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Matla Stooping Project: Groundwater Impact Assessment

Report

Final

07 December 2016

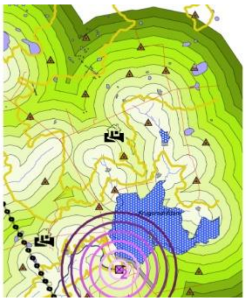
Exxaro Coal (Pty) Ltd

GCS Project Number: 13-400

Client Reference: GCS 13-400

POWERING POSSIBILITY

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EXECUTIVE SUMMARY

GCS (Pty) Ltd was contracted by Exxaro Coal to conduct a geohydrological study and report on findings as specialist input to the Environmental Impact Assessment (EIA) and Environmental Management Program (EMP) for Matla Colliery's proposed Stooping Project.

Mining commenced during 1973 and is currently producing approximately 15 mega tons per annum of power station coal to Eskom's Matla Power Station. With mining activities approaching the life of mine using a combination of underground bord and pillar, short-wall and long-wall mining methods, Exxaro Coal (Pty) Ltd identified areas (Figure 1.1) within the reserve where extraction of coal can be attained from the coal pillars through total extraction of the pillars (process better known as stooping). This investigation focused on the "Phase I" stooping areas, consisting only of Eskom and Exxaro owned land surface areas.

Key Issues: *The main aim/objective of this study was to determine the impact of the planned "Phase 1" mining activities on the local/surrounding groundwater regime.*

A hydrocensus was conducted by GCS in August 2014, which focused on the identification and/or verification of groundwater use, groundwater recharge and discharge points and possible sources of contamination across the greater project area. A total of 150 boreholes were identified during the desktop review of the previous hydrocensus/user surveys conducted by Groundwater Square (2007) and Golder Associates (2011), which included the existing Matla Colliery monitoring boreholes.

GCS visited 79 of these boreholes during their survey in August 2014 (Figure 3.1). Due to the size of the project area, data was gathered within pre-selected areas, spatially distributed across the project area. Thirty four (34) of the 79 boreholes were accessible for groundwater level measurement, with the remaining 45 boreholes being either blocked/vandalised, collapsed or inaccessible. The remaining 71 boreholes weren't visited and/or could not be found.

Key Issues: *Widespread pollution or depletion of the groundwater resource will impact negatively on:*

- *The groundwater resource itself and interrelations with other natural resources (e.g. rivers and streams), and*
- *The users that depend on groundwater as sole source of domestic water as well as for livestock and gardening.*

Regional static groundwater levels generally vary between ± 2 and 22 meters below surface (Figure 3.4). The highest static water level elevation within the mine lease area is approximately 1 630 mamsl and occurs in the topographic higher regions. The lowest static water level elevation where no impact from abstraction occurs is at approximately 1 560 mamsl (Figure 3.5).

***Key Issues:** On a regional scale, groundwater follows the natural/unaffected flow patterns/directions. Impacts on groundwater levels and subsequent flow patterns do however occur (be it from groundwater abstraction for domestic/other purposes or mine dewatering), but are largely restricted due to the generally low hydraulic properties of the aquifer host rock.*

Information from geological maps and previously conducted geohydrological studies shows two possible types of aquifers to be present in the mining area:

- The **first** aquifer is a shallow, semi-confined or unconfined aquifer that occurs in the transitional soil and weathered bedrock zone or sub-outcrop horizon. According to the Parsons Classification system, this aquifer is usually regarded as a minor- and in some cases a non-aquifer system.
- The **second**, main aquifer system is the deeper secondary fractured rock aquifer that is hosted within the sedimentary rocks of the Karoo Supergroup. According to the Parsons Classification system, the aquifer could be regarded as a minor aquifer system, but also a sole aquifer system in some cases where groundwater is the only source of domestic water.

No aquifer testing was performed for the purpose of this investigation. All previously conducted groundwater related studies were consulted in order to obtain a better indication of the average hydraulic properties of the aquifer underlying the mining area. The average hydraulic conductivity (permeability) of the shallow weathered zone aquifer is 0.14 m/d, which based on an average aquifer thickness of approximately 12 meters, translates to a transmissivity of around 1.7 m^2/d *(GCS, 1998)*.

Pumping tests that were performed on the deeper fractured rock aquifer revealed transmissivity values of between 0.1 m^2/d and 7 m^2/d *(GCS, 1998)*, confirming the aquifer to be highly heterogeneous.

According to Figure 3.8 the mean annual recharge to the aquifer underlying the Matla mine lease area is in the region of 32 mm, which based on an average rainfall of approximately 754 mm/a (Graph 2.2) translates to a recharge percentage of just over 4%.

Groundwater samples were collected from six hydrocensus/user boreholes and were analysed for a range of chemical and physical parameters. The positions of these six boreholes are indicated in Figure 3.10, while the results of the analyses are provided in Table 3.4 together with the guidelines used in the assessment.

Key Issues:

- *Groundwater is considered to be of good quality according to the two sets of guidelines used in the assessment.*
- *Boreholes are situated in the open field and far away from potential surface sources of groundwater contamination.*

- *Typical impacts associated with coal mining related activities include elevated groundwater salinity (TDS/EC), elevated concentrations of sulphate and iron and a decrease in groundwater pH conditions. Groundwater from all six boreholes displays no such signs of coal mining related impacts.*
- *Please note that the underground workings will continue to act as a sink for both groundwater and any potential contamination that may originate from the Matla mining activities for as long as it takes groundwater levels to recover from the impacts of mine dewatering.*

No acid base accounting was performed for the purpose of this investigation, however the surrounding mines are known to generate acid *(GCS, 1998)*. The weathered sandstone, shale, and the 5 seam roof and floor all have the potential for acidification. Groundwater flowing through these areas is likely to generate acid when exposed to oxygen and water. The coarse sandstone, on the other hand, has a very large neutralising potential and will give groundwater flowing through it an alkaline character *(GCS, 2000)*.

Key Issues:

- *The coal and overburden material have the potential to generate an acidic leachate high in sulphate and iron content due to acid mine/rock drainage. This characteristic behavior of material containing metal sulphide minerals (usually pyrite), significantly increases a source's potential to adversely affect the quality of groundwater.*
- *Water collecting in the mine workings will stratify with time, i.e. the "heavier" polluted water will sink to the bottom or floor of the mine leaving the "lighter" relatively clean water to occupy the upper reaches of the water column. The water that will eventually decant should therefore be of reasonably good quality.*
- *This stratified system may however be disturbed in areas experiencing high water ingress and subsequent turbulent flow, i.e. adversely affecting the quality of the decanting water.*
- *High extraction mining has led to surface subsidence throughout the Matla mine lease area. Wherever subsidence has occurred, recharge to the underground workings is expected to have increased exponentially. If the Matla underground workings are to decant, the water is expected to be of poor quality.*

Numerous water balance models have been done for Matla throughout the years, of which the most recent one was completed in June 2015 by Mine Water Consultants.

Key Issues:

- *The planned stooping areas are either partially or completely flooded and would require dewatering before Matla can safely commence with mining. We therefore recommend that Matla undertakes a study which details the dewatering schedule.*

- *The planned stooping activities are expected to cause an increase in the vertical recharge component. The areas earmarked for stooping are however small in comparison with the larger mining area and their effect/impact on the water balance is therefore expected to be small.*

The potential impacts associated with the planned stooping activities were assessed according to an impact and risk assessment criterion provided by GCS **(Table 4.1)**:

Operational phase

Status of impact	Magnitude	Duration	Scale	Probability	Significance
Before mitigation					
-	Moderate	Long term	Local	Highly probable	Medium
After mitigation					
-	Moderate	Long term	Local	Highly probable	Medium

Key Issues:

- *The planned stooping activities are expected to cause a lowering of the local groundwater levels, for which no mitigation measures are available.*
- *The effective recharge will increase to the mine workings, but the increase is very small in the larger Matla groundwater make.*
- *The generally low hydraulic properties of the aquifer host rock are however expected to significantly restrict the extent of the affected areas.*
- *Residual impacts will remain for as long as it takes groundwater levels to recover and establish a new equilibrium.*

Decommissioning and closure phase

Status of impact	Magnitude	Duration	Scale	Probability	Significance
Before mitigation					
+	Moderate	Long term	Local	Definite	Medium
After mitigation					
+	Moderate	Long term	Local	Definite	Medium

Key Issues:

- *The decommissioning and closure phase activities are expected to have a positive effect/impact on the surrounding groundwater levels.*
- *Once groundwater levels have recovered from the impacts of mine dewatering, groundwater flow patterns will return to normal/pre-mining - allowing any potential contamination to migrate in the down gradient groundwater flow directions. The residual impacts are therefore expected to change from being quantitative by nature to now being qualitative.*

The Processing Modflow 8 modelling package was used for the model simulations. The finite difference model grid constructed to include the entire Matla mine lease area is indicated Figure 5.1. Model dimensions and aquifer parameters used in the construction and calibration of the model are provided in Table 5.1.

Key Issues:

- *Ten groundwater user boreholes were simulated to be affected by the planned stooping activities.*
- *These boreholes were simulated to experience water level decreases of between two and six meters.*
- *We therefore recommend quarterly monitoring (at least) of groundwater levels in the model simulated affected areas at the user boreholes.*
- *Monitoring data should be assessed on a regular basis to determine/quantify the impact (if any) on groundwater levels.*
- *Groundwater users should be compensated for their loss should the monitoring program indicate adverse groundwater level impacts.*

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1 INTRODUCTION

1.1 Background Information and Project Summary

GCS (Pty) Ltd was contracted by Exxaro Coal to conduct a geohydrological study and report on findings as specialist input to the Environmental Impact Assessment (EIA) and Environmental Management Program (EMP) for Matla Colliery's proposed Stooping Project. Matla Colliery is an existing Eskom-tied mega-colliery with a three shaft complex (named Mine 1, Mine 2 and Mine 3) across an approximately 22,000 hectares area, along the northern margins of the Highveld Coalfield of South Africa. Matla Colliery is located approximately 100 km east of Johannesburg, 45km south of Witbank (eMalahleni), in-between the towns of Kriel (±10 km to the east) and Leandra (±25 km to the west). A locality map of the mining area is provided in Figure 1.1.

Mining commenced during 1973 and is currently producing approximately 15 mega tons per annum of power station coal to Eskom's Matla Power Station. With mining activities approaching the life of mine using a combination of underground bord and pillar, short-wall and long-wall mining methods, Exxaro Coal (Pty) Ltd identified areas (Figure 1.1) within the reserve where extraction of coal can be attained from the coal pillars through total extraction of the pillars (process better known as stooping). This investigation focused on the "Phase I" stooping areas, consisting only of Eskom and Exxaro owned land surface areas.

Key Issues: *The main aim/objective of this study was to determine the impact of the planned "Phase 1" mining activities on the local/surrounding groundwater regime.*

1.2 Scope of Work

The scope of work and structure of the report can be summarised as follow:

- Assessment of all previously conducted groundwater related studies, which provided the information for this study (Section 1.3).
- Topographic maps were consulted and used in the general description of the surface topography and major water courses located within the immediate vicinity of the Matla mining area (Section 2.1).
- Climatic conditions namely the mean annual rainfall, temperatures and evaporation were evaluated and discussed (Section 2.2).
- Relevant reports from previously conducted studies and the 1:250 000 scale geological map of the mining area were consulted in the assessment and applied in the discussion of the local geology (Section 2.3).
- The findings of previously conducted hydrocensus/user surveys were assessed and summarised (Section 3.1) as part of the baseline study.
- Topographic and geological maps were used in the delineation of the aquifer underlying the mining area (Section 3.2).

- Groundwater level information collected during previous studies as well as from the monitoring program was used in the assessment of the groundwater level depth (Section 3.3).
- Groundwater level information was also used to calculate groundwater flow directions, gradients and velocities as accurate as possible (Section 3.4).
- Geological information together with the findings of previous studies were used to identify and characterise the aquifer/s underlying the mining area (Section 3.5).
- Relevant reports from previously conducted studies were consulted for aquifer parameters such as transmissivity and storativity (Section 3.6).
- Dedicated groundwater recharge studies (Vegter, 1995) were consulted in the assessment of aquifer recharge and discharge rates for the mining area (Section 3.7).
- Relevant reports from previously conducted studies were consulted and their findings used in the assessment of the local groundwater quality conditions (Section 3.8).
- The findings of previous studies were consulted and provided an indication of the acid generating potential of the Karoo Supergroup rocks underlying the mining area (Section 3.9).
- Maps and all relevant information were assessed and used in the identification of potential source areas (Section 3.10).
- Geological maps and all relevant information were used in the identification of preferred pathways that may possibly conduit/assist the flow of contamination (Section 3.11).
- All possible receptors were identified within the mining area with the help of information gathered during previous hydrocensus/user surveys and topographic maps (Section 3.12).
- Previous studies were consulted to improve our understanding of the mine water balance (Section 3.13).
- All relevant information was combined in a holistic manner to construct the conceptual model of the mining area (Section 3.14).
- The potential impacts associated with the planned stooping activities were assessed according to an impact and risk assessment criterion. (Section 4).
- A numerical flow model was constructed and used in the assessment/prediction of groundwater level impacts associated with the planned stooping activities (Section 5).
- A comprehensive groundwater monitoring plan/protocol was proposed and discussed in detail (Section 6).

1.3 Review of Relevant Hydrogeological Investigations

This report was compiled as a desk top assessment. The following hydrogeological investigation reports provided background information on the general hydrogeological setting (conceptual model) and input data for flow directions, gradients, mine water volumes and other:

- Geohydrological Investigation: Matla Coal Ltd, GCS Water and Environmental, June 1998 (Report No 98.06-123),

- Matla Colliery: Environmental Management Programme Report (EMPR) Amendment, Volume 1, GCS, June 2006 (Project No 2004.01.006),
- Groundwater Supplement to EMP Addendum, Matla Coal No. 1 Shaft, Groundwater Square, April 2008 (Report No 092),
- Phase I Hydrogeological report to support the EIA for stooping and opencast mining; Matla Colliery, Golder Associates, August 2011 (Report No 10613143-11209-3),
- Hydrogeological Impact Assessment, Matla Water Treatment Plant, Golder Associates, March 2012 (Report No 10613143-11209-3), and
- Matla Colliery: Update of the Groundwater Balance, Mine Water Consultants, June 2015 (Report No 03/2015/PDV).

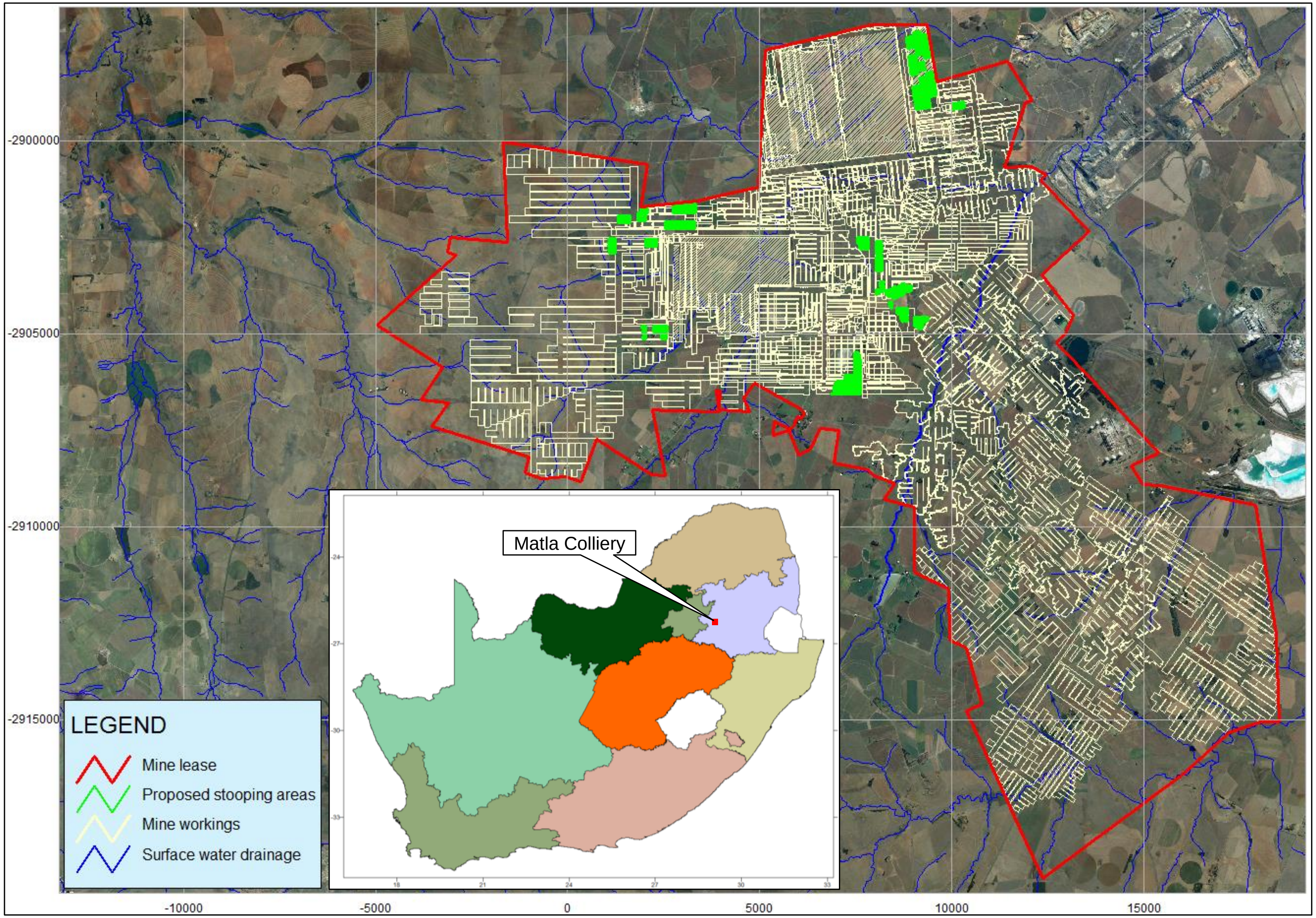


Figure 1.1: Locality map of the mining area

2 SITE SETTING

2.1 Surface Topography and Water Courses

The surface topography of the mine lease area is characterised by gently rolling hills and valleys that drain towards the north. Surface elevations generally vary between approximately 1 565 and 1 650 meters above mean sea level (mamsl). The surface slope varies between 3 % and 8 % and 0 % to 3 %. The slope length varies from 500 m to 1 000 m and the slope shape varies from convex to concave. In various areas the topography has been altered due to surface subsidence of undermined areas. Surface subsidence has resulted in an uneven topography, which in some places has resulted in the formation of ponds and wetlands *(GCS, 2006)*.

Matla Colliery stretches over three quaternary catchments, namely B11D, B11E and B20E. These three catchments are located within the Upper Olifants Water Management Area. The southern bounds of the Matla reserve are constituted by the Vaalbank Spruit and the Dwars-in-die-weg Spruit, while the northern portion of the reserve is transected by the Blesbok Spruit and the Riet Spruit. The central reserve area is transected by a tributary of the Riet Spruit.

Surface elevations of the wider project area are indicated in Figure 2.1 together with the surface water courses.

