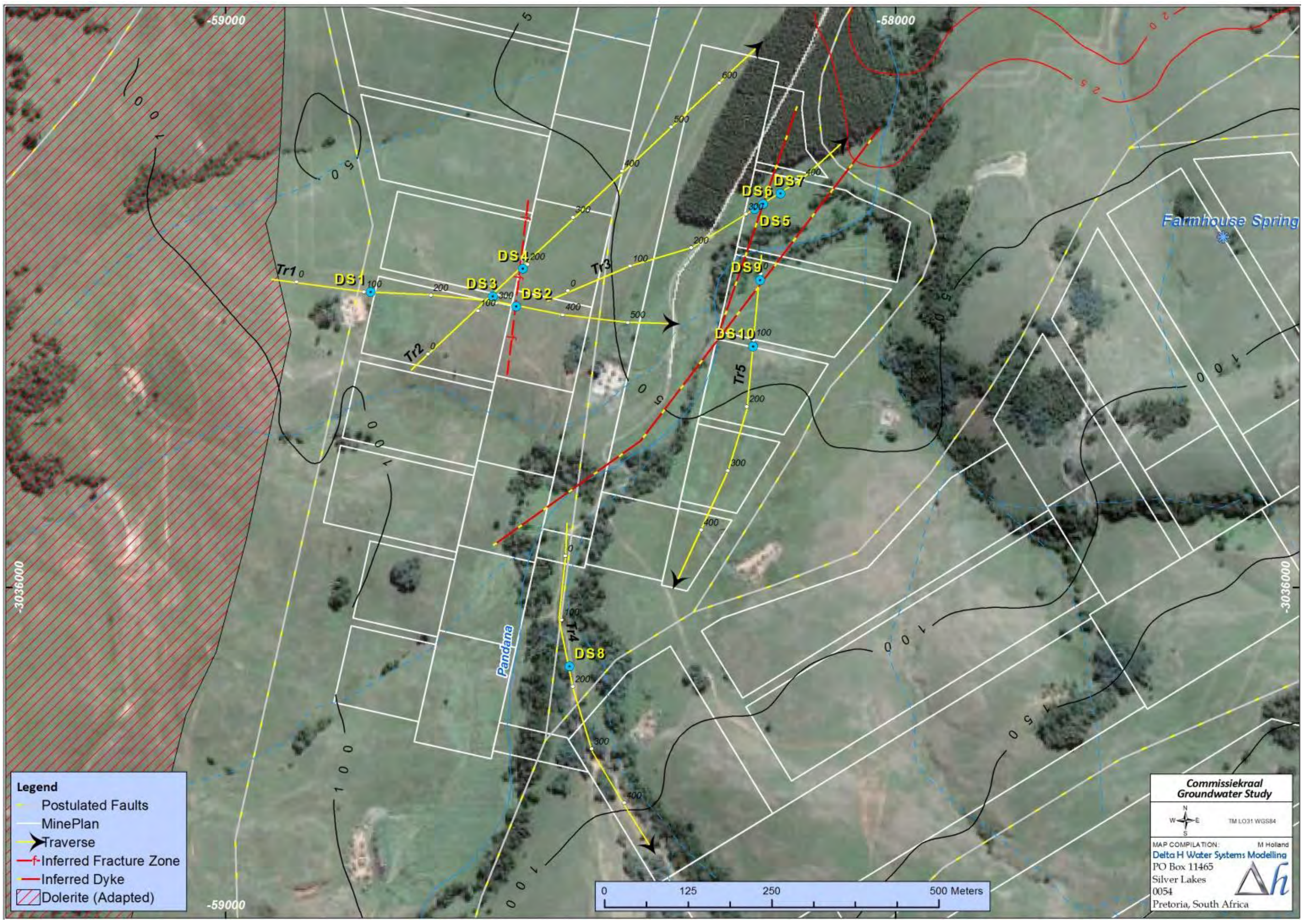


Figure 3.2: Geophysical traverses and provisional drills sites.

3.3. BOREHOLES (NEWLY DRILLED)

Five (5) boreholes (2 deep and 3 shallow) (Photo 2) were drilled as part of this investigation with the aim to improve the understanding the hydraulic link between the shallow and deeper aquifer system overlying the proposed underground coal mine.

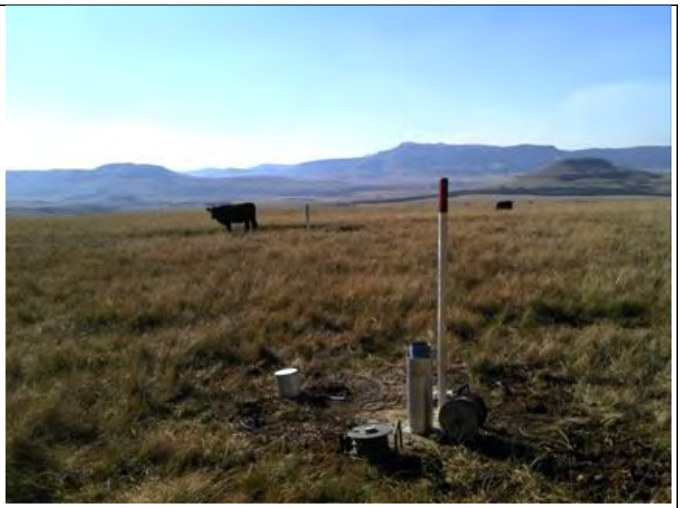
	
CK-BH1	**CK-BH2**
	
CK-BH4 (Drilled)	**CK-BH4**
	
CK-BH5 (Drilled)	**CK-BH5 (Test)**

Photo 2: Setting of the newly drilled boreholes (no photo taken from CK-BH3).

The two shallow boreholes (CK-BH 1 and 2) were drilled in close proximity to the existing exploration (core) holes to show the existence of two water levels (i.e. deeper regional and shallow perched water levels) largely relating to the hills side slopes and steeps. The deeper boreholes (CK-BH3, 4 and 5) were drilled in the vicinity where the Pandana River (overlies) the proposed underground coal mine. The ground geophysics was used to optimally site these boreholes (although positons were altered based on accessibility). The final drill positions in relation to the adit and underground mine workings are shown in Figure 3.3.

The two shallow monitoring boreholes were constructed with 140 mm uPVC, while the three deeper boreholes drilled were constructed with 165 mm (inner diameter) steel casing, which is solid (un-slotted) in the weathered zone and slotted (prefabricated screened casing) in the lower sections of the shallow boreholes. A granular filter pack (approximately 70% of the formation grain size) was placed in the annular space between the borehole and casing. The borehole construction was intended to prevent inflow of fine particles into the borehole and borehole collapse, whilst at the same time not influencing the quality of retrieved groundwater samples. Information on the borehole drilling depths, water intersections, borehole construction /completion details and groundwater level information for the newly drilled monitoring boreholes are provided in Table 3.2, while the geological logs of drilled boreholes are presented in Appendix C.

The typical stratigraphy observed and recorded during the drilling can be summarised as follow:

- Weathered zone: Brownish red, fine and medium grained sand or clay with traces (<10%) of dark grey sub-angular very fine weathered shale or sub-rounded medium grained weathered sandstone.
- Fractured rock:
    - Sandstone: Brownish white, medium grained sand with traces (<10%) of brown medium grained un-weathered sandstone (or siltstone).
    - Shale: Dark grey, fine to medium.

Table 3.2: Borehole locations drilled at the proposed Commisiekraal Coal Mine.

BH Name	Coordinates		BH Depth (mbgl)	Water strike (yield)	Static Water Level (mbgl)
	Latitude	Longitude			
CK-BH1	-27.43564	30.43175	15	Seepage	12.3
CK-BH2	-27.43456	30.42553	21	Seepage	5.6
CK-BH3	-27.43636	30.40856	45	Seepage	12.19
CK-BH4	-27.43133	30.40761	60	20, 31 (~1 l/s)	19.64
CK-BH5	-27.43011	30.41131	40	8, 12 (~1 l/s)	3.06

Two shallow boreholes intersected seepage water, with final rest water levels of 12.3 mbgl and 5.6 mbgl, respectively (Table 3.2). At these sites, drilling confirmed an overlying weathered (upper) aquifer extending to a depth of between 10 and 20 m (although over the study area the weathering depth is highly variable). Water intersections observed with the drilling of CK-BH4 and 5 seem to be largely related to the contact between the upper weathered zone comprising of sandstone and the underlying (less weathered) shale.

Figure 3.3: Positions of newly drilled boreholes in relation to proposed mine workings.

3.4. HYDRAULIC TESTS

The hydraulic testing programme for the Commisiekraal project involved:

- Seven slug (rising/falling head) tests on existing exploration (core) holes and the newly drilled shallow monitoring boreholes (CK-BH1 and 2).
- Pumping tests of the newly drilled boreholes (CK-BH3, 4 and 5) and one existing water supply borehole (CGW1) included
  - Constant discharge and recovery tests of varying duration (mainly 8 hours).
  - Based on these results CK-BH4 and CK-BH5 were subjected to step-tests and a higher pumping rate and of longer duration (12 hours) in order to determine recommended yields for potential water supply to the project.

3.4.1. Slug tests

Slug tests were performed during the intrusive investigations and analysed with the software package AQTESOLV Pro version 4.5. The aquifer and well parameters were obtained from the inverse curve-fitting procedure using automatic curve fitting or manual fitting of late time data with the appropriate analytical solution/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).

The Cooper et al. (1967) method for confined aquifers was used to screen the data and determine initial aquifer parameters.

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.

3) 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.

A summary of the borehole parameters and determined transmissivity (T-value) and hydraulic conductivity (K) values is given in Table 3.3, while the diagnostic plots with fitted data are provided in Appendix D.

Table 3.3: Aquifer parameter estimates based on slug tests conducted at the Commisiekraal project site.

Borehole Number	Casing Diameter (mm)	Water Level (mbgl)	Cooper et al. (1967)		KGS Model (Hyder et al. 1994)	Bouwer-Rice (1976)	
			T-value m^2/d	K*	K-value m/d	K-value m/d (Early)	K-value m/d (Late)
CGW 1	165	6.1	22.5	0.23	0.81	1.3	0.2
MCK 07	74	22.0	0.02	0.0002	0.0005	0.007	0.002
MCK 09	65	35.8	-	-	1.0E-04	-	3.0E-04
MCK 11	74	28.0	18	0.18	0.45	-	0.44
MCK 14	65	19.3	0.003	-	1.0E-04	0.005	1.0E-04
CK BH1	165	12.3	1.858	0.0186	0.1347	-	0.083
CK BH2	165	5.7	-	-	-	-	0.0056

* Assuming 100 m aquifer thickness

3.4.2. Pumping Test Results

The pumping tests included short step-tests of around 60 minutes each in addition to constant discharge tests varying from 180 minutes to 48 hours duration followed by a recovery monitoring period. The aquifer parameter estimates are therefore based on the step-test results as well as the drawdown and recovery data of the constant discharge test (CDT). The detailed schedule of the pumping tests summary is provided in Table 3.4.

Table 3.4: Aquifer parameter estimates based on pumping tests at the Commisiekraal project site.

Borehole Number	Water Level (mbgl)	Pump Intake (mbgl)	Step Test No. (Yield in l/s)	Pump Suction* (l/s)	Constant Discharge Rate (l/s)	Final Drawdown (m)	Comment
CGW1	6.1	27	-	-	0.63	2.93	8 hour test and recovery
CK-BH3	12.2	40	-	0.1	0.6	PI	Reach pump intake after 60 minutes of CDT
CK-BH4	19.6	33.5	-		0.58	4.1	8 hour test and recovery
CK-BH5	3.1	34	-		0.62	2.7	12 hour test and recovery
CK-BH4 (re-test)	19.5	53.5	1 (0.5), 2 (0.9), 3 (1.9)	1.2	0.8	PI	Reach pump intake after 12 hours of CDT
CK-BH5 (re-test)	3.6	36.5	1 (0.7), 2 (1.3), 3 (2.6)	1.5	1.3	PI	Reach pump intake after 12 hours of CDT

* Approximate discharge rate at which water level is drawn down to pump intake depth.

The following process was followed for estimating aquifer parameters based on the pumping test data.

1) Develop a conceptual understanding of the geological setting of the test.
2) Create the diagnostic plots from pumping test data and define the flow regime.
3) Choose the appropriate analytical solution (e.g. Theis, 1935; Cooper and Jacob, 1946; Hantush and Jacob 1955; Neuman, 1974; Moench, 1997) and determine the aquifer and well parameters from the curve fitting of the drawdown (and derivative) and/or the recovery data.
    a. Data captured during the pump testing programme were also analysed using the Flow Characteristic (FC) method developed by Van Tonder et.al. (2001).
4) The recovery of a pumped aquifer can be interpreted in the same way as the drawdown by using diagnostic plots. Through a simple transformation of the time variable, Agarwal (1980) devised a procedure that uses solutions developed for drawdown analysis (i.e. the Theis type-curve) to analyse recovery data.

A summary of the derived aquifer parameters for each tested borehole is provided in Table 3.5, while the pumping test diagnostic plots, with fitted data, are provided in Appendix D.

Table 3.5: Aquifer parameters based on pumping tests conducted at the Commisiekraal project site.

Borehole Number	Step Test (Theis)	Confined		Unconfined		Agarwal (recovery)	FC-Method	Average T-Value (K-value#)	Comments
		Theis	Cooper-Jacob	Neuman	Moench				
CGW1		9.2	7.3	5	4.6	6.8	11	7.3 (0.07)	
CK-BH3		0.45	0.68	0.13				0.4 (0.004)	
CK-BH4		4.3	4.1	4.1	5.8	3.4	4	4.3 (0.04)	
CK-BH5		9.3	6.9	6.5	7.8		5.9	7.0 (0.07)	
CK-BH4 (re-test)*	5.2				3.4		4.9	4.5 (0.045)	Determined storativity of 1.5e -6
CK-BH5 (re-test)*	9.6				3.2		4.6	5.8 (0.06)	

* Fitted with observation borehole
\# Assuming 100 m aquifer thickness

From the analysis and interpretation of the pumping test data, the following conclusion can be drawn:

- Calculated transmissivity values range from 0.4 to 7 m^2/d within the weathered/fractured aquifer. Transmissivities in these aquifers vary greatly with fracture frequency and structural geological position.
- The drawdown behaviour in response to constant pumping rate is for most boreholes characterised by a pronounced so-called double porosity dip in the derivative. In other words, the drawdown increases once a major water strike (associated with e.g. fractured or depth of weathering) is dewatered.

- Early flow towards the well is from fracture storage, supported at intermediate times by drainage of the rock matrix before water is derived from both systems at late times with frequent dewatering of discrete fracture systems. Once these fractures are dewatered, a marked increase in drawdown and decrease in transmissivity becomes apparent.
- During pumping some of the fractures will be dewatered at the position of a fracture and derivative will decrease and after dewatering of a fracture it will increase again.

- If the pump rate exceed the flux from the fracture (as seen from the re-test) a characteristic steepening of the drawdown towards (this essentially leads to the failure of the borehole).
  - The delayed recovery and residual drawdown are indicative of limited aquifer (fracture) storage and slow flow from the less permeable rock matrix contributing to the recovery.
- The potential water supply from tested boreholes more specifically (CK-BH4 and 5) will be of lower yields (i.e. 0.8 l/s) for limited period (i.e. 8 hours) to allow for sufficient recovery.
  - Based on the recommended yields these boreholes could supply the water demand of 0.5 l/s for the construction period (i.e. pre-mine dewatering). After 4 years of mining up to life of mine the water demand of between 0.4 and 0.5 l/s could easily be sourced from these boreholes. If pumping rates are limited to 8 hours per day no significant drawdown will occur and groundwater levels will recover to pre-abstraction levels.
- The simultaneous fit of the drawdowns from the observation and the respective abstraction boreholes where used to obtain an indication of the aquifer storativity (Table 3.4).

3.5. Water Quality

The groundwater baseline water quality assessment (i.e. hydrocensus) will set the current ambient background water quality and signatures characterising the aquifers in the study area. Specific samples requested by the client included the Kemplust and Makatees Kop historical mine (area) (see map insert Figure 3.3).

The water samples were analysed for major and trace elements to provide an evaluation of the ambient groundwater quality that serves as a baseline. Based on the results of the analyses (i.e. hydrocensus samples), the following aspects were described:

- A description of the site-specific groundwater chemistry based on the major and trace element analyses;
- Comparison of the physical and chemical parameters to water standards as proposed by the and South African National Standards (SANS 241 – 2011), World Health Organization drinking water standards (WHO – 2011), International Finance Corporation (World Bank) Effluent standards (IFC - 2007) and Department of Water affairs and Forestry (1991) Volume 7: Aquatic Ecosystems.

Note that the comparison to drinking water standards and guidelines does not suggest that drainage from the mine site will be used for drinking purposes. While the drinking water standards are for obvious reasons very stringent, the less stringent IFC effluent guidelines are for example more applicable for any site run-off and treated effluents to surface waters and should be achieved without dilution. It should also be noted that while the limits for aquatic ecosystems are listed the majority of the proposed limits fall below the analytical detection limit of the laboratory. Site-specific discharge levels will be determined by DWS as part of the issuing of a WUL and are usually established based on the receiving water use classification and the resource quality objectives.

Twenty-eight (28) water samples were collated during the hydrocensus and from the newly drilled boreholes. A list of the water samples collected during the hydrocensus is given in Appendix A, while the laboratory certificates provided in Appendix E. The groundwater samples (including the springs) collected during the hydrocensus are characteristic of freshly recharged groundwater, which has had limited time to equilibrate with the aquifer material along its flow path. The dominant magnesium-bicarbonate (Mg-HCO_3) and (Ca-HCO_3) calcium-bicarbonate water facies shown in the Piper plot and Durov diagram (Figure 3-4) is a result of the rainwater chemistry, limited weathering reactions and CO_2 equilibrium with the atmosphere via the soil vapour (elevated CO_2 due to decomposition of organic material) to form a dominant bicarbonate anion.

However, the groundwater samples from the core holes MCK07 and 11 is characterised by a more sodium rich ion dominance. The most obvious observation from the Durov diagram is the outlying pH (of 2.7) and, elevated sulphate and EC levels of the Makatees Kop samples, which can be related to the acid mine drainage from the abandoned mine workings.

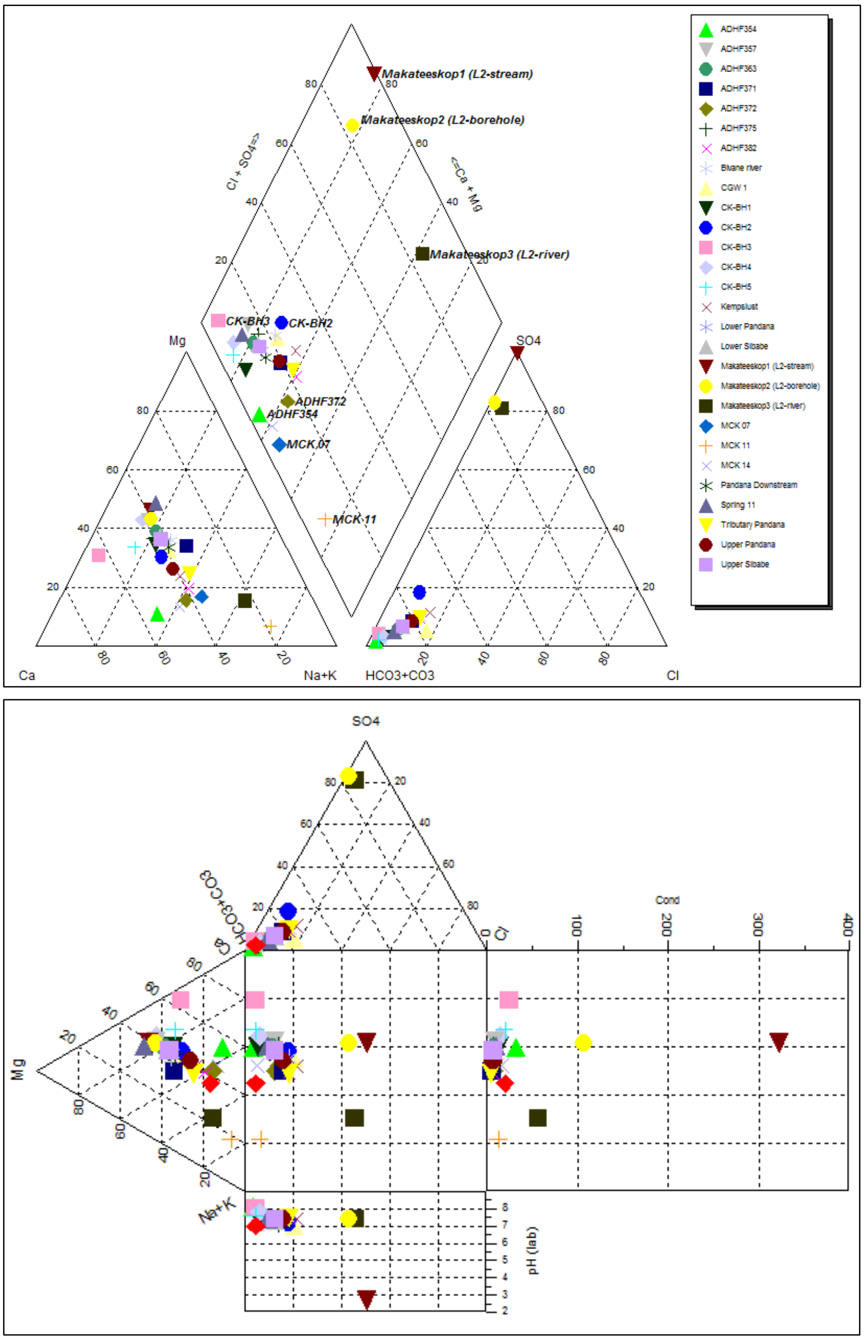


Figure 3-4: Piper and Durov diagram of water samples collected during the hydrocensus.