Key Issues:

- *High extraction of coal has led to roof collapse and ensuing subsidence of the surface. This will greatly increase recharge to the underground mine workings.*
- *The mine lease area is transected by numerous perennial streams, which may be vulnerable to contaminated groundwater base flow.*

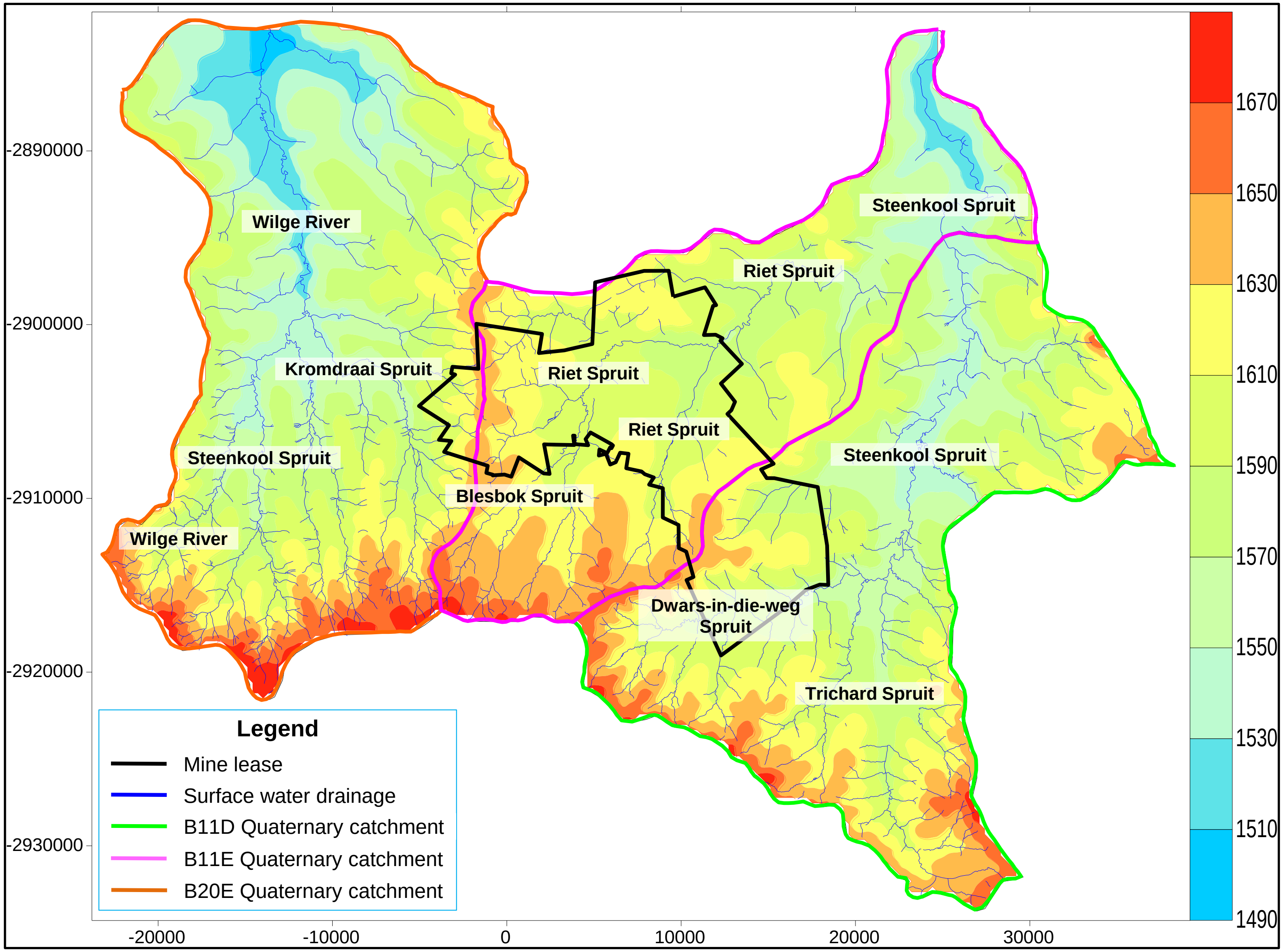


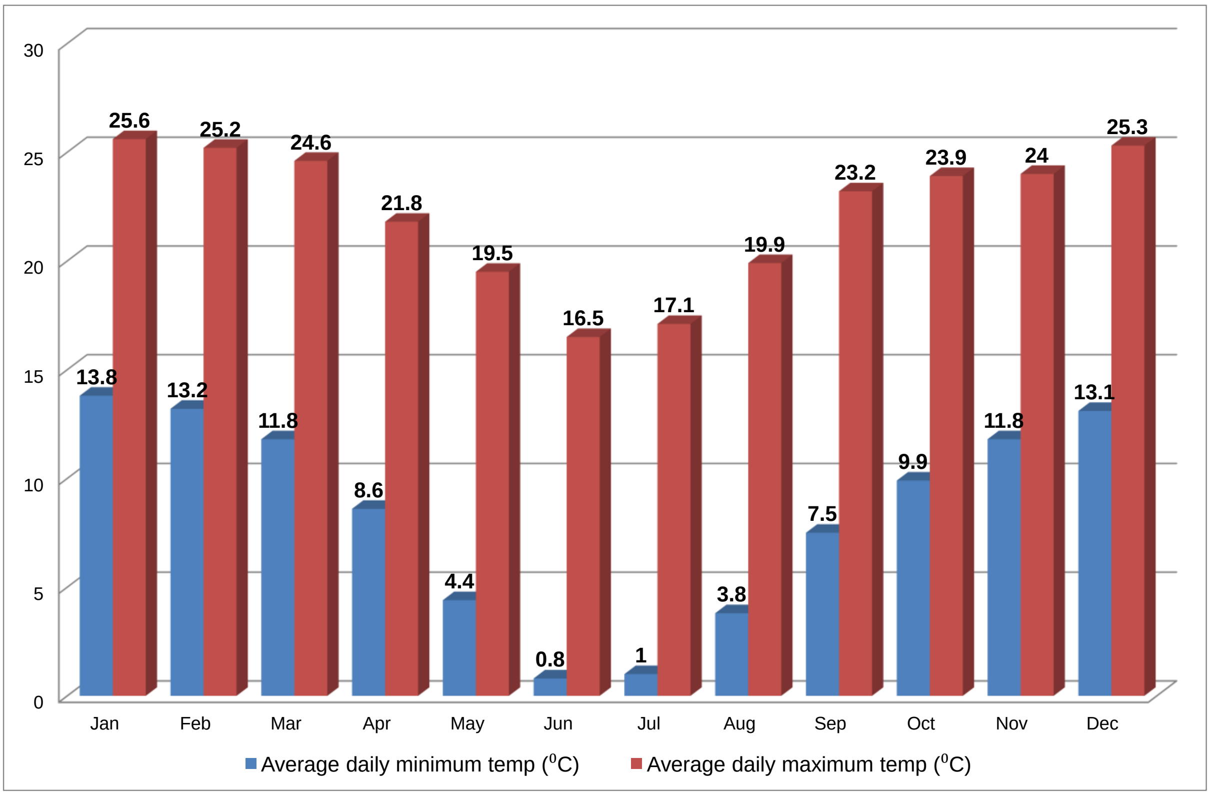
Figure 2.1: Surface elevation contours for the project area (mamsl)

2.2 Climatic Conditions

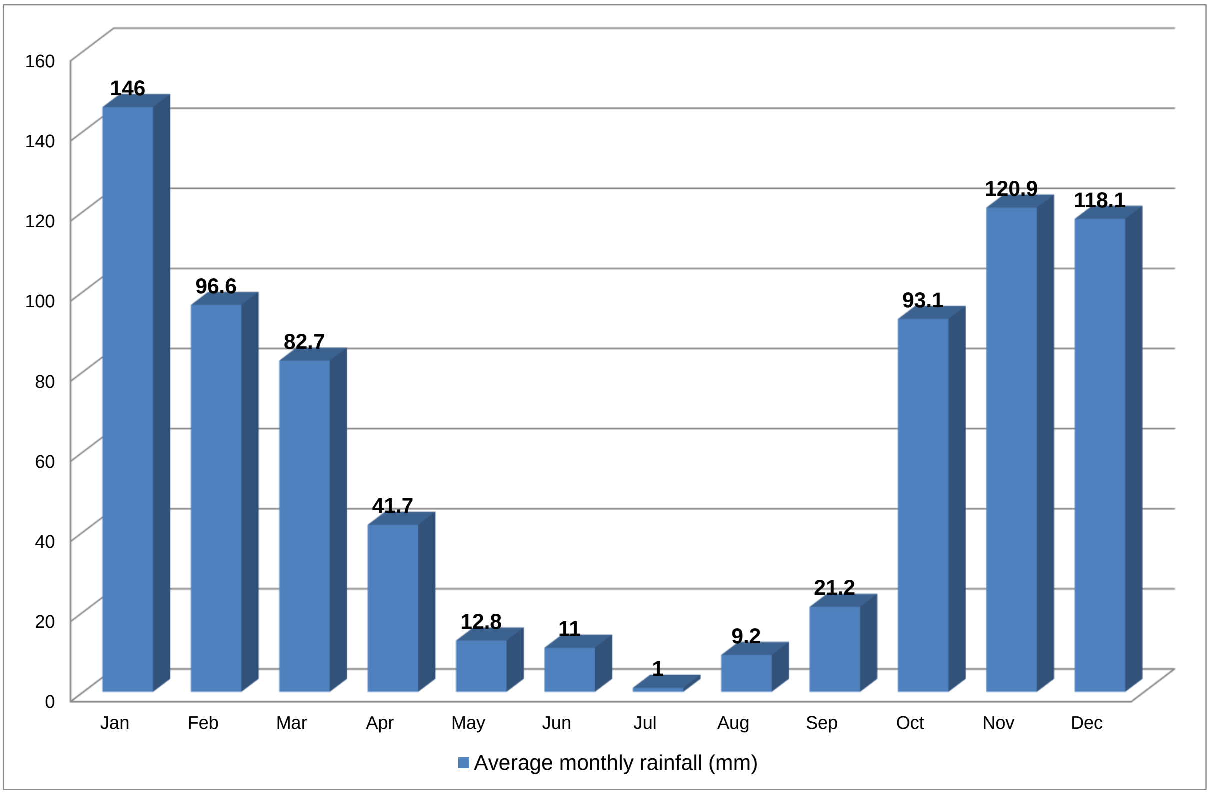
Matla Colliery is located in an area that is characterised by warm to hot summers and cool winters *(GCS, 2006)*. Temperatures in the vicinity of the mine vary from 26°C in the summer to 15°C in the winter (Graph 2.1). Most of the precipitation occurs from November to January with an average of approximately ninety (90) rain days per annum. Rainfall over the period May to September is generally low or absent, with a noticeable increase in the months of October to April. Rainfall events in the region occur mainly in the form of thunderstorms and heavy showers. The annual average precipitation at Matla Colliery is relatively low and variable. Annual rainfall values range from 550 mm – 800 mm with an average of approximately 754 mm per annum (Graph 2.2**)**.

The mean annual evaporation rate for the B11E quaternary catchment is in the order of 1 600 mm (Graph 2.3), which far exceeds rainfall (Graph 2.1).

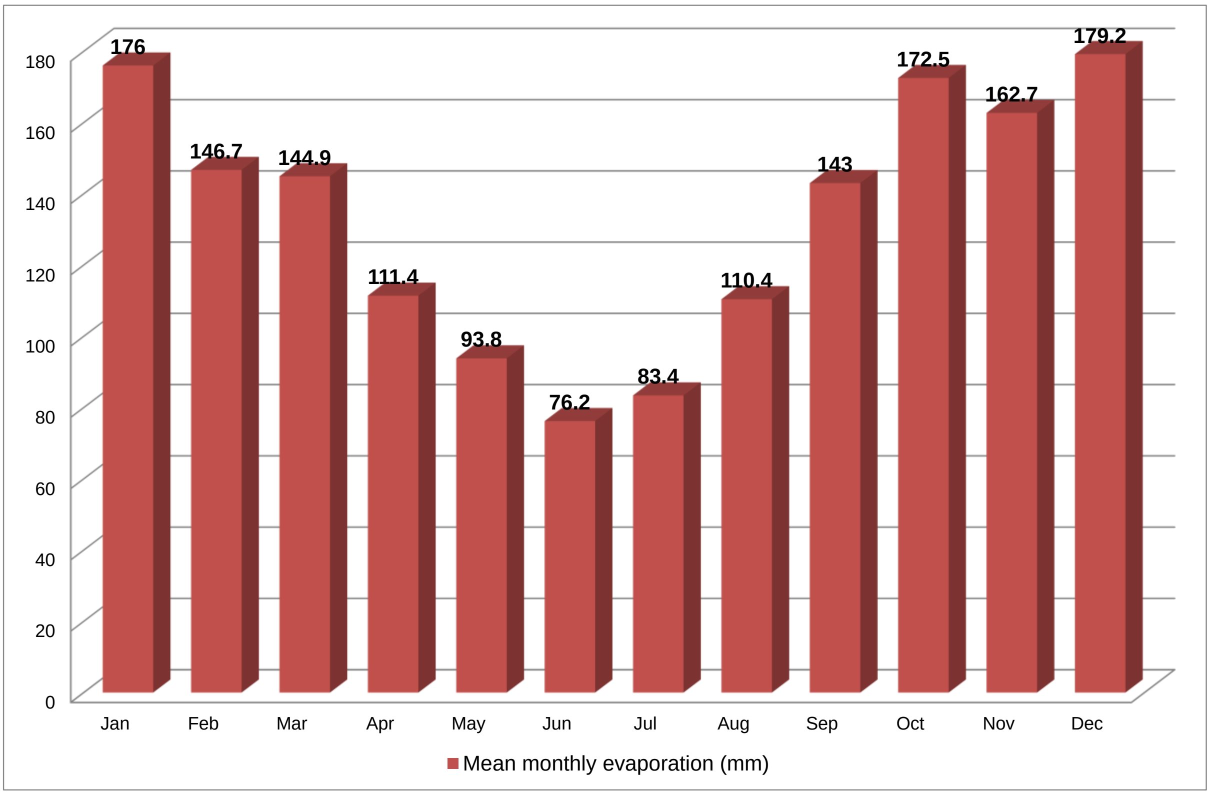
Key Issues*: The Matla area has a net environmental moisture deficit for the entire year.*



Graph 2.1: Mean monthly minimum and maximum temperatures for Matla Colliery



Graph 2.2: Mean monthly rainfall for Matla Colliery



Graph 2.3: Mean annual evaporation for B11E quaternary catchment

2.3 Geology

The Matla Colliery coal reserves form part of the Highveld Coal Field *(GCS, 2006)*. The coal seams are found within the Vryheid Formation of the Karoo Sequence **(**Figure 2.2**)**. The Karoo Supergroup in the Matla area comprises the Ecca Group and the Dwyka Formation. The Ecca sediments consist predominantly of sandstone, siltstone, shale and coal. Combinations of these rock types are often found in the form of interbedded siltstone, mudstone and coarse-grained sandstone. The Ecca sediments overlie the Dwyka Formation (loosely referred to as the Dwyka tillite). The latter consists of a proper tillite, sandstone and sometimes a thin shale development. The upper portion of the Dwyka sediments may have been reworked, in which case carbonaceous shale and even inclusions of coal may be found. The Dwyka sediments are underlain by felsitic rocks of the Bushveld Complex.

The stratigraphic sequence within the Matla area includes five coal seams that are numbered from the bottom upwards from 1 to 5. Economic reserves are found in the 2 seam, 4 seam (lower) and the 5 seam. The seam depths vary, but are on average as follows:

- 5 Seam: - 35 to 50 m below surface,
- 4 Seam: - 75 to 85 m below surface, and
- 2 Seam: - 100 to 120 m below surface.

The number 1, 3 and 4 upper seams only sporadically attain acceptable qualities and thickness.

Tectonically, the Karoo sediments are practically undisturbed. Faults are rare, however fractures are common in rocks such as sandstone and coal. Dolerite intrusions in the form of sills or dykes cause various mining problems, i.e. devolatised coal, weakened roof strata and/or displaced coal seams. The intrusion of a sill in the Mine 1 area caused extensive devolatisation of the overlying 2 Seam, resulting in the exclusion of the 2 seam from mineable reserves in Mine 1. Pressure on the overlying strata, due to the intrusion, resulted in two intersecting joint patterns, which generally have a NE to SW and NW to SE strike respectively. Dolerite from the underlying sill intruding the overlying strata through the joint patterns resulted in a high frequency of dykes in the Mine 1 area. In the Mine 2 total extraction area there are almost no intrusions, except for one small dyke, which affords Matla Colliery the opportunity to utilise total extraction mining methods.

Key Issues:

- *The dolerite occurrences in the area have specific significance with regard to the geohydrology. Not only can groundwater compartments exist as a result of these features, but the possible groundwater interaction between mines will also be a function of the dolerite distribution.*
- *Geological structures also have the ability to act as preferred pathways for groundwater and any potential contamination.*
- *The limit of weathering roughly averages in depth between 9 and 12 meters, deeper zones of weathering are however present. This weathered zone, wherever located below the local groundwater level, may also act as a preferred pathway.*

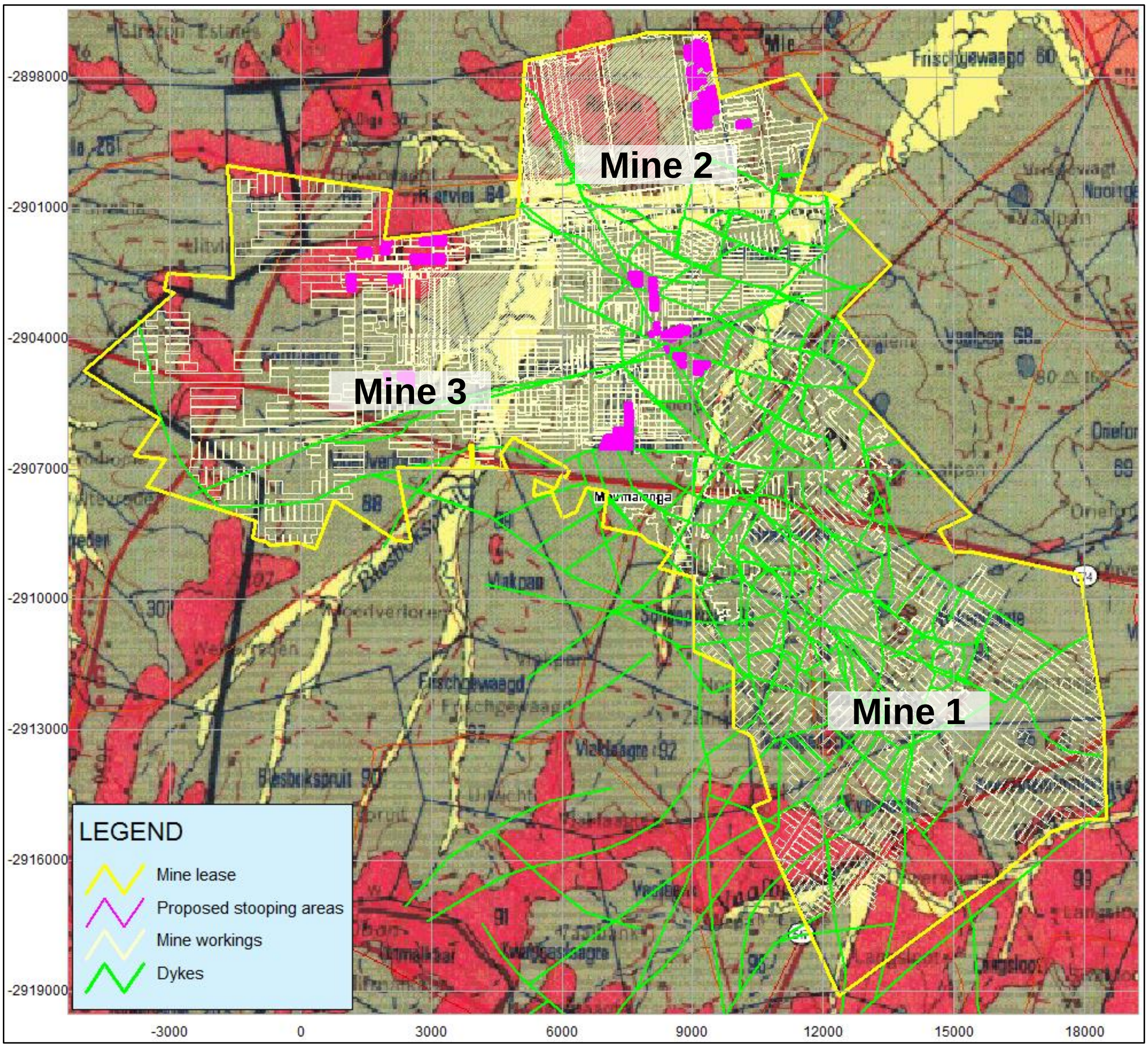


Figure 2.2: 1:250 000 scale geological map of the mine lease area

***Notes:** Jd (pink) = Dolerite, Pv (light brown) = Sandstone/siltstone/shale/coal of the Ecca Group, Karoo Supergroup, Qs (yellow) = Unconsolidated quaternary deposits.*

3 CONCEPTUAL MODEL OF GEOHYDROLOGY

A conceptual model is in reality our holistic understanding of the workings and nature of the aquifer regime underlying the Matla mining area. A good understanding of the geohydrological environment is key to the accurate assessment of potential groundwater impacts associated with the mining activities. All components of the conceptual model are discussed in as much detail as possible in the following subsections.

3.1 Results of the Hydrocensus/User Survey

A hydrocensus was conducted by GCS in August 2014, which focused on the identification and/or verification of groundwater use, groundwater recharge and discharge points and possible sources of contamination across the greater project area (cadastral farms: Strehla261IR, Kortlaagte67IS, Moedverloren88IS, Grootpan86IS, Haasfontein85IS, Kruisementfontein95IS, Nooitgedacht59IS, Schaapkraal93IS, Vlakpan89IS, Vaalbank96IS, Vierfontein61IS and Bakenlaagte84IS).

A total of 150 boreholes were identified during the desktop review of the previous hydrocensus/user surveys conducted by Groundwater Square (2007) and Golder Associates (2011), which included the existing Matla Colliery monitoring boreholes.

GCS visited 79 of these boreholes during their survey in August 2014. Due to the size of the project area, data was gathered within pre-selected areas, spatially distributed across the project area. Thirty four (34) of the 79 boreholes were accessible for groundwater level measurement, with the remaining 45 boreholes being either blocked/vandalised, collapsed or inaccessible. The remaining 71 boreholes weren't visited and/or could not be found. The results of the hydrocensus survey are summarised in Table 3.1, while borehole positions are indicated in Figure 3.1.

Key Issues*: Widespread pollution or depletion of the groundwater resource will impact negatively on:*

- *The groundwater resource itself and interrelations with other natural resources (e.g. rivers and streams), and*
- *The users that depend on groundwater as sole source of domestic water as well as for livestock and gardening.*

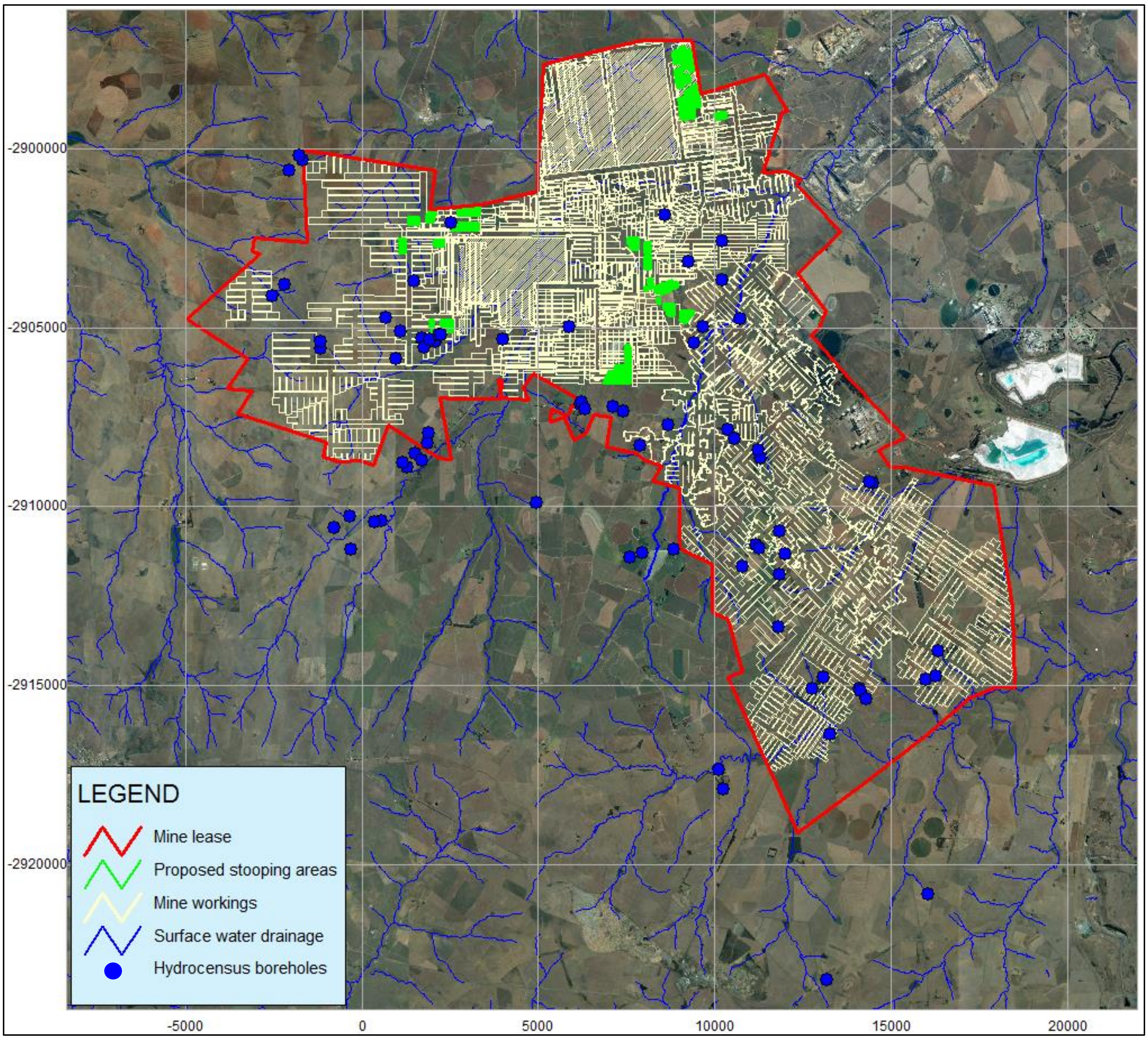


Figure 3.1: Positions of boreholes located during hydrocensus and user survey

Table 3.1: Results of hydrocensus/user survey *(GCS, 2014)*

BH ID	Coordinates & Elevation Information			Borehole Construction Information				Static Water Level Information		Borehole Status & Water Application Information					Owner / Village Information
	Coordinates		Elevation	Borehole Depth	Casing Diameter	Screen/Perforated Casing Length	Reference Level Height	Static Water Level		Status	Water Application				
	Easting	Northing									Domestic	Livestock	Irrigation	None	
	[m]	[m]	[m aMSL]	[m]	[m]	[m]	[m aGL]	[m bGL]	[m aMSL]						
BKL2	14390	-2909326	1602	Unknown	Unknown	Unknown	0.12	1.63	1600.37	Submersible	x	x	-	-	Bakenlaagte: Mr. E. Muller
M-24	7127	-2907219	1632	3	Unknown	Unknown	0.22	1.72	1630.28	Open	-	-	-	x	Grootpan: Me. N. de Vos
MDVL8	1290	-2908894	1619	Unknown	Unknown	Unknown	0.7	2.03	1616.97	Handpump	x	-	-	-	Moedverloren: Mr. M. Erasmus
KRTL3	1087	-2905096	1628	Unknown	Unknown	Unknown	0.04	2.43	1625.57	Open	-	-	-	x	Kortlaagte
ZGFN1	13189	-2923237	1644	Unknown	Unknown	Unknown	0.25	2.48	1641.52	Submersible	x	x	x	-	Kruisementfontein: Me. N. de Vos
HFTN2	10576	-2908097	1615	5	Unknown	Unknown	0.14	2.66	1612.34	Open	-	-	-	x	Haasfontein
KRTL6	1913	-2905326	1619	50	Unknown	Unknown	0.52	3.1	1615.9	Windmill	-	x	-	-	Kortlaagte
HFTN1	10367	-2907852	1611	Unknown	Unknown	Unknown	Surface	3.17	1607.83	Submersible	x	-	-		Haasfontein
MDVL9	1173	-2908765	1624	Unknown	Unknown	Unknown	0.13	3.78	1620.35	Submersible	x	-	-	-	Moedverloren: Mr. M. Erasmus
NdV1	16057	-2920835	1622	12	Unknown	Unknown	0.3	3.98	1618.02	Submersible	x	x	x	-	Onverwacht: Me. N. de Vos
VPN1	4967	-2909893	1637	Unknown	Unknown	Unknown	0.27	4.17	1632.83	Submersible	x	x	-	-	Vlakpan: Mr. P. Streicher
M-31	16277	-2914721	1611	Unknown	Unknown	Unknown	0.38	4.25	1606.75	Windmill	-	-	-	x	Kruisementfontein: Me. N. de Vos
HFTN4	11252	-2908433	1615	10	Unknown	Unknown	0.21	4.46	1610.54	Open	-	-	-	x	Haasfontein: Mr. J. Bezuidenhout
M-23	6322	-2907286	1623	6	Unknown	Unknown	0.22	4.72	1618.28	Submersible	x	x	-	-	Grootpan: Me. N. de Vos
VBK1	10112	-2917357	1589	Unknown	Unknown	Unknown	0.6	4.9	1584.1	Submersible	x	-	-	-	Vaalbank: Mr. J. Barnard
GRP1	8688	-2907731	1607	8	Unknown	Unknown	0.06	5.11	1601.89	Open	-	-	-	x	Grootpan
HJFV2	2090	-2905395	1615	80	Unknown	Unknown	0.38	5.4	1609.6	Submersible	-	-	-	x	Kortlaagte

BH ID	Coordinates & Elevation Information			Borehole Construction Information				Static Water Level Information		Borehole Status & Water Application Information					Owner / Village Information
	Coordinates		Elevation	Borehole Depth	Casing Diameter	Screen/Perforated Casing Length	Reference Level Height	Static Water Level		Status	Water Application				
	Easting	Northing									Domestic	Livestock	Irrigation	None	
	[m]	[m]	[m aMSL]	[m]	[m]	[m]	[m aGL]	[m bGL]	[m aMSL]						
HFTN3	11314	-2908645	1616	8	Unknown	Unknown	Surface	5.42	1610.58	Open	-	-	-	x	Haasfontein: Mr. J. Bezuidenhout
SHL3	-1663	-2900312	1639	7	Unknown	Unknown	0.23	5.46	1633.54	Open	-	-	-	x	Strehla: Mr. M. Erasmus
M-53	11854	-2911890	1653	Unknown	Unknown	Unknown	0.11	5.96	1647.04	Handpump	x	-	-	-	Nooitgedacht: Mr. B. Roux
M-37	12770	-2915080	1606	Unknown	Unknown	Unknown	0.3	6.01	1599.99	Submersible	x	x	-	-	Onverwacht: Mr. J. Barnard
M-32	16348	-2914032	1608	Unknown	Unknown	Unknown	0.26	7.89	1600.11	Submersible	x	x	x	-	Kruisementfontein: Me. N. de Vos
MDVL3	-345	-2910278	1625	Unknown	Unknown	Unknown	0.28	8.03	1616.97	Submersible	x	-	-	-	Moedverloren: Mr. P. Streicher
M-72	-1161	-2905377	1634	24	Unknown	Unknown	0.2	9.18	1624.82	Submersible	x	x	x	-	Kortlaagte
M-28	13089	-2914756	1614	Unknown	Unknown	Unknown	0.06	10.54	1603.46	Submersible	x	x	x	-	Onverwacht: Me. N. de Vos
SKL1	8837	-2911197	1617	Unknown	Unknown	Unknown	0.3	12.18	1604.82	Submersible	x	-	x	-	Schaapkraal: Mr. B. Roux
M-69	544	-2910405	1617	Unknown	Unknown	Unknown	GL	12.3	1604.7	Submersible	x	x	x	-	Moedverloren: Mr. P. Streicher
M-55	11832	-2913376	1656	Unknown	Unknown	Unknown	0.29	13.87	1642.13	Submersible	x	-	x	-	Nooitgedacht: Mr. B. Roux
M-70	373	-2910441	1620	Unknown	Unknown	Unknown	0.21	14.24	1605.76	Submersible	x	-	x	-	Moedverloren: Mr. P. Streicher
HJFV5	1713	-2905307	1621	36	Unknown	Unknown	Surface	14.29	1606.71	Submersible	x	-	x	-	Kortlaagte
M-98	-2528	-2904111	1606	16	Unknown	Unknown	GL	15	1591	Submersible	x	x	-	-	Kortlaagte: Mr. P. Streicher
M-57	1875	-2908218	1623	45	Unknown	Unknown	0.21	15.63	1607.37	Open	-	-	-	x	Moedverloren: Mr. M. Erasmus
M-56	1898	-2907932	1631	Unknown	Unknown	Unknown	0.26	18.77	1612.23	Submersible	-	x	-	-	Moedverloren: Mr. M. Erasmus
GRP4	7419	-2907329	1631	26	Unknown	Unknown	0.58	22.49	1608.51	Open	-	-	-	x	Grootpan: Me. N. de Vos
BKL1	14492	-2909335	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Blocked	-	-	-	x	Bakenlaagte: Mr. E. Muller

BH ID	Coordinates & Elevation Information			Borehole Construction Information				Static Water Level Information		Borehole Status & Water Application Information					Owner / Village Information
	Coordinates		Elevation	Borehole Depth	Casing Diameter	Screen/Perforated Casing Length	Reference Level Height	Static Water Level		Status	Water Application				
	Easting [m]	Northing [m]	[m aMSL]	[m]	[m]	[m]	[m aGL]	[m bGL]	[m aMSL]		Domestic	Livestock	Irrigation	None	
GRP2	6201	-2907134	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Open	-	-	-	x	Grootpan: Me. N. de Vos
GRP3	5877	-2904965	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Mono pump	-	-	-	x	Grootpan: Me. N. de Vos
GRP5	10746	-2904743	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Windmill	-	-	-	x	Grootpan: Me. N. de Vos
KRTL1	1757	-2905537	Unknown	Unknown	Unknown	Unknown	0.19	NM	NM	Blocked	-	-	-	x	Kortlaagte
KRTL10	2246	-2905210	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Blocked	-	-	-	-	Kortlaagte: Mr. J. Venter
KRTL11	2539	-2902082	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Open	-	-	-	-	Kortlaagte: Mr. J. Venter
KRTL2	1485	-2903706	Unknown	Unknown	Unknown	Unknown	0.07	NM	NM	Windmill	-	x	x	-	Kortlaagte
KRTL4	675	-2904730	Unknown	Unknown	Unknown	Unknown	0.33	NM	NM	Windmill	-	x	-		Kortlaagte
KRTL5	674	-2904730	Unknown	Unknown	Unknown	Unknown	Surface	NM	NM	Blocked	-	-	-	x	Kortlaagte
KRTL7	-1151	-2905576	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Windmill	-	-	-	x	Kortlaagte
KRTL8	2196	-2905202	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Blocked	-	-	-	-	Kortlaagte: Mr. J. Venter
KRTL9	2236	-2905210	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Blocked	-	-	-	-	Kortlaagte: Mr. J. Venter
KTFN1	15983	-2914844	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Windmill	-	-	-	x	Kruisementfontein: Me. N. de Vos
M-17	10230	-2903657	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Mono pump	-	-	-	x	Vierfontein: Mr. E. Muller
M-18	10222	-2902590	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Mono pump	-	-	-	x	Vierfontein: Mr. E. Muller
M-19	9268	-2903152	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Windmill	-	x	-	-	Vierfontein: Mr. E. Muller
M-22	6237	-2907072	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Submersible	-	-	-	x	Grootpan: Me. N. de Vos
M-26	9433	-2905423	Unknown	Unknown	Unknown	Unknown	0.27	NM	NM	Submersible	x	-	-	-	Grootpan: Me. N. de Vos
M-27	9666	-2904977	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Submersible	-	-	-	x	Grootpan: Me. N. de Vos
M-29	13292	-2916362	Unknown	Unknown	Unknown	Unknown	0.04	NM	NM	Submersible	x	x	-	-	Onverwacht: Me. N. de Vos

BH ID	Coordinates & Elevation Information			Borehole Construction Information				Static Water Level Information		Borehole Status & Water Application Information					Owner / Village Information
	Coordinates		Elevation	Borehole Depth	Casing Diameter	Screen/Perforated Casing Length	Reference Level Height	Static Water Level		Status	Water Application				
	Easting	Northing									Domestic	Livestock	Irrigation	None	
	[m]	[m]	[m aMSL]	[m]	[m]	[m]	[m aGL]	[m bGL]	[m aMSL]						
M30	14113	-2915076	Unknown	Unknown	Unknown	Unknown	0.1	NM	NM	Submersible	x	x	-		Onverwacht: Me. N. de Vos
M-50	11175	-2911074	Unknown	100	Unknown	Unknown	0.33	NM	NM	Submersible	x	x	x	-	Nooitgedacht: Mr. B. Roux
M-51	11266	-2911150	Unknown	100	Unknown	Unknown	Surface	NM	NM	Submersible	X	-	x	-	Nooitgedacht: Mr. B. Roux
M-52	11853	-2910678	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Handpump	x	-	-	-	Nooitgedacht: Mr. B. Roux
M-54	12016	-2911334	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Windmill	-	x	-	-	Nooitgedacht: Mr. B. Roux
M-71	-790	-2910594	Unknown	Unknown	Unknown	Unknown	0.17	NM	NM	Submersible	-	-	-	x	Moedverloren: Mr. P. Streicher
M-81	10789	-2911667	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Windmill	-	-	-	x	Schaapkraal: Mr. B. Roux
M-94	7883	-2908299	Unknown	Unknown	Unknown	Unknown	Surface	NM	NM	Submersible	x	x	-	-	Grootpan: Me. N. de Vos
M-99	-2176	-2903801	Unknown	98	Unknown	Unknown	NM	NM	NM	Submersible	x	x	-	-	Kortlaagte: Mr. P. Streicher
MDVL1	972	-2905863	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Windmill	x	x	-		Moedverloren
MDVL2	-311	-2911211	Unknown	6	Unknown	Unknown	0.28	NM	NM	Windmill	-	-	-	x	Moedverloren: Mr. P. Streicher
MDVL4	4002	-2905317	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Mono pump	-	-	-	-	Moedverloren: Mr. P. Streicher
MDVL5	1510	-2908515	Unknown	Unknown	Unknown	Unknown	0.33	NM	NM	Submersible	-	x	-	-	Moedverloren: Mr. M. Erasmus
MDVL6	1715	-2908708	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Blocked	-	-	-	x	Moedverloren: Mr. M. Erasmus
MDVL7	1714	-2908705	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Blocked	-	-	-	x	Moedverloren: Mr. M. Erasmus
OVWT1	14157	-2915163	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Blocked	-	-	-	x	Onverwacht: Me. N. de Vos
OVWT2	14319	-2915386	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Blocked	-	-	-	x	Onverwacht: Me. N. de Vos
SFNBH2	10247	-2917892	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Open	-	-	-	-	Vaalbank: Mr. J. Barnard
SHL1	-2064	-2900619	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Mono pump	-	-	-	x	Strehla: Mr. M. Erasmus

BH ID	Coordinates & Elevation Information			Borehole Construction Information				Static Water Level Information		Borehole Status & Water Application Information					Owner / Village Information
	Coordinates		Elevation	Borehole Depth	Casing Diameter	Screen/Perforated Casing Length	Reference Level Height	Static Water Level		Status	Water Application				
	Easting	Northing									Domestic	Livestock	Irrigation	None	
	[m]	[m]	[m aMSL]	[m]	[m]	[m]	[m aGL]	[m bGL]	[m aMSL]						
SHL2	-1662	-2900312	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Mono pump	x	-	-	-	Strehla: Mr. M. Erasmus
SHL4	-1777	-2900186	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Windmill	x	-	-	-	Strehla: Mr. M. Erasmus
SKL2	7969	-2911300	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Windmill	x	x	-	-	Schaapkraal: Mr. B. Roux
SKL3	7596	-2911408	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Windmill	-	x	-	-	Schaapkraal: Mr. B. Roux
VFN1	8599	-2901849	Unknown	Unknown	Unknown	Unknown	NM	NM	NM	Mono pump	-	-	-	x	Vierfontein: Mr. E. Muller

Note/s:

- Coordinates - Projection: *Universal Transverse Mercator*
  - Datum: *WGS84*
- m - metres
- m aMSL - metres above Mean Sea Level
- m bGL - metres below Ground Level
- NM - not measured (either blocked (/vandalised) / collapsed / not accessible)

3.2 Aquifer Delineation

Because the main aquifer is a fractured rock type and fractures could assume any geometry and orientation, the physical boundary or 'end' of the aquifer is very difficult to specify or quantify. Aquifer boundary conditions that are generally considered during the delineation process are described below:

- **No-flow** boundaries are groundwater divides (topographic high or low areas/lines) or impermeable geological structures across which no groundwater flow is possible.
- **Constant head** boundaries are positions or areas where the groundwater level is fixed at a certain elevation and does not change (perennial rivers/streams or dams/pans).

Topographic highs and lows were used to roughly delineate the aquifer system underlying the Matla mine lease area (Figure 3.2). The aquifer was estimated to cover an area of roughly 1 000 km^2. Please note that geological structures such as dykes are known to occur within the area and have the ability to act as aquifer boundaries, thus subdividing the regional aquifer into various 'sub-aquifers' or compartments. The structural integrity of these potential boundaries remains an uncertainty, therefore aquifer boundaries as indicated in Figure 3.2 are considered to be conceptual and based on topographic controls only.

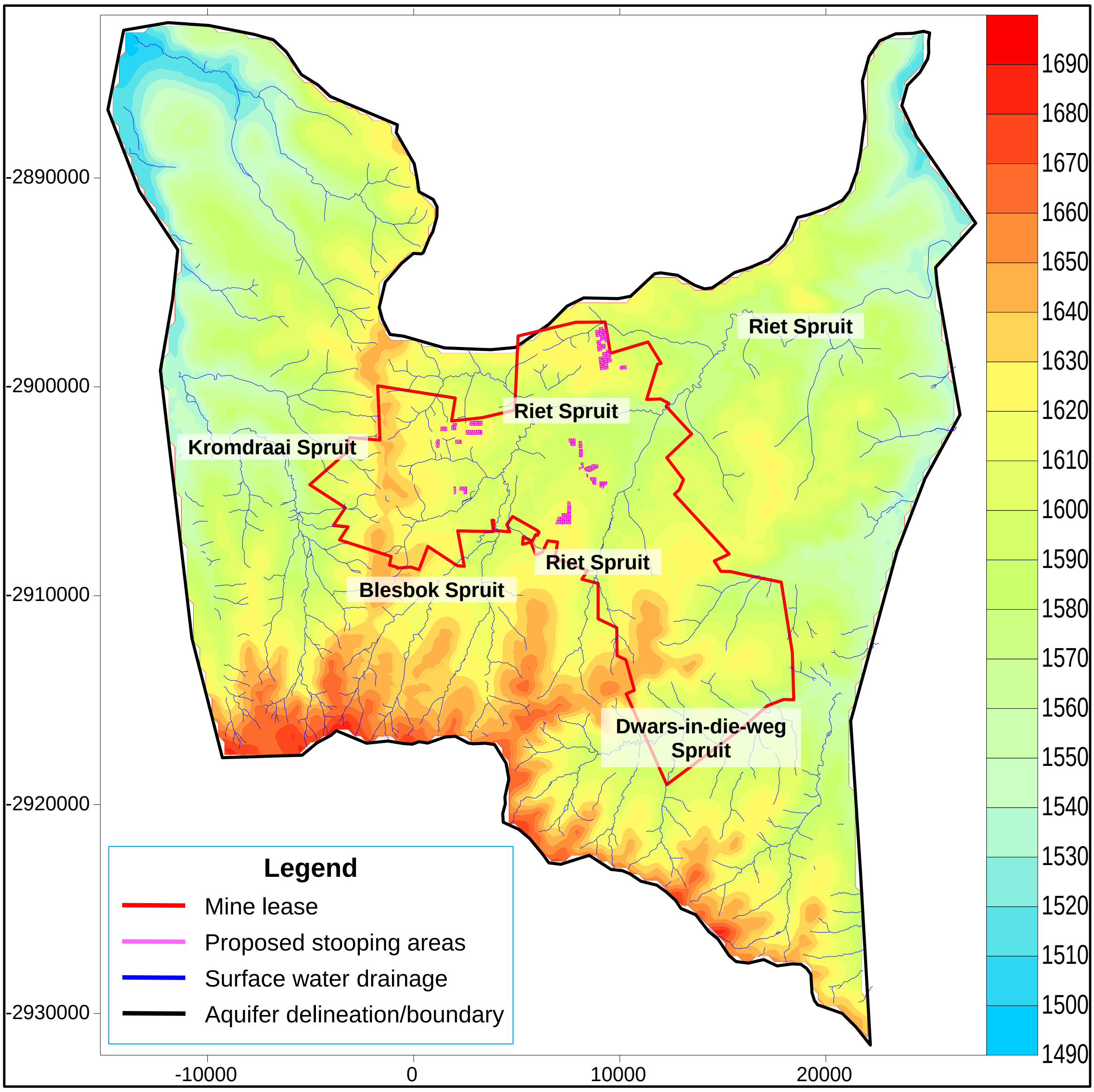


Figure 3.2: Aquifer delineation for project area

3.3 Groundwater Level Depth

Groundwater level information was collected during a hydrocensus conducted by GCS in 2014. Please refer to Table 3.1 for a summary of the findings. A thematic groundwater level map of the entire mining area is provided in Figure 3.4. These water levels are essential as they were used in the generation of static groundwater level elevations with the use of the Bayesian interpolation method (Figure 3.5).

Regional static groundwater levels generally vary between ± 2 and 22 meters below surface (Figure 3.4). Due to the generally low aquifer transmissivity the pumping causes deep drawdown of the groundwater level/piezometric head and a depression cone forms that is deep, but very limited in lateral extent. This concept is explained in Figure 3.3.