The water samples were compared in Table 3.6 to the SANS 241, WHO and IFC water quality standard guidelines and exceedances discussed below. Note that the trace elements (parameters) not listed in Table 3.6 was either below the analytical limit of detection or the concentration levels did not trigger major health risks.

Table 3.6: Water quality results for the Commissiekraal samples.

SiteName	SiteType	Date	pH	EC mS/m	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	MALK CaCO3/L	Cl mg/l	SO4 mg/l	N_Amonia mg/l	Al mg/l	Fe mg/l	Mn mg/l	Ni mg/l	Pb mg/l
CGW 1	Borehole	07/05/2015	7.0	9.4	70.0	5.7	2.9	4.0	1.1	36.0	6.0	<5	0.30	0.39	33.61	0.24	0.35	<0.010
MCK 07	Corehole	07/05/2017	7.0	19.6	90.0	11.9	3.3	16.4	2.0	104.0	<5	<5	3.30	0.40	17.80	0.43	0.16	<0.010
MCK 11	Corehole	07/05/2018	7.3	12.6	62.0	4.4	<2	19.1	2.5	68.0	<5	<5	0.50	1.03	18.23	0.12	0.18	<0.010
MCK 14	Corehole	07/05/2019	7.1	15.9	122.0	14.3	2.5	14.1	1.2	92.0	<5	<5	<0.2	1.17	4.54	1.55	0.06	0.01
ADHF354	Handpump	08/05/2015	8.1	31.3	154.0	27.2	3.3	20.0	<1.0	144.0	<5	<5	<0.2	<0.100	0.64	0.08	0.01	<0.010
ADHF372	Handpump	08/05/2015	7.4	6.9	60.0	4.5	<2	4.5	1.0	32.0	<5	<5	<0.2	<0.100	1.07	0.05	0.01	<0.010
ADHF357	Spring	08/05/2015	7.4	7.9	74.0	5.8	3.7	2.3	<1.0	32.0	<5	<5	<0.2	0.25	0.17	<0.025	<0.010	<0.010
ADHF371	Spring	09/05/2015	7.3	5.3	22.0	3.2	2.0	3.4	<1.0	24.0	<5	<5	<0.2	2.66	1.23	0.13	<0.010	<0.010
ADHF375	Spring	08/05/2015	7.2	6.4	56.0	4.7	2.5	2.4	<1.0	28.0	<5	<5	<0.2	0.15	0.15	<0.025	<0.010	<0.010
ADHF363	Surface Water	09/05/2015	7.4	7.8	56.0	5.7	3.3	3.1	<1.0	36.0	<5	<5	<0.2	<0.100	0.18	<0.025	<0.010	<0.010
ADHF382	Surface Water	08/05/2015	7.5	5.6	46.0	3.3	<2	3.3	1.2	20.0	<5	<5	<0.2	<0.100	0.30	<0.025	<0.010	<0.010
Bivane river	Surface Water	06/05/2015	7.5	4.2	30.0	2.9	1.7	2.1	<1.0	20.0	<5	<5	<0.2	<0.100	0.19	<0.025	<0.010	<0.010
Kempslust	Surface Water	08/05/2015	7.4	4.6	32.0	2.8	<2	2.6	<1.0	16.0	<5	<5	<0.2	<0.100	0.11	<0.025	<0.010	<0.010
Lower Pandana	Surface Water	06/05/2015	7.3	7.5	54.0	5.2	2.8	3.5	<1.0	32.0	<5	<5	<0.2	0.12	0.28	<0.025	<0.010	<0.010
Lower Sibabe	Surface Water	06/05/2015	7.3	7.4	50.0	5.3	3.0	3.2	<1.0	32.0	<5	<5	<0.2	<0.100	0.09	<0.025	<0.010	<0.010
Pandana Downstream	Surface Water	06/05/2015	7.4	6.6	54.0	4.4	2.3	3.2	<1.0	32.0	<5	<5	<0.2	0.19	0.39	<0.025	<0.010	<0.010
Spring 11	Surface Water	06/05/2015	7.4	9.2	40.0	6.5	5.4	3.0	<1.0	44.0	<5	<5	<0.2	2.61	2.34	0.05	0.02	<0.010
Tributary Pandana	Surface Water	06/05/2015	7.5	4.4	36.0	2.5	<2	2.7	<1.0	20.0	<5	<5	<0.2	0.20	0.29	<0.025	<0.010	<0.010
Upper Pandana	Surface Water	06/05/2015	7.4	6.9	38.0	4.3	1.7	3.7	<1.0	24.0	<5	<5	<0.2	0.26	0.17	<0.025	<0.010	<0.010
Upper Sibabe	Surface Water	06/05/2015	7.4	6.9	46.0	4.9	2.7	3.0	<1.0	32.0	<5	<5	<0.2	<0.100	0.08	<0.025	<0.010	<0.010
Makateeskop3 (L2-river)	Surface Water	27/05/2015	7.4	107.0	852.0	114.0	46.0	41.0	2.4	100.0	6.0	520.0	<0.2	0.12	0.23	0.26	<0.010	<0.010
Makateeskop2 (L2-borehole)	Borehole	27/05/2015	7.4	56.8	434.0	48.0	29.0	17.0	1.2	40.0	10.0	226.0	<0.2	<0.100	<0.025	<0.025	<0.010	<0.010
Makateeskop1 (L2-stream)	Spring	27/05/2015	2.7	322.0	2984.0	371.0	109.0	34.0	6.8	<5	5.0	2050.0	2.90	35.00	56.00	19.00	0.80	<0.010
CK-BH1	New Borehole	26/05/2015	7.5	13.2	102.0	18.0	13.0	6.0	4.2	80.0	<5	<5	<0.2	8.59	23.00	0.49	0.18	0.03
CK-BH2	New Borehole	26/05/2015	7.2	6.0	42.0	14.0	9.0	4.0	5.3	28.0	<5	7.0	<0.2	7.93	14.00	0.52	0.14	0.04
CK-BH3	New Borehole	27/05/2015	8.0	24.6	200.0	13.0	5.0	39.0	4.1	140.0	<5	6.0	0.40	5.93	21.00	0.32	0.15	0.02
CK-BH4	New Borehole	27/05/2015	7.8	13.7	130.0	12.0	6.0	7.0	1.0	72.0	<5	<5	<0.2	<0.100	0.27	0.05	<0.010	<0.010
CK-BH5	New Borehole	27/05/2015	7.6	19.3	154.0	16.0	7.0	12.0	<1.0	104.0	<5	<5	<0.2	<0.100	0.33	0.11	<0.010	<0.010
Makateeskop1 (L2-stream)	Spring	10/09/2015	2.7	302.0	3036.0	341.0	129.0	51.0	5.3	<5	<5	2049.0	3.3	28	44	21	0.891	<0.010
Makateeskop3 (L2-river)	Surface Water	10/09/2015	6.70	114	946	136.0	51.0	39.0	5.7	80	8.0	582.0	<0.2	0.171	0.166	0.34	0.027	<0.010
Kempslust (Re-Sample)	Surface Water	10/09/2015	7.3	5.5	58.0	3.0	2.0	4.0	1.0	20.0	<5	<5	0.20	0.37	0.31	<0.025	<0.010	<0.010
SANS 241-1 (2011) (*2006)			5 - 9.7	170	1200	150*	70*	200	-	-	300	250/500	0.05	1.5	0.3	0.3 / 2	0.07	0.01
WHO 2011			-	-	-	-	-	50	-	-	-		0.05	-	0.9*	-	0.07	0.01
IFC 2007			6 - 9	-	-	-	-	-	-	-	-	-	-	-	-	2	0.5	0.2
DWAF, 1991 (Aquatic)			<0.5 & >0.5%	-	>15%	-	-	-	-	-	-	-	≤0.007	≤0.005	>10%	≤0.18	-	≤0.0002

Based on the results the groundwater and surface water samples taken during the hydrocensus have a relatively low mineralisation with electrical conductivities of around 120 mS/m and a pH of around 7.5. Excluding the Makatees Kop samples, all of the major ions analysed in the groundwater and surface water samples are within drinking water limits. Elevated trace elements and metals (i.e. Al, Fe, Mn, Ni and Pb) exceedances highlighted in the tables (apart from the Makatees Kop samples) appear to be of geogenic or natural nature. For example the elevated concentrations of Fe and Al observed from the two springs (ADF375 and Spring 11) can be attributed to the host rock lithologies and not due to an anthropogenic surface induced origin. These elements including Mn are often naturally elevated in ground water within lithological units of the Karroo Super group. The extremely elevated Fe concentration observed from the water supply borehole (CGW1) and core hole (MCK) samples suggests iron oxidation probably related to the dissolution of ferrous borehole components (i.e. casing). It's also an indication of the stagnant nature of the water (i.e. samples were grabbed with a bailer) and not purged. Similarly high Fe concentrations (including Al and Mn) were observed for the newly drilled monitoring borehole (CK-BH3). However, this could relate to the very low permeability of the aquifer and the borehole was sampled towards the end of the pumping test which resulted in a disturbance of the filter pack. This increased (excessive) turbidity (> 4000 observed) can radically alter analytical results for water samples, causing spurious increases in analysed metal concentrations. This is particularly true for the major constituents of the aquifer mineral matrix, such as iron, aluminum, calcium, magnesium and manganese. The ambient background water quality for the site is overall characterised as very good and of potable quality.

Samples obtain downstream of the Makatees Kop (in May and Sep. 2015) abandoned mine workings is highly mineralized with sulphate values ranging from 520 to 2050 mg/l. Mining of the Coking, Dundas and Gus Seams took place between 1934 and 1945 (Hill, 1993). Mining in the Alfred Seam commenced in 1991 initially over the Dundas goaf, and later over both the Dundas and Gus Seam goafs. The workings were only around 100 m in depth. Hill (1993) reported roof and floor stability problems and numerous roof falls when two goafs were mined over. Sulphate can be regarded as a conservative determinant that doesn't undergo retardation or significant degradation in the aquifer and is often used as an indicator of mining related contamination (i.e. discharges/seepages of groundwater from the deeper underground coal mine voids).

4. CONCEPTUAL MODEL

4.1. SITE SPECIFIC AQUIFER SYSTEMS

The results from the site investigation confirm generally the Karoo aquifer systems described in section 2.3, i.e. the differentiation of an upper weathered and deeper fractured Karoo aquifer. A conceptual groundwater model for the aquifer setting in relation to the mine is shown in a South to North cross section for the site (Figure 4.1).

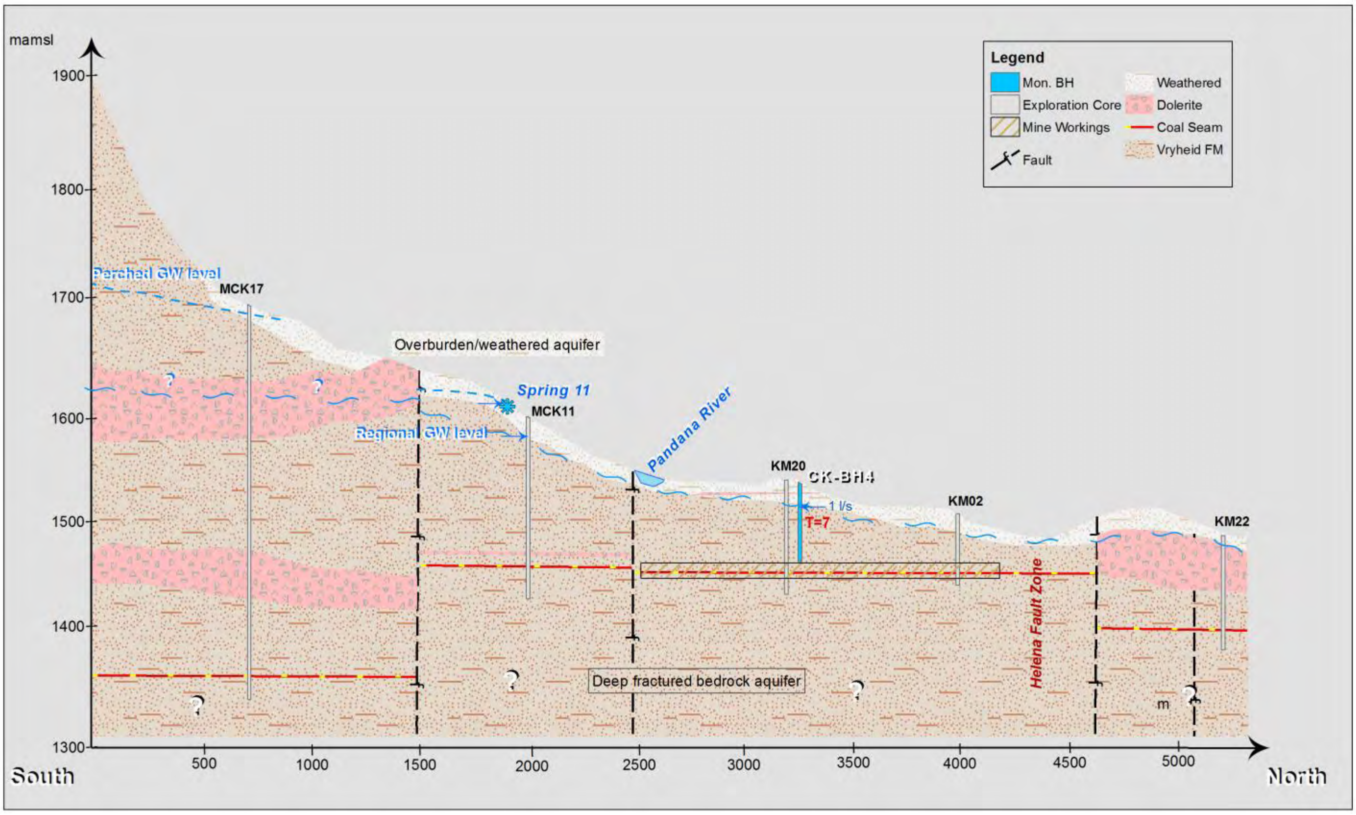


Figure 4.1: Conceptualisation of the Karoo aquifer and the dolerite sills of the Commisiekraal site.

The following aquifers are therefore conceptualised:

1. Localised perched aquifer systems (< 10 mbgl) within the colluvium or on weathered sandstone/dolerite. Associated water levels due to infiltrating rainwater perched on (shallow) low permeability layers are generally shallow, with lateral flow on the layer potentially feeding seasonal hillside seeps and springs.
2. A shallow weathered Karoo aquifer system comprising of an intergranular, water table (unconfined) aquifer that is likely to be hydraulically connected to surface drainages. The average water level is around 10 mbgl, while the depth of weathering reaches less than 20 mbgl on site and is better developed lower down the hillslope towards the Pandana Valley. An average hydraulic conductivity of 0.05 m/d was determined for the tested shallow boreholes respectively aquifer system overlying the mine voids. Vertical infiltration of water in the weathered aquifer is typically limited by impermeable (or semi-permeable layers of sediments below the weathered zone, with subsequent lateral movement following topographical gradients. From the drilling results it was clearly evident that the water strikes were associated with the contact (base of weathering/transitional zone) between the weathered sandstones and potentially less permeable shales. From the diagnostic drawdown curves it was evident that once these discrete fractures are dewatered a marked increase in drawdown and decrease in transmissivity becomes apparent.
    - The aquifer is directly recharged by rainfall and discharges via springs and baseflow in the area of interest.

3. A deeper, fractured Karoo aquifer system characterised as a secondary, semi-confined aquifer. The average water level is around 28 m and hydraulic conductivity of the fractured Karoo aquifer determined from the slug tests conducted on the exploration (core) holes is between 1E-4 and 2E-3 m/d. Higher conductivities expected along (but not across) coal seams and dyke/sill contacts or major faults. In the southern underground mine workings drilling (MCK17) confirmed thick (~50 m) dolerite sills which forms an aquiclude and constricts vertical percolation of groundwater.

4.2. GROUNDWATER ELEVATION AND FLOW DIRECTION

Eighteen water levels were collated from exploration (core) holes and boreholes over the study area which includes data from the hydrocensus and the Kwazulu Natal Groundwater Information Project (GRIP). Water levels range from 2.6 mbgl to 36 mbgl with an average of 16 mbgl. The observed water levels show a very good correlation (R^2=0.98) between absolute surface and groundwater table elevations in metres above mean sea level (mamsl) for the study area (Figure 4.2).

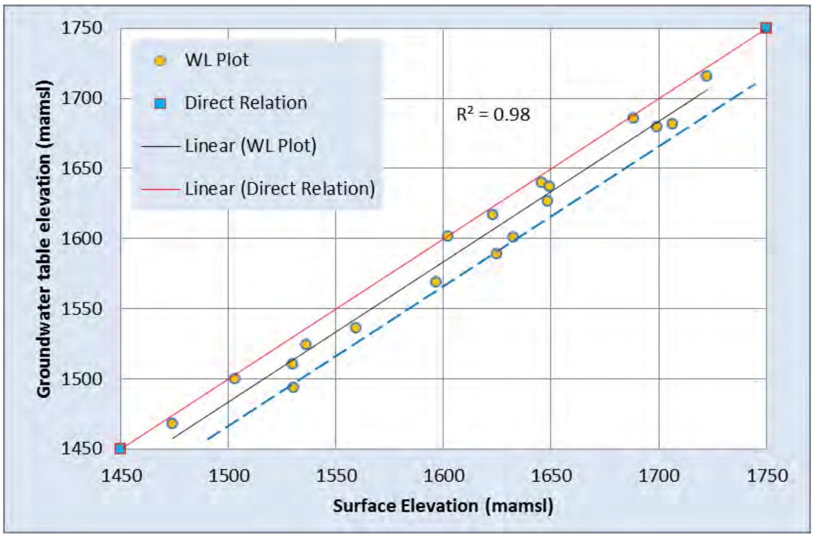


Figure 4.2: Correlation between surface topography and groundwater elevation.

Correlation coefficients above 95% are usually observed for unconfined aquifers and indicate in such instances that the groundwater table is a subdued replica of the surface topography. The distribution of water levels above and below the linear correlation line suggests the occurrence of two distinct aquifer systems (plus local perched aquifers) with different water levels. It is evident that even with the mountainous terrain or ridges the water tables are relatively close to the land surface. In terms of surface-groundwater interaction both shallow perched and deeper weathered/fractured aquifers may contribute to surface water bodies (baseflow). Groundwater perched on low permeability material in the weathered zone or in colluvium may be a source of water to hillside seeps and springs. Springs appear to be associated with the dolerite sill that is present at higher altitudes in the project area. The springs are considered to be fed by water bodies perched on the dolerite (sills). However, groundwater on horizontal and semi-horizontal contacts between different rock types may also be a source for springs. Many of these springs are seasonal and reduced flows are expected in the dry season. This mimicry of groundwater flows and levels to terrain entails that regional groundwater discharge areas would primarily be located in valley bottoms. As a result both the shallow and deeper aquifer mimic the topography and groundwater flows from higher lying ground towards lower lying ground and drainage systems (natural streams).

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). 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 for the Commissiekraal study area below (Figure 4.3) 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.