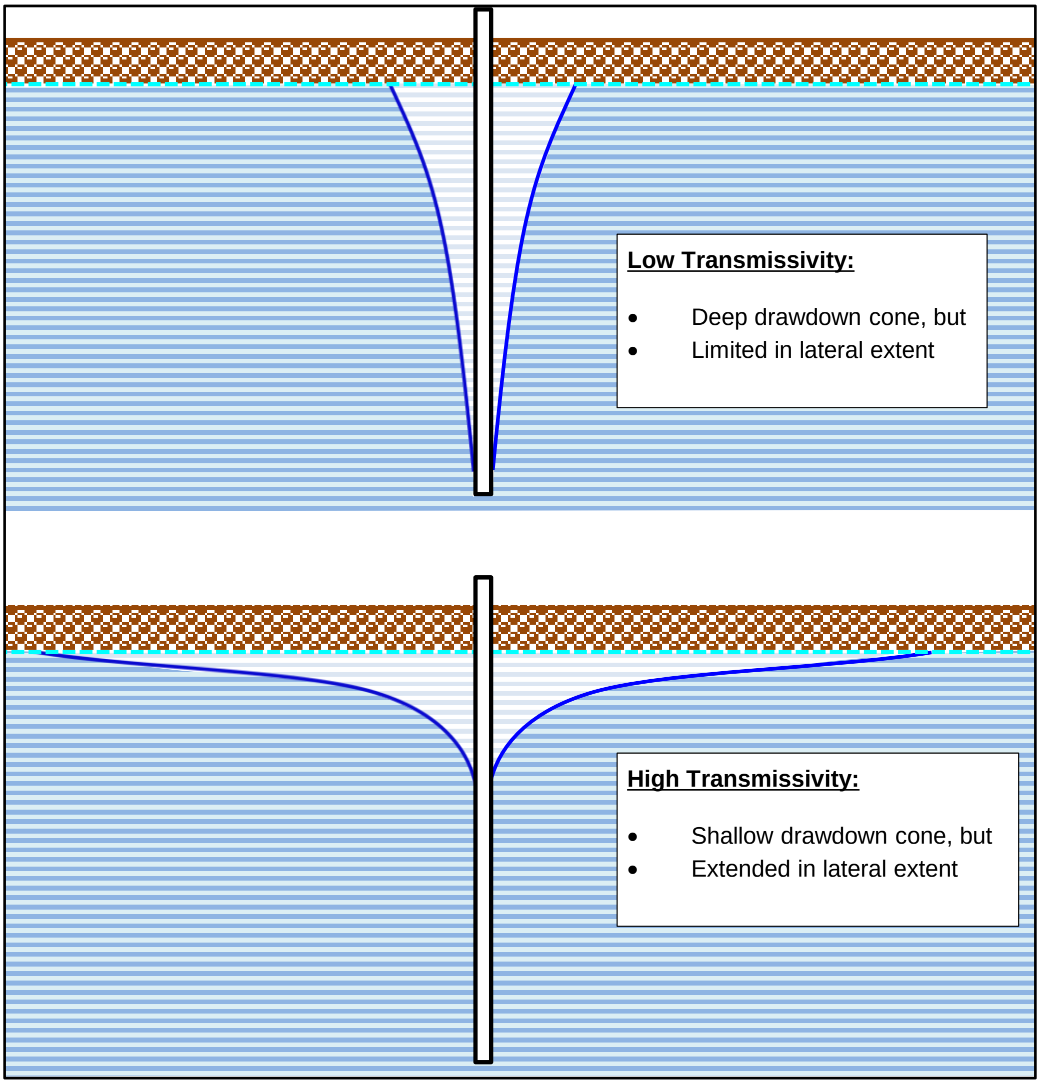
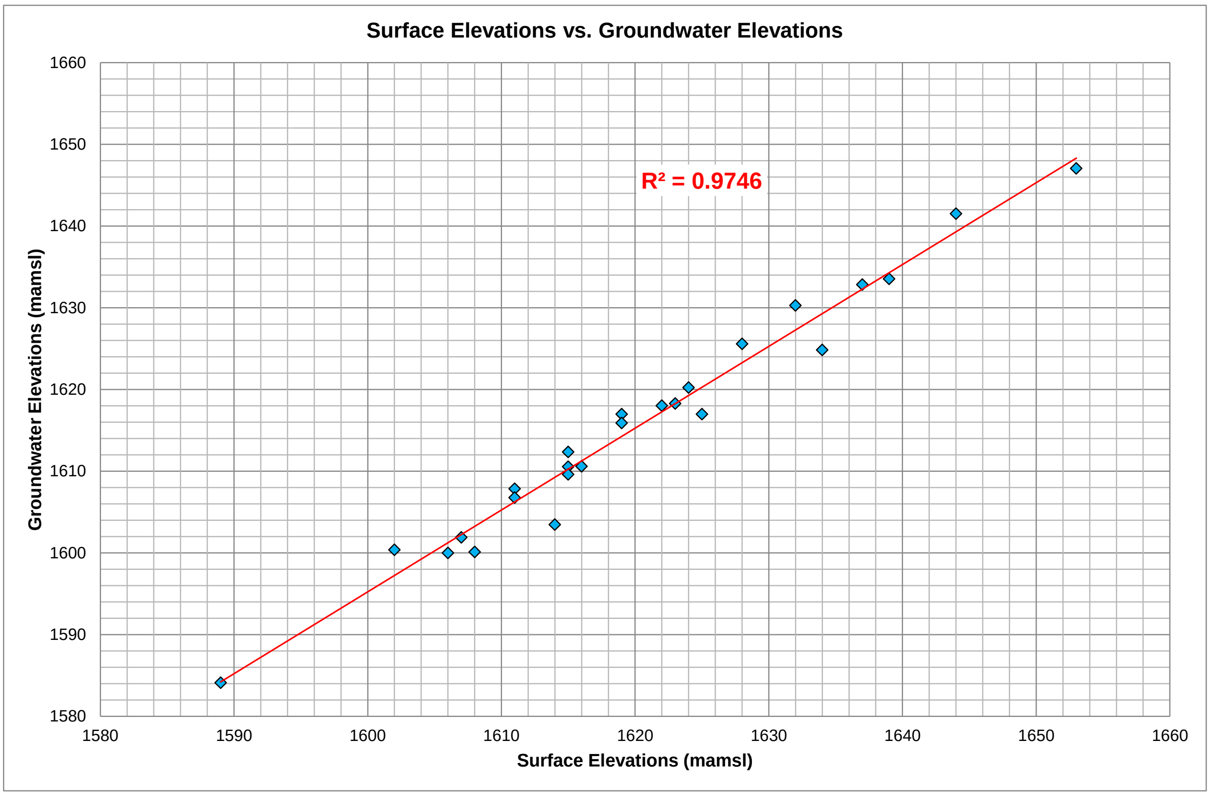


Figure 3.3: Effect of aquifer transmissivity on depression cone

The static groundwater elevation contour map provided in Figure 3.5 was constructed through the utilisation of the Bayesian interpolation technique. The Bayesian interpolation technique utilises the natural relationship that exists between the surface topography and the depth-to-groundwater level to estimate groundwater levels in areas where borehole data is scarce.

Because impacts on the natural groundwater level already exist due to mine dewatering and/or groundwater abstraction for domestic, irrigation and mining purposes, only boreholes where the linear correlation between borehole collar elevation and groundwater level elevation exists were used in the interpolation. The static groundwater contours presented in Figure 3.5 therefore represent conditions without impacts from sources or actions other than natural conditions.

A graph of borehole collar elevation versus groundwater level elevation is presented in Graph 3.1 where the linear correlation of approximately 97% can be seen. It should be noted that groundwater levels from some boreholes (generally those in excess of ten meters deep) were discarded because impacts associated with groundwater abstraction (either for domestic or mine dewatering purposes) affect the natural groundwater level/topography relationship.



Graph 3.1: Relationship between surface- and groundwater elevations

The highest static water level elevation within the mine lease area is approximately 1 650 mamsl and occurs in the topographic higher regions. The lowest static water level elevation where no impact from abstraction occurs is at approximately 1 560 mamsl. Groundwater flow directions within the modeled area are also indicated in Figure 3.5 with the use of blue arrows.

Seen in the light of water level differences because of mining, pumping and recharge effects, filtering and processing of water levels are required to remove water levels considered anomalous high or low. **The final interpolated potentiometric surface of the water levels is thus bound to contain local over- or under estimations of the actual water levels, but it will be representative of the general regional trend of the static groundwater level.**

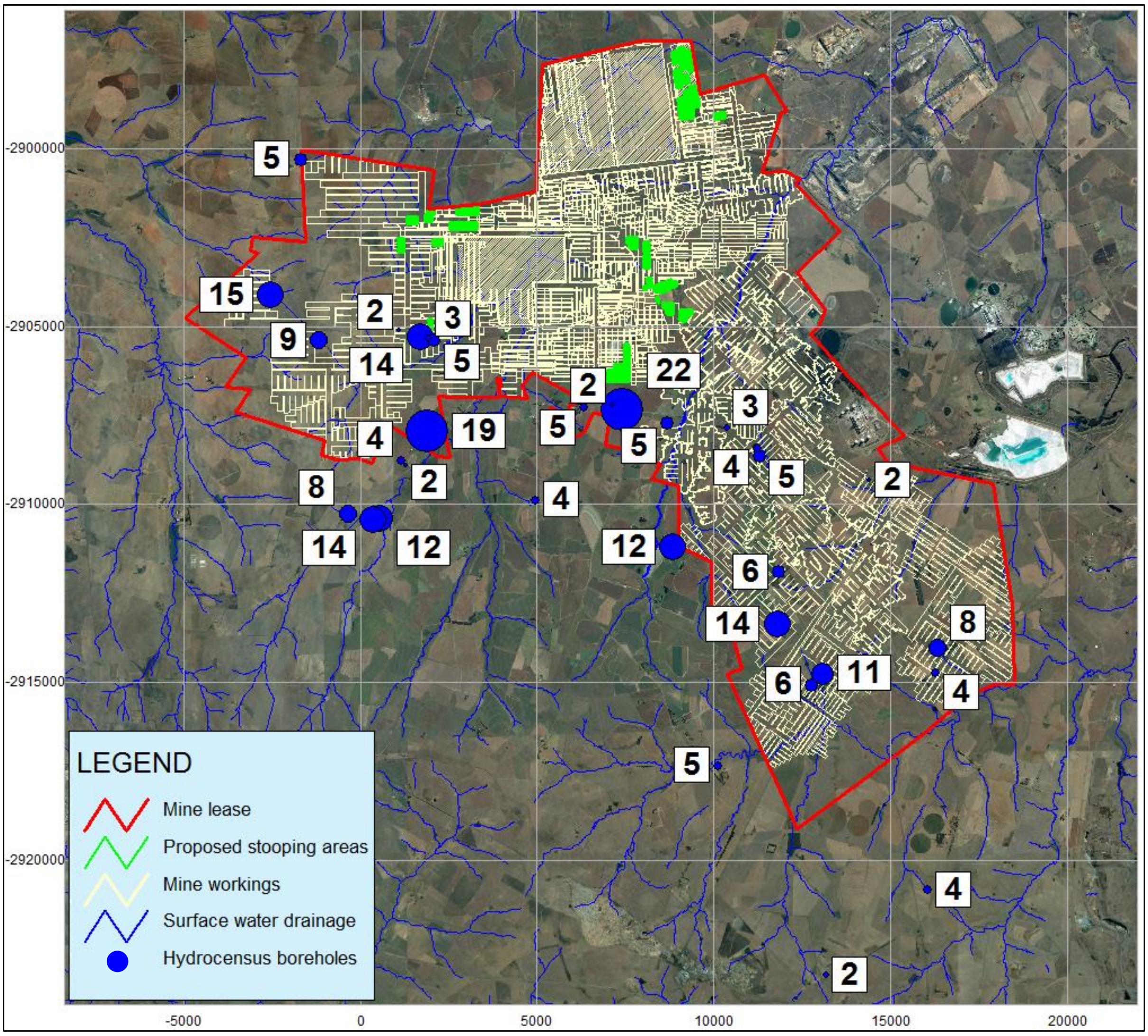


Figure 3.4: Thematic map of measured groundwater level depths (mbs)

Notes: *- The numbers in the above figure indicate the groundwater level depth below surface in meters,*
- The size of the blue circles is directly proportional to the groundwater level depth, hence the largest circle represents the deepest water level.

Key Issues: *On a regional scale, groundwater follows the natural/unaffected flow patterns/directions. Impacts on groundwater levels and subsequent flow patterns do however occur (be it from groundwater abstraction for domestic/other purposes or mine dewatering), but are largely restricted due to the generally low hydraulic properties of the aquifer host rock.*

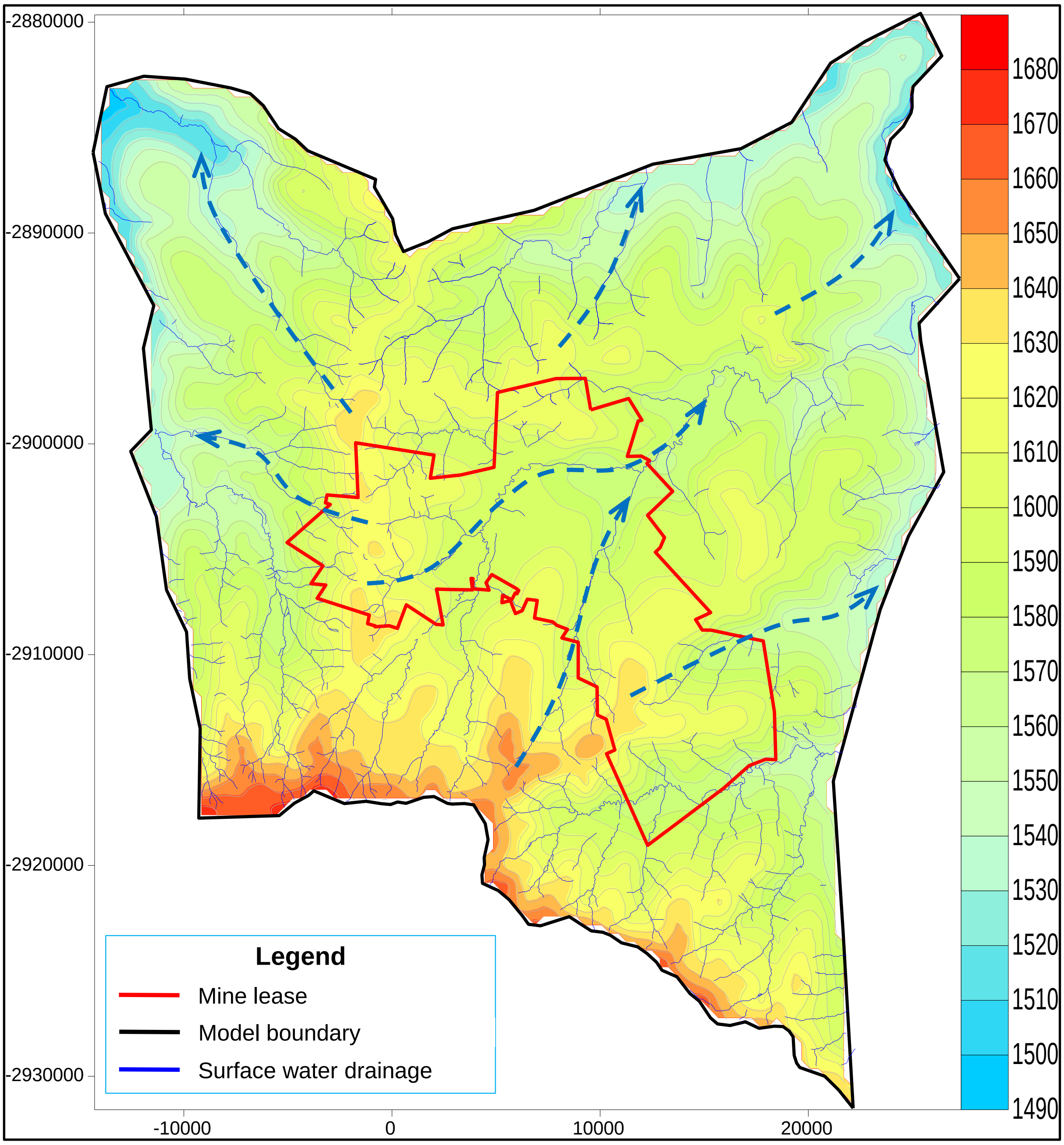


Figure 3.5: Bayesian interpolated groundwater elevation contour map of the modelled area (mamsl)

3.4 Groundwater Flow Evaluation (directions, gradients and velocities)

Contours of the static water levels or piezometric heads in and around the mining area are indicated in Figure 3.5. Path lines or flow lines of groundwater particles are lines perpendicular to the contours, as indicated with arrows. Flow occurs faster where contours are closer together and gradients are thus steeper. Natural groundwater drainage from the Matla mine lease area is towards the west/north-west and north-east.

The groundwater gradient is calculated with the following formula:

$$i = dH / dL$$

Where: i = *Hydraulic gradient*
dH = *Head difference*
dL = *Lateral distance over which gradient is measured*

Groundwater gradients were calculated with the above formula from the water level elevation data (Figure 3.5). By substituting the hydraulic head difference over lateral distance an average hydraulic gradient of approximately 0.7% was calculated for the mine lease area (Figure 3.6).

The groundwater flow gradient was in turn used to calculate the rate of groundwater movement (the so-called 'Darcy flux') in the mine lease area, which is also indicated in Figure 3.6. The following equation was used in the calculations *(after Fetter, 1994)*:

$$v = \frac{KI}{\phi}$$

Where: *v = flow velocity (m/day)*
K = hydraulic conductivity (m/day) = 0.14 (GCS, 1998)
I = average hydraulic gradient (%) = 0.7%
ϕ = probable average porosity = 0.06 (Groundwater Square, 2008)

The hydraulic conductivity and average porosity were chosen so as to provide a liberal estimation of seepage velocity. The actual seepage through the aquifer matrix should be lower than the products calculated, but highly transmissive fracture zones or areas of steeper gradient might cause higher transport rates.

The hydraulic conductivity and the average hydraulic gradient are known parameters. By making use of these values, the average steady state flow velocity *(Darcy flux)* in the mining area was calculated to be in the order of 5.8 m/y (Figure 3.6).

These estimates do however not take into account all known or suspected zones in the aquifer like preferential flow paths formed by igneous contact zones like intrusive dykes that have higher than average hydraulic properties. In secondary fractured aquifer media, the transport velocity is usually significantly higher than the average velocities calculated with this formula and may increase several meters or even tens of meters per year under steady state conditions. Under stressed conditions such as at groundwater abstraction areas the seepage velocities could increase another order of magnitude.

Table 3.2: Summary of groundwater flow evaluation

Groundwater flow direction	Groundwater flow gradient	Groundwater flow velocity (m/d)	Groundwater flow velocity (m/y)
West/north-west and north-east	0.7%	0.016	5.8

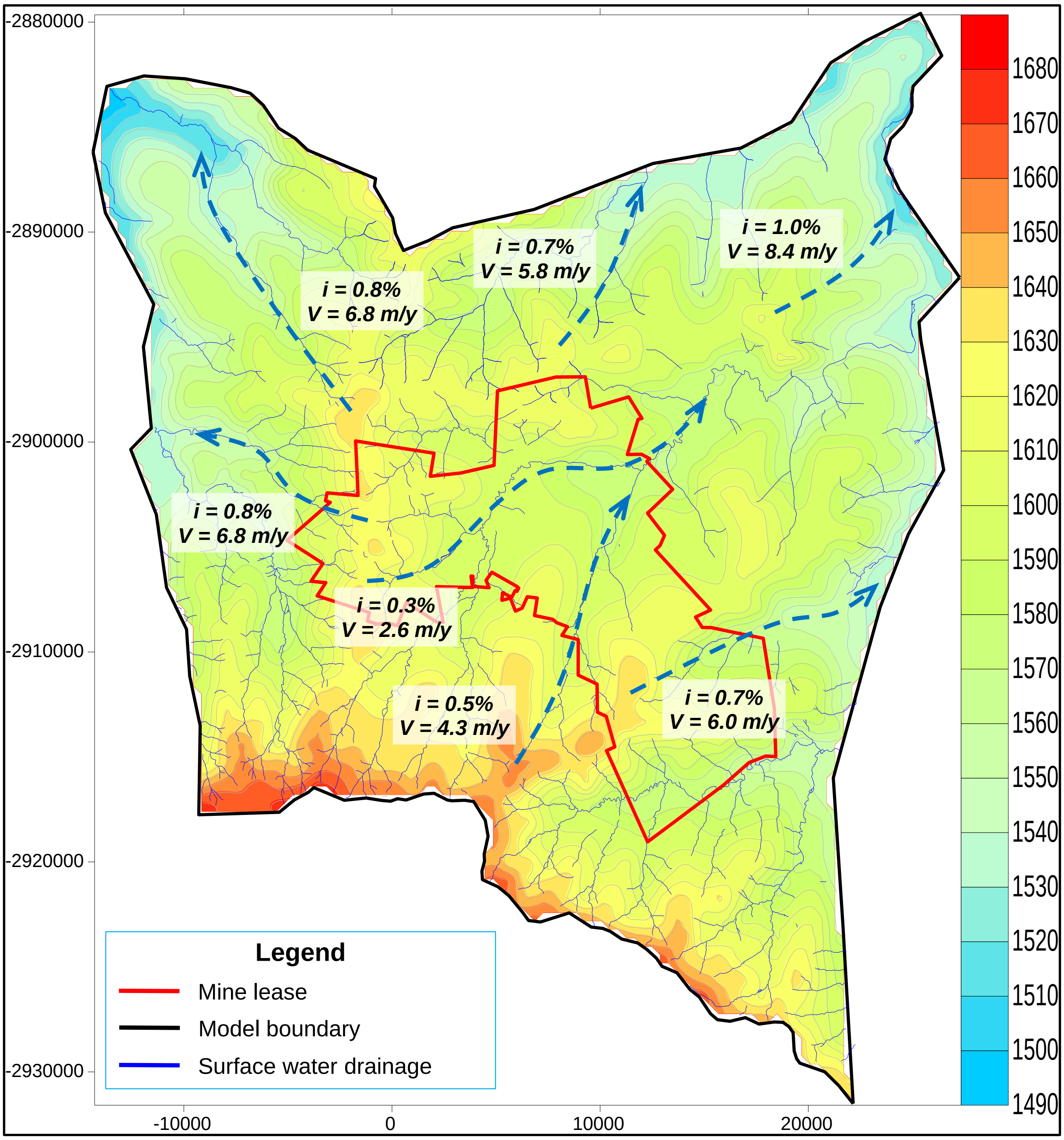


Figure 3.6: Average groundwater gradients and velocities

3.5 Aquifer Types

Two main types of aquifers are believed to be present in the mine lease area. For the purpose of this study an aquifer is defined as a geological formation or group of formations that can yield groundwater in economically useable quantities. Aquifer classification according to the Parsons Classification system is summarised in Table 3.3.