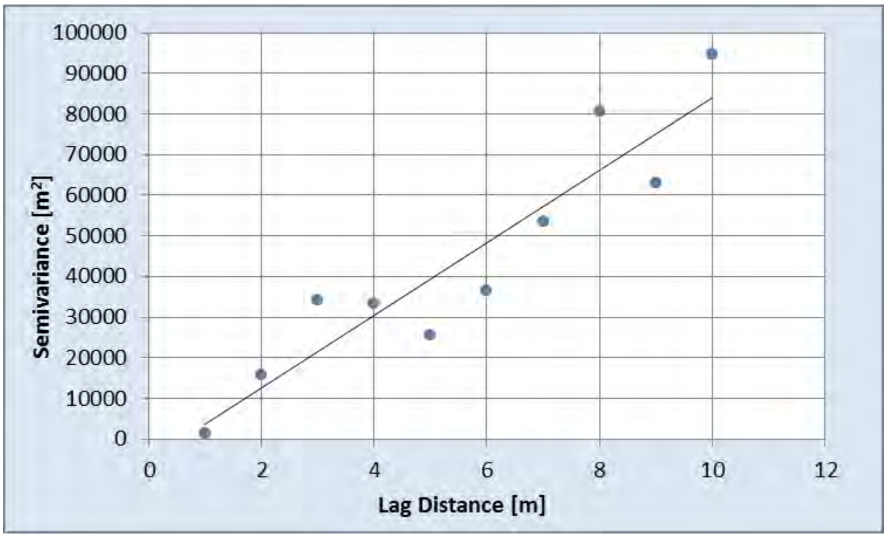


Figure 4.3: Empirical semi-variogram and fitted Bayesian model for the study area.

The interpolated groundwater piezometric map using Bayesian interpolation (with the model parameters given above) is shown in Figure 4.4 and was subsequently used as initial heads for the model calibration. It must be noted that initial heads 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.

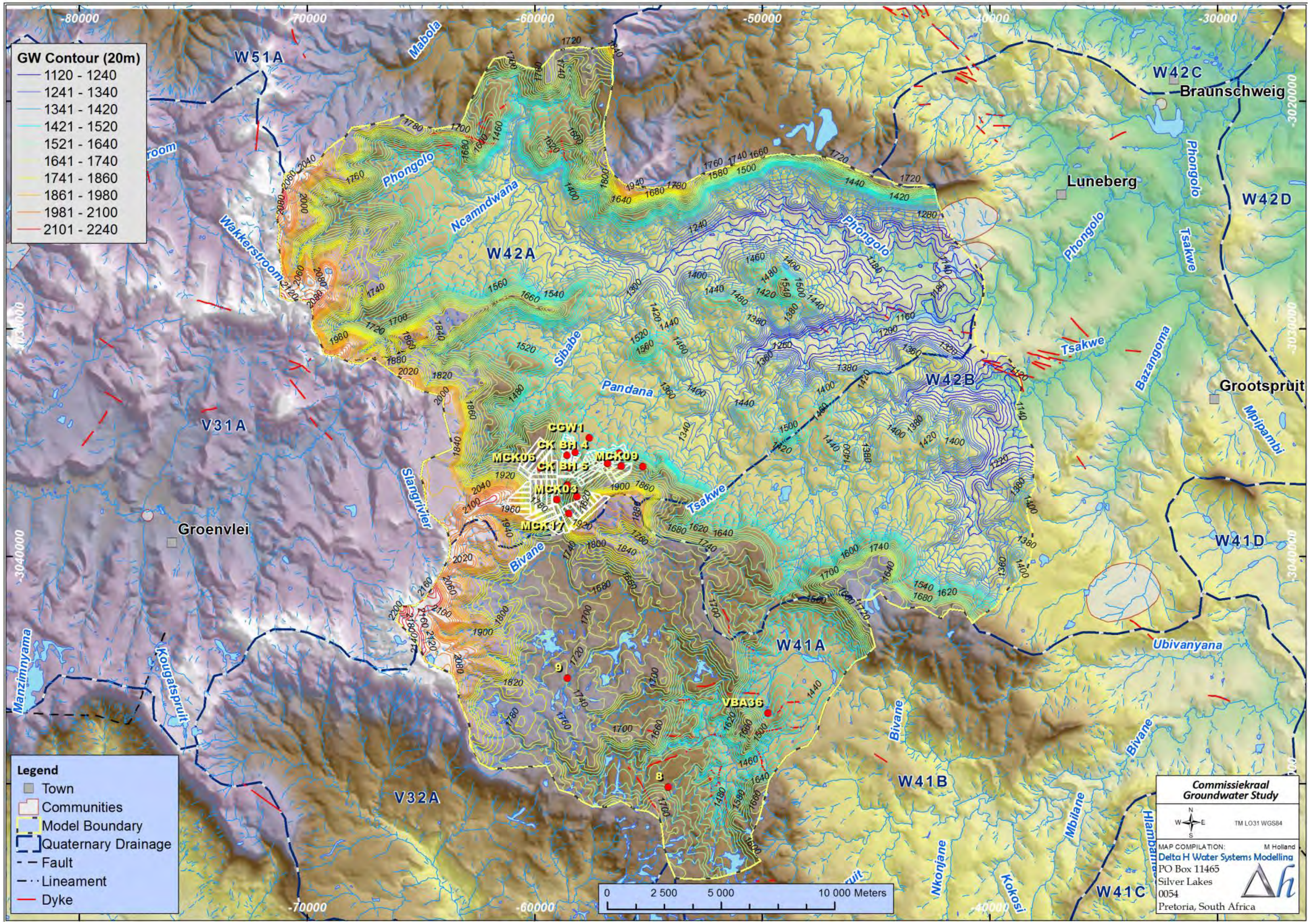


Figure 4.4: Interpolated shallow water table elevations.

4.3. Sources and Sinks

A summary of the groundwater resource (and harvest potential) and aquifer characteristics for the two quaternary catchment of the project area is provided in Table 4.1.

Table 4.1: Summary of information concerning quaternary catchments W42A and W41A (GRAII).

Quaternary Catchment	Area (Km^2)	MAP (mm/a)	Recharge (% of MAP)	Baseflow (Pittman) Mm^3/a)	*Harvest Potential ($m^3/km^2/a$)	Transmissivity (m^2/day)	Water Level (mbgl)	Weather Thickness (m)	Aquifer Thickness (m)
W42A	397	1061	11.1	47	25196	1.3	16.3	22.9	149
W41A	188	1016	10.8	21	17037	0.9	17.9	23.5	137

* - Maximum of groundwater that may be annually abstracted per surface area of an aquifer system to preserve sustained abstraction.

The main sources of groundwater recharge were identified as

- direct rainfall recharge of the weathered Karoo aquifer,
- limited leakage from the weathered to the fractured Karoo aquifer via fault planes.

Owing to many uncertainties, recharge calculations are generally over estimations of the actual recharge taking place from precipitation. While recharge estimates of around 11 per cent of MAP is given for the project area (based on the GRA II dataset Table 4.1) research on sandstone aquifer and local knowledge suggest an annual recharge range of 3 to 7 per cent of MAP. Based on topographic information, aquifer composition and spring flow it is estimated that recharge will not exceed 5 per cent of MAP. The baseflow in the study area varies from to 2 – 5 percent of the MAP and forms that part of stream flow (including groundwater discharges through seeps and springs) that derives from groundwater and shallow subsurface storage. Vegter (1995) estimated the minimum recharge rate of 45 mm/a and a mean rate of 65 mm/a. Delta H adopted a regional recharge rate of 45 mm/a.

Springs and seepages occur throughout the region and known springs are captured as part of the KwaZulu-Natal Groundwater Resources Information Project (GRIP). Although their flows are very markedly seasonally affected these springs are extensively exploited as a water supply source for domestic use and agricultural use in rural settings. Average spring discharge rates for springs within 5 km of the Commissiekraal project area is 0.1 l/s. Many springs of very low yield dry up completely during dry seasons and much of this water is evaporated. The mean annual evaporation (MAE) is 1 350 mm.

The general gaining nature of rivers in the W42A and W41A catchment is confirmed by groundwater levels exceeding the surface water level in the vicinity of river courses as well as groundwater contribution to baseflow estimates from the GRAII dataset. The interaction between groundwater and surface water courses was therefore simulated under the assumption of continuous gaining river systems. The main groundwater sinks in the wider area of interest are:

- spring discharges from the perched weathered aquifer, often utilised for domestic purposes,
- groundwater baseflow towards surface water courses,
- regional groundwater outflow,
- and for the predictive simulations inflows into the proposed underground mine voids.

5. MODEL DEVELOPMENT

5.1. 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 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:

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

∇ $\left(\frac{\partial}{\partial x},\frac{\partial}{\partial y},\frac{\partial}{\partial z}\right)$
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. 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.

5.2. Model Domain

The model domain covers a surface area of 719 km^2 and coincides with the W42A and W41A quaternary catchment boundaries but extends into the upper catchments of W42B towards the south-east (Figure 5.1). A topographical divide was used as the south-eastern model boundary with a short section along the Phongolo- and Tsakwe River assigned as river boundaries. This ensures a dependable water balance for the model with recharge being the main driver of groundwater flow. The boundaries follow mostly topographic highs or natural drainage features and are considered to also define groundwater divides or the outer flow model boundaries.

The finite-element model was set-up as a three-dimensional eight element layer, steady-state groundwater model. In view of the capabilities of the used software to simulate outcropping layers, the layers were arranged to represent the conceptual model as well as the proposed mine voids (Figure 5.2). Not all layers used to represent the mine geometry are therefore present throughout the model domain (Table 5.1).

The model domain was spatially discretised into 95 771 nodes on nine node layers, which make up eight element layers with 115 683 elements (triangles and quadrangles) per layer (not all of which are active due to outcropping layers beyond the mine area). The horizontal element size (side length) varies from a minimum of 10 m in the proposed mining area to a maximum of 150 meters (Figure 5.1) further away from the area of interest and expected steep groundwater head or concentration gradients. The spatially variable discretisation of the (finite-element) model domain allows a sufficiently accurate incorporation of discrete mine voids and infrastructure in a regional groundwater flow model used to ensure a defendable water balance.

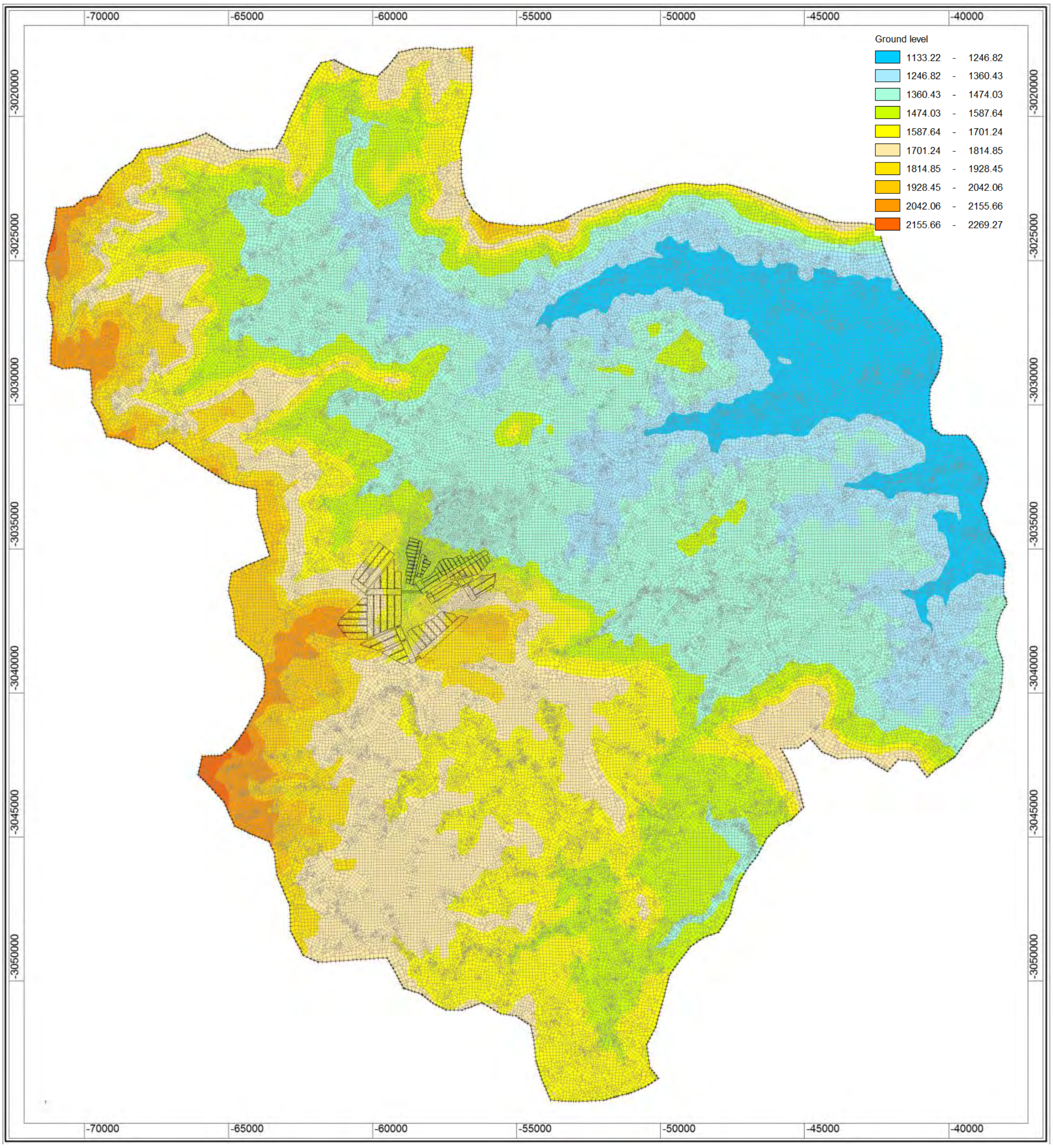


Figure 5.1: Finite element mesh of the Commissiekraal Groundwater Model (mine infrastructure indicated in black, drainages in blue).

In accordance with the developed conceptual model, the upper model layer (I) simulate the shallow weathered aquifer. The lower model layers (III to IIX) represent the dolerite aquitard, fractured Karoo aquifer and the proposed mine voids (layer V). The extensive dolerites sill toward the south of the project area was incorporated as separate model layers (III and VI). The dolerite is conceptualised as a semi-permeable aquitard which limits vertical exchange (leakage) between the two aquifer systems.

Table 5.1: Layer arrangement for the Groundwater Model.

Node layer	Element layer	Aquifer / Mining feature	Data used for interpolation
1	I, top	Surface elevation	Digital Elevation Model (5 m contours)
2	I, bottom	Bottom of weathered zone	DEM – 15 m
3	II, bottom	Fractured Karoo aquifer	Top of dolerite sill (1) (MCK logs)
4	III, bottom	Dolerite (aquitard)	Bottom of sill (MCK logs)
5	IV, bottom	Fractured Karoo aquifer	Top of dolerite sill (2) (MCK logs)
6	V, bottom	Dolerite (aquitard)	Bottom of sill (MCK logs)
7	VI, bottom	Fractured Karoo aquifer (bottom of Underground mine = Gus Seam	MCK Logs and Floor contour Average thickness 2.75 m (ECMA, 2014)
8	VII, bottom	Vryheid Formation (weathered) and semi- confined underlying the dolerites/mine/weathered layer	Thickness 100 m
9	IIX, bottom	Bottom of flow system (Vryheid Formation)	Thickness between 100 and 350 m

The top elevation of the shallow weathered aquifer (i.e. element layer I) is based on the Digital Elevation Model (DEM) for the site. The bottom elevation of the shallow weathered aquifer (i.e. the base of layer II) was, based on the average depth of weathering, offset by 15 m. The dolerite sill thickness were interpolated from the geological logs and augmented with image points in areas of no coverage in order to create a continuous layer representing the aquiclude. The lower fractured Karoo aquifer layer (element layers V-IIX) is split within the proposed underground mining area to represent the underground mine workings (Gus coal seam, representing the local drainage elevation) (Table 5.1). The lower boundary of the active flow system in the fractured aquifer varies between 80 and 350 m below surface, ensuring sufficient distance to simulate groundwater flow processes below the deepest envisaged mining depth.

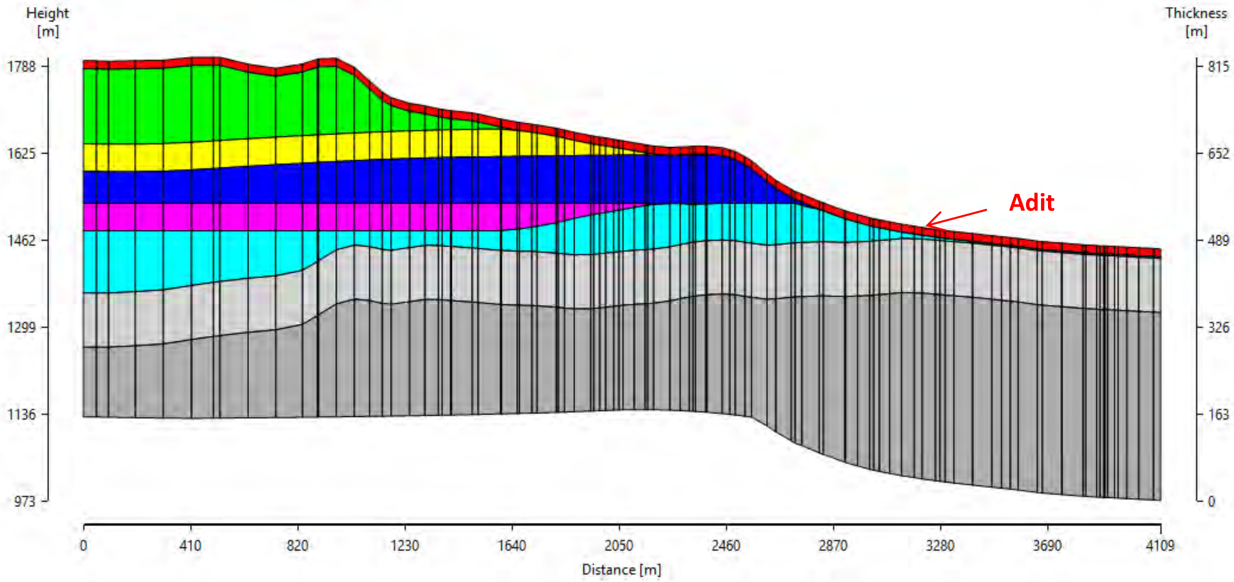


Figure 5.2: Example of the vertical grid layout across the proposed underground mining areas (colours indicate numerical model layers only).

5.3. SOURCES AND SINKS

5.3.1. Groundwater Recharge

Groundwater enters the model domain as direct recharge from rainfall to the shallow weathered aquifer. Delta H adopted an average regional recharge rate of 45 mm/a. Most of recharge that enters the shallow weathered aquifer exits the modelled domain (or shallow aquifer system) as outflow (baseflow) to rivers, indicating significant surface and groundwater interaction, though it is most likely limited to the rainy season. For the predictive simulation a low recharge (25 mm/a) and a high recharge (65 mm/a) scenario was applied to establish the volume of groundwater contributing to the Pandana River and the associated impact once underground mine workings commence.

5.3.2. Rivers and Streams

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. The streams/rivers were generally classified as potentially gaining streams/rivers and no leakage of surface water into the aquifer or 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 not be constricted by semi-pervious layers in the river bed and a leakage coefficient equivalent to the aquifer permeability was assigned to the river. An incision of 2.5 m below the surrounding topography is assumed for the hydraulic active river bed.

5.3.1. Underground Mine Workings

The proposed underground mine workings were integrated into the model domain at the bottom of the local element layer VI and aligned with the elevation of the mine voids as provided by the client (Table 5.1).

For the predictive flow simulations after 4 and 10 years of mining, and at life of mine (20 years) (see development plan Figure 5.3), a free seepage boundary was assigned to the grid nodes representing the mine voids (bottom of the Gus seam) representing the lowest drainage elevation. Groundwater is only allowed to discharge into the underground mine voids and it is assumed that any groundwater entering the mine voids is removed instantly, i.e. pumped out.

For the post closure simulations, the seepage boundary was removed from the mine void model layers, so that the mine voids become an integral, though highly altered part of the fractured Karoo aquifer. Water flow from the mine voids into the aquifers (return flows) was then simulated. The changes relate to an increased, essentially infinite hydraulic conductivity and elevated porosity (60%) for the mine voids.

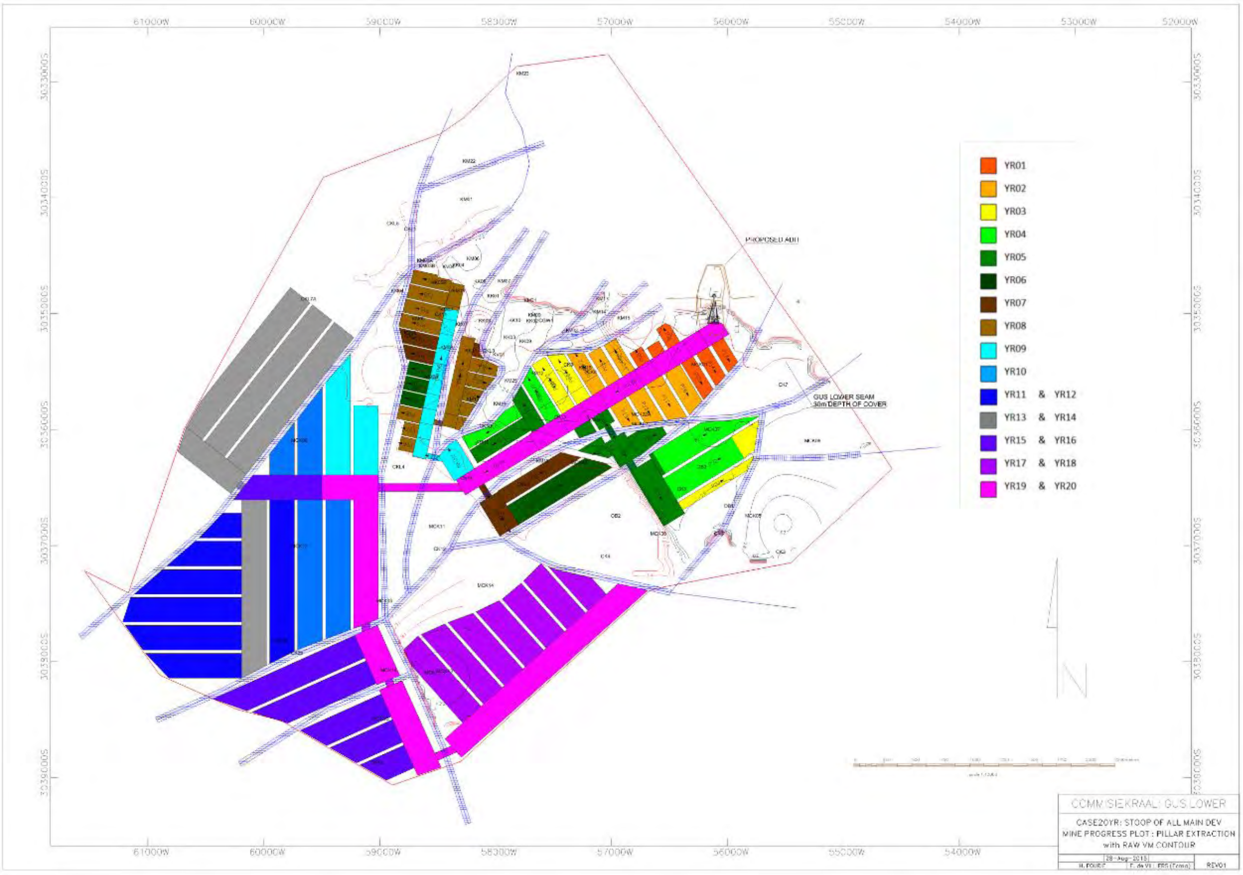


Figure 5.3: Underground mine development plan.

5.3.2. Seepage from surface infrastructure and underground mine workings

The coal and ROM stockpiles is regarded as a potential for pollution and it's expected that during the feasibility assessment more detailed geochemical analysis will inform the pollution potential together with the appropriate liner system to minimise seepage.

The proposed underground coal mine once operation represents a groundwater sink with groundwater seeping into the mine voids being removed (pumped out) and discharged into PCDs and/or re-used as process water. The rate of groundwater inflows into the final mine voids at or after closure can as a worst case scenario be equated to potential decant volumes (neglecting the reduction of groundwater gradients towards the mine voids once active dewatering cedes).

The quality associated with groundwater entering the mine voids is a function of the ambient groundwater quality and its interaction with the dewatered rocks and coal exposed to the atmosphere. Since the exposed coal seams are generally acid generating, a deterioration of the groundwater potentially decanting to surface (in the future) is expected. Based on recent geochemical modelling[2] using PHREEQC post-closure decant from the proposed Commissiekraal underground workings is estimated to have neutral pH with elevated concentrations of Ca and Mg. The model results suggest a range of 1 500 mg/L to 3 000 mg/L sulphate. Model results suggest Al, Fe, and Mn concentrations are unlikely to be of concern.

[2] Technical Memo – Solution H+ (Mr. Terry Harck) 1 October 2015

5.4. Targets and Goals

The groundwater levels (in metres above mean sea level) observed in 18 borehole were considered representative of the aquifers and used as calibration targets. 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 was therefore considered fixed for the calibration.

5.4.1. Initial Conditions

The initial conditions specified in numerical model were as follows:

- Starting heads for the shallow aquifer 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 2E-06 m/s for the weathered and of 5E-07 m/s for the fractured aquifer.
- Vertical hydraulic conductivities were set at 5% of the horizontal conductivities.
- Porosity values do not influence the outcome of the steady-state flow model, but only the transient transport model results. Effective porosity values were conservatively specified as 5% for the weathered and 1% for the fractured aquifer.

5.5. Numerical Parameters

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 10 iterations. The relative difference between the two computed potential heads or capillary pressures after 10 iterations was usually below an acceptable 0.01 m.

6. MODEL CALIBRATION

6.1. Steady State Calibration

The groundwater levels (in metres above mean sea level) observed in 18 boreholes and springs were considered representative of the aquifers and used for the calibration. No discharge measurements in the river courses were available for steady-state calibration purposes. The original model was run with the initial conditions and the hydraulic conductivities adjusted using sensible boundaries until a best fit between measured and computed heads was achieved. The hydraulic conductivity values vary according to the underlying geology and within different aquifers and aquitards.

An excellent correlation between observed and modelled water levels (R^2 = 0.98 or 98% correlation, Figure 6.1) with no bias towards too high or low modelled heads (even distribution of data points around regression line in, Figure 6.1) was achieved for the steady-state calibration.

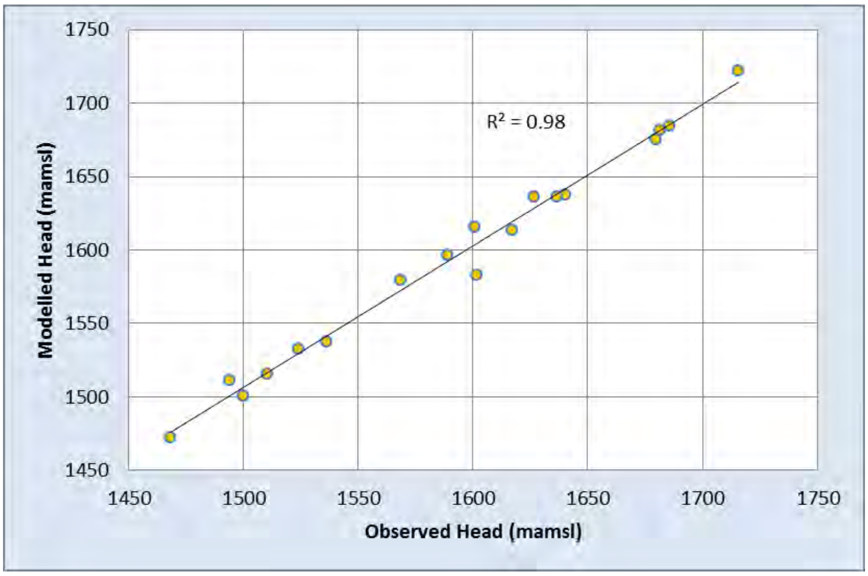


Figure 6.1: Steady-state calibration of the Commissiekraal Groundwater Model.

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 34 (=*n*) observed (h_{obs}) and simulated (h_{sim}) water levels:

$$RMSE = \sqrt{\frac{\sum(h_{obs} - h_{sim})^2}{n}} = 8.5$$

$$NRMSE = \frac{RMSE}{h_{max} - h_{min}} = 3.4\%$$

The normalised root mean square error scales the error value to the overall range of observed heads within a model domain (here $h_{max} - h_{min}$ =1722 mamsl – 1474 mamsl = 248 m), with values lower than 10% considered acceptable. As expected already from the excellent correlation, the corresponding root mean square error of 8.5 and normalised root mean square error of 3.4 % are considered more than acceptable for the model.

The calibrated conductivity values (Table 6.1) appear plausible and correlate well with literature values and more importantly the site specific hydraulic parameters obtained during the intrusive investigation. No site specific hydraulic test results are yet available for the dolerite sills, but the calibrated values fall within literature ranges. The low permeability of the dolerite intrusions limits flow across these structures. The calibrated conductivity values were subsequently used for the predictive model runs described below. The spatial distribution of the calibrated conductivity values for the Karoo aquifer is shown in Figure 6.2, while a cross-section along the underground mine is shown in Figure 6.3. Expectedly, the modelled groundwater contours (Figure 6.2) are closely related to the topography, and groundwater flows from higher lying ground towards lower lying valleys (drainage lines).

Table 6.1: Calibrated hydraulic conductivities.

Aquifer	Hydraulic conductivity	
	[m/s]	[m/d]
Alluvium and colluvium	5E-6	0.43
Weathered Karoo Aquifer	1E-6 to 2.5E-06	0.09 to 0.22
Fractured Karoo Aquifer	6E-08 to 3E-7	0.005 to 0.03
Aquitard (dolerite sill)	5E-09	4E-4

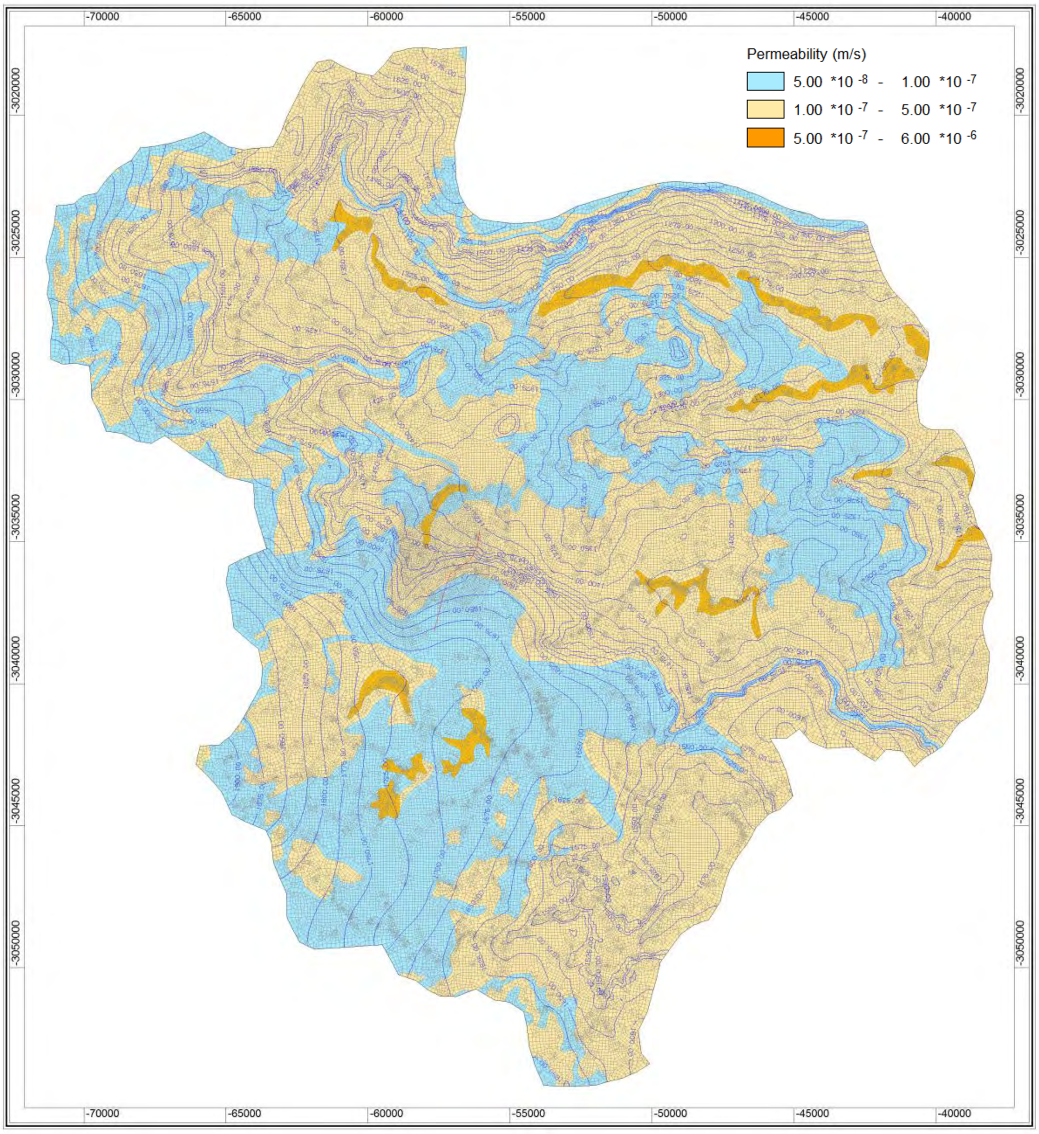


Figure 6.2: Distribution of permeabilities (layer 4) and simulated steady state heads (25 m) (section line in red).

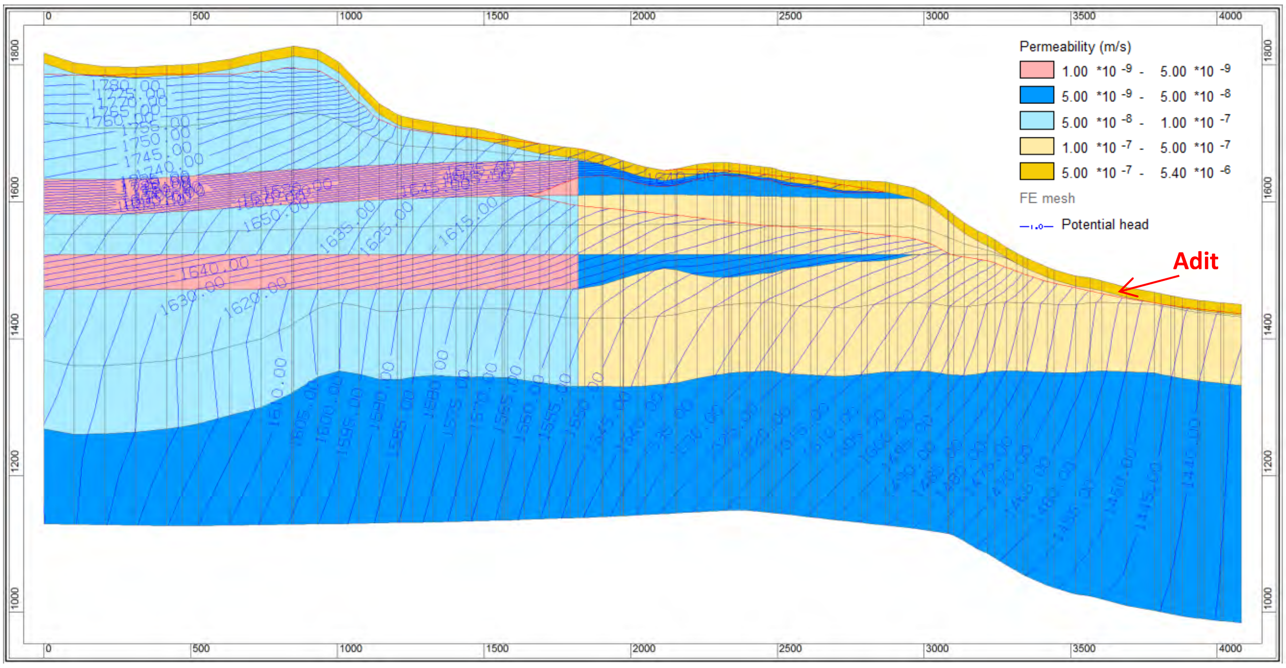


Figure 6.3: Cross-section of permeabilities together with steady state heads (5 m contour interval).

6.2. SENSITIVITY ANALYSIS AND MODEL VERIFICATION

No sensitivity analysis with regard to modelled groundwater levels was performed. However, the predictive modelling results of the mine inflows and groundwater contribution to the Pandana River was simulated under different recharge scenarios, namely average, low and high in order to establish the impact on the water balance under different climate conditions.

Due to the prevalence of water level measurements in the shallow weathered aquifer, the model proved during the calibration process, as would be expected, to be most sensitive to hydraulic conductivity values assigned to the weathered aquifer and the dolerite sill below the weathered aquifer (with assumed fixed recharge values).

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 limited water level data available for the study, no model verification could be done.

7. PREDICTIVE SIMULATIONS

7.1. Estimated Mine Inflow Rates

The calibrated groundwater flow model was used to estimate the annual average steady-state groundwater inflows into the underground mine voids. Based on the annual mining plans the following mine development stages was simulated:

- 4 years (section east of the Pandana River)
- 10 years (section underlying the Pandana River)
- 20 years life of mine (fully developed underground mine voids)

It must be noted that any steady-state groundwater model is likely to be a rough estimate of time dependent groundwater inflows, as it does not account for the increasing dewatering of the aquifer over time and hence reduced yields approaching the simulated steady-state inflows. However, in the absence of groundwater level measurements or variable recharge rates over time, the chosen approach appears justified. Several counteracting factors influence inflows into underground mine workings and are notoriously difficult to predict. While the stress-induced increase (up to two orders of magnitude) of the rock-mass permeability in the vicinity of the excavations due to the excavation damaged zone (which are amongst others dependent on the rock strength and excavation method) will increase the inflows, unsaturated flow processes in the vicinity of mine workings decrease the rock-mass permeability and hence inflows by similar orders of magnitudes. Simulated mine inflow values should therefore be seen as an initial estimate, which should be reviewed once actual inflow data becomes available. The steady-state groundwater inflows into the developed Commissiekraal Underground Coal Mine voids predicted with the calibrated groundwater flow model is shown in Table 7.1.

Table 7.1: Estimated inflow rates for the proposed Commissiekraal Underground Coal Mine.

Simulated Underground Mine (steady-state) Inflow Rates				
		Ave. Recharge	Low Recharge	High Recharge
Mine Development	Coal Seam (Approximate Area)	m^3/a [L/s]	m^3/a [L/s]	m^3/a [L/s]
4 years	1.9 km^2	239 414 [7.6]	203 101 [6.4]	259 831 [8.2]
10 years	3.7 km^2	483 301 [15.3]	391 202 [12.4]	532 713 [16.9]
Life of Mine 20 years	10.3 km^2	660 572 [20.1]	603 667 [19.1]	734 680 [23.3]

A major risk for the mining operations due to excessive inflows and for the environment due to associated water table drawdown is therefore at the intersection of highly permeable water bearing fractures or faults, especially if they transect also the river and the underground workings, which may lead to direct infiltration from the Pandana River. However, such small scale heterogeneity of aquifer properties is essentially impossible to assess based on the limited surface drilling campaigns. The potential intersection of water bearing fractures should therefore be investigated using appropriate methods during the development of the mine and associated risks and potential impacts minimised by pre-grouting.

7.2. IMPACTS ASSOCIATED WITH MINE INFLOWS

7.2.1. Description of Impacts

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

- the partial dewatering of the aquifer above and in the vicinity of the underground mine voids with subsequent impacts on groundwater dependant eco-systems and groundwater users,
- 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 and fractured Karoo aquifer due to mine inflows is depicted in Figure 7.1 to Figure 7.3 after 4 years, 10 years and at Life of Mine (20 years) 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 cones of dewatering are presented as contour areas with cut-off values of 2 m (weathered aquifer) and 5 m (fractured aquifer) respectively, representing the perceived seasonal variability of water levels (water level fluctuations are typically larger in lower porosity, fractured aquifers) as well as the uncertainties associated with the model predictions for the different aquifers (fractured aquifers are generally more heterogeneous and hence difficult to characterise hydraulically).

Due to the limited hydraulic connectivity between the shallow weathered and deeper fractured Karoo aquifers, the cone of dewatering is expectedly far more pronounced in the deeper fractured aquifer, where mining is planned to take place. The cone of dewatering in the shallow aquifer will preferentially extend along the slopes downstream of the proposed mining area. This suggests that the proposed underground mine would capture some lateral flow components in the fractured aquifer, which would have otherwise fed seeps along the ridges in the shallow aquifer (and also contributes to the Pandana River). The drawdown of the shallow aquifer is more pronounced along the Pandana valley after 10 years when the mine development extends underneath the River.