The **first aquifer** is a shallow, **semi-confined or unconfined aquifer** that occurs in the transitional soil and **weathered bedrock zone** or sub-outcrop horizon. Depending on the depth of the groundwater level and extent/depth of weathering, this aquifer may occur at depths of between 0 and 12 meters. Yields in this aquifer are generally low (less than 0.5 l/s) and the aquifer is usually not fit for supplying groundwater on a sustainable basis. Consideration of the shallow aquifer system becomes important during seepage estimations from pollution sources to receiving groundwater and surface water systems. The shallow weathered zone aquifer plays the most important role in mass transport simulations from process and mine induced contamination sources because the lateral seepage component in the shallow weathered aquifer often dominates the flow. **According to the Parsons Classification system, this aquifer is usually regarded as a minor- and in some cases a non-aquifer system.**

Due to the mainly lateral flow and sometimes phreatic nature of the weathered zone aquifer, it is usually only affected by opencast mining or by high extraction or shallow underground mining where subsidence occurs and the entire roof strata above the mined area is destroyed. Where mining becomes deeper the weathered zone aquifer is usually affected to a very limited extent. The shallow aquifer system is undeveloped/absent in areas where the groundwater level is deeper than the contact between the weathered zone and fresh bedrock.

The **second aquifer** system is the deeper **secondary fractured rock aquifer** that is hosted within the sedimentary rocks of the Karoo Supergroup and occurs at depths generally exceeding 12 meters below surface. Groundwater yields, although more heterogeneous, can be higher. This aquifer system usually displays semi-confined or confined characteristics with piezometric heads often significantly higher than the water-bearing fracture position. Fractures may occur in any of the co-existing host rocks due to different tectonic, structural and genetic processes. Groundwater flow is fully restricted to open fractures and discontinuities, which become increasingly scarce at depths exceeding 30 meters below surface.

According to the Parsons Classification system, the aquifer could be regarded as a minor aquifer system, but also a sole aquifer system in some cases where groundwater is the only source of domestic water.

Table 3.3: Parsons Aquifer Classification *(Parsons, 1995)*

Sole Aquifer System	An aquifer that is used to supply 50% or more of domestic water for a given area, and for which there is no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.
Major Aquifer System	Highly permeable formation, usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (less than 150 mS/m).
Minor Aquifer System	These can be fractured or potentially fractured rocks that do not have a primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large volumes of water, they are important both for local suppliers and in supplying base flow for rivers.
Non-Aquifer System	These are formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer unusable. However, groundwater flow through such rocks, although impermeable, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.
Special Aquifer System	An aquifer designated as such by the Minister of Water Affairs, after due process.

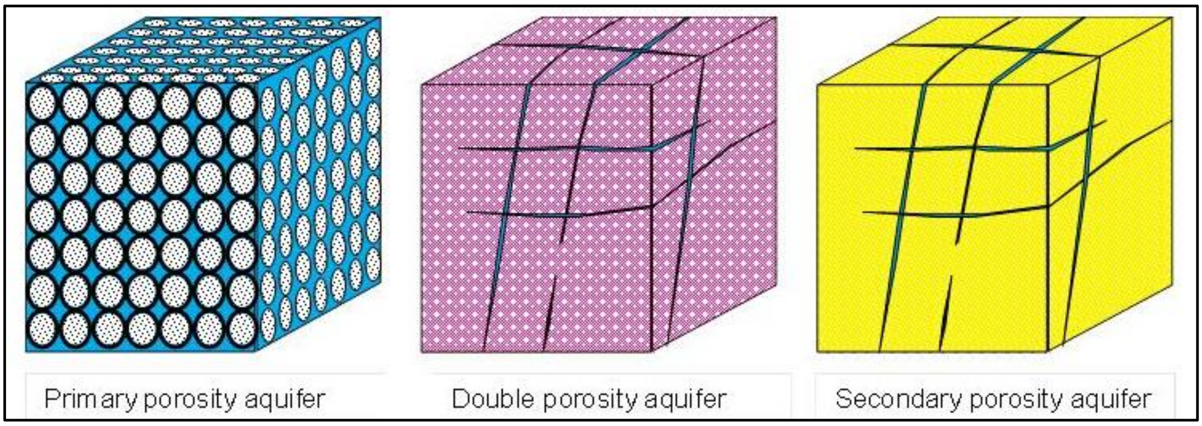


Figure 3.7: Types of aquifers based on porosity

3.6 Aquifer Transmissivity and Storativity

No aquifer testing was performed for the purpose of this investigation. All previously conducted groundwater related studies were consulted in order to obtain a better indication of the average hydraulic properties of the aquifer underlying the mining area.

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

Storativity (or the storage coefficient) is the volume of water that a permeable unit will absorb or expel from storage per unit surface area per unit change in piezometric head. Storativity (a dimensionless quantity) cannot be measured with a high degree of accuracy in slug tests or even in conventional pumping tests. It has been calculated by numerous different methods with the results published widely and a value of 0.002 to 0.01 is taken as representative for the proposed mining area. The storage coefficient values calculated from the pump tests proved to be in this order of magnitude.

The fractured rock aquifer underlying the mining area is known for being highly heterogeneous, which may result in significant variations in aquifer transmissivity/storativity over relatively short distances.

The average hydraulic conductivity (permeability) of the shallow weathered zone aquifer is 0.14 m/d, which based on an average aquifer thickness of approximately 12 meters, translates to a transmissivity of around 1.7 m^2/d *(GCS, 1998)*.

Pumping tests that were performed on the deeper fractured rock aquifer revealed transmissivity values of between 0.1 m^2/d and 7 m^2/d *(GCS, 1998)*, confirming the aquifer to be highly heterogeneous.

3.7 Aquifer Recharge and Discharge Rates

According to Figure 3.8 the mean annual recharge to the aquifer underlying the Matla mine lease area is in the region of 32 mm, which based on an average rainfall of approximately 754 mm/a (Graph 2.2) translates to a recharge percentage of just over 4%. During the model calibration process, changes are made to the aquifer recharge (among other model input parameters) until an acceptable correlation is achieved between the model simulated and measured/actual groundwater elevations. During this calibration process, a much lower recharge of between 0.6% and 1.2% was eventually assigned to the aquifer regime underlying the Matla mine lease area **(Section 5)**.

Where outcrop occurs, the effective recharge percentage can be slightly higher while in low-lying topographies where discharge generally occurs and thicker sediment deposits, the effective recharge will be lower or even zero. Based on this estimate, the mean annual recharge to the aquifer regime as defined in Figure 3.2 should be ± 34.6 Mm^3.

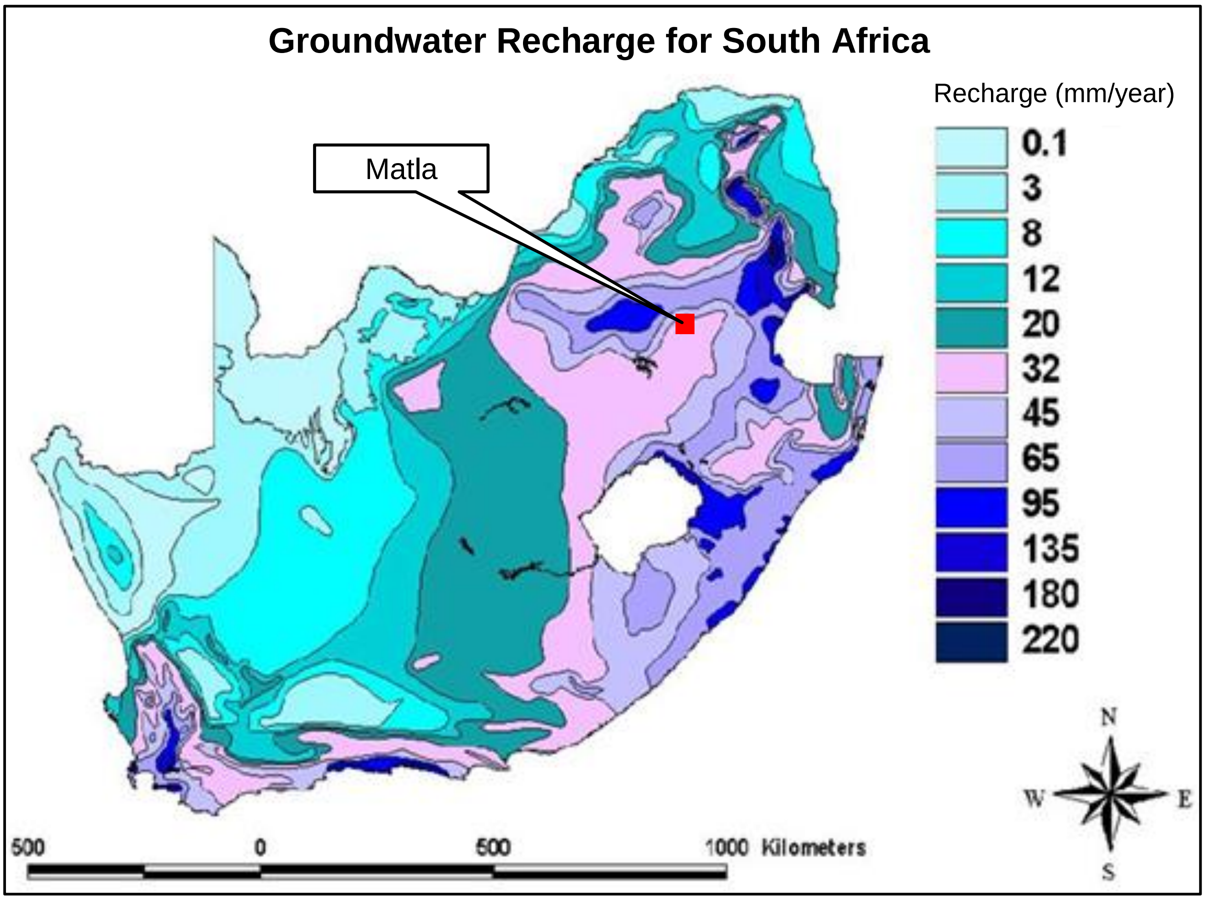


Figure 3.8: Mean annual aquifer recharge for South Africa *(Vegter, 1995)*

3.8 Groundwater Quality Characteristics

Aquatico Laboratory (a South African National Accreditation System (SANAS) accredited laboratory according to ISO/IEC 17025:2005 standards No: T0374) in Pretoria, South Africa, was commissioned to undertake the analytical testing for the collected groundwater samples. Samples were collected from six boreholes located during the hydrocensus/user survey and their positions are indicated in Figure 3.10. The results of the groundwater analyses are provided in Table 3.4 together with the guidelines used in the assessment.

Groundwater quality data was evaluated with the aid of diagnostic chemical diagrams and by comparing the inorganic concentrations to the:

- Department of Water Affairs'(DWA) South African Water Quality Guidelines (SAWQG) target range, Volume 1, Domestic Use (1996), and
- SABS South African National Standards for Drinking Water (SANS 241:2011).

The four main factors usually influencing groundwater quality are:

- **Annual recharge** to the groundwater system,
- **Type of bedrock** where ion exchange may impact on the hydrogeochemistry,
- **Flow dynamics** within the aquifer(s), determining the water age and

- **Source(s) of pollution** with their associated leachates or contaminant streams.

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

One of the most appropriate ways to interpret the type of water at a sampling point is to assess the plot position of the water quality on different analytical diagrams like a Piper, Expanded Durov and Stiff diagrams. Of these three types, the Expanded Durov diagram probably gives the most holistic water quality signature.

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

Field 1:

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

Field 2:

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

Field 3:

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

Field 4:

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

Field 5:

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

Field 6:

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

Field 7:

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

Field 8:

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

Field 9:

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

The layout of the fields of the Expanded Durov diagram (EDD) is shown in **Figure 3.9**.

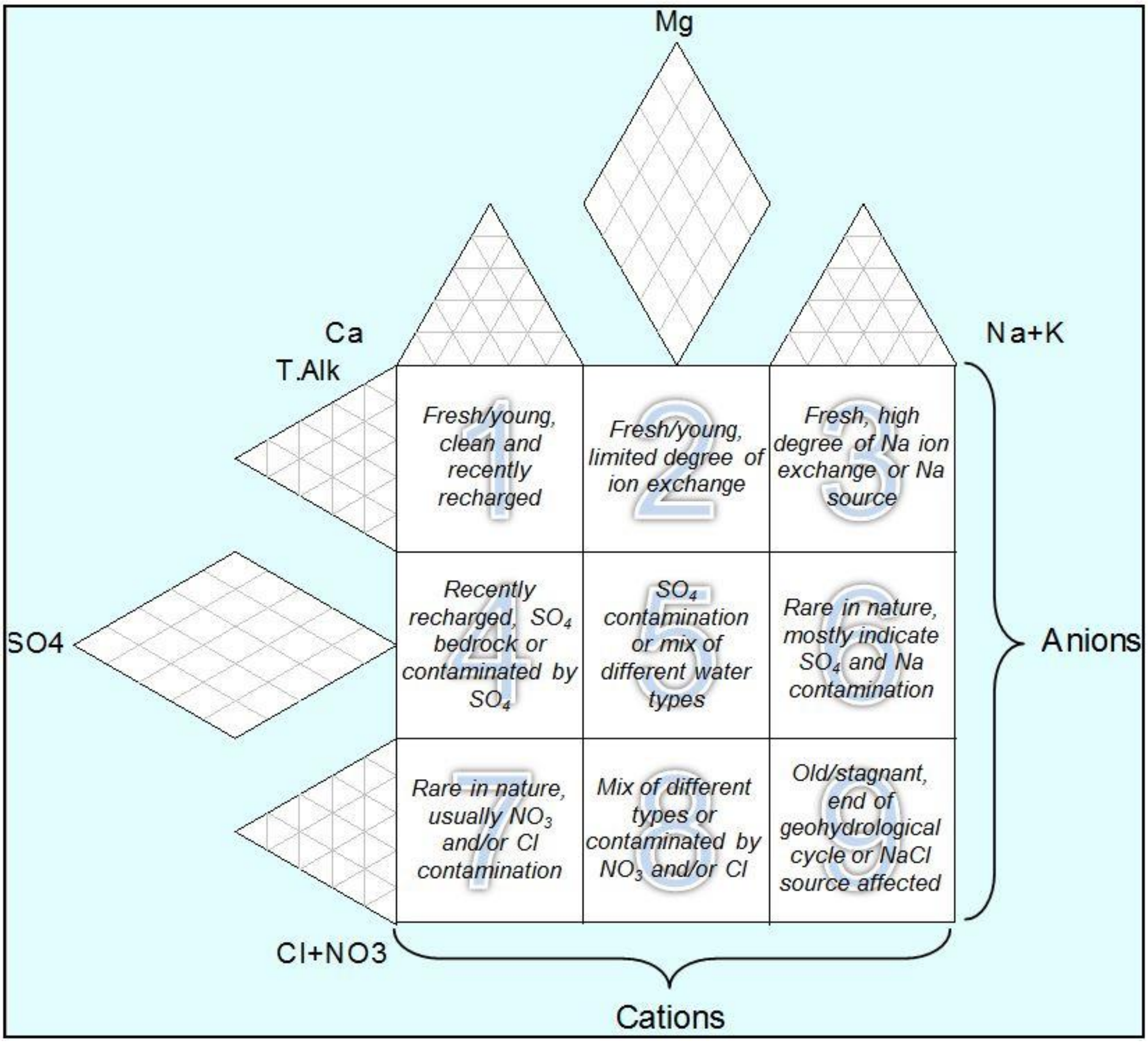


Figure 3.9: Layout of fields of the Expanded Durov diagram

Another way of presenting the signature or water type distribution in an area is by means of Stiff diagrams. These diagrams plot the equivalent concentrations of the major cations and anions on a horizontal scale on opposite sides of a vertical axis. The plot point on each parameter is linked to the adjacent one resulting in a polygon around the cation and anion axes. The result is a small figure/diagram of which the geometry typifies the groundwater composition at the point. Groundwater with similar major ion ratios will show the same geometry. Ambient groundwater qualities in the same aquifer type and water polluted by the same source will for example display similar geometries.

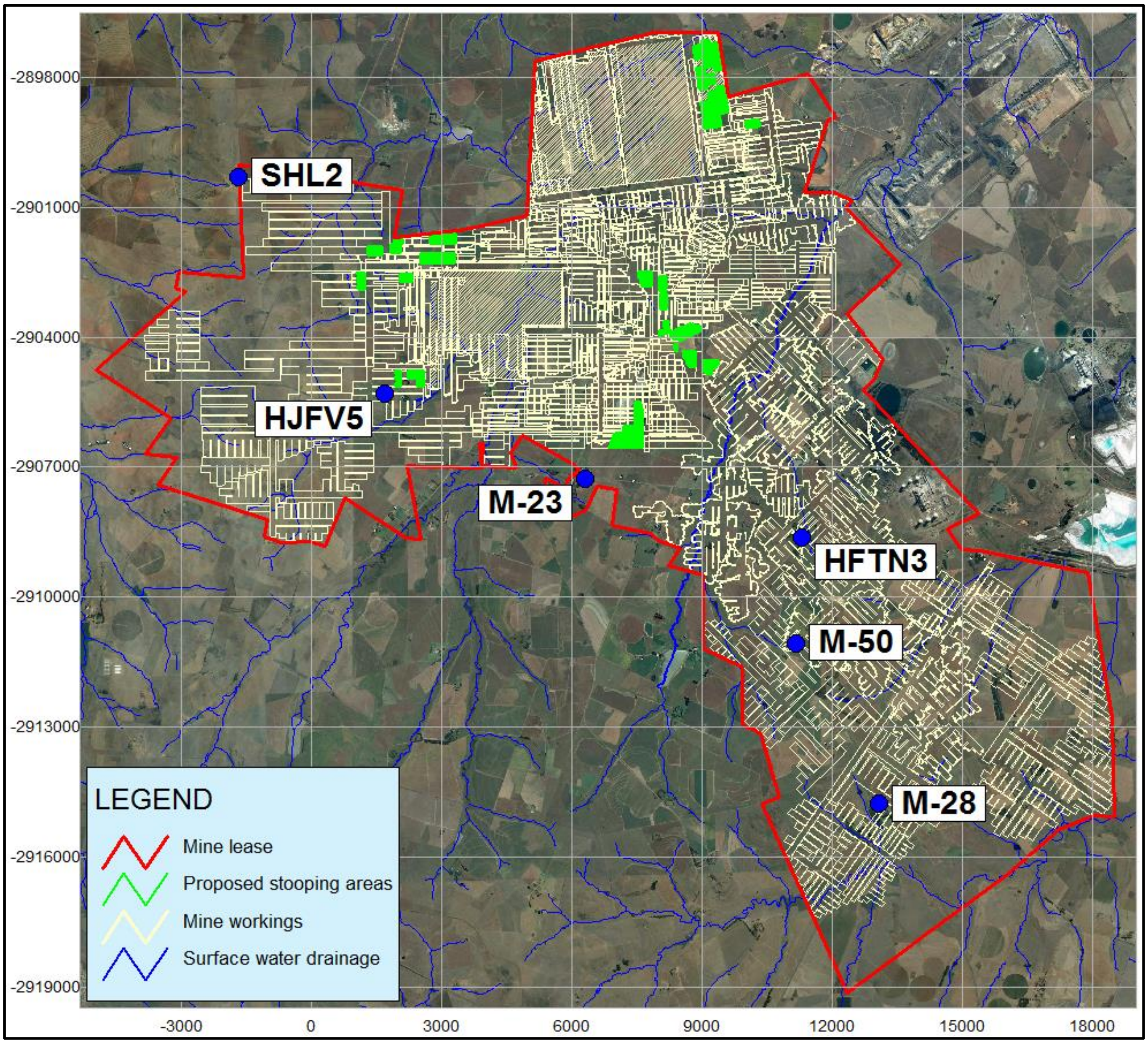


Figure 3.10: Positions of boreholes sampled

The electrical conductivity (EC) of the groundwater varies between 24 mS/m and 66 mS/m. Groundwater pH varies between 7.4 and 8.1 (pH unit), indicating neutral to slightly alkaline conditions. The elevated electrical conductivity and subsequent total dissolved solids (TDS) readings observed in borehole SHL2 can be attributed to the elevated calcium concentrations.

An analysis of the major ionic constituents was undertaken using Expanded Durov (Figure 3.11) and Stiff (Figure 3.12) diagrams to assess the proportions of these constituents and broadly characterise the aquifer water type/s. Groundwater is mainly dominated by calcium and magnesium cations, while bicarbonate alkalinity dominates the anion content. The dominant plot positions of groundwater in fields one and two of the EDD are indications of fresh, clean, relatively young groundwater that has undergone natural magnesium and sodium ion exchange.

In general, the water from the sampled boreholes is considered to be of good quality. Comparison with relevant guidelines/standards is summarized in the following bullet points:

Major Ionic Constituents Parameters

- The concentrations of cations and anions reported from the various sample locations are below the relevant DWA SAWQG and SANS 241-1 water quality criteria for domestic/drinking water use, except for calcium.
- Calcium exceeded the DWA SAWQG quality tolerance level of 32 mg/L at M50, SHL2, HJFV5, M28 and HFTN3. Although, no health effect is associated with the elevated calcium concentrations, potential scaling and lathering of soap impairments are expected.