Due to its generally low permeability, the cone of dewatering in the fractured aquifer is steeper and extends far further than the cone in the shallow aquifer. It is also more influenced by the topography and depth of mining with a more pronounced distinction between the two aquifer systems due to the aquitard (dolerite sills) towards the south of the mine. The dewatering cone of the fully developed mine (20 years) is limited to an extent of 5 km east and south, and 3 km north from the underground mine workings. It extends more than 3.7 km westwards and reaches the western boundaries of the model domain. Since this is a no-flow boundary, simulated potential drawdown values are exaggerated. While this indicates obviously a too small model domain, an extension of the model domain covering the western plateau would increase computational efforts substantially while not adding much value to the contentious issue, i.e. the drawdown in the shallow aquifer.

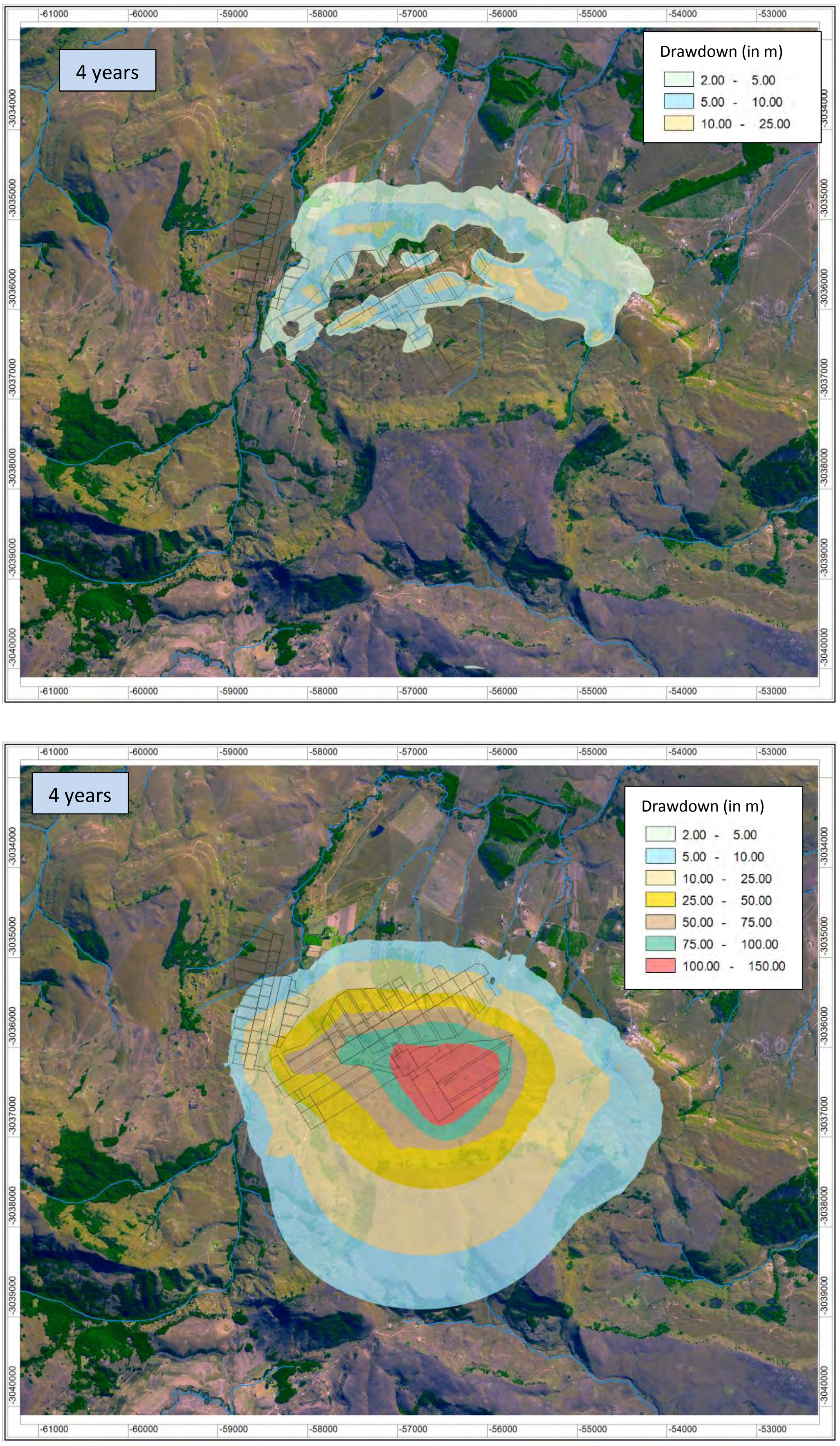
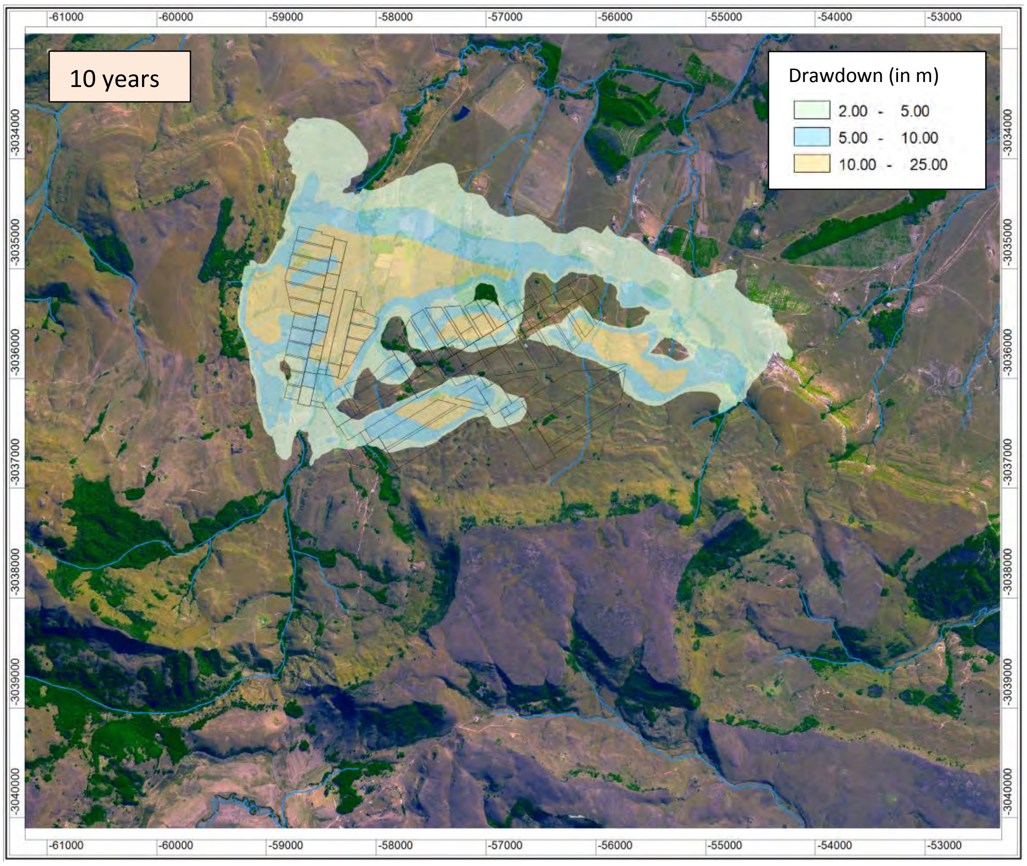


Figure 7.1: Simulated groundwater table drawdown (meters) in the shallow weathered and deeper fractured aquifer for life of mine (4 years) (underground mining area indicated by black line).



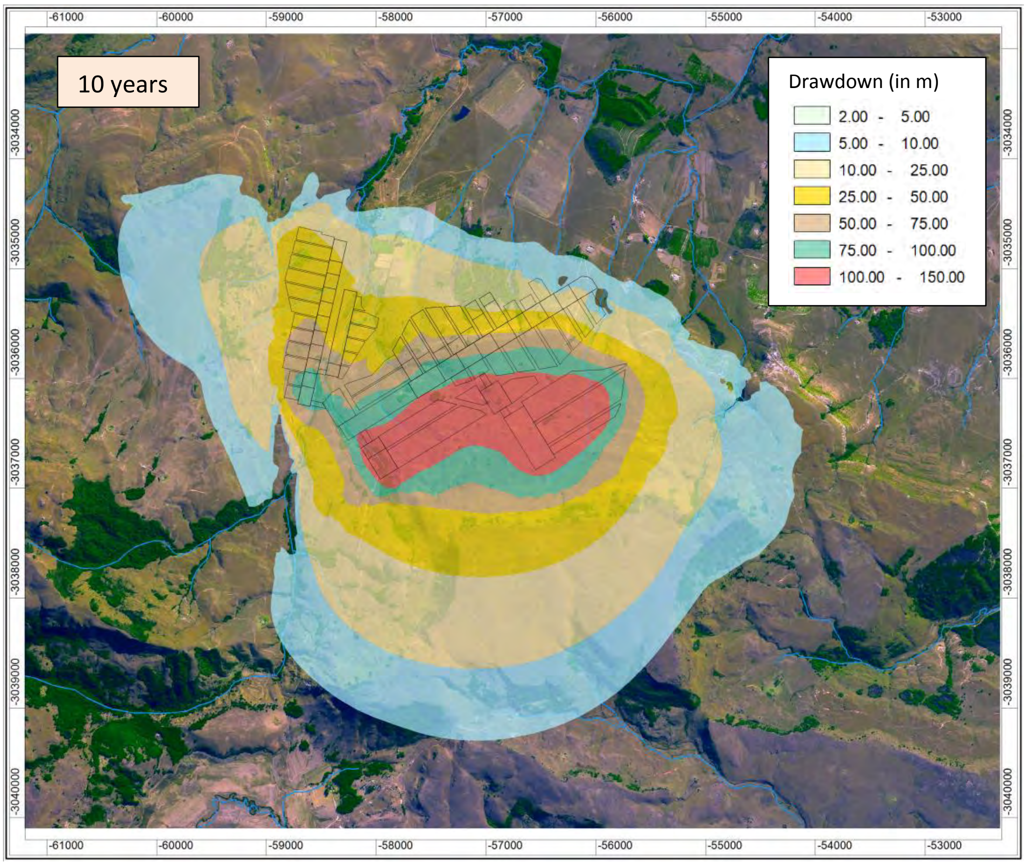
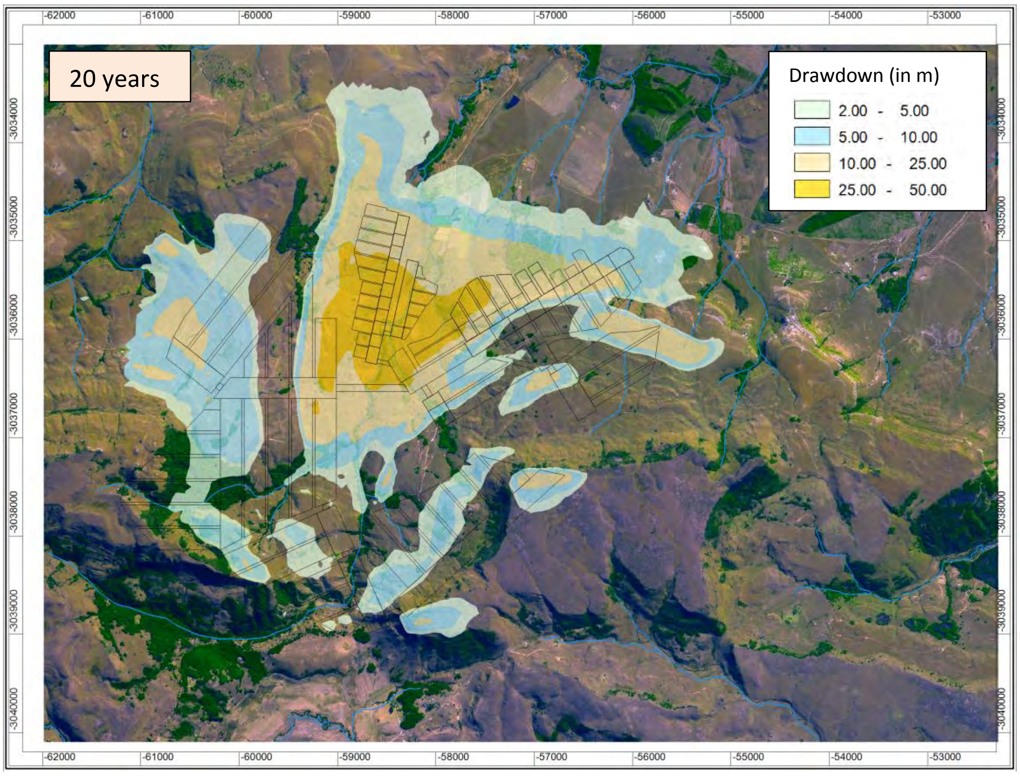


Figure 7.2: Simulated groundwater table drawdown (meters) in the weathered and deeper fractured aquifer for life of mine (10 years) (underground mining area indicated by black line).



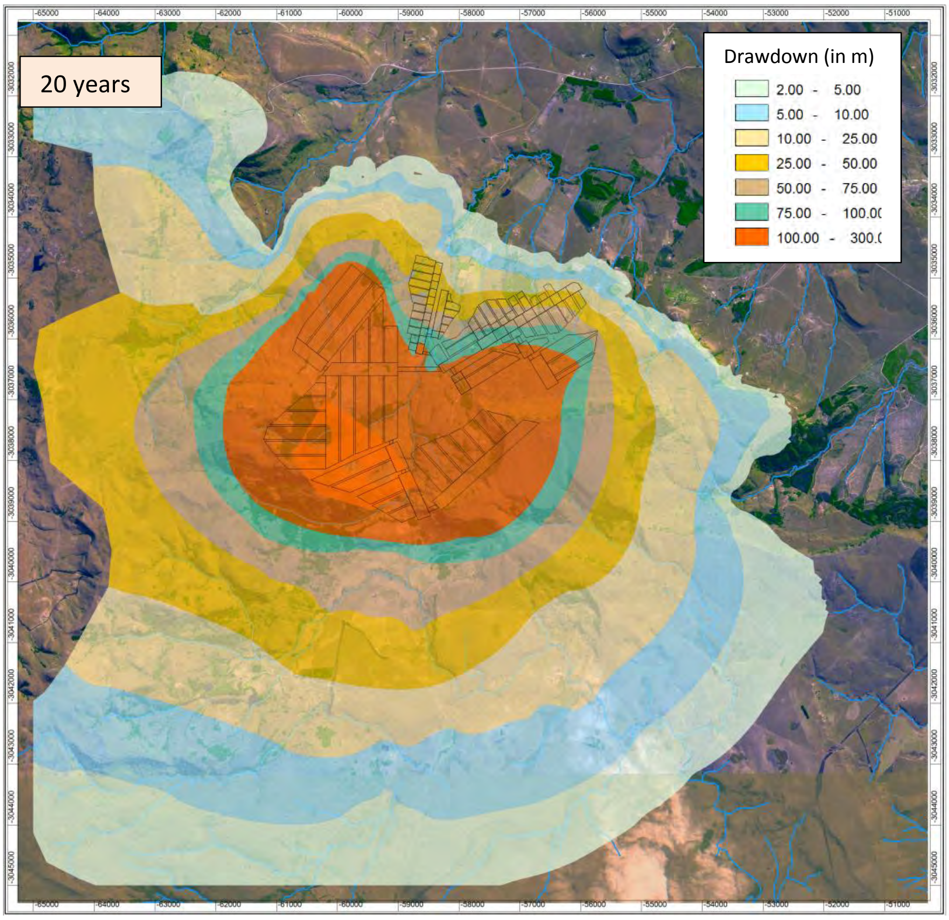


Figure 7.3: Simulated groundwater table drawdown (meters) in the shallow weathered and deeper fractured aquifer for life of mine (20 years) (underground mining area indicated by black line).

7.2.2. Reduction of baseflow

Groundwater dependant eco-systems and yields of (water supply) springs located within the significant zone of dewatering of the shallow aquifer, limited to the site boundaries, could be negatively impacted and some may dry up during the life of mine. However, not all wetlands are groundwater dependant and some of these wetlands might be supported by perched aquifers with a significant contribution from inter flow (in the vadose zone) and surface run-off in the rainy seasons. Surface water runoff (including interflow) accumulated in the wetlands during the rainfall season, and after storm events, is retained by dense silt/clay surface soil that limits infiltration of water until it is removed from the soil by evaporation and transpiration. Measured groundwater levels range from 2.6 mbgl to 36 mbgl. As a result it is expected that the lowering of the water table due to mining will not impact significantly on the soil moisture contained in the upper soil zone. It must be emphasised that groundwater models might not accurately reflect the absolute groundwater contributions to every single wetland or sensitive ecosystem due to the scarcity regarding their occurrence, hydrogeological setting and water levels.

Groundwater contributes to baseflow throughout the upper Pandana River catchment via sub-surface seepage into surface water courses. A manual flow measurement was collated by Scientific Aquatic Services (SAS) [3] in September 2015 downstream of the Commissiekraal proposed mine workings. The river section where the flow was measured is shown in Figure 7.4. The flow volume calculated by SAS at the section site was approximately 29 L/s. Based on the modelling results (Table 7.2) the groundwater contribution of 17.3 L/s is 59 % of the surface flow measured. It must be noted that the modelling results is averaged over the year and seasonally it will fluctuate according to the wet and dry season.

Figure 7.4: Pandana River balance section and flow measurement location.

[3] Technical Memo - Scientific Aquatic Services (20 September 2015)

Due to the underlying mine workings the downward head gradient provides potential for the Pandana River to lose water to the groundwater system. However, the connection between a river and the underlying aquifer is dependent on numerous factors including river bed transmissivity, degree of ground content and silt deposition in bed sediments. The simulated reduction (from the base case/pre-mining) of groundwater potentially contributing to the River is shown in Table 7.2. The position of the section used for the balance is shown in Figure 7.4. From the results a reduction of 8 L/s is seen between the base case and 20 years life of mine based on the average recharge scenario. While an obvious reduction of baseflow is expected towards the Pandana River due to the underground mine its flow is also largely dependent on surface water run-off and interflow (stored and transported) in the vadose zone.

Table 7.2: Groundwater contribution to the upper section of the Pandana River.

Mine Development	Ave. Recharge	Low Recharge	High Recharge
	m^3/a [L/s]	m^3/a [L/s]	m^3/a [L/s]
Base Case (Pre-mining)	545 061 [17.3]	378 137 [12.0]	690 923 [21.9]
4 years	481 698 [15.3]	340 679 [10.8]	639 031 [20.3]
10 years	354 832 [11.3]	205 715 [6.5]	506 871 [16.1]
Life of Mine (20 years)	292 766 [9.3]	150 297 [5.8]	459 497 [14.6]

7.2.3. Impact Rating

Assuming re-use or other environmentally acceptable disposal practices of the groundwater entering the underground mine voids, it is expected that the mine inflows are a “sink of groundwater” during life of mine and do therefore not change the groundwater quality.

It is expected that the groundwater inflows into the proposed underground mine voids will change the volume of groundwater in the aquifer storage (lowering of water table) in the shallow weathered aquifer:

- Highly likely to occur.
- Localized within site boundary.
- Reduction of spring or seep yields (groundwater contribution to baseflow) within the zone of dewatering (see Figure 7.1).
- Long term beyond mine closure with a permanent lowering of the water table unless the mine voids are backfilled or sealed.
- Of moderate severity with a drawdown of the water table in the vicinity of the mine and the Pandana river valley.

It is expected that the groundwater inflows into the proposed underground mine voids will change the deep regional groundwater flow regime. The predicted impacts are:

- Highly likely to occur.
- Localized within Commisiekraal boundaries (by definition of regional flow).
- Moderate to significant reduction of baseflow to the Pandana River (note: maximum of total inflow volumes if evapotranspiration close to river banks is neglected, i.e. a part of the abstracted water would under natural conditions be lost to evapotranspiration and not contribute to baseflow).
- Long term beyond mine closure with a gradual increase of groundwater baseflow (i.e. reduction of impact) once mine voids are flooded.

7.3. POST CLOSURE (FLOODING)

For the post-closure model scenario, groundwater seepage into the underground mine voids was included (water balance) by removing the seepage boundary conditions. In other words, pumping is assumed to cease at the end of the 'life of mine' and the ground-water levels in the deeper fractured Karoo aquifer are allowed to rebound freely and flood the underground mine. A porosity of 60% (equal to stoping ratio) and an essentially infinite hydraulic conductivity (1 m/s) was assigned to the underground mine voids, representing a mostly mined, but not scavenged mine void with no collapse of the pillars and respectively, no land subsidence. The recharge rate above the mining area therefore remained unchanged in the post-closure simulations.

7.3.1. Impacts associated with Mine Flooding

Post-closure, the mine voids represent a highly permeable flow path, which will result in new equilibrium water levels within the area of influence, different from the pre-mining water levels. The highly permeable mine voids "equilibrate" the water pressures at their southern extension, i.e. further upstream (towards the mountains) with the water levels at the mine adit (principle of communicating pipes), resulting in a likely decant of water from the mine void (Figure 7.5).

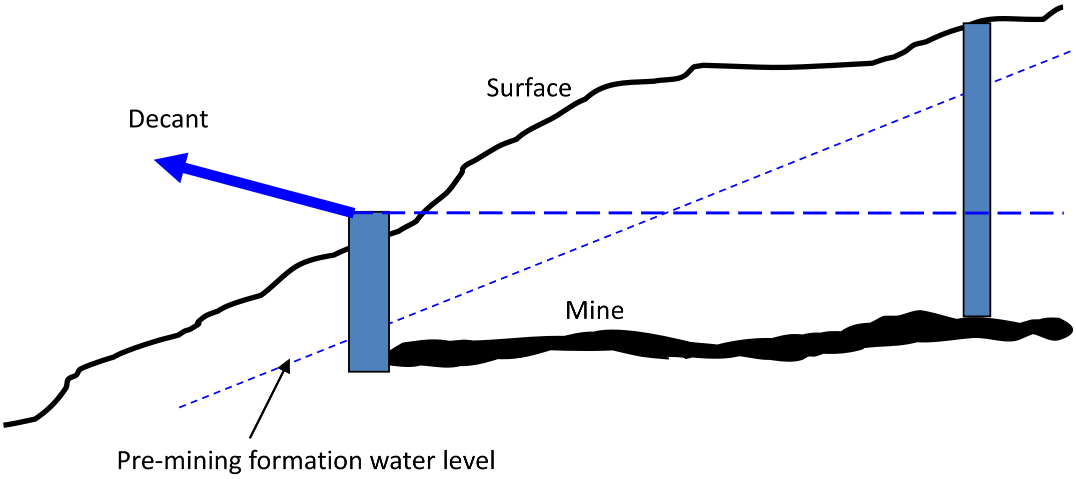


Figure 7.5: Principle of equilibrating water levels in a flooded underground mine.

A simple water balance approach can be utilised to estimate the minimum time required to fill the open mine voids under the assumption of constant groundwater gradients towards and subsequent inflows into the mine. This assumption results in a minimum time frame of mine flooding, as the groundwater gradients towards the mine and subsequent inflows will in reality recede with the rebounding water levels in the aquifers. Considering a proposed final underground mining area of 10.7 km^2, an average seam height of 1.8 m and an average stooping ratio of 75% (i.e. 25% of coal is not mined and remains behind as pillars), the total underground mine volume to be flooded amounts to approximately 14 Mm^3. With a simulated steady-state groundwater inflow rate of 20.1 l/s), it would take theoretically 22 years before the mine voids are completely flooded. It is widely accepted that the underground mines also decant, usually at the same rate as recharge (inflows).

Once the entire mine voids are flooded the mine becomes a completely saturated part of the aquifer and the piezometric head of the mine will rise, while the flux from the overlying aquifers will decrease as the deeper and shallow water levels converge. Eventually a dynamic equilibrium is achieved between inflow and outflow. This could potentially result in poor water quality underground mine water seeping or decanting out as springs in lower-lying areas from the shallow weathered aquifer.

The post-closure modelling results indicate that it will take around 25 to 40 years for the aquifers above the mine to return to pre-mining conditions (Figure 7.6). While it is evident that decant onto surface is likely, in this context the term 'decant' also refers to seepage from the mine workings into the shallow aquifer which is in hydraulic connection with the surface drainages.

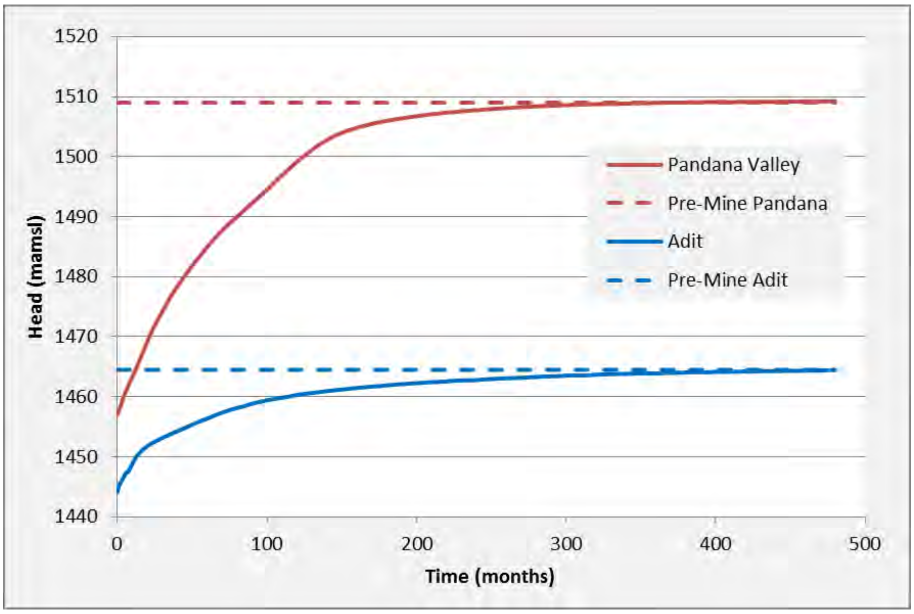


Figure 7.6: Simulated water level rebound of selected observation sites.

7.4. NON-REACTIVE TRANSPORT MODEL

The solution of the calibrated steady-state groundwater model was used as the basis for the transport model using the transport code built into SPRING (Chapter 5.1). Following the precautionary principle, only advective-dispersive (longitudinal dispersivity 50 m) transport of a potential pollutant without any retardation or transformation was assumed. One of the uncertainties encountered during transport modelling of pollutants is the kinematic or effective porosity of the aquifer. Effective (transport) porosity values were conservatively specified as 5% for the weathered aquifer and 1% for the fractured aquifer. These values affect only the transport model and do not influence the outcome of the steady-state flow model.

In the absence of a geochemical characterisation of the potential decant water quality a unit source concentration of 100% was applied. The contamination plumes are expressed as percentages of input/source concentrations with a minimum and increment of 10 %. Since no element specific retardation or transformation is simulated, concentrations for individual elements of concern can be easily derived by multiplying given percentages with the respective source concentration for an element. If a constant source term of 100 % is assumed for the decant (seepage) water quality, a shallow pollution plume will develop downstream of the Pandana valley and downstream of the adit (Figure 7.7). The simulated plume, with a cut-off value of 10 % mg/l sulphate, 25 years after flooding of the mine, extends approximately 700 m from the Adit down gradient and approximately 400 m from the mine workings along the Pandana River. More noticeable is that plume concentrations of between 30 and 60 % are likely to occur within the weathered aquifer underlying and contributing to a number of tributaries. However, the associated mass fluxes are likely to be small (compared to interflow and surface run-off) and likely to dilute quickly in the surface water.

Table 7.3: Example of relative source term concentrations in relation to potential concentrations.

Unit (%)	Sulphate (mg/l)
10%	200
20%	400
30%	600
40%	800
50%	1000
60%	1200
70%	1400
80%	1600
90%	1800
100%	2000

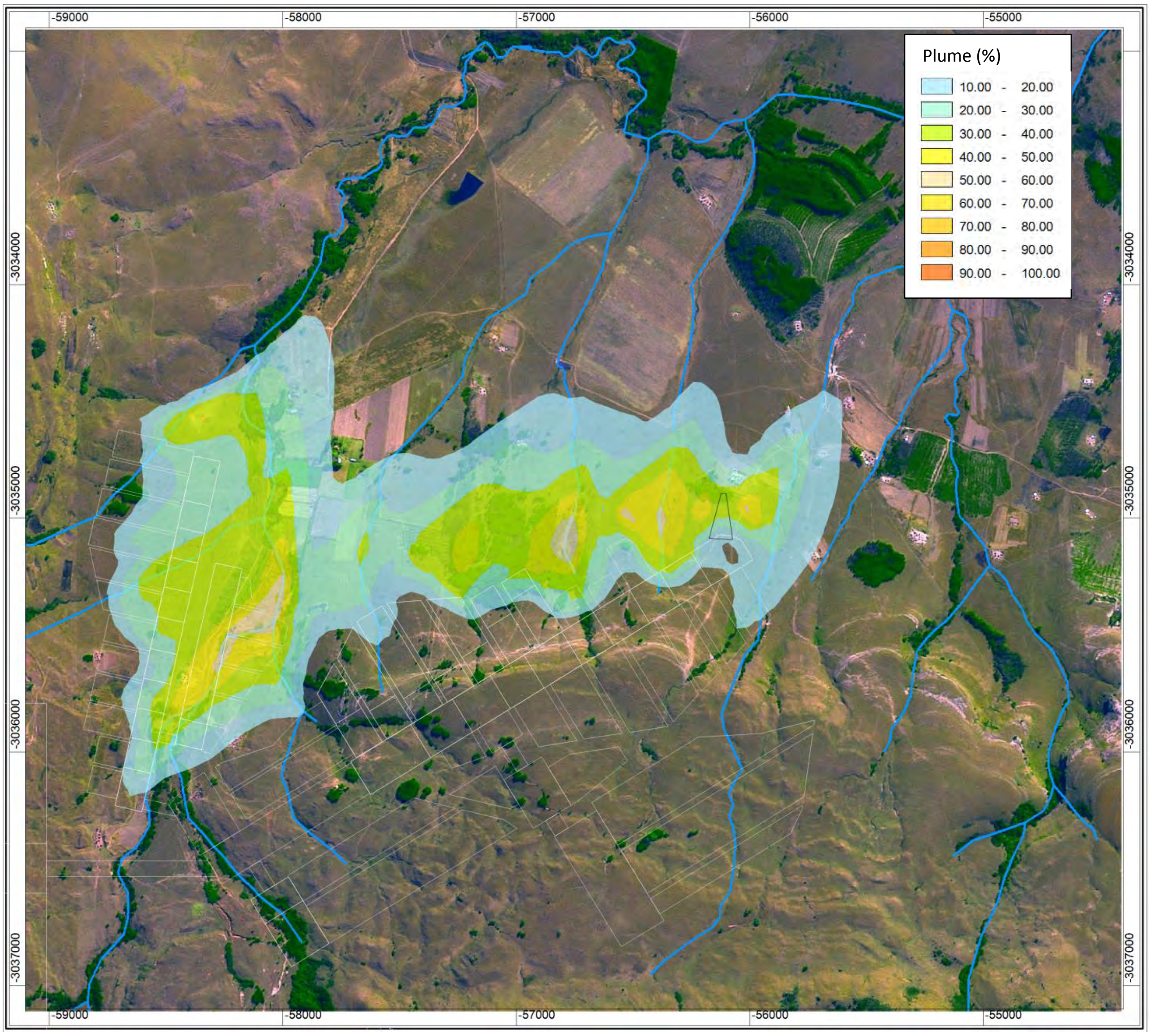


Figure 7.7: Potential decant (seepage) plume in the shallow weathered aquifer 25 years after flooding of the mine void.

7.4.1. Impact Rating

The potential post closure impacts of decant/seepage from the underground mine voids on the groundwater quality are:

- Distinct possibility to occur.
- Widespread beyond site boundary (regional) due to potential interaction with surface waters. Localised if mitigated by treatment of decant.
- Long-term, with increases of pollutant concentrations in surface waters beyond closure. Depending on mitigation measures, i.e. treatment system, limited increases of pollutant concentrations beyond closure.
- The intensity of the impact is highly likely and will result in a deterioration in the ambient water quality, if not mitigated by treatment or capture of the decant. Depending on the treatment method, the impact can be mitigated/reduced to a minor to moderate intensity.

The post-closure sealing of the mine adit should allow access to monitor the water levels within the mine void and to manage water levels below critical levels to prevent diffuse seepage into the weathered aquifer utilising suitable engineering designs (e.g. active pumping or passive dewatering of adit by drain systems). These levels should be defined based on site specific data (ie. interface between weathered and fractured rock) as the mine is developed and the adit is sunk. Any potential post-closure decant from the mine should be captured and treated to applicable standards before being released into the environment. A more confident prediction of post-closure decant rates and quality can only be achieved based on site-specific monitoring and geochemical data gathered during the life of mine and subsequent model updates.

7.5. 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.

7.5.1. 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 Table 7.4, 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 10 year transient calibration period would be required for a high confidence prediction over 10 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).

Table 7.4: 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.	• 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	• 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 as that used in calibration. • Mass balance closure error is less than 1% of	• 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*
	• Streamflow data and baseflow estimates available at a few 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.	included in the predictive model are outside the 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.	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.

While a model may fall into different classes for the various criteria (data, calibration and prediction, see Table 7.4), 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. Models for newly proposed developments fall typically in this category.

7.5.2. 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 7.5).

Table 7.5: Criteria specific and overall model confidence level classification.

Criteria	Confidence level classification	Key indicators
Data	1	No available records of metered groundwater extraction Single water level measurements (2015)
Calibration	1	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 (steady-state) calibration period
Overall	1	All criteria fall into a Class 1, model to be updated once more data become available

7.5.3. Implications for predictions

Despite all efforts to account for data uncertainties, the model predictions are intrinsically of low confidence. While Delta H would classify the confidence in the conceptualisation of the aquifer system as well as the steady state model calibration alone as medium, the fact that the predictive time frame and stresses exceed the calibration timeframe and considered stresses pushes the overall model confidence back. The model predictions should therefore be verified once more groundwater monitoring data and hydraulic conductivities become available. Predicted mine inflows and plume migration rates for later years of mine development can significantly be improved by observation data from earlier years and subsequent updates of the groundwater model.

8. RECOMMENDATIONS

8.1. MONITORING PROGRAMME

Based on the outcome of this investigation, a number of geosites (i.e. boreholes, springs and surface water drainages) were identified to be included into a monthly/quarterly monitoring programme for the Commissiekraal operations. While the current monitoring sites are regarded as sufficient for the accurate setting of a pre-mining baseline, a number of future monitoring sites are proposed to fill this gap. The positions of the current (proposed) monitoring network is shown in Figure 8.1 and listed in Table 8.1. It is proposed that the existing monitoring network should be augmented and adapted as follows (refer to Figure 8.1):

- Additional monitoring boreholes to be drilled downstream of adit (based on potential decant plume and shallow cone of dewatering)
- Additional surface water monitoring sites along the Pandana River

Table 8.1: Current (proposed) monitoring sites for the Commissiekraal Project.

ID	Monitoring	Component	Frequency
CK-BH1	Underground workings (shallow aquifer)	Groundwater quality and groundwater level	Quarterly (monthly groundwater levels)
CK-BH2			
CK-BH3	Underground workings		
CK-BH4	Underground workings (Pandana River)		
CK-BH5			
MBH6	Potential decant/seepage (adit) (Post closure)		
MBH7	Potential decant/seepage (Post closure)		
MBH8			
Spring-11	Spring (baseline quality)		
Upper Pandana	Upstream baseline quality	Surface water quality	Initially quarterly*
Tributary Pandana	Baseline quality		
Tributary Pandana 2			
Lower Pandana			
SW-P1	Underground workings (downstream)		
SW-P2	Discard dump (after tributary confluence)		
SW-P3	Compliance monitoring (Pandana)		

* - should be reduced to monthly when operation commence

The proposed, water quality monitoring programme considers the source-pathway-receptor approach of risk assessments and will rely on the three “pillars” of monitoring, namely;

- Source monitoring of process water (i.e. underground inflows) or material (i.e. adit)
- Pathway monitoring downstream of potential pollution sources, as well as
- Receptor monitoring by “ring fencing” the Commissiekraal site with strategically located surface monitoring points up- and downstream of the proposed infrastructure.

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),).

Figure 8.1: Commissiekraal (proposed) monitoring sites.

8.2. PROPOSED MITIGATION MEASURES

- An environmental monitoring programme should be established in order to monitor changes in groundwater quality (quarterly, full chemical analysis for major constituents and trace elements), groundwater levels (monthly) and spring discharges (monthly). The gathered data should be reviewed annually to differentiate seasonal variations and general trends due to the proposed mine activities. The gathered data should also be used for annual updates of the flow and transport model to improve the confidence in the model predictions.
- A standard operating procedure for water level monitoring and water sampling should be developed according to best practice (e.g. purge boreholes prior to sampling, filter and acidify samples on site for metal analyses).
- Development of a continuous water balance for the mining operations using suitable measurement points and devices for expected flow rates, focussing especially on groundwater inflows into the underground mine workings.
- The potential intersection of water bearing fractures by underground mining should be investigated using appropriate methods during the development of the mine (especially mining underneath the Pandana River). Associated risks and potential impacts of such intersections should be minimised by i.e. pre-grouting.
    - The area where groundwater and surface water interaction are most likely to be affected by mining is shown in Figure 8.1.
- The predicted rate of mine flooding and quality of decant should be re-evaluated once more site-specific groundwater monitoring and geochemical data become available.
- Although it was predicted that no groundwater users (i.e. springs and boreholes) on site and on surrounding farms will likely be affected by the proposed Commissiekraal Project, an alternative source of water supply should be provided for groundwater users (capturing mostly spring discharges) if they are impacted by the proposed mining activity.
- The mine adit should be rehabilitated post-closure to limit risk of water contamination, i.e. hydraulically sealed post-closure.
- The post-closure water level in the mine voids should be monitored and managed below critical levels to prevent diffuse seepage into the weathered aquifer utilising suitable engineering designs (e.g. active pumping or passive dewatering of adit by drain systems).
- Any potential post-closure decant from the mine should be captured and treated to applicable standards before released into the environment. A suitable treatment facility should be designed to cater for post-closure decant quantities and qualities (to be developed and refined once mine becomes operational).

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10. 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 groundwater specialist report has been compiled by experienced, fully qualified and duly registered Professional Natural Scientists.

The model development is largely 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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11. DECLARATION OF INDEPENDCE

Delta-H Water System Modelling Pty Ltd (Delta H) and its associates have no direct or indirect business, financial, personal or other interests in the activity application or appeal other than fair remuneration for work performed in connection with that activity, application or appeal and there are no circumstances that may compromise the objectivity of the persons performing such work. The remuneration of the services provided by Delta-H is in no way contingent upon the conclusions or opinions expressed in this report.