Metals/Metalloids Constituents

- All metals/metalloids reported from the various sample locations are below the relevant DWA SAWQG and SANS 241-1 water quality criteria for domestic/drinking water use.

Nitrogen-species parameters

- Nitrate (NO_3 as N) concentrations at M28 and M23 exceed the DWA SAWQG quality tolerance level of 6 mg/L, while concentrations at SHL2 also exceed the SANS 241-1 quality tolerance level of 11 mg/L.
- Accordingly to the relevant guidelines, the potential health effects associated with the elevated nitrate concentrations include methaemoglobinaemia in infants and/or mucous membrane irritation in adults.

Key Issues:

- *Groundwater is considered to be of good quality according to the two sets of guidelines used in the assessment.*
- *Boreholes are situated in the open field and far away from potential surface sources of groundwater contamination.*
- *Typical impacts associated with coal mining related activities include elevated groundwater salinity (TDS/EC), elevated concentrations of sulphate and iron and a decrease in groundwater pH conditions. Groundwater from all six boreholes displays no such signs of coal mining related impacts.*

- *Please note that the underground workings will continue to act as a sink for both groundwater and any potential contamination that may originate from the Matla mining activities for as long as it takes groundwater levels to recover from the impacts of mine dewatering.*

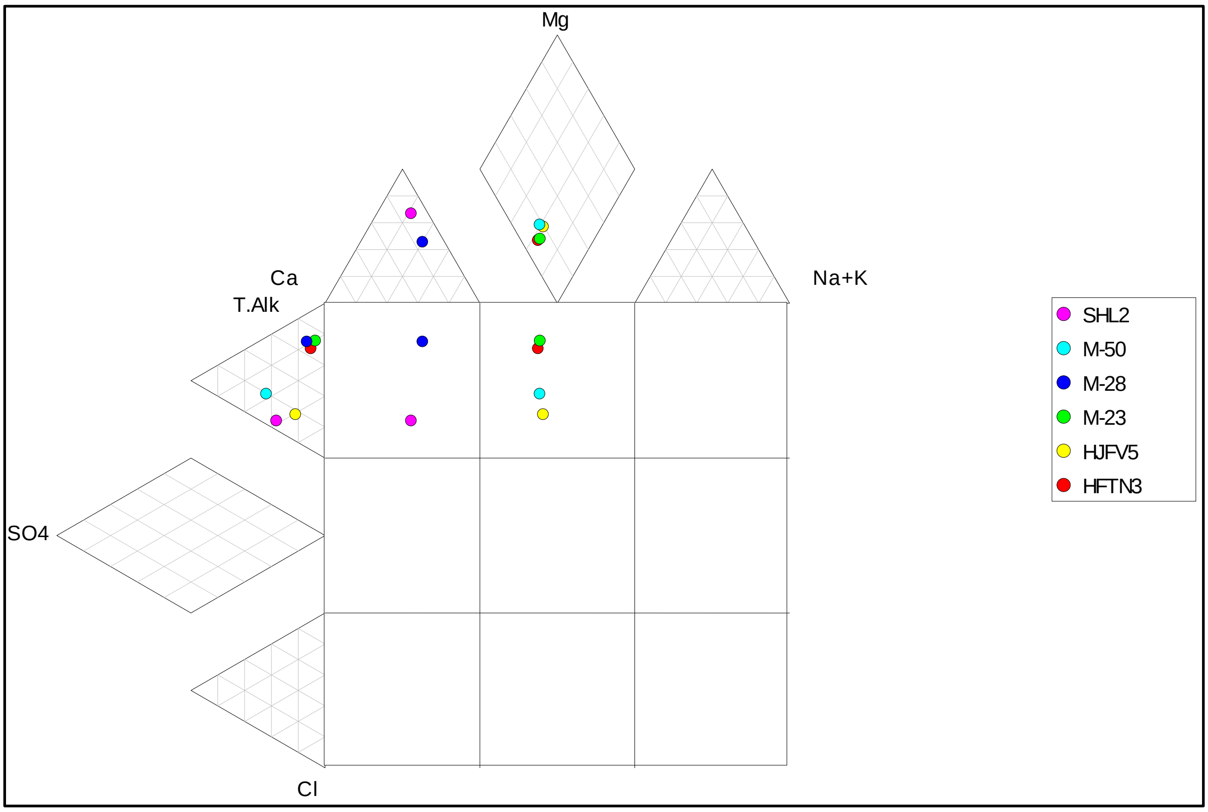


Figure 3.11: Expanded Durov diagram of groundwater chemistries

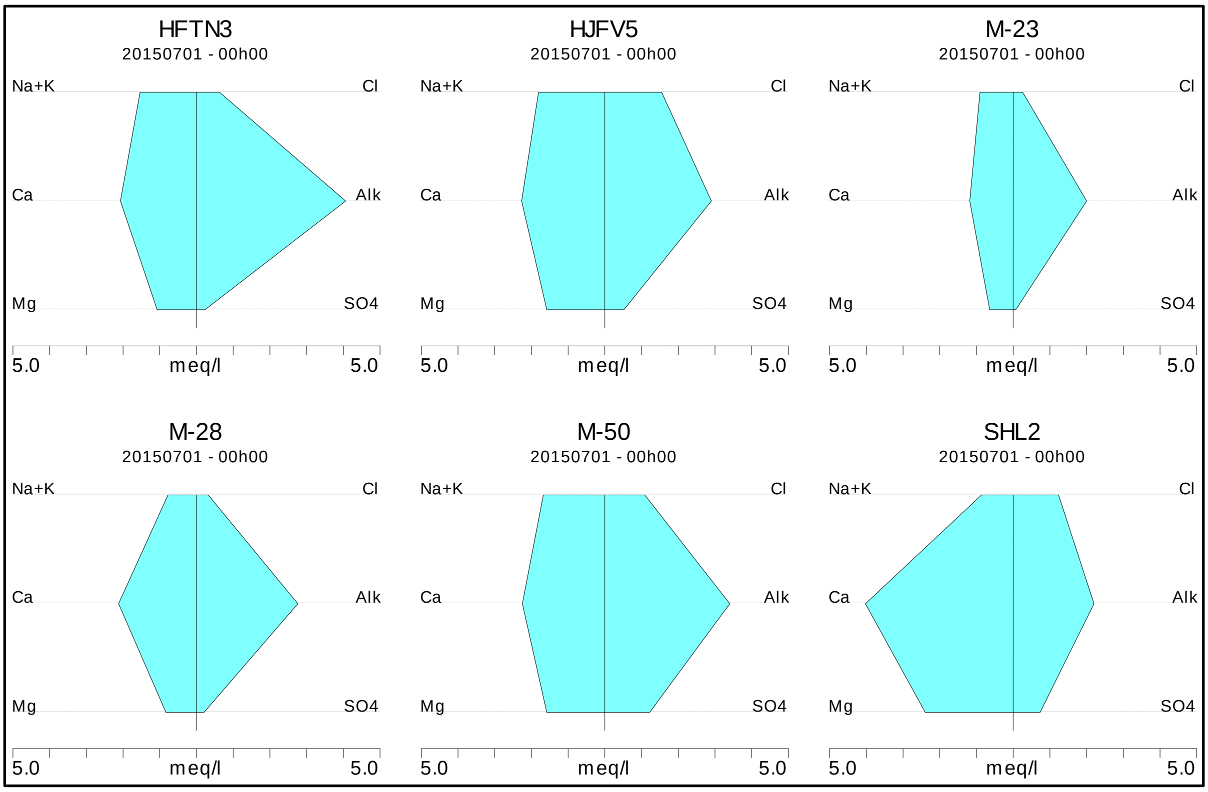


Figure 3.12: Stiff diagrams of groundwater chemistry

Table 3.4: Results of physical and chemical analyses of groundwater samples

Analyses	Unit	Detection Limit	DWA SAWQTV	SANS 241-1	M50	SHL2	HJFV5	M28	HFTN3	M23	*Minimum*	*Maximum*	*Mean*	*Geomean*
Physio-Chemical Parameters														
pH	pH unit	n/a	6 - 9	5 - 9.7	7.99	7.7	7.35	7.68	8.13	7.43	*7.35*	*8.13*	*7.71*	*7.71*
Electrical Conductivity	mS/m	0.1	<70	<170	48.3	66.1	49.6	33.3	41.6	24	*24*	*66.1*	*43.8*	*41.7*
Total Dissolved Solids	mg/L	10	<450	<1200	310	452	299	222	253	160	*160*	*452*	*283*	*269*
Total Alkalinity	mg $CaCO_3$/L	2.477	NS	NS	170	110	145	138	203	100	*100*	*203*	*144*	*140*
Total Hardness	mg $CaCO_3$/L	n/a	NS	NS	191	321	192	148	157	91	*91*	*321*	*183*	*171*
Inorganic and Metal Parameters														
Major Ionic Constituents														
Calcium	mg/L	0.0259	<32	NS	45	80.6	45.4	42.5	41.5	23.7	*23.7*	*80.6*	*46.5*	*43.6*
Magnesium	mg/L	0.009	<30	NS	19.2	29.1	19.2	10.1	13	7.77	*7.77*	*29.1*	*16.4*	*14.9*
Potassium	mg/L	0.018	<50	NS	5.98	4.46	8.69	4.01	9.06	8	*4.01*	*9.06*	*6.7*	*6.38*
Sodium	mg/L	0.013	<100	<200	35	17.2	36.4	15.5	30	16.1	*15.5*	*36.4*	*25.03*	*23.4*
Sulphate	mg/L	0.04	<200	<500	58.6	35.2	24.9	9.83	11.2	3.42	*3.42*	*58.6*	*23.86*	*16.38*
Chloride	mg/L	0.423	<100	<300	38.6	43.8	54.9	11.4	22.3	9.17	*9.17*	*54.9*	*30.03*	*24.5*
Fluoride and Phosphorus Constituents														
Fluoride	mg/L	0.055	<1	<1.5	0.132	0.128	0.172	0.132	0.218	0.17	*0.128*	*0.218*	*0.159*	*0.156*
Orthophosphate	mg/L	0.008	NS	NS	0.009	0.013	0.014	0.027	0.012	0.02	*0.009*	*0.027*	*0.016*	*0.015*

Analyses	Unit	Detection Limit	DWA SAWQTV	SANS 241-1	M50	SHL2	HJFV5	M28	HFTN3	M23	*Minimum*	*Maximum*	*Mean*	*Geomean*
Metals/Metalloids Constituents														
Aluminum	mg/L	0.003	<0.15	NS	BDL	BDL	BDL	BDL	BDL	BDL	*na*	*na*	*na*	*na*
Cadmium	mg/L	0.001	<0.005	<0.003	BDL	BDL	BDL	BDL	BDL	BDL	*na*	*na*	*na*	*na*
Cobalt	mg/L	0.001	NS	<0.5	BDL	BDL	BDL	BDL	BDL	BDL	*na*	*na*	*na*	*na*
Copper	mg/L	0.001	<1	2	BDL	BDL	BDL	BDL	BDL	BDL	*na*	*na*	*na*	*na*
Chromium (total)	mg/L	0.001	NS	0.05	BDL	BDL	BDL	BDL	BDL	BDL	*na*	*na*	*na*	*na*
Iron	mg/L	0.003	<0.1	2	BDL	BDL	BDL	BDL	BDL	BDL	*na*	*na*	*na*	*na*
Manganese	mg/L	0.001	<0.05	0.5	BDL	BDL	BDL	BDL	BDL	BDL	*na*	*na*	*na*	*na*
Nickel	mg/L	0.001	NS	<0.15	BDL	BDL	BDL	BDL	BDL	BDL	*na*	*na*	*na*	*na*
Lead	mg/L	0.004	<0.01	0.01	BDL	BDL	BDL	BDL	BDL	BDL	*na*	*na*	*na*	*na*
Zinc	mg/L	0.002	<3	5	BDL	0.035	0.063	0.05	BDL	0.021	*0.021*	*0.063*	*0.042*	*0.039*
Nitrogen-Species Parameters														
Ammonia	mg/L	0.005	<1	<1.5	0.083	0.089	0.091	0.098	0.092	0.224	*0.083*	*0.224*	*0.113*	*0.105*
Nitrate	mg/L	0.017	<6	<11	0.935	39.3	4.71	9.87	0.293	6.77	*0.29*	*39.3*	*10.31*	*3.88*

Note/s:
- mS/m - milli Siemens per metre,
- mg/L - milli grams per Litre,
- mg $CaCO_3$/L - milli grams calcium carbonate per Litre,
- NS - no standards/guideline trigger values,
- BDL - below detection limit,
- na - not applicable.

3.9 Potential for Acid Mine Drainage

Metal sulphides, of which pyrite is the most common, are very prone to oxidation when brought into contact with water and oxygen. The chemical reactions are collectively referred to as acid mine drainage (AMD). The root of the problem lies in the chemical and bacteriological oxidation of the metal sulphides, which is explained/illustrated with the following reaction train:

$$2FeS_2 + 7O_2 + 2H_2 - 2FeSO_4 + H_2SO_4 \ldots\ldots \text{(1)}$$
$$4FeSO_4 + 2H_2SO_4 + O2 - 2Fe_2\ (SO_4)_3 + 2H_2O \ldots\ldots \text{(2)}$$
$$3Fe_2\ (SO_4)_3 + 12H2O - 2HFe_3(SO_4)_2\ (OH)_6 + 5H_2SO_4 \ldots\ldots \text{(3)}$$

The pH and bicarbonate values of the water are expected to decrease. Metals go into solution and sulphate (SO_4) and Total Dissolved Solids (TDS) values increase. As the water leaves the mining area, it usually mixes with better quality water and the pH and bicarbonate values will be buffered back to more acceptable levels. Metals then also precipitate and the sulphate and TDS concentrations decrease again.

Acid Base Accounting (ABA) is done to determine the net acid generating and neutralising potentials of material. The main principles of acid-base accounting are:

- Samples are exposed to complete oxidation of all sulphide-bearing minerals.
- This generates acid, which is counteracted by the natural base potential of the material.
- The initial pH before oxidation and the oxidised pH are recorded for each sample.

Little or no drop in pH occurs whenever the base potential exceeds the acid potential. The opposite holds true when the acid potential exceeds the base potential – such a sample is therefore expected to generate acidic conditions when exposed to oxygen and water.

No acid base accounting was performed for the purpose of this investigation, however the surrounding mines are known to generate acid *(GCS, 1998)*. The weathered sandstone, shale, and the 5 seam roof and floor all have the potential for acidification. Groundwater flowing through these areas is likely to generate acid when exposed to oxygen and water. The coarse sandstone, on the other hand, has a very large neutralising potential and will give groundwater flowing through it an alkaline character *(GCS, 2000)*.

3.10 Potential Sources of Contamination

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

Point sources

The contamination can easily be traced back to the source and typically includes mine infrastructure such as a processing plant, overburden/waste rock dump, pollution control dam, underground workings, ROM stockpile, etc.

Diffuse sources

Diffuse sources of groundwater contamination are typically associated with poor quality leachate formation through numerous surface sources.

An evaluation of the mining area and related activities revealed numerous potential source areas, which are listed and briefly discussed below in Table 3.5.

Table 3.5: Potential sources of groundwater contamination

Source	Contamination risk	Comments
1) Plant area	High	- Impact on the groundwater only occurs through leachate formation from surface. Impacts thus only occur as a result of rainfall recharge or when water is introduced in some form where leachate can form that seeps to the groundwater.
2) Waste rock dumps and stockpiles	High	- Effective recharge through waste rock dumps and stockpiles is much higher than the natural recharge of the area due to lower evaporation rates. - Surface water run-off originating from these source areas, toe-seeps and seepage through the base may potentially be of poor quality and could cause adverse groundwater quality impacts should it enter the aquifer. - Seepage from waste rock dumps and stockpiles is likely to be affected by acid mine/rock drainage and therefore high in iron and sulphate content.
3) Underground mining areas	High	- Contamination will only leave these areas after groundwater levels have recovered from the impacts of mine dewatering. - Water collecting in these areas is usually characterised by high concentrations of iron and sulphate and low pH due to acid mine drainage.
4) Dirty water retaining facilities (pollution control dam, sewage, etc.)	Low/Medium	- These facilities are developed and constructed for the sole purpose of containing dirty/affected water and therefore minimising the risk of it contaminating the groundwater. Mismanagement of these facilities may however lead to spills and/or leakages that have the potential to contaminate the underlying groundwater.
5) Workshops and washing/cleaning bays	Low/Medium	- Impact on the groundwater only occurs through leachate formation from surface. Impacts thus only occur as a result of rainfall recharge or when water is introduced in

Source	Contamination risk	Comments
		some form where leachate can form that seeps to the groundwater. - Organic contaminants are usually the main pollutants of concern (e.g. oil, grease, diesel, petrol, hydraulic fluid, solvents, etc.).

Key Issues:

- *The coal and overburden material have the potential to generate an acidic leachate high in sulphate and iron content due to acid mine/rock drainage. This characteristic behavior of material containing metal sulphide minerals (usually pyrite), significantly increases a source's potential to adversely affect the quality of groundwater.*
- *Water collecting in the mine workings will stratify with time, i.e. the "heavier" polluted water will sink to the bottom or floor of the mine leaving the "lighter" relatively clean water to occupy the upper reaches of the water column. The water that will eventually decant should therefore be of reasonably good quality.*
- *This stratified system may however be disturbed in areas experiencing high water ingress and subsequent turbulent flow, i.e. adversely affecting the quality of the decanting water.*
- *High extraction mining has led to surface subsidence throughout the Matla mine lease area. Wherever subsidence has occurred, recharge to the underground workings is expected to have increased exponentially. If the Matla underground workings are to decant, the water is expected to be of poor quality.*

3.11 Potential Pathways for Contamination

In order for contamination to reach and eventually affect a receptor/s, it needs to travel along a preferred pathway. The effectiveness of a pathway to conduit contamination is determined by three main factors, namely:

- Hydraulic conductivity of pathway,
- Groundwater hydraulic gradient, and
- Area through which flow occurs.

All three abovementioned factors have a linear relationship with the flow of contamination through a preferred pathway, meaning an increase in any one of the three will lead to an increase in flow. The following potential pathways were identified in the mine lease area:

3.11.1 Saturated Weathered Zone (weathered zone aquifer)

As discussed in **Section 3.5** of the report, the weathered zone aquifer is composed of soil and weathered bedrock, which depending on the weathering depth and depth to groundwater level may be between 0 and 12 meters thick.

The rate of flow depends on the hydraulic conductivity of the aquifer and groundwater hydraulic gradient that were already discussed in **Section 3.4**. Groundwater/contaminant flux in this aquifer is expected to be in the order of 6 m/y, which is considered to be relatively slow. Please note that the weathered zone aquifer system is undeveloped in areas where the groundwater level is deeper than the contact between the weathered zone and fresh bedrock.

3.11.2 Geological Structures

Dykes and faults are known to occur throughout the mine lease area, which may act as sufficient pathways for contamination. The crystalline nature of an igneous dyke is characteristic of an aquiclude, however rapid cooling during intrusion caused highly transmissive fracture zones to form along the contact between the intrusive and surrounding rock.

The flow rates provided in **Section 3.4** may increase by several orders of magnitude should a transmissive geological structure be located in the down gradient groundwater flow direction and if it is also orientated parallel to the local flow direction.

3.12 Potential Receptors of Contamination

A receptor of groundwater contamination usually occurs in the form of a groundwater user that relies on groundwater for domestic, irrigation or livestock watering purposes. Surface water features (stream, river, dam, etc.) that rely on groundwater base flow for the sustainment of the aquatic environment are also considered to be important receptors.

Numerous groundwater users were located during the user surveys and their positions are indicated in Figure 3.1. Numerous perennial surface water streams cut through the mine lease area, which are also considered to be potential receptors (Figure 2.1).

Key Issues:

For a negative groundwater quality impact to be registered the following three components should be present:

- *A source to generate and release the contamination,*
- *A pathway along which the contamination may migrate, and*
- *A receptor to receive the contamination.*

All three these components are present within the Matla mine lease area, which stresses the importance of a comprehensive early detection groundwater monitoring program (source monitoring).

3.13 Mine Water Balance

Numerous water balance models have been done for Matla throughout the years, of which the most recent one was completed in June 2015 by Mine Water Consultants.

3.13.1 Water currently residing in the workings:

The proposed stooping areas are located within existing underground mining areas:

- 1 Mine – 4 seam mining (bord- and pillar only),
- 2 Mine – 2 seam mining (bord- and pillar and longwall),
- 2 Mine – 5 seam mining (bord- and pillar and longwall),
- 3 Mine – 2 seam mining (bord- and pillar only), and
- 3 Mine – 4 seam mining (bord- and pillar and longwall).

These areas are either partially or completely flooded and would require dewatering before Matla can safely commence with their planned stooping activities. For this reason it is important to have a good understanding of the dewatering requirements. The bulk water volumes that are currently (June 2015) present in the underground workings was calculated by Mine Water Consultants and are indicated in Figure 3.13 and Figure 3.14.

The labels shown in the two abovementioned figures indicate the water level elevation and the volume of water in the compartments. Only the major compartments are labelled. The indicated volumes represent the maximum amount of water currently residing in the underground workings. The current presence of water in the underground workings may (and should) differ from the calculated results as the latter indicates maximum rather than measured values.

Most of the areas outside the service lines (main development) are closed off with walls to improve ventilation of the workings. Although these ventilation walls are not designed to be watertight they will have a restraining effect on the water bodies. This may result into sections with more water or sections with less water than calculated. Confirmation of water levels inside these sections is needed to accurately calculate the volumes of water inside the various compartments of the workings.

3.13.2 Recharge calculations – Lateral recharge component (groundwater)

When a mine cavity is abandoned water will enter the void. The time it takes to fill the void is dependent on numerous factors like type of mining, depth of mining, type of overlaying strata, water level in the direct surroundings and the amount of annual rainfall. The mining void will slowly be filled by water from a lateral source (groundwater) and by recharge water from above. Unless mining goes through major faults and/or sheer zones the recharge from groundwater will be very small in comparison with recharge from rainfall.

Darcy's Law is used to calculate the recharge from groundwater flow (lateral recharge). The average lateral recharge value for all the workings combined is 12.9 m^3/d. The recharge per working is expected to be below 3 m^3/d *(Mine Water Consultants, 2015)*.

3.13.3 Recharge calculations – Vertical recharge component (rainfall)

The projections are made under average annual rainfall conditions of 678 mm/a as measured at Kriel weather station. As long as there is enough space in the mine to accommodate excess recharge during excessively wet years, this prediction is valid. Over a period of 10 years or more, predictions average out and average rainfall may be used in the model. The combined daily recharge for all five underground workings (lateral and recharge from rainfall which take place from the top) varies from a low recharge range value of 8 800 m^3/d to a high range of 17 000 m^3/d, with an average of approximately 12 900 m^3/d *(Mine Water Consultants, 2015)*.

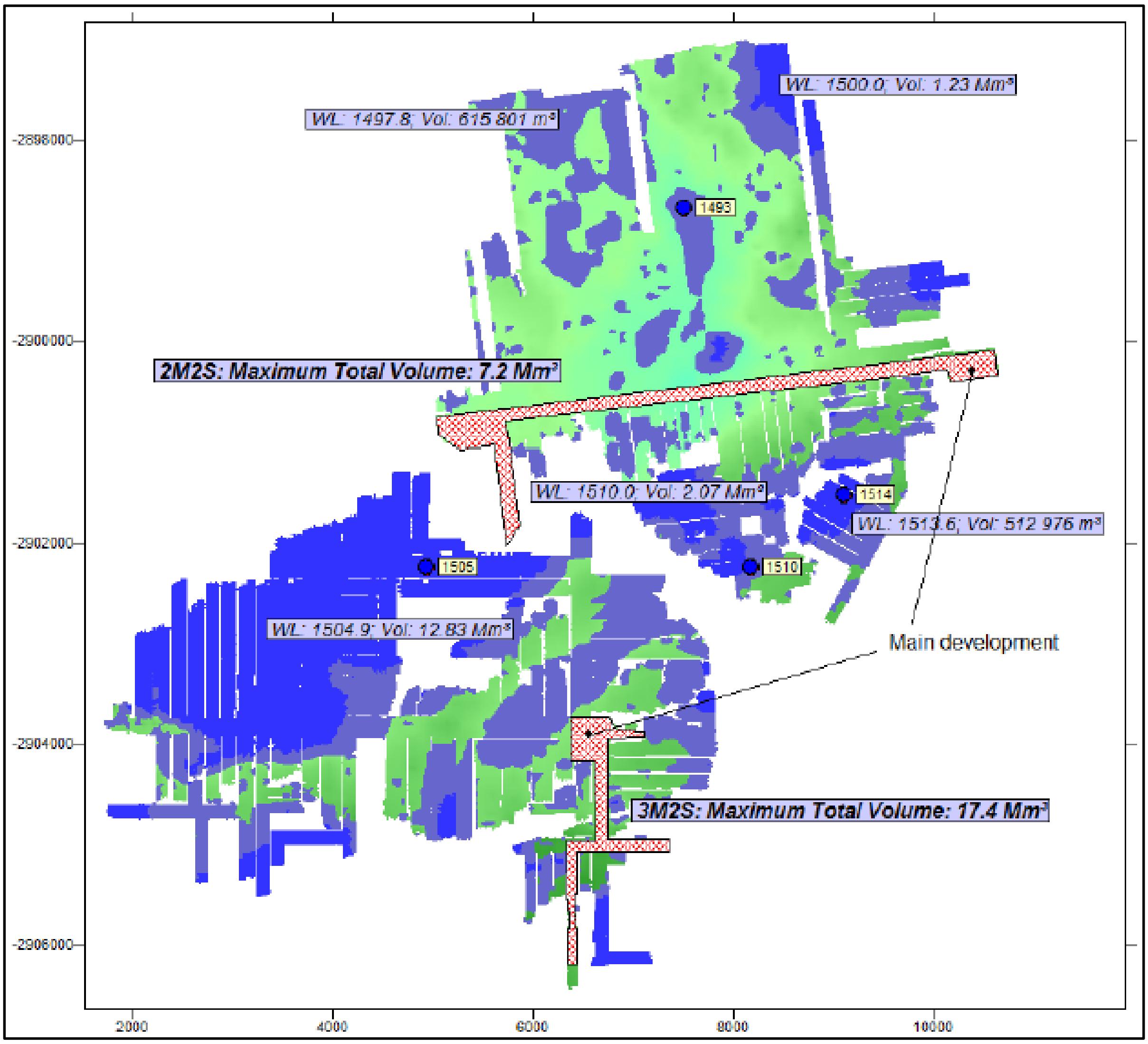


Figure 3.13: Potential water in the 2 seam mines *(Mine Water Consultants, 2015)*

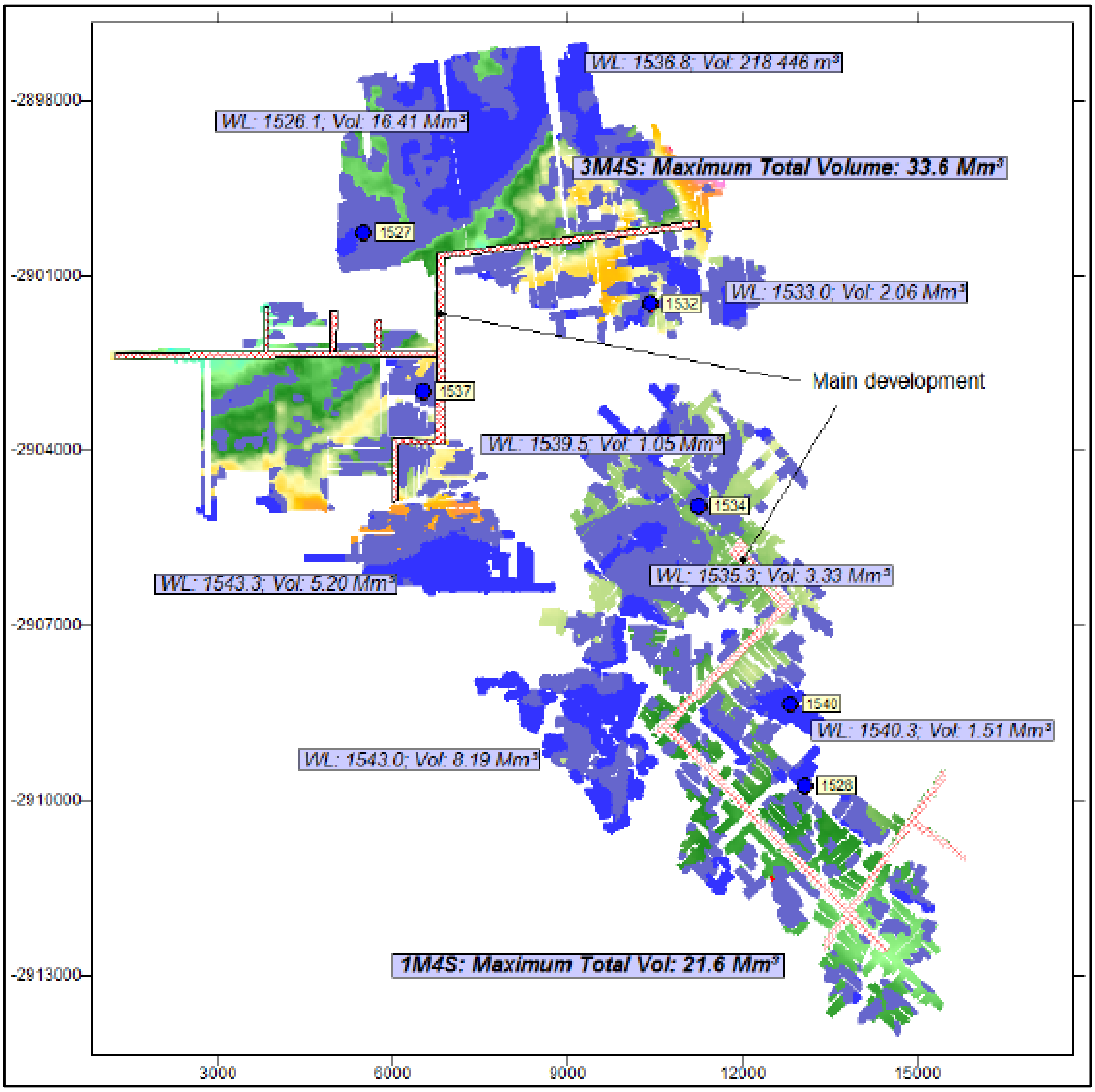


Figure 3.14: Potential water in the 4 seam mines *(Mine Water Consultants, 2015)*

Key Issues:

- *The planned stooping areas are either partially or completely flooded and would require dewatering before Matla can safely commence with mining. We therefore recommend that Matla undertakes a study which details the dewatering schedule.*
- *The planned stooping activities are expected to cause an increase in the vertical recharge component. The areas earmarked for stooping are however small in comparison with the larger mining area and their effect/impact on the water balance is therefore expected to be small.*

3.14 Summary of Conceptual Model

A vertical cross section of the mine lease area is provided in Figure 3.15. Based on our assessment of all groundwater related aspects and previous groundwater studies, we conceptualize the hydrogeological system underlying the Matla mine lease area as follows:

- The mine lease area is underlain by sedimentary rocks (mainly sandstone, siltstone, shale and coal) of the Ecca Group, Karoo Supergroup.
- Two aquifer systems are present, namely a shallow aquifer composed of soil and weathered bedrock and a deeper fractured rock aquifer hosted within the solid/unweathered bedrock.
- The average transmissivity of the weathered zone aquifer is approximately 1.7 m^2/d, while the transmissivity of the more heterogeneous fractured rock aquifer generally varies between 0.1 m^2/d and 7 m^2/d.
- Approximately 4% of the mean annual rainfall reaches the groundwater table to recharge the aquifer.
- Natural groundwater drainage from the Matla mine lease area is towards the west/north-west and north-east.
- The average hydraulic gradient was calculated to be in the order of 0.7%, resulting in a groundwater seepage velocity/flux of approximately 5.8 m/y.
- Groundwater levels around the mining area generally vary between ± 2 and 22 meters below surface (mbs).
- Groundwater levels in excess of ten meters deep are considered to be affected (be it from groundwater abstraction for domestic/other purposes or mine dewatering), however impacts are largely restricted due to the generally low hydraulic properties of the aquifer host rock.
- Groundwater is considered to be of good quality according to the two sets of guidelines used in the assessment of the chemical and physical groundwater analyses.
- Numerous potential sources of groundwater contamination occur within the mine lease area. Studies have shown that the coal and waste material have the potential to generate acidic leachate due to acid mine/rock drainage, significantly increasing the source's potential to adversely affect groundwater quality.
- The saturated weathered zone and geological structures (dykes and faults) within the mine lease area were identified as possible pathways along which groundwater and potential contamination may migrate at accelerated rates.
- Numerous groundwater users and perennial surface water streams occur throughout the mine lease area, which are considered to be important receptors of contamination that may potentially originate from the coal mining and related activities.
- The planned stooping areas are either partially or completely flooded and would require dewatering before Matla can safely commence with their stooping activities.

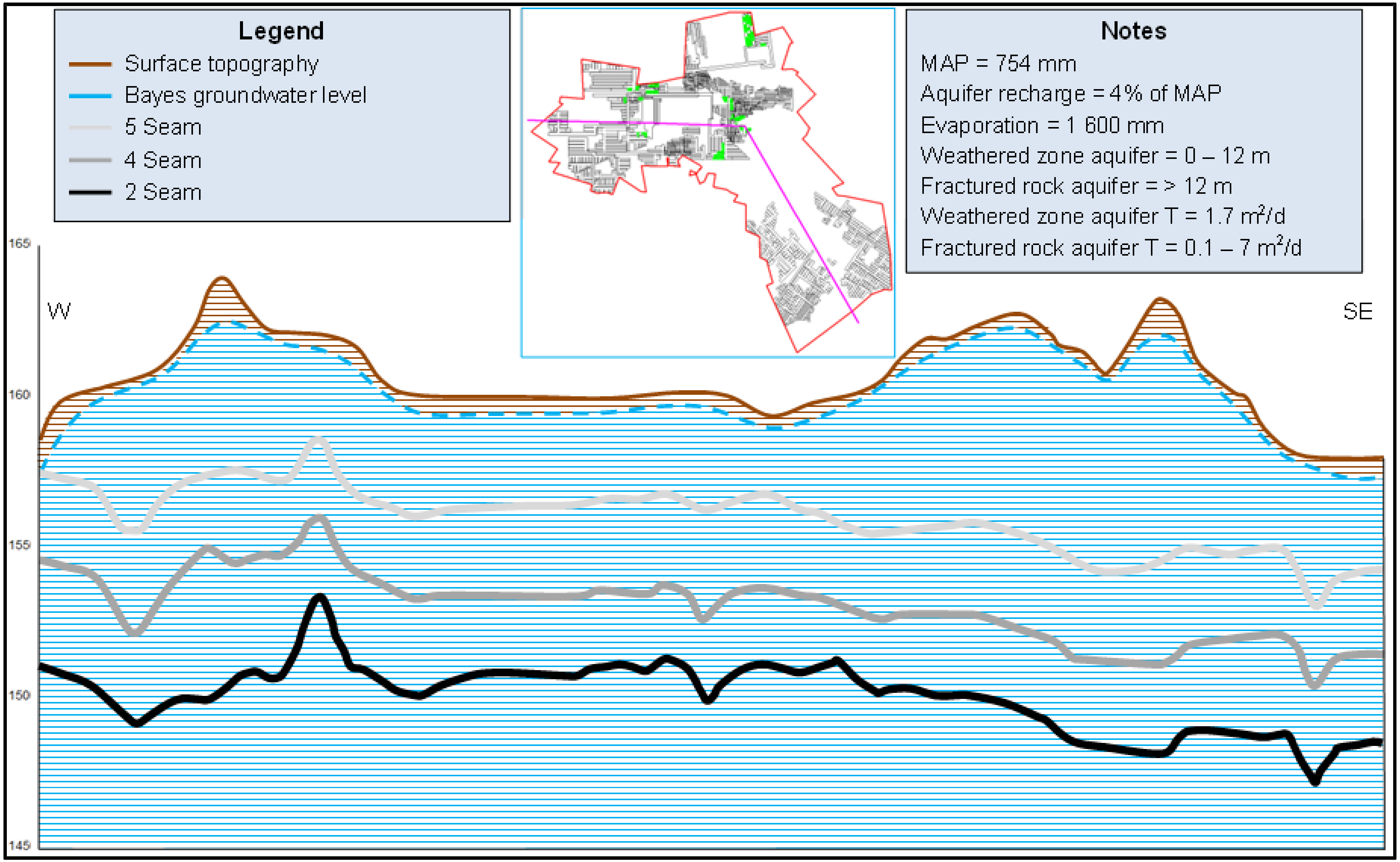


Figure 3.15: Vertical cross section through mine lease area

4 ENVIRONMENTAL IMPACT ASSESSMENT AND MITIGATION MEASURES

This part of the geohydrological input to the EMP report describes and evaluates the potential impact associated with the planned **stooping activities alone**. The criterion used for the risk evaluation was provided by GCS and are provided in Table 4.1.

According to the Information Series 5: Impact Significance of the Integrated Environmental Management Information Series *(Department of Environmental Affairs and Tourism, 2002)*:

'The concept of significance is at the core of impact identification, prediction, evaluation and decision-making. Deciding whether a project is likely to cause significant environmental effects is central to the practice of EIA.'

Impact assessment is therefore based on the description of an impact, the significance of this impact, and how the impact can be managed. Impact assessment and management measures must be based on the requirements as set out in the relevant Regulations and guidelines of the National Environmental Management Act No 107 of 1998 (as amended), the Minerals and Petroleum Resources Development Act No 28 of 2002 (as amended) and the National Water Act No 36 of 1998 (as amended).

It must be noted that many of the potential negative consequences can be mitigated successfully. It is however necessary to make a thorough assessment of all possible impacts in order to ensure that environmental considerations are taken into account in a balanced way, thus supporting the aim of minimising adverse impacts on the environment.

Key Issues:

- *The proposed stooping areas are located within and are surrounded by existing mine workings.*
- *Six groundwater samples were collected within the mine lease area and the results of their chemical and physical analyses revealed overall good groundwater quality conditions.*
- *Impacts associated with the planned stooping activities are therefore expected to be related to groundwater levels, rather than groundwater quality.*
- *Given Matla's long and extensive mining history, the impact of the proposed stooping activities (over and above the already existing groundwater level impacts) is expected to be low in the context of the existing operation.*

Table 4.1: Criteria for assessing the impact

Description		Rating
Magnitude		
Not applicable/none/negligible		0
Minor		2
Low		4
Moderate		6
High		8
Very high/don't know		10
Duration		
Not applicable/none/negligible		0
Immediate		1
Short-term (0-5 years)		2
Medium-term (5-15 years)		3
Long-term (ceases with the operational life)		4
Permanent		5
Scale		
Not applicable/none/negligible		0
Site only		1
Local		2
Regional		3
National		4
International		5
Probability		
Not applicable/none/negligible		0
Improbable		1
Low probability		2
Medium probability		3
Highly probable		4
Definite/don't know		5
Significance		
High (positive)	>60	H
Medium (positive)	30 to 60	M
Low (positive)	<30	L
Neutral	0	N
Low (negative)	>-30	L
Medium (negative)	-30 to -60	M
High (negative)	<-60	H

***Note:** The maximum value that can be achieved is 100 Significance Points (SP).*

4.1 Groundwater Impacts Associated with the Stooping of Existing Underground Mine Workings

4.1.1 Operational Phase

Potential Environmental Impact:
Impacts are expected to be quantitative by nature, rather than qualitative. Impacts on groundwater levels already occur as a result of groundwater abstraction for domestic/other purposes or mine dewatering.

Most of the existing mine workings occur at depths of between ±75 and 120 meters below surface. At these depths the mine's impact on groundwater levels in the shallower overlying aquifer/s is low. High extraction mining has however caused the roof to collapse in some areas, which ultimately led to subsidence of the surface. In such an event a hydraulic connection is created between the deep mine workings and overlying aquifer/s. Water from the aquifer is now free to drain into the mine workings, ultimately causing water levels to decrease. The proposed stooping is expected to have such an impact as all supporting pillars will be mined out, thus causing the roof to collapse followed by surface subsidence.

The recharge to the stooping areas will increase once roof collapse and surface subsidence start to occur. The overall groundwater make in the catchment will thus increase, however slightly due to the limited size of the areas proposed for stooping. At an increase in effective recharge of approximately 5% of MAP, the average increase will be approximately 220 m^3/d. This increase is but 2% of the current estimated recharge of 12 900 m^3/d to the Matla workings *(Mine Water Consultants, 2015)*.

Table 4.2: Impact rating Operational Phase

Status of impact	Magnitude	Duration	Scale	Probability	Significance
Before mitigation					
-	Moderate	Long term	Local	Highly probable	Medium
After mitigation					
-	Moderate	Long term	Local	Highly probable	Medium

As stated previously, the medium impact (Table 4.2) of the proposed stooping will be very small in the context of the existing larger Matla operation footprint.

Recommended mitigation measures:
Stooping should not be conducted below surface water courses, wetlands or any other surface water features.

Other than the comprehensive monitoring of groundwater levels and early detection of impacts, no mitigation measures are available for the stooping, roof collapse and shallow aquifer dewatering. No other impacts from the proposed stooping operation are discussed because the water and waste management, processing, storm water will be incorporated in the existing infrastructure. All such activities and infrastructure are covered in the existing and approved EMP of Matla Colliery.

Key Issues:

- *The planned stooping activities are expected to cause a lowering of the local groundwater levels, for which no mitigation measures are available.*
- *The effective recharge will increase to the mine workings, but the increase is very small in the larger Matla groundwater make.*
- *The generally low hydraulic properties of the aquifer host rock are however expected to significantly restrict the extent of the affected areas.*
- *Residual impacts will remain for as long as it takes groundwater levels to recover and establish a new equilibrium.*

4.1.2 Decommissioning and Closure Phase

Potential Environmental Impact:

During the decommissioning and closure phase, mining activities will gradually come to an end and all mining equipment and remaining infrastructure will be removed and cleared. Mine dewatering/pumping will also cease, allowing groundwater levels to slowly recover. Only once the entire underground void has been flooded, will groundwater levels recover to establish a new equilibrium. The decommissioning and closure phase activities are therefore expected to have a positive effect/impact on surrounding groundwater levels.

Please note that decant and any post closure contaminant plumes have not been assessed given the fact that this should be assessed on a mine wide basis.

Table 4.3: Impact rating Decommissioning and Closure Phase

Status of impact	Magnitude	Duration	Scale	Probability	Significance
Before mitigation					
+	Moderate	Long term	Local	Definite	Medium
After mitigation					
+	Moderate	Long term	Local	Definite	Medium

Key Issues:

- *The decommissioning and closure phase activities are expected to have a positive effect/impact on the surrounding groundwater levels.*
- *Once groundwater levels have recovered from the impacts of mine dewatering, groundwater flow patterns will return to normal/pre-mining – allowing any potential contamination to migrate in the down gradient groundwater flow directions. The residual impacts are therefore expected to change from being quantitative by nature to now being qualitative.*

5 NUMERICAL GROUNDWATER MODEL

5.1 Model Restrictions and Limitations

The numerical groundwater model, despite all efforts and advances in software and algorithms, remains a very simplified representation of the very complex and heterogeneous interacting aquifer systems underlying the site. The integrity of a numerical model depends strongly on the formulation of a sound conceptual model and the quality and quantity (distribution, length of records etc.) of input data:

Garbage In = Garbage Out

Where accurate long term monitoring and test data over the entire project area is not available the model results should therefore be regarded as providing qualitative rather than quantitative results and also need to be verified and updated regularly by means of a comprehensive groundwater monitoring program. Nonetheless, a numerical model can be used quite successfully to assess the effectiveness of various management and remediation options/techniques, especially if the shortcomings in information and assumptions made in the construction and calibration of the model are clearly listed and kept in mind during modelling.