APPENDIX A – HYDROCENSUS RESULTS

2730ADHF354 1

2730ADHF354

2730ADHF357 1

2730ADHF357

2730ADHF358 1

2730ADHF358

2730ADHF359 1

2730ADHF359

2730ADHF360 1

2730ADHF360

2730ADHF361 1

2730ADHF361

2730ADHF362

2730ADHF362 1

2730ADHF362 2

2730ADHF364 1

2730ADHF364

2730ADHF368 1

2730ADHF368

2730ADHF369 1

2730ADHF369

2730ADHF369

2730ADHF370 1

2730ADHF370

2730ADHF371 1

2730ADHF371

2730ADHF372 1

2730ADHF372 2

2730ADHF372

2730ADHF374 1

2730ADHF374 2

2730ADHF374

2730ADHF375 1

2730ADHF375 2

2730ADHF375

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2730ADHF380 1

2730ADHF380

2730ADHF381 1

2730ADHF381

2730ADHF382 1

2730ADHF382

2730ADHF383 1

2730ADHF383

2730ADHF384 1

2730ADHF384 2

2730ADHF384

BH 1-HP 1

BH 1-HP

Bivane 1

Biavane 2

Biavane

CGWG 1 2

CGW 1 3

CGW 1

Kempslust 1

Kempslust 2

Kempslust

Lower Pandana 1

Lower Pandana

Lower Sibabe 1


Lower Sibabe 2


MCK 01 1


MCK 01 02


MCK 01


MCK 02 1


MCK 02


MCK 07 1


MCK 07


MCK 11 1


MCK 11


MCK 14 1


MCK 14


MCK 03 1


MCK 03


Pandana downstream


Springs 11 1


Springs 11


SW near 383 1


SW near 383


Tributary Pandana 1


Tributary Pandana


Upper Pandana 1


Upper Pandana 3


Upper Pandana


Upper Sibabe 1


Upper Sibabe 2


Upper Sibabe


Makatees Kop (Spring)

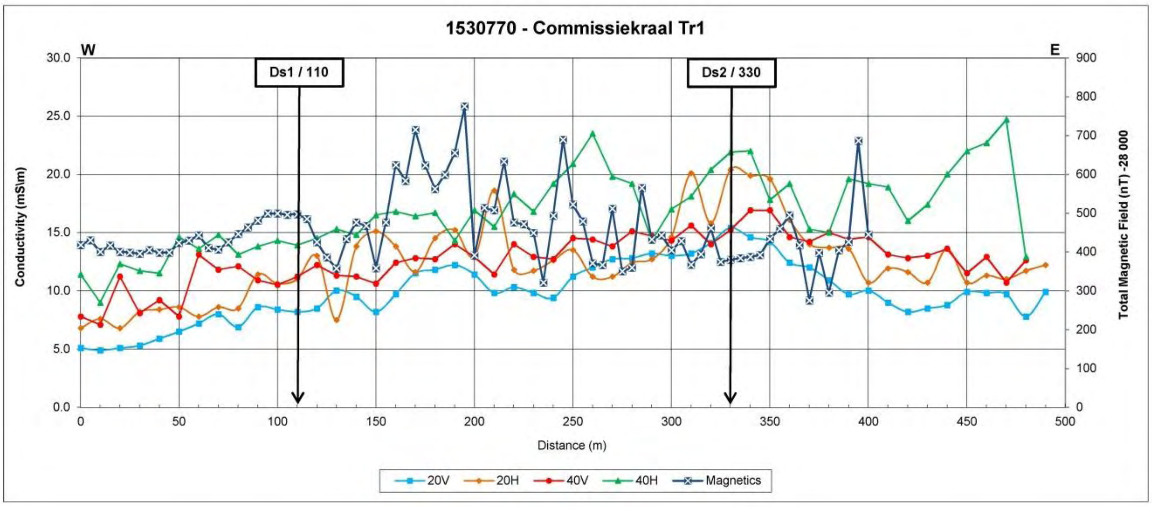

Makatees Kop Sample Point 2

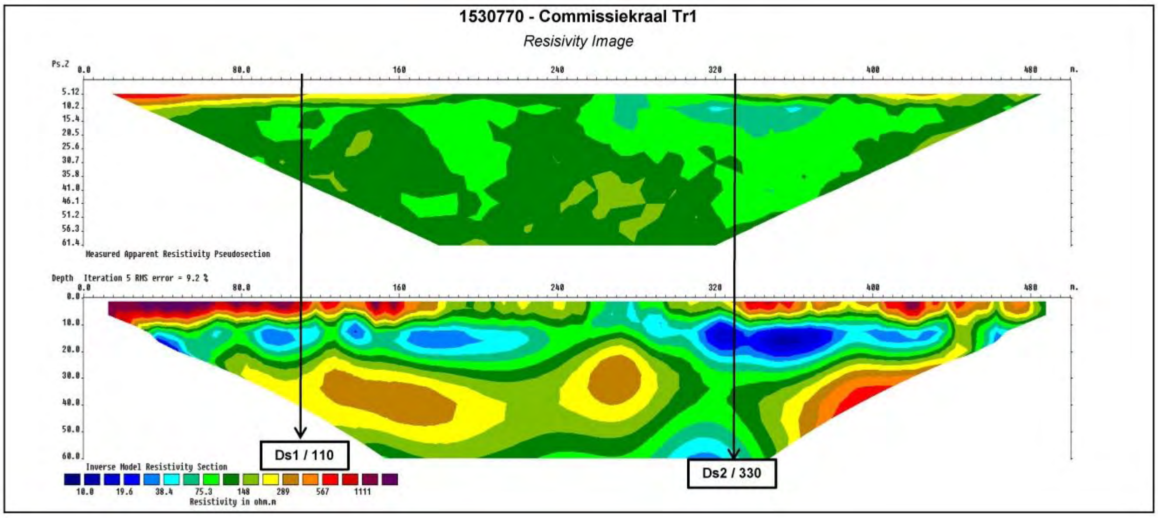

Makatees Kop Farm Borehole

BHID	LONG	LAT	DATE OF SURVEY	EQUIPMENT	SAMPLE TAKEN Y/N	WATER LEVEL (mbgl)	SITE PURPOSE	CASING ID	COMMENT	FARM NAME
2730ADHF354	-27.40371	30.37486	08/05/2015	Handpump	Yes		Production	165	At village	Vredehof
2730ADHF357	-27.39578	30.39933	08/05/2015		Yes				Spring (close to road)	Vredehof
2730ADHF358	-27.39368	30.40257	08/05/2015		No				Spring (close to road)	Vredehof
2730ADHF359	-27.39137	30.40675	09/05/2015		No				Spring	Vredehof
2730ADHF360	-27.39548	30.40594	08/05/2015		Yes				Spring (close to road)	Vredehof
2730ADHF361	-27.40244	30.40316	09/05/2015		Yes				Spring (near village)	Vredehof
2730ADHF362	-27.40135	30.41487	08/05/2015		Yes				Spring	Vredehof
2730ADHF363	-27.38440	30.40920	09/05/2015		Yes				Stream	Vredehof
2730ADHF364	-27.39223	30.39834	09/05/2015		No				Spring	Lusthof
2730ADHF368	-27.39695	30.39623	08/05/2015		No				Spring (close to road)	Vredehof
2730ADHF369	-27.41469	30.40242	09/05/2015		No				Dry	Commissiekraal
2730ADHF370	-27.41374	30.40448	09/05/2015		No				Spring	Commissiekraal
2730ADHF371	-27.41134	30.40299	09/05/2015		Yes				Spring	Vredehof
2730ADHF372	-27.39605	30.43230	08/05/2015	Handpump	Yes			165	At School	Rooipoort
2730ADHF374	-27.40708	30.42184	08/05/2015		No				Spring	Commissiekraal
2730ADHF375	-27.40672	30.41985	08/05/2015		Yes				Spring	Commissiekraal
2730ADHF376	-27.40313	30.42409	08/05/2015		Yes				Spring	Vredehof
2730ADHF377	-27.40322	30.42194	08/05/2015		No				Spring	Vredehof
2730ADHF378	-27.39344	30.43441	08/05/2015		No				Spring	Rooipoort
2730ADHF379	-27.39419	30.43341	08/05/2015		No				Spring (near school)	Rooipoort
2730ADHF380	-27.40008	30.43616	08/05/2015		No				Dry	Rooipoort
2730ADHF381	-27.39588	30.44616	08/05/2015		No				Spring	Rooipoort
2730ADHF382	-27.39341	30.45336	08/05/2015		Yes				Stream (from spring)	Rooipoort
2730ADHF383	-27.39417	30.46589	08/05/2015		Yes				Spring	Rooipoort
2730ADHF384	-27.39242	30.45848	08/05/2015		No				Spring	Rooipoort
BH-1	-27.39376	30.40315	09/05/2015	Handpump	No			165	Handpump (near village)	Vredehof
Bivane river	-27.49455	30.44963	06/05/2015		Yes				Surface Water	Pivaanspoort
CGW 1	-27.42437	30.41763	07/05/2015	None	Yes	6.09	Production	165	Slug Test	Commissiekraal
Kempslust	-27.46553	30.51576	08/05/2015		Yes				Surface Water	Dumbe
KM 03	-27.40366	30.41925	08/05/2015	None	No		Exploration	110	Casing sealed	Vredehof
Lower Pandana	-27.40981	30.42889	06/05/2015		Yes				Surface Water	Rooipoort
Lower Sibabe	-27.39552	30.40966	06/05/2015		Yes				Surface Water	Vredehof
MCK 01	-27.43052	30.43073	07/05/2020	None	No	23.21	Exploration	65	Collapsed at 7m	Commissiekraal
MCK 02	-27.43437	30.42550	07/05/2021	None	No		Exploration		Collapsed	Commissiekraal
MCK 07	-27.43561	30.43180	07/05/2017	None	Yes	21.97	Exploration	74	Slug Test	Commissiekraal
MCK 09	-27.43592	30.44139	07/05/2016	None	Yes	135.82	Exploration	65	Slug Test	Commissiekraal
MCK 11	-27.44303	30.40779	07/05/2018	None	Yes	28	Exploration	74	Slug Test	Commissiekraal
MCK 14	-27.44764	30.41197	07/05/2019	None	Yes	19.34	Exploration	65	Slug Test	Commissiekraal
Pandana Downstream	-27.39969	30.47672	06/05/2015		Yes				Surface Water	Rooipoort
Spring 11	-27.44355	30.40759	06/05/2015		Yes				Surface Water	Commissiekraal
Tributary Pandana	-27.42689	30.43512	06/05/2015		Yes				Surface Water	Commissiekraal
Tributary Pandana 2	-27.42689	30.43755	06/05/2015		No				Surface Water	Commissiekraal
Upper Pandana	-27.45405	30.40591	06/05/2015		Yes				Surface Water	Commissiekraal
Upper Sibabe	-27.41290	30.38468	06/05/2015		Yes				Surface Water	Vredehof
Makatees Kop 1	-27.43703	30.71794	27/05/2015		Yes				Spring	Makateeskop
Makatees Kop 2	-27.42292	30.70503	27/05/2015		Yes				Surface Water	Makateeskop
Makatees Kop 3	-27.42731	30.70992	27/05/2015		Yes				Borehole	Makateeskop

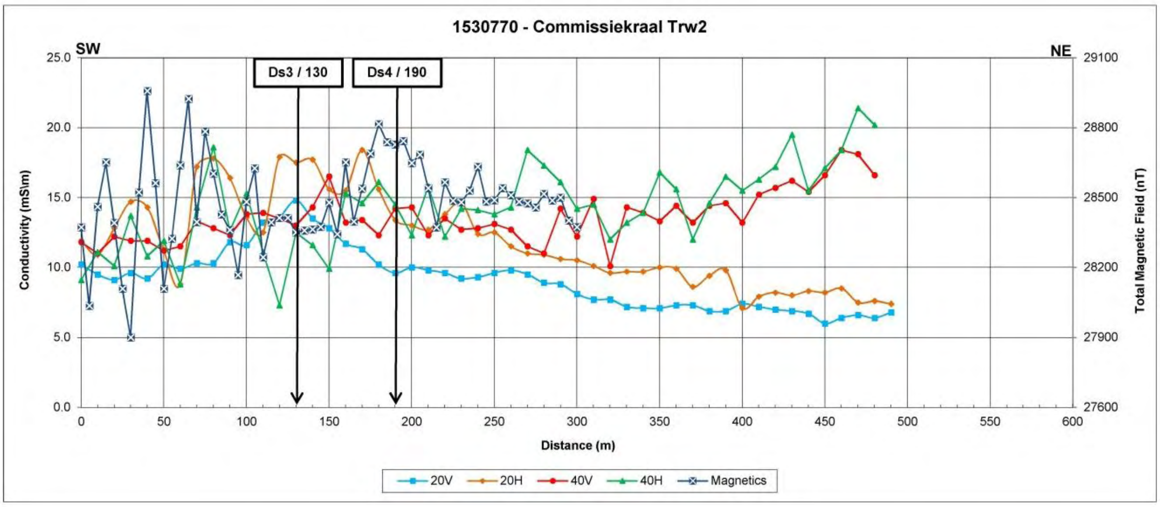
APPENDIX B – GEOPHYSICS RESULTS

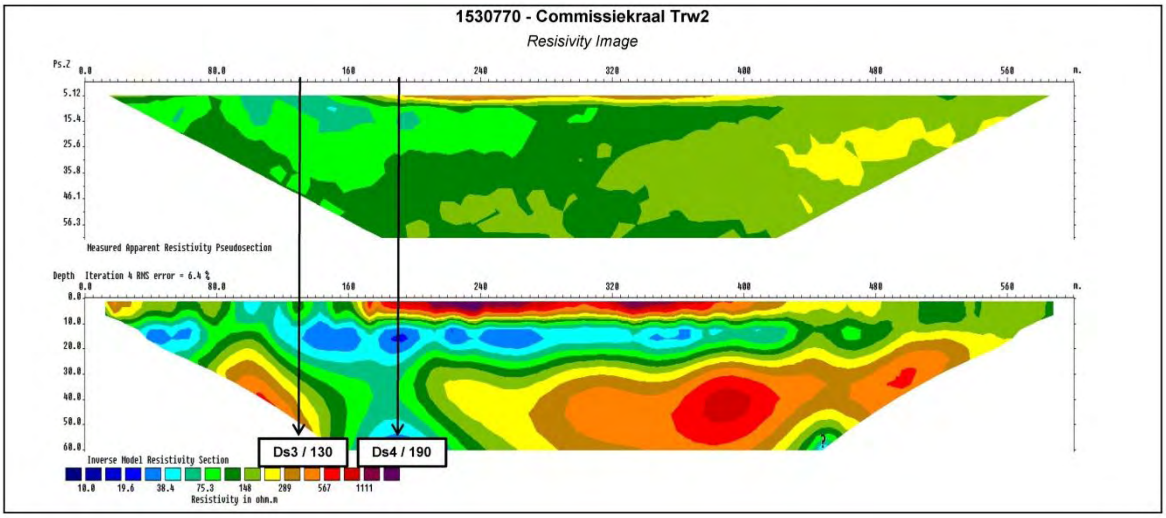
Traverse 1



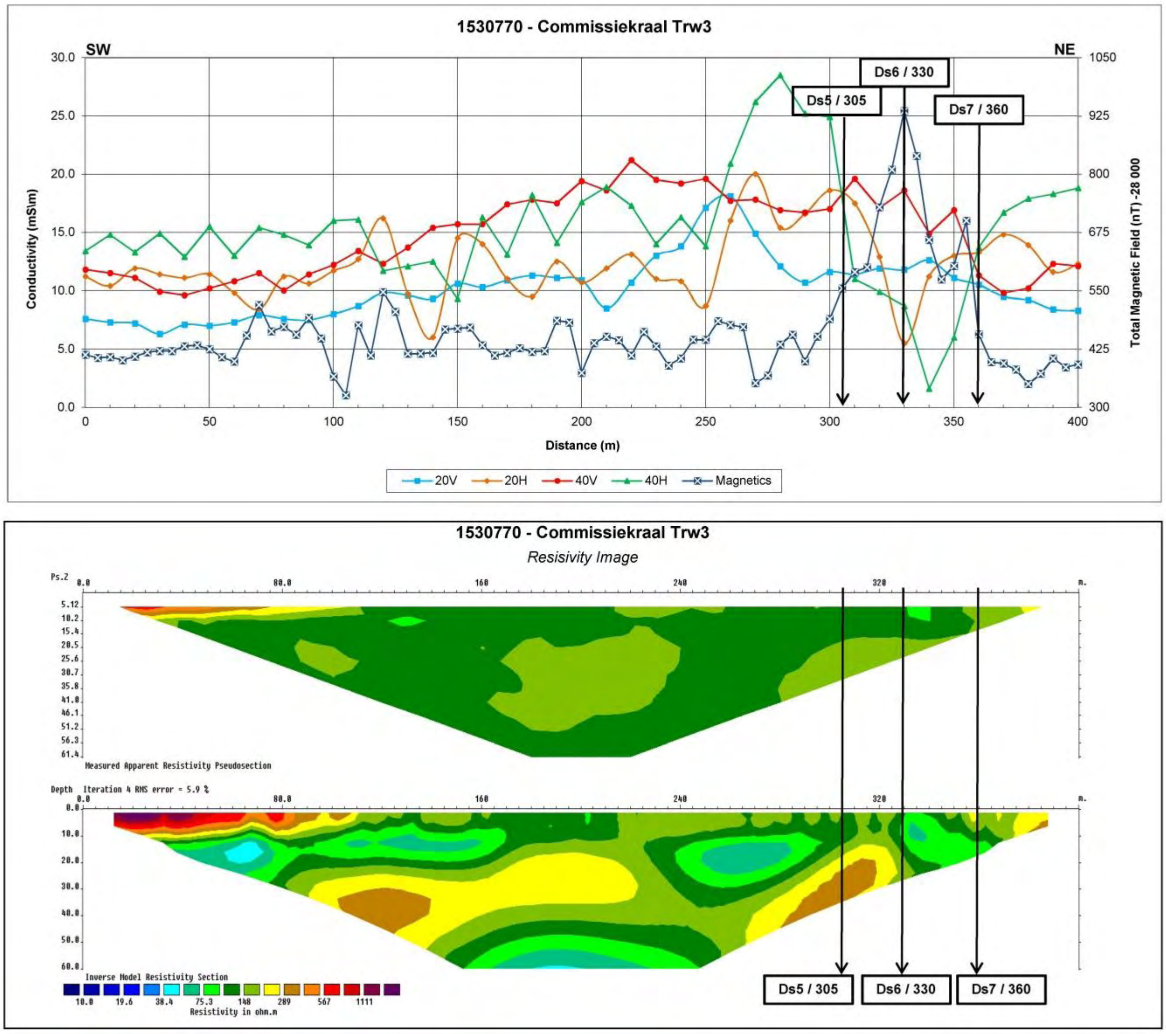


Traverse 2

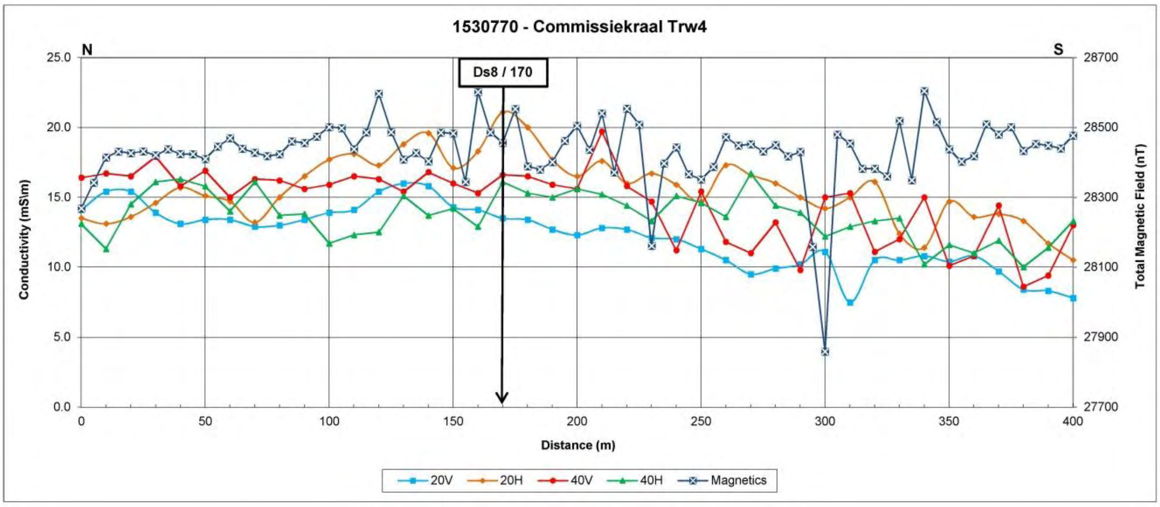

1530770 - Commissiekraal Trw2
SW
NE
Ds3 / 130
Ds4 / 190
Conductivity (mS/m)
Total Magnetic Field (nT)
Distance (m)
20V
20H
40V
40H
Magnetics

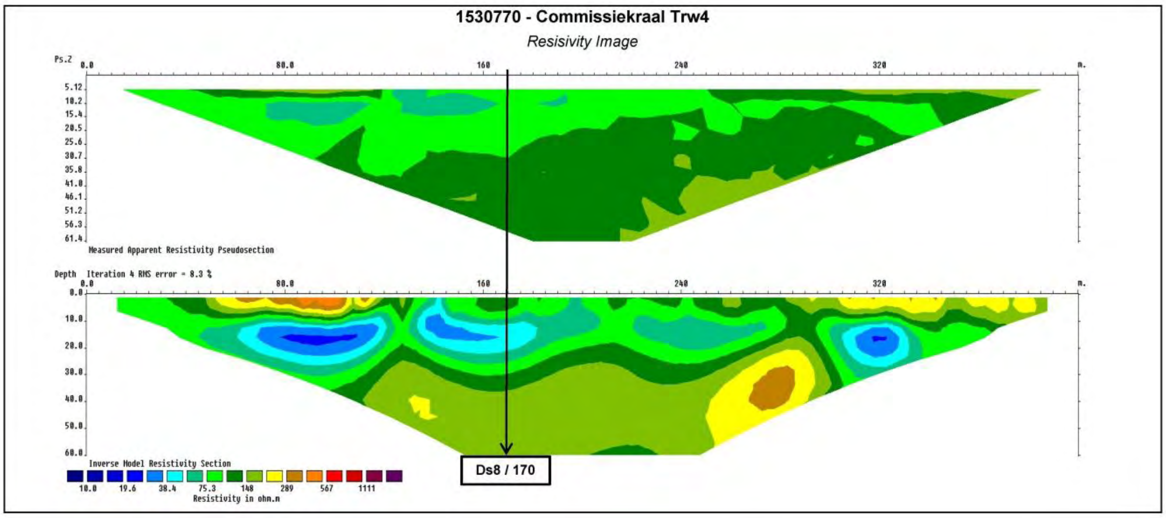

1530770 - Commissiekraal Trw2
Resisivity Image
Measured Apparent Resistivity Pseudosection
Iteration 4 RMS error = 6.4 %
Inverse Model Resistivity Section
Ds3 / 130
Ds4 / 190
Resistivity in ohm.m

Traverse 3

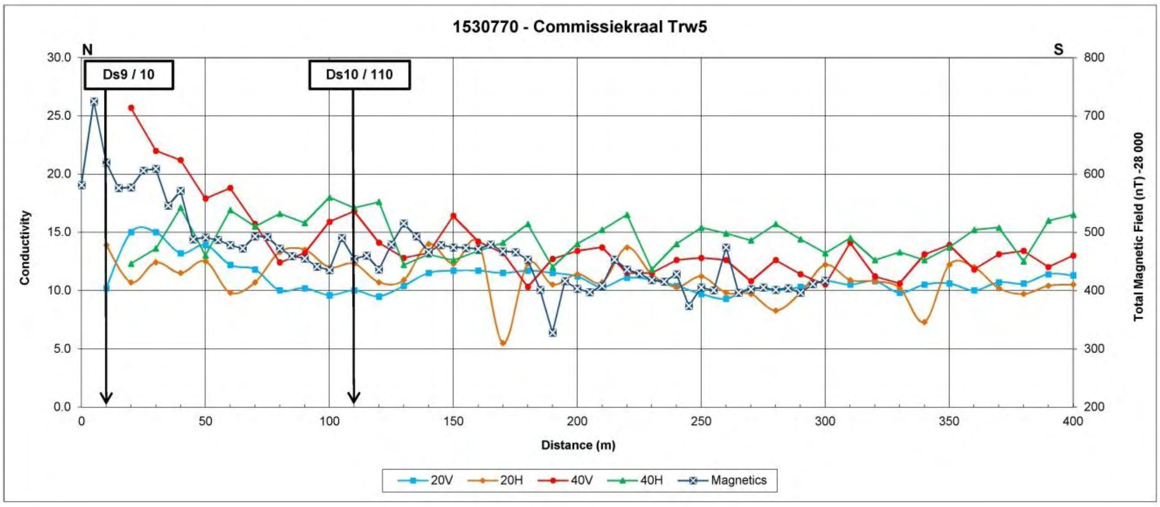

1530770 - Commissiekraal Trw3
SW
NE
Conductivity (mS\m)
Total Magnetic Field (nT) -28 000
Distance (m)
Ds5 / 305
Ds6 / 330
Ds7 / 360
20V
20H
40V
40H
Magnetics
1530770 - Commissiekraal Trw3
Resisivity Image
Measured Apparent Resistivity Pseudosection
Depth Iteration 4 RMS error = 5.9 %
Inverse Model Resistivity Section
10.0 19.6 38.4 75.3 148 289 567 1111
Resistivity in ohm.m

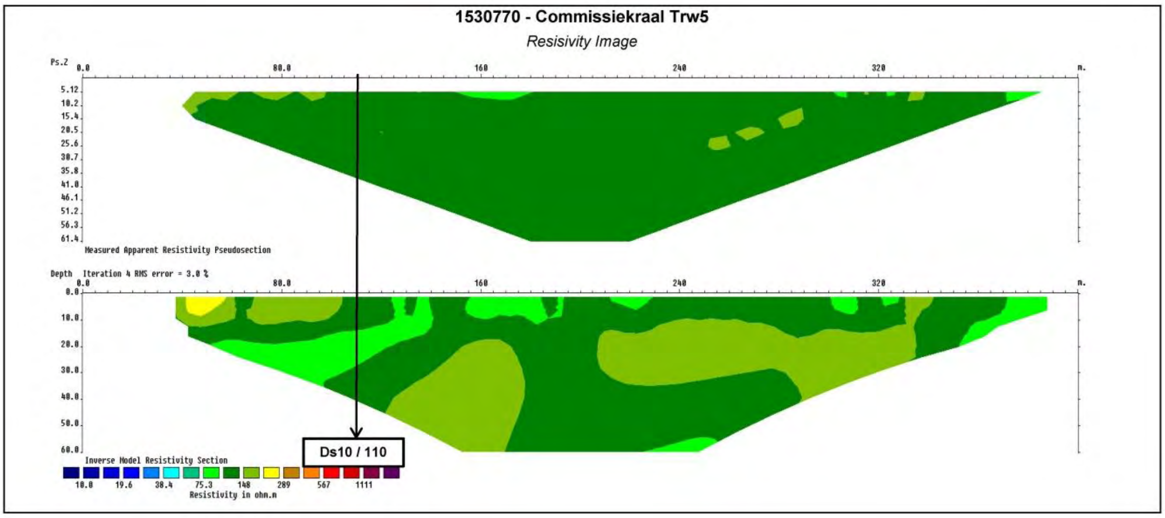
Traverse 4


1530770 - Commissiekraal Trw4
N
S
Ds8 / 170
Conductivity (mS/m)
Total Magnetic Field (nT)
Distance (m)
20V
20H
40V
40H
Magnetics


1530770 - Commissiekraal Trw4
Resisivity Image
Measured Apparent Resistivity Pseudosection
Inverse Model Resistivity Section
Resistivity in ohm.m
Ds8 / 170

Traverse 5

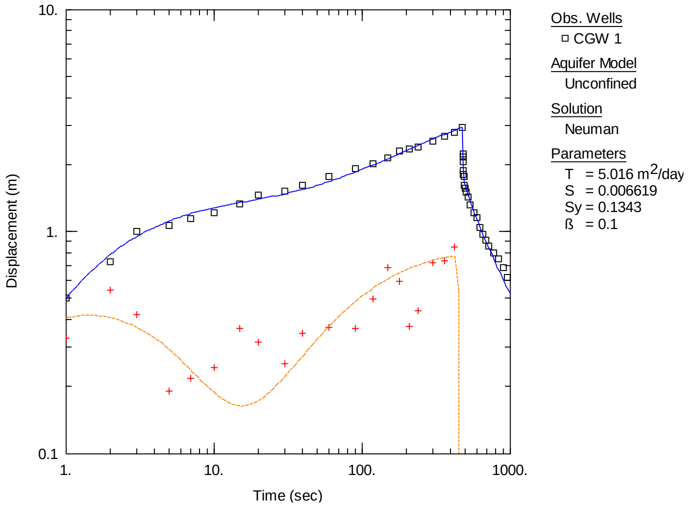

1530770 - Commissiekraal Trw5
N
S
Ds9 / 10
Ds10 / 110
Conductivity
Total Magnetic Field (nT) -28 000
Distance (m)
20V
20H
40V
40H
Magnetics


1530770 - Commissiekraal Trw5
Resisivity Image
Measured Apparent Resistivity Pseudosection
Iteration 4 RMS error = 3.0 %
Ds10 / 110
Inverse Model Resistivity Section
Resistivity in ohm.m

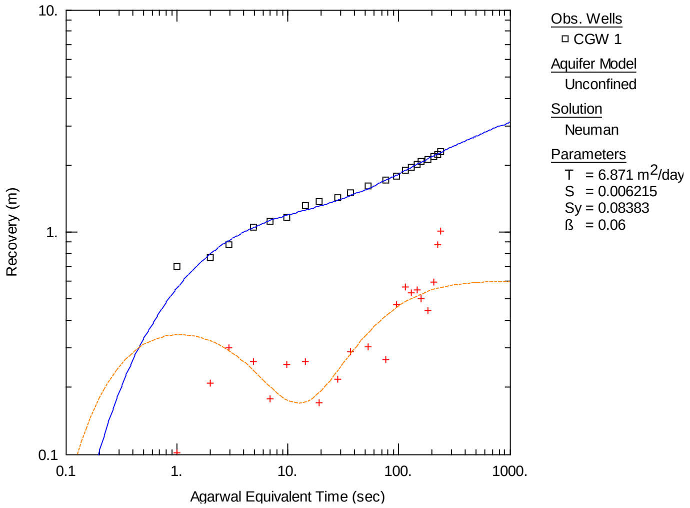
APPENDIX C – BOREHOLE LOGS

APPENDIX D – DIAGNOSTIC PLOTS

CGW1 - Pumping Tests

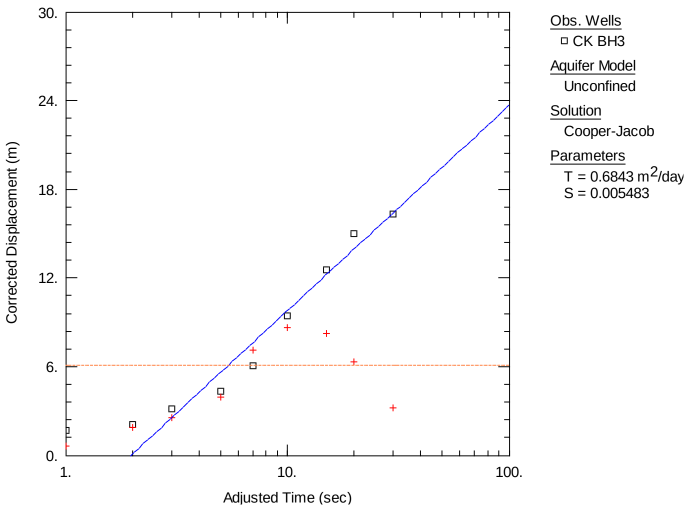


Diagnostic plot (log-log) of the constant rate pumping test of CGW1 fitted with a Neuman solution.



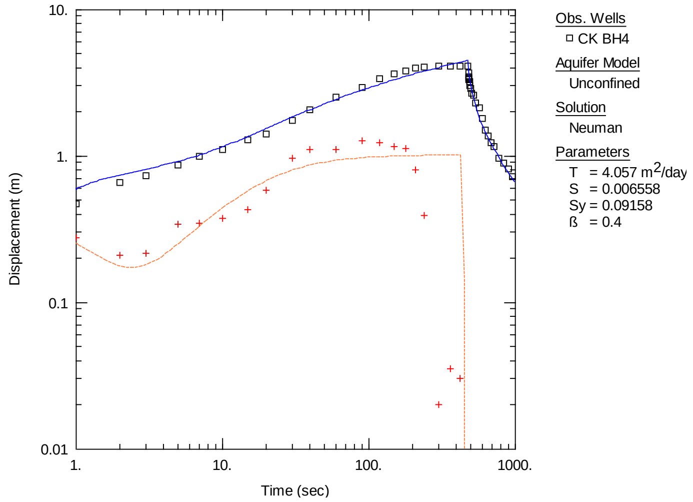
Diagnostic Agarwal plot (log-log) of the recovery data of CGW1 fitted with a Neuman (unconfined) solution.

CK-BH3 - Pumping Tests

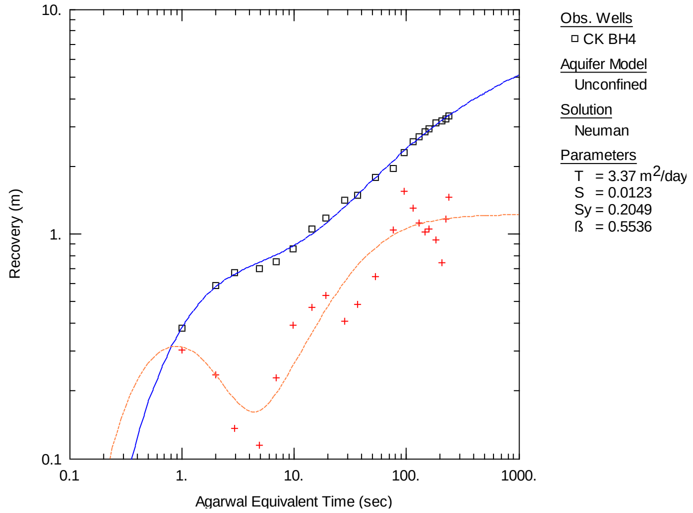


Diagnostic plot (log-log) of the constant rate pumping test of CK-BH3 fitted with a Cooper-Jacob solution.

CK-BH4 - Pumping Tests

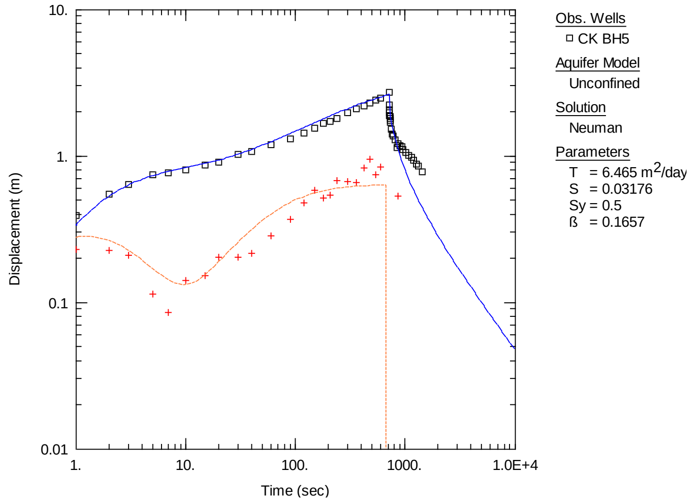


Diagnostic plot (log-log) of the constant rate pumping test of CK-BH4 fitted with a Neuman solution.

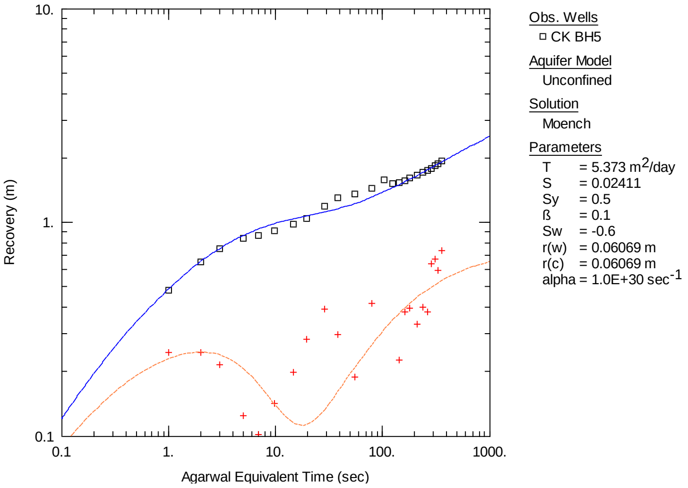


Diagnostic Agarwal plot (log-log) of the recovery data of CK-BH4 fitted with a Neuman (unconfined) solution.

CK-BH5 - Pumping Tests

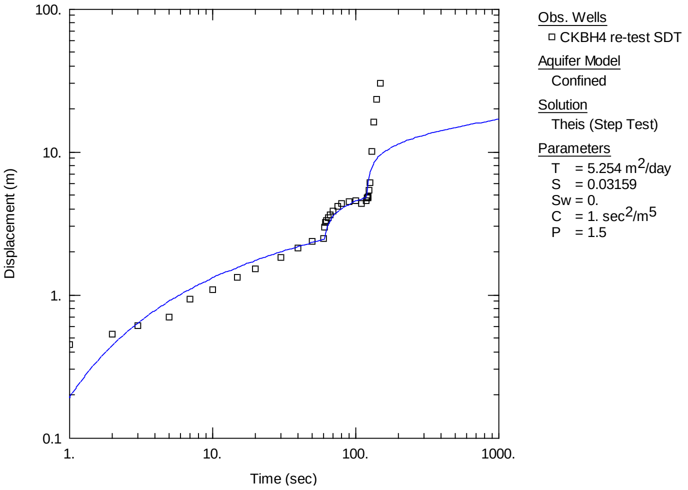


Diagnostic plot (log-log) of the constant rate pumping test of CK-BH5 fitted with a Neuman solution.



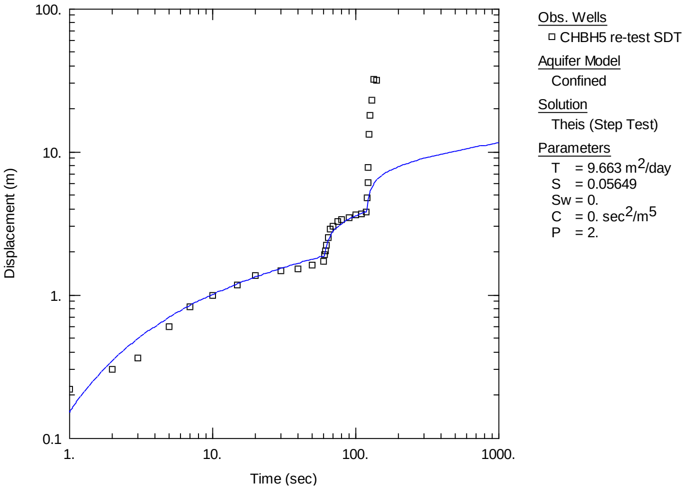
Diagnostic Agarwal plot (log-log) of the recovery data of CK-BH5 fitted with a Neuman (unconfined) solution.

CK-BH4 (re-test) - Step Test



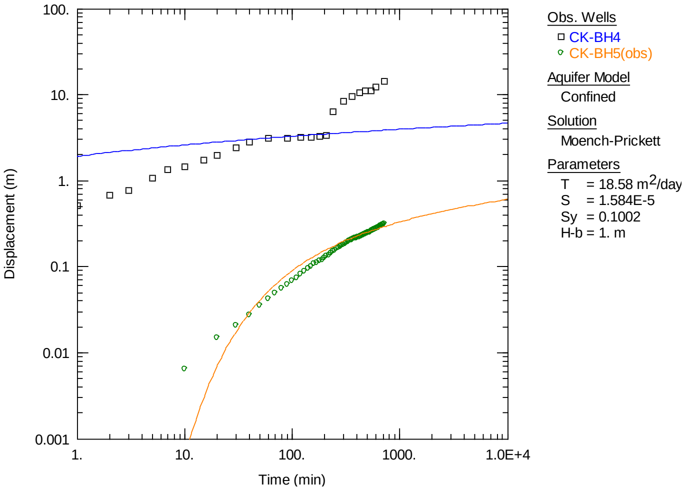
Diagnostic plots (log-log) of the step test of borehole (CK-BH4) fitted with a Theis (step test) solution.

CK-BH5 (re-test) – Step Test



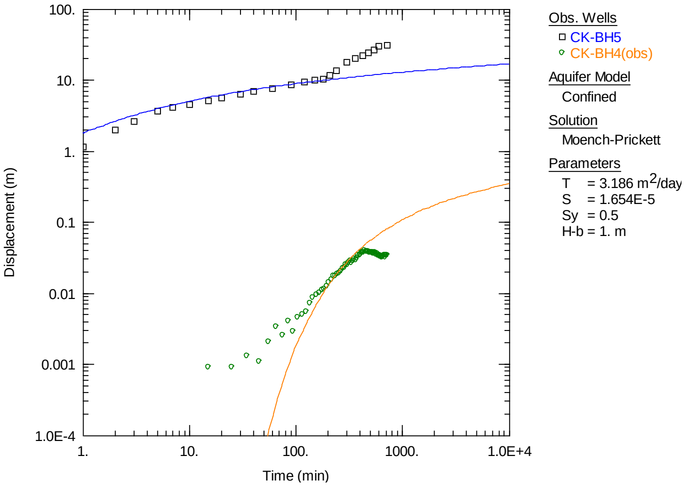
Diagnostic plots (log-log) of the step test of borehole (CK-BH5) fitted with a Theis (step test) solution.

CK-BH4 (re-test) - Pumping Tests (fit obs. BH)



Diagnostic plot (log-log) of the constant rate pumping test of CK-BH4 fitted with a confined (modified with an unconfined) Moench solution.

CK-BH5 (re-test) - Pumping Tests (fit obs. BH)



Diagnostic Agarwal plot (log-log) of the recovery data of CK-BH5 fitted with a confined (modified with an unconfined) Moench solution.

APPENDIX E – LABORATORY CERTIFICATES