All available information regarding the geological makeup (especially geological structures) of the mining area was considered in the construction of the numerical model. Geological structures such as dykes and faults, because the aquifer is of a secondary fractured nature, usually have higher transmissivities in comparison to the host rock and serve as preferred flow paths or conduits for groundwater movement. These structures therefore have the ability to significantly affect the outcome of a model. Areas still exist where such structural geological information is not available, therefore modelling (i.e. updating of the model) should be an ongoing process as new information becomes available with time.

No stooping schedules were available for the Phase 1 areas, therefore a worst case approach was followed whereby all the areas were simulated to be stooped during the same period.

5.2 Model Domain and Boundary Conditions

The Processing Modflow 8 modelling package was used for the model simulations. The finite difference model grid constructed to include the entire Matla mine lease area is indicated in Figure 5.1. Model dimensions and aquifer parameters used in the construction and calibration of the model are provided in Table 5.1.

The following model boundaries were used to define the model area and are also indicated in Figure 5.1:

- **No-flow boundaries** in a model, as in nature, are groundwater divides (topographic high or low areas/lines) and geological structures (dykes) across which no groundwater flow is possible.

- **General head boundaries** are boundaries through which groundwater movement is possible. The rate at which the groundwater moves through the boundary depends on the groundwater gradients as well as the hydraulic conductivities on opposite sides of the boundary position.

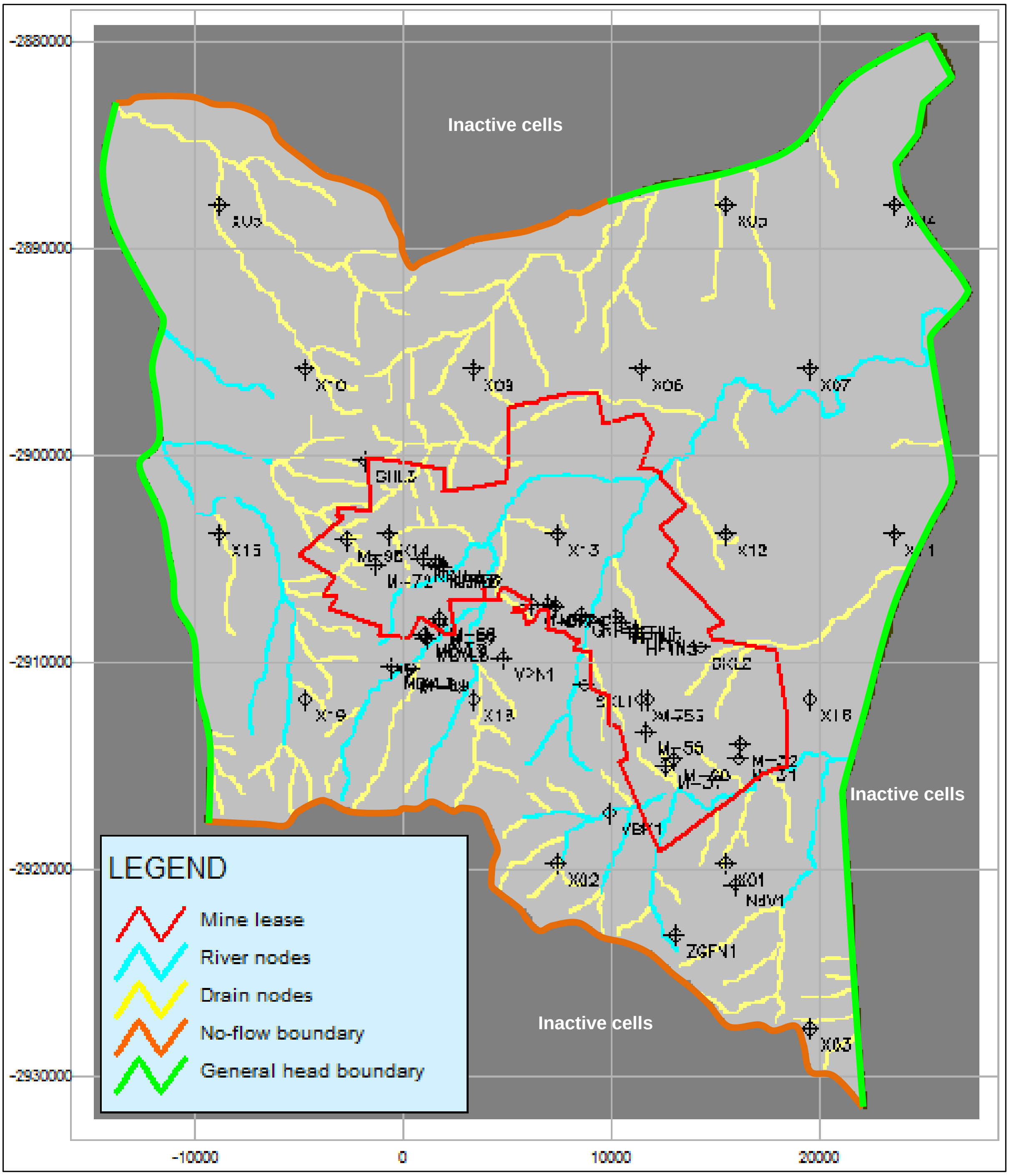


Figure 5.1: Numerical model grid

Table 5.1: Model dimensions and aquifer parameters

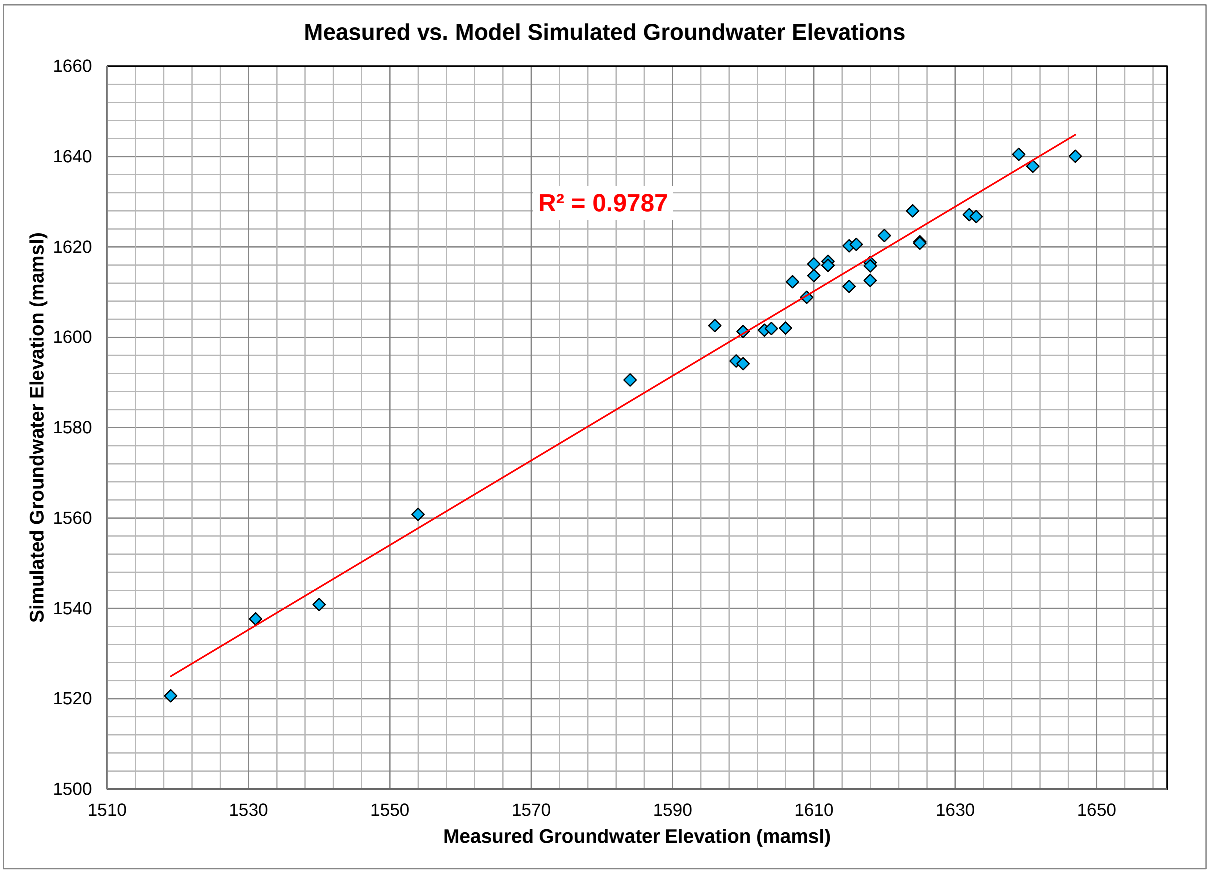
Grid size	Easting = 42 210m Northing = 52 640m
Rows and Columns	Rows = 752, Columns = 603
Cell size	70m by 70m
Transmissivity: Shallow aquifer	1.8 m^2/day
Transmissivity: Deeper aquifer	0.35 m^2/day
Specific yield: Shallow aquifer	0.06
Storage coefficient: Deeper aquifer	0.001
Effective porosity: Shallow aquifer	6%
Effective porosity: Deeper aquifer	2%
Recharge	0.6% - 1.2 % of MAP

5.3 Model Calibration Results

During the steady state calibration of the flow model changes were made to mainly the hydraulic properties (transmissivity) of the aquifer host rock and effective recharge (Table 5.1) until an acceptable correlation was achieved between the measured/observed groundwater elevations and those simulated by the model. Groundwater level information from user boreholes was used in the calibration process. A correlation of ± 97% was achieved with the calibration of the flow model and the results are provided in Graph 5.1.

The calibrated groundwater elevations were exported from the flow model and used to construct contour map of the steady state groundwater elevations (

Figure 5.22). The lowest groundwater elevations were simulated to occur in the north-western and north-eastern down gradient directions. Groundwater elevations follow the surface topography and increase towards the south.



Graph 5.1: Numerical flow model calibration results

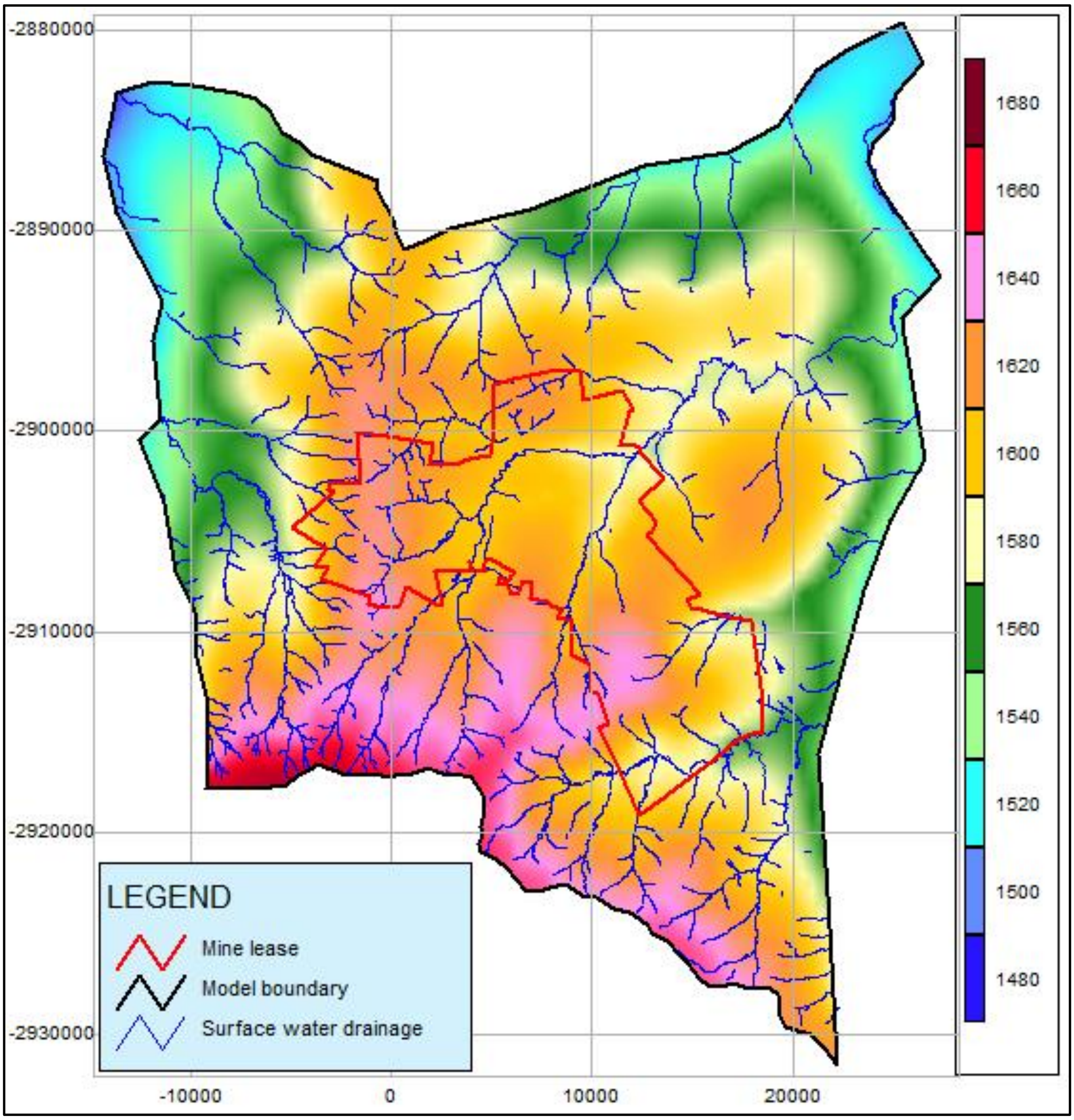


Figure 5.2: Model simulated steady state groundwater elevations (mamsl)

5.4 Flow Model

Impacts on groundwater levels are expected to occur as a result of roof collapse followed by surface subsidence. The flow model was therefore used to simulate this potential impact. A mine plan and schedule are yet to be finalised for the planned stooping areas, which is considered to be a serious shortcoming in the model simulations.

The extent of the groundwater level impacts is governed by the hydraulic properties of the aquifer host rock and time. The influence of time on the radius/extent of the cone of depression (water level impact) is explained by means of the following equation *(Bear, 1979)*:

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

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

From the equation it is made clear that an increase in time will lead to an increase in the radius of influence (extent of depression cone), which is why the mine plan/schedule plays such an important role in the model simulations. The same holds true for aquifer transmissivity, i.e. impacts on groundwater levels are expected to extend along transmissive geological structures. Such structures may also greatly increase groundwater discharge into the active mine workings.

The planned stooping was simulated to occur over an assumed time period of five years. We strongly recommend an update of the model simulations once the mine plan/schedule has been finalised.

In order to better indicate the impact of the planned stooping activities on the surrounding groundwater levels, initial groundwater elevations were subtracted from the simulated groundwater elevations at the end of year five. The difference between these two data sets therefore represents the total decrease in water level experienced over the simulation time. This data was used to construct a contour map of the model simulated groundwater depression cones, which are indicated in Figure 5.3. Groundwater user boreholes located within the mine lease area are indicated in the abovementioned figure with the use of blue place marks.

5.4.1 Summary of simulation:

A maximum groundwater level drawdown/decrease of 11 meters was simulated to occur in an area bordered by low transmissivity dykes (green lines in Figure 5.3). On average, drawdown was simulated to vary between approximately four and nine meters.

A total area of ± 25 km^2 was simulated to experience decreases in water levels. Ten groundwater user boreholes are located within this affected area as seen in Table 5.2.

Table 5.2: Potentially affected groundwater user boreholes

BH	Model simulated drawdown (m)
HJFV2	5
HJFV5	3
KRTL1	3
KRTL6	5
KRTL8	6
KRTL9	6
KRTL10	6
KRTL11	6
M-19	3
VFN1	2

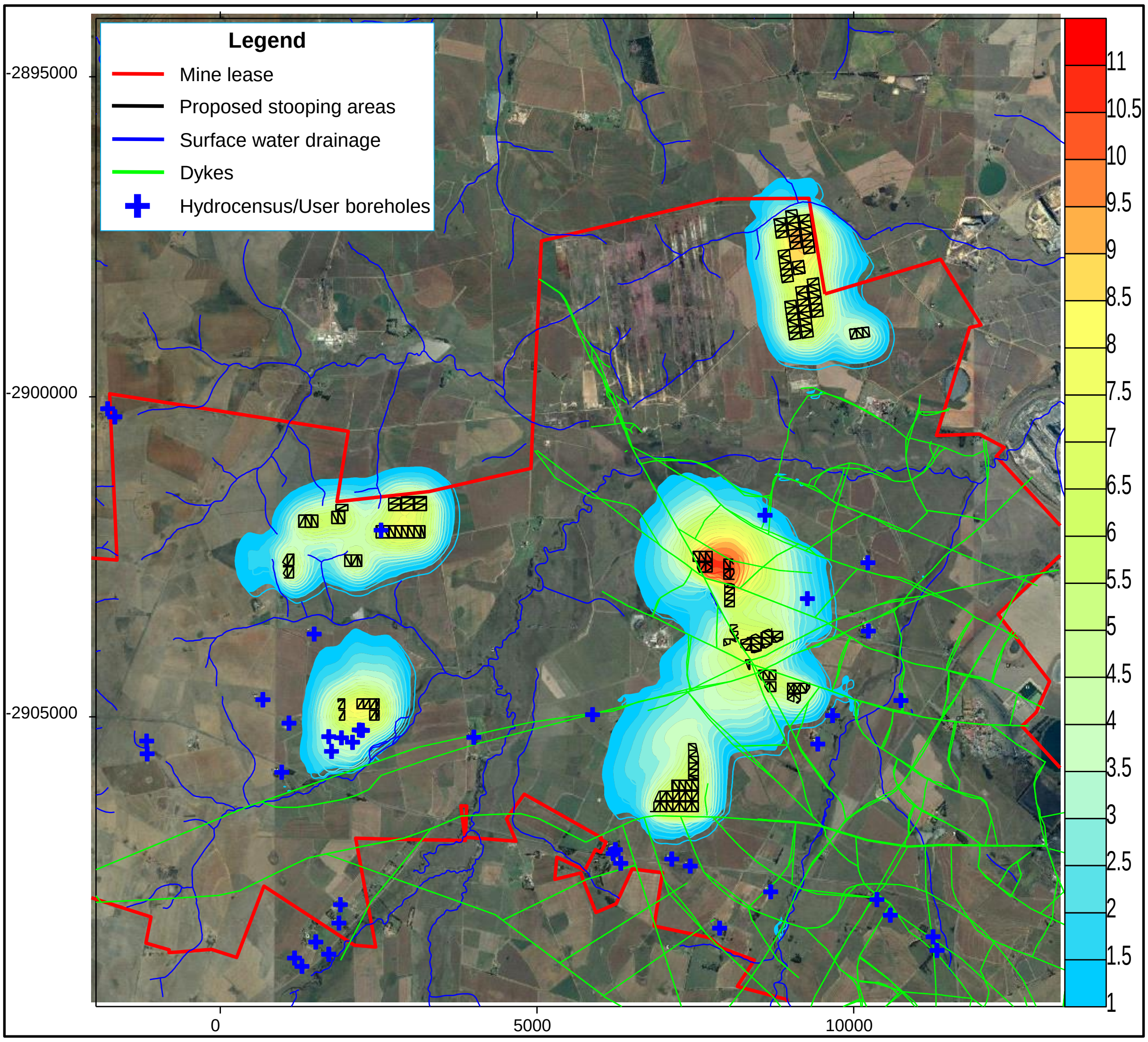


Figure 5.3: Model simulated groundwater depression cones (meters)

Key Issues:

- *Ten groundwater user boreholes were simulated to be affected by the planned stooping activities.*
- *These boreholes were simulated to experience water level decreases of between two and six meters.*
- *We therefore recommend quarterly monitoring (at least) of groundwater levels in the model simulated affected areas at the user boreholes.*
- *Monitoring data should be assessed on a regular basis to determine/quantify the impact (if any) on groundwater levels.*
- *Groundwater users should be compensated for their loss should the monitoring program indicate adverse groundwater level impacts.*

6 GROUNDWATER MONITORING PROTOCOL

We recommend the quarterly sampling of purpose drilled source monitoring boreholes around the mining area. Groundwater samples should be analysed for chemical and physical constituents normally associated with coal mining activities (Table 6.1). Water levels should also be determined on a quarterly basis when the sampling is done.

Regular revision of the efficiency of the monitoring program by a qualified geohydrologist is recommended. Should the sampling program be changed, it should be done in consultation with the Department of Water and Sanitation (DWS).

Table 6.1: Groundwater constituents for routine analysis

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

The following maintenance activities should be adhered to:

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

The quarterly report should be an update of the database with time-series graphs and statistical analysis (average, maximum, minimum, 5 -, 50 – and 95 percentile values as well as linear performance). Data should also be presented in a map format to present a clear picture of the water quality situation. Laboratory results should be analysed against the target water quality guidelines for domestic use (South African National Standards for drinking water; *SANS 241:2015*).

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

An annual detailed evaluation report on the surface and groundwater quality should be prepared that will analyse the water quality situation in detail to investigate trends and non-compliance.

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

- Data presentation in tabular format,
- Time-series graphs with comparison abilities,
- Statistical analysis (minimum, maximum, average, percentile values) in tabular format,
- Graphical presentation of statistics,
- Linear trend determination,
- Performance analysis in tabular format,

- Presentation of data, statistics and performance on diagrams and maps, and
- Comparison and compliance to the South African National Standards for drinking water *(SANS 241:2015)*.

As far as possible, the same monitoring points should be used to develop a long data record and enable trend analysis and recognition of progressive impacts with time.

Key Issues:

- *For as long as the underground mine workings remain groundwater sinks, groundwater level monitoring should take priority over groundwater quality monitoring.*
- *Dedicated monitoring of water levels in the abandoned underground mine workings plays a crucial role in the development of an accurate water balance model.*
- *See previous: Diligent water level monitoring at nearest users to proposed stooping areas to detect impacts timeously.*

